BIF Response to TRAI CP on Auction of Spectrum in frequency bands identified for IMT/5G

Preamble

The three basic models for regulating spectrum are (i) a command and control model (e.g. assignment of bands for public service use); (ii) a market-oriented model (i.e. through licensed auctions); or (iii) a generic licensing or common use model (i.e. any user can access the band, provided that, and for as long as the user complies with the technical specifications set out in the generic license). The command and control model is least flexible while generic licensing is the most flexible regime.

In 1959, Ronald Coase, a Nobel Prize winner, declared that the command and control model was not an economically efficient way of assigning a scarce resource. He said, "in the same way as land is protected by clear property rights, spectrum should be, too". The nudge towards market oriented allocation was based on the fact that auctions allow spectrum to be placed in the hands of operators who are able to use it best. Auctions are also more transparent, eliminating the subjectivity of a beauty contest. However, auctions are not entirely free from challenges. Auctions can be affected by the presence of externalities, market power and collusion on the buyer side and asymmetric information between buyers and sellers.

Auction Outcomes Affected by Externalities

Auction outcomes get affected by factors ranging from macro-economic situation, sectoral performance and various auction related variables including reserve price, amount of spectrum already allocated to operators, timing of auction, carrier size, etc. For instance, the 2010 auctions were held against the backdrop of the license cancellation and there was no clear roadmap on spectrum availability or when auctions would be held next. Spectrum had not been allocated since 2004, resulting in a lot of pressure on the operators in picking up 3G spectrum at over-enthusiastic prices. The German auction, concluded within 24 hours of the Indian event, revealed that the Indian reserve prices were ~10 times higher than German prices.

The next auctions of 900 MHz band in 2014 and 2015 can be termed as the renewal auctions, as operators whose licenses were expiring had to bid enormous amounts to stay in business. This artificially raised the price of spectrum disproportionately. The 2016 auctions were largely subdued with a large amount of spectrum left on the table as reserve prices were set too high and never curated to correct for the anomalies. Since externalities have a huge bearing on the auction outcome, the effectiveness of auction in achieving the twin objectives of resource mobilization and public welfare is highly questionable.

Spectrum Lying Idle Causes an Irretrievable Economic Loss

The greatest value of radio spectrum lies in its usage. Idle or unused spectrum benefits no one – neither the government, nor the economy, society or consumers, and results in an irretrievable loss. The sale of spectrum results in direct upfront revenue generation as well as indirect long-term socio-economic gains. Through auctions held since 2010, the Government has been able to directly sell spectrum worth INR 4 lakh crores (USD 47.14 Billion). The Government has gained about INR 4 lakh crores through license fee, SUC and service tax over the same period.

There are many indirect benefits that flow – according to a report by ICRIER, a 10% increase in mobile penetration delivers a 1.9% increase in the rate of State GDP growth. Against this background, one can make back of the envelope calculation of economic losses caused due to spectrum remaining unsold. In the October 2016 auctions, deemed to be India's largest spectrum sale, more than 1300 MHz of radio spectrum (approximately 59%) remained unsold. India had 762 million active mobile connections in 2016, served by over 3800 MHz of spectrum allocated to licensees. This would indicate that the idle spectrum with the government could enable connectivity for roughly 278 million additional active connections or 21% of the total Indian population. Applying the result of the ICRIER economic impact study, the financial cost of this idle spectrum can then be estimated at INR 5.40 lakh crores, or over 160% of the financial benefit of INR 3.30 lakh crores from all spectrum auctions so far. This is a rough conservative estimate and actual losses may far exceed this figure. *Auctions leading to unsold spectrum cause huge loss to the economy.*

Loss of Consumer Surplus
High spectrum costs lower the incentives to invest in network expansion and upgrades, and lead to higher consumer prices. In price sensitive markets such as India, this adverse impact on consumers can significantly delay both the rollout as well as the eventual adoption of new services. The lost consumer surplus far outweighs any gain from auction revenues.

Failed Auction Could Fail Digital India
If auctions are not successful, the ones who get most disadvantaged are the weaker sections of the society as they are the ones who are deprived of the benefits of technology. This aspect is of particular relevance to India with its high proportion of low-income citizens as well as the strong National Vision of moving to Digital India. Lesser spectrum allocation to the sector results in services not reaching to weaker as well as remote/rural subscribers due to higher price of the service offering or high cost of roll-out. An overload of subscribers per MHz of radio spectrum, as would be emblematic of spectrum starved regimes, may even manifest as generally poor quality of services.

Consolidated Market Desires Optimum Spectrum Use
Around 2008, there was hyper-competition in the Indian telecom market with as many as 14 players in some circles. With cancellation of licenses following the February 2012 judgment of the Hon'ble Supreme Court, and the consolidation that followed coupled with the financial burden on the sector, the market has now reached a stage where there are only 4 players left in the market, including the state owned player. Auctions were relevant or required for allocating 2G, 3G and 4G spectrum in those times but it is no longer the case as the market

structure has changed fully. As we are advancing towards 5G and higher technologies, any duplication of resources or their under-utilization is undesirable and unacceptable in a country like ours. Spectrum hungry applications will require optimum use of spectrum, and auctions which fail to sell the 'much in demand' spectrum owing to their faulty design, need to be done away with.

A lot of countries are realizing that the most successful auctions aren't the ones that bring in the most money. "The objective of awarding the frequencies was not to maximize auction revenue, but to allocate the frequencies efficiently to ensure excellent mobile communications services for Switzerland," the country's regulator (ComCom) stated after awarding spectrum in bands (including 3.5 GHz) in 2019.

5G and Higher Technologies Need a Different Approach

5G uses higher radio frequencies that are less cluttered. This allows for it to carry more information at a much faster rate. While higher bands are faster at carrying information, there can be problems with sending over large distances. They are easily blocked by physical objects such as trees and buildings. In order to circumvent this challenge, 5G will utilize multiple input and output antennae to boost signals and capacity across the wireless network. 5G is a completely different technology and requires a different approach than 2G, 3G and 4G. In 2018, the Finnish regulator and the national mobile operators managed to agree on a mutually beneficial split of 5G spectrum (also in the 3.5 GHz band) for a fair price, thus removing the need for an auction. Such agreements will not always be possible but are an option when consensus can be reached.

Thus, there appear to be significant difficulties and challenges posed as a result of the current methodology for valuing spectrum in India. These may have arisen at different points in time and in different circumstances over several years. While these might have been relevant or required at those times, many legacy issues and environmental factors have changed significantly since then. Hence it would be advantageous for India to revisit the methodology followed and make appropriate revisions. India stands at a juncture where the auction process has to be designed very carefully and cautiously, to overcome the problems issued in the past. India's open and transparent auction methodology must be reinforced with a kind of market-based mobile access spectrum management that allows for the fair discovery of the market value for spectrum, with reserve prices playing a pivotal role in the success of auctions.

Protection of Already Allocated C-Band frequencies to Satellite Broadcasting

The C-Band (3.3 - 4.2 GHz) is a cornerstone for many satellite services including broadcasting services. In India, the spectrum frequencies 3.7 – 4.2 GHz are earmarked for providing broadcasting services. The large geographic coverage of C-band satellite beams represents a cost-effective communication solution, while its low susceptibility and robustness to weather impairments, especially in sub-equatorial regions like India, makes C-band the most suitable band to guarantee high service availability. Additionally, services in the C band are essential in emergencies and disaster recovery. For these reasons, C-band is irreplaceable and not substitutable.

Indian broadcasting industry has depended on C-band satellite connections to reach Indian homes receiving cable TV or satellite DTH services for over two decades now. At present, roughly 100 million Indian households receive their news and entertainment via cable TV services, and another 70 million via direct-to-home satellite (Although the direct consumer link for DTH services is provided in different frequency bands, the programming reaches the DTH operator's headend via C-band distribution). In the cable industry, 1724 registered MSOs and over 30,000 last-mile cable operators depend on C-band transmission to receive the TV signals that they retransmit to consumers. Thus, the stakes for Indian society and the Indian economy in the smooth operation of C-band satellite distribution of broadcast signals are high.

Other users of C-band satellite networks include maritime services in India's waters, aeronautical services in Indian airspace, education services in India's schools, oil and gas production, and emergency/disaster relief services. All of these rely on C-band's nationwide distribution and tropical weather resilience to ensure the functioning of the Indian society.
Therefore, the protection of the existing satellite systems operating in the C-band from any form of interference is crucial while allocating C-band frequencies for the upcoming 5G deployment.

A) <u>Issues related to Quantum of Spectrum and Band Plan</u>

Q.1 Whether spectrum bands in the frequency range 526-617 MHz, should be put to auction in the forthcoming auction? Kindly justify your response.

<u>BIF Response</u>

Yes and No.

1. With reference to the recent Addendum issued by TRAI on 30th December 2021 as regards use of MIB Broadcasting Transmitters in the Band from 526-582 MHz, it is apparent that the band between 526-582 MHz can only be allocated in an administrative manner with appropriate separation distances as mentioned in the various locations in the said addendum.
2. The Band 582-612 MHz is an excellent low-band spectrum for applications viz. IoT (especially in rural and remote areas) and other similar uses. Studies conducted by IIT Bombay (under Prof. Abhay Karandikar) indicate that significant majority of the UHF (470-582 MHz) spectrum is not used. Further, the analysis also points to various techniques in the context of utilizing the same spectrum for broadband while still ensuring protection to broadcast operations. Due to the ongoing digitalisation of the terrestrial broadcasting network by the public broadcaster, it is expected that the total spectrum requirement in this precious VHF/UHF band would be reduced to one fifth or one sixth of what is being used currently.

Therefore, to deal with the assignment/allocation issue in this frequency band, the aforesaid frequency range maybe required to be split into 2 distinct parts and dealt with separately viz.

(i) 526 to 582 MHz and

(ii) 582-612 MHz

(i) *The 526 to 582 MHz band: Since this band is still under developmental phase for 5G and band plans for the same are also awaited from 3GPP, we suggest this band be reserved for IMT/5G future deployment and not be included in this part of auctions. As and when it is ready to be taken up for consideration, the method of allocation should be decided at that stage.*

(ii) 582-612 MHz may be made available for co-primary allocation for possible IMT deployment through auction.

3. There is a need for sufficient measures to be taken to mitigate any form of interference to Cable TV and broadcasting sector while auctioning of sub-gigahertz band (<1 GHz) for IMT services.

Q.2 If your answer to Q1 above is in affirmative, which band plans and duplexing configuration should be adopted in India? Kindly justify your response.

BIF Response

1. All the above bands should be permitted for FDD (Frequency Division Duplexing) configuration and operation only, as it is a well-established practice for all sub-GHz bands. This means that there should be a separate band plan for uplink and downlink frequencies with a suitable guard band in between.
2. Due to need for close coordination with MIB to make spectrum available for Mobile/IMT usage in this portion of the band i.e. 526-582 MHz, efforts should be made to engage with the industry in identifying the best use of this spectrum with an appropriate band plan for ensuring rural broadband penetration and IoT based applications.

Q.3 In case your answer to Q1 is in negative, what should be the timelines for adoption of these bands for IMT? Suggestions to make these bands ready for adoption for IMT may also be made along with proper justification.

BIF Response

Not Applicable

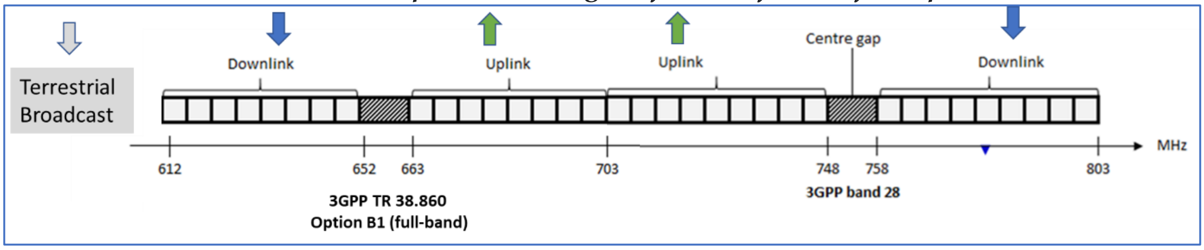
Q.4 Do you agree that 600 MHz spectrum band should be put to auction in the forthcoming auction? If yes, which band plan and duplexing configuration should be adopted in India? Kindly justify your response.

BIF Response

Yes. The 600 MHz spectrum band should be put to auction for IMT usage. However, there are two views as regards how the spectrum band is to be utilised which are presented below:

A1. VIEW 1: The Band Plan may be based on the ITU-Region 3 activities on extending the 600 MHz US band allocation based on the 3GPP Option B1 plan. In this plan, it has been proposed that the band gap between band n71 and Band 28 may be removed and additional 5 MHz from the lower frequencies may be included in this band. Accordingly, the proposed band plan is based on **reverse Frequency Division Duplexing (FDD) configuration,** i.e. Mobile station transmitter (uplink) frequencies from 663-703 MHz and Base station transmitter (Downlink) frequencies from 612-652 MHz, with a guard band from 652-663 MHz (11 MHz) which remains the same as that in band plan n71. This is similar to what was adopted in the 700 MHz band (APT 700 MHz Band 28) for the APT Region.

1. ***The 80 megahertz of wireless spectrum consists of eight paired five-megahertz blocks, with each block having five megahertz in the uplink band (663-703 MHz) and five megahertz in the downlink band (612-652 MHz). This is a reverse duplex arrangement of uplink downlink frequencies to enable efficient coexistence with the adjoining 700 MHz band, so that the uplinks are aligned for interference free operation.***



2. The existing usage of terrestrial broadcast in India, especially the high-power broadcast, is well below 612 MHz (actual usage is below 582 MHz as per recent Addendum issued by TRAI on 30th December 2021 as regards use of MIB Broadcasting Transmitters in the Band from 526-582 MHz), thereby ensuring most effective usage of spectrum. This ensures that all the prime spectrum with excellent propagation characteristics is not lying fallow and is put to the most optimum use towards providing 5G connectivity to the masses, especially in remote areas, and rural India.
3. 3GPP TR 38.860 discusses that existing n71 UEs may be able to work in the network supporting option B1 configuration using multiple FBI feature of 3GPP. Since this band is going to be harmonized for entire APT Region, just like the APT 700 MHz band plan, this is going to bring economies of scale to the region and will also be the prime mover for international roaming, especially in the APT Region.

A2. VIEW 2: In view of the development of the global ecosystem around n71 band plan, we may adopt the n71 band plan for 600 MHz. We give the reasons as follows.

1. Since in View 1, APT is considering two options for expanding the usable spectrum by 2x5 MHz through a new spectrum band plan and configuration, in one of the options,

duplexing separation will increase to 11 MHz and in the other option, the duplexing separation will reduce the Rx & Tx gap from 11 MHz to 6 MHz. This would:

i. Impact the design of the radio unit at the base station and user equipment
ii. Need new development of radio modules
iii. Not be able to take benefits of economies of scale of existing smartphones supporting n71 band
iv. Smartphones supporting the n71 band would not be able to work on this configuration (e.g. for global roaming)
v. Similarly, smartphones supporting new band configuration will not be able to work with networks deployed with n71 band
vi. Changing band configuration in future (if initial deployments are made in n71 and then changed to new band configuration to expand 5 MHz spectrum) would need a change of radio units deployed at the site

2. *Therefore, it maybe decided to use globally defined spectrum band configuration (n71) in the current auctions to leverage the existing ecosystem, ensure interoperability and reap benefits of economies of scale. The new APT band plan (3GPP Option B1) may be considered in future auctions, depending upon the adoption of the APT proposal*.
3. As is applicable for all sub GHz spectrum, the duplexing configuration should be based on FDD (Frequency Division Duplexing).

Having presented the opinions of both the sides, **BIF is unable to make any clear Recommendations in this case and wishes** to leave it to the Authority to kindly take the most appropriate decision in this regard.

Q.5 For 3300-3670 MHz frequency range, which band plan should be adopted in India? Kindly justify your response.

BIF Response

1. Given the fact that there would be four possible operators/users of this frequency band for rollout of Public 5G Networks, it would be advisable to provide contiguous spectrum bands to all of them, since in-band interference is likely to be less in this band as compared to sub-GHz bands.
2. Keeping in view that C band and extended C band above 3705 MHz is extensively used by Satellite Broadcasters, and therefore, to avoid any possible interference to them as mentioned in response to Q16 later, possible interference issues and mitigation processes and procedures have been suggested to ensure incumbent satellite users are provided complete protection. International Best Practices in this regard have also been cited.

Q.6 Do you agree that TDD based configuration should be adopted for 24.25 to 28.5 GHz frequency range? Kindly justify your response

BIF Response

Yes. As is applicable for all higher spectrum bands, TDD based duplexing configuration should be used.

Justification:

A metaphor for FDD spectrum is the double road with a divider. One side of the road supports traffic in only one direction and the other side support traffic in the opposite direction. Similarly, FDD (Frequency Division Duplex) spectrum is structured to transmit signals in opposite direction in two separate blocks, spaced out by a guard band. Whereas TDD (Time Division Duplex) is like a road without a divider, where both sides of the road are used simultaneously for transmitting signals in either direction. The TDD receiver has to be synchronized such that it opens up to receiving signals only when the transmitter (on the other side) is radiating - unlike FDD which is always on. This creates a problem if TDD is used at lower frequencies (sub-GHz) as the radio waves at lower frequencies travel far, and therefore, the receivers (which are spaced apart as compared to those at higher frequencies) have to remain blocked for a duration of time (this is large compared to those located at higher frequencies) to take care of the "traveling time" of the transmitting signal to reach the receiver (to prevent interference). This results in inefficiencies (higher the blocking time more is the inefficiency), compared to FDD where no such synchronization is required.

Q.7 In case your response to Q6 is in affirmative, considering that there is an overlap of frequencies in the band plans n257 and n258, how should the band plan(s) along with its frequency range be adopted? Kindly justify your response.

BIF Response

1. As per band plans identified by 3GPP, there is no single band plan which covers the entire frequency range identified by India. However, there are three band plans i.e. n257 (26.5 to 29.5 GHz), n258 (24.25 to 27.50 GHz) and n261 (27.50 to 28.35 GHz), which cover part of the frequency range identified by India and there are some overlaps of frequencies in these band plans.
2. 5G-HLF committee, in its report dated 23 August 2018, included multiple bands for 5G. In the mmWave bands, it had recommended 24.25-27.5 GHz for immediate use, and 27.5-29.5 GHz in "announce tier" for 5G in India. DoT had initiated 5G Technology and Spectrum Trials in India in May 2021 in multiple bands, including the range 24.25-27.5 GHz and additionally 27.5-28.5 GHz. As referenced from the CP, DoT, through its reference communication to TRAI dated 13th September 2021, has proposed to include 24.25 – 28.5 GHz band amongst the bands to be auctioned in the forthcoming auction. DoT has also informed that 24.25 to 28.5 GHz could be used in all the LSAs, except certain portion of this frequency range at 5 locations where it could be used with protection distance of 2.7 km. These 5 locations are at Delhi, Shadnagar (Hyderabad), Khambaliya (Gujarat), Hut Bay (A&N Islands) and Tirunelveli (Tamil Nadu). Having said that, DoT has also asked TRAI to earmark spectrum for Satellite Communication

and method of allocation of spectrum in such bands including the regulatory/technical requirements as enunciated in the relevant provisions of the latest International Telecommunication Union (ITU)-R Radio Regulations.

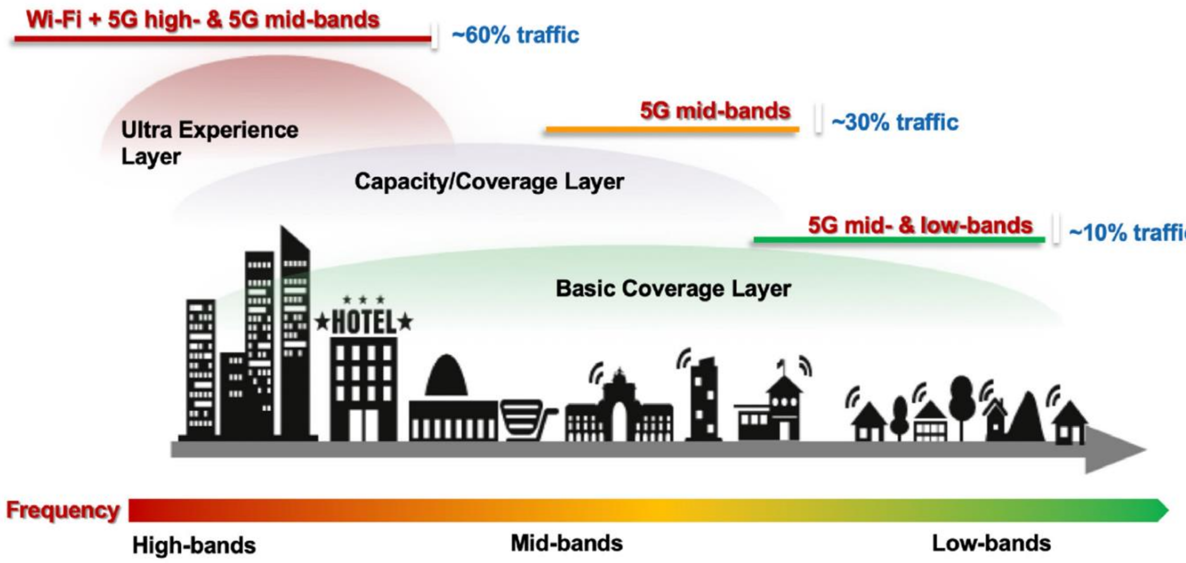
3. **WRC-19 has identified 24.25 – 27.5 GHz globally for IMT purpose.** As per 3GPP, there are three band plans i.e. n257 (26.5 to 29.5 GHz), n258 (24.25 to 27.50 GHz) and n261 (27.50 to 28.35 GHz), which partially cover the frequency range mentioned by DoT beyond 27.5 GHz.
4. **Some experts are of the view** that India must follow/comply to the WRC-19 guidelines which has identified the 24.25-27.5 GHz spectrum bands for allocation for IMT/5G use on a global basis. ITU Members States have harmonised an additional total of 17 GHz of other mmWave bands for use by 5G/IMT systems and additional spectrum is identified for IMT/5G deployment in the 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2 GHz and 66-71 GHz. It should be ensured that any portion of the Ka band (27.5-28.5 GHz), if identified for IMT use, must provide protection for incumbent satellite services in this band.
5. The Ka-band 27.5-30.0 GHz frequency range (uplink), paired with the 17.3-20.2 GHz frequency range downlink is used for satellite gateway earth stations and customer terminals in current satellites designs, and access to the full bandwidth is a business and operation continuity requirement for such satellite operators in India and throughout South Asia. Ka-band is critical for the operation of modern Ka-band broadband satellite systems which support a wide variety of offerings, including aeronautical and maritime broadband, mobile backhaul connectivity, fixed broadband services, and government universal service programs among others.[1]
6. However, some ITU Member States in the world, e.g. USA, Japan, Korea, etc., have already deployed 5G services in the 28 GHz band (Ka Band).
7. Both the bands i.e. 26 GHz and 28 GHz are specified only for TDD mode of duplexing configuration. The assignment of contiguous blocks of 50 MHz or 100 MHz in the mmWave bands should be done for each operator.
8. For the purpose of deployment flexibility, the band plan choice between n257 and n258 may be left to the operators. If the total spectrum assigned to one operator in the mmWave band is around 800 MHz, then there will be no issue of overlap of frequency ranges between n257 and n258.

Q.8 Whether entire available spectrum referred by DoT in each band should be put to auction in the forthcoming auction? Kindly justify your response.

<u>BIF Response</u>

Yes and No. The justification for the same is provided in our response to the earlier questions.

[1] Spectrum assignment for satellite services should be based on an administrative process, as spectrum assignment by auction is not suitable for frequency bands that can be shared between multiple satellite operators such as in the C-, Ku- and Ka-bands.



All three types of spectrum are necessary for 5G as shown in the above diagram.

1. Low-band spectrum: The propagation characteristics of low-band spectrum is the backbone of rural penetration due to its wide area coverage, and is vital to provide economical deployment of mobile services. The digitalisation of services, in many instances, is freeing up low-band spectrum and provides for the re-purposing of underutilized spectrum to be more effectively provisioned and allocated for mobile.
2. Mid-band spectrum: The propagation characteristics of mid-band spectrum, while not as coverage beneficial as low-band spectrum, does support the extended wide area delivery of mobile services with the added advantage of wider spectrum bands being available to deliver high data throughput applications. Combined with low-band spectrum, good outdoor and some indoor coverage needs can be met.
3. High-band spectrum: As mentioned in the TRAI CP, with large amounts of bandwidth, it is suitable for high throughput applications such as media consumption and data hungry applications such as AR/VR which are growing rapidly. High-band spectrum is suited for hot-spot coverage as well. The short-range propagation characteristics of high-band spectrum requires multiple cells to be deployed using range extending techniques such as Massive-In Massive-Out (MIMO) antenna configurations, and these deployments are expected to be concentrated in city-centres, high traffic areas and high capacity arenas, for example. High-band spectrum is also ideally suited for in-building deployment due to this band's propagation characteristic.
4. Access to all three bands, low, mid and high will enable outdoor and indoor coverage needs to be fully met to ensure the full range of 5G services to the consumer.

Therefore, BIF recommends that there should be an attempt to make maximum spectrum available for deployment of 5G after suitably protecting incumbent operations in each of the adjacent bands.

B) Issues related to Block Size

Q.9 Since upon closure of commercial CDMA services in the country, 800 MHz band is being used for provision of LTE services, a. Whether provision for guard band in 800 MHz band needs to be revisited? b. Whether there is a need to change the block size for 800 MHz band? If yes, what should be the block size for 800 MHz band and the minimum number of blocks for bidding for existing and new entrants? (Kindly justify your response)

BIF Response

1. Keeping in view that all FDD modes of duplexing configuration in the sub-GHz bands require some form of guard bands, it is felt that provision of guard band in 800 MHz band needs to be revisited.
2. The block size for 2021 auction in this band was kept as 5 MHz. The block size maybe increased to 10 MHz paired for the forthcoming auctions in this spectrum band, keeping in view the capacity requirements of IMT/5G.
3. As regards minimum number of blocks for bidding, the spectrum quantum available and the number of operators (4) may be kept in mind, before determining that. It is generally agreed that Block size for deployment of IMT/5G may be done according to global/international best practices.
4. Given below are the global best practices/norms being followed for block sizes
    i. For 600 MHz band, it should be 5 MHz (paired) in FDD mode.
    ii. For 3.5 GHz band, it should be contiguous band with block size of 10 or 20 MHz in TDD mode.
    iii. For mmWave Band, it should be contiguous band with block size of 50 or 100 MHz in TDD mode.

Q.10 Do you agree that in the upcoming auction, block sizes and minimum quantity for bidding in 700 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2300 MHz and 2500 MHz bands, be kept same as in the last auction? If not, what should be the band-wise block sizes and minimum quantity for bidding? Kindly justify your response.

BIF Response

1. Keeping in view the need for capacity in the upcoming 5G auction, the block sizes should be higher as compared to previous auctions and should be consistent with the block sizes as provided in response to international/global norms as indicated in our response to Q9 above.
2. The quantum of spectrum to be auctioned should depend on the quantum of spectrum available in each band, the global norms as regards Block size as mentioned above, and the number of likely bidders/operators.

Q.11 In case it is decided to put to auction spectrum in 526-698 MHz bands, what should be the optimal block size and minimum quantity for bidding? Kindly justify your response.

BIF Response

1. As mentioned earlier in response to Q1, 526-582 MHz needs to be used in close coordination with MIB and hence, should be allocated administratively instead of an auction.
2. Frequencies in the band between 582-612 MHz can be assigned to IMT as a co-primary usage in conjunction with other mobile use cases.
3. However, the frequencies in the band between 612-703 MHz maybe put to auction.
4. The only clear case of auction happens to be the frequency band from 612-703 MHz band. As regards the band plan, we have provided two distinct views in response to Q4, with the request to the Authority to take the most appropriate decision in this regard.
5. Keeping in view that there are 8 blocks of 5 MHz carriers paired which are available, it is proposed that the optimal block size be kept as 10 MHz (2 carriers of 5 MHz each) and the entire quantity be put up for auction viz. 612-703 MHz.

Q.12 What should be optimal block size and minimum quantity for bidding in 3300-3670 MHz band? Kindly justify your response.

BIF Response

1. BIF recommends that operators have 85-90 MHz contiguous spectrum in the 3300-3670 MHz band.
2. Mode of Duplexing shall be TDD.

Q.13 What should be optimal block size and minimum quantity for bidding in 24.25-28.5 GHz? Kindly justify your response.

BIF Response

1. BIF recommends that the minimum block size of 800 MHz and up to 1000 MHz (subject to availability) be used for the mmWave bands. Typically, operators have been deploying mmWave networks using carrier aggregation with component carriers. For e.g. with 8x100 MHz (8CC), speeds of up to 4.3 Gbps have been demonstrated[2].
2. Mode of Duplexing shall be TDD.

C) Issues related to Eligibility Conditions for Participation in Auction

Q.14 Whether any change is required to be made in the existing eligibility conditions for participation in Auction as specified in the NIA for the spectrum Auction held in March 2021, for the forthcoming auction? If yes, suggestions may be made in detail with justification.

[2] https://www.ericsson.com/en/news/2020/2/ericsson-achieves-record-5g-mmwave-speed

BIF Response

No change is required for existing operators. To facilitate new operators or new players to participate, the eligibility conditions could be suitably relaxed.

Q.15 In your opinion, should the suggested/existing eligibility conditions for participation in Auction, be made applicable for the new spectrum bands proposed to be auctioned? If not, what should be the eligibility conditions for participating in Auction? Kindly justify your response. Issues related to Interference mitigation in TDD bands

BIF Response

1. For Digital Transformation and to accelerate the march to a 1Tn Digital Economy, India needs huge swathes of adequate quantum of spectrum at affordable rates in all the bands - lower, mid and upper bands. While the upper bands are required for meeting the capacity required to meet the needs of enhanced broadband and Massive M2M & IoT, the lower and mid bands are required to meet the coverage requirements, especially in the rural areas.
2. Yes, there should be no change in eligibility criteria for new players to participate in the auction. This would presume that they would be primarily interested in new 5G specific spectrum bands viz. 600 MHz, 700 MHz, 3.3 GHz and 24.25-28.5 GHz.

Q.16 Is there a need to prescribe any measure to mitigate possible interference issues in 3300-3670 MHz and 24.25-28.5 GHz TDD bands or it should be left to the TSPs to manage the interference by mutual coordination and provisioning of guard bands? Kindly provide justification to your response.

BIF Response

1. The topic of Synchronization of IMT-2020 TDD Networks has been studied in ITU-R, and a final draft new Report[3] on the topic of synchronization of TDD networks operating in the same frequency band of operation. GSMA published a report on the importance of TDD synchronization for the success of 5G[4]. Additionally, ECC reports studied various options including synchronized, unsynchronized, and semi-synchronized as a toolbox for operations of multiple networks[5]. ECC also recently published a report on the efficient use of spectrum at the border of CEPT countries in the TDD bands[6].

[3] ITU-R draft New Report, Synchronization of IMT-2020 TDD Networks, https://www.itu.int/md/R19-SG05-C-0050/en

[4] https://www.gsma.com/spectrum/resources/3-5-ghz-5g-tdd-synchronisation/

[5] National synchronization regulatory framework options in 3400-3800 MHz: a toolbox for coexistence of MFCNs in
synchronised, unsynchronised and semi-synchronised operation in 3400-3800 MHz.
https://docdb.cept.org/download/1381

[6] Efficient usage of the spectrum at the border of CEPT countries between TDD MFCN in the frequency band 3400-

A) PROTECTION OF INCUMBENT C-BAND SERVICES IN ADJACENT BANDS

2. It may be pertinent to note about the adjacent band compatibility between FSS and IMT, which needs to be carefully considered in order to protect C-band FSS operations. FSS earth stations are very sensitive to interference from IMT systems. While the separation distances related to adjacent band compatibility issues are smaller than those for co-frequency operations, it may not be feasible to ensure separation, in particular if FSS earth stations are deployed in large numbers or without the knowledge of their locations. Hence, careful consideration should be given to adjacent band compatibility issues as indicated in Figure 3 below, where interference to satellite receiver earth stations could happen in the following ways:

   A) IMT emissions in the 3300-3670 MHz saturate the LNB of the FSS earth station which traditionally operates in the 3400-4200 MHz, even if the mobile 5G signal is adjacent to the satellite signal; and
   B) Unwanted (out of band and spurious) emissions of the mobile 5G signal falling within the operating FSS operating band 3700-4200 MHz can cause in-band interference to FSS signals.

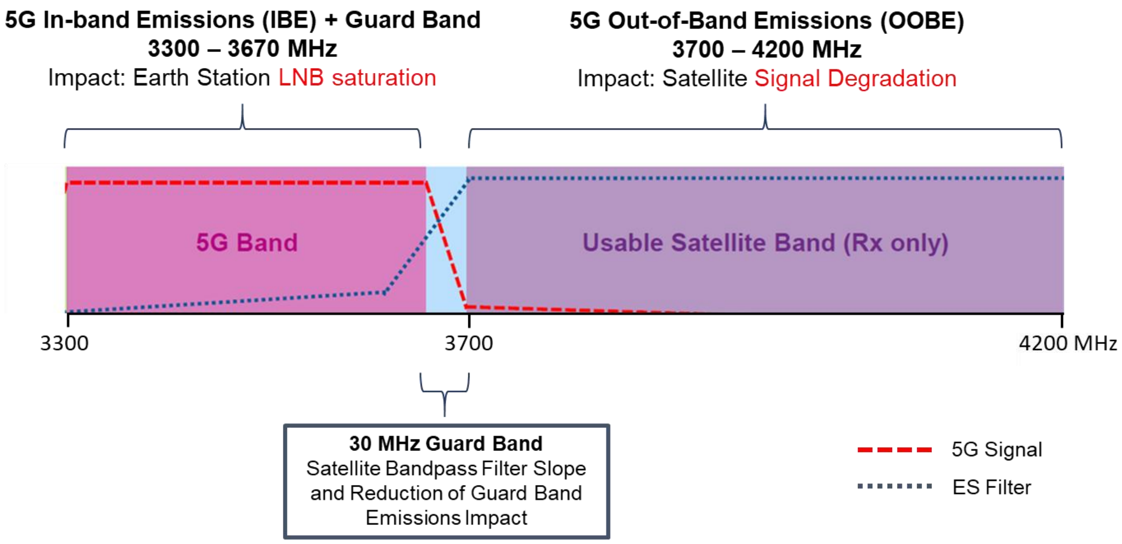


Figure 3: Adjacent band compatibility between FSS & IMT

3. Typically, earth station LNBs are designed to receive the entire 3400-4200 MHz band. The IMT/5G signals in the 3300-3670 MHz band therefore can saturate the amplifier stage in the LNB or bring it into non-linear operation, thus blocking reception of signals. Moreover, emissions from IMT/5G systems will cause the LNBs in the FSS Earth Stations to produce unwanted signals in the form of intermodulation products.

