

Consultation Paper No. 6/2011



Telecom Regulatory Authority of India

Consultation Paper

on

IMT – Advanced

Mobile Wireless Broadband Services

New Delhi: 19th August, 2011

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Preface

Last two decades have witnessed a rapid growth in the number of mobile subscribers and equally rapid advancement in the mobile technology. With ever increasing demand for wireless multimedia applications requiring more and more bandwidth, radio access technologies are continuously evolving to provide higher data rates and improved spectral efficiency.

As third generation (3G) International Mobile Telecommunication 2000 (IMT-2000) systems are being deployed, evolution of further advanced systems, known as IMT-Advanced Systems is taking place. International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile systems that include the new capabilities of IMT that go beyond those of IMT-2000. Such systems provide access to a wide range of telecommunication services including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based.

In order to facilitate introduction of IMT Advanced mobile broadband services, the Authority has decided to deliberate on various related issues including suitable spectrum bands, block size of spectrum to be auctioned, maximum spectrum permitted to bidder, eligibility criteria for bidding, rollout obligations, spectrum usage charges, QoS parameters, security issues and other related issues.

Written comments on the issues raised in this consultation paper are invited from the stakeholders by 20th September, 2011 and counter-comments on the comments by 27th September, 2011. The comments and counter-comments may be sent, preferably in electronic form, to Shri Sudhir Gupta, Pr. Advisor (MS), TRAI, who may be contacted at Tel No. +91-11-23220018 Fax No. +91-11-23212014 or email at pradvmn@trai.gov.in.

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Introduction

1. Since the inception of mobile communications in the early 1980s, there has been ever-growing increase in the development of mobile communication technology. Analog wireless communication systems have been replaced by digital ones, voice services are being complemented with data services, supported data transfer speeds have increased by more than a thousand-fold, network coverage has been stretched to cover virtually entire countries and continents, and many other remarkable achievements have taken place in a relatively short period.
2. As the wireless industry is witnessing explosive growth in the demand for both voice and data services, the number of mobile telephone subscribers, as well as usage rates, have also grown considerably. Consequently, the Service providers have been upgrading their networks with advanced technologies to meet this growing demand for high quality voice and data services. The equipment vendors are driving technical innovations with the latest wireless technologies showing significant gains in the efficiency of spectrum used, thus providing more capacity out of a given bandwidth.
3. With the availability of higher data speeds, the user requirements are also continually increasing with regard to different services and applications, expecting a dynamic, continuing stream of new capabilities that are ubiquitous and available across a range of devices using a single subscription and a single identity (number or address).
4. The bandwidth intensive services that users will want, and the rising number of users, are placing increasing demands on access networks. These demands may eventually not be met by the enhancement of radio access systems (in terms of peak bit rate to a user, aggregate throughput, and greater flexibility to support many different types of service simultaneously). Therefore there will be a requirement for new

radio access technologies to satisfy the anticipated demands for higher bandwidth services. As third generation (3G) International Mobile Telecommunication 2000 (IMT-2000) systems are being deployed, further developments aiming at their enhancement are being conducted on a worldwide scale. Many operators in the developed countries are focussing on deploying IMT – advanced system networks to cater to the growing requirement of data, speed and content delivery.

5. International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile systems that include the new capabilities that go beyond those of IMT-2000. Such systems provide access to a wide range of telecommunication services including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based. In order to fulfil the requirement of higher bandwidth systems like LTE Advanced and Wireless MAN-Advanced, are designed to enable high speed Internet anytime, anywhere. It is expected that these systems will facilitate higher bandwidth, higher data rate, lower authentication load, and will support higher level of user-level customization. They are expected to provide virtual environment agnostic to network and devices being used.
6. An IMT- Advanced cellular system is expected to provide a comprehensive and secure all-IP based solution where services such as IP telephony, ultra-broadband Internet access, gaming services and streamed multimedia may be provided to users. According to the ITU requirements for IMT- Advanced, the targeted peak data rates will be up to 100 Mbit/s for high mobility and up to 1 Gbit/s for low mobility, scenario. Scalable bandwidths up to at least 40 MHz should be provided.
7. IMT- Advanced systems support low to high mobility applications and a wide range of data rates in accordance with user and service demands in multiple user environments. They will also have capabilities for high

quality multimedia applications within a wide range of services and platforms, providing a significant improvement in performance and quality of service having the following key features:

- a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
 - compatibility of services within IMT and with fixed networks;
 - capability of interworking with other radio access systems;
 - high quality mobile services;
 - user equipment suitable for worldwide use;
 - user-friendly applications, services and equipment;
 - worldwide roaming capability and
 - enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research)¹.
8. The framework for the development of IMT-Advanced systems can be considered from multiple perspectives, including the users, manufacturers, application developers, network operators, and service and content providers. From the user's perspective, there will be a demand for a variety of services, content and applications whose capabilities will increase over time. Similarly, users will expect services to be ubiquitously available through a variety of delivery mechanisms and service providers, using a wide variety of devices that will be developed to meet their differing requirements. User demands will be addressed by a large community including content providers, service providers, network operators, manufacturers, application and hardware

¹ Data rates sourced from Recommendation ITU-R M.1645.

developers. The objectives of various stakeholders from IMT-advanced services are tabulated below:

Objectives from multiple perspectives

Perspective	Objectives
END USER	Ubiquitous mobile access Easy access to applications and services Appropriate quality at reasonable cost Easily understandable user interface Long equipment and battery life Large choice of terminals Enhanced service capabilities User-friendly billing capabilities
CONTENT PROVIDER	Flexible billing capabilities Ability to adapt content to user requirements depending on terminal, location and user preferences Access to a very large marketplace through a high similarity of application programming interfaces
SERVICE PROVIDER	Fast, open service creation, validation and provisioning Quality of service (QoS) and security management Automatic service adaptation as a function of available data rate and type of terminal Flexible billing capabilities
NETWORK OPERATOR	Optimization of resources (spectrum and equipment) QoS and security management Ability to provide differentiated services Flexible network configuration Reduced cost of terminals and network equipment based on global economies of scale Smooth transition from IMT-2000 to systems beyond IMT-2000 Maximization of sharing capabilities between IMT-2000 and systems beyond IMT-2000 (sharing of mobile, UMTS subscriber identity module (USIM), network elements, radio sites) Single authentication (independent of the access network) Flexible billing capabilities Access type selection optimizing service delivery
MANUFACTURER/ APPLICATION DEVELOPER	Reduced cost of terminals and network equipment based on global economies of scale Access to a global marketplace Open physical and logical interfaces between modular and integrated subsystems Programmable platforms that enable fast and low-cost development

Table 1

9. In India Broadband penetration is far behind the target. However from the year 2011, data usage is expected to grow at a faster pace with 3G

and BWA deployments. Increasing use of smart mobile devices like I-Phones are also expected to catalyze the data usage growth. Social networking sites demand high throughput for better experience. The emerging trend shows that mobile networks capable of providing higher data exchange would be preferred and therefore deployment of IMT-Advanced technologies is imminent. Therefore, to keep pace with the latest technological development in the world, TRAI issued a pre-consultation paper on 10th February 2010 for comments/ views from all the stakeholders on the subject.

10. TRAI received overwhelming support from the stakeholders for the initiative on development of future roadmap for the ever-growing mobile services in the country. The stakeholders while forwarding their comments/ view on the different aspects of the subject matter, have raised a number of relevant issues, which have been summarised below:
 - a. Identification of frequency bands, harmonisation aspect at International and Regional level;
 - b. Requirements of large chunk of contiguous spectrum bandwidths, respective band plans and FDD & TDD modes;
 - c. Refarming of spectrum from the Government agencies for the newer technologies in the internationally identified spectrum bands;
 - d. Candidate technologies for the IMT-Advanced and convergence of different technologies and services;
 - e. Issues & challenges in extending the broadband access to the rural India;
 - f. Licensing, Pricing and assignment mechanism;
 - g. Backward compatibility aspects;
 - h. Issues pertaining to VoIP;

- i. Need to migrate from IPv4 to IPv6;
 - j. Capacity requirements of backhaul and core networks;
 - k. Spectrum usage charges for operators holding only IMT- Advance or holding a combination of spectrum bands;
 - l. Making voice mandatory for new technologies or fall back option;
 - m. Active Infrastructure Sharing.
11. Based on the comments received from the stakeholders, this consultation paper has been prepared with the following structure of the paper. In Chapter I, an Overview of IMT- Advanced System has been given. Chapter- II deals with the Regulatory issues, while Chapter- III covers the International practices. Chapter-IV summarises all the issues raised in the paper.

Chapter I

Overview of IMT-Advanced systems

- 1.1 ITU's Radio communication Sector (ITU-R) has completed the assessment of six candidate submissions for the global 4G mobile wireless broadband technology, otherwise known as IMT-Advanced in October 2010. Harmonization among these proposals has resulted in two technologies, "LTE-Advanced" and "WirelessMAN-Advanced" being accorded the official designation of IMT-Advanced, qualifying them as true 4G technologies. ITU-R Working Party 5D, which is charged with defining the IMT-Advanced global 4G technologies, decided on these technologies for the first release of IMT-Advanced. These technologies will now move into the final stage of the IMT-Advanced process, which provides for the development in early 2012 of an ITU-R Recommendation specifying the in-depth technical standards for these radio technologies.
- 1.2 Pre 4G technologies such as mobile WiMax and the first release Long Term Evolution (LTE) has been in market since 2006 and 2009 respectively and often branded as 4G in marketing material. The current versions of these technologies do not fulfil the IMT- Advanced requirement. IMT- Advanced compliant version of the above two standards are under development and called "LTE Advanced" and "WirelessMAN Advanced" respectively. ITU has decided that "LTE Advanced" technology based on 3GPP release 10 and "WirelessMAN Advanced" technology based on IEEE 802.16m should be accorded the official designation of IMT- Advanced. Both LTE-Advanced technology and the IEEE WirelessMAN -Advanced technology make use of same key technologies viz. Orthogonal Frequency Division Multiple Access (OFDMA), Multiple Input Multiple Output (MIMO) and System Architecture Evolution (SAE). These are discussed in the following paragraphs.