3800 MHz, https://docdb.cept.org/download/3541

These products will act as additional interfering signals and further degrade the performance of the satellite service.

4. As described above, the IMT systems' signal power at the input of an FSS earth station LNB can easily saturate the LNB and wipe out the satellite signal. The best solution to mitigate the IMT systems' interference is to insert a RF waveguide filter between the output of the antenna and the input of the LNB. This will filter out, to a great extent, the unwanted IMT signal from saturating the LNB.

5. Narrowing the frequency response of FSS earth stations could be an effective mitigation technique for those earth stations that do not need to receive the same frequencies used by IMT systems, to lower the magnitude of the interfering IMT signal received. This can be achieved by adding a filtering function before the LNB.

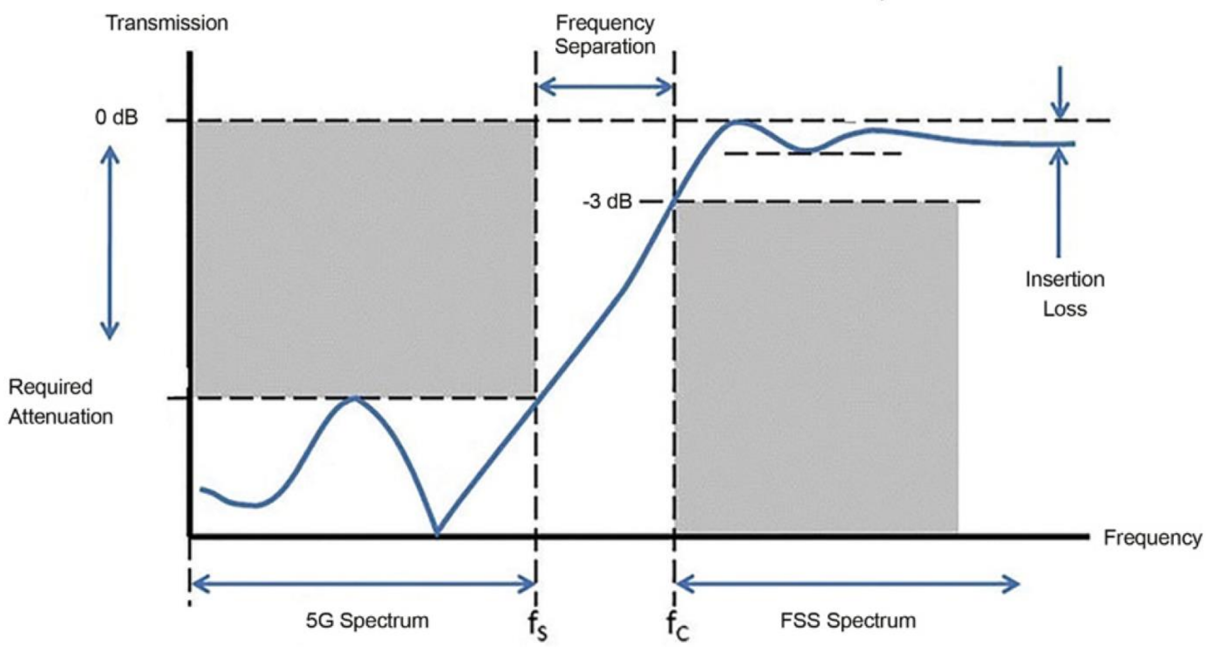


Figure 4: Filter and Guard Band

6. As shown in Figure 4 above, the filter could only be operated properly if there is frequency separation (i.e. Guard band) between the edge of the IMT/5G transmission and the FSS transmission, to provide the waveguide filter the necessary bandwidth to reject the 5G interference at the earth station. However, it is still important to note that the implementation of such filters on the FSS earth station receivers presents a certain number of drawbacks:
   i. Cost of filter and implementation rollout.
   ii. Impact on the receiver performances (e.g., filter insertion loss, increase of the system noise temperature, phase and group delay).

iii. Special enhanced filters for a response with rapid attenuation increase within lower guard bands will imply elevated insertion losses that may generate the need to change the antenna to maintain the original G/T (and station operation) and avoid service interruption. In addition, according to previous calculations made by satellite operators, we notice that for systems employing adaptive coding and modulation, the introduction of the enhanced filter will result in a reduction in throughput of over 30% in some cases. We are happy to share this analysis if necessary.

7. In addition, this frequency separation would guarantee some level of attenuation of the unwanted signals from the IMT/5G operations falling in the FSS ES receiving frequency band 3700-4200 MHz. As opposed to the emissions in the 3400-3670 MHz that can be mitigated by the implementation of a filter at the FSS earth station, the 5G/IMT unwanted emissions falling within the 3700-4200 MHz band cannot be filtered. Regulation on specific IMT/5G unwanted emissions limits versus frequency separation is key in this context to limit the impact of these unwanted emissions on adjacent band operating services.

8. *To summarise, it would be important to establish adjacent band protection criteria for FSS earth stations vis a vis 5G/IMT, e.g. a guard band in the IMT portion of the band, and an out-of-band PFD limit for IMT transmitters to protect FSS earth stations in the adjacent band.*

9. There are several countries that have done some field test experiment on how to deploy IMT including 5G, while preserving satellite services in the band 3400-4200 MHz. Below are some Asia Pacific countries that have performed field tests to study the coexistence between IMT and FSS, and implement the conclusion of those field test outcome into the 5G spectrum roadmap in their countries:

I. **Hong Kong**
IMT allocation: 3400-3600 MHz
Guard band: 100 MHz (3.6-3.7 GHz)
FSS allocation: 3700-4200 MHz
Filter retrofitted @ FSS earth stations with the following specifications:
- at least 55 dB rejection for the band below 3.6 GHz band
- Adoption of restriction zones to protect TT&C stations

The details on the OFCA decision on the reallocation of the 3.5 GHz band for IMT deployment including its applicable mitigation measures could be found at the following link:
https://www.coms-auth.hk/filemanager/statement/en/upload/441/ca_statements20180328_en.pdf

II. **Singapore**

IMT allocation: 3450-3650 MHz with 3600-3650 MHz and 3450-3500 MHz limited for indoor and underground use

Guard band: 50 MHz (3650-3700 MHz)

FSS allocation: 3700-4200 MHz

Filter retrofitted @ FSS earth stations with the following specifications:

- at least 45 dB rejection for the band below 3.65 GHz
- Adoption of 2 Exclusion zones to protect critical FSS operations (e.g. TT&C stations) and 5 precautionary zones for high density areas of C-band FSS operations

The details on the IMDA decision on the reallocation of the 3.5 GHz band for IMT deployment including its applicable mitigation measures could be found at the following link:
https://www.imda.gov.sg/-/media/Imda/Files/Regulation-Licensing-and-Consultations/Consultations/Consultation-Papers/Second-Public-Consultation-on-5G-Mobile-Services-and-Networks/5G-Second-Consultation-Decision.pdf

III. **China**

IMT allocation: 3300-3600 MHz with 3300-3400 MHz limited for indoor use

Guard band: 100 MHz (3600-3700 MHz)

FSS allocation: 3700-4200 MHz

Filter retrofitted @ FSS earth stations with the following specifications:

- at least 55 dB rejection for the band below 3.6 GHz.
- Adoption of interference coordination areas with a specific separation distance between IMT and FSS

The details on the MIIT decision on the reallocation of the 3.5 GHz band for IMT deployment including its applicable mitigation measures can be found at the following link (in Chinese language): http://www.srrc.org.cn/article22361.aspx.

IV. Beside the above 3 countries, **Indonesia** has recently performed field test experiments to study the coexistence between IMT and FSS in the band 3400-4200 MHz. Based on their field test experiments, the conclusions of their coexistence study between IMT and FSS are as follows:

IMT allocation: 3400-3600 MHz

FSS allocation: 3700-4200 MHz

Guard band: 100 MHz (i.e. 3600-3700 MHz)

- Additional Band Pass Filter with specifications 60 dB rejection for the band below 3.6 GHz

The above conclusion could be found in the attached document which have been submitted to AWG-27 meeting (Attachment: APT Description of Indonesian Sharing Study.pdf).

V. Since **Myanmar** is one of India's neighbouring countries, it is also worth mentioning their 5G spectrum roadmap in C-band with the intention of preserving their satellite services with the following conditions:
IMT allocation: 3400-3520 MHz
FSS allocation: 3625-4200 MHz
Guard band: 105 MHz (i.e. 3520-3625 MHz)

The above conditions could be found at the following link: https://www.ptd.gov.mm/Uploads/Reports/Attach/122020/200471330122020_Spectrum%20Roadmap%20(2020)'%20Facilitate%20the%20sustainable%20growth%20of%20Industry%20(Draft).pdf

10. It is also true that countries like **US** have paid millions of dollars and have compensated the FSS players/broadcasters to vacate the C band, so that the entire band is made available for IMT/5G. Of course, it is also a fact that not all incumbents have agreed to vacate the band. Given the fact that India cannot afford to do so, we must find suitable ways for peaceful and harmonious co-existence between the incumbent broadcasters (FSS) and the IMT players, and take necessary measures to restore the same quality of the service of the received signals, thereby ensuring that the quality of the transmissions that are currently being made will be maintained without imposing additional costs to satellite or earth station operators.

11. **Brazil**: In Brazil, the 3625-4200 MHz frequency band (C-band) is widely used by TV receive-only (TVRO) application in the fixed satellite service (FSS). The 3400-3600 MHz adjacent band can be used by International Mobile Telecommunications (IMT) systems, but many low noise block downconverters (LNB) of TVRO sold in Brazil don't have a C-band filter. Thus, it is likely that the low cost LNB used in TVRO receivers would be overloaded by the IMT-systems emissions within the LNB wideband receiver, even the IMT stations operating accordingly to international standards. A paper (attached) shows that both systems can coexist harmoniously depending on the characteristics of the IMT system and on the FSS receiver specifications.

12. **GSMA**: Additionally, studies conducted by GSMA indicate that when interference is sourced from an IMT Macro deployment, the results indicate that an 18 MHz Guard Band would allow an FSS protection criterion of I/N = -10dB to be satisfied on the FSS links over all combinations of spectrum masks considered in their study.
    a. The margins available between aggregate interference and noise are in the range -3.02 to -22.86 dB. The GSMA study also notes that this Guard Band

delivers some very significant margins for the combinations of spectrum masks with the best Out-of-Band attenuation. If the interference is sourced from an IMT Small Cell deployment, then a 0 MHz Guard Band allows for the FSS protection criterion of I/N = -10 dB to be satisfied on the FSS links over all combinations of spectrum masks. Margins are in the range -0.91 to -8.61dB over the FSS links and all combinations of spectrum masks, again with very significant margins for some spectrum mask combinations. Therefore, based on the assumptions and inputs used in the GSMA study, it can be concluded that an 18 MHz Guard Band mitigates co-frequency interference to acceptable levels, covering both Macro and Small Cell analyses.

In view of the above data, two distinct views in case of adjacent band coordination issues and one for in-band coordination issues have emerged, which are given below.

VIEW A: For adjacent band coordination issues:

I. View A.1:

a. In view of the above, some experts are of the opinion that to mitigate interference from provision of IMT up to 3670 MHz in C-band, it is desired that the 5G operators use special filters to restrict any out of band emissions which may affect satellite signals in adjacent bands. Additionally, it has been suggested that appropriate high quality Band Pass Filters can be made available by the authorized body, to be used by the DPOs (Cable TV, IPTV and HITs operators) for per downlink chain for receiving the satellite TV signals.

b. These experts feel that for the specific case of protection of FSS services in the 3700-4200 MHz, it is important that a process be defined by the Authority to ensure that defined adjacent band protection levels are respected, thereby ensuring that there is ample frequency separation for the FSS filters to efficiently mitigate any interference from 5G/IMT in the band 3300-3670 MHz and ensuring that key FSS earth station sites are protected through the implementation of exclusion zones.

c. The Process should also clearly define that costs associated with installation of such filters shall be the responsibility of the IMT/5G Operator.

II. **View A.2:**

a. Keeping in view that C band and extended C band above 3705 MHz is extensively used by Satellite Broadcasters, to avoid any possible interference to them, it may be advisable to use the band till the upper limit of 3670 MHz while keeping a guard band of 35 MHz on the upper side, between the IMT Networks and the Broadcasters who are using 3705 MHz spectrum band and upwards.

VIEW B: For in-band coordination issues

I. Interference issues between operators could be solved through consultation and coordination and this has been proven to work effectively in India from past experiences. It is desired that an approach of mutual coordination should be adopted.

Having presented the above views for adjacent band and in-band coordination issues, **BIF is unable to make any clear Recommendations in this case and wishes** to leave it to the Authority to kindly decide whatever is most appropriate.

Q.17 In case your response to the above question is in affirmative, a. whether there is a need to prescribe provisions such as clock synchronization and frame structure to mitigate interference issues, as prescribed for existing TDD bands, for entire frequency holding or adjacent frequencies of different TSPs? If yes, what should be the frame structure? Kindly justify your response. b. Any other measures to mitigate interference related issues may be made along with detailed justification.

BIF Response

No Comments.

D) Issues related to Roll-out Obligations

Q.18 Whether the roll-out obligations for 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2300 MHz and 2500 MHz as stipulated in the NIA for last auctions held in March 2021 are appropriate? If no, what changes should be made in the roll out obligations for these bands?

BIF Response

Based on the Coverage obligations, DoT have clearly stated in NIA 2021/2016 that there is no need for any new requirement of rollout obligations if TSPs have completed the rollout for any single technology in any band. Hence, the same response should be aligned to 5G as well. Considering ease of doing business, rollout obligations should not a compulsion for TSPs. Only for new entrants, this should be obligated/mandated.

Q.19 What should be associated roll-out obligations for the allocation of spectrum in 526-698 MHz frequency bands? Should it be focused to enhance rural coverage? Kindly justify your response.

&

Q.20 What should be associated roll-out obligations for the allocation of spectrum in 3300-3670 MHz frequency band? Kindly justify your response.

&

Q.21 What should be associated roll-out conditions for the allocation of spectrum in 24.25 to 28.5 GHz frequency range? Kindly justify your response.

BIF Response

1. 5G, unlike the preceding mobile generations, is not only meant for enhanced Broadband penetration but also for digital transformation of other verticals viz. healthcare, transport, manufacturing, logistics, smart cities and others. It is therefore essential, that rollout obligations include use cases with at least one industry vertical each successive year.
2. Also, for the lower bands viz. 600 and 700 MHz, there should be obligations for enhancing rural coverage progressively each year.
3. For legacy spectrum bands, Roll-out obligations should be left to the operators depending on their respective business models and plans. However, this may be subjected to boundary conditions of utilisation of the spectrum in the given service area within 2 years of allocation, failing which the spectrum would be considered as withdrawn.

Q.22 While assessing fulfilment of roll out obligations of a network operator, should the network elements (such BTS, BSC etc.), created by the attached VNO, be included? If yes, kindly suggest the detailed mechanism for the same. Kindly justify your response.

BIF Response

No. VNOs are not associated with creation of Digital Infrastructure viz. Core or RAN Networks. They are into delivering services using the Core and RAN networks of the TSPs. Hence the network rollout obligations shall remain the exclusive preserve and obligation of the network operator only.

E) Issues related to Spectrum Cap

Q.23 Whether there is a need to review the spectrum cap for sub-1 GHz bands? If yes, what should be the spectrum cap for sub-1 GHz bands. Kindly justify your response.

BIF Response

1. India is at the cusp of Digital Transformation. We need more of 5G use cases across all verticals to accelerate the pace of ushering in a USD 1Tn Digital Economy. Enhanced Mobile Broadband is a key requirement for that. To meet the explosive data and enhanced capacity needs, we need adequate quantity of spectrum in each band.
2. The current spectrum cap conditions have effectively served the interest of consumers, competition and the Industry. Spectrum caps have served well in the era when there were a large number of operators – up to ten or more, in comparison to today's typical number of 3-4 major mobile networks in a national market.
3. To cope with the pressures of Broadband and explosive data requirements, BIF believes that spectrum caps need to be significantly relaxed. This will be crucial for the data explosion and the advent of 5G in India.
4. Over time, spectrum caps have been substantially modified and even removed in some countries in light of progress in wireless technology, growing demands for mobile services, and the attribution of new spectrum bands for commercial mobile

communications. Many countries have done away with spectrum caps. In North America, the major developments that are relevant for the development of mobile broadband, the attribution of spectrum and issues of competition, include the removal of spectrum caps since 2000, on the grounds that the mobile market had become sufficiently competitive. Hence the rationale behind them was no longer valid. Europe did not introduce spectrum caps but relied on conditions of mobile licensing, for example the number of licenses that were issued, to ensure competitiveness in the mobile market.

5. For Broadband, more the spectrum available, the better it is. Also, as per global best practices, many countries have done away with Spectrum Cap. However, keeping in view the Indian situation, removal of spectrum cap could possibly lead to monopoly/duopoly situations. Hence, spectrum cap may be retained for now.
6. For sub-GHz bands, a cap equal to overall, i.e. 35% is more relevant since supply in sub-GHZ is being increased with new bands.

Q.24 Keeping in mind the importance of 3300-3670 MHz and 24.25- 28.5 GHz bands for 5G, whether spectrum cap per operator specific to each of these bands should be prescribed? If yes, what should be the cap? Kindly justify your response.

BIF Response

In light of the rationale provided in above response to Q23, we advocate there is need to retain the spectrum caps as of now.

Q.25 Whether there should be separate spectrum cap for group of bands comprising of 1800 MHz, 2100 MHz, 2300 MHz and 2500 MHz bands together? If yes, kindly suggest the cap along with detailed justification.

BIF Response

No.

Q.26 Whether overall spectrum cap of 35% requires any change to be made? If yes, kindly suggest the changes along with detailed justification.

BIF Response

As highlighted in the responses above, spectrum caps maybe retained as of now.

Q.27 For computation of overall spectrum cap of 35%, should the spectrum in 3300-3670 MHz and 24.25-28.5 GHz bands be included? Kindly justify your response.

BIF Response

Response as in Q23.

Q.28 Any other suggestion regarding spectrum cap may also be made with detailed justification.

BIF Response

None.

F) Issues related to Surrender of Spectrum

Q.29 What should be the process and associated terms and conditions for permitting surrender of spectrum for future auctions? Kindly justify your response.

&

Q.30 What provisions may be created in the spectrum surrender framework so that any possible misuse by the licensees, could be avoided? Kindly justify your response.

BIF Response

1. In this regard, it is noted that provision for surrender of spectrum has been created by the Government as part of the Telecom Reforms. Provision for surrender of spectrum was one part of structural reforms.
2. As an example, FCC has a regulatory framework where spectrum was repurposed and refarmed on a case-by-case basis to ensure that any spectrum lying fallow is taken away for the greater good and also existing incumbent users with active use like Government, Satellite and Broadcasters be incentivized to surrender the spectrum.
3. Prior to this, the only practical option available with TSPs to surrender surplus spectrum was through the process of spectrum trading. As per the spectrum trading guidelines, the TSPs are permitted to trade their partial/entire spectrum holding to another TSP after a lock in period of 2 years post assignment of such spectrum.
4. The Government has decided to create a provision for surrender of spectrum after a period of 10 years from date of allocation of such spectrum. To surrender the spectrum, TSPs will be required to inform about its decision to surrender the spectrum to the Government, one year prior to surrendering such spectrum. It is understood that the period of 10 years would be counted from the date of assignment of such spectrum.
5. We are of the opinion that detailed T&Cs for permitting surrender of spectrum should be in sync with the current processes and terms as given in the Spectrum Trading guidelines.

Q.31 In case a TSP acquires spectrum through trading, should the period of 10 years to become eligible for surrender of spectrum, be counted from the date of original assignment of spectrum or from the date of acquisition through spectrum trading? Kindly justify your response.

BIF Response

It should be counted from the date of acquisition of spectrum by the current lessee through the process of spectrum trading, as the spectrum allocation validity is also from the date of spectrum allocation.

Q.32 Whether provision for surrender of spectrum should also be made available for the existing spectrum holding of the TSPs? If yes, what should be the process and associated terms and conditions? Kindly justify your response.

BIF Response

We are of the opinion that detailed T&Cs for permitting surrender of spectrum should be in sync with the current processes and terms as given in the Spectrum Trading guidelines.

Q.33 Whether spectrum surrender fee be charged from TSPs? If yes, what amount be levied as surrender fee? Kindly justify your response.

BIF Response

We are of the opinion that no surrender fee should be charged. This is because if a TSP is surrendering spectrum, the Government can very well put to auction such surrendered spectrum in a timely manner as the TSP is required to inform one year in advance.

G) Issues related to Valuation and Reserve price of Spectrum

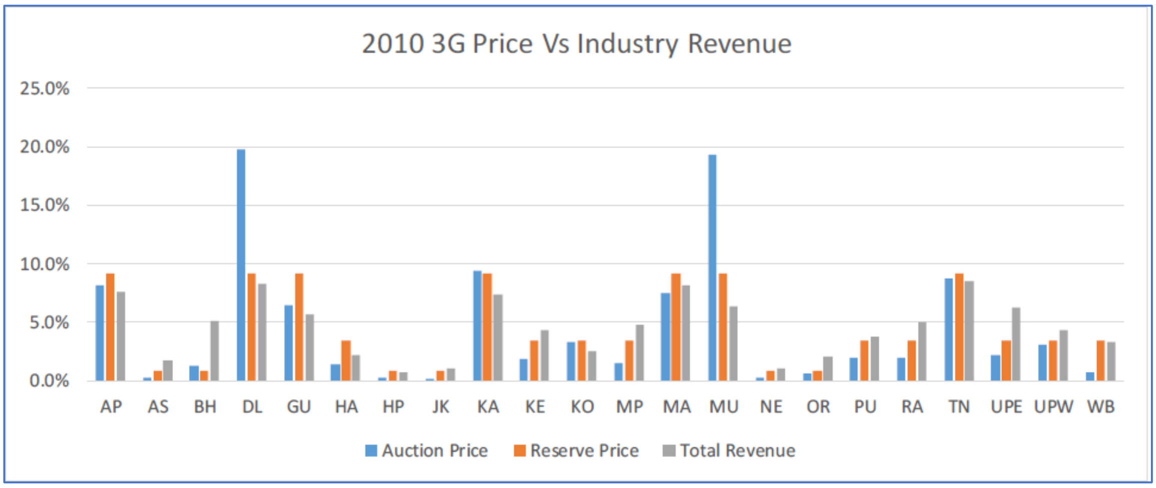
Q.34 Which factors are relevant in the spectrum valuation exercise and in what manner should these factors be reflected in the valuation of spectrum? Please give your inputs with detailed reasoning.

BIF Response

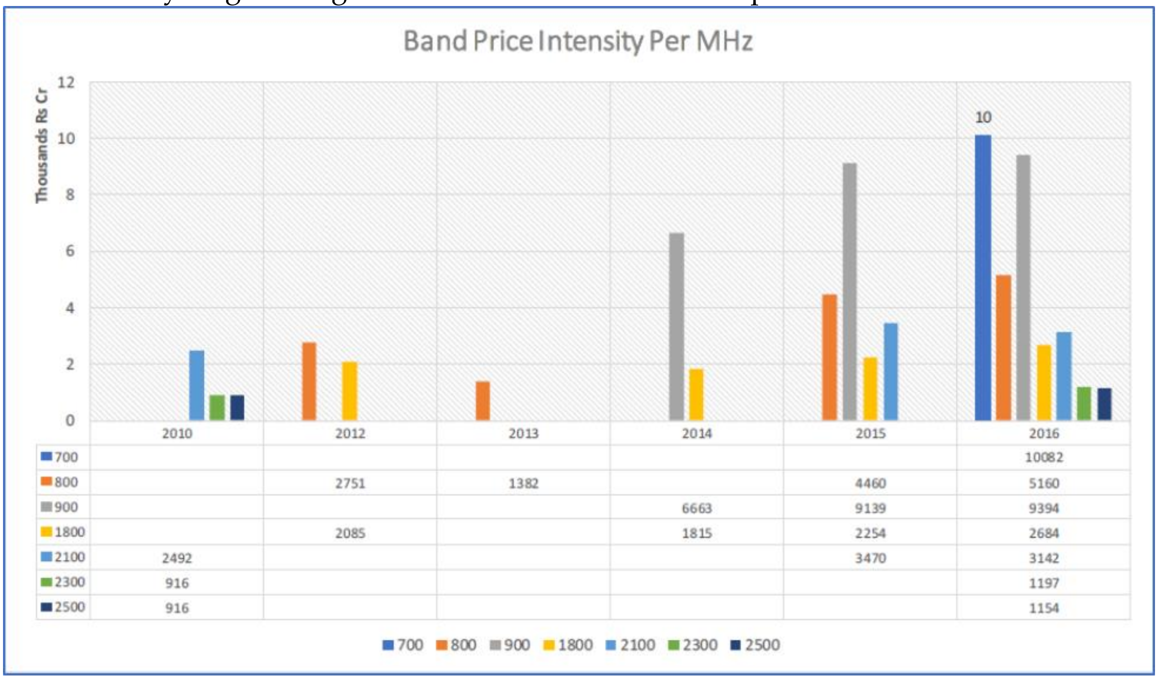
1. Since a spectrum auction is held for allocating spectrum in an open and transparent manner and result in true market discovery, there are two parameters that define success in an auction – the market/clearing price is significantly above reserve price, arrived by vibrant market discovery and the sale of substantial amount of spectrum put up for auction.
2. A review of recent auctions around the world reveals that most have been successful in selling the entire spectrum offered in auctions. To illustrate, in the UK 5G and 4G spectrum auctions held in 2018 and 2013, respectively, 100% spectrum was sold. In stark contrast, in the Indian 2016 mega auctions where a total of 2350 MHz in 7 bands was put up for auction in 22 circles, only 964 MHz, or barely 41% was procured by the industry. In the March 2021 auction, 63% of spectrum remained unsold. The success of spectrum auctions is also defined by the market/clearing price being significantly above reserve price, i.e., the auction process must help discover the true market price of the spectrum. Here again, we see a marked difference between the Indian and UK spectrum auctions. In the 5G UK auction, the total 190 MHz in 2.3 GHz and 3.4 GHz were sold for £1.35 billion more than 19 times of the reserve price of £70 million. In 2021 in India, while 700 MHz got no takers at all, other auctions saw similarly poor enthusiasm and responses, with the reserve price (RP) turning out to be the final clearing price in most cases. Effectively, there was no market discovery of spectrum prices in India.

3. We believe that high reserve price is one of the major reasons for spectrum remaining unsold in the previous auction and the prices discovered in the Indian spectrum auctions are not a true reflection of its value.
4. It all started with an overenthusiastic bidding by the operators in the year 2010 (3G and BWA auction) and became worse at the time of the renewal auctions of 900 MHz band in 2014 and 2015. The 2010 auctions were held at the backdrop of the license cancellation when spectrum was earlier given to new operators at a subsidized rate (without auctions). This increased the number of bidders, thereby raising the price of spectrum disproportionately high. In 2014 and 2015, the operators whose licenses were expiring had no choice but to bid enormous amount to stay in business. Apart from these few instant, the spectrum auctions in India remained largely subdued resulting in a large quantum of unsold spectrum. But the reserve price always stayed high and was never curated to correct these abbreviations, resulting in huge chunks of unsold spectrum and whatever got sold was taken only at the reserve price. This high and distorted reserve price, coupled with forced bidding (to protect existing business), totally destroyed the value of spectrum acquired in the auctions.
5. The issues with spectrum pricing can be summarized as:
    a. Low proportion of spectrum sold
    b. Few circles with premium over reserve price indicate no real market discovery
    c. No correlation between prices and revenue
    d. No correlation between prices across bands
    e. Prices increasing exponentially
    f. Anomaly in calculation (700 MHz price)
    g. Indian price among the highest although tariffs are lowest in India
    h. High outflow in buying more spectrum

a. **<u>Low proportion of licensed spectrum sold</u>**: Except for 2010 auctions due to artificial scarcity and lack of roadmap, much spectrum has remained unsold. In 2014, 900 MHz got sold 100% because of license extension/renewal compulsions. Thus, it is the artificial scarcity combined with license extension/renewal compulsions which led to spectrum sale in the initial years. In 2016, the entire 700 MHz, and 60% of the total spectrum put for sale remained unsold due to unreasonably high prices. Despite the deficiency of spectrum for Indian telecom operators, only 62% spectrum put-up for auction so far has been sold - indicating that Reserve Price was too high.
b. **<u>Few circles with premium over reserve price indicate no real market discovery</u>**: In most cases, reserve price turned out to be clearing price. Hence, there was no market discovered price.
c. **<u>No correlation between prices and revenue:</u>** The value of licensed spectrum is not proportional with the market realities. There is no correlation of value amongst different bands in same circle as well as band-wise correlation amongst various circles.

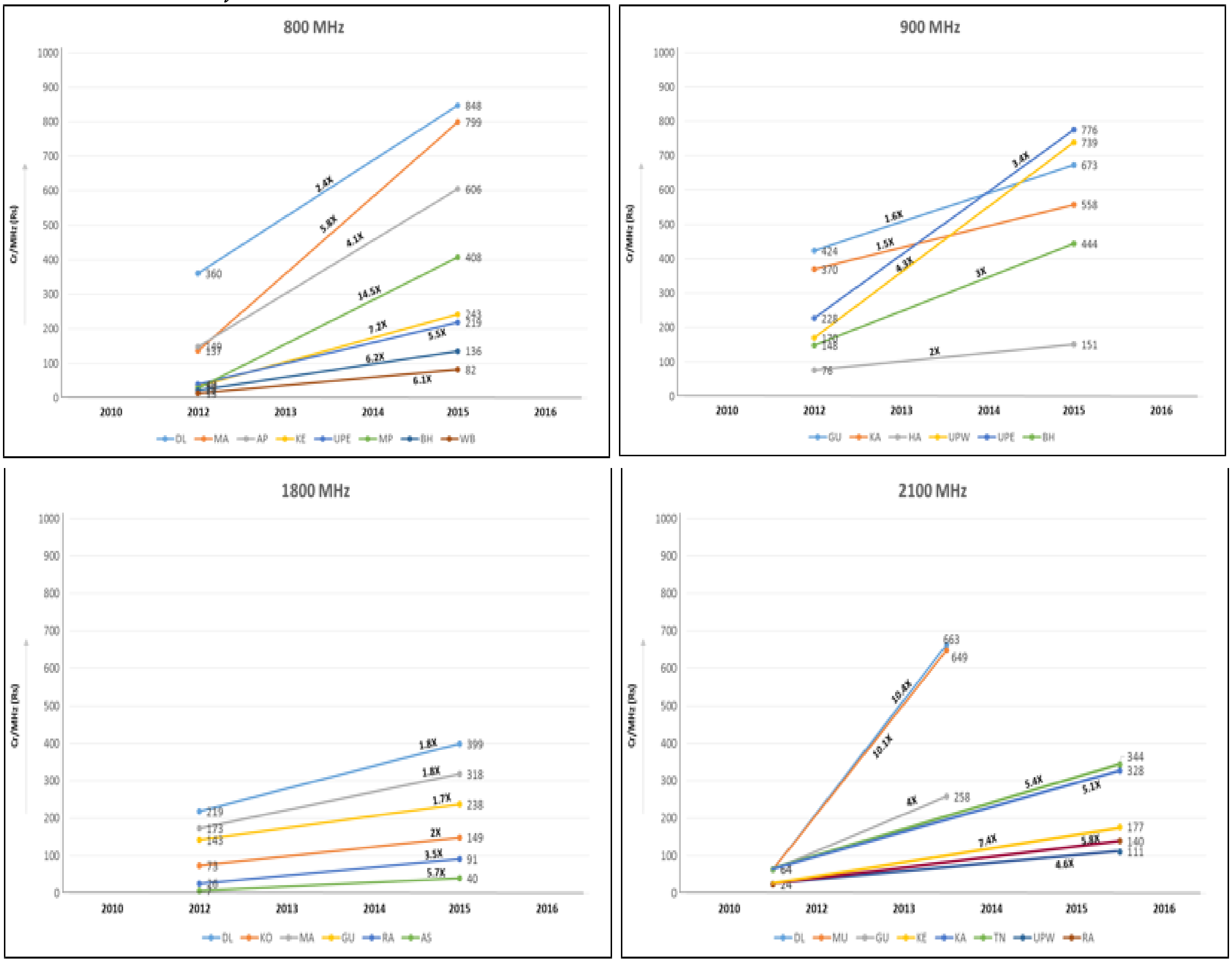


d. **<u>No correlation between price across bands</u>**: At present, the prices of lower frequency bands are not always higher. Higher revenue circles have lower prices than lower revenue circles.



e. **<u>Prices increasing exponentially</u>**: Reserve prices in various licensed bands have increased exponentially over the years.

Increase in Prices of 800 MHz, 900 MHz, 1800 MHz and 2100 MHz Band



f. **<u>Anomaly in calculation (700 MHz price):</u>** A serious challenge in the last auction which did not witness any sale of 700 MHz was the reserve price of 700 MHz band, which was set at 4x of the 1800 MHz band due to a calculation error of TRAI. TRAI assumed that radio waves in 800 and 900 MHz band travelled 2 times more compared with 1800 and 2100 MHz and priced 800 and 900 MHz band at 2 times that of 1800 and 2100 MHz band. TRAI broke the logic while calculating price of 700 MHz band and linked with that of European Auctions of 800 MHz and, even so, made serious arithmetical errors in the calculation which resulted in an exorbitantly high multiplier for 700 MHz, as shown in the table alongside.

Country (£/MHz/pop)	800 MHz	1800 MHz	Ratio
France	0.5809		-
Germany	0.6217	0.0218	28.5
Italy	0.6993	0.2252	3.1
Portugal	0.3616	0.2651	1.4
Spain	0.4043		-
Sweden	0.3174	0.1788	1.8
As per TRAI : Total	**2.99**	**0.69**	**4.3**
Actual : Total (Countries with both 800 and 1800 MHz bands)	**2.00**	**0.69**	**2.8**
(-) Outlier Germany : Total (Removing Germany for real comparison)	**1.38**	**0.67**	**2.1**

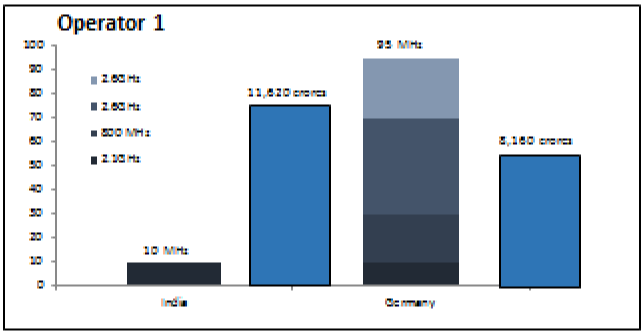
The above point is borne out also by analysis of the auction results below which shows that the Indian 700 MHZ auction reserve price was effectively 46 times more than the US auction price of 600 MHz.