A Multiple Input Multiple Output (MIMO)

- 1.3 Multiple Input Multiple Output (MIMO) technology is a wireless technology that uses multiple antennas at both transmitter and receiver. The use of multiple antennas allows independent channels to be created in space and is one of the most interesting and promising areas of recent innovation in wireless communications.
- 1.4 There are various approaches to use the multiple antenna elements at transmitter and receiver ends and are often collectively referred to as multiple input multiple output (MIMO) communication. These approaches are discussed here.

i. Spatial Diversity

- 1.5 Spatial Diversity gain results from the creation of multiple independent channels between the transmitter and the receiver and is a product of the statistical richness of those channels. One main advantage of spatial diversity relative to time and frequency diversity is that no additional bandwidth or power is needed in order to take the advantage of spatial diversity. Traditionally, the main objective of spatial diversity is to improve the communication reliability by decreasing the sensitivity to fading by picking up multiple copies of the same signal at different locations in space. A potential diversity gain is achieved and maximized if the antennas are sufficiently separated such that the fading characteristics are independent. Diversity techniques are very effective at averaging out fades in the channel and thus increasing the system reliability. The benefits of diversity can also be harnessed to increase the coverage area and to reduce the required transmit power, although these gains directly compete with each other, as well as with the achievable reliability and data rate.

ii. Beamforming

- 1.6 In contrast to the spatial diversity techniques, the available antenna elements can instead be used to adjust the strength of the transmitted and received signals, based on their direction. This focusing of energy is achieved by choosing appropriate weights for each antenna elements with a certain criterion. Beamforming techniques are an alternate to directly increase the desired signal energy while suppressing or nulling, interfering signal.

iii. Spatial Multiplexing

- 1.7 From a data rate standpoint, the most exciting type of MIMO communication is spatial multiplexing. Increased capacity is achieved by introducing additional spatial channels that are exploited by using space-time coding. It allows multiple data streams to be simultaneously transmitted using sophisticated signal processing. Thus, the nominal spectral efficiency is increased by a factor equal to number of spatial channels. This implies that adding antenna elements can greatly increase the viability of high data rates desired for wireless broadband Internet access.

iv. Interference Cancellation

- 1.8 Another important MIMO technique is interference cancellation (IC). This is particularly important for users who are experiencing low Signal-to-Interference-and-Noise Ratio (SINR), i.e. users who are at the radio cell-edge (which will coincide with the geographical cell-edge but will also include other regions). For such users, spatial multiplexing is typically not an option, nor is diversity important since the link performance is too poor in any case. In this situation, multiple antennas at the transmitter can be used to null interference co-operatively to another user. This requires feedback from user terminals and co-operation amongst base stations, which is being considered in

the IMT-A standards. Multiple antennas at the receiver can be used to cancel interference, using the multiple independent realizations of the interfering signals obtained from the antennas. MIMO-IC is particularly important for the Indian deployments, since operators will often have small cells and 1:1 spectrum reuse in all sectors. Both these conditions increase the fraction of users who experience low SINR.

1.9 These approaches can be used to

- Increase the system reliability (decrease the bit or packet error rate)
- Increase the achievable data rate and hence system capacity.
- Increase the coverage area.
- Decreases the required transmit power.

1.10 However, these four desirable attributes usually compete with one another; for example, increase in data rate often accompanies with an increase in either the error rate or transmit power. The way in which the antennas are used generally reflects the relative value attached by the designer to each of these attributes, as well as such considerations as cost and space. Despite the cost associated with additional antenna elements and their accompanying RF chains, the gain from antenna arrays is so enormous that it plays critical role in new wireless technologies.

1.11 When using MIMO, it is necessary to use multiple antennas to enable the different paths to be distinguished. There can be various MIMO configurations. For example, a 2x2 MIMO configuration is 2 antennas to transmit signals (from base station) and 2 antennas to receive signals (mobile terminal). Similarly 4X4 or even higher order configurations are possible in MIMO. While it is relatively easy to add further antennas to a base station, the same is not true of mobile handsets, where the

dimensions of the user equipment limit the number of antennas which should be placed at least a half wavelength apart.

B Orthogonal Frequency Division Multiple Access (OFDMA)

- 1.12 Orthogonal Frequency Division Multiple Access (OFDMA) is essentially a hybrid of FDMA and TDMA. Users are dynamically assigned sub-carriers (FDMA) in different time slots (TDMA). The advantages of OFDMA start with the advantages of single user OFDM in terms of robust multi-path suppression and frequency diversity. It is a flexible multiple access technique that can accommodate many users with widely varying applications, data rates and QoS requirements. It has the potential to reduce the transmit power and to relax the peak to average power ratio problem. Because the multiple accesses are performed in the digital domain, dynamic and efficient bandwidth allocation is possible. Lower data rates and data in burst are handled much more efficiently in OFDMA, since rather than having to blast at high power over the entire bandwidth; OFDMA allows the same data rate to be sent over a longer period of time using the same total power.
- 1.13 OFDM belongs to a family of transmission schemes called multi-carrier modulations, which is based on the idea of dividing a given high-bit-rate data stream into several parallel lower bit-rate streams and modulating each stream on separate carrier – often called sub-carriers or tones.
- 1.14 Multi-carrier modulation scheme eliminates or minimizes inter-symbol interference (ISI) by making the symbol time large enough so that the channel-induced delays are an insignificant (typically <10 percent) fraction of the symbol duration. Therefore, in high-data-rate systems in which the symbol duration is small, being inversely proportional to the data rate, splitting the data stream into many parallel streams increases the symbol duration of each stream such that the delay spread is only a small fraction of the symbol duration.

- 1.15 OFDM is a spectrally efficient version of multi-carrier modulation where the sub-carriers are selected such that they are all orthogonal to one another over the symbol duration, thereby avoiding the need to have non overlapping sub-carrier channels to eliminate inter-carrier interference.
- 1.16 In order to completely eliminate ISI, guard intervals are used between OFDM symbols. By making the guard intervals larger than the expected multi-path delay spread, ISI can be completely eliminated.
- 1.17 OFDM can be used as a multi-access scheme, where the available sub-carriers may be divided into several groups of sub-carriers called sub-channels. Different sub channels may be allocated to different users as a multiple access mechanism. These sub-channels may be constituted using either contiguous sub-channels or sub-carriers pseudo randomly distributed across the frequency spectrum.
- 1.18 OFDMA achieves its high performance and flexible accommodation of many users through multiuser diversity and adaptive modulation.

i. Multiuser Diversity

- 1.19 This type of diversity is naturally inherent in systems where several users are communicating with a base station (BS) on a shared frequency band. The diversity is attributed to the fact that for a given moment in time, different users usually have different channel conditions. In this situation, the total system throughput can be maximized by only letting the user having the best channel quality to transmit at any given time. However, repeatedly scheduling the best user might not be a fair strategy to communicate on a shared frequency band, since the same favorable user might end up being selected every time. Hence, scheduling users in a multiuser system by exploiting multiuser diversity also involve fairness and latency issues.

ii. Adaptive Modulation and Coding

- 1.20 In order to achieve high-speed transmission of data on a wireless channel, a reliable and spectrally efficient transmission scheme is needed. However, the hostility of the wireless channel makes this a challenging task, since signals tend to propagate along different paths due to reflection, scattering, and diffraction from obstructing objects. The received signal will then be a sum of randomly delayed signal components which will add either constructively or destructively, causing rapid fluctuations in the received signal level. This is called multipath fading, and through the years, it has been perceived as a phenomenon with detrimental effects on spectral efficiency. Based on this perception, wireless transmission schemes have traditionally been designed for the worst-case scenario by focusing on enabling the system to perform acceptably even in deep fading conditions. With such a design principle, spectral efficiency is sacrificed for link reliability.
- 1.21 A design principle focusing more on spectral efficiency is rate-adaptive transmission, where the basic concept is to exploit and track the time varying characteristics of the wireless channel to transmit with as high information rate as possible when the channel quality is good, and to lower the information rate (and trade it for link reliability) when the channel quality is reduced. With such a transmission scheme, a feedback channel is required, on which the receiver reports channel quality information (CQI) to the transmitter. Based on the reported CQI, the transmitter can make a decision on which rate to employ for the next transmission period. In particular, the transmitter may choose to select symbols from the biggest constellation meeting a pre-defined bit-error-rate (BER) requirement, to ensure that the spectral efficiency is maximized for an acceptable (target) BER.

1.22 A promising method is to vary the constellation size and the channel coding scheme (error control) according to the channel conditions, in which case a rate-adaptive transmission scheme is called as adaptive Modulation and Coding.

C SAE (System Architecture Evolution):

1.23 With the very high data rate and low latency requirements for IMT systems, it is necessary to evolve the system architecture to enable the improved performance to be achieved. One change is that a number of the functions previously handled by the core network have been transferred out to the periphery. Essentially this provides a much "flatter" form of network architecture. In this way latency time is reduced and data can be routed more directly to its destination.

1.24 As discussed earlier, ITU-R has selected LTE-Advanced and WirelessMAN-Advanced as the technologies for IMT-Advanced. Some of key features are discussed below.

D LTE (Long Term Evaluation):

1.25 To date, there has been widespread adoption of GSM/CDMA as 2G technologies and WCDMA/UMTS/HSPA/CDMA 2000/EVDO for 3G service. LTE has been defined as the next step in the technological roadmap. LTE evolves from the Third-generation technology which is based on WCDMA and defines the long term evolution of the 3GPP UMTS/HSPA cellular technology. The specifications of these efforts are formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UTRAN), commonly referred to by the 3GPP project LTE. It offers higher data rates, lower latency and greater spectral efficiency than previous technologies. LTE supports high performance mobile access functional upto 350Km/h with 500Km/h under consideration. Peak data rates range from 100 to 326.4Mbps on the downlink and 50 to 86.4 Mbps on

the uplink depending on the antenna configuration and modulation depth. LTE is compatible with HSPA, UMTS and GSM-based technologies and hence offers a simple evolutionary path for all existing GSM and HSPA operators. However, LTE's complementary core network also offers the ability to support the handover of services between LTE and CDMA-2000 networks, making it a compelling option as a next step for CDMA-2000/EV-DO operators as well.

1.26 LTE has been developed to offer both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes, enabling TD-SCDMA networks to also make a smooth transition to TDD LTE. Indeed, a combined FDD and TDD LTE deployment is expected to gain a broad foothold in many markets.