Parameters	USA	India	
Population (mn) No. of Subscribers (mn)* ARPU (USD)*	325 377 39.9	1,310 997 2.71	
Band	**600 MHz**	**800/1800/2100/2300/2500 MHz**	**700 MHz******
MHz Bid (USD Bn) Price/MHz (USD Bn)	70 19.77 0.28	56 10.17 0.18	70 61.84 0.88
ARPU Multiple (x) Price Multiple (x) **Price Multiple adjusted for ARPU (x)**		15 0.6 **9**	15 3 **46**
*Data as of 3Q16; ** Reserve Price has been taken for calculation			

It can be seen from the above that, even if 700 MHz not considered and only the other bands put up in 2016, the Indian prices are way above US levels by 9 times.

g. **<u>Indian price among the highest although tariffs are lowest in India</u>**: In 2010, in the 2100 MHz spectrum band, comparison with the German auction (concluded within 24 hours of the Indian event) revealed that the Indian auction reserve prices were unreasonably high:

2.1 GHz Comparison – India vs Germany – Unreasonably High Price in India



	India Operator	Germany Operator
Auction End Date	19 May 2010	20 May 2010
Total Spectrum	10MHz	95MHz
• 800MHz	-	2x10 MHz
• 2.1 GHz	2x5MHz	2x5 MHz
• 2.6 GHz	-	2x20 MHz
• 2.6GHz (unpaired)	-	25 MHz
Tenure	20 years	15 years
Price	Rs. 11,620 crores	Rs. 8160 crores
Price /MHz	Rs. 1,162 crores/MHz	Rs. 86 crores/MHz
Price /MHz/year	**Rs. 58 crore/MHz/year**	**Rs. 5.73 crores/MHz/year**

2010 Indicators	India	Germany
Subscribers Million	680	105
Mobile Revenues USD Billion	25	26
ARPU USD/sub/month	3	21

- 6.5 times more subscribers, but equivalent / lower revenues.
- 7 times lower ARPU

- Spectrum auctions held simultaneously
- 11% the spectrum went at 1.4 times the price
- **Paid a 10 times higher price for spectrum for 7 times lower ARPU (return) in India as compared to Germany**

India auction price was effectively 70 times more than Germany auction price

The industry has already spent a total of INR 3.5 lakh Cr (approx.) to acquire 31 MHz. The industry will have to spend additionally INR 13.6 Lakh Cr (at reserve price) to acquire 100 MHz additional spectrum.

6. **The price discovered in the last auctions should not be treated as the market price.** Rather BIF is of the view that spectrum should be treated/viewed as the 'raw material' for socio-economic benefit for the nation rather than be seen as a measure to fill /augment the exchequer revenues.
7. **Reserve prices play a pivotal role in the auction design**. There is a need to review the auction rules for reserve prices, which are out-of-line with international norms and result in non-discovery of market prices. Reserve prices should be set at levels that are high enough to keep non-serious bidders at bay, but low enough to achieve vibrant price discovery. In past, the reserve prices were mostly linked to the most current auctions. This resulted in its exponential increase, as it was hardly ever corrected to curate market distortions.
8. **Calculating reserve prices correctly is critical for ensuring a properly designed auction.** It must be such that it is able to steer the auction "price discovery system" to reflect the optimal value of the "band" and the "circle" in question. Currently, the prices emanating out of past auction are highly erratic and arbitrary. If not then how can the price of the 800 MHz band (with better propagation characteristics) be valued at 50% of the 900/700 MHz band?
9. **Hence, well-defined formulae based on sound assumptions** will not only increase transparency in the system but also will empower the government officials with the ability to take the right decision. It would also help prevent changing rules in the middle and will make

the spectrum auctions more robust, thereby motivating the companies to buy more spectrum - leading to better network coverage and connectivity - enhancing consumer interests.

10. **The formula for calculating reserve price must be declared in advance**, which can help in:
    a. Avoiding/minimizing bidding distortions
    b. Promoting responsible bidding
    c. Ensuring optimal price

11. The present methodologies need to be corrected for the following anomalies:
    a. Using incorrect price escalation metric: Telecom business does not correlate with financial business. MCLR is a reflection of financial business and not telecom.
    b. Using last auction price as a reference for market determined price.
    c. Using mean (instead of median) for aggregating the prices emanating out of various models. Median is the correct statistical tool for aggregation and not mean.

12. The inputs needed for calculating reserve price for future auctions are:
    a. Auction Prices of all past years.
    b. Propagation weights of all spectrum bands. Cost Inflation Index for past years.
    c. For the valuation of spectrum in the 1800 MHz band, the revenue surplus approach is most appropriate.
    d. Indexation is not required as we have recommended that reserve price should not be referenced back to the last auction price. However, if required, any indexation should be done using the cost inflation index. The spectrum pricing recommendations suggest a reserve price to valuation ratio of 80%. This is another factor that results in high reserve price and may lead to unsuccessful auctions.
    e. The reserve prices should be set at levels that are high enough to keep non-serious bidders at bay, but low enough to achieve vibrant price discovery. Since, reserve price is just the starting point of auctions, we recommend a reserve price to valuation ratio of 50% and let the market forces determine how the final auction prices pan out and lead to true market discovery of prices. Valuation of all other bands could be benchmarked to 1800 MHz band.

13. 5G uses higher radio frequencies that are less cluttered. This allows for it to carry more information at a much faster rate. While higher bands are faster at carrying information, there can be problems with sending over large distances. They are easily blocked by physical objects such as trees and buildings. In order to circumvent this challenge, 5G will utilize multiple input and output antennae to boost signals and capacity across the wireless network. 5G is a completely different technology and requires a different approach than 2G, 3G and 4G. In 2018, the Finnish regulator and the national mobile operators managed to agree to a mutually beneficial split of 5G spectrum (also in the 3.5 GHz band) for a fair price, thus removing the need for an auction. Such agreements will not always be possible but are an option when consensus can be reached.
14. There appear to be significant difficulties, challenges & inaccuracies posed as a result of the current methodology for valuing spectrum in India. These may have arisen at different points

in time and in different circumstances over several years. While these might have been relevant or required at those times, many legacy issues and environmental factors have changed significantly since then. Hence, it would be advantageous for India to revisit the methodology followed and make appropriate revisions. India stands at a juncture where auction process has to be designed very carefully and cautiously to overcome the problems issued in the past. India's open and transparent auction methodology must be reinforced with a kind of market-based mobile access spectrum management that allows for the fair discovery of the market value for spectrum, with reserve prices playing a pivotal role in the success of auctions.

15. While arriving at the calculation of Reserve Price, other perspectives likes Per Capita income, ARPU, GDP, Inflation, etc. and moreover, sustainability of the Telecom industry in mid-long term must also be taken into consideration.

Q.35 In what manner, should the extended tenure of spectrum allotment from the existing 20 years to 30 years be accounted for in the spectrum valuation exercise? Please support your response with detailed rationale/ inputs.
&
Q.36 What could be the likely impact of the following auction related telecom reforms announced by the Government in September 2021 on the valuation of various spectrum bands? (a) Rationalization of Bank Guarantees to securitize deferred annual spectrum payment instalments in future auctions (b) No spectrum usage charges (SUC) for spectrum acquired in future auctions (c) Removal of additional SUC of 0.5% for spectrum sharing (d) Provision for surrender of spectrum In what manner, should the above provisions be accounted for in the valuation of spectrum? Please support your response with detailed justification.

BIF Response

1. The telecom reforms in form of (a) Rationalization of Bank Guarantees to securitize deferred annual spectrum payment instalments in future auctions; (b) No spectrum usage charges (SUC) for spectrum acquired in future auctions; (c) Removal of additional SUC of 0.5% for spectrum sharing; (d) Provision for surrender of spectrum are incentives that have been given to telecom sector in order to overcome the legacy issues and financial stress that the sector has been facing for last many years.
2. In no manner, these incentives should have a bearing on the valuation of spectrum and the reserve price of spectrum, which is the starting point of the auction. These reforms are incentives given to the telecom sector and any effect of these reforms in raising the reserve price of spectrum will have a negative bearing on the results of the auction.
3. In fact, in the event that Net Revenue Realisation is the same over 30 years, as was the case 20 years earlier, for it to truly qualify as operator friendly reforms, the Outgo on account of Spectrum Charges to be paid per annum would be at least 2/3=66% lower than if the Spectrum Charges were to be paid over 20 years

Q.37 Whether the auction determined prices of March 2021 auction be taken as the value of spectrum in the respective band for the forthcoming auction in the individual LSA? Should the prices be indexed for the time gap (even if less than one year or just short of one year)? If yes, please indicate the basis/ rate at which the indexation should be done, with reasons.

BIF Response

a. **Spectrum Lying Idle Causes an Irretrievable Economic Loss**
    1. The greatest value of radio spectrum lies in its usage. Idle or unused spectrum benefits no one – neither the government, nor the economy, society or consumers and results in an irretrievable loss. The sale of spectrum results in direct upfront revenue generation as well as the indirect long-term socio-economic gains. Through auctions held since 2010, the Government has been able to directly sell spectrum worth INR 4 lakh crores (USD 47.14 Billion). The Government has gained about INR 4 lakh crores through license fee, SUC and service tax over the same period.
    2. There are many indirect benefits that flow – according to a report by ICRIER, a 10% increase in mobile penetration delivers a 1.9% increase in the rate of State GDP growth. Against this background, one can make back of the envelope calculation of economic losses caused due to spectrum remaining unsold. In the October 2016 auctions, deemed to be India's largest spectrum sale, more than 1300 MHz of radio spectrum (approximately 59%) remained unsold. India had 762 million active mobile connections in 2016, served by over 3800 MHz of spectrum allocated to licensees. This would indicate that the idle spectrum with the government could enable connectivity for roughly 278 million additional active connections or 21% of the total Indian population. Applying the result of the ICRIER economic impact study, the financial cost of this idle spectrum can then be estimated at INR 5.40 lakh crores, or over 160% of the financial benefit of INR 3.30 lakh crores from all spectrum auctions so far. This is a rough conservative estimate and actual losses may far exceed this figure. Auctions leading to unsold spectrum cause huge loss to the economy.

b. **Loss of Consumer Surplus**
    1. High spectrum costs lower the incentives to invest in network expansion and upgrades and lead to higher consumer prices. In price sensitive markets such as India, this adverse impact on consumers can significantly delay both the rollout as well as the eventual adoption of new services. The lost consumer surplus far outweighs any gain from auction revenues.

c. **Failed Auction Could Fail Digital India**
    1. If auctions are not successful, the ones who get most disadvantaged are the weaker sections of the society, as they are the ones who are deprived of the benefits of technology. This aspect is of particular relevance to India with its high proportion of low-income citizens as well as the strong National Vision of moving to Digital India. Lesser spectrum allocation to the sector results in services not reaching to weaker as well as remote/rural subscribers due to higher price of the service offering or high cost of roll-out. An overload of subscribers per MHz of radio spectrum, as would be

emblematic of spectrum starved regimes, may even manifest as generally poor quality of services.

d. Consolidated Market Desires Optimum Spectrum Use

1. Around 2008, there was hyper-competition in the Indian telecom market with as many as 14 players in some circles. With cancellation of licenses following the February 2012 judgment of the Hon'ble Supreme Court, and the consolidation that followed coupled with financial burden on the sector, the market has now reached a stage where there are only 4 players left in the market including the state owned player. Auctions were relevant or required for allocating 2G, 3G and 4G spectrum in those times but it is no longer the case as the market structure has changed fully. As we are advancing towards 5G and higher technologies, any duplication of resources or their under-utilization is undesirable and unacceptable in a country like ours. Spectrum hungry applications will require optimum use of spectrum, and auctions which fail to sell the 'much in demand' spectrum owing to their faulty design, need to be done away with.
2. A lot of countries are realizing that the most successful auctions aren't the ones that bring in the most money. "The objective of awarding the frequencies was not to maximize auction revenue, but to allocate the frequencies efficiently to ensure excellent mobile communications services for Switzerland," the country's regulator (ComCom) stated after awarding spectrum in bands including 3.5 GHz in 2019.

Thus, as highlighted, there appear to be significant difficulties, challenges & inaccuracies posed as a result of the current methodology for valuing spectrum in India. These may have arisen at different points in time and in different circumstances over several years. While these might have been relevant or required at those times, many legacy issues and environmental factors have changed significantly since then. Hence it would be advantageous for India to revisit the methodology followed and make appropriate revisions. India stands at a juncture where auction process has to be designed very carefully and cautiously to overcome the problems issued in the past. India's open and transparent auction methodology must be reinforced with a kind of market-based mobile access spectrum management that allows for the fair discovery of the market value for spectrum, with reserve prices playing a pivotal role in the success of auctions.

So, the auction determined prices of March 2021 auction should not be taken as the value of spectrum in the respective band for the forthcoming auction in the individual LSA. We have provided detailed methodology and rationale as to how spectrum valuation should be done in Q34 above.

Q.38 If the answer to the above question is in negative, whether the valuation for respective spectrum bands be estimated on the basis of the various valuation approaches/methodologies being followed by the Authority in the previous recommendations, including for those bands (in an LSA) for which either no bids were received, or spectrum was not offered for auction?

BIF Response

We have provided rationale to choose a different methodology and have suggested some approaches which could be possibly adopted in this regard, in response to Q34 above.

Q.39 Whether the method followed by the Authority in the Recommendations dated 01.08.2018 of considering auction determined prices of the auctions held in the previous two years be continued, or the prices revealed in spectrum auctions conducted earlier than two years may also be taken into account? Kindly justify your response.

BIF Response

No. The reason and rationale for the same has been provided in response to Q34 above.

Q.40 Whether the valuation exercise be done every year in view of the Government's intention to have an annual calendar for auction of spectrum? Please support your response with detailed justification.

BIF Response

Yes.

In light of Government's announcement that spectrum auction will take place each financial year going forward, the valuation exercise maybe reviewed in light of the results/outcomes of spectrum auctions in each preceding year and the market trends that are visible.

Q.41 Whether there is a need to bring any change in the valuation approaches/ methodologies followed by the Authority for spectrum valuation exercises in view of the changing dynamics in the telecom sector largely due to the usage of various spectrum bands by the TSPs in a technologically neutral manner? If yes, please provide suggestions along with a detailed justification about the methodology.

BIF Response

Yes. We have provided and suggested some new approaches/methodologies in light of the changing dynamics and trends in this sector.

Q.42 In your opinion, what could be the possible reasons for the relative lack of interest for the spectrum in the 2500 MHz band? Could this be attributed to technological reason(s) such as development of network/device ecosystem or availability of substitute spectrum bands or any other reasons(s)? Please support your response with detailed justification.

BIF Response

1. In view of the repeated lack of interest shown by the operators both in 2018 and 2021 spectrum auctions as it was left completely unsold and due to lack of sufficient development of IMT/5G use cases in this band, we think high reserve price as one of the important parameters that has led to this situation. It may be advised to review the

Reserve Price in this band and probably unconventional methods for utilisation of spectrum in this band.
2. We have provided in response to Q34 above, the actual outcomes in the previous auctions in this particular band which will help provide possible conclusions as regards the question asked.

Q.43 Whether the March 2021 auction determined prices be used as one possible valuation for the spectrum in 2300 MHz band for the current valuation exercise? If yes, should these prices be indexed for the time gap and at what rate? Please justify your response.
&
Q.44 Whether auction determined prices of October 2016 (i.e. for the auction held earlier than two years) be used as one possible valuation for the spectrum in 2500 MHz band for the current valuation exercise? If yes, should these prices be indexed for the time gap and at what rate? Please justify.

BIF Response

1. 2300 and 2500 MHz bands represent a set of spectrum bands that can be reasonably considered together with regard to usage in 4G/LTE networks. Therefore, a factor of 0.83 applied to these spectrum bands on the Reserve Price of 1800 MHz band may be reasonable, as suggested in the recommendation of 2100 MHz. Hence, the Reserve price of these bands may be 0.83 times the Reserve Price of 1800 MHz.
2. Additionally, this should be looked from other perspectives also like Per Capita income, ARPU, GDP, Inflation, etc. and moreover, sustainability of the Telecom industry in mid-long term. Reserve price should be referenced with the incremental revenue a band can generate. Simply looking at relative efficiency is not a sustainable approach. In fact, in 5G, higher bands will need more densification, and hence more CAPEX/OPEX. So relation to incremental revenue becomes crucial, given the industry's financial health.

Q.45 Whether the value of the spectrum in 2300 MHz/ 2500 MHz bands should be derived by relating it to the value of spectrum in any other band by using technical efficiency factor? If yes, which band and what rate of efficiency factor should be used? If no, then which alternative method should be used for its valuation? Please justify your response with rationale and supporting studies, if any.

BIF Response

1. 2300 and 2500 MHz bands represent a set of spectrum bands that can be reasonably considered together with regard to usage in 4G/LTE networks. Therefore, a factor of 0.83 applied to these spectrum bands on the Reserve Price of 1800 MHz band may be reasonable as suggested in the recommendation of 2100 MHz. Hence, the Reserve price of these bands may be 0.83 times the Reserve Price of 1800 MHz.
2. Additionally, this should be looked from other perspectives also like Per Capita income, ARPU, GDP, Inflation, etc. and moreover, sustainability of the Telecom industry in mid-long term. Reserve price should be referenced with the incremental revenue a band can

generate. Simply looking at relative efficiency is not a sustainable approach. In fact, in 5G, higher bands will need more densification, and hence more CAPEX/OPEX. So, relation to incremental revenue becomes crucial, given the industry's financial health.

Q.46 In your opinion, what could be the possible reasons for the relative lack of interest for the spectrum in the 700 MHz band? Could this be attributed to technological reason(s) such as development of network/device ecosystem or availability of substitute spectrum bands or any other reasons(s)?

BIF Response

Following are some of the reasons in our humble opinion, which have led to lack of interest shown by the operators to spectrum in the 700 MHz band:

1. Very High Reserve Price viz. 492 Crores/MHz. This is almost 4x than the closest valuation of spectrum in this band based on International Spectrum Auctions that have taken place in this band.
2. Focus on previous auctions has been more on 3G and 4G spectrum.
3. Lack of sufficient focus on rural penetration.
4. Lack of focus on in-building penetration in urban areas.
5. Lack of sufficient development of the IMT/5G ecosystem in the past.

Q.47 Whether the value of spectrum in 700 MHz band be derived by relating it to the value of other spectrum bands by using a technical efficiency factor? If yes, with which spectrum band, should this band be related and what efficiency factor or formula should be used? Please justify your views with rationale and supporting studies, if any.

BIF Response

1. No. With regard to 4G/LTE technologies, spectrum in the 700-900 MHz bands represents a continuum. Therefore, a factor of 2 applied for this spectrum band 700-900 MHz may be reasonable. Therefore, the Reserve Price for the 700-900 MHz may be 2 times the Reserve price for the 1800 MHz band.
2. Additionally, this should be looked from other perspectives also like Per Capita income, ARPU, GDP, Inflation, etc. and moreover, sustainability of the Telecom industry in mid-long term. Reserve Price should be referenced with the incremental revenue a band can generate. Simply looking at relative efficiency is not a sustainable approach. In fact, in 5G, higher bands will need more densification, and hence more CAPEX/OPEX. So relation to incremental revenue becomes crucial, given industry financial health.

Q.48 If your response to the above question is in negative, what other valuation approach(es) be adopted for the valuation of 700 MHz spectrum band? Please support your response with detailed methodology.

BIF Response

YES. As mentioned, we have provided a detailed methodology as to how to arrive at a reasonable and justifiable price for the 700MHz band. This has been provided in response to Q34 above.

Q.49 Whether the valuation of the 3300-3670 MHz spectrum band should be derived from value of any other spectrum band by using technical efficiency factor? If yes, what rate of efficiency factor should be used? If no, which other method(s) should be used for its valuation? Please justify your response with rationale and supporting documents, if any.

BIF Response

1. The spectrum pricing recommendations propose an index of 0.3 which in the present understanding of technical factors relating to 5G systems is fair and reasonable. Hence the Reserve price of spectrum in this band may be 0.30 times the Reserve price of the 1800 MHz band. It is pertinent to note that while it is recommended to benchmark valuation of other bands where eco-system and past auction experience is available to 1800 MHz band; but for newer bands where no past experience is available, it is also worthwhile to take into account the international experience and set reserve prices which are in line with international norms. The valuation per MHz of 1800 MHz spectrum in revenue surplus method is INR 1647 crore (USD 235.29 Million). Depending upon the reserve price to valuation ratio and by applying the technical factor of 0.3, we can calculate the per MHz reserve price of 3.5 GHz. This is lower than the 3.5 GHz price of INR 492 crores (USD 70.29 Million).
2. Additionally, this should be looked from other perspectives also like Per Capita income, ARPU, GDP, Inflation, etc. and moreover, sustainability of the Telecom industry in mid-long term. Reserve price should be referenced with the incremental revenue a band can generate. Simply looking at relative efficiency is not a sustainable approach. In fact, in 5G, higher bands will need more densification, and hence more CAPEX/OPEX. So relation to incremental revenue becomes crucial, given the industry's financial health.

Global 5G spectrum prices operators wise

Country	Currency	Auction Date	Spectrum Band	Type	Total Qty under Auction (MHz)	Opr1 Qty (MHz)	Opr1 Dur (Yrs)	Opr2 Qty (MHz)	Opr2 Dur (Yrs)	Opr3 Qty (MHz)	Opr3 Dur (Yrs)	Opr4 Qty (MHz)	Opr4 Dur (Yrs)	Currency Conversion (to US$)	Avg FP/MHz (Mn US$)	Opr1 Paid (Mn US$/MHz)	Opr2 Paid (Mn US$/MHz)	Opr3 Paid (Mn US$/MHz)	Opr4 Paid (Mn US$/MHz)
South Korea	KRW	Apr-18	3.5 GHz	TDD	280	100	10	100	10	80	10			0.00	9.67	11.02	8.76	9.15	
South Korea	KRW	Apr-18	28 Ghz	TDD	2400	800	5	800	5	800	5			0.00	0.23	0.23	0.24	0.23	
UK	Pound	Sep-18	2.3 GHz	TDD	40	40	20							1.29	6.65	6.65			
UK	Pound	Sep-18	3.4 GHz	TDD	150	40	20	50	20	40	20	20	20	1.29	9.91	10.27	9.7	9.7	9.7
Italy	Euro	Oct-18	3.7 GHz	TDD	160	80	19	80	19					1.15	24.22	24.22	24.29		
Italy	Euro	Oct-18	26 GHz	TDD	400	200	19	200	19					1.15	0.19	0.19	0.189		
Italy	Euro	Oct-18	700 MHz	FDD	20	10	15.5	10	15.5					1.15	78.36	78.36	78.3		
Spain	Euro	Aug-18	3.7 GHz	TDD	200	90	20	60	20	50	20			1.15	2.81	2.82	2.82	2.75	
Finland	Euro	Sep-18	3.6 GHz	TDD	390	130	15	130	15	130	15			1.15	0.23	0.27	0.23	0.19	
Australia	US$	Dec-18	3.6 GHz	TDD	125	17	10	10	10	47	10	51	10	1.00	0.97	1.58	0.26	0.80	1.1
Germany	Euro	Jun-19	3.5 GHz	TDD	300	90	30	90	30	70	30	50	30	1.15	1.64	1.26	1.26	1.69	2.36
Norway	Euro	Jun-19	700 MHz	FDD	20	10	20	10	20					1.15	0.22	0.20	0.25		
India	INR	Mid 2019	700 MHz	FDD	35	35	20							0.01	938.29				
India	INR	Mid 2019	3.4 GHz	TDD	300	300	20							0.01	70.28				

South Korea	Opr#1- SKT; Opr#2 - KT; Opr#3 - LGU+
South Korea	Opr#1- SKT; Opr#2 - KT; Opr#3 - LGU+
UK	Opr#1 - Telefonica
UK	Opr#1 - Telefonica; Opr#2 - Vodafone; Opr#3 - EE; Opr#4 - 3UK
Italy	Opr#1 - Vodafone; Opr#2 - Telecom Italia
Italy	Opr#1 - Vodafone; Opr#2 - Telecom Italia
Italy	Opr#1 - Vodafone; Opr#2 - Telecom Italia
Spain	Opr#1 - Vodafone; Opr#2 - Orange; Opr#3 - Telefonica
Finland	Opr#1 - Telia; Opr#2 - Elisa; Opr#3 - DNA
Australia	Opr#1 - Optus; Opr#2 - Dense; Opr#3 - Mobile; Opr#4 - Telstra
Germany	Opr#1 : Deutsche Telekom; Opr#2: Voda; Opr#3 :Telefonica; Opr#4 : 1&1 Drillisch
Norway	Opr#1 - Telenor; Opr#2 - Telia

Global 5G spectrum Price Compared with India

Non Recurring Revenue Reduction Factor				0.7									3.5 GHz Band		700 MHz Band	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Country	Auction Date	Spectrum Band	Type	Total Qty under Auction (MHz)	Average Price/MHz (Mn US$)	License Duration (Yrs)	Country Mobile Revenue (Million USD)	$/MHz/Rev (6 div by 8)	$/MHz/Rev (Adjusted to India's License Duration)	Country Population (Million)	$/MHz/PoP (6 div by 11)	$/MHz/PoP (Adjusted to India's License Duration)	$/MHz/Rev (No of times Indian Price is dearer)	$/MHz/PoP (No of times Indian Price is dearer)	$/MHz/Rev (No of times Indian Price is dearer)	$/MHz/PoP (No of times Indian Price is dearer)
South Korea	Apr-18	3.5 GHz	TDD	280	9.67	10	18,981	0.0005	0.0010	51.45	0.1880	0.3759	3.41	0.14	NA	NA
South Korea	Apr-18	28 Ghz	TDD	2400	0.23	5	18,981	0.0000	0.0000	51.45	0.0045	0.0182	NA	NA	NA	NA
UK	Sep-18	2.3 GHz	TDD	40	6.65	20	16,880	0.0004	0.0004	66.92	0.0994	0.0994	NA	NA	NA	NA
UK	Sep-18	3.4 GHz	TDD	150	9.91	20	16,880	0.0006	0.0006	66.92	0.1481	0.1481	5.92	0.36	NA	NA
Italy	Oct-18	3.7 GHz	TDD	160	24.22	19	11,918	0.0020	0.0021	60.48	0.4005	0.4215	1.63	0.13	NA	NA
Italy	Oct-18	26 GHz	TDD	400	0.19	19	11,918	0.0000	0.0000	60.48	0.0031	0.0033	NA	NA	NA	NA
Italy	Oct-18	700 MHz	FDD	20	78.36	15.5	11,918	0.0066	0.0085	60.48	1.2955	1.6717	NA	NA	5.47	0.42
Spain	Aug-18	3.7 GHz	TDD	200	2.81	20	10,961	0.0003	0.0003	46.93	0.0599	0.0599	13.56	0.89	NA	NA
Finland	Sep-18	3.6 GHz	TDD	390	0.23	15	2,113	0.0001	0.0001	5.52	0.0415	0.0553	24.08	0.96	NA	NA
Australia	Dec-18	3.6 GHz	TDD	125	0.97	10	9,970	0.0001	0.0002	25.41	0.0382	0.0763	17.87	0.70	NA	NA
Germany	Jun-19	3.5 GHz	TDD	300	1.64	30	16,937	0.0001	0.0001	83.00	0.0198	0.0132	53.86	4.03	NA	NA
Norway	Jun-19	700 MHz	FDD	20	0.22	20	2,344	0.0001	0.0001	5.33	0.0413	0.0413	NA	NA	494.55	17.16
															NA	NA
India	Late 2019	700 MHz	FDD	35	938.29	20	20,214	0.0464	0.0464	1,324.17	0.7086	0.7086	NA	NA	1.00	1.00
India	Late 2019	3.4 GHz	TDD	275	70.28	20	20,214	0.0035	0.0035	1,324.17	0.0531	0.0531	1.00	1.00	NA	NA

3. Some claim that India's 5G spectrum price in terms of $/MHz/Population is the lowest in the world. Though this claim is almost true (barring Germany), this metric cannot be used to measure the spectrum valuation of countries with vastly dissimilar financial structures. The reason is simple – the paying capacity of most Indians is far below that of its global counterparts whose price has been used as a reference. Therefore, India's high population does not translate into proportionate revenues – resulting in lower cash flows for mobile operators. Hence, instead of using $/MHz/PoP, one should actually use $/MHz/Revenue for comparing spectrum price across markets. Please see the table above, which compares global 5G prices with that of India using both $/MHz/PoP and $/MHz/Revenue.
4. While making this comparison, the following assumptions have been used - A) Total mobile wireless revenue for countries have been extracted from the GSMA database; B) While doing so it has been assumed that the non-recurring revenues from the sale of

handset and equipment are 30% of the total wireless revenue; C) This value has been deducted from the total wireless revenue of the respective country from enabling apples to apple comparison with India (Indian operators do not have such revenues); D) The $/MHz/Rev value used for comparison has been also adjusted with the license duration, as these are different across countries.

Global 5G spectrum Price Compared with India using GDP PPP

													3.5 GHz Band		700 MHz Band	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Country	Auction Date	Spectrum Band	Type	Total Qty under Auction (MHz)	Average Price/MHz (Mn US$)	License Duration (Yrs)	Country GDP PPP (Million USD)	$/MHz/GDP (6 div by 8)	$/MHz/GDP (Adjusted to India's License Duration)	Country Population (Million)	$/MHz/PoP (6 div by 11)	$/MHz/PoP (Adjusted to India's License Duration)	$/MHz/Rev (No of times Indian Price is dearer)	$/MHz/PoP (No of times Indian Price is dearer)	$/MHz/Rev (No of times Indian Price is dearer)	$/MHz/PoP (No of times Indian Price is dearer)
South Korea	Apr-18	3.5 GHz	TDD	280	9.67	10	2,136,000	0.000005	0.000009	51.45	0.1880	0.3759	0.68	0.14	NA	NA
South Korea	Apr-18	28 Ghz	TDD	2400	0.23	5	2,136,000	0.000000	0.000000	51.45	0.0045	0.0182	NA	NA	NA	NA
UK	Sep-18	2.3 GHz	TDD	40	6.65	20	3,128,000	0.000002	0.000002	66.92	0.0994	0.0994	NA	NA	NA	NA
UK	Sep-18	3.4 GHz	TDD	150	9.91	20	3,128,000	0.000003	0.000003	66.92	0.1481	0.1481	1.93	0.36	NA	NA
Italy	Oct-18	3.7 GHz	TDD	160	24.22	19	2,397,000	0.000010	0.000011	60.48	0.4005	0.4215	0.58	0.13	NA	NA
Italy	Oct-18	26 GHz	TDD	400	0.19	19	2,397,000	0.000000	0.000000	60.48	0.0031	0.0033	NA	NA	NA	NA
Italy	Oct-18	700 MHz	FDD	20	78.36	15.5	2,397,000	0.000033	0.000042	60.48	1.2955	1.6717	NA	NA	1.94	0.42
Spain	Aug-18	3.7 GHz	TDD	200	2.81	20	1,864,000	0.000002	0.000002	46.93	0.0599	0.0599	4.07	0.89	NA	NA
Finland	Sep-18	3.6 GHz	TDD	390	0.23	15	256,456	0.000001	0.000001	5.52	0.0415	0.0553	5.15	0.96	NA	NA
Australia	Dec-18	3.6 GHz	TDD	125	0.97	10	1,313,000	0.000001	0.000001	25.41	0.0382	0.0763	4.15	0.70	NA	NA
Germany	Jun-19	3.5 GHz	TDD	300	1.64	30	4,356,000	0.000000	0.000000	83.00	0.0198	0.0132	24.42	4.03	NA	NA
Norway	Jun-19	700 MHz	FDD	20	0.22	20	395,867	0.000001	0.000001	5.33	0.0413	0.0413	NA	NA	147.22	17.16
															NA	NA
India	Late 2019	700 MHz	FDD	35	938.29	20	11,468,000	0.000082	0.000082	1,324.17	0.7086	0.7086	NA	NA	1.00	1.00
India	Late 2019	3.4 GHz	TDD	275	70.28	20	11,468,000	0.000006	0.000006	1,324.17	0.0531	0.0531	1.00	1.00	NA	NA

Q.50 In case you are of the opinion that frequencies in the range 526- 698 MHz should be put to auction in the forthcoming spectrum auction, whether the value of 526-698 MHz be derived by using technical efficiency factor? If yes, with which spectrum band, should this band be related and what efficiency factor or formula should be used? Please justify your suggestions.

<u>**BIF Response**</u>

As mentioned in response to Q1 above, the entire band is not suitable to be auctioned. The Range of frequencies from 618-698 MHz could possibly be put to auction. Valuation/Pricing methodology to be followed should be similar to the approach suggested in Q49 for 700 MHz spectrum band.

Q.51 If your response to the above question is in negative, which other valuation approach(es) should be adopted for the valuation of these spectrum bands? Please support your suggestions with detailed methodology, related assumptions and any other relevant factors.

<u>**BIF Response**</u>

Please refer to our Response to Q50 above.

Q.52 Whether the value of spectrum in 24.25 - 28.5 GHz band be derived by relating it to the value of other bands by using technical efficiency factor? If yes, with which spectrum

band, should this band be related and what efficiency factor or formula should be used? Please justify your suggestions.

BIF Response

No, we have a different methodology as proposed in response to Q49 above. The prices should be benchmarked to global auction prices in this band.

Q.53 If your response to the above question is in negative, which other valuation approaches should be adopted for the valuation of these spectrum bands? Please support your suggestions with detailed methodology, related assumptions and other relevant factors.

BIF Response

Please refer to our response to Q52 & Q49 above.

Q.54 Whether international benchmarking by comparing the auction determined price in countries where auctions have been concluded be used for arriving at the value of these new bands? If yes, then what methodology can be followed in this regard? Please explain.

BIF Response

Yes. We have provided the rationale in response to Q49 above.

Q.55 For international benchmarking, whether normalization techniques be used for arriving at the valuation of these new bands in the Indian context? If yes, please justify your response with rationale /literature, if any.

BIF Response

Yes - normalisation techniques viz. PPP between those countries and ours could possibly be used to determine valuation of spectrum in these bands. Please see our response to Q49 above, in this regard.