1.27 The objective for developing LTE is to provide an extremely high performance radio-access technology that offers full vehicular speed mobility and that can readily coexist with HSPA and earlier networks. Because of scalable bandwidth, it will be possible for the operators to migrate their networks and users from HSPA to LTE over time. LTE assumes a full Internet Protocol (IP) network architecture and is designed to support voice in the packet domain. It incorporates top-of-the-line radio techniques to achieve performance levels particularly in larger channel bandwidths. As 3G can coexist with 2G systems in integrated networks, it is possible that LTE systems coexist with 3G and 2G systems. Multimode devices will function across LTE/3G or even LTE/3G/2G, depending on market circumstances.

i. LTE capabilities include:

- Downlink peak data rates up to 326 Mbps with 20 MHz bandwidth
- Uplink peak data rates up to 86.4 Mbps with 20 MHz bandwidth
- Operation in both TDD and FDD modes

- Scalable bandwidth up to 20 MHz, covering 1.4, 3, 5, 10, 15, and 20 MHz.
- Increased spectral efficiency over Release 6 HSPA by a factor of two to four
- Reduced latency, up to 10 milliseconds (ms) round-trip times between user equipment and the base station, and to less than 100 ms transition times from inactive to active

ii. LTE specification overview

1.28 Summary of the key parameters of the 3G LTE specification is given in the table 1.1.

Parameter	Details
Peak downlink speed with 64QAM in Mbps	100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
Peak uplink speeds (Mbps)	50 (QPSK), 57 (16QAM), 86 (64QAM)
Data type	All packet switched data (voice and data). No circuit switched.
Channel bandwidths (MHz)	1.4, 3, 5, 10, 15, 20
Duplex schemes	FDD, TDD and half FDD.
Mobility	0 - 15 km/h (optimised), 15 - 120 km/h (high performance)
Latency	Idle to active less than 100ms Small packets ~10 ms
Spectral efficiency	Downlink: 3 - 4 times Rel 6 HSDPA Uplink: 2 -3 x Rel 6 HSUPA
Access schemes	OFDMA (Downlink) SC-FDMA (Uplink)
Modulation types supported	QPSK, 16QAM, 64QAM (Uplink and downlink)

Table 1.1

1.29 These specifications give an overall view of the performance that LTE will offer. It meets the requirements of industry for high data download speeds as well as reduced latency - a factor important for many applications from VoIP to gaming and interactive use of data. It also provides significant improvements in the use of the available spectrum.

iii. LTE - Advanced

1.30 Key features of LTE-Advanced are

- Compatibility of services
- Enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility). Peak data rate of 1 Gbps will be achieved by 4- by 4- MIMO and transmission bandwidth wider than approximately 70 MHz
- Spectrum efficiency: 3 times greater than LTE.
- Peak spectrum efficiency: downlink – 30 bps/Hz; uplink – 6.75 bps/Hz.
- Spectrum use: the ability to support scalable bandwidth use and spectrum aggregation where non-contiguous spectrum needs to be used.
- Latency: from Idle to Connected in less than 50 ms and 10 msec (dormant state to active state)
- Cell edge user throughput to be twice that of LTE.
- Average user throughput to be 3 times that of LTE.
- Mobility: Same as that in LTE
- Compatibility: LTE Advanced shall be capable of inter-working with LTE and 3GPP legacy systems.

1.31 The development of LTE Advanced / IMT Advanced has evolved from various 3GPP releases from Rel99/4 onwards as summarised in Table1.2.

	WCDMA (UMTS)	HSPA	HSPA+	LTE	LTE Advanced
Max downlink speed(bps)	384 k	14 M	28 M	300M	1G
Max uplink speed (bps)	128 k	5.7 M	11 M	75 M	500 M
Latency round trip time (approx)	150 ms	100 ms	50ms (max)	~10 ms	less than 5 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8	Rel 10
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008/ 9	2009/ 10	
Access methodology	CDMA	CDMA	CDMA	OFDMA /SC-FDMA	OFDMA / SC-FDMA

Table 1.2

E The WiMAX (IEEE 802.16 standard)

1.32 It comes from IEEE family of protocols and extends the wireless access from the Local Area Network (typically based on the IEEE 802.11 standard) to Metropolitan Area Networks (MAN) and Wide Area Networks (WAN). It uses a new physical layer radio access technology called OFDMA (Orthogonal Frequency Division Multiple Access) for uplink and downlink. It provides wireless transmission of data using a variety of transmission modes, from point-to-multipoint links to portable and fully mobile internet access. According to the industry forum WiMax Forum, many technologies currently available for fixed wireless access can only provide line of sight (LOS) coverage, the technology behind WiMAX has been optimised to provide non line of sight (NLOS) coverage as well. WiMAX's advanced technology can cover distances of up to 50 kilometers under LOS conditions and typical cell radii of up to 5 miles under NLOS conditions.

1.33 The Mobile WiMAX uses an all IP backbone with uplink and downlink peak data rate capabilities of upto 75 Mbps depending on the antenna configuration and modulation, practicable to 10 Mbps within a 6 miles (10 Km) radius. The earliest iterations of WiMAX was approved with the TDMA TDD and FDD with line of sight (LOS) propagation across the 10 to 66 GHz frequency range which was later expanded to include operation in the 2 to 11 GHz range with non line of sight (NLOS) capability using the robust OFDMA PHY layer with sub-channelization allowing dynamic allocation of time and frequency resources to multiple users. The 802.16m (Mobile WiMAX Release 2) Task-force is currently working on the next-generation systems with an aim for optimizations for improved interworking and coexistence with other access technologies such as 3G cellular systems, WiFi and Bluetooth and enhance the peak rates to 4G standards set by the ITU under 'IMT-Advanced' umbrella which calls for data rates of 100 Mbps for high mobility and 1 Gbps for fixed/nomadic wireless access.

F IEEE802.16m:

1.34 The IEEE 802.16e-2005 amendment to the IEEE Std 802.16-2004 Air Interface Standard which added Scalable-Orthogonal Frequency Division Multiple Access (S-OFDMA) and many other features for support of mobility has provided the basis for WiMAX System Release 1. Further specification enhancements for Release 1 were provided with IEEE Std 802.16-2009. The first WiMAX System Release 1 deployments took place in 2006.

1.35 In December 2006 the IEEE launched an effort to further evolve the IEEE 802.16 WirelessMAN OFDMA specification. This amendment, known as 802.16m, is designed to meet or exceed the requirements of IMT-Advanced (the 4th generation of cellular systems). With a number of stringent requirements for backward compatibility, the 802.16m amendment will provide the basis for WiMAX System Release 2 and

provide existing WiMAX operators a graceful migration path to gain performance enhancements and add new services. 802.16m is designed to support frequencies in all licensed IMT bands below 6 GHz and include TDD and FDD duplexing schemes as well as half-duplex FDD (H-FDD) terminal operation to ensure applicability to the wide range of worldwide spectrum assignments.

i. Coverage and Spectral Efficiency

1.36 The IEEE 802.16m amendment provides an improvement in the link budget over WiMAX System Release 1 of at least 3 dB with the same antenna configuration. This will provide a 20-30% increase in cell coverage area in a typical non line-of-sight environment. Several other enhancements included in IEEE 802.16m will improve spectral efficiency for data services. These enhancements include:

- Extended and improved MIMO modes with emphasis on multi-user MIMO (MU-MIMO) on both downlink (DL) and uplink (UL) to enable support for up to 8 data streams in the DL and up to 4 data streams in the UL.
- Improved open-loop and closed-loop power control.
- Advanced interference mitigation techniques including fractional frequency reuse and inter-base station coordination, collision-free interlaced pilots and conjugate data repetition.
- More efficient use of pilot tones with new sub-channelization schemes and a cyclic prefix of 1/16 vs. 1/8 to reduce layer 1 overhead in both DL and UL.
- Enhanced control channel design on both DL and UL with:
 - Reduced overhead
 - Improved coverage through power boosting and optimized channel coding
 - HARQ protection for control messages

1.37 The net result of these enhancements will provide more than 2 times improvement in average channel spectral efficiency. The spectral efficiency enhancements described in the previous section lead directly to increased channel data capacity and increased peak data rates.

ii. Multi-Carrier Support

1.38 The IEEE 802.16m amendment also supports channel aggregation of contiguous or non-contiguous channels to provide an effective bandwidth up to 100 MHz. The channels do not need to have the same bandwidth nor do they need to be in the same frequency band. This capability will enable operators with access to multiple channels or licenses to achieve significantly higher peak and average data rates than is achievable with individual channels. Aggregating several 20 MHz channels, for example, could support peak data rates exceeding 1 Gigabit/sec.

1.39 The key goal for 802.16m is to minimize latency for all aspects of the system including air link delay, state transition delay, access delay, and handover interruption time to guarantee QoS for all services called for in IMT-Advanced. Specific latency objectives for IEEE 802.16m are:

- Link Layer/User Plane: < 10 ms DL or UL
- Hand-Off Interruption: < 30 ms
- Control Plane, Idle to Active: < 100 ms

1.40 IEEE 802.16m will be able to support multiple QoS parameter sets for a single service flow. This will provide the flexibility to meet the individual QoS parameters established for individual multimedia classes established by IMT-Advanced. These classes are defined as follows:

- Low Multimedia: Data speed up to 144 kbps
- Medium Multimedia: Data speed up to 2 Mbps
- High Multimedia: Data speed up to 30 Mbps

- Super High Multimedia: Data speed up to 100 Mbps or possibly 1 Gbps.

1.41 Comparison² of the Legacy Mobile WiMAX features with IEEE 802.16m

Feature	Legacy Mobile WiMAX based on Release 1.0	IEEE 802.16m
Duplexing Scheme	TDD	TDD and FDD
Operating Bandwidth	5,7,8.75 and 10 MHz	5,7,8.75,10 and 20 (up to 100 MHz with carrier aggregation)
Downlink Multi-User MIMO	Not Supported	Multi-user Zero-forcing pre-coding based on transformed codebook or sounding.
Uplink Multi-User MIMO	Single-transmit-antenna Collaborative MIMO	Collaborative MIMO for up to four transmit antennas.

Table 1.3

1.42 Comparison of IEEE 802.16m with LTE- Advanced specifications viz-a-viz requirement of IMT-Advanced is given in table³ 1.4.

Requirement	IMT-Advanced	IEEE 802.16m	3GPP LTE-Advanced
Peak spectrum efficiency (bit/sec/Hz) System level.	DL: 15 (4x4) UL: 6.75(2x4)	DL: 8/15 (2x2/4x4) UL: 2.8/6.75 (1x2/2x4)	DL: 30 (8x8) UL: 6.75(4x4)
Cell spectral efficiency (bit/sec/Hz/sector) System level	DL: 2.2 (4x2) UL: 1.4 (2x4) (Base Coverage Urban)	DL: 2.6 (2x2) UL: 1.3 (1x2) (Mixed Mobility)	DL: 2.6 (4x2) UL: 2.0 (2x4)
Cell-edge user spectral efficiency (bit/sec/Hz) System level	DL: 0.06 (4x2) UL: 0.03 (2x4) (Base Coverage Urban)	DL: 0.09 (2x2) UL: 0.05 (1x2) (Mixed Mobility)	DL: 0.09 (4x2) UL: 0.07 (2x4) (Base Coverage Urban)

² “Mobile WiMAX Approach: A System Approach to Understanding IEEE802.16m Radio Access technology” by Sassan Ahmadi, 2011 Edition.

³ “Mobile WiMAX Approach: A System Approach to Understanding IEEE802.16m Radio Access technology” by Sassan Ahmadi, 2011 Edition.

Requirement	IMT-Advanced	IEEE 802.16m	3GPP LTE-Advanced
Antenna Configuration	Not specified	DL:2x2 (baseline), 2x4, 4x2, 4x4, 8x8 UL:1x2 (baseline), 1x4,2x4,4x4	DL:2x2 (baseline), 2x4, 4x2, 4x4, 8x8 UL:1x2 (baseline), 1x4,2x4,4x4
Operating Bandwidth	Up to 40MHz (with band aggregation)	5-20MHz (up to 100 MHz through band aggregation)	1.4-20 MHz (up to 100 MHz through band aggregation)
Duplex Scheme	Not specified	TDD, FDD(support for HDD terminals)	TDD, FDD(support for HDD terminals)
Latency	C-Plane: 100 msec (idle to active) U-Plane: 10msec	C-Plane: 100 msec (idle to active) U-Plane: 10msec	C-Plane: 50 msec (idle/camped state to connected), 10 msec (dormant state to active state) U-Plane: 10msec

Table 1.4

G LTE UE category

1.43 The LTE UE (User Equipment) categories or UE classes are needed to ensure that the base station, or eNodeB, eNB can communicate correctly with the user equipment. By relaying the LTE UE category information to the base station, it is able to determine the performance of the UE and communicate with it accordingly.

1.44 As the LTE category defines the overall performance and the capabilities of the UE, it is possible for the eNB to communicate using capabilities that it knows the UE possesses. Accordingly the eNB will not communicate beyond the performance of the UE.

i. LTE UE category definitions

1.45 In the pre-consultation paper one of the stakeholders has raised the issue of congenial eco-system in terms of user equipment (UE) for LTE,

since there are nearly 5 categories of UE defined by 3GPP with significant variations in speeds. It is also mentioned that there are issues related to different architectures of LTE used by the vendors. In view of this, the issue is whether there is a need to define a particular user equipment or architecture to be used by the vendors.

- 1.46 There are five different LTE UE categories that are defined. As can be seen in the table below, the different LTE UE categories have a wide range in the supported parameters and performance e.g. LTE category 1 does not support MIMO, but LTE UE category five supports 4x4 MIMO.
- 1.47 It is also worth noting that UE class 1 does not offer the performance offered by that of the highest performance HSPA category. Additionally all LTE UE categories are capable of receiving transmissions from up to four antenna ports.
- 1.48 A summary of the different LTE UE category parameters provided by the 3GPP Rel 8 standard, for 20MHz bandwidth, is given in the tables 1.51, 1.6 and 1.7.

LTE UE category data rates (Mbps)

Category	1	2	3	4	5
Downlink	10	50	100	150	300
Uplink	5	25	50	50	75

Table 1.5

LTE UE category modulation formats supported

Category	1	2	3	4	5
Downlink	QPSK, 16QAM, 64QAM				
Uplink	QPSK, 16QAM				QPSK, 16QAM, 64QAM

Table 1.6

LTE UE category MIMO antenna configurations

Category	1	2	3	4	5
2 Rx diversity	Assumed in performance requirements across all LTE UE categories				
2 x 2 MIMO	Not supported	Mandatory			
4 x 4 MIMO	Not supported				Mandatory

Table 1.7

1.49 In broadband wireless standards systems such as 3G HSPA, Mobile WiMAX, LTE, and IMT-A, transmission and reception on each link is highly adaptive. For example, dynamic power control is used on the uplink, and the coding rate and modulation are adapted on both downlink and uplink. Adaptation impacts the performance not only of the individual link on which it is done, **but that of the entire network**. Further, the adaptation is based on estimates of channel quality made by the receiver and fed back to the transmitter. The standards do not specify the algorithms for, or the quality required of, these estimates. UEs with poor estimation/adaptation capabilities may affect the performance of the network and impact existing subscribers if they enter the network without proper characterization. On the other hand, an open policy of permitting multiplicity of UE vendors is important for delivering value to the subscribers at the most competitive prices. The issue here is regarding how one can specify a minimal set of qualifications for a UE before it is permitted by an operator to enter a network.

Issues for consultation:-

- Q1. Whether there is a need to define a particular user equipment or architecture to be used by the vendors or this may be left to the market forces?**

Q2. Whether there is a minimal set of performance characteristics the UE has to meet before it is permitted to enter a network? These characteristics are over and above the inter-operability, protocol conformance and emission tests which presumably the UE has already passed.

1.50 The Internet and Broadband connections would require large supply of IP addresses, which may not be easily available through the present version of Internet, i.e., IPv4. The next generation Internet protocol, i.e., IPv6 is seen as one solution for this, in addition, it is claiming to provide better security, QoS, Mobility support. The primary motivation for the deployment of IPv6 is to expand the available address space on the Internet, thereby enabling millions of new devices, viz. Personal Digital Assistants (PDAs), cellular phones, home appliances in addition to computers/ PC to be made always connected to Internet. The next generation technologies are purely IP based and there is a need to migrate from existing IPv4 addressing to IPv6.

1.51 In its recommendations on “Telecommunications Infrastructure Policy” Dated 12.04.2011, TRAI has recommended that (i) TEC may develop IPv6 standards keeping in view country specific requirements based on global standards. (ii) IPv6 test bed facilities should be created for simulating and testing products in end to end IPv6 traffic environment. The IPv6 test bed facilities, already available with academic institutions like IITs, IISc should be extended to National Institutes of Technology (NITs) for easy access to stakeholders. (iii) All Government websites should be made IPv6 compliant by 2012.

H IMT -Advanced security issue

1.52 Security is an issue that is of paramount importance. It is necessary to ensure that IMT- Advanced security measures provides the level of security required without impacting the user.

- 1.53 IMT- Advanced brings with it packet-based access up to the user terminal. A packet infrastructure with a large number of IP addressed devices implies ease of proliferation of malware attacks, and complex requirements for their detection, prevention and cure. A new threat assessment framework and a security policy in line with this framework are necessary to secure these networks and their users.
- 1.54 Due to open architectures and IP based protocols, these networks will be prone to security attacks similar to those of Internet. As a result, IMT-Advanced networks will be more prone to Trojans, Malwares and Virus attacks than 3G wireless systems.
- 1.55 Packet based voice will be potentially prone to IP telephony attacks such as SPAM for VoIP (SPIT), SIP registration hijacking, eavesdropping. SPITs can also consume bandwidth thereby degrading quality of voice.
- 1.56 MAC layer security issues in both LTE-Advanced and WiMAX include bandwidth stealing, location tracking, denial of service (DoS) attacks etc.
- 1.57 Pico and Femto base stations are likely to be more popular in IMT-Advanced and are likely to pose more security threats due to high accessibility architecture.
- 1.58 These networks present significantly higher capacity challenges to legal-intercept systems deployed today. A large, dynamic public IP pool places enormous demands on infrastructure used by law enforcement agencies for call traces, and the capacity of current deployments seems inadequate.
- 1.59 With the level of sophistication of security attacks growing, it is necessary to ensure that IMT- Advanced security allows users to operate freely and without fear of attack from hackers. Additionally the network must also be organized in such a way that it is secure against a variety of attacks.

1.60 When developing the IMT- Advanced security elements there were several main requirements that were borne in mind:

- It has to provide at least the same level of security that was provided by 3G services.
- The security measures should not affect user convenience and QoS.
- The security measures taken should provide defence from attacks from the Internet.
- The security functions should not affect the transition from existing 3G services to IMT- Advanced.
- The USIM used for 3G services should still be used.
- To ensure these requirements for security are met, it is necessary to add further measures into all areas of the system from the UE through to the core network. The security infrastructure should be scalable and accounts for new usage patterns like social networking and peer-to-peer applications.

Q3. In addition to what has been described above, what can be the other security issues in IMT-Advanced services? How can these security issues be addressed?

Q4. What basic security frameworks should be mandated in all networks to protect customer?

Chapter II

Regulatory Issues in IMT-Advanced systems

- 2.1 As mentioned in the Introduction, TRAI issued a pre-consultation paper on 'IMT-advanced Mobile Wireless Broadband Services' for comments/ views from all the stakeholders on the subject. It received various comments from the stakeholders. Some of the stakeholders have opined that there should be a well defined path for moving towards IMT-Advanced services which include timely availability of sufficient spectrum, identification of frequency band, keeping in mind the harmonisation aspect worldwide, allocation and pricing methodology, spectrum usages charges, infrastructure sharing including spectrum sharing etc.
- 2.2 The issues involved in implementation of IMT-Advanced systems are described in the subsequent Paragraphs.

A Spectrum bands

- 2.3 Spectrum being the basic resource for any wireless technology, it is important to identify and make available internationally harmonized bands for the use of IMT services in India. This will facilitate economies of scale, worldwide roaming, wide availability of handsets/terminals/devices, favourable investment climate etc. Internationally , the following bands have been identified for IMT and IMT-Advanced for public telecommunication services: 450 MHz, 585–806 MHz, 800 MHz, 900 MHz, 1800 MHz, 1900 MHz, 2,1 GHz, 2.3-2.4 GHz, 2.5-2.69 GHz, 3.3-3.4 GHz and 3.4–3.6 GHz. The present status of availability of spectrum in these bands in Indian context is discussed in following paragraphs.

- 2.4 800 MHz and 900 MHz spectrum bands are presently being used for 2G mobile services. Though, the Authority has recommended⁴ that in future when the spectrum in 800, 900 MHz is available (by allocating spectrum in 1800 and 1900 for the licensees at the time of renewal), it may be refarmed and allocated for the IMT services. At present spectrum in these bands is not available. In 1800 MHz band, out of 75 MHz of paired spectrum, only 35 MHz is available for commercial services in a number of service areas. As per WPC, it is expected that Defence will vacate 2x20 MHz of spectrum in 1800 MHz band which will be required to compensate for the refarmed 900 MHz spectrum. Similarly, spectrum in PCS1900 MHz bands will be needed so that the service providers in 800 MHz can be relocated in 1900 MHz bands.
- 2.5 Spectrum has been auctioned in the blocks of 2x5MHz in the 2.1GHz band for 3G services. The number of blocks auctioned varied from 3 to 4 subject to availability in different telecom service areas. 1 block is allotted to BSNL / MTNL (PSU). The maximum spectrum allotted to any operator is 2x5 MHz only. Obviously there is further requirement of spectrum for 3G services. Therefore, whenever additional spectrum is available in the 2100 MHz band, it will be utilised for 3G services only.
- 2.6 In this scenarios, following spectrum bands are only available for future technologies in India :
- 700 MHz band (698-806 MHz).
 - 2010-2025 MHz band.
 - 2.3-2.4 GHz band.
 - 2.5-2.69 GHz band.
 - 3.4-3.6 GHz band.
- 2.7 In pre-consultation on the subject, one stakeholder was of the view that it is more suitable to use regionally and internationally harmonized

⁴ TRAI Recommendations on Spectrum Management and Licensing Framework, 11th May 2010.

spectrum for 4G, preferably in 700 MHz band (Digital Dividend) and 2.6 GHz band. Another stakeholder commented that the Govt should decide and communicate the time frame for auctioning 700 MHz band at the earliest, which will ensure that the precious financial and technical investments will not be wasted on older generation technologies rather industry would focus on investing in future. One stakeholder observed that by specifying the type of technologies and type of services to be offered (i.e. 2G, 3G or 4G) while allocating spectrum, government has created bottleneck in the deployment of broadband wireless access in the country. He was of the view that we should move towards the technology agnostic spectrum policy, which shall remove any mandate on specific technologies and services to be used in specific spectrum band. However, even with such a policy, the UL, DL bands will need to be specified, and in the case of TDD operation, frame synchronization based on network or satellite-based timing, and a permissible set of UL/DL ratios may have to be specified while licensing. This is necessary to enable co-existence of multiple operators on adjacent bands.