Q.56 Whether a common methodology/ approach should be used for valuation of all sub-1 GHz bands, which are currently planned for IMT? If yes, suggest which methodology/ approach should be used. Please give your views along with supporting reasoning and documents/ literature, if any.

BIF Response

Yes. Please refer to our response to Q49 above.

Q.57 Whether the extrapolated ADP based on a time-series analysis, may be considered as the valuation itself or some normalization may be performed taking into account the financial, economic and other parameters pertaining to a particular auction? If yes, which factors should be considered and what methodology should be followed?

BIF Response

Please refer to **BIF's WP on Spectrum Pricing in India** for an exhaustive study on aspects related to a) need for revision of spectrum pricing in India; b) Spectrum Pricing issues and challenges; c) Approaches used for valuation of spectrum; d) Use of mean; e) use of previous auction price as reference point; f) why spectrum valuation is not used while determining Reserve Prices in most of the cases; g) Indexation/Index rate; and h) Solutions for reaching reasonable reserve price for next auctions.

Q.58 Whether the value arrived at by using any single valuation approach for a particular spectrum band should be taken as the appropriate value of that band? If yes, please suggest which single approach/ method should be used. Please justify your response.

BIF Response

No. Please refer to our response to Q 57 above.

Q.59 In case your response to the above question is negative, will it be appropriate to take the average valuation (simple mean) of the valuations obtained through the different approaches attempted for valuation of a particular spectrum band, or some other approach like taking weighted mean, median etc. should be followed? Please justify your response

BIF Response

Please refer to suggested methodology /approach as mentioned in response to Q57 above. Instead of taking a simple mean, it is felt that median would perhaps be more appropriate.

Q.60 Is there any valuation approach other than those discussed above or any international auction experience/ approach that could be used for arriving at the valuation of spectrum for 700 MHz/ 800 MHz/ 900 MHz/ 1800 MHz/ 2100 MHz/ 2300 MHz/ 2500 MHz/ 3300-3670 MHz/ 24.25 - 28.5 GHz/ 526 - 698 MHz bands? Please support your suggestions with a detailed methodology and related assumptions.

BIF Response

Please refer to our response to Q49 and Q57 above.

Q.61 Should the reserve price be taken as 80% of the valuation of spectrum? If not, then what ratio should be adopted between the reserve price for the auction and the valuation of the spectrum in different spectrum bands and why?

BIF Response

1. There is a need to set reserve prices at levels that are high enough to keep non-serious bidders at bay, but low enough to achieve vibrant price discovery. There needs to be a meaningful correlation across bands based on factors such as efficiency, coverage and the existing ecosystem. Every failed auction results in missed opportunity for the economy, lower investor interest in the industry, revenue loss to the exchequer and inefficient allocation of spectrum. Therefore, sensible reserve prices are important.

2. In the past, TRAI has fixed reserve price at 80% of valuation. We suggest the reserve price of the all the spectrum bands be fixed at 50% of valuation.

Q.62 Whether the realized/ auction determined prices achieved in the March 2021 auction for various spectrum bands can be directly adopted as the reserve price in respective spectrum bands for the forthcoming auction? If yes, should these prices be indexed for the time gap since the auction held in March 2021 and at which rate the indexation should be done?

<u>BIF Response</u>
No. Please refer to our detailed response to Q57 above in this regard.

Q.63 Should the method followed by DoT in the previous auction in respect of collecting bid amount from the successful bidder in case spectrum is not available in a part of the LSA be followed in the forthcoming auction? Please justify your response in detail.

<u>BIF Response</u>
No. DoT should only collect the bid amount from the successful bidder in proportion to the spectrum and licensed coverage area assigned.

Q.64 What percentage rate of upfront payment should be fixed in case of each spectrum band?

<u>BIF Response</u>
No upfront payment for the upcoming 5G auction. The complete payment should be required to be made in form of annual spectrum payments. Also, interest on payment should be aligned with RBI Repo rate policy.

Q.65 What should be the applicable period of moratorium for deferred payment option?

<u>BIF Response</u>
Moratorium of 6 years can be proposed. The Government has already given 4 years' moratorium period considering the prevailing financial health of the sector. Beyond these 4 years, the TSPs would need at least another 2 years to make the payment for the upcoming spectrum auction. Hence a moratorium period of 6 years is proposed.

Q.66 How many instalments should be fixed to recover the deferred payment?

BIF Response

With moratorium for first 4 years, the balance payment should be recovered in equitable instalments over the next 24 years.

Q.67 What rate of discount should be used while exercising prepayment/deferred payment option, in order to ensure that the net present value of payment/ bid amount is protected? (Please support your suggestions for Q64 to Q67 with proper justifications.)

BIF Response

It should be discounted on Market Rate of Interest which could possibly average out at 8-10%.

H) Issues related to Spectrum for Private Cellular Networks

Q.68 To facilitate the TSPs to meet the demand for Private Cellular Networks, whether any change(s) in the licensing/policy framework, are required to be made. If yes, what changes are required to be made? Kindly justify your response.

BIF Response

1. With many private 4G/5G networks already rolled out or in the process of being implemented globally, it has become clear that private 5G will require the participation of a wide range of participants – from telecommunications service providers to automotive manufacturers, logistics service providers, ports, healthcare institutions and many others.
2. Given that private network deployments typically cater to highly specialized use cases, end-user/industrial participation in rollouts is now manifesting globally as companies and institutions working directly with equipment manufacturers and telecom service providers and often leading the effort to build and operationalize private networks.
3. The above is also reflected in the global market for private 5G networks. The German Federal Networks agency, BNetzA, has already awarded 123 spectrum licenses for private 5G campus networks, with automotive manufacturers such as Audi, BMW, Daimler, Mercedes-Benz Porsche and others leading the charge. In UK and Italy, Port of Southampton and Port of Livorno respectively operate private 5G networks. In the United States of America, John Deere – an agricultural farm equipment manufacturer, was recently awarded a private 5G licence to build and operate a flexible factory network. The market for private 5G is dynamic and will undoubtedly see significant participation of non-traditional players in the rollout and operation of these networks.
4. The Global mobile Suppliers Association (GSA) maintains an updated global database of private mobile network deployments and revealed significant coverage of pilot and commercial private mobile networks across the world in a recent report[7].The association

[7] Private Mobile Networks: Executive Summary – August 2021, GSA, Available at https://gsacom.com/paper/private-mobile-networks-executive-summary-august-2021/

identified 45 countries/territories with private network deployments based on LTE or 5G where 5G-suitable private network spectrum licences have been assigned. In addition, they also found private mobile network installations in various offshore locations serving the oil and gas industries, as well as on ships and tankers. At least 370 private mobile network deployments are being deployed all around the world, according to the report[8]. LTE is used in 64% of the catalogued private mobile network deployments, and 5G is also being deployed (or planned) in 44% of these networks. The report also found the manufacturing sector to be an early and leading adopter of local area private mobile networks. At least 79 manufacturing companies were identified to be holding suitable licences or involved in pilots or deployments of local networks. Mining followed in second place, with ports actively trialling/deploying local area private mobile networks. Their analysis of the data also suggested that utilities, police/security/public safety/defence, communications/IT and rail tend to be the biggest users of wide area private mobile networks.

5. A Report on "**Non-Public 5G Networks in India: Policy, Regulatory and Sector Perspective"** authored by Prof. Rekha Jain[9], Senior Visiting Professor at ICRIER is enclosed herewith as an integral part of our response. The Report covers among other things - Drivers of NPN, Deployment models of NPN in several countries including India, besides overview of Spectrum for NPN and various business models. The key **Analysis and Recommendations of the Report** are as follows:
   a. Early availability of spectrum for NPN is necessary for enterprises to become more competitive.
   b. Earlier, spectrum licenses were exclusively awarded to telcos. NPN would require development of frameworks for shared license access between telcos and/or enterprises. Regulators may need to develop appropriate regulatory framework for allocation of spectrum to enterprises, in case of a user led NPN deployment model. Developing regulatory and technology models for Licensed Shared Access would be critical.
   c. So far, the role of telcos was predominant in rolling out networks and devising innovative marketing strategies. NPNs will entail them to devise end-to-end solutions for enterprises as they roll out domain specific applications. NPNs also challenge enterprises to devise new business models with innovative services. On the other hand, NPNs would create opportunities for revenue generation from the consequent new business opportunities. This could address telcos' concern regarding sharing spectrum with enterprises and hence losing out on some services. Enterprises would also require new kinds of network capabilities, especially regarding the network requirements for their domain specific applications (such as latency, bandwidth). Organizations would need to ensure that their NPNs comply not only with their own security and user administration aspects, but also with the 3GPP framework.

[8] Ibid
[9] rekha@iima.ac.in

d. Unlicensing of spectrum is required as several use cases for 5G are driven by the propagation characteristics and device ecosystem in the unlicensed bands. Making adequate spectrum available in other licensed bands requires central coordination across other government departments/ministries such as Space and Defence, that are currently using the identified 5G bands. Similarly, new unlicensed spectrum bands viz. 6 GHz and also 60 GHz (V band) need to be opened up to help unleash next-gen Wi-Fi technologies viz. Wi-Fi6/Wi-Fi6E and Wi-Fi7, which can complement 5G. The coordination should be done in the context of experience of other countries that had similar situations and on the basis of co-existence studies carried out in India. Further, NPNs would require developing domain specific use cases and hence coordination with regulatory/standards bodies in those domains is of utmost importance.
e. A collaborative approach between academia, service providers, user industry, vendors and most importantly, adequate funding support from the government is necessary. Identifying focus areas of testbed implementation in real life contexts as was done in the COREALIS project is important to influence industry and policy makers regarding adoption of NPN.
f. The Department of Telecommunications (DoT), India has supported the creation of 5G testbed in India through a network of Indian Institute of Technology, Hyderabad, Indian Institute of Technology, Bombay and Indian Institute of Technology, New Delhi. This support provides for hardware and software for testing. Application agnostic testbeds as the one implemented in India are critical for vendors, equipment providers, telcos and start-ups to test potential 5G deployments in India. In addition, an NPN implementation as a series of pilots in a specific sector such as a port, airport, manufacturing enterprise across several locations, etc. is critical for understanding the key/different drivers in each sector. This is because each enterprise context (port, manufacturing, airport) would have varying needs and priorities for bandwidth, reliability, connectivity, latency, etc. Further, even within a specific type of enterprise, these needs would vary. For example, for ports with congested berths, operating rubber tyred gantry cranes may be more important, while for another, condition monitoring could be more important.
g. As an example, EU Horizon 2020 program supported 5G initiatives in several areas such as Ports, Smart Manufacturing, etc. were taken up. The projects typically involved telcos, network integrators, equipment vendor and most importantly, the user organizations. Since enterprise context is important for NPN, we suggest that MeitY, in collaboration with the industry and academia, prioritise funding for a series of end-to-end pilot test bed implementation along several sectors, as suggested above. Along with this, it should undertake systematic baseline studies to scientifically be able to establish the value addition due to NPN as was done in the COREALIS project.
h. Various models of NPN deployment are possible. Most sustainable will be the ones that leverage the inherent unique strengths of the vendors, telcos and the user-industry.
i. Early licensing models for NPN deployments indicate an administrative price based on amount of spectrum, geographical area and duration seem to work. Further, use it-

or-lose-it models to encourage industries to deploy NPN in an accelerated manner would be useful. Technology neutrality is an important characteristic of these licenses.

j. Innovative applications emerging from early NPN deployments could see many ICT products/services from India, contributing to Atmanirbhar Bharat. This would also give an impetus to the start-ups and could help create a leading position for India in the Internet and knowledge/service sector.

6. Given the wide range of market participants expected to play a role in private 5G, the licensing/policy framework must provision for the authorization of local use cases, and when required, have mechanisms to authorize end users/industry/institutions to roll out private networks.
7. We therefore urge the authority to consider that spectrum for Private Cellular Networks may be directly assigned to the end users (viz. enterprise) at a nominal cost, allowing them the flexibility to partner with other stakeholders, including TSPs, OEMs, ASPs, etc. TSPs may be assigned the RTU for that spectrum, once they have been contracted by the end user to build the Private Network on behalf of the enterprise.
8. The other option could be where TSPs purchase the spectrum and lease it to the enterprise at an affordable cost.
9. In either of the options, it needs to be ensured that the enterprise pays uniform charges and there is no fiscal arbitrage.
10. In case of leasing from TSPs, appropriate discounting of the spectrum charges (fraction of the cost of auctioned spectrum) for the specific geography and purpose of Private 5G Networks should be made.
11. Spectrum for use by Private Network should be in a different band than the Public 5G Networks. Possible Candidate bands could include amongst the following - 1.8 GHz, 2.6 GHz, 3.4-3.8 GHz, 3.8-4.2 GHz, 24.25-27.5 GHz. Some of these bands have been deployed for Private 5G Networks in other countries.
12. Since these Networks are essentially campus based (in a specific geographic location) and are not connected to Public 5G Networks, they can be provided in an administrative manner through a light touch licensing mechanism.
13. Quantum of spectrum would also depend on the requirement of the specific industry/vertical - based on priorities for bandwidth, reliability, connectivity, latency, etc.
14. Spectrum be priced nominally - essentially to cover the charges of administration and regulation.

Q.69 To meet the demand for spectrum in globally harmonized IMT bands for private captive networks, whether the TSPs should be permitted to give access spectrum on lease to an enterprise (for localized captive use), for a specific duration and geographic location? Kindly justify your response.

BIF Response

Please refer to our response to Q68 above

Q.70 In case spectrum leasing is permitted, i. Whether the enterprise be permitted to take spectrum on lease from more than one TSPs? ii. What mechanism may be prescribed to keep the Government informed about such spectrum leasing i.e., prior approval or prior intimation? iii. What timeline should be prescribed (in number of days) before the tentative date of leasing for submitting a joint request by the TSPs along with the enterprise, for approval/intimation from/to the Government? iv. Whether the spectrum leasing guidelines should prescribe duration of lease, charges for leasing, adherence of spectrum cap provisions, roll out obligations, compliance obligations. If yes, what terms and conditions should be prescribed? v. What other associated terms and conditions may be prescribed? vi. Any other suggestion relevant to leasing of spectrum may also be made in detail. (Kindly justify your response)

BIF Response

1. The leasing should be done on a voluntary and mutually negotiable basis, with due intimation to the licensor/regulator.
2. On one hand, it will allow Industries to make use of licensed spectrum that it may need in certain use cases; on the other hand, it will allow TSPs to monetise its expensive spectrum apart from deploying it efficiently.
3. The Government will also be able to earn a revenue share on the revenue generated from leased licensed spectrum, in addition to fact that the TSP will be able to factor in this opportunity while bidding for the spectrum.
4. As regards consideration of leasing from more than one TSP, it is felt that market is still unexplored, very nascent and demand for this is not yet clearly established. Hence, we do not foresee any requirement that enterprises would need to lease spectrum from more than one TSP. It is felt that bandwidth provided by one TSP will effectively meet the requirement of an enterprise. Accordingly, one enterprise may be allowed to take spectrum on lease from only one TSP in one LSA. If at all need arises for augmenting capacity, TSPs are in a position to do so, since they hold multiple licensed bands, and thereby give a better experience to the enterprise user.
5. The framework of leasing spectrum to enterprises should allow market forces to drive it, as it happens even today in enterprise segment driven by mutually agreed SLAs. Thus:
    a. The duration of leasing arrangements between TSP and enterprise should be left to be decided mutually by both parties, and up to the TSPs' spectrum expiry period.
    b. Commercials of spectrum leasing be decided mutually between TSP and enterprise. However, it should be ensured that the cost of spectrum is affordable for the enterprise.
    c. No cap should be prescribed on spectrum that an enterprise can lease from a TSP.
    d. Only condition that may be specified is that enterprise must lease spectrum from one Access Service Provider in one LSA.
    e. Allow enterprise the choice of which TSP from whom it wants to lease spectrum from.

f. No rollout obligation should be specified as this IMT/access spectrum is being used exclusively for Private Networks
g. Since the arrangement is to be done only under intimation to the DoT and TRAI, no administrative overheads and no charges should be levied for leasing of spectrum.
h. Further, with such a leasing arrangement, the revenues to the government will also increase in the form of higher licence fee and spectrum usage charge to be paid by TSPs since the revenue earned by TSPs from spectrum leasing will always be subjected to applicable regulatory levies.
i. Thus, a simple, liberal policy allowing TSPs to lease their assigned spectrum to enterprises should be formulated. Any heavy regulatory requirement, without any demonstrable evidence of harm, may adversely affect the wide uptake of such a framework.

Q.71 Whether some spectrum should be earmarked for localized private captive networks in India? Kindly justify your response

BIF Response

YES. Please refer to our detailed response to Q68 above.

Q.72 In case it is decided to earmark some spectrum for localized private captive networks, whether some quantum of spectrum be earmarked (dedicatedly) from the spectrum frequencies earmarked for IMT services and/or spectrum frequencies earmarked for non-IMT services on location-specific basis (which can coexist with cellular-based private captive networks on shared basis)? Kindly justify your response with reasons.

BIF Response

We are of the following view:

1. Some dedicated spectrum viz. about 100 MHz may be earmarked exclusively for localised/captive Private Networks.
2. This spectrum should be in bands other than the ones selected for rollout for Public 5G Networks.
3. Possible candidate bands for Captive Private Networks could be bands like 2500 MHz band or between 582-612 MHz – candidate bands earmarked for non-IMT services on location-specific basis. Bands viz. 582-612 MHz can possibly co-exist with other services on shared basis.

Q.73 In case it is decided to earmark some quantum of spectrum for private captive networks, either on exclusive or shared basis, then a) Spectrum under which band(s) (or frequency range) and quantum of spectrum be earmarked for Private Network in each band? Inputs may be provided considering both dedicated and shared spectrum (between geographically distinct users) scenarios. b) What should be the eligibility conditions for assignment of such spectrum to private entities? c) What should be the assignment

methodology, tenure of assignment and its renewal, roll-out obligations? d) What should be the pricing mechanism for assignment of spectrum in the band(s) suggested for private entities for localized captive use and what factors should be considered for arriving at valuation of such spectrum? e) What should be the block size and spectrum cap for different spectrum band(s) suggested in response to point (a) above. f) What should be the broad framework for the process of (i) filing application(s) by enterprise at single location, enterprise at multiple locations, Group of companies. (ii) payment of spectrum charges, (iii) assignment of frequencies, (iv) monitoring of spectrum utilization, (v) timeline for approvals, (vi) Any other g) Any other suggestion on the related issues may also be made with details. (Kindly justify your response with reasons)

BIF Response

1. Detailed Response as regards possible candidate spectrum bands and Quantum of Spectrum have been provided in response to Qs 68 & 72 above.
2. Eligibility Criteria:
    a. Private entities must exist in one of the named non-telecom verticals viz. Industry 4.0, Utilities, Automotive, Hospitals, Educational & Research Institutions, and likewise.
    b. The entity shall provide a self-declaration that the spectrum thus provided shall be used only for captive/internal usage and not for public networks.
    c. The entity shall provide declaration of meeting the necessary obligations for rollout and compliance as may be required.
3. Assignment methodology: Spectrum assignment should be done for a specific location and should be done in an administrative manner using light–touch regulation.
4. Tenure of assignment: May be set at 10 years, with provisions for extensions, and should be transferrable.
5. Roll-out obligations: The enterprise should be able to start operations within at least 2 years of assignment of spectrum.
6. As mentioned in our earlier response to Q68 and Q72, the licensing framework should be light-touch, area/location specific. The spectrum should be assigned administratively and should be licensed for use at a rate that reflects the administrative costs associated with licensing the same. To encourage better spectrum utilisation, the authority may consider recommending use-it-or-lose-it provisions in the assignment guidelines.
7. Block size: Should be 20-40 MHz.
8. Spectrum Cap: No cap is required as this is area/location specific.
9. Broad Licensing Framework should include spectrum assignment duration, spectrum charges, rollout obligations, compliance obligations, process for filing application(s) by enterprise at single location and at multiple locations, Company details, monitoring of spectrum utilization, timeline for approvals, etc.

Q.74 What steps need to be taken to facilitate identification, development and proliferation of India specific 5G use cases for different verticals for the benefit of the economy and citizens of the Country? Kindly provide detailed response with rationale.

BIF Response

5G technologies vastly expand applications to go beyond those offered today on personal phones, to new classes serving different economic verticals. Also, many of these applications will be specific to the country's developmental, geographical and cultural differences. In 5G, the use cases relevant to India may differ in many respects from those in Japan, and the use cases in Japan may differ in some respects from those in the US. Therefore, India may require customization of use cases or even designing completely new use cases.

a. Applications and Use Case labs can provide many useful functions viz. Showcasing applications, testing interoperability, and promoting development of innovative applications.
b. Applications and Use Case labs can be used by industry verticals, wireless technology companies and application developers.
c. UCL Economic Verticals: UCLs should be set up in each economic vertical with the support of the corresponding ministry and public or private sector industries. We recommend Agriculture, Health, Banking, Railways, Education, Urban Development, Manufacturing and Utilities viz. Water and Power.
d. The scope may be extended to other vertical ministries e.g. Defence, Transport, later.
e. We recommend starting with two UCLs on a trial basis to better understand business models and management structures before expanding to other verticals. Each UCL may evolve in three phases of six months each. Phase 1 - design and set-up of the UCL, Phase 2 - conceptualize use cases based on demonstrations and simulations, and Phase 3 - offer proof of concept, interoperability and pilot testing.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Enclosed: Report on "**Non Public 5G Networks in India – Policy, Regulatory and Sector Perspective**" by Prof. Rekha Jain

ASIA-PACIFIC TELECOMMUNITY
The 27th Meeting of the APT Wireless Group (AWG-27)
22 – 30 March 2021, Virtual/Online Meeting

Document No:
AWG-27/INP-86
15 March 2021

Indonesia (Republic of)

REPORT ON SHARING AND COMPATIBILITY STUDIES IN INDONESIA BETWEEN IMT-2020 (5G-NR) AND FIXED SATELLITE SERVICE (FSS) IN 3400 – 4200 MHZ BAND

1. Introduction

Indonesia has conducted a successful experiment of coexistence trial between IMT-2020 (5G-NR) and Fixed Satellite Service (FSS) for the extended C-band in Bandung, Indonesia in October - November 2020. The experiment was performed at 11.00 PM – 04.00 AM (GMT+7) considering the lowest traffic data for FSS under clear sky condition. The results are presented to improve the study on coexistence between IMT-2020 (5G-NR) and FSS in: (1) AWG-26/TMP-29(Rev.1) "*Working document towards a draft new Report on mitigation measures to improve coexistence of 4G-LTE and 5G-NR systems around 3300 MHz and 3600 MHz with other systems operating in adjacent and in-band spectrum*" and/or (2) AWG-26/TMP-32 "*Working document towards a draft new Report on sharing and compatibility studies between IMT systems in 3300 – 3400 MHz and applications in other radiocommunication services in the Asia pacific region*".

In this experiment, the 5G-NR used 3500-3600 MHz band, while FSS used 3700-3702 MHz band for DVB-S2 and PTP services which performed by using Satellite News Gathering (SNG) station, where Band Pass Filter (BPF) is used as a mitigation technique to reduce the interference impact to the FSS Earth Station. Before making the real-field experiment, 4 types of BPF filters were verified, while only one type of BPF filter is used during the coexistence experiment.

This experiment is expected to provide experimental contributions to the coexistence operation between IMT-2020 (5G-NR) and FSS in 3300–4200 MHz band, especially in Asia Pacific Region.

2. Scope of Experiment

Ministry of Communications and Informatics (MCI) in collaboration with Telkom Group (PT. Telekomunikasi Selular (Telkomsel), PT. Telekomunikasi Satelit Indonesia (Telkomsat), and Telkom University) have conducted coexistence trial between IMT-2020 (5G-NR) and FSS in 3400–4200 MHz band which was held in Bandung, on October - November 2020 with the scope of experiment focusing on:

Contact: Adis Alifiawan (Mr.)
Wijanarko Joko Hastyo (Mr.)
Ministry of Communications and Informatics, Republic of Indonesia

Email:
adis005@kominfo.go.id
wija002@kominfo.go.id

a. 5G-NR Static and Mobility Performance Test

Trial on 5G-NR static test was conducted at the optimum location to test the 5G-NR peak throughput. To test the 5G-NR power transmit configuration impacts, 5G-NR static test is also conducted at the cell edge for user throughput experience. Furthermore, the mobility test is also conducted to test for signal quality distribution.

Table 1. Parameters to evaluate the 5G-NR static and mobility performances

Test Item	Objective	Distance	5G Power Configuration
5G-NR Static Test for Peak Throughput	Single user peak throughput	UE is located at 50 m away from Base Station	53 dBm (200 Watt)
5G-NR Static Test at the cell edge	Impact on power configuration to user throughput experience at the cell edge	UE is located at 840 m away from Base Station	• 47 dBm (50 Watt) • 50 dBm (100 Watt) • 53 dBm (200 Watt)
5G-NR Mobility Test	Impact power configuration to signal quality distribution	Mobility	• 50 dBm (100 Watt) • 53 dBm (200 Watt)

Table 1 shows parameters of 5G-NR with several power configurations from 50 to 200 Watt to evaluate the impact of interference from 5G-NR to the FSS.

b. Field trial for 3.4-4.2 GHz Adjacent Channel Frequency Sharing

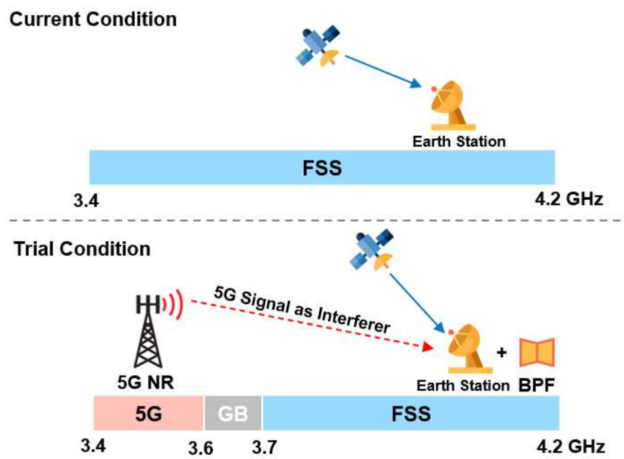


Fig. 1 Configuration of coexistence experiment between 5G-NR and FSS at 3.4-4.2 GHz including the use of BPF filter.

Coexistence field trial of 5G-NR in 3400 –3600 MHz and FSS in 3700-4200 MHz was performed through adjacent channel frequency sharing without interfering FSS. Mitigation technique during trial implemented by having an additional BPF installed at the FSS Earth Station with Guard Band of 100 MHz (3600-3700 MHz), and Separation Distance as described in Table 2.

Table 2. Allocated frequencies for 5G-NR and FSS

Item	Frequency	Note
5G-NR	3500–3600 MHz	Fixed at height of 20 m located at (107.629389, -6.97585). The BS is equipped with MIMO 64x64. The power is shown in Table 1 with gain of 25 dBi. Maximum Code Rate DL/UL 256QAM/64QAM, Polarization -45 to +45.
FSS (Geostationary satellite orbit/GSO)	3700-3702 MHz	SNG For DVB-S2 services and for PTP (sequentially). Telkom 3S satellite at 118E. FEC DVB-S2 8-PSK ¾ and Point-to-Point (PTP) 16-APSK, polarization 55.8, maximum input of LNB -53 dBm, maximum antenna gain 36.6 dBi, and VSAT antenna diameter 1.8 m.
Guard Band (GB)	3600-3700 MHz	100 MHz considering the recent coexistence study in Hongkong and China.
BPF Suppression	3700-4200 MHz	Minimum rejection (below 3.6 GHz) is 60 dB with maximum insertion loss 0.4 dB.

Many variables are tested during the coexistence field trial for two scenarios, where FSS earth station lower than 5G-NR transmitter in LOS condition and earth station lower than 5G transmitter in NLOS condition. The experiment conducted with various distance between 5G and FSS earth station, varying 5G power transmit configuration, and UE near-far location relatively to the FSS earth station. The tests are conducted for two different services which are SNG DVB-S2 and VSAT PTP (Point-To-Point).

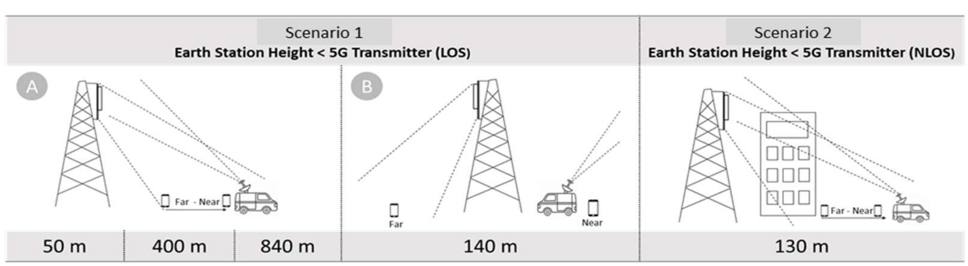


Fig. 2. Scenarios used during the real-field trial.

The different locations of earth station for various distances (see Fig. 2) for Scenario 1A, Scenario 1B, and Scenario 2 are defined as in Point 1, Point 2, Point 3, Point 4, and Point 5 (see Table 2) are shown in Fig. 3.

Table 2. Distance and channel conditions considered during the experiment.

Scenario	Point	Distance	Location (Long/Lat)
Scenario 1A	Point 1 - LOS	50 m	(107.6289138, -6.976264)
Scenario 1A	Point 2 - LOS	400 m	(107.6258139, -6.9768417)
Scenario 1A	Point 3 - LOS	840 m	(107.6263731, -6.9767862)
Scenario 2	Point 4 – NLOS	130 m	NLOS: (107.6289459, -6.9774088) UE Far: (107.6295722, -6.9757246)
Scenario 1B	Point 5 - Backlobe	140 m	(107.6289138, -6.976264)

Fig. 3 Map showing the Points 1, 2, 3, 4, and 5 for all testing scenarios in Telkom University in Bandung and surrounding area.

c. Band Pass Filter (BPF) verification Lab Test

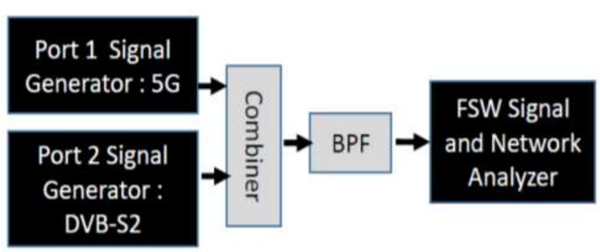


Fig. 4. Structure of BPF testing for coexistence mitigation.

Simulation to verify band pass filter rejection is also conducted in the lab environment using Signal Generator and Signal Analyzer. Four different types of band pass filter were tested.

3. Results of Experiment

The results are concluded as follows:

a. 5G-NR Static and Mobility Performance Result

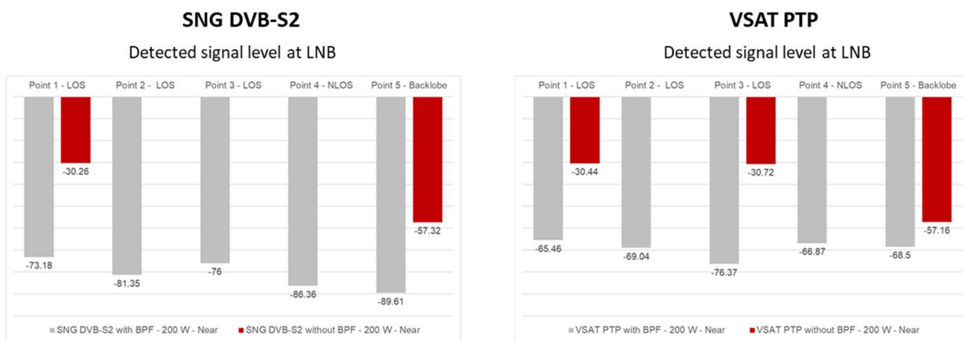
The results show that some degradations of 5G-NR performance appear due to power transmit configurations as shown in Table 1, since the power limitation is used to evaluate the interference impact to the FSS.

Table 3. 5G performance test result.

Test Item	**Result**
5G Static Test for Peak Throughput	5G Single User Peak Throughput can be achieved by using 100 MHz TDD for 1-transmit 4-receive (1T4R) UE with throughput up to 1.6 Gbps for DL and 73 Mbps for UL.
5G Static Test at the cell edge	Results of static test on cell edge with reduced power compared to 5G maximum power of 53 dBm (200 Watt) EIRP as the baseline are: a. Power 50 dBm (100 Watt) Throughput degradation DL 17% (from 567.5 Mbps to 473 Mbps), UL 11% (from 39.1 Mbps to 34.85 Mbps) b. Power 47 dBm (50 Watt) Throughput degradation: DL 23% (from 567.5 Mbps to 437.5 Mbps), UL 44% (from 39.1 Mbps to 21.9 Mbps)
5G Mobility Test	5G with transmit power 50 dBm (100 Watt) has worse signal strength distribution compared to 5G maximum Power of 53 dBm (200 Watt) resulting: a. 15.5% difference of RSRP levels above -95 dBm b. Cell Radius shrinks 12.5 % from 825 m to 728 m for sidelobe direction.

b. 3.5 GHz Adjacent Channel Frequency Sharing Field Trial Result

With BPF as a mitigation method with suppression of more than 60 dB, the results of trials on all scenarios (including the worst scenario) show that impact of 5G in 3400–3600 MHz to satellite service in Standard C-band (3700–4200 MHz) are acceptable as indicated that the FSS services can still run smoothly without any service interruption as indicated in Fig. 5.



Modem

C/N	Point 1 - LOS	Point 2 - LOS	Point 3 - LOS	Point 4 - NLOS	Point 5 - Backlobe
With BPF	0.1	-0.1	-0.2	-0.1	-0.3
Without BPF	-11.7	-	-	-	0.2

BER	Point 1 - LOS	Point 2 - LOS	Point 3 - LOS	Point 4 - NLOS	Point 5 - Backlobe
With BPF	Maintain	Maintain	Maintain	Maintain	Maintain
Without BPF	No Service	-	-	-	Maintain

Modem

C/N	Point 1 - LOS	Point 2 - LOS	Point 3 - LOS	Point 4 - NLOS	Point 5 - Backlobe
With BPF	-0.07	-0.24	-0.32	-0.43	-0.18
Without BPF	-7.81	-	-7.19	-	0

BER	Point 1 - LOS	Point 2 - LOS	Point 3 - LOS	Point 4 - NLOS	Point 5 - Backlobe
With BPF	Maintain	Maintain	Maintain	Maintain	Maintain
Without BPF	No Service	-	Degrade	-	Maintain

Fig. 5. Recorded parameter of measurement on FSS received signals.