700 MHz band

- 2.8 The 700 MHz (698-806 MHz) spectrum band is considered the most important band for broadband deployment. It is suitable from the point of both capacity and coverage. The digital dividend spectrum in the UHF range has very good propagation characteristics and is highly suitable for the roll-out of mobile broadband in rural and other difficult-to-reach areas. Allocating this spectrum to mobile will mean that network operators require fewer base stations, meaning less capital investment is needed to bring broadband to all areas. Following the recommendations of the ITU's World Radio communication Conference (WRC) in 2007, Governments across the globe have actively pursued

policies to facilitate use of this spectrum for mobile broadband as soon as possible.⁵

2.9 The World Radio communications Conference (WRC) in 2007 identified the following blocks of spectrum in 700 MHz band, for different regions of the world (according to the ITU's system of regional classification)⁶:

Region 1: (Europe, Africa, the Middle East west of the Persian Gulf including Iraq, the former Soviet Union and Mongolia) 790-862 MHz band (72MHz).

Region 2: (The Americas, Greenland and some of the eastern Pacific Islands) 698-806MHz band (108MHz).

Region 3: (Asia, east of and including Iran and most of Oceania) The majority to follow Region 1 and nine countries to follow Region 2.

2.10 As per the NFAP foot note IND 37, the 585-806MHz band is predominantly for broadcasting services including mobile TV and the requirements of IMT and BWA services may be considered and co-ordinated in the 698-806 MHz band.

2.11 The allocation of spectrum in the band 585 to 806 MHz (UHF Band-V) was discussed in the recommendations on "Spectrum Management and Licensing Framework" dated 11th May,2010 and the authority has recommended the following:-

- 585-698 MHz may be earmarked for digital broadcasting services including Mobile TV.
- 698-806 MHz be earmarked only for IMT applications.

⁵ http://www.gsmworld.com/documents/DD_brochure_2010-FINAL.pdf

⁶ GSMA: Digital Dividend for Mobile : Bringing Broadband to all,
<http://hspa-titian.professionhosting.com/upload/news/files/05032009135612.pdf>

2010-2025 MHz band

2.12 As per the ITU Radio Regulations, Table of Frequency Allocations, this spectrum band is allocated to fixed and mobile radio communication services on a primary basis⁷. The bands 1885-2025 MHz and 2110-2200 MHz are intended for use, on a worldwide basis, by administrations wishing to implement International Mobile Telecommunications-2000 (IMT-2000). Such use does not preclude the use of these bands by other services to which they are allocated. The bands should be made available for IMT-2000 in accordance with Resolution 212 (Rev.WRC-97) and also Resolution 223 (WRC-2000). In Regions 1 and 3, the bands 1885-1980 MHz, 2010-2025 MHz and 2110-2170 MHz and in Region 2, the bands 1885-1980 MHz and 2110-2160 MHz may be used by high altitude platform stations as base stations to provide International Mobile Telecommunications-2000 (IMT-2000), in accordance with Resolution 221 (Rev.WRC-03). Their use by IMT-2000 applications using high altitude platform stations as base stations does not preclude the use of these bands by any station in the services to which they are allocated and does not establish priority in the Radio Regulations. (WRC-03).

2.13 Regarding 2010-2025 MHz band, NFAP 2008 mentions that

“Requirements of IMT (3G) applications in the frequency bands 1920-1980 MHz paired with 2110-2170 MHz (FDD mode) and 2010-2025 MHz (TDD mode) may be coordinated with existing users depending upon the availability, as far as possible.”

2.14 The Department of Telecommunications (DoT) vide its letter no. L-14016/72/2006-NT dated 6 April, 2009 had identified the frequency band 2010-2025 MHz for **broadband wireless access** (emphasis supplied) subject to its availability and compatibility of new systems/technologies with existing systems had requested TRAI to furnish its recommendations in terms of clause 11(1) (a) of TRAI Act

⁷ This band is also allocated to Mobile-Satellite (earth to space) services on primary basis in Region 2.

1997 as amended by TRAI Amendment Act, 2000, on the following issues with regard to allocations of frequency bands 1785-1805 MHz and 2010-2025 MHz:

- i. Methodology for allotment of spectrum and eligibility criteria, etc
- ii. Reserve price in case of allotment of spectrum through auction,
- iii. Any other terms and conditions applicable for auction, etc.

2.3-2.4 GHz Band

2.15 As per the Radio Regulation provisions, this band is among the IMT identified bands. In India also, this band has been allocated for IMT applications including BWA on a case to case basis. Out of the total 100 MHz spectrum, 40 MHz has been allocated for BWA services. 24 MHz spectrum in this band is with Government agencies and 36 MHz is with captive users. It is imperative that remaining 60 MHz of spectrum in this band needs to be refarmed in a short span of time.

2.5 GHz Band (2500 – 2690 GHz)

2.16 WRC-2000 identified three additional bands for terrestrial IMT-2000 including 2500-2690 MHz. As a result, starting in the year 2008, as much as 140 MHz of spectrum in FDD is allocated in many countries; 2500-2570 MHz for uplink and 2620-2690 MHz for downlink. Additionally up to 50 MHz (2570 MHz-2620 MHz) is allocated as an unpaired TDD band. As a globally common band plan, this spectrum band will also enable economies of scale and global roaming. Many countries, including the United States, Brazil, Mexico, Singapore, Japan, Hong Kong, and Canada, have identified and allocated the 2.5 GHz band for all types of wireless systems. The ITU's Radio Regulations identify this band as an extension band for IMT-2000 and beyond. In this band, spectrum has been auctioned by many European Countries viz Sweden (2008), Germany (2010), Finland (2009) and Netherlands (2010) for advanced wireless mobile systems.

2.17 The Authority in its recommendations on “Allocation and pricing of spectrum for 3G and broadband wireless access services” dated 27th September 2006 had recommended that 40 MHz of spectrum being in use for Local Multipoint Distribution Service (LMDS) and Multi-channel Multipoint Distribution Service (MMDS) (2.535-2.550 GHz and 2.630-2.655 GHz) be vacated or refarmed by end 2007, and that an additional 40 to 80 MHz be coordinated with Department of Space in the same timeframe. The Department of Telecommunications (DoT) has assigned 20MHz of spectrum to BSNL/MTNL for BWA services in most of the service areas in the 2635-2655 MHz band, under sharing/ co-ordination with Department of Space.

3.4-3.6 GHz

2.18 At WRC-07, new bands were identified for use by IMT. The identifications differ from region to region and are not fully globally harmonized but there is a strong common factor. 3.4- 3.6 GHz is one of these bands.

2.19 In Bangladesh, China, India, Iran, New Zealand, Singapore and French Overseas Communities in Region 3, the band 3400-3500 MHz is allocated to the mobile, except aeronautical mobile, service on a primary basis, subject to agreement obtained under No.9.21 with other administrations and is identified for IMT. This identification does not preclude the use of this band by any application of the services to which it is allocated and does not establish priority in the Radio Regulations.

2.20 In Bangladesh, China, Korea (Rep. Of), India, Iran, Japan, New Zealand, Pakistan and French Overseas Communities in Region 3, the band 3500-3600 MHz is identified for IMT. This identification does not preclude the use of this band by any application of the services to which it is allocated and does not establish priority in the Radio Regulations.

2.21 As per NFAP 2008⁸, the requirement of IMT including Broadband Wireless Access (BWA) in the frequency band 3400-3600 MHz may be considered for coordination on a case by case basis subject to availability of spectrum in this band and appropriate protection from out of band emission to the networks in the Fixed Satellite Services (FSS) in the frequency band 3600-4200 MHz.

2.22 In respect of spectrum in 3.4-3.6 GHz band, in its recommendation on 'Allocation and Pricing of 2.3-2.4 GHz, 2.5-2.69 GHz, 3.3-3.6 GHz' dated 11th July, 2008, the Authority decided not to make any recommendation for 3.4-3.6 GHz unless DoT assess the compatibility of satellite based services with the terrestrial BWA services and a detailed analysis is done in a transparent and time bound manner to ascertain the feasibility of mitigation of the interference problems reported by some of the stakeholders including Department of Space, considering the fact that there was no clarity on the use of this band in the country.

Q5. Which spectrum bands should be identified for the IMT-A Services in India?

2.23 TRAI in its recommendations on "Review of license terms and conditions and capping of number of access providers" dated August 28, 2007 recommended that in future all spectrum excluding the spectrum in 800, 900 and 1800 bands should be auctioned so as to ensure efficient utilization of this scarce resource. Based on the recommendations of TRAI, it was decided by Department of Telecommunications that spectrum for 3G and BWA shall be awarded through auction process and accordingly, the spectrum for 3G and BWA were auctioned. On the similar lines, spectrum allocation for IMT-Advanced shall be done through auction.

⁸ Footnote IND 62, NFAP 2008

B Block size and Cap on maximum spectrum for a licensee

2.24 Having decided that the methodology of allocating spectrum is auction, the issue of block size and the reserve price comes up. In the recently held auction for 3G and BWA services the spectrum block size for auction was 2x5 MHz (FDD) in 2.1 GHz band for 3G and 20MHz (TDD) in 2.3GHz band for BWA services. Both, the LTE Advanced and IEEE 802.16m technologies support variable channel bandwidth as shown in Table 2.1

Nominal Channel Bandwidth supported by IMT Advanced Technologies (In MHz)						
LTE Advanced	1.4	3	5	10	15	20
IEEE 802.16m		5	7	8.75	10	20

Table – 2.1

2.25 In their comments on the pre-consultation paper on this subject one of the stakeholders has commented that unlike 3G (e.g. WCDMA) which requires a minimum of 2x5 MHz carrier, 4G technologies such as LTE can operate using a minimum of 2x1.25 MHz carrier. Another stakeholder has observed that spectral efficiencies of 4G technologies typically kick in when larger bandwidths are available with the operator. Internationally; a minimum of 2x15 MHz of spectrum has been allocated to operators for rolling out 4G networks. He further commented that considering the under penetration of broadband in India, a minimum block size of 2x20 MHz per operator should be auctioned to achieve better efficiencies and throughputs.