Based on the field trial, in Line-of-Sight (LOS) condition for the case of 5G Base Station (BS) located higher than Earth Station (ES), we found that the coexistence in adjacent channel between IMT-2020 (5G) in 3.5 GHz (3400–3600 MHz) and FSS in Standard C-band (3700–4200 MHz) can be implemented using BPF with suppression of larger than 60 dB at ES Guard Band of 100 MHz for 5G maximum power of 53 dBm (200 Watt).

Without BPF, coexistence is not feasible if earth station of FSS and 5G are in Head-to-Head Scenario, even with 840 m separation distance, and longer separation need to be tested in the future for feasible coexistence without BPF mitigation. Based on result, the only feasible scenario for coexistence without BPF is the scenario when earth station of FSS and 5G are in Backlobe side. Please note that all distances obtained in this experiment are from the real-field test.

UE Near-Far scenario to earth station with BPF does not give any significant impacts. Therefore, UE near-far to/from the ES can be ignored.

c. Band Pass Filter (BPF) verification Lab Test Result

4 types of BPF have been verified in Lab test, where we found that the recommended BPF are only two types of BPF. Those BPF can fulfill the suppression requirement of larger than 60 dB to stop the 5G signals in frequency range 3400-3600 MHz.

Table 4. Results of BPF rejection and insertion loss verification.

BPF Type	Verification Result		Compliance
	5G Signal Rejection	Insertion Loss	
Type-1	65 dB	0.4 dB	Comply
Type-2	34 dB	2.5 dB	Not Comply
Type-3	48 dB	1.8 dB	Not Comply
Type-4	68 dB	1.9 dB	Comply

The BPF used for mitigation in this coexistence field trial is BPF Type-1 and installed at the SNG.

4. Conclusion

A real-field experiment for coexistence between 5G and FSS in 3.5 GHz band has been conducted in Indonesia with results on 5G Static and Mobility Performance Test, Field trial of 3.5 GHz Adjacent Channel Frequency Sharing, and Band Pass Filter (BPF) verification Lab Test.

Based on field trial, in Line-of-Sight (LOS) condition for the case of 5G Base Station (BS) with maximum power configuration of 53 dBm (200 Watt) located higher than Earth Station (ES) where 5G was in main lobe coverage and FSS was in sidelobe coverage (ES elevation angle 75 degree), we found that the coexistence in adjacent channel frequency usage between IMT-2020 (5G-NR) operated in 3.5 GHz band (3400–3600 MHz) and FSS operated in Standard C-band (3700–4200 MHz) can be implemented using:

(a) an additional BPF with suppression of larger than 60 dB below 3600 MHz at a typical earth station; and

(b) guard band of 100 MHz (3600–3700 MHz).

Wireless Netw (2019) 25:105–115
https://doi.org/10.1007/s11276-017-1544-8

Coexistence conditions of LTE-advanced at 3400–3600 MHz with TVRO at 3625–4200 MHz in Brazil

Leandro Carísio Fernandes[1] · Agostinho Linhares[1]

Published online: 19 June 2017

Abstract In Brazil, the 3625–4200 MHz frequency band (C-band) is widely used by TV receive-only (TVRO) application in the fixed satellite service (FSS). The 3400–3600 MHz adjacent band can be used by International Mobile Telecommunications (IMT) systems, but many low noise block downconverters (LNB) of TVRO sold in Brazil have not a C-band filter. Thus, it is likely that the low cost LNB used in TVRO receivers would be overloaded by the IMT-systems emissions within the LNB wideband receiver, even the IMT stations operating accordingly to international standards. This paper shows that both systems can coexist harmoniously depending on the characteristics of the IMT system and on the FSS receiver specifications.

Keywords Overloading · TVRO · LTE-advanced · Monte Carlo · Seamcat

1 Introduction

Some reports forecast that the mobile traffic will increase exponentially in the next years [1, 2]. As a result, some researches show that more frequency bands for International Mobile Telecommunications (IMT) systems are necessary [3–5]. In Brazil, which is the focus of this paper, even the refarming of the current frequency bands and the network evolution will not be sufficient to support the expecting traffic increase in the next years [5]. So, it is necessary to identify new frequency bands for IMT systems, use more efficient technologies, and deploy more base stations.

Since 1999 Brazil allows the use of the 3400–3600 MHz frequency band for wireless broadband applications. The Brazilian regulation is adequate for IMT implementations [6], but it is not used yet in its plenitude due to possible harmful interferences caused by the IMT implementation in its upper adjacent band. Currently, the most used IMT system is the long term evolution (LTE) and its evolutions, which is also the technology expected to be deployed at this frequency band.

The 3600–4200 MHz frequency band is allocated for fixed satellite service (however, the C-band satellites operating in Brazil start at 3625 MHz or above). The signal is received using very small aperture terminal—VSAT (blanket licensing procedure), licensed stations with known geographical coordinate, and TVRO systems. In Brazil, the latter is not regulated and usually uses low cost and low quality equipment without appropriate filtering. TVRO stations dońt have protection rights against harmful interference caused by other systems. Despite this, considering unofficial estimations of about 20 million TVRO users in Brazil [7], there is a social cost deploying a new service without taking care of harmful interference in the TVRO receivers.

This paper investigates and defines operation constraints for LTE-advanced (LTE-A) system deployed at 3400–3600 MHz so that the TVRO receiver can operate in the adjacent band with an acceptable interference level. This study has been done using a Monte Carlo simulation,

Disclaimer This paper reflects the authors' own opinion and do not necessarily reflects the official policy or position of Anatel.

✉ Leandro Carísio Fernandes
carisio@gmail.com

Agostinho Linhares
linhares@anatel.gov.br

1 National Telecommunications Agency – Anatel, Brasília, Brazil

which is one approach recommended by the International Telecommunications Union (ITU) [8].

2 Problem modeling

The LTE-A system transmits at its assigned frequency band (in this case, 3400–3600 MHz). A TVRO system should receive the satellite signal at 3625–4200 MHz frequency band (also known as C-band), process it using a low noise block downconverter (LNB), and dispatches it to the TV. Figure 1 shows the LNB block diagram: the received signal is band pass filtered at the C-band and then amplified by the low noise amplifier (LNA). The result signal is down-converted to an intermediate frequency at the L-band (1–2 GHz), when it will be filtered and amplified again and dispatched to the TV.

The interference problem mainly arises because most of the LNB sold in the Brazilian market does not have a C-band filter, but only an L-band filter. So, the receiver system normally has relevant frequency response over the entire 3400–4200 MHz band. Besides, the overload threshold (O_{th}) of the TVRO receiver system (the first LNA) is very low (e.g. $O_{th} = -60$ dBm). Thus, depending on the characteristics of the LTE-A system (e.g. transmitted power, antenna height, antenna gain, etc.), the interference's signal power at the input of the first LNA can be greater than O_{th}, overloading it.

Additionally, by far, most of the TVRO stations have the feeder and the LNB combined into a single unit (LNB Feedhorn or LNBF). In these cases, the insertion of a band pass filter between feeder and LNB (in a product in the market) is unfeasible.

We used the software Seamcat [9, 10] to model both systems and find the coexistence conditions between them. Then, we investigated the overloading caused by the LTE-A at the TVRO. In a nutshell, Seamcat works with the concept of a victim system (in this case, TVRO) and one or more interfering systems (in this case, the uplink and the downlink of the LTE-A). The input of all systems is specified using statistical distribution functions. One simulation consists of a set of events, where each event is a random selection of the inputs of the system: in the first event, the software randomly chooses the input parameters based on their definitions (some inputs might be random; others might be constant) and calculates if the interfering systems cause some harmful interference at the victim system. Then, in the following event, it chooses a new set of input parameters and does all the calculation again. This procedure is performed some thousands times. At the end of the simulation, it is possible to retrieve statistical information about the interference at the victim system. In other words, Seamcat uses the Monte Carlo methodology to calculate interference among systems [9, 10].

There are some types of interference [11, 12]. In this paper, we focus on the overloading of the first LNA. The first step is to model the LTE-A (interfering systems) and the TVRO (victim system). The characteristics of IMT systems that should be used in interference studies are available at Rep. ITU-R M.2292-0 [13]. This document also describes predefined scenarios that should be used in interference studies. Based on these parameters, we defined the inputs for LTE-A base stations (LTE-BS) and LTE-A user equipment (LTE-UE), which is shown in Tables 1 and 2.

The interfering system is a TD-LTE-advanced transmitting a 40 MHz bandwidth signal (3560–3600 MHz, at the 3GPP Band 42). The carrier of a LTE system has a maximum bandwidth of 20 MHz. A 40 MHz bandwidth can be achieved using carrier aggregation, which is available for LTE-A systems. Three scenarios were considered: a suburban macrocell (SMa), an urban macrocell (UMa) and an outdoor urban small cell (USm). In each case, we analyzed hexagonal cells with two or three different radius. For a given scenario, the equivalent isotropically radiated power (*eirp*) of the base station with largest radius was set

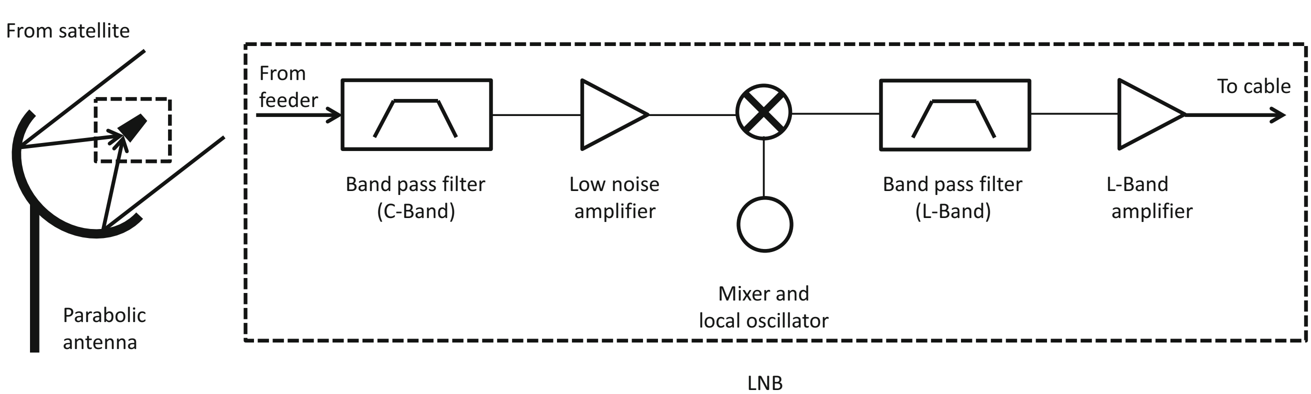


Fig. 1 The *dotted box* in the *right* shows the LNB block diagram. Most of the low cost LNB sold in Brazil do not have the C-band filter

Table 1 Input parameters for LTE-BS

Parameters	Scenario name		
	SMa	UMa	USm
Cell radius (km)	1, 0.6, 0.3	0.6, 0.3, 0.15	0.15, 0.1
Base station per km^2 (BS/km^2)[a,b]	0.38, 1.1, 4.3	1.1, 4.3, 17.1	17.1, 38.5
Antenna height (m)	25	20	6
Sectors per cell	3	3	1
Tilt (°)	−6	−10	0
Transmitter bandwidth (MHz)	40	40	40
Reuse factor	1	1	1
Maximum *eirp* (dBm)[a,c]	64, 59, 53	64, 58, 46	43, 35
Average base station activity	50%	50%	50%
Polarization	±45°	±45°	±45°
Simulated base station *eirp* (dBm)[a,d]	58, 53, 47	58, 52, 40	37, 29
Emission mask	3GPP [14]	3GPP [14]	3GPP [14]
Maximum antenna gain (dBm)	18	18	5
Antenna pattern	3GPP	3GPP	Omnidirectional

[a] These lines should be read as follow: when one is considering the cell with the *n*th biggest radius, the *n*th option of the input parameters should be considered

[b] To calculate the base station density we consider hexagonal cells. The area of each cell is $\frac{3R^2\sqrt{3}}{2}$, where R is the cell radius (see Fig. 2)

[c] Rep. ITU-R M.2292-0 defines parameters for a maximum 20 MHz bandwidth [13]. To simulate a bandwidth of 40 MHz, we considered two 20 MHz carriers with maximum power. Thus, the output power of a 40 MHz aggregated carrier is 3 dB higher than the one of a 20 MHz carrier

[d] The system is simulated with an *eirp* 6 dB lower than the maximum. This is due to the average base station activity (50%, which reduces the simulated power in 3 dB [15, 16]) and the polarization of the TVRO signal. Although the signal of the satellite of interest is transmitted using vertical and horizontal polarization (frequency reuse with polarization diversity), the reception of the TVRO tunes only vertical or only horizontal polarization at a time. Considering that the LTE-A transmits with cross-polarization, this represents a polarization discrimination of 3 dB in the simulated power

Table 2 Input parameters for LTE-UE

Parameters	Scenario name		
	SMa	UMa	USm
Indoor user terminal usage (%)	70	70	70
Indoor user terminal penetration loss (dB)	20	20	20
User terminal density in active mode ($/5\ MHz/km^2$)	2.16	3	3
Typical antenna gain (dBi)	−4	−4	−4
Transmitted power (dBm)	The transmitted power varies from −40 to 23 dBm. Simulations consider the power control method defined in [10]. The emission mask is the one defined by the 3GPP [17]		

as the maximum defined in the Rep. ITU-R M.2292-0 (shown in the "maximum *eirp*" row of Table 1). Then, when we reduce the cell radius, we also reduce the *eirp* of the base station to compensate the smaller path loss at the cell border. This ensures that, for a given scenario, the signal level at the border is approximately the same whatever the cell radius.

Table 3 shows the input parameters for the TVRO, whose antenna is installed at the top of a house. Rec. ITU-R S.465-6 defines reference diagram for use in coordination and interference assessment [18]. The maximum antenna gain in the main beam direction is 32 dBi (antenna diameter of 1.5 m). For incident angles (θ, which is the angle between the axis of the main beam of the parabolic antenna and the virtual line connecting the interferer and the parabolic antenna) lower than θ_{min}, the antenna gain (G) is $G = 32$ dBi. For $\theta_{min} \leq \theta < \theta_{env}$, the antenna gain ($G$) is $G = 32 - 25\log(\theta)$ dBi. For $\theta \geq \theta_{env}$, $G = G_{env}$. Using Rec. S.465-6, we have $\theta_{min} = 5°$, $\theta_{env} = 48°$, and $G_{env} = -10$ dBi [18]. However, operators

Table 3 Input parameters for TVRO

Parameter	Value
Height (m)	6
Antenna elevation (°)[a]	*Uniform*(48, 80)
Maximum antenna gain (dBi)	32
Antenna gain, G (dBi)	$G = 32$, for $\theta < \theta_{min}$
	$G = 32 - 25\log(\theta)$, for $\theta_{min} \leq \theta < \theta_{env}$
	$G = G_{env}$, for $\theta \geq \theta_{env}$
	For $G_{env} = -10$ dBi, $\theta_{env} = 48°$
	For $G_{env} = -4$ dBi, $\theta_{env} = 28°$
	For $G_{env} = 0$ dBi, $\theta_{env} = 19°$
Center of receiver frequency (MHz)	3628
Receiver bandwidth (MHz)	6
Overload threshold (dBm)	−60, −45

[a] *Uniform*(x, y) is a continuous uniform distribution function with boundaries x and y

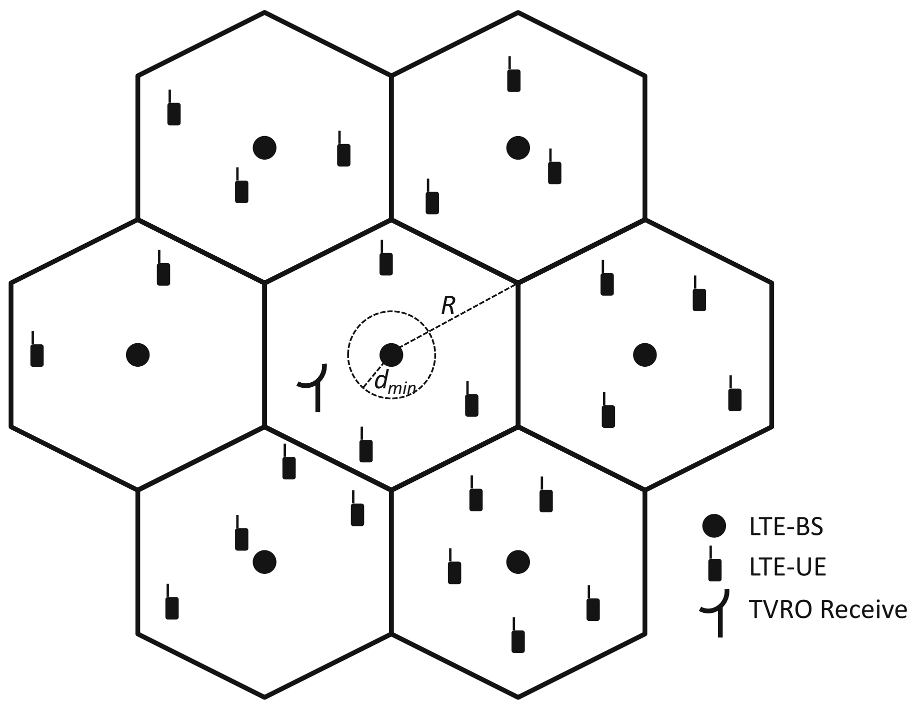


Fig. 2 Relative position between the TVRO and LTE-A

and manufactures in Brazil consider that the installed antennas are of low quality and therefore the envelope should be considered as $G_{env} = 0$ dBi. Although for some incident angles the antenna gain could indeed reach 0 dBi, this value for the whole envelope is very conservative. A not so conservative estimate for the envelope would be $G_{env} = -4$ dBi, which considers the aggregate signals that could reach the antenna with different angle of arrivals [19]. So, our simulations consider three possible antennas envelopes (−10, −4 and 0 dBi). To use these distinct envelopes, the radiation pattern defined in Rec. ITU-R S.465-6 was adapted (the value for θ_{env} was recalculated so $G \geq G_{env}$), as shown in Table 3. The antenna elevation is between 48° and 80°, which correspond to antennas installed at the south and the north of Brazil and pointing to the most used satellite for TVRO reception in Brazil.

Figure 2 shows the relative position between the TVRO receiver and the LTE-A network, which is simulated as a 7-cell network. The aim of the simulation is to check for overload in the TVRO, which is randomly located inside this LTE-A network with a minimum distance (d_{min}) from the base station. So, the distance between the TVRO antenna and the LTE-A base station is *Uniform*(d_{min}, R), where R is the cell radius. In the simulations scenarios, $d_{min} = 10$ m. This is also the minimum distance between the user equipment and the TVRO receiver.

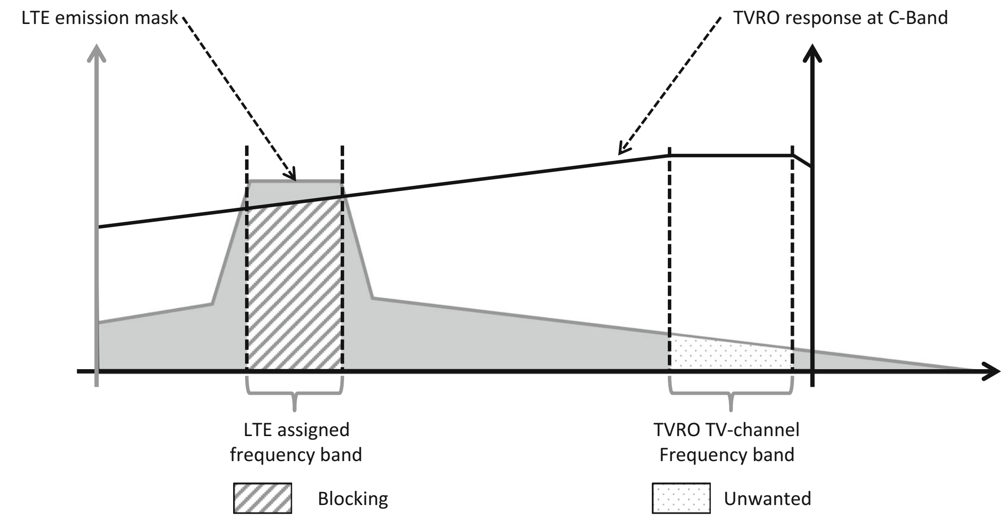


Fig. 3 Blocking and unwanted signals (not in scale)

The path loss between the LTE-BS and the LTE-UE and between the LTE-BS and the TVRO receiver antenna in the macrocell environments are represented by:

$$PL(\mathrm{dB}) = \begin{cases} FSPL + X_\sigma, & d < 0.04 \\ FSPL + \dfrac{d - 0.04}{10d_k - 0.04} A_h + X_\sigma, & 0.04 \le d < 10d_k \\ FSPL + A_h + X_\sigma, & d \ge 10d_k \end{cases}, \quad (1)$$

where FSPL $= 92.44 + 20 \log_{10}(f_{\mathrm{GHz}}) + 20 \log_{10}(d)$ is the free space path loss model, f_{GHz} is the frequency (GHz), d is the distance between transmitter and receiver (km), and X_σ is a Gaussian random variable with zero mean and standard deviation σ. X_σ models the slow fading. Typical values for σ for the SMa and UMa scenarios are, respectively, 8 and 6 dB [20, 21]. Therefore, these values were used in the simulations.

A_h is the additional clutter loss [22]:

$$A_h(\mathrm{dB}) = 10.25 F_{fc} e^{-d_k}\left\{1 - \tanh\left[6\left(\frac{h}{h_a} - 0.625\right)\right]\right\} - 0.33, \quad (2)$$

where $F_{fc} = 0.25 + 0.375\{1 + \tanh[7.5(f_{GHz} - 0.5)]\}$, d_k is the distance from nominal clutter point to the receiver antenna (km), h is the height of the receiver antenna (m), and h_a is the height of the clutter (m). For suburban environment, $h_a = 9$ m and $d_k = 0.025$ km. For urban environments, $h_a = 20$ m and $d_k = 0.02$ km [22]. Considering the TVRO antenna height ($h = 6$ m—Table 3), these parameters represent clutter loss of 7.2 and 19.4 dB for suburban and urban environment, respectively. Considering the LTE-UE height ($h = 1.5$ m—Table 2), they represent clutter loss of 19.6 dB and 19.7, respectively.

Note that Eq. (1) defines a propagation model based on the one defined in Rec. P.452-16, which is usually used in sharing studies [11]. However, it is only valid when d is significantly greater than d_k. Thus, this paper considers the Rec. P.452-16 model only when $d \ge 10d_k$.

For short distance, the free space path loss (FSPL) model usually describes the measures with good accuracy [11]. Some measures [23, 24] and model [9] at nearby frequencies (2.5 and 3 GHz) show that 40 m is a good breakpoint for the FSPL model. That is why Eq. (1) considers this model for distances below 40 m.

For distances between 40 m and $10d_k$, Eq. (1) describes a linear transition from the FSPL model to the Rec. P.452-16 model.

The propagation model between the LTE-UE and the TVRO receiver antenna of the macrocell environments and all the propagation environment of the small cell scenario are described by [25]:

$$PL(\mathrm{dB}) = PL_{LOS} \cdot p_{LOS}(d_m) + PL_{NLOS} \cdot [1 - p_{LOS}(d_m)] + X_{3.89} \quad (3)$$

where $PL_{LOS} = 102.93 + 20\log_{10}(d)$, $PL_{NLOS} = 153.5 + 40\log_{10}(d)$, d is the distance between transmitter and receiver (km), d_m is the same distance in meters, $X_{3.89}$ is a Gaussian random variable with zero mean and standard deviation 3.89 dB, and $p_{LOS}(d)$ is:

$$p_{LOS}(d_m) = \left\{1 + \frac{1}{\exp[-0.1(d_m - 70)]}\right\}^{-1} \quad (4)$$

In Eqs. (1) and (3), after adding the slow fading, there is a possibility of the path loss be lower than the free space path loss. If this occurs, we set the path loss as the one given by the free space model.

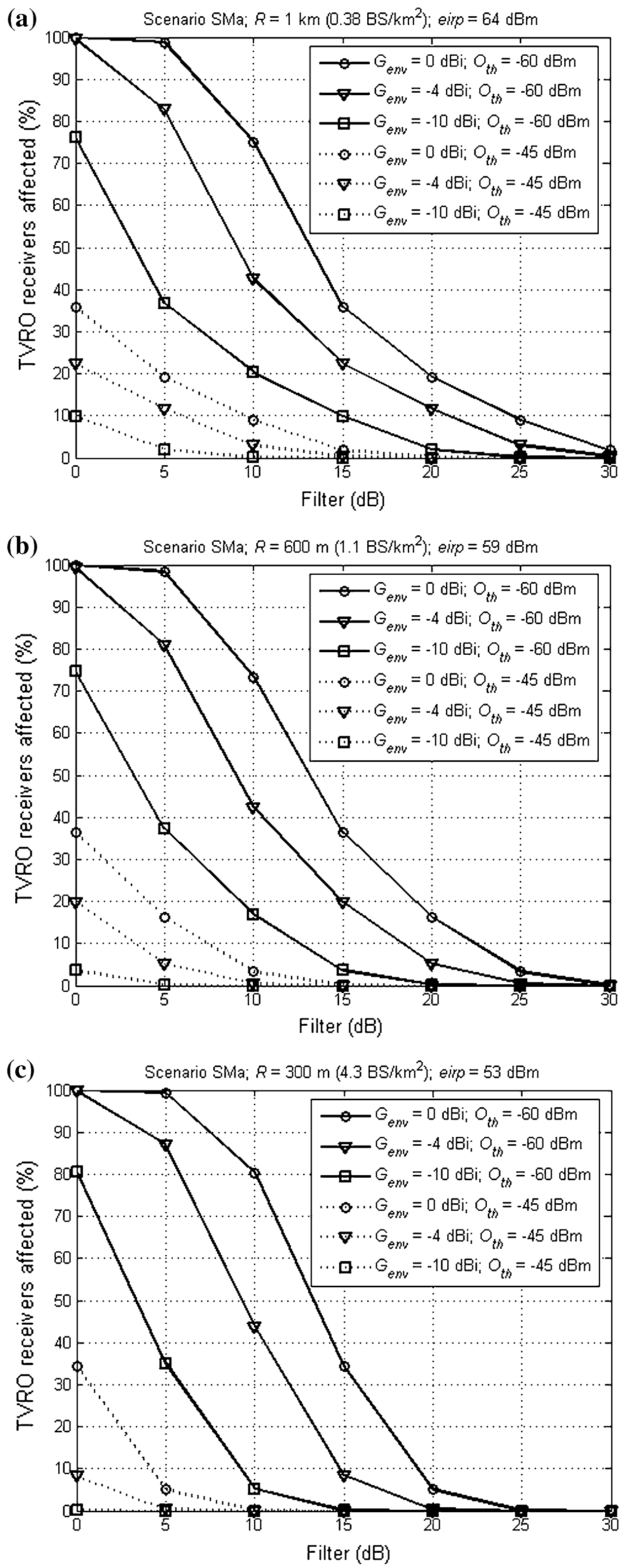


Fig. 4 Scenario SMa. **a** $R = 1$ km; **b** $R = 600$ m; **c** $R = 300$ m

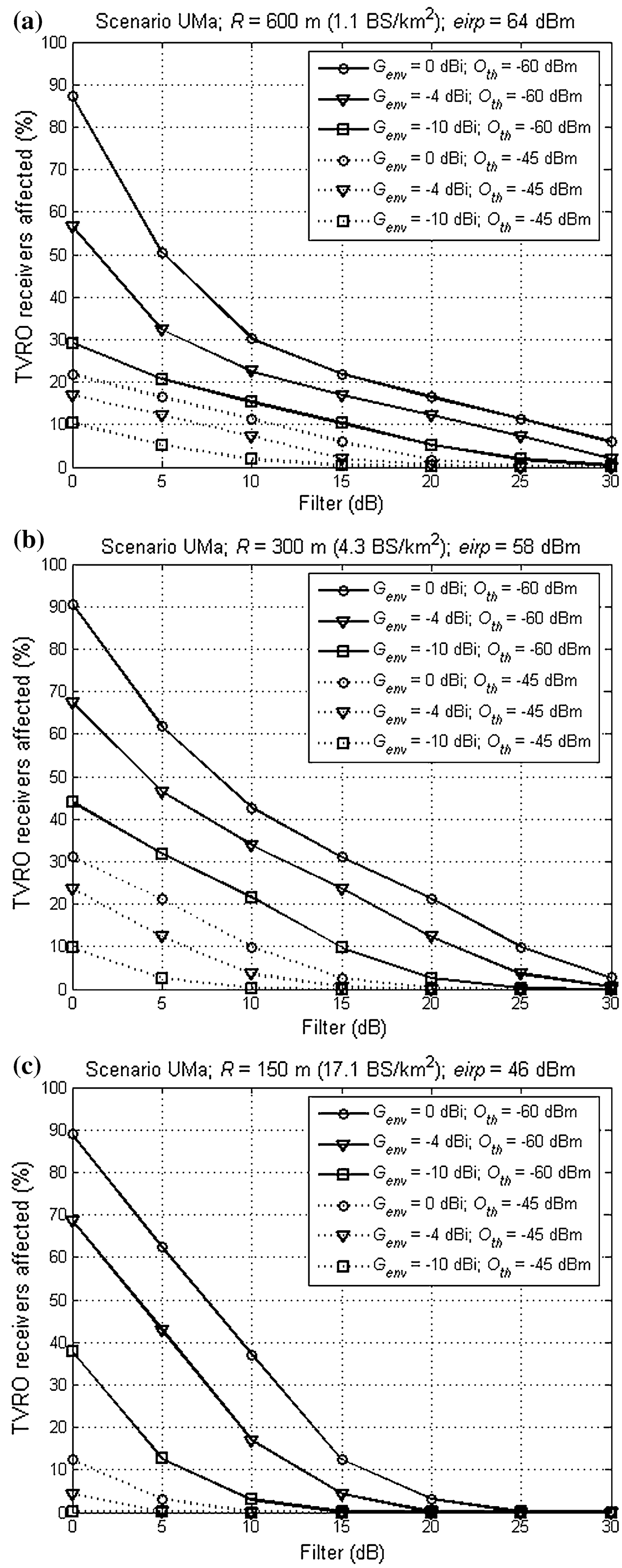


Fig. 5 Scenario UMa. **a** $R = 600$ m; **b** $R = 300$ m; **c** $R = 150$ m

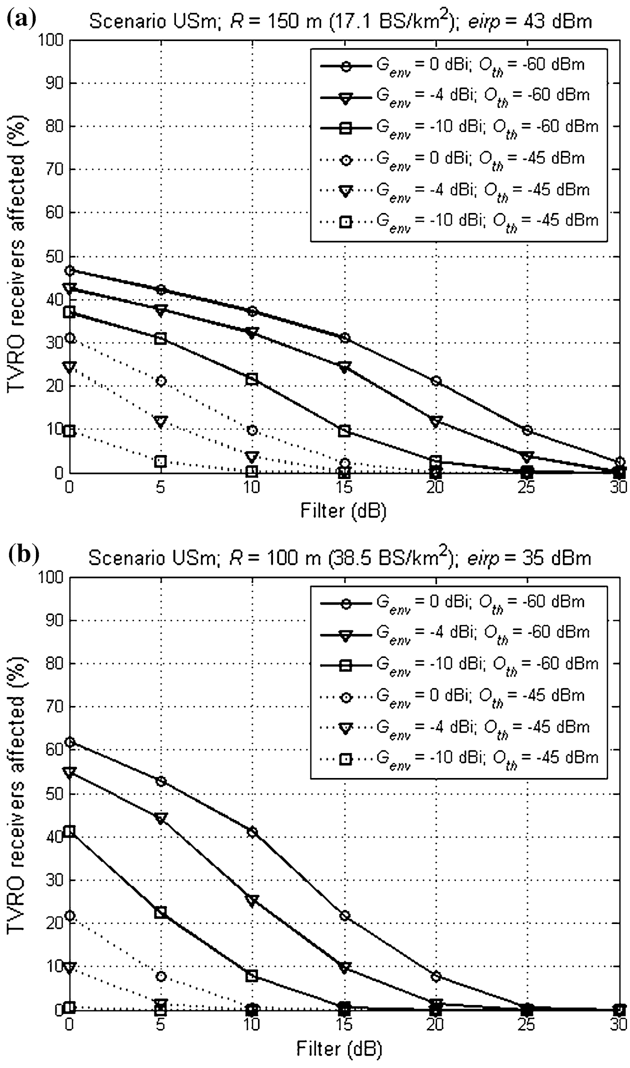


Fig. 6 Scenario USm. **a** $R = 150$ m; **b** $R = 100$ m

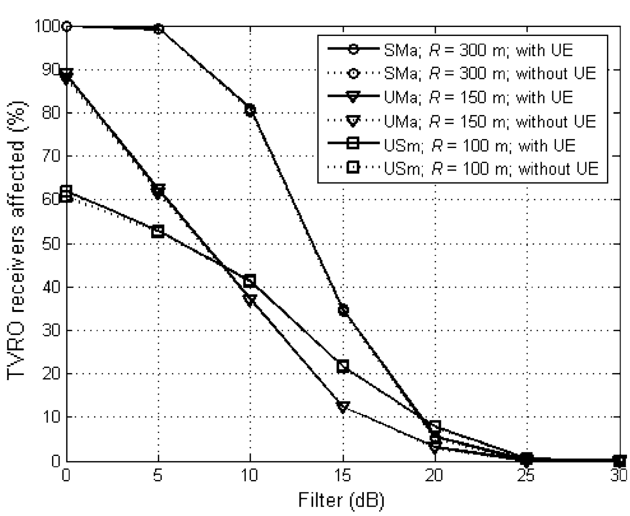


Fig. 7 Percentage of TVRO receivers affected by the LTE-BS and by the LTE-BS plus LTE-UE

Note that the following inputs are described by random variables: elevation angle of the TVRO antenna (uniform distribution), propagation models (Gaussian distribution), if the user equipment is located outdoor or indoor (binomial distribution), and the position of the interferers (uniform distribution). Moreover, the test scenarios are simulated for different cell radius and antenna radiation pattern of the TVRO receiver.

These systems definitions implies eight configurations for the transmitter systems (scenarios SMa and UMa with three cell radius each and scenario USm with two cell radius) and 6 configurations for the receiver systems ($G_{env} = 0$ dBi, $G_{env} = -4$ dBi, and $G_{env} = -10$ dBi; $O_{th} = -60$ dBm and $O_{th} = -45$ dBm). So, there are a total of 48 configurations.