2.26 View of one of the stakeholders was that since large bandwidths would be required to cater to these speeds, it is essential that fragmentation of bands be avoided; instead large contiguous blocks and sufficient quantum are made available to the operators to achieve better

efficiencies and throughput. Another comment was that all IMT-Advanced technologies will require wider contiguous channels (20 MHz or more) to provide the desired services and level of performances. One stakeholder was of the view that not less than 2X 20 MHz bandwidth chunks for FDD and 30MHz for TDD spectrum should be made available to the operators.

2.27 Some of the stakeholders have commented that issue of performance and spectral efficiency required by the new technologies need to be considered while deciding the size of the block. One view was that in order to avoid hoarding of spectrum and also to encourage fair competition among service providers, there is a need to put a limit on the amount of spectrum that can be allotted to a bidder. The cap on maximum spectrum should be different in different frequency band.

Q6. What should be the block size of spectrum to be put on auction? How many blocks of spectrum should be auctioned per service area?

Q7. What is the minimum spectrum block size for effective use of 4G technologies?

Q8. What should be the maximum amount of spectrum which a service provider can be allocated through auction?

C Duplex schemes: TDD Vs FDD

2.28 LTE-Advanced and IEEE 802.16m support both TDD as well as FDD mode of duplexing. There are a number of the advantages and disadvantages of TDD and FDD that are of particular interest to mobile or cellular telecommunications operators.

Advantages / disadvantages of TDD and FDD

Parameter	TDD	FDD
Paired spectrum	Does not require paired spectrum as both transmit and receive occur on the same channel.	Requires paired spectrum with sufficient frequency separation to allow simultaneous transmission and reception.
Hardware cost	Lower cost as no diplexer is needed to isolate the transmitter and receiver. As cost of the UEs is of major importance because of the vast numbers that are produced, this is a key aspect.	Diplexer is needed and cost is higher.
Channel reciprocity	Channel propagation is the same in both directions which enables transmit and receive to use on set of parameters	Channel characteristics different in both directions as a result of the use of different frequencies
UL / DL asymmetry	It is possible to dynamically change the UL and DL capacity ratio to match demand	UL / DL capacity determined by frequency allocation set out by the regulatory authorities. It is therefore not possible to make dynamic changes to match capacity. Regulatory changes would normally be required and capacity is normally allocated so that it is the same in either direction.
Guard period / guard band	Guard period required to ensure uplink and downlink transmissions do not clash. Large guard period will limit capacity. Larger guard period normally required if distances are increased to accommodate larger propagation times.	Guard band required to provide sufficient isolation between uplink and downlink. Large guard band does not impact capacity.
Discontinuous transmission	Discontinuous transmission is required to allow both uplink and downlink transmissions. This can degrade the performance of the RF power amplifier in the transmitter.	Continuous transmission is required.

<p>Cross slot interference</p>	<p>Base stations need to be synchronized with respect to the uplink and downlink transmission times. If neighboring base stations use different uplink and downlink assignments and share the same channel, then interference may occur between cells.</p>	<p>Not applicable</p>
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Table 2.2

2.29 While it can be anticipated both TDD and FDD will be widely used, it is anticipated that FDD will be the more widespread, Since LTE has become backward compatible with 3G and 2G technologies which use paired spectrum, therefore it can be said that LTE FDD using the paired spectrum can form the migration path for the current 3G/2G services. Although LTE TDD has a number of significant advantages, especially in terms of higher spectrum efficiency that can be used by many operators.

2.30 If TDD technologies are used, and co-located operators in adjacent bands are to be permitted the choice of say IMT-A technologies, then there might be a requirement to mandate frame synchronization based on network or satellite-derived timing. Further, a subset of UL-DL ratios in the IMT-A standards that minimize overlap of UL and DL sub-frames will have to be specified as the only ones permissible. The base stations and terminals will need to be equipped with specific measures to handle the interference caused by operators in the same geography operating in neighbouring bands. Even for a single operator, if adjacent cells are to have different UL/DL sub-frame ratios, such measures will be necessary.

Q9. Whether there is a need to specify the use of particular duplexing scheme based on the band in which spectrum allocation is done? If yes, in the case of TDD, is it required to specify further the frame duration, mandate frame synchronization using one of a specified

set of timing sources, and a permissible set of Uplink/Downlink sub-frame schemes compatible with the IMT-A standards?

D Reserve Price and Eligibility Criteria:

- 2.31 A market price is a fair payment criterion for the use of scarce resources. It is therefore, reasonable to adopt the same for pricing of spectrum. However, a balance has to be struck, so that an efficient organization is not unduly disadvantaged. In this, both pricing as well as allocation principles have an important role to play. Having decided the allocation methodology, a reserve price for the block of spectrum need to be set. The reserve price should be set at such a level that reflects the scarcity of spectrum, recovers administrative costs, promotes its efficient utilisation and reflects accurately the demand and supply equations.
- 2.32 In the recent 3G auction the Reserve price for 2x5MHz of paired spectrum in the 2.1GHz band was kept at Rs. 320 cr. for Delhi, Mumbai & category 'A' service areas, Rs. 120 cr. for Kolkata & category 'B' service areas and Rs. 30 cr. for category 'C' service areas. In case of BWA Auction, the Government auctioned two blocks of 20MHz unpaired spectrum in each of the 22 service areas. Reserve price was kept at Rs. 160 cr for Delhi, Mumbai & category 'A' service areas, Rs. 60 cr. for Kolkata & category 'B' service areas and Rs. 15 cr. for category 'C' service areas.
- 2.33 In the pre-consultation paper, one of the stakeholders has commented that the spectral efficiency (i.e. capacity per Hertz of spectrum per cell) of LTE is found to be almost 40 times using 4G technologies compared to 2G. Another stakeholder commented that the reserve price of 4G spectrum should be in line with the reserve price set for BWA auctions.
- 2.34 One of the stakeholders has quoted the World Bank's econometric analysis of 120 countries, that for every 10 percentage point increase in the penetration of broadband services, there is an increase in the

economic growth of 1.3 percentage points. The growth effect of broadband is stronger and significant in developing countries like India than developed countries and is higher than that of telephony and Internet.⁹ As per one stakeholder, broadband technologies like 3G and 4G need to be encouraged by the Government to increase the penetration of broadband.

2.35 Looking at the factors like higher spectral efficiency provided by upcoming technologies, winning auction price in the recently concluded auction, excellent propagation characteristics of sub 1Ghz bands, scarcity of spectrum and looking at the facts that broadband penetration has not been up to the mark, the determination of reserve price for IMT-advanced services becomes important.

2.36 Another linked issue is the eligibility of the service providers for auction. In the recently concluded auction of 3G/BWA spectrum, it is seen that for 3G, only CMSPs and UASLs were eligible alongwith New Entrant Nominee UAS Licensee¹⁰ whereas for BWA in addition to CMSPs and UASLs & New Entrant Nominee UAS Licensee, ISPs (A & B) were also eligible. It is evident that the eligibility criteria was based upon kind of services to be offered using the given spectrum band. With technological developments it is possible to offer all types of services using these spectrum bands. In view of above, the main issue for consideration is what should be the eligibility criteria for allocation of spectrum in the two bands under consideration.

2.37 The Authority in its recommendations on ‘Spectrum Management and Licensing Framework’ of May, 2010 has recommended that all future licences should be Unified Licences and that spectrum be delinked from licence. Therefore one view could be that any entity eligible to apply for

⁹ Qiang and Rossotto, 2009

¹⁰ Any entity that gives an undertaking to obtain a UAS licence through a New Entrant Nominee UAS Licensee as per DoT guidelines before starting telecom operations.

Unified Licence should be eligible for participating in the bidding process for the IMT spectrum.

Q10. What should be the reserve price per MHz in different spectrum bands?

Q11. What should be the eligibility conditions for bidding for spectrum?

E Roll-out Obligations:-

2.38 In the pre-consultation, on the issue of roll out obligations, one opinion was that there should be no roll out obligations for these bands as the spectrum is allotted through market driven mechanism. The purpose of allocation of spectrum is to allocate it to those service providers who value it the most. However it needs to be ensured that the available spectrum with the service providers is put to effective and efficient use at the earliest.

2.39 In the access service licences, there are provisions of roll-out obligations with the provisions of liquidated damage charges in case of delayed/no roll-out. In 3G and BWA spectrum auction, following roll-out obligations were mentioned:-

3G spectrum roll-out obligations:

Metro service area

The licensee to whom the spectrum is assigned shall be required to provide required street level coverage using the 3G Spectrum in at least 90% of the service area within five years of the Effective Date.

Category A, B and C service areas

The licensee to whom the spectrum is assigned shall ensure that at least 50% of the District Headquarters (“DHQ”) in the service area will be covered using the 3G Spectrum, out of which at least 15% of the DHQs

should be rural Short Distance Charging Areas (“SDCA”) within five years of the Effective Date.

BWA spectrum roll-out obligation

Metro service area

The licensee to whom the spectrum is assigned shall be required to provide required street level coverage using the BWA Spectrum in at least 90% of the service area within five years of the Effective Date.

Category A, B and C service areas

The licensee to whom the spectrum is assigned shall ensure that at least 50% of the rural SDCAs are covered within five years of the Effective Date using the BWA Spectrum. Coverage of a rural SDCA would mean that at least 90% of the area bounded by the municipal/ local body limits should get the required street level coverage.”

2.40 To ensure that broadband is also available in rural and remote areas, the German Telecom Regulator, Federal Network Agency (FNA) in its auction of spectrum in 800 MHz band in 2010 has mandated that for the newly auctioned spectrum, operators must roll out their networks in four stages starting in :

- Smaller towns and districts with 5000 or fewer inhabitants (priority stage I).
- Towns and districts with between 5000 and 20000 inhabitants (priority stage II), then
- Towns and districts with between 20000 and 50000 inhabitants (priority stage III)
- The 4th stage is for towns and districts with more than 50000 inhabitants.

Priority stage II rollout can only begin in a federal state with at least 90% population in the towns and districts specified by that federal state for priority stage I have been provided with access. The same principle applies with regard to transition from priority stage II to priority stage III and from priority stage III to priority stage IV. If in the period upto 1 January, 2016 , towns and districts are covered by some other service providers/ technologies using equivalent or advanced broadband solutions such as DSL, this coverage will count towards the 90% target roll out obligations.

2.41 Considering the low penetration of broadband in rural areas and the suitability of 700 MHz band for rural areas, one option is to link the roll out of network in the rural areas on the lines of policy adopted by Germany. Another option could be to specify the roll out obligations on the lines of 3G or BWA spectrum auction.

Q12. Should there be any roll out obligations for spectrum given through auction? Should it be different in different bands?

Q13. Whether there should be any specific rollout obligations in respect of rural areas?

F Annual Spectrum usage charges

2.42 Spectrum is a national resource. Apart from obtaining its rights for use using the auction methodology, annual usages charges are also payable in the form of annual spectrum usage charges so that the service providers use it rationally, effectively and efficiently.

2.43 In the present scenario, Annual spectrum charges payable quarterly in advance by 2G licensees are as per a certain % of AGR. The share as % of Adjusted Gross Revenue (AGR) increases in slabs with the amount of spectrum held by the licensee. The Annual spectrum charges payable quarterly in advance by the 3G licensees who were having 2G license also, is the same % of combined AGR of both 2G and 3G services,

which is paid by 2G licensees without 3G spectrum. Slab rate for standalone 3G operators prescribed is equal to 3% of AGR.

2.44 Licensees using BWA Spectrum need to pay 1% of AGR from services using this spectrum as annual spectrum charge irrespective of the licence held by them. There is moratorium of one year for the stand-alone 3G as well as stand-alone 3G + BWA operators (i.e. winners of 3G/BWA Spectrum who do not hold 2G spectrum). There was no provision of moratorium to the licensees holding 2G + 3G Spectrum.

2.45 Therefore in the scenario of IMT Advanced services, there are many views on the Annual Spectrum Charges. One option is The Annual spectrum charges payable quarterly in advance by the IMT licensees who were having 2G/3G license also, should be the same % of combined AGR, which is paid by them today. But this shall cause different amount of Annual spectrum charges for different licensees for the same amount of IMT spectrum, depending upon their 2G/3G spectrum. The difference could be as much as 5% as the 2G operators are to pay 8% of AGR as Annual Spectrum Charges in the highest slab, whereas 2G operators in lowest slab (i.e. GSM operators with up to 4.4 MHz and CDMA operators with up to 5 MHz Spectrum) and also the standalone 3G operators shall pay 3% AGR as Annual Spectrum Charges. Another view is to apply Annual spectrum charges at a flat rate. These charges may be linked with the highest bid of the spectrum in the service area.

Q14. What should be the spectrum usages charges? Should it be based on revenue share or be a fixed charge?

G Infrastructure sharing

2.46 DoT vide its letter no. 6/21/2007-Policy-I dated 2nd April 2008 has issued Guidelines on Infrastructure Sharing among the Service Providers and Infrastructure Providers. In the guidelines, DoT has

permitted the sharing of active infrastructure amongst service providers based on the mutual agreements entered amongst them. Active infrastructure sharing will be permitted to antenna, feeder cable, Node B, Radio Access Network (RAN) and transmission system only. Sharing of the allocated spectrum will not be permitted. The licensing conditions of UASL/CMSF will be suitably amended wherever necessary to permit such sharing. Previous to this, the sharing of infrastructure by the LICENSEE was limited to Sharing of “passive” infrastructure viz., building, tower, dark fiber etc.

2.47 Though at present the sharing of active (except spectrum) and passive infrastructure is permitted within the license, however in case of IMT Advanced technologies, where MIMO technology for antennas will be used, there may be issues related to sharing of infrastructure. With the access technologies evolving towards 4G technologies, the global standardization forums have specified a converged Core Network which can have multiple heterogeneous access networks connected to a single Core Network. This further aids in sharing of RAN infrastructure.

Q15. Using MIMO technology what can be the possible infrastructure sharing issues and what can be the probable solutions.

H Key Performance Indicators (KPI)

2.48 Since IMT-Advanced will be supporting all packet based services even for voice, QoS models will be vastly different than that of traditional wireless systems.

2.49 Packet based conversational voice services will be more tolerant to packet loss than latency and jitter. The main KPI for packet voice is Mean Opinion Score reflecting perceptual voice quality. Similarly for video, perceptual video quality constitutes KPI. For data traffic, throughput, packet loss, transactions latency, object hits are some of the KPIs

2.50 In IMT-Advanced, significant statistical gains can be realized with mix of data and voice traffic. As a result, Quality of Experience (QoE) which is a measure of overall satisfaction of the customer depends on complex interplay of QoS management and KPIs.

Q16. What regulatory mechanisms are to be provided for delivery of voice services over IMT-A systems?

Q17. Should the interoperability of services to legacy 2G/3G systems be left to market forces?

Q18. What are the QoS measurements that can be reported on IMT-A systems? Suggest the appropriate KPI for data and voice services to guarantee customer satisfaction.

I New Access Models (Relays, Femto Cells and Pico cells)

2.51 In India we need access models for (i) low emission (ii) low energy (iii) high capacity (and speed) wireless communications technology. Since there is trade-off between emission level and coverage radius, we will witness deployment scenarios where the cell radius scalable to much smaller levels using concepts of femto and pico cells of IMT-A. These femto and pico cells will be overlaid over macro cells. Self-organizing networks (SON) in 4G may prove to be a very cost effective way of deploying distributed 4G infrastructure. Since self-organizing networks are self-configuring and self-optimizing, a policy framework that allows this with appropriate checks and balances may have to be formulated.

Q19. In view of the likely deployment of scenarios where the cell radius is scalable to much smaller levels using the concepts of femto and pico cells:

a. What will be the impact of femto cells/SoN architecture on KPI?

- b. What will be the impact of Relays/femto cells on spectrum policy?**
- c. What will be the impact on infrastructure sharing?**
- d. What policy guidelines are required to encourage low emission low energy and high capacity architecture like femto cells overlaid over macro cells?**

Chapter-III

International Practices on IMT-Advanced

U.S.A.¹¹

3.1 The 700 MHz band was previously used for analog television broadcasting, specifically UHF channels 52 through 69 (698 MHz-806 MHz). The FCC was of the view that the switch to digital television has made these frequencies no longer necessary for broadcasters, due to the improved spectral efficiency of digital broadcasts. Thus all broadcasters were moved to channels 2 through 51 (54 MHz-698 MHz) as part of the digital T.V transition. The last transmissions by the incumbent television broadcasters using the channels 52 through 69 ceased on June 12, 2009 except for LPTV (Low Power T.V) stations, which were permitted to stay on the air with an analog signal until the winning bidders start operations.

Spectrum auctioned

- In 698-806 MHz band following bandwidths were auctioned.

Block A: 12 MHz (698-704 / 728-734 MHz)

Block B: 12 MHz (704-710 / 734-740 MHz)

Block E: 6 MHz (722-728 MHz)

Block C: 22 MHz (746-757 / 776-787 MHz)

Block D: 10 MHz (758-763 / 788-793 MH)

Total : 62 MHz.

Auction Features

3.2 The United States 700 MHz FCC Wireless spectrum auction, officially known as Auction 73, was started by the Federal Communications

¹¹ Fact sheet of auction 73, http://wireless.fcc.gov/auctions/default.htm?job=auction_factsheet&id=73

Commission (FCC) on January 24, 2008 for the rights to operate the 700 MHz frequency band in the United States.

The main features were:

- Duration of Auction: 24th January, 2008 to 18th March, 2008
- Rounds: 261, Bidding Days: 38, Qualified Bidders: 214
- Winning Bidders: 101 Bidders won 1090 Licenses
- Net Bids: \$18,957,582,150

Permissible Operations

3.3 As per the FCC guidelines, 700 MHz Band licenses may be used for flexible fixed, mobile, and broadcast uses, including fixed and mobile wireless commercial services (including FDD- and TDD-based services); fixed and mobile wireless uses for private, internal radio needs; and mobile and other digital new broadcast operations. These uses may include two-way interactive, cellular, and mobile television broadcasting services.

License Period and Construction Requirement

3.4 The term of the nationwide D Block license will not exceed 10 years. The nationwide D Block licensee must provide signal coverage and offer service to (1) at least 75 percent of the population of the license area by the end of the fourth year, (2) at least 95 percent of the population by the end of the seventh year, and (3) at least 99.3 percent of the population by the end of the tenth year.

Denmark¹²

3.5 An auction of 190 MHz spectrum in 2500-2690 MHz (2.5 GHz band) and 15 MHz spectrum in 2010 MHz band was completed on May 10,

¹² Auction of frequencies in the frequency bands 2500-2690 MHz and 2010-2025 MHz: Information Memorandum, February 2010, Issued by National IT and Telecom Agency Denmark . www.itst.dk

2010, with spectrum being awarded to Hi3G Denmark ApS, TDC A/S, Telia Nattjanster Norden AB and Telenor A/S.

Spectrum auctioned

3.6 Spectrum was auctioned in the following lots.

- A. 2010 MHz Band: The 15 MHz of spectrum in the 2010 MHz Band auctioned as a single Lot (Lot A1)
- B. 2.5 GHz paired: 2x5 MHz – 14 lots in 2500-2570 MHz and 2620-2690MHz spectrum bands. (Lot B1- B14)
- C. 2.5 GHz unpaired: The sub-band 2570-2620 MHz auctioned as ten Lots, each consisting of one Block of 5 MHz unpaired spectrum (Lot C1-10).

Reserve Price

3.7 The Reserve Price for each Lot was fixed as follows:

- 2010 MHz Band DKK 500000 for the 15MHz
- 2.5 GHz paired DKK 1000000 per 2x5MHz Lot
- 2.5 GHz unpaired DKK 500000 per 5 MHz Lot.

Maximum freq that an operator can bid

3.8 A Bidder may bid for Lots in more than one Category, subject to not breaching an overall cap which has the effect of limiting Bidders to bidding for a maximum of 4 Category B Lots (2x20 MHz). The cap does not preclude a Bidder from bidding for Category B Lots (2x20 MHz) plus the Lot A1 or two Category C lots, nor does it preclude a Bidder from bidding for all available A and C Lots.