3 Results

3.1 Overload of the TVRO receiver keeping the station at a minimum distance of 10 m from the LTE-A system

Each configuration described in the previous section is a simulation in Seamcat v.5.0.1. For each one, it will run thousands of events (in this paper, each simulation consists of 20,000 events), where in each event the inputs are randomly chosen according to its probability distribution function.

After one simulation, Seamcat will calculate two main interference signals. The first is the signal transmitted by the interference systems in its regular allocated bandwidth (in this case, the 3560–3600 MHz frequency band). Due to the adjacent channel selectivity (ACS) of the victim receiver filter, some of this signal is also received (Seamcat named this signal as "blocking"). The second interference signal is due to the adjacent channel leakage ratio (ACLR) of the interference systems: some out-of-band and/or spurious emissions can be received by victim system in its bandwidth, which in this simulation is the 3625–3631 MHz (Seamcat named this signal as "unwanted"). Figure 3 represents the unwanted and the blocking signals. Note from Fig. 3 that Seamcat considers the ACS of the victim receiver filter only at the interferer frequency band, and the ACLR of the interferer system only at the victim frequency band. This is an approximation of the complete source of interference, which could be computed using a frequency dependence rejection (FDR) evaluation [26].

To verify if the TVRO receiver overloads due to the LTE-A system in the adjacent band, we need to check if the interferer's power at the TVRO receiver is greater than or equal some overload threshold (O_{th}). In the Brazilian market, a common value for O_{th} is -60 dBm, but there is

Table 4 Minimum necessary distance between the LTE-A base station and the TVRO antenna for coexistence between both systems for scenario SMa

	$R = 1$ km (0.38 BS/km^2) $eirp = 64$ dBm		$R = 600$ m (1.1 BS/km^2) $eirp = 59$ dBm		$R = 300$ m (4.3 BS/km^2) $eirp = 53$ dBm	
	O_{th}		O_{th}		O_{th}	
G_{env}	−60 dBm	−45 dBm	−60 dBm	−45 dBm	−60 dBm	−45 dBm
−10 dBi	–	75 m	–	10 m	–	10 m
−4 dBi	–	245 m	–	155 m	–	110 m
0 dBi	–	–	–	430 m	–	230 m

Table 5 Minimum necessary distance between the LTE-A base station and the TVRO antenna for coexistence between both systems for scenario UMa

	$R = 600$ m (1.1 BS/km^2) $eirp = 64$ dBm		$R = 300$ m (4.3 BS/km^2) $eirp = 58$ dBm		$R = 150$ m (17.1 BS/km^2) $eirp = 46$ dBm	
	O_{th}		O_{th}		O_{th}	
G_{env}	−60 dBm	−45 dBm	−60 dBm	−45 dBm	−60 dBm	−45 dBm
−10 dBi	270 m	55 m	170 m	45 m	95 m	10 m
−4 dBi	–	90 m	–	75 m	–	10 m
0 dBi	–	120 m	–	105 m	–	60 m

Table 6 Minimum necessary distance between the LTE-A base station and the TVRO antenna for coexistence between both systems for scenario USm

	$R = 150$ m (17.1 BS/km^2) $eirp = 43$ dBm		$R = 100$ m (38.5 BS/km^2) $eirp = 35$ dBm	
	O_{th}		O_{th}	
G_{env}	−60 dBm	−45 dBm	−60 dBm	−45 dBm
−10 dBi	60 m	20 m	50 m	10 m
−4 dBi	70 m	40 m	70 m	15 m
0 dBi	80 m	50 m	70 m	30 m

also better quality receivers with $O_{th} \sim -45$ dBm (or even better, with $O_{th} = -40$ dBm [27]), which is an example of LNBF sold as a "robust LNB that protects against other terrestrial signals". So, each scenario will be simulated for O_{th} equals −60 and −45 dBm. Besides, we will check antennas with G_{env} equals to 0, −4 and −10 dBi.

For each scenario (SMa, UMa, and USm), we will evaluate the effect of LNBF with embedded C-band filters with different rejection ratio (from 5 to 30 dB) at the LTE-A frequency band. The filters impact the blocking signal, but they do not change the unwanted signal. Figures 4, 5, and 6 show the percentage of TVRO receivers whose interferers' signal strength is greater than O_{th} for C-band filters with different rejection ratio below 3600 MHz.

We will consider that a percentage of 5% of TVRO receivers affected is acceptable.[1] The results show that LNBF with $O_{th} = -60$ dBm (solid lines) is not acceptable without an embedded C-band filter.

On the other hand, if the receivers use good equipment ($G_{env} = -10$ dBi and $O_{th} = -45$ dBm), both system can coexist in several of configurations. For example, suburban macrocells with $eirp = 53$ dBm/40 MHz and 4.3 BS/km^2 (Fig. 4c) can be deployed. Or urban macrocells with $eirp = 46$ dBm/40 MHz and 17.1 BS/km^2 (Fig. 5c). Or even urban small cells with $eirp = 35$ dBm/40 MHz and 38.5 BS/km^2 (Fig. 6a).

Simulation results suggest that filtering in the C-band with at least 30 dB is a solution to solve the overload issue.

Note that Figs. 5c (urban macrocell—UMa) and 6a (urban small cell—USm) show the results for cells of same size. Even the base station transmitting more power in the UMa scenario, the line charts for $O_{th} = -45$ dBm show that the number of interfered TVRO receivers is lower in the UMa scenario than in the USm scenario. This is mainly due to the side lobes of the base station antenna in the UMa scenario. The base station in the UMa scenario is 14 m higher than the TVRO station and there is a tilt in the antenna. In the USm scenario, they are at the same height, without tilt.

A relevant finding in these simulations is that the main overloading problem is caused by the base stations, and not by the user equipment. To illustrate it, we simulated all these scenarios again without the user equipment (UE).

[1] This value is used in several interference studies, e.g. [28–31]. Besides, in a recent analysis using Seamcat, Anatel (the Telecommunications Regulatory Body of Brazil) analyzed the harmful interference caused by a LTE base station (operating at the 700 MHz frequency band) in TV receivers. Simulations using

Footnote 1 continued
Seamcat showed a probability of harmful interference of about 5% for an LTE base station with equivalent radiated power of 54 dBm [29]. Nevertheless, by the time this paper is being written, no critical interference from the recently deployed LTE-700 MHz network to the broadcasting receivers was detected, following the same pattern experience of other countries [32].

Figure 7 shows the percentage of TVRO receivers affected by the LTE-BS and by the LTE-BS plus LTE-UE in three cases (one for each scenario). In all cases, the TVRO receivers has $G_{env} = 0$ dBi and $O_{th} = -60$ dBm. Note that the user equipment is not relevant in these cases (the dotted line is close to the continuous line).

3.2 Finding the minimum distance between the TVRO receiver and the LTE-A base station to keep the overload level at an acceptable level

The results from Sect. 3.1 consider that the minimum distance between the LTE-BS and the TVRO antenna is $d_{min} = 10$ m. If we increase this distance, both systems can coexist in some situations without a C-band filter. We kept the coexistence criteria as the percentage of TVRO receivers affected below 5%. Tables 4, 5 and 6 show the value of d_{min} to allow the coexistence between them. The minimum distance between the LTE-UE and the TVRO antenna remains unchanged (10 m). To find d_{min}, we tested distances between the TVRO receiver and the LTE-A base station greater than 10 m and only for multiples of 5 m. The marker '–' in Tables 4 and 5 means that it is not possible to get a minimum distance lower than R to isolate the TVRO antenna from the LTE-BS to get a percentage of interference lower than 5%.

The coexistence between both systems without a C-Band filter in a suburban macro cell environment (scenario SMa) is not possible for low quality TVRO receivers. In a given location, if the receivers have good reception characteristics ($G_{env} = -10$ dBi and $O_{th} = -45$ dBm), then a separation of 10 meters between the LTE-BS and the TVRO receiver is sufficient to allow an $eirp = 53$ dBm/40 MHz for 4.3 BS/km^2 (or even an $eirp = 59$ dBm/40 MHz for 1.1 BS/km^2). If a higher coverage is necessary (0.38 BS/km^2), a minimum distance of 75 m from the base station is necessary to use an $eirp = 64$ dBm/40 MHz.

In the macrocell urban scenario (scenario UMa), the LTE-BS height decreases and the path loss increases. To cover the same area of the suburban scenario, a higher *eirp* is used. As in the SMa scenario, the coexistence without a C-band filter is impossible for low quality TVRO receivers. But if it is possible to deploy the LTE-BS at least at some distance from a good quality TVRO receiver, both systems can coexist. For example, for a base station density of 1.1 BS/km^2, an $eirp = 64$ dBm/40 MHz would be acceptable with a minimum separation distance of 55 m. For a base station density of 4.3 BS/km^2, the minimum distance decreases to 45 m if the $eirp = 58$ dBm/40 MHz. In the case of a base station density of 17.1 BS/km^2, 10 m is enough to use an $eirp = 46$ dBm/40 MHz.

Scenario USm represents urban small cells (base station height of 6 m with no tilt, and low coverage). For this scenario, in all cases, even with low quality TVRO receivers, a minimum distance of 80 m is sufficient for the coexistence of both systems. For good quality receivers, a minimum separation distance of 10 m assures the coexistence of both systems when the base station density is 38.5 BS/km^2 and the $eirp = 35$ dBm/40 MHz (or 20 m for a base station density of 17.1 BS/km^2 with $eirp = 43$ dBm/40 MHz).

The USm scenario considers a cellular network (one cell surrounded by others). In some situations, small cells are used to support a high traffic demand in a certain area. In these cases, it is common to use only one cell without surrounding cells. Thus, the total interference level decreases and the minimum separation distance may be even lower than that shown in Table 6.

4 Conclusions

This paper presents the coexistence problem between the LTE-A and TVRO systems in Brazil. Due to the low quality TVRO receivers, there are some restrictions for the coexistence between both systems, which are analyzed in this paper.

Without a C-band filter, coexistence is possible using robust receiving equipment in urban small cells or for some configurations of urban or suburban macrocells. Using an adequate C-band filter, coexistence is possible in every scenario. Depending on the necessary decay of the filter, the 25 MHz gap between the beginning of the FSS frequency band and the end of the LTE-A frequency band might not allow the design and implementation of cost effective C-band filers, which can hamper the spread of this solution into this market. In this case, a mixed solution could be used considering a filter with an intermediate decay, robust LNB (specifically the first LNA), better antenna and reducing the *eirp* of the base station.

In some cases, deploying the LTE-advanced base stations at a minimal distance from the TVRO receivers mitigates the overloading of the TVRO receivers. This is especially important when deploying small cells. Because the minimal distance is short, the TVRO antennas (usually parabolic antennas with ~ 1.5 m of diameters) can be identified through visual inspection.

Note that the simulations consider the scenarios defined in Sect. 2, which were defined by ITU as reference scenarios. Scenarios representing specific cities or locations may change results. However, the overall conclusion remains: the use of a better antenna and an optimized

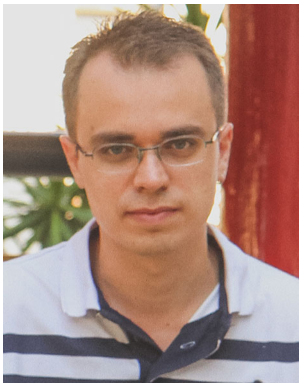
LNB(F), with adequate separation distance between interferer-interfered can significantly mitigate the overload problem.

Even with the proposed technical solutions, punctual cases of harmful interference may occur and should be analyzed on a case-by-case basis. Further mitigation techniques may include the use of a more robust filter, change the receiver antenna position, or even deploy antenna shielding.

The current situation of the Brazilian TVRO receivers was used to define the values for overloading threshold and the antenna envelope. The results shown in this paper might be useful for any country that also have TVRO receivers operating at the C-band and intend to deploy a LTE network at the lower adjacent band if the TVRO receivers have similar properties of those analyzed in this paper. For example, some Latin America countries face similar problems and are also analyzing this issue. This is one of the reasons that the use of this band for IMT is being studied in Citel (Inter-American Telecommunication Commission) [33].

References

1. Cisco. (2016). *Cisco Visual Networking Index: Global mobile data traffic forecast update, 2015–2020*. White paper, Cisco.
2. ITU. (2015). *Report ITU-R M.2370-0: IMT traffic estimates for the years 2020 to 2030*. Technical report, ITU-R.
3. LS telcom. (2014). *Mobile spectrum requirements estimate: Getting the inputs right*. Technical report, LS telcom.
4. Russian Federation. (2012). *Document 5D/118-E: Future IMT spectrum requirements assessment for the Russian Federation*. Technical report, ITU-R.
5. Fernandes, L. C., Linhares, A., & Ferreira, L. R. N. (2017). Spectrum forecasting for IMT-advanced. *Telecommunication Systems*. doi:10.1007/s11235-017-0276-5.
6. Anatel. (2010). Resolution no 537. Feb 2010 [In Portuguese: Resolução no 537, de 17 de fevereiro de 2010].
7. ITU. (2011). Report ITU-R S.2199-0: Studies on compatibility of broadband wireless access (BWA) systems and fixed-satellite service (FSS) networks in the 3400–4200 MHz band. Retrived from https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-S.2199-2010-PDF-E.pdf.
8. ITU. (2003). Recommendation ITU-R M.1634-0: Interference protection of terrestrial mobile sharing systems using Monte Carlo simulation with application to frequency sharing.
9. ITU. (2002). Report ITU-R SM.2028-1: Monte Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems.
10. CEPT. (2016). ECC report 252: SEAMCAT handbook, 2nd edn.
11. ITU. (2015). Report ITU-R S.2368-0: Sharing studies between International Mobile Telecommunication-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3400–4200 MHz and 4500–4800 MHz frequency bands in the WRC study cycle leading to WRC-15.
12. WiMAX Forum. (2007). Compatibility of services using WiMAX technology with satellite services in the 2.3–2.7 GHz and 3.3–3.8 GHz bands.
13. ITU. (2013). Report ITU-R M.2292-0: Characteristics of terrestrial IMT-advanced systems for frequency sharing/interference analyses.
14. 3GPP. (2016). 3GPP TS 36.104 v13.2.0.
15. ITU. (2014). Report ITU-R M.2324-0: Sharing studies between potential International Mobile Telecommunication systems and aeronautical mobile telemetry systems in the frequency band 1429–1535 MHz.
16. ECC. (2015). ECC report 227: Compatibility studies for mobile/fixed communication networks (MFCN) supplemental downlink (SDL) operating in the 1452–1492 MHz band.
17. 3GPP. (2016). 3GPP TS 36.101 v14.0.0.
18. ITU. (2010). Recommendation ITU-R S.465-6: Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz.
19. Anatel. (2013). Report of the 3.5 GHz workgroup (GT 3.5 GHz).
20. ITU. (2009). Report ITU-R M.2135-1: Guidelines for evaluation of radio interference technologies for IMT-advanced.
21. Walden, M. C., & Rowsell, F. J. (2005). Urban propagation measurements and statistical path loss model at 3.5 GHz. In *IEEE antennas and propagation society international symposium, 2005*.
22. ITU. (2015). Recommendation ITU-R P.452-16: Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz.
23. Nwawelu, U. N., Nzeako, A. N., & Ahaneku, M. A. (2012). The limitations of campus wireless networks: A case study of University of Nigeria, Nsukka [Lionet]. *International Journal of Networks and Communications, 2*(5), 112–122.
24. Yamada, W., Sasaki, M., Kita, N., Sugiyama, T. New prediction method using visibility factor for path loss between mobile terminals in residential area in microwave band.
25. Rodriguez, I., Nguyen, H. C., Jørgensen, N. T. K., Sørensen, T. B., Elling, J., Gentsch, M. B., & Mogensen, P. (2013). Path loss validation for urban micro cell scenarios at 3.5 GHz compared to 1.9 GHz. In *2013 IEEE global communications conference (GLOBECOM)*, Dec. 2013 (pp. 3942–3947).
26. ITU. (2008). Recommendation ITU-R SM.337-6: Frequency and distance separations.
27. Greatek. http://www.greatek.com.br/produtos/37/pro-2100a.
28. Ancans, G., Stankevicius, E., Bobrovs, V., & Paulikas, S.: Evaluation of LTE 700 and DVB-T electromagnetic compatibility in adjacent frequency bands. In *Progress in electromagnetics research symposium proceedings*.
29. Cheng, Y., Wang, Y., Yun, H., & Lee, I. (2014). Interference impact of LTE on mobile WiMAX in TV white spaces. *International Journal of Information and Electronics Engineering, 4*(5), 403–408.
30. CEPT. (2014). ECC report 207: Adjacent band co-existence of SRDs in the band 863–870 MHz in light of the LTE usage below 862 MHz.
31. Anatel. (2014). Technical Note no 07/ORER/2014: Estimates of the percentage of Brazilian households that will need to adopt an additional filter in TV reception, June 2014 [In Portuguese: Nota Técnica no 07/ORER/2014: Estudo para estimativa do percentual de domicílios brasileiros para os quais será necessária adoção de filtro adicional na recepção de TV, de 17 de junho de 2014].
32. Watson, J. (2014). When it comes to interference, you can't beat real world experience. Policy Tracker, 2014.
33. Citel. (2016). Working document toward a draft recommendation. CCP.II-RADIO/doc. 4202/16 rev.1: Frequency arrangements for the terrestrial componente of IMT in the bands 3300–3400 MHz, 3400–3600 MHz and 3600–3700 MHz.



Leandro Carísio Fernandes received his Ph.D. degree in 2012, and the M.Sc. degree in 2007, both in Telecommunications Engineering from the University of Brasília, Brazil. He received his B.Eng. degree in Electrical Engineering from Federal University of Minas Gerais, Brazil. He already worked as a developer and system analyst. Leandro currently works at Anatel (the telecommunications regulatory body of Brazil), in the spectrum, orbit and broadcasting office. His research interests include frequency sharing between radiocommunication systems, human exposure to electromagnetic fields (EMF) and EMF computational simulations. He is a reviewer of Conferences and Journals on Wireless Communications.

Agostinho Linhares received his Ph.D. degree in Telecommunications from University of Brasilia in 2015 and M.Sc. degree in Telecommunications from University of Campinas in 2003. He joined Anatel in 2005 and has already worked in the Enforcement Division, Spectrum Engineering Division, Board of Directors Advisory and, currently, is Manager of Spectrum, Orbit and Broadcasting. Before Anatel, he has worked at Petrobras as a Telecommunications Engineer developing projects related to optical communications systems, RF links and IP Networks. He is the Coordinator of the Brazilian Communication Commission - Radiocommunication Sector (CBC-2), participates in ITU-R and ITU-T Study Groups, and was Head of Brazilian Delegation in the World Radiocommunication Conference 2015 (WRC-15). His research interests include sharing and compatibility between radiocommunication systems, human exposure to EMF andspectrum management. Additionally, he is a reviewer of Conferences and Journals on Wireless Communications.

BROADBAND INDIA FORUM
"Think Tank for Digital Transformation"

JANUARY
2022

NON-PUBLIC 5G NETWORKS IN INDIA

Policy, Regulatory and Sector Perspective

Author: **Prof. Rekha Jain**
Senior Visiting Professor, ICRIER

Non-Public 5G Networks in India: Policy, Regulatory and Sector Perspective

Prof. Rekha Jain[1]

Senior Visiting Professor, ICRIER

1 rekha@iima.ac.in
Research support provided by Ms. Neha Hathiari is gratefully acknowledged
The research was commissioned by BIF.

Acknowledgements

This report was commissioned by Broadband India Forum (BIF). However, the views expressed here are independent of BIF. We benefited from the experience and expertise of the wider BIF team and long-time associates. Our thanks to Mr. TV Ramachandran (President, Broadband India Forum) for facilitating most of these interactions and for providing his insights.

This report draws from the expertise of Prof. A Paulraj (Professor Emeritus, Department of Electrical Engineering, Stanford University) and Captain Yashoverman Sharma (Expert in the shipping industry and Visiting Faculty in various institutes) especially for data for the port/shipping sector. Mr. Abdurazak Mudesir (Senior VP - Service & Platform, Telekom Germany) and Mr. Srini Gopalan (Board member for Germany at Deutsche Telekom) who we interacted with and their experiences helped us tremendously. We are grateful for their time and inputs during interviews, email interactions and feedback sessions.

Mr. Adrian Scrase (CTO of 3GPP) shared useful documents with us.

CONTENTS

EXECUTIVE SUMMARY

Greater digitalization and increasing use of sensors and sensor networks has given rise to business cases where applications require extremely high bandwidth, low latencies or high reliability. Such deployment priorities may be specific to each enterprise in terms of network investments aligned with specific use cases.

5G has the requisite protocols to support massive sensor networks. The specifications provide for defining virtual network characteristics embedding ultra-reliability, low latency and extremely high bandwidths. This allows for a variety of domain specific applications to be developed and implemented that may have differing requirements of latency, reliability and/or bandwidth. The attributes of 5G make it feasible to implement it in enterprises, independent of the public roll-out – called Non-Public 5G Networks (NPN). On one hand, this allows the enterprise to be responsive to its business needs, on the other, it also provides the TSP with potential revenue, if the business and TSP work together to roll-out and manage the enterprise network.

Given that public 5G networks could take a few years to be deployed as TSPs go through the auction/allocation process, get ROW and roll-out services, it would be worthwhile to consider NPN as an effective network deployment strategy. NPNs would allow Industry 4.0 to be realized on a larger scale. Several countries have implemented NPNs with a view to be leaders in 5G and also to give their enterprises a competitive edge. India should also leverage 5G's features to give a competitive edge to Indian manufacturing and enterprises. This will provide an opportunity for local applications to be developed on Indian use cases, thus supporting Atmanirbhar Bharat. With the advent of successful 5G test beds for NPN and use cases across the world, India is at an advantage to leapfrog in this domain.

This White Paper identifies the policy, regulatory and industry specific issues in the roll-out of NPN Private 5G. This aims to address the concerns of the Parliamentary Standing Committee on IT by providing a roadmap to DoT/TRAI and TSPs and ISPs.

The White Paper is based on extensive desk research, interactions with various industry experts and contextualizing an existing use case model for the Indian port and smart manufacturing sectors.

Analysis and Recommendations

- Early availability of spectrum for NPN is necessary for enterprises to become more competitive.

- Earlier, spectrum licenses were exclusively awarded to telcos. NPN would require development of frameworks for shared license access between telcos and/or enterprises. Regulators may need to develop appropriate regulatory framework for allocation of spectrum to enterprises, in case of a user led NPN deployment model. Developing regulatory and technology models for Licensed Shared Access would be critical.

- So far, the role of telcos was predominant in rolling out networks and devising innovative marketing strategies. NPNs will entail them to devise end-to-end solutions for enterprises as they roll out domain specific applications. NPNs also challenge enterprises to devise new business models with innovative services. On the other hand, NPNs would create opportunities for revenue generation from the consequent new business opportunities. This could address telcos' concern regarding sharing spectrum with enterprises and hence losing out on some services. Enterprises would also require new kinds of network capabilities, especially regarding the network requirements for their domain specific applications (such as latency, bandwidth). Organizations would need to ensure that their NPNs comply not only with their own security and user administration aspects, but also with the 3GPP framework.

- Unlicensing of spectrum is required as several use cases for 5G are driven by the propagation characteristics and device ecosystem in the unlicensed bands. Making adequate spectrum available in other licensed bands requires central coordination across other government departments/ministries such as Space and Defence, that are currently using the identified 5G bands. Similarly, new unlicensed spectrum bands viz. 6 GHz and also 60 GHz (V band) need to be opened up to help unleash next-gen Wi-Fi technologies viz. Wi-Fi6/Wi-Fi6E and Wi-Fi7, which can complement 5G. The coordination should be done in the context of experience of other countries that had similar situations and on the basis of co-existence studies carried out in India. Further, NPNs would require developing domain specific use cases and hence coordination with regulatory/standards bodies in those domains is of utmost importance.

- Pilot NPN testbeds in the port sector and manufacturing in Europe have shown significant positive outcomes, both from a financial and sustainability perspective.

- Contextualizing an existing model for five key use cases, we found that Indian ports and smart manufacturing shows substantial benefits and helps to identify the sequence of implementation amongst the selected use cases.

- A collaborative approach between academia, service providers, user industry, vendors and most importantly, adequate funding support from the government is necessary. Identifying focus areas of testbed implementation in real life contexts as was done in the COREALIS project is important to influence industry and policy makers regarding adoption of NPN.

- The Department of Telecommunications (DoT), India has supported the creation of 5G testbed in India through a network of Indian Institute of Technology, Hyderabad, Indian Institute of Technology, Bombay and Indian Institute of Technology, New Delhi. This support provides for hardware and software for testing. Application agnostic testbeds as the one implemented in India are critical for vendors, equipment providers, telcos and start-ups to test potential 5G deployments in India. In addition, an NPN implementation as a series of pilots in a specific sector such as a port, airport, manufacturing enterprise across several locations, etc. is critical for understanding the key/different drivers in each sector. This is because each enterprise context (port, manufacturing, airport) would have varying needs and priorities for bandwidth, reliability, connectivity, latency, etc. Further, even within a specific type of enterprise, these needs would vary. For example, for ports with congested berths, operating rubber tyred gantry cranes may be more important, while for another, condition monitoring could be more important.

- As an example, EU Horizon 2020 program supported 5G initiatives in several areas such as Ports, Smart Manufacturing, etc. were taken up. The projects typically involved telcos, network integrators, equipment vendor and most importantly, the user organizations. Since enterprise context is important for NPN, we suggest that MeitY, in collaboration with the industry and academia, prioritise funding for a series of end-to-end pilot test bed implementation along several sectors, as suggested above. Along with this, it should undertake systematic baseline studies to scientifically be able to establish the value addition due to NPN as was done in the COREALIS project.

- Various models of NPN deployment are possible. Most sustainable will be the ones that leverage the inherent unique strengths of the vendors, telcos and the user-industry.

- Early licensing models for NPN deployments indicate an administrative price based on amount of spectrum, geographical area and duration seem to work. Further, use-it-or-lose-it models to encourage industries to deploy NPN in an accelerated manner would be useful. Technology neutrality is an important characteristic of these licenses.

- Innovative applications emerging from early NPN deployments could see many ICT products/services from India, contributing to Atmanirbhar Bharat. This would also give an impetus to the start-ups and could help create a leading position for India in the Internet and knowledge/service sector.

- Both public and private sector enterprises could benefit from NPN deployments.

- Service providers (telcos and vendors) will need to address the specific network requirements and SLAs. This may require upgradation of technical skills. NPN deployments could create new non-linear revenue channels for telcos.

DRIVERS FOR THE WHITE PAPER

As per the Standing Committee on Information Technology (2020-21) titled "India's Preparedness for 5G", February 2021, *"...there are apprehensions that India is set to miss the '5G bus' due to lack of preparedness, spectrum issues, inadequate use-case development, uncertainty around sale of radio waves for 5G, etc"*. The time lag in India's deployment of various telecom technologies with respect to global deployments is highlighted in Table 1 and substantiates the concerns regarding delays in 5G deployment.

Table 1: Global and Indian Deployment for 2G, 3G, 4G and 5G

Technology	2G	3G	4G	5G
Global Deployment	1993/94	2000	2008	2019
Indian Deployment	1995	2011	2016	-

Source: The Standing Committee on Information Technology (2020-21), February 2021[2], other sources

Further, the Committee was *"...inclined to conclude that sufficient preparatory work has not been undertaken for launching of 5G services in India...unless time-bound action is taken in core areas where Governmental intervention is required"*, India would lag in 5G deployments. Going forward, the Committee directed the DoT to study the experience gained by other countries in successfully rolling out 5G for better understanding the complexities involved in the process. Further, the DoT was expected to *"explore all possible issues needed for the success of Industry 4.0, so that spectrum can be allocated and proper policies are laid down for industrial growth of the country using 5G"*. Given that public 5G networks could take a few years to be deployed as TSPs go through the auction/allocation process, get ROW and roll-out services, it would be worthwhile to consider private 5G networks as an effective network deployment strategy. In the latter case, the 5G network is limited to the enterprise. 3GPP Release 17 defines ***"A non-public network is a network that is intended for non-public use. Deployments of non-public networks in private environments (e.g., factories, enterprises) to provide coverage within a specific geographic area for non-public use is a key demand of emerging 5G applications and verticals. Non-public networks may be deployed as completely standalone networks or with the support of a PLMN. The 5G system supports non-public networks"***.

5G has the requisite protocols to support massive sensor networks. The specifications provide for defining virtual network characteristics embedding ultra-reliability, low latency and extremely high bandwidths. This allows for a variety of domain specific applications to be developed and implemented that may have differing requirements of latency, reliability and/or bandwidth. The attributes of 5G make it feasible to implement 5G in enterprises, independent of the public roll-out – called Non-Public 5G Networks (NPN). On one hand, this allows the enterprise to be responsive to its business needs, on the other, it also provides the TSP with potential revenue, if the business and TSP work together to roll-out and manage the enterprise network.

2 https://eparlib.nic.in/bitstream/123456789/799780/1/17_Information_Technology_21.pdf

Objectives

The White Paper identifies the policy, regulatory and industry specific issues in the roll-out of Private 5G Networks. This would address the concerns of the Parliamentary Standing Committee on IT by providing a roadmap to DoT/TRAI and TSPs and ISPs.

Introduction

Greater digitalization and increasing use of sensors and sensor networks has given rise to business cases where applications require extremely high bandwidth, low latencies or high reliability. Such deployment priorities may be specific to each enterprise in terms of network investments aligned with specific use cases. 5G specifications allow for extremely High Bandwidth for Mobile Devices (eMBB), Massive Sensor Connectivity (mMTC) and Ultra-Reliable Low-Latency Communication (ULRCC). Specific network properties based on the requirements of various applications can be configured through "network slicing", an intrinsic characteristic of 5G.

We give below the performance characteristics of 5G in relation to 4G

Table 2: Performance Characteristics of 5G

No.	Performance	4G	5G
1	Peak date rate (Gbit/s)	1	20
2	User experience data rate (Mbit/s)	10	100
3	Spectrum efficiency	1x	3x
4	Speed (km/h)	350	500
5	Latency (ms)	10	1
6	Connection density (number of objects/km^2)	105	106
7	Network energy efficiency	1x	100x
8	Area traffic capacity (Mbit/s/m^2)	0.1	10
9	Network Slicing	NA	Possible

Source: Recommendation ITU-R M.2083-0 (09/2015)[3]

The Department of Telecommunications has permitted 5G trials in different bands 3.2-3.67 GHz, 24.25-28.5 GHz and 700 MHz, along with the existing licensed spectrum in the 800 MHz, 900 MHz, 1800 MHz and 2500 MHz.

3 https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509- I!!PDF-E.pdf, accessed on October 9, 2017.

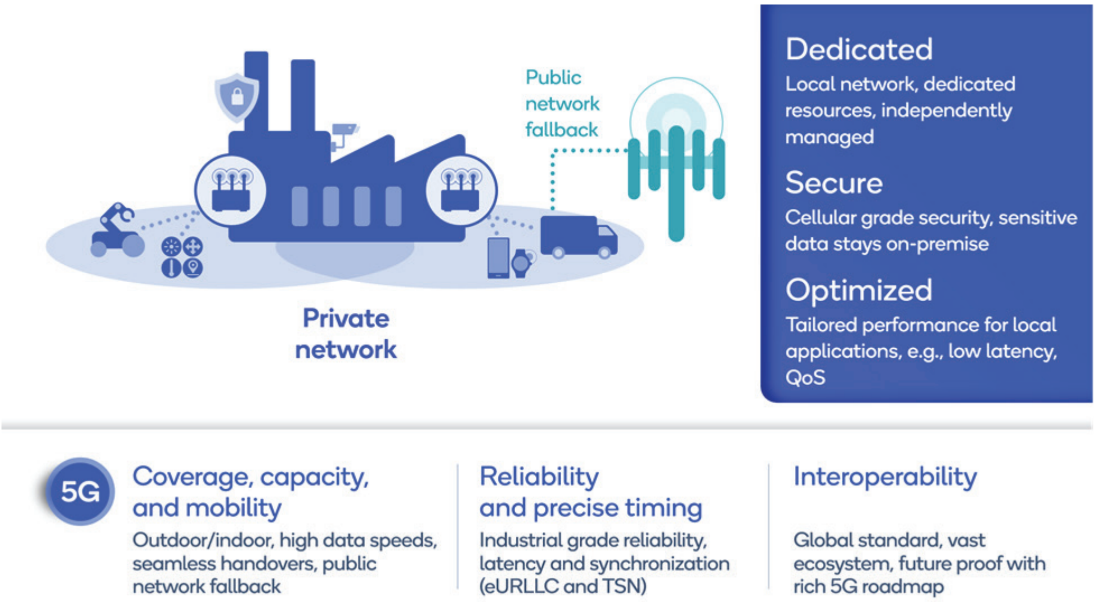
DRIVERS FOR NPN

Developments in edge computing, availability of dedicated or shared spectrum, a mature device ecosystem, simultaneous and synchronous developments in cellular 5G and Wi-Fi standards (Wi-Fi 6/6E and 5GNR) allow enterprises to deploy highly tailored networks. Edge computing allows for low latency and isolation by establishing a physical or logical boundary close to or inside the organizations. Networks that combine features of both traditional enterprise Wi-Fi and 3GPP standardized 5G networks allow for highly tailored networks when leveraged with edge computing. Processing at the edge allows for low latency, granular control and measures of security. These advancements have led to deployment costs of NPN being reduced drastically, thus making it easier for enterprises to adopt them.

- High quality-of-service requirements,
- High security requirements, met by dedicated security credentials,
- Isolation from other networks, as a form of protection against malfunctions in the public mobile network. Also, isolation may be desirable for reasons of performance, security, privacy, and safety.
- Accountability - A non-public network makes it easier to identify responsibility for availability, maintenance and operation[4] (Rel 17).

For example, one port may be first interested in providing support for massive bandwidth as it implements remote tower crane maintenance while another port may focus on automatic guided vehicles, where latency requirements may be more stringent. The telco designed public networks may not be engineered to serve such specific requirements. However, a telco does have the expertise to design contextually engineered networks for enterprises. Such networks require partnerships with the enterprise to take into account the business complexity reflected in different scenarios. Moreover, since such networks embed enterprise critical data, security of the network and localization of data is of concern to the enterprises.

Figure 1: Private 5G networks promise to connect people, sensors and machines within factories, universities, ports, farms and other facilities



Source: Qualcomm

4 3GPP releases 17 available on https://www.3gpp.org/release-17

Context of NPN

Several countries have implemented NPNs with a view to be leaders in 5G and also to give their enterprises a competitive edge. India should also leverage 5G's feature of softwarization, eMBB, ULRCC, mMTC and other characteristics mentioned above to give a competitive edge to Indian manufacturing and enterprises. This will provide an opportunity for local applications to be developed on Indian use cases, thus supporting Atmanirbhar Bharat.

Providing NPN would require development of a policy and regulatory framework for assigning 5G spectrum to enterprises or for TSPs to lease/share with enterprises. So far, the regulatory regime has allowed spectrum sharing only between licensed TSPs, but a framework for sharing the same between a TSP and a private enterprise would have to be developed. A policy for provisioning of adequate licensed spectrum in the relevant bands and similarly, a policy for unlicensing new and globally harmonised spectrum bands in accordance with international best practices, would have to be developed in a time bound manner. NPNs would allow Industry 4.0 to be realized on a larger scale. Thus, by starting roll-out of NPN, India could still catch the 5G bus, albeit as a laggard.

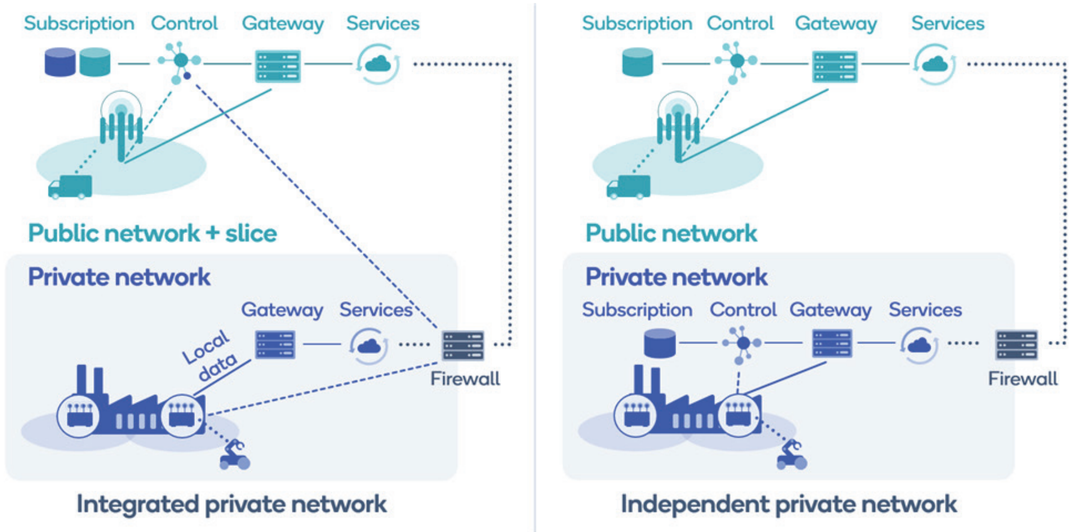
The broad picture above is a microcosm of the various policy, regulatory and industry specific issues in the context of private 5G Networks. It may appear that following the tried and tested method of first allocating spectrum for macro 5G networks, then waiting for deployments as has happened in 2G, 3G and 4G is a safe strategy, but this would be further putting India behind in the 5G race, as several other countries have already started deploying Private 5G Networks and have also allocated spectrum for licensed services for public 5G Networks.

Deployment Models for NPN

Release 17 of 3GPP identifies the following variety of configurations for NPNs utilising both virtual and physical network functions:

- Stand-alone Non-Public Network (SNPN), i.e., operated by an NPN operator and not relying on network functions provided by a PLMN.
- Public network integrated NPN (PNI-NPN), i.e., a non-public network deployed with the support of a PLMN.

Figure 2: Private networks can operate standalone or with public networks through network slicing



Source: Qualcomm

Overview of NPN Spectrum

The various bands that have been considered globally for NPN include the following:

- 1.7817-1.7850 / 1.8767–1.880 GHz
- 2.390-2.400 GHz
- 2.6 GHz
- 3.4-3.8 GHz
- 3.8-4.2 GHz
- 24.25-27.5 GHz

The specific bands selected in different countries would take into account national contexts of spectrum availability. The 3.4 - 3.8 GHz bands have been most widely used so far for NPN as they provide a good balance between coverage and throughput. More importantly, while considering specific bands for NPN, regulators need to be sensitive to the varied application requirements of reliability, latency, bandwidth associated with different use cases in various sectors. For example, while high bandwidth requirements and large channel sizes are critical in remote, automated maintenance of (say) cranes in a port, low latency is important for automated guided vehicles in the port area. Thus, spectrum bands for NPN would depend on the selected applications. Therefore, regulators need to make available a large number of bands for NPN effectiveness.

NPN Deployments in Different Countries

Several countries have taken the lead while few others have barely begun deployment of NPN. We list below the key aspects of NPN deployments in Germany, UK, Japan, USA, Italy and France with data available from public sources. These are listed in Table 3.

Four countries have provided NPN licenses as shared access spectrum. In UK there were three classes of licenses, depending on power emitted.

The license area in the case of Germany and Japan is the area of the premise. In UK, it also included the number of base stations in a radial distance of 500 m for low power licenses.

There are roll-out conditions in the form of use-it-or-lose-it in a year's time in Germany. Licenses are technology neutral.

The enterprises that have rolled out NPN have normally done so in partnership with telcos, equipment providers, and other players.

Table 3: 5G Private Network Deployment Characteristics in Germany, UK, Japan, USA and other countries

Country Regulator Band for Private Network	Process/License Characteristics	Deployment and Use Cases
Germany [5] The German federal network agency is Bundesnetzagentur BNetzA 3.700 – 3.800 GHz	• **License Eligibility** Land ownership or right of use. **License Fees** Fee = $1000 + b \cdot t \cdot 5 \cdot (6 \cdot a1 + a2)$, where 1000 indicates the base amount in euros, b denotes the bandwidth in MHz (10 to 100 MHz), t is the duration of the allocation in years (e.g. 10 years), and a is the area in km^2 with a differentiation between the populated area and transportation areas (a1) and other areas (a2). The locations and the area of the region can be defined by the applicants. • **License Blocks and Duration** 10 MHz blocks for maximum of 10 years, and are transferable. In any case, the regulatory framework will be reviewed by BNetzA after a year in use. Applicants can also apply for a shorter license duration, which will reduce their fees. • **Technology** Approach is service and technology neutral, though TDD is the only allowed duplex technology, and networks must be synchronized. Efficient use of the assignment is required, with a use-it-or-lose-it principle.	BNetzA has already awarded 123 spectrum licenses for private 5G campus networks. Some of the companies running campus networks based on 5G frequencies include: • Audi • BMW Deutsche Messe • Fraunhofer Institut fur Integrierte Schaltungen IIS • Daimler • Mercedez-Benz • Porsche • Rohde & Schwarz and • ThyssenKrupp
United Kingdom Ofcom 1.800 GHz 2.3 GHz 3.8 - 4.2 GHz	• **License Type** Shared Access licenses in four shared access bands in two categories - low power license (per area license) and medium power license. For low power license to deploy a required number of base stations in a circular area of a 50 m radius, while the terminals are covered by the same license. • **License Fees** Cost based administrative fees, reflecting Ofcom's cost of issuing the license, charged annually on a per area based or on a per base station basis For the 3.8-4.2 GHz band, the annual fee is also 80 GBP per 10 MHz per area • **License Blocks and Duration** 2 x 3.3 MHz portion of the 1800 MHz band is best suitable for narrowband applications in the rural areas. 3.8-4.2 GHz band is currently used by several incumbent services, but in addition, the band can be used for private networks as there are unused spectrum resources. • **Technology** Licenses are technology neutral	Associated British Ports (ABP) operated U.K. Port of Southampton with a private 5G network. Verizon provided the first mainland U.K. port with a private 5G network.

5 https://www.researchgate.net/publication/340563891_Location_Dependent_Spectrum_Pricing_of_Private_LTE_and_5G_Networks_in_Europe

Country Regulator Band for Private Network	Process/License Characteristics	Deployment and Use Cases
Japan Kanto Bureau of Telecommunications 28.2 - 28.3 GHz 25.75 -25.95 GHz	• **License Type** 28,000 square meters on the grounds of Fujitsu Shin-Kawasaki Technology Square • **License Fees** • **License Blocks and Duration** • **Technology** To be in compliance with the standards set by the Radio Law. 5G for data transmission, LTE for connection control between base stations and land mobile stations	Fujitsu - Japan's first commercial Private 5G radio station license from the Kanto Bureau of Telecommunications and will begin operating a Private 5G network at its Shin-Kawasaki Technology Square office (Location: Kawasaki City, Kanagawa Prefecture).
Italy AGCOM (Italian Communication Authority) 3.7 GHz	• **License Fees** • **License Blocks and Duration** • **Technology** For Port of Livorno, the 5G NR network installed in the port area was based on 3GPP R15 Option 3.x architecture based on Ericsson AIR 6488 operating at 3.7 GHz. The gNodeB is an Ericsson Baseband 6630 installed in the same cabinet where the cloud platform is also located.	122 5G projects are in the trial phase, some via public grants.[6] The 5G trial underway in Livorno is also part of the European project H2020 Corealis.
USA FCC 3.550-3.700 GHz	• **License Fees** • **License Blocks and Duration** • **Technology** Governed by Citizens Broadband Radio Service (CBRS)	John Deree – an agricultural farm equipment manufacturer paid $500 k in private 5G licenses to support flexible factory networks.
France ARCEP Electronic Communications, Postal and Print media distribution Regulatory Authority (L'Autorité de régulation des communicationsélectroniques, des postes et de la distribution de la presse) 2.570-2.620 MHz Band 38	• **License Fees** • **License Blocks and Duration** 2600 TDD MHz band • **Technology** Governed by net neutrality requirements and regularly reviewed by ARCEP	The airport operator, ADP Group and its subsidiary Hub One, have been granted a 10-year 4G and 5G license by ARCEP in February 2020 to be used in Paris' airports. EDF, the major electricity company in France has been awarded a 10-year license in the 2.6 GHz TDD band (20 MHz) on the Blayais nuclear power plant. The mobility company TransDev has also been allowed to use the 2575-2595 MHz spectrum in Rouen, North West of France for three years from 12 March 2020. Other verticals like national railway company SNCF and Airbus have expressed their interest to ARCEP.[7]

6 According to a recent study by the 5G & Beyond Observatory of the School of Management at the Politecnico of Milan

7 https://5gobservatory.eu/5g-private-licences-spectrum-in-europe/

Results of NPN Deployment

Deployments of NPN include private initiatives such as Mercedes Benz, Daimler, Porsche, Rohde & Schwarz and ThyssenKrupp, and Fujitsu (Japan). These have reached different levels of maturity. In addition, significant initiatives at the national/supranational level such as EU have been undertaken. In Appendix 1, we provide some examples/initiatives in the NPN context. In the following, we consider two specific scenarios: smart ports and smart automotive factories in greater detail.

For ports, under the EU H2020[8], the European Commission had funded the COREALIS[9] project. The focus was on "Port of the Future for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges". The project duration was from May 2018 – April 2021. The project funding included 5.1 million Euros, 17 partners from 10 European and associated countries. The objective of the innovative technology deployment was to increase efficiency, optimize land use, and contribute to financial viability and increasing environment sustainability. The deployment was done in real operating conditions in five ports: Piraeus port, Valencia port, Antwerp port, Livorno port and Haminakotka port.

For smart factories, the EU, Smart Factory Europe[10] project aims to accelerate the digitalization of the European manufacturing industry. This alliance was established between 3 European partners: Smart Factory Kaiserslautern (this is a German cooperation platform consisting of over 50 partners from industry and research), Flanders Make (this is a strategic research centre for the manufacturing industry with over 600 researchers) and Brainport Industries. To accelerate adoption of industry 4.0 practices, this project provides exchange of best practices and Smart Manufacturing Hubs/Centers that offer facilities to the manufacturing industry.

Port Automation

Ports face challenges in remaining competitive, due to the demands of trade, customers and economic development and differential ability to leverage technology. This increases pressure on them to be more efficient and hence be able to attract more shipping lines through better and effective pricing. Significant amount of automation has happened around container ports due to the fact that they deal with standardized cargo type: a container.

Optimizing yard and terminal operations is a key priority for port operators. This includes decongesting yards for both greater efficiencies and lower impact on the environment. Port operators have to contend with ever increasing demand in the context of limited quay lengths, berth space and related equipment for loading and unloading.

Ports are generally geographically spread, have varying levels of network and computing requirements, and are in the process of increasing digitalization. Driven by competition, ever increasing size of ships and greater move towards containerization, ports are increasingly using automation. From the perspective of environmental impact and safety, ports find it necessary to minimise ship anchorage time, reduce berthing delays, manage within port and entry & exit of truck traffic, efficient use of ship to shore cranes and forklifts. Digital initiatives to manage the above include using sensors for RFID for container tracking, automated guided vehicles, sensor-based rubber tyred gantry cranes and forklifts.

---

8 Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness Seen as a means to drive economic growth and create job, details available on https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020

9 Capacity with a positive environmental and societal footprint: ports in the future era – COREALIS, details available on https://www.corealis.eu/

10 https://smartfactory.eu/

Existing LTE/4G, fibre and Wi-Fi have their limits and may not support all port related use cases. This is because while freedom from interference is guaranteed in LTE/4G networks, the sharing of radio resources restricts the quality of SLA for enterprise customers. Fibre networks do not allow for mobility of devices and equipment. While Wi-Fi 6E does offer 5G like capabilities, 5G offers a degree of mobility that is not possible with Wi-Fi. Also, where there is a need to cover a large number of devices, especially outdoors (as transmission power/Wi-Fi Access point is limited). 5G deployments in ports as potential test bed is, therefore, attractive.

Network slicing, a key feature of 5G, allows for these varied requirements to be implemented. Leveraging 5G cellular capabilities allows for "• Low and predictable latencies, even with a heavy load and many users • Quality of service to guarantee low latency and bit rates • More deployment flexibility for sparse and dense options • Mobility capabilities to ensure a smooth handover between base stations • Flexible scaling of network capacity, depending on demand • Reliability of device interoperability • The full deployment of multiple use cases, involving many sensors and devices, which require LTE/NB-IoT/5G cellular capabilities, to ensure reliability and security".[11]

The case studies below have detailed out the specifics of two ports, among the many such implementations.

Case Studies

a. Port of Hamburg

The Port of Hamburg is spread over a wide area and covers several transport networks, including waterways, 118 bridges, 300 km of railways. Port of Hamburg competes with the other North European Ports for servicing the entire European hinterland. In commercial shipping, there is 'A-R-B-H Range' - Antwerp, Rotterdam, Bremen, Hamburg. If the cargo is destined for interior Europe, shippers most likely choose between these four ports (and intermediate Ports like Zeebrugge, Bremerhaven, etc.) for their ship calls. As the port of Hamburg has geared up being adaptive to future technology, it has an upper hand in the competition among other European ports.

Identifying the areas that require maintenance or create bottlenecks is important for the efficient functioning of the port. The port requires SLAs in terms of guaranteed minimum throughput, reliability, coverage, resilience, and latency across a number of applications.

The port had a mix of fibre optic, radio technologies, including Wi-Fi and LoRa in the unlicensed bands. While fibre optic connectivity allows for high bandwidth, this can only be used for devices that are fixed in one place. In a port, a number of equipment (tower cranes, forklifts, trucks, tugboats, etc. are mobile). Further, both Wi-Fi and LoRa do not guarantee quality of service or interference free communication. These properties do not make it amenable for critical applications. The Hamburg Port Authority (HPA) worked with Deutsche Telekom (DT) and Nokia[12] to implement a 5G testbed (Appendix 2). The following use cases along with their respective 5G requirements were identified:

eMBB: AR/VR with holoLenses to manage port assets.

mMTC: Barges with sensors require dual connectivity.

URLLC: Connected traffic lights.

11 https://www.corealis.eu/wp-content/uploads/2020/06/Livorno__LL_webinar_Ericsson_5G-Sustainability-Benefits.pdf

12 https://gsacom.com/paper/5g-smart-sea-port-hamburg-authority-nokia-white-paper/

Table 4: Relative Importance of Slicing, Latency and Jitter for the Use Cases

Use Case/Requirements	Slicing	Latency	Jitter
Sensors installed on mobile barges (mMTC)	Important	Not important	Important
HoloLenses– AR and video streaming (eMBB)	Important	Very important	Occasionally acceptable
Traffic Light (URLLC)	Very important (slice isolation)	Very important	Important

Source: Excerpts from 5G Smart Sea Port: Hamburg Authority – Nokia White Paper [13]

b. Port of Livorno[14]

Similar to the drivers and initiative above, Port of Livorno also undertook a 5G test bed implementation since 2015. The port has established an innovation lab with Italian Interuniversity Consortium for Telecommunication (CNIT), Ericsson Research, Italy and has attracted public and private players to test and invest in it.

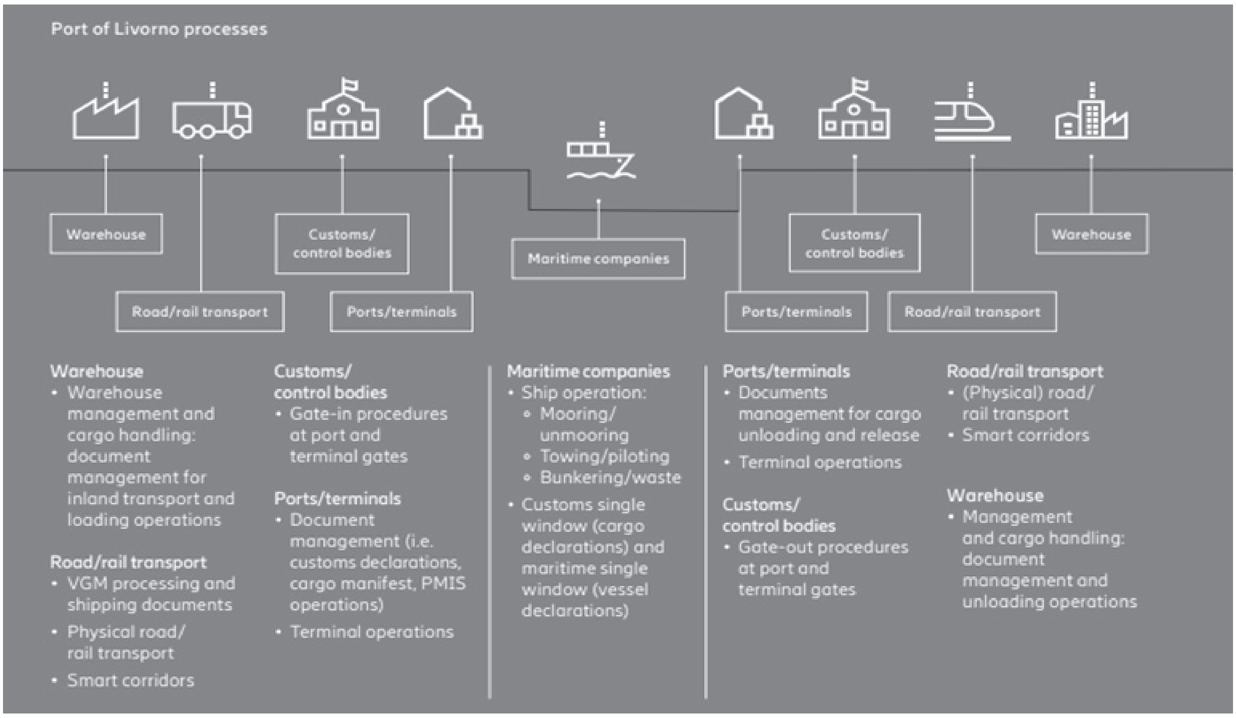


Figure 3: Processes Handled at Port of Livorno (Excerpted from the report Port of the Future[15])

Ericsson, in partnership with ifm, carried out a research project to identify key applications that could be beneficial for the smart port. Five use cases, also considered as the most important and relevant cases for NPN over the port operation chain for containers were identified as potential starting points. These were:

13 5G Smart Sea Port: Hamburg Authority – Nokia White Paper https://www.hamburg-port-authority.de/de/themenseiten/giganetz-5g-monarch

14 Report report Port of the future available on https://www.ericsson.com/4a0630/assets/local/cases/customercases/2020/ericsson_portofthefuture_report.pdf

15 https://www.ericsson.com/4a0630/assets/local/cases/customercases/2020/ericsson_portofthefuture_report.pdf

i. Remote-controlled ship-to-shore cranes
ii. Automated rubber-tyred gantry cranes (ATGC)
iii. Automated guided vehicles (AGV)
iv. Condition monitoring
v. Drones for surveillance and deliveries.

To assess the net economic, social, and environmental value, data from implementation (from deployment until operational steady state) at various ports was collected and analyzed. Each of the key application was analysed in terms of its incremental value (Appendix 3).[16]

i. Remote-controlled ship-to-shore cranes
Significant savings come from increased revenues from reduced downtime and improved productivity due to system benefits. Other benefits include reduced cost of operator labour and reduction in efforts from checkers.

ii. Automated rubber-tyred gantry cranes
Significant savings come from reduced cost of operator labour and system benefits.

iii. Automated guided vehicles
Significant savings come from reduced costs for operator labour and system benefits as above.

iv. Condition monitoring
Significant savings come from reduction in maintenance labour and monitoring.

v. Drones for surveillance and deliveries
Significant savings come from reduction in cost of security labour.

The test bed implementation showed not only substantial economic benefit but also considerable savings in fuel due to more efficient turnaround of ships at anchor, reduced berthing time and more efficient operation of ship to shore cranes, forklift cranes, automated guided vehicles, condition monitoring and drone surveillance. The 5G implementation for one terminal operation at the Port of Livorno showed a nearly 8.2% reduction in carbon-di-oxide emissions.

The operational economic benefit analysis for 5G was analysed on the following dimensions:

a. Faster ship turnaround at the quay, showing benefits to shipping companies (20-25% reduction in berthing time).
b. Faster freight release through port gates, implying lower costs for haulers at the terminals due to more precise detection and freight handling.
c. Remote controlled gantry and quay cranes efficiencies leading to efficiencies for terminal operators (Port of the Future Report).

Thus, overall benefit is the reduction of operational time and quantifiable increase in the efficiencies of the port, besides adding to worker safety and reduction in environmental emissions.

16 "Steady state means the use case is fully deployed, so the full benefits are activated, and only the operational costs are active (no additional CAPEX-investments).
Net value is the value after subtracting all costs from the value of the benefits, i.e. the real" savings".

Table 5: Results of Qualitative Analysis of Some of Port Livorno 5G Enabled Operations

Port Process	Focus Area	Attributes of 5G Leveraged	Benefits Enabled by 5G
Container terminal operations	Automation	Remotely controlled quay cranes (URLLC, mMTC)	Lower vessel completion time, improved personnel safety, fewer human mistakes and operational inefficiencies, and working profile upgrade
	Transport and logistics	Connected/smart ship with augmented navigation information, predictive maintenance for on-field machinery (cranes, forklifts, stackers and trucks)	Improved security/safety during navigation, new business models, increased number of stakeholders involved in data exchange and reduced maintenance costs, CO^2 and power consumption
	Environmental sustainability and personnel safety	Personnel and environmental monitoring with potential critical and dangerous situations identification (URLLC, mMTC, network slicing)	Less exposure to polluting agents for on-field personnel, CO^2 and environmental impact reduction

Source: Excerpts from the report Port of the Future[17]

Putting It All Together

Ericsson has generalized the findings from various testbed implementations to generate some representative assessment for similar ports anywhere by developing a "calculator", essentially a model that captures the empirical benefits based on representative values of size of the port, revenues, throughput, and operating margin. The ranges within which the calculator values are most effective are:

- Baseline port is a container terminal, represents one of the top 100 container ports in the world, approximately, the 50th largest.
- Throughput of approximately 4 million TEUs (twenty-foot equivalent unit) per year.
- It generates roughly $400 million in revenue with an operating margin of around 30%.[18]

In the following text we analyse the Indian context to assess benefits that NPN may bring.

Analysis for Indian Ports

Ports play an important role in India's competitiveness and economic growth as nearly 95% of the country's trade by volume and 68% by value is moved through maritime transport. There are 12 major ports (those under the central government) and nearly 200 non-major/ intermediate ports, out of which 64 ports are functionally equipped to handle the EXIM cargo.

Several port operations have been digitalized, to varying levels, leading to an increase in its productivity. These include RFID for container tracking, gate automation, RFID based gate automation leading to considerable reduced truck turnaround times, mobile container scanners, apps to track container carrying vehicles and mobile wallet have been implemented. However, there is scope for greater improvement with more integrated applications and greater digitalization. For example, in being able to coordinate the truck traffic coming in to the port to enable reduction in truck build ups at the port, where the bulk of freight — estimated at roughly 85 percent — is handled by road.

17 https://www.ericsson.com/4a0630/assets/local/cases/customercases/2020/ericsson_portofthefuture_report.pdf

18 'Connected port' report based on research partnership from IFM and Ericsson.

Jawaharlal Nehru Port Trust

Jawaharlal Nehru Port Trust (JNPT) is the largest major port and container port in India, while Mundra is the largest private port. JNPT handles over 55 per cent of India's container traffic and is ranked 24th among global container ports. JNPT has a capacity of 4.7 million twenty-foot equivalent units (TEU). It is a pioneer in involving private sector participation in major ports and operates under a landlord model.

Despite such initiatives and great improvements in productivity, JNPT faces competition from both private Indian and foreign ports. It continues to face pressures to handle higher throughput, adapt to larger and more specialized vessels, improve productivity, and adopt new technology and information systems that can meet the increasingly demanding service standards expected by shippers, logistics companies and shipping operators.

A benchmarking study "SAGARMALA: Master Plan for Jawaharlal Nehru Port"[19] indicated a number of initiatives including IT based planning support for dual cycling of quay cranes, more efficient yard side planning for the smooth flow of trucks for both import and export cargo, improvement in crane productivity, reduction in manual operations and greater automation as some activities that could increase productivity of JNPT port.

It is in this context that NPN implementation could enhance JNPT's competitiveness. In the following analysis, we estimate the economic value add that could accrue due to NPN. For this, we use the Ericsson Port Calculator for assessing NPN benefits for the five use cases (Appendix 3), implemented at different levels of automation. Along with the specification of the applicable use case, the Ericsson Port Calculator when applied to any port takes into account the revenue, traffic, margins and area of the port.

The parameters of JNPT for the revenue, traffic, margins and area are close to the benchmark values for the Ericsson Port Calculator (Table 6).

Table 6: Baseline and JNPT Parameters

Parameters *(1)*	**Units** *(2)*	**Ericsson Baseline Port** *(3)*	**JNPT Port**[20] *(4)*
Port Ranking		A container terminal that is around the 50th largest in the world.	Ranked 33rd in the list of top 100 container ports globally.
Revenue	*mn USD*	400	261
Area	*km^2*	10	3.5[21]
Throughput	*Mn TEUs/year*	4	4.7
Margin	*%*	30	30 (Assumed)

Source: Column 3-Based on Ericsson's Connected Port Report [22]
Column 4-JNPT http://www.jnport.gov.in/

19 McKinsey & Company, in consortium with AECOM provided to provide fact-based analysis and insights in form of report to Ministry of Shipping / Indian Ports Association available at http://sagarmala.gov.in/sites/default/files/20161222_Sagarmala_final%20report_volume%2004.pdf

20 Available on https://www.devex.com/organizations/jawaharlal-nehru-port-trust-jnpt-122170#:~:text=The%20total%20land%20area%20in,maritime%20requirements%20of%20the%20country.

21 As per the IIMA working paper "Enhancing Port Performance: A Case of Jawaharlal Nehru Port Trust "
Current working area of JNPT is 261.41 hectare, but the usage yard area is around 350 hectares on full commencement.

22 Based on Ericsson's Connected Port Report available on https://www.ericsson.com/en/internet-of-things/audience-page/measure-ports-productivity

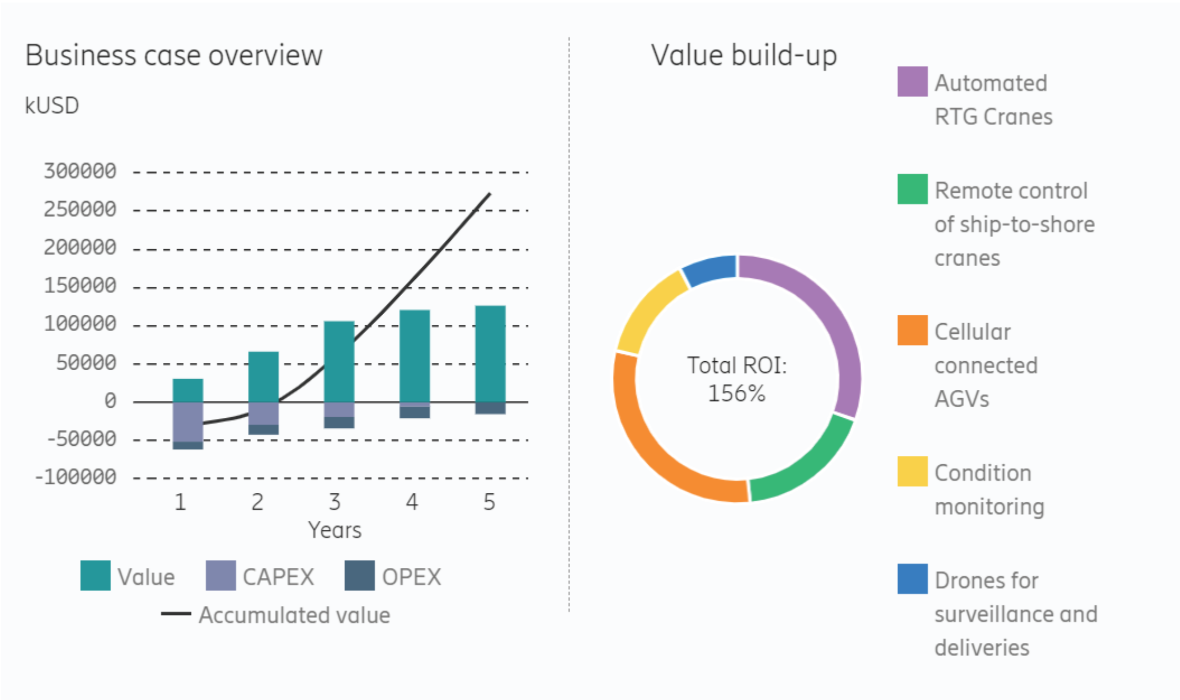
Table 7: Estimated RoI for JNPT with Implementation of Five Use Cases of NPN

Five Use Cases for JNPT	RoI *(%)*	
	Individual Implementation	**All Five Use Cases Implemented Together**
Automated RTG cranes	53	156
Remote control of ship-to-shore cranes	58	
Cellular connected AGVs	98	
Condition monitoring	138	
Drones for surveillance and deliveries	93	

Source: The Smart Ports Value Calculator[23]

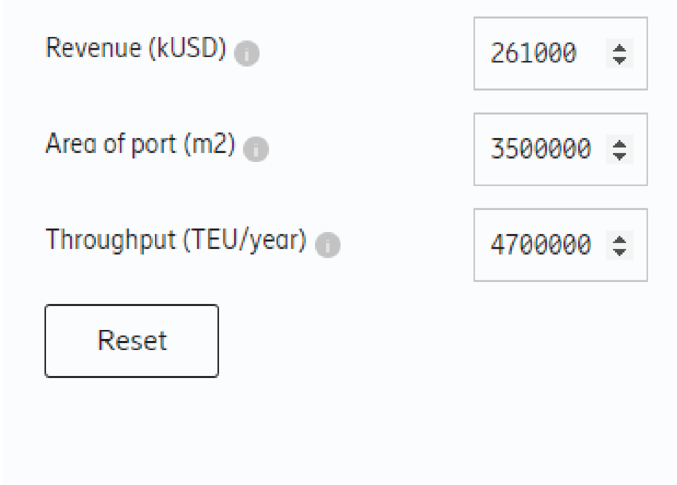
NPN implementation at JNPT has ROI ranges from 53% - 138% with the highest value for condition monitoring (138%), followed by cellular connected AGVs (98%) and drones for surveillance (93%). Thus, NPN implementation has very short payback periods, making them an attractive investment area.

Figure 4: Integrated Implementation of Five Cases at JNPT Port



Source: The Smart Ports Value Calculator

23 Available at https://www.ericsson.com/en/internet-of-things/audience-page/measure-ports-productivity



Source: The Smart Ports Value Calculator[24]

Chennai Port

Chennai port is India's second largest public sector container port. The port currently handles 3 million TEUs and with the ongoing commission of third mega container terminal, traffic handling capacity will go up to 8 million TEUs.

We analysed data for Chennai port container operation from 2018-19 and 2019-20 to assess the economic benefits of a possible NPN implementation[25]. The raw data related to ship operations at Chennai port included ship arrival time, anchorage, berth start time, service start and end time, and allied data for all ship arrivals for the above period.

Analysis of the idle berthing time showed that on an average this was nearly 5 hours (4 hours, 54 minutes). Better planning and higher automation as is done in leading ports could easily reduce this to around 30 min to an hour. The average ship charter costs for 24 hours were nearly $10,000 over this period[26]. Reduction in idle berthing time could mean 15-20% saving on this daily charter costs to ship operators for each arrival or departure at Chennai port. Considering the corresponding reduction in fuel consumption (and hence costs) and consequent benefits to the environment, the payoffs are economically higher and environmentally more sustainable. Such savings for ship operators could make the port attractive and enhance its competitiveness. From a public sector perspective, increase in environment sustainability is important. Table 8 gives the Chennai port details vis-à-vis the baseline port.

Table 8: Baseline and Chennai Port Parameters

Parameters *(1)*	**Units** *(2)*	**Ericsson Baseline Port** *(3)*	**Chennai Port** *(4)*
Revenue	mn USD	400	103
Area	km^2	10	23.74
Throughput	Mn TEUs/year	4	3
Margin	%	30	30 (Assumed)

Source: Column 3-Based on Ericsson's Connected Port Report [27]
Column 4-Chennai Port[28]

24 Available at https://www.ericsson.com/en/internet-of-things/audience-page/measure-ports-productivity

25 Grateful thanks to Captain Y Sharma for sharing the data and helping with understanding operational issues.

26 Shipping Intelligence Weekly Issue No 1447, dated 27 Aug 2021, page 7 available on paid access at https://www.crsl.com/acatalog/shipping-intelligence-weekly.html

27 Based on Ericsson's Connected Port Report available on https://www.ericsson.com/en/internet-of-things/audience-page/measure-ports-productivity

28 https://www.chennaiport.gov.in/content/performance-indicators

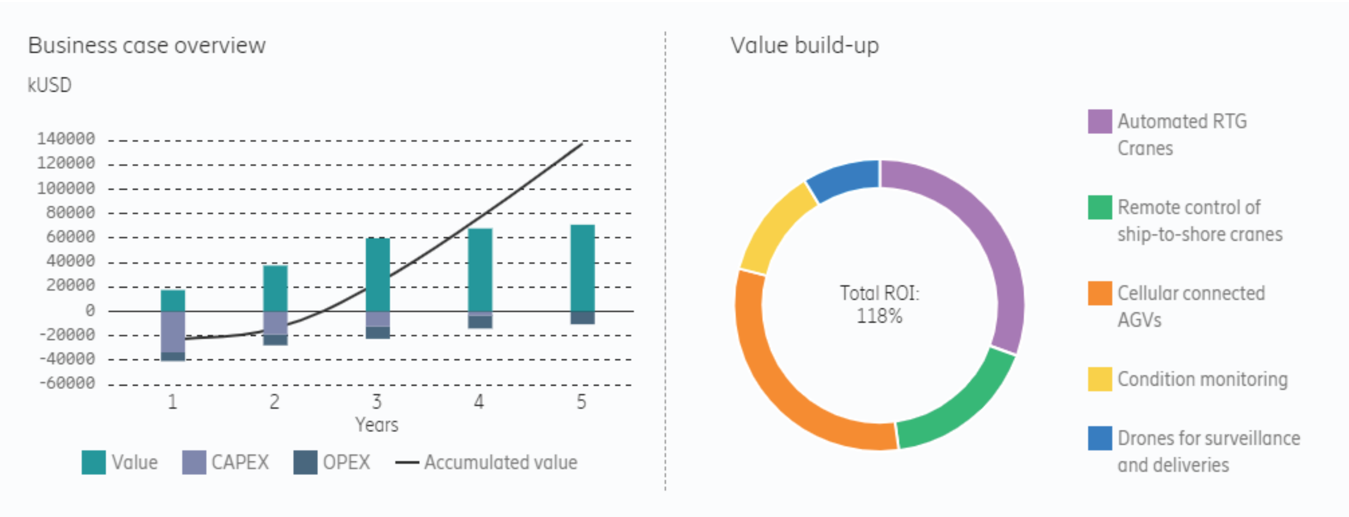
Table 9: Estimated RoI for Chennai Port with Implementation of Five Use Cases of NPN

Use Cases	RoI *(%)*	
	Individual Implementation	All Five Cases Implemented Together
Automated RTG cranes	39	118
Remote control of ship-to-shore cranes	31	
Cellular connected AGVs	76	
Condition monitoring	50	
Drones for surveillance and deliveries	41	

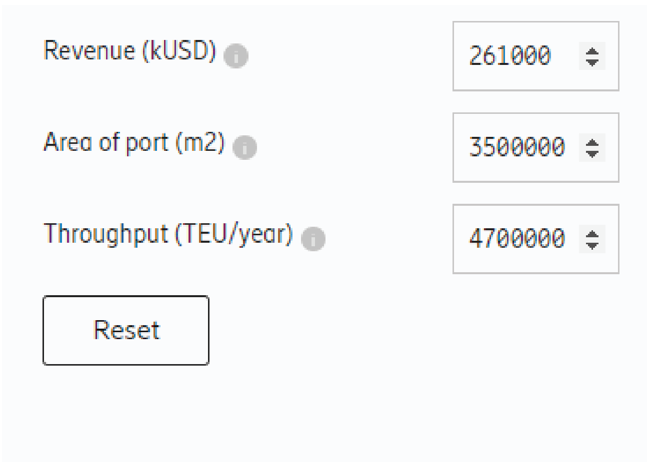
Source: The Smart Ports Value Calculator[29]

NPN implementation at Chennai Port has RoI ranging from 31% - 76% with the highest value for cellular connected AGVs (76%), followed by condition monitoring (50%), and drones for surveillance (41%). We take these values with some caution as the parameters for Chennai port were outside the range indicated in the Ericsson port calculator framework.

Figure 5: Integrated Implementation of Five Cases at Chennai Port



Source: The Smart Ports Value Calculator



Source: The Smart Ports Value Calculator

29 Available at https://www.ericsson.com/en/internet-of-things/audience-page/measure-ports-productivity

Smart Factory

The manufacturing sector is in a state of flux as new automation tools, Internet, AI, robots, ML create disruption in the entire manufacturing value chain. The need to adopt environmentally sustainable processes while focusing on worker safety are important concerns. With an increasing focus on customer-oriented products and enhanced competition, companies are looking for a competitive edge through greater automation and digitalization. Autonomous robots, working independently or in a collaborative mode, using AR for training and asset condition monitoring are important use cases in this scenario. NPN facilitates these use cases. Similar to the logic used for smart ports, smart factories find the current mobile, Wi-Fi and Fixed connectivity limiting. It is in this context that NPN opens up the possibility of implementing the use cases above for more effective management.

As a part of research on the most value-adding use cases in the manufacturing industry, Ericsson, Arthur D. Little and Hexagon[30] developed models of economic, social and environmental value based on KPIs from actual factories that supply parts to automotive manufacturing units. For each of the possible use cases of NPN, the incremental value generated by each use case independently and jointly was used. The model develops a calculator based on a "standard" factory. For specified values of revenues, products manufactured, area, number of employees, the calculator/model comes out with the possible RoI for the selected use case.[31] The use cases take into account - the reduction in environmental emissions, worker safety and economic benefit arising out of increased productivity, increased quality orientation and lower human intervention. The RoI is based on reaching an operational steady state. The model is based on a mid-sized automotive factory with $100 million USD in revenue, around 500 employees and a gross profit of 10%.

We use the above calculator for the Indian automotive sector. In this case, we are assuming that the vehicle manufacturing unit also manufactures parts.

The Ericsson report[32]considers the following:

- "Autonomous mobile robots (AMR) for real-time production chain automation
- Collaborative robots for more efficient operations
- Augmented Reality (AR) for efficient quality inspections
- Asset condition monitoring for increased uptime
- Digital twins for optimized operations"

The details of these use cases are in Appendix 4.

30 A provider of sensor, software and autonomous solutions for applications including discrete manufacturing

31 The incremental value from each use case is aggregated to a total benefit for a standard factory. The overall analysis and output values are thoroughly validated with Hexagon and other experts.

32 https://www.ericsson.com/assets/local/internet-of-things/docs/connected-manufacturing-report.pdf?_ga=2.208141522.1154190197.1634725625-1451284321.1626256069

Ola Electric Mobility Private Ltd

We have taken the case of Ola Electric Mobility Factory, which is proposed to be the state-of-the art facility in Kishangiri, Tamil Nadu. From August 15, 2021, around 2 million units production is planned with 540 employees and estimated revenue of $178.2 million for the year. However, currently the mega factory is under construction and is working at 10% capacity.

Table 10: Baseline and Ola Electric Mobility Factory Parameters

Parameters *(1)*	**Units** *(2)*	**Smart Factory**[33] *(3)*	**Ola Electric Mobility Pvt. Ltd.**[34] *(4)*
Basic Info		A mid-sized automotive factory	A mid-sized automotive factory
Revenue	*mn USD*	100	178
Size of factory	*m^2*	3000	41000
Output/year	*products*	1,000,000	2,000,000
Employees	*FTE*	500	540

Source: Column 3- Based on Connected Manufacturing Report [35]
Column 4- Based on Ola Electric Mobility Pvt. Ltd., Financial data

Table 11: Estimated RoI for Ola Electric Mobility with Implementation of Five Uses Cases of NPN

Five Use Cases	**RoI** *(%)*	
	Individual Implementation	**All Five Cases Implemented Together**
Autonomous Mobile Robots	139	231
Collaborative Robots	131	
AR Inspection & Support	157	
Asset Condition Monitoring	309	
Digital Twin	-100	

Source: The Smart Manufacturing Value Calculator[36]

The RoI is very significant at 231% and shows a payback period of three years after five years. All use cases should pay for themselves in three to five years, and if all five are deployed together, payback within two years. The highest RoI is for asset condition monitoring (309%) followed by AR inspection and support (157%). Autonomous mobile robots (139%) and collaborative robots (131%) also have significant values.

Caveat: The values for revenues, area and products considered in the Ola Electric Mobility, case are very far from the "standard" factory values specified in the smart factory calculator. Hence, these values must be taken with caution. Further, the model is based on a European context, so its relevance to India may be questioned. However, the reason this model is used in this report is to indicate how similar studies could be done in the Indian case. The value

33 https://www.ericsson.com/en/internet-of-things/audience-page/measure-manufacturing-productivity

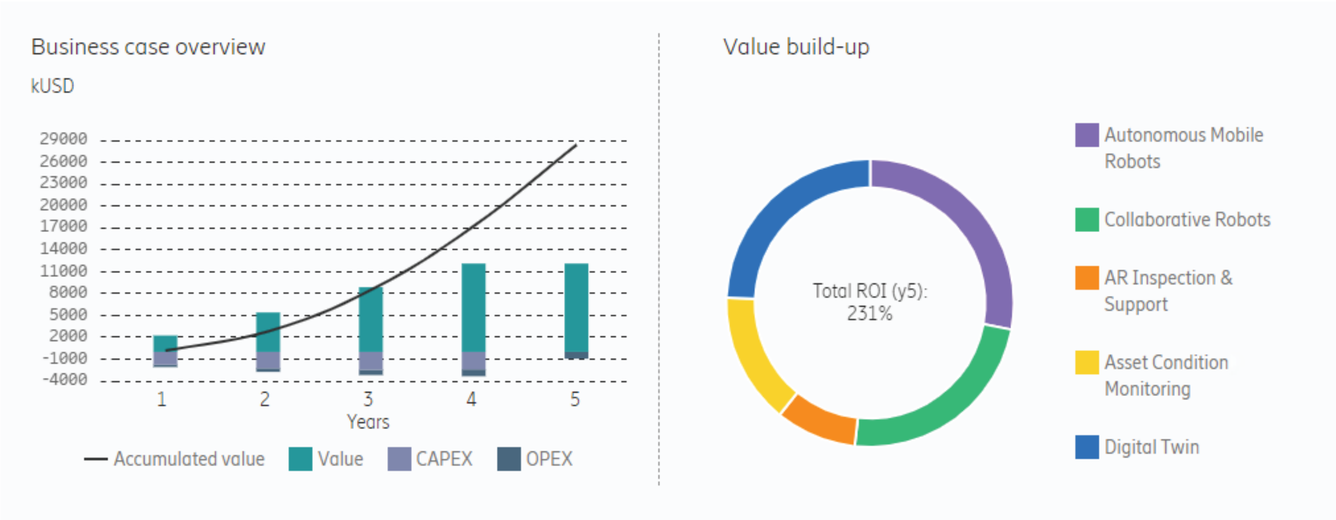
34 https://growjo.com/company/Ola_Electric_Mobility_Pvt._Ltd.

35 https://www.ericsson.com/assets/local/internet-of-things/docs/connected-manufacturing-report.pdf?_ga=2.208141522.1154190197.1634725625-1451284321.1626256069

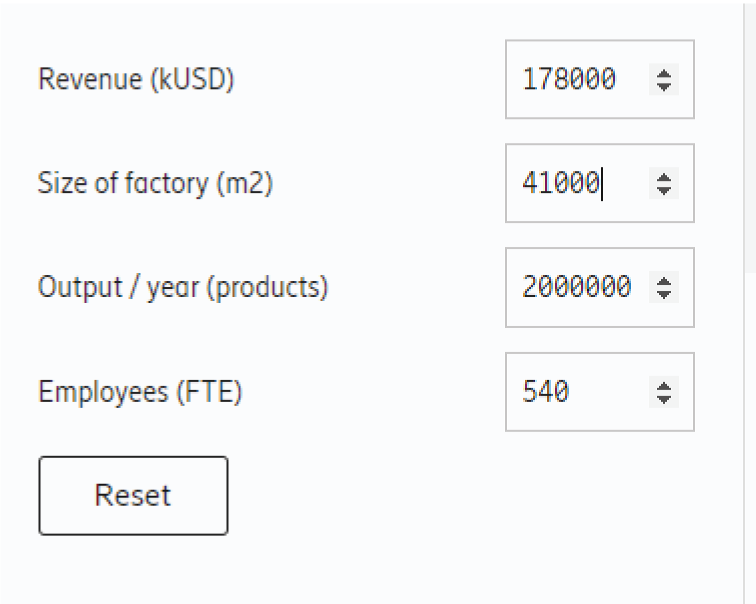
36 https://www.ericsson.com/en/internet-of-things/audience-page/measure-manufacturing-productivity

of such studies is in indicating the priorities for NPN use cases. Since NPN has not been implemented in India, it was not possible to develop any empirical model for our context.

Figure 6: Integrated Implementation of Five Cases at Ola Electric Manufacturing Facility



Source: The Smart Manufacturing Value Calculator



For the Indian case, we consider the TVS two-wheeler manufacturing example. TVS has three national and one international factory location for their two-wheeler manufacturing. We consider the case when NPN is implemented in a single location.

Table 12: Baseline and Factory Parameters

Parameters *(1)*	**Units** *(2)*	**Smart Factory**[37] *(3)*	**TVS Motor**[38] *(4)*
Basic Info		A mid-sized automotive factory	A mid-sized automotive factory in a single location
Revenue	*mn USD*	100	700
Size of factory	*m2*	3000	72000
Output/year	*products*	1000000	75000
Employees	*FTE*	500	880

Source: Column 3- Based on Connected Manufacturing Report [39]
Column 4 - Based on TVS Motor Annual report 2020-21[40]

Table 13: Estimated RoI for TVS Motor with Implementation of Five Uses Cases of NPN

Five Use Cases	**RoI** *(%)*	
	Individual Implementation	**All Five Cases Implemented Together**
Autonomous Mobile Robots	176	193
Collaborative Robots	326	
AR Inspection & Support	319	
Asset Condition Monitoring	103	
Digital Twin	-36	

Source: The Smart Manufacturing Value Calculator41

The RoI is very significant and shows a payback period of two years after five years. The highest RoI 326% is for collaborative robots (326%) and AR inspection and support (319%), followed by autonomous mobile robots (176%) and asset condition monitoring (103%). All use cases should pay for themselves in three to five years, and if all five are deployed together, payback within two years.

37 https://www.ericsson.com/en/internet-of-things/audience-page/measure-manufacturing-productivity

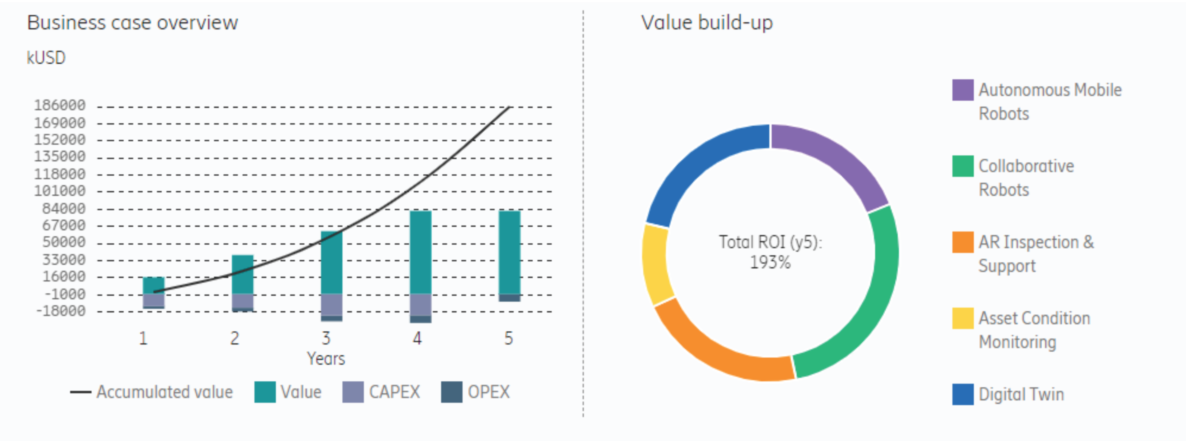
38 https://www.tvsmotor.com/en/About-Us/Overview

39 https://www.ericsson.com/assets/local/internet-of-things/docs/connected-manufacturing-report.pdf?_ga=2.208141522.1154190197.1634725625-1451284321.1626256069

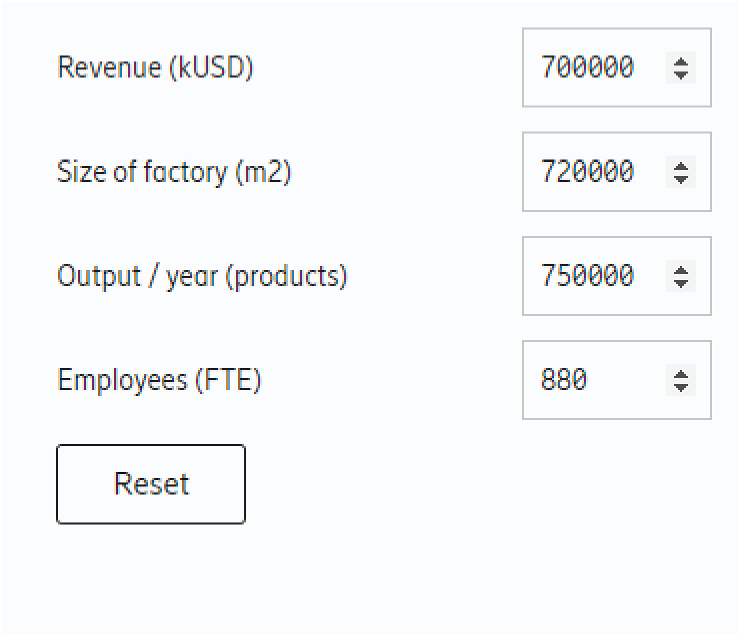
40 Available on https://www.tvsmotor.com/api/InvestorDownloadData?ItemId=fce3826c-b6e8-4b66-a7e7-13c7ec070cbe

41 https://www.ericsson.com/en/internet-of-things/audience-page/measure-manufacturing-productivity

Figure 7: Integrated Implementation of Five Cases at TVS Motor Manufacturing Facility



Source: The Smart Manufacturing Value Calculator



Caveat: The values considered in the TVS case are very far from the "standard" factory values specified in the smart factory calculator. Hence, these values must be taken with caution. Further, the model is based on a European context, so its relevance to India may be questioned. However, the reason this model is used in this report is to indicate how similar studies could be done in the Indian case. The value of such studies is in indicating the priorities for NPN use cases. Since NPN has not been implemented in India, it was not possible to develop any empirical model for our context.

Analysis and Recommendation

1. Early availability of spectrum for 5G and NPN is necessary for enterprises to become more competitive. The deployment of NPN would require an appropriate regulatory regime to be designed as while earlier generations of telecom services licensed spectrum to TSPs, NPN may require regulators to include enterprises. License conditions such as duration of licenses and prices may need to be more flexible and innovative.

   Early licensing models for NPN deployments indicate an administrative price based on amount of spectrum, geographical area and duration seem to work. Further, use-it-or-lose-it models to encourage industries to deploy NPN in an accelerated manner would be useful. Technology neutrality is an important characteristic of these licenses.

2. Earlier spectrum licenses were exclusively awarded to telcos. NPN would require development of frameworks for shared license access between telcos and/or enterprises. There is a need to develop appropriate regulatory framework for allocation and sharing of spectrum to/with enterprises, for a user/telco led NPN deployment model. Thus, early development of regulatory and technology models for Licensed Shared Access would be critical.

   So far, the role of telcos was limited to rolling out networks and devising innovative marketing strategies. NPNs will entail them to devise end-to-end solutions for enterprises as they roll out domain specific applications that could create new non-linear revenue channels for telcos. These could address telcos' concern regarding sharing spectrum with enterprises. Service providers (telcos and vendors) will need to address the specific network requirements and SLAs. This may require upgradation of technical skills.

3. NPNs challenge enterprises to devise new business models with innovative services. On the other hand, NPNs would create opportunities for revenue generation from the consequent new business opportunities for both telcos and enterprises. Enterprises would also require new kinds of network capabilities, especially regarding the network requirements for their domain specific applications (such as latency, bandwidth). Organizations would need to ensure that their NPNs comply not only with their own security and user administration aspects but also with the 3GPP framework.

4. Unlicensing of spectrum is required as several use cases for 5G are driven by the propagation characteristics and device ecosystem in the unlicensed bands. Further, making adequate spectrum available in other licensed bands requires central coordination across other government departments/ministries such as Space and Defence that are currently using the identified 5G bands. Similarly, new unlicensed spectrum bands viz. 6 GHz and also 60 GHz (V band) need to be opened up to help unleash next-gen Wi-Fi technologies viz. Wi-Fi6/Wi-Fi6E and Wi-Fi7, which can complement 5G. The coordination should be done taking into account the experience of other countries that had similar situations and on the basis of co-existence studies carried out in India. Further, NPNs would require developing domain specific use cases and hence coordination with regulatory/standards bodies in those domains is of utmost importance.

5. Pilot NPN testbeds in the port sector and manufacturing in Europe have shown significant positive outcomes, both from a financial and sustainability perspective.

6. The Ericsson Smart Port model for JNPT shows significant values for RoI for NPN roll out. These range from 53% - 138% with the highest value for condition monitoring (138%), followed by cellular connected AGVs (98%) and drones for surveillance (93%). For the Chennai Port it shows substantial RoI ranging from 31% - 76% with the highest value for cellular connected AGVs (76%), followed by condition monitoring (50%) and drones for surveillance (41%).

The Ericsson Smart Factory model for Ola Electric Mobility Pvt. Ltd. shows high RoI range from 131% - 309% with highest value for asset condition monitoring (309%) followed by AR inspection and support (157%), autonomous mobile robots (139%) and collaborative robots (131%). For the TVS Motor Manufacturing facility, it shows considerable RoI range from 103% - 326% for collaborative robots (326%) and AR inspection and support (319%), followed by autonomous mobile robots (176%) and asset condition monitoring (103%).

7. Using the model could help prioritize the NPN deployment sequence among the five use cases considered. Hamburg Port has considered other use cases. Indian ports would need to do an in-depth analysis regarding priority for sequencing NPN deployment.

8. A collaborative approach between academia, service providers, user industry, vendors and most importantly adequate funding support from the government is necessary. Identifying focus areas of testbed implementation in real life contexts as was done in the COREALIS project is important to influence industry and policy makers regarding adoption of NPN.

   In the Indian context, the DoT has supported the creation of 5G testbed in India through a network of IITH, IITM, IITB and IITD. However, this support is limited to the availability of hardware and software for testing. What is required for an NPN implementation as a pilot in a specific context such as a port, airport, manufacturing enterprise across several locations, etc. In Europe, this was done through EU Horizon 2020 program. Several areas such as Ports, Smart Manufacturing, etc. were taken up. These involved telcos, network integrators, equipment vendor and most importantly, the user organizations.

   Application agnostic testbeds as the one implemented in India are critical for vendors, equipment providers, telcos and start-ups to test potential 5G deployments in India. But for NPN to take off, testbeds would need to be implemented in an enterprise context. This is because each enterprise context (port, manufacturing, airport) would have varying needs and priorities for bandwidth, reliability, connectivity, latency, etc. Further, even within a specific type of enterprise, these needs would vary. For example, for ports with congested berths, operating rubber tyred gantry cranes may be more important, while for another, condition monitoring could be more important.

   Since enterprise context is important for NPN, we suggest that MeitY, in collaboration with the industry and academia, prioritises funding for a series of end-to-end pilot test bed implementation along several sectors, as suggested above. Along with this, it should undertake systematic baseline studies to scientifically be able to establish the value addition due to NPN as was done in the COREALIS project.

9. Various models of NPN deployment are possible. Most sustainable will be the ones that leverage the inherent unique strengths of the vendors, telcos and the user-industry.

10. Innovative applications emerging from early NPN deployments could see many ICT products/services from India, contributing to Atmanirbhar Bharat. This would also give an impetus to the start-ups and could help create a leading position in India in the Internet and knowledge/service sector.

11. Both public and private sector enterprises could benefit from NPN deployments.

Appendix 1: Use Cases in Rail, Manufacturing and Surveillance

5G Test Bed at Rail Innovation & Development Centre, Melton, UK[42]

RIDC Melton (formerly known as the Old Dalby Test Track) is a dedicated testing and trialling facility for use by Network Rail and the rail industry[43].

The 5G Testbeds and Trials programme commissioned Department for Digital, Culture, Media & Sports (DCMS) is part of the government's £740 million National Productivity Investment Fund (NPIF) activities, to support the next generation of digital infrastructure, including 5G and full fibre broadband.

In November 2017, funding was announced by DCMS to create the 5G rail testbed at the Rail Innovation & Development Centre (RIDC) at Melton Mowbray in Leicestershire.

From May 2019, it was able to support trials and Alpha phase testing, as well as the preparation of technologies for early mainline rail Beta testing and infrastructure deployment for 5G Testbeds and Trials Program.

42 Excerpts from Report "Innovating for a connected rail future Enabling 5G for rail" available on https://cdn.networkrail.co.uk/wp-content/uploads/2019/05/Enabling-5G-for-the-rail.pdf

43 https://uk5g.org/discover/testbeds-and-trials/enabling-5g-rail/

Use Case in Manufacturing in Taiwan - Compal Electronics

Compal Electronics, Taiwan is one of the largest original design manufacturers (ODMs). It has deployed the Enea 5G MicroCore[44] to manage data on its private wireless 5G network and enhance its smart manufacturing and Industry 4.0 capabilities in areas such as agritech, digital healthcare, robotics and immersive gaming, to utilize 5G technology.

As a part of its manufacturing strategy, Compal Electronics needed to securely authenticate and provision various devices, including Virtual Reality (VR) and Augmented Reality (AR) headsets over 5G radio and small cells. Using NPN deployment, it leveraged the high bandwidth and coverage over a large number of devices.

On the enterprise side, Enea's 5G MicroCore portfolio includes Unified Data Repository (UDR), Unified Data Management (UDM), Authentication Server Function (AUSF) and Mini-Home Subscriber Server (HSS). These services are compliant with 3GPP telco standards. Along with adherence to telco standards, security was another key consideration for Compal Electronics. This demonstrated the need for integrating enterprise side user management and security services with 3GPP standards.

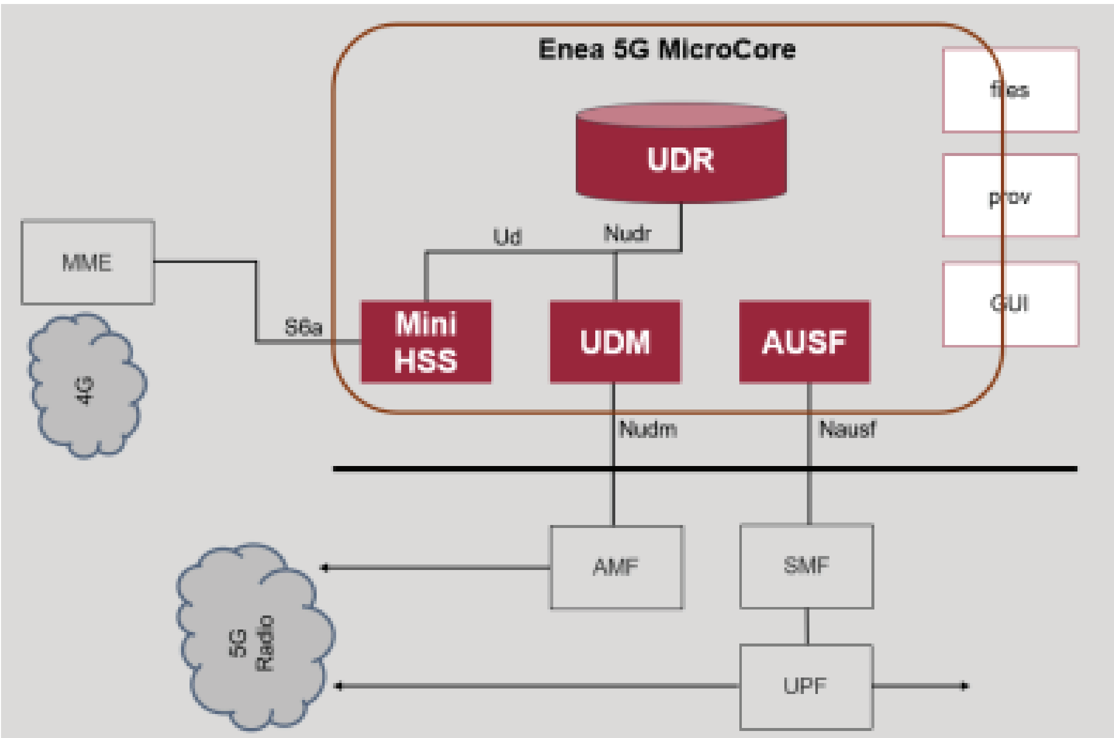


Figure 1. Enea's 5G MicroCore Solution for Private 5G Networks

Source: https://www.enea.com/globalassets/_for-this-site/enea-5g-microcore-for-private-5g---ebrief-q2-2021.pdf

44 Details available on https://www.enea.com/globalassets/_for-this-site/enea-5g-microcore-for-private-5g---ebrief-q2-2021.pdf

Use Case of 5G NPN[45] in Surveillance

A use case of NPN for safety surveillance using robots was implemented in Universidade de Vigo, Spain. The implementation involved Cisco (provider of the NPN core network, computing resources and switches), Telefonica (a major global telco), Securitas (security service provider), Alisys (partner of Boston Dynamics in Spain, provider of the robots and the software platform for remote control), ZTE (provided the 5G stand-alone radio) and the University as an active collaborator in the design and deployment.

The robots complement the requirement of security services in the university and are remotely controlled from a control centre. There are two possible scenarios for support provided by the robot. Firstly, it sends several video sequences in real-time with zoom, or thermal/360-degree vision and thus extends the physical perceptual capabilities of the human guard. Secondly, it pre-inspects the environment for any potential physical risk to the environment. For this functionality, low latency and high bandwidth are critical.

Thus, using the technical capabilities characteristic of NPN, a collaborative deployment involving all the relevant stakeholders has resulted in an application that augments and complements human capabilities.

45 Europe's First Private 5G SA Network with Slicing Capabilities Surveillance Use Case available on https://blogs.cisco.com/sp/europes-first-private-5g-sa-network-with-slicing-capabilities-surveillance-use-case#:%7E:text=In%20Spain%2C%20 5G%20Core%20(5GC,slicing%20in%20a%205G%20infrastructure

Appendix 2: Architecture of Hamburg Port Authority 5G Test Bed

One network slice was created for each use case described according to the specific requirements of the services and applications of the use case – with all slices using the same 5G radio infrastructure. Two Nokia Air scale base stations were deployed with one antenna each using a 10 MHz FDD carrier at 700 MHz. The antennas were mounted at an elevation of 180 above ground on the Hamburg TV tower, in order to guarantee a good coverage of the port area. These base stations were then connected to a local data center of Deutsche Telekom ("DT") in Hamburg located about three kilometres from the port, as well as to a regional data centre 500 kms away in Nuremberg. The slices requiring low latency rely on the local data center, while slices with higher performance but less strict latency requirements were deployed at the regional data center. Low latencies of less than 20 milliseconds could be achieved in this 5G testbed. Latency results varied according to how close to the edge, the data center used is. In any case, the local data center is also important not only to maintain low latencies, but also to keep the sensitive data on premise.

Appendix 3: Revenue and RoI Benefits of Various Use Cases for Smart Port

The revenue and RoI benefits come from:

i. Ship to Shore Cranes:

Increased revenue from decreased downtime	37%
Improved productivity due to system benefits	35%
Reduced cost of operator labour	16%
Reduction in efforts from checkers	12%

ii. Automated rubber-tyred gantry cranes

Reduced cost for operator labour	73%
Improved productivity due to system benefits	22%
Reduction in labour and maintenance materials	5%

iii. Automated guided vehicles

Reduced cost for operator labour	74%
Improved productivity due to system benefits	23%
Decrease in energy costs	3%

iv. Condition monitoring

Reduction in maintenance labour	53%
Reduction in the cost of monitoring	40%
Decrease in the cost of maintenance materials	7%

v. Drones for surveillance and deliveries

Reduced cost for security labour	83%
Decrease in offshore deliveries costs	10%
Decrease in insurance premiums	7%

Appendix 4: Revenue and RoI Benefits of Various Use Cases for Smart Factory[46]

i. Autonomous Mobile Robots

When conducting quality inspections today, measuring systems are often inflexible and stationary. These inspections require a lot of time-consuming manual work. The financial benefit reaches about 1.5% of the revenue as yearly steady state net value. The return on investment in year five is 50% and payback is less than four years.

Reduced downtime due to route optimization on the floor, speeding up material movement	49%
Forklift operators being freed up to do other tasks in the factory	46%
Reduction in rework	3%
Cost for quality inspections decreases as quality improves	2%

ii. Collaborative Robots

Collaborative robots, or cobots, work side by side with operators to conduct manufacturing tasks such as operational work, drilling or assembly, as well as automated quality inspections of products that are still on the production line. Dedicated cobots need dedicated networks. Cobots need to be flexible and easily move throughout the facility, so they can be rearranged for multiple purposes. Cobots must connect wirelessly to the facility network, and a 5G-ready private cellular network can provide the reliable, low latency connection cobots require. The financial benefit of investing in cobots reaches about 1.4% of the revenue as yearly steady state net value. The return on investment in year five is 44%. Payback is less than four years.

More efficient use of labour resources	68%
Decreased downtime	19%
Decreased cost of quality inspections	10%
Fewer quality issues	3%

iii. AR Inspection & Support

AR devices enable instant support and measurement and can be used by technicians, maintenance workers and operators throughout the entire facility. Instructions can be rapidly visualized, allowing experts to support on-site personnel remotely.

There are additional benefits of AR within a manufacturing context. For example, because service experts can support local inspectors remotely, about half of their travel to appear on-site can be avoided, reducing the CO^2 impact by 50%. The return on investment in AR in year five is 68% while payback is less than three years.

More efficient use of labour resources	46%
Decreased cost of quality inspections	34%
Decreased downtime because diagnostics and inspections can be conducted faster	10%
Maintenance labour cost savings	8%
Decreased cost of expert service trips	2%

46 This is excerpted from Report -Connected Manufacturing-A guide to Industry 4.0 transformation with private cellular technology

iv. Asset Condition Monitoring

Automated asset condition monitoring enables manufacturers to optimize maintenance, ensuring that facilities do not experience downtime due to insufficient maintenance, nor will they invest more time and money than is required to keep equipment running well. The financial benefit reaches about 0.8% of the revenue as yearly steady state net value. The return on investment in year five is 151% and payback is less than three years.

Decreased downtime	51%
Maintenance material cost savings	36%
More efficient use of labour resources	13%

v. Digital Twin

Optimized production flow	60%
Decreased configuration time	31%
Rework reduction	6%
Decreased downtime	3%

Digital twins enable manufacturers to determine how best to streamline the production environment without physically changing any processes.