Results of the auction:¹³

3.9 The National IT and Telecom Agency ended the final stage of the 2.5 GHz auction at the 10th of May 2010. Details and Prices for the licenses were as below:

Operator	Spectrum	Licence Price
Hi3G	2x10 MHz paired. 25 MHz unpaired	DKK 7,091,000
TDC	2x20 MHz paired.	DKK 333,333,000
Telenor	2x20 MHz paired. 10 MHz unpaired	DKK 333,333,000
Telia Nättjänster Norden AB	2x20 MHz paired. 10 MHz unpaired	DKK 336,331,000

Germany:

Spectrum auctioned

3.10 The spectrum up for bids included 41 frequency blocks split amongst the different bands:

- A. Six blocks of 2 x 5 MHz paired spectrum in the 800 MHz band;
- B. Five blocks of 2 x 5 MHz paired spectrum in the 1.8 GHz band;
- C. Four blocks of 2 x 5 MHz paired spectrum, one block of 1 x 5 megahertz unpaired spectrum and one block of 14.2 megahertz unpaired spectrum in the 2 GHz band;

¹³ <http://en.itst.dk/spectrum-equipment/Auctions-and-calls-for-tenders/2-5-ghz/results-of-the-auction>

- D. 14 blocks of 2 x 5 MHz paired spectrum and 10 blocks of 1 x by unpaired spectrum in the 2.6 GHz band.

Details of auction

3.11 Following are the main features of the auction.

- Bidders were Deutsche Telecom, KPN/E-Plus, Telefonica O2 and Vodafone.
- Auction commenced from April 12, 2010.
- 800 MHz allocations were the most expensive; 6 X 5 MHz paired blocks (791-821 MHz and 832-862 MHz).
- Coverage obligations and restrictions including spectrum caps apply.

Roll out obligations:

3.12 By 2016, 90% of the population of cities and areas selected by regional governments must be either served by high speed wireless or wireline Internet access. Small villages will get precedence over larger towns by grouping them into 4 priorities:

- Priority 1: Areas and villages with a population less than 5.000 inhabitants.
- Priority 2: Towns and areas with a population up to 20.000 inhabitants.
- Priority 3: Cities up to 50.000 inhabitants.
- Priority 4: Beyond that, anything goes.

Priority 2 towns can only be served once at least 90% of the priority 1 areas are covered, and so on.

Auction result:

3.13 The winning bids were:

- Vodafone D2 : €1,422,503,000 (\$1,758,907,135), for 12 blocks in total.
- Telefónica O2 Germany GmbH & Co. OHG : €1,378,605,000 (\$1,703,564,840), 11 blocks
- Telekom Deutschland GmbH : €1,299,893,000 (\$1,605,122,503), 10 blocks
- E-Plus Service GmbH & Co. KG : €283,645,000 (\$350,113,159), 8 blocks

T-Mobile, Vodafone and Telefonica paid around €1.2bn each for a couple of paired 5MHz channels (totalling 20MHz per operator).

FINLAND¹⁴

Spectrum auctioned

3.14 In the spectrum auction held by the Finnish Communications Regulatory Authority (FICORA), the spectrum blocks to be auctioned were divided into blocks.

- A. 2.5GHz paired: 2x5 MHz – 14 lots in 2500-2570MHz and 2620-2690MHz spectrum bands. (blocks FDD1 to FDD14)
- B. 2.5GHz unpaired: Spectrum block 2570-2620 MHz. (called TDD-block.)

¹⁴ FICORA

<http://www.ficora.fi/en/index/palvelut/palvelutaiheittain/radiotajuuudet/huutokauppa.htm>

1

Reserve Price

3.15 Reserve price was 15,000 euros per megahertz for all the blocks including TDD block.

Maximum freq that an operator can bid

3.16 A bidder may bid for either TDD block or at the most for five separate FDD blocks.

3.17 The spectrum auction was concluded on Monday 23 November 2009. The auction ran for 5 days and it had 27 bidding rounds. The winning parties regarding the spectrum for FDD were Elisa Oyj (50MHz), TeliaSonera Finland Oyj (50MHz) and DNA Oy (40MHz). The winner of the 50MHz spectrum for TDD was Pirkanmaan Verkko Oy. Total revenue collected in the auction was 3,797,800 euros.

Spectrum blocks	Winner	Price
2500-2520 MHz and 2620-2640	DNA Oy	675,700 euros
2520-2545 MHz and 2640-2665 MHz	TeliaSonera Finland Oyj	819,200 euros
2545-2570 MHz and 2665-2690 MHz	Elisa Oyj	834,700 euros
2570-2620 MHz	Pirkanmaan Verkko Oy	1,468,200 euros

Table 3.1 : Winning bids in Finland's 2.6GHz spectrum auction

AUSTRIA¹⁵

Spectrum auctioned

3.18 Austrian regulator Telekom Control Commission (TKK) divided the frequency range 2500 - 2690 MHz, which was to be auctioned, as given below :

¹⁵ TKK : http://www.rtr.at/en/tk/FRQ_2600MHz_2010_FS

- A. 2.5GHz paired: 2x5 MHz – 14 blocks in 2500-2570MHz and 2620-2690MHz spectrum bands. (Blocks A1 to A14).
- B. 2.5GHz unpaired: The sub-band 2570-2620 MHz auctioned as ten blocks, each consisting of one Block of 5MHz unpaired spectrum (Blocks B1-B10).

3.19 The frequencies were for assignment for use throughout the entire territory of Austria. It was decided that the frequencies would be assigned in such a way that bidders can only acquire contiguous frequency blocks in whole multiples of 2x5 MHz in the paired range and in whole multiples of 5 MHz in the unpaired range.

Roll Out Obligations:

3.20 Each frequency assignment holder will be required to ensure a coverage level of at least 25% for the spectrum allocated in this procedure by December 31, 2013. The "level of coverage" (or "coverage level") is defined as the percentage of the resident population covered in relation to the total resident population. In the areas covered, a bearer service must be offered with a data transmission rate of at least 1 Mbit/s on the downlink and at least 256 Kbit/s on the uplink. In case of non-fulfilment of coverage requirements

3.21 Frequency assignment holders who fail to roll out their networks will be charged a penalty in the amount of EUR 25 million. This amount is based on a coverage level of 0%. Should an operator fall short of the required coverage level, the penalty will be reduced in proportion to the coverage level actually attained. Example: If the operator falls short of the required coverage level by 10% as of the deadline, the penalty will be 10% of EUR 25 million (EUR 2.5 million). This penalty will be due annually from December 31, 2013 onward until the frequency assignment holder has reached the required coverage level. The penalty

will also be charged in cases where a frequency assignment holder falls below a previously attained coverage level.

Reserve Price

3.22 The minimum bid (starting price) for each frequency block for A (paired frequencies) and B (unpaired frequencies) was 400,000 EUR and 200,000 EUR respectively.

Spectrum limitations:

3.23 In order to ensure a competitive market structure and to prevent monopolization of the spectrum, the following spectrum limitations were applied:

Bidders who already hold frequency assignments in the

- 880 – 915 MHz
- 925 – 960 MHz
- 1710 – 1785 MHz
- 1805 – 1880 MHz

may acquire a maximum of six frequency blocks in Category A (paired frequency blocks).

3.24 All other bidders may acquire a maximum of eight frequency blocks in Category A (paired frequency blocks). For frequency blocks in Category B, there are no spectrum limitations; in this category, package bids for less than three frequency blocks are not permitted. No such lower limit is defined for Category A.

Successful Bidders	Paired Frequency blocks allotted	Un-paired Frequency blocks allotted	Price
A1 Telekom Austria AG	4 (A1-A4, 2x20MHz)	5 (B6-B10, 25MHz)	13.248.223
T-Mobile Austria GmbH	4 (A5-A8, 2x20MHz)	-	11.247.323
Orange Austria Telecommunication GmbH	2 (A9-A10, 2x10MHz)	-	4.001.003
Hutchison 3G Austria GmbH	4 (A11-A14, 2x20MHz)	5 (B1-B5, 25MHz)	11.030.560
Total:	14 (2x70MHz)	10 (50MHz)	39.527.109

Table 3.2

FRANCE

3.25 ARCEP will conduct sealed bid auctions to allocate 2.5 GHz frequencies in autumn 2011 and 800 MHz spectrum at the beginning of 2012.¹⁶ France set a €50 million standard reserve price for each duplex 5 MHz block in the 2.6 GHz frequencies, with varying reserves in the 800 MHz band in the following amounts:

- €400 million for the 791 - 801 MHz and 832 - 842 MHz block (2 x 10 MHz)
- €300 million for the 806 - 811 MHz and 847 - 852 MHz block (2 x 5 MHz)
- €800 million for the 811 - 821 MHz and 852 - 862 MHz block (2 x 10 MHz)

Spectrum limitations

3.26 Spectrum caps apply in both bands in order to ensure competition. The cap in the 2.6 GHz band is 2 x 30 MHz. Operators can be awarded no more than 2 x 15 MHz in the 800 MHz band, and any licensee awarded more than 2 x 5 MHz in that band must satisfy reasonable requests for roaming in rural areas from 2.6 GHz operators that were qualified but

¹⁶ Hogan Lovells: Telecommunication & Radio Spectrum News & Trends
<http://www.hlspectrumreview.com/2011/06/articles/auctions/french-4g-auctions-are-officially-launched/>

unsuccessful candidates in the 800 MHz award process. In order to be able to benefit from this 800 MHz roaming provision, the operator's 2.6 GHz network must first cover at least 25% of the metropolitan French population. No time limitation is provided for this roaming obligation.

Roll Out Obligations

3.27 Each operator awarded spectrum in the 800MHz band will have to cover 99.6 percent of the population of mainland France in 15 years, according to Arcep.¹⁷ The spectrum is neutral, meaning that operators can use any technology they want, as long as they follow the rules set by the regulator.

Norway

3.28 In Norway, the Norwegian Post and Telecommunications Authority, auctioned the 2010 MHz and 2.6 GHz bands in November 2007. The 2010 MHz band was acquired by Inquam Broadband for 1m kroner (£89,807 at prevailing exchange rates, £0.001 per MHz per head of population). The licence permits use of the band for terrestrial radio services, is tradable and is valid until 31 December 2022.

Slovenia

3.29 In 2001, the Slovenian government had announced that it will grant 3 UMTS licenses by tender valid for 15 years. The license was to include the right to use the radio frequency of 1900-1980 MHz, 2010-2025 MHz and 2110-2170 MHz across the whole of Slovenia. The reserve price was kept at EUR 126million (Rs. 863 crores approx.) each (and the price/MHz/population comes out to be 1.51 USD¹⁸). In the case of Israel for 2G/3G mobile license auction in 2001/2002, the reserve price

¹⁷ http://www.computerworld.com.au/article/390272/france_invites_mobile_operators_4g_spectrum_auction/

¹⁸ Licenses, auctioned in 2001, included the right to use the radio frequency of 1900-1980 MHz, 2010-2025 MHz and 2110-2170 MHz. It is assumed that each licensee was allocated 2X20 MHz of FDD and 10 MHz of TDD spectrum. Population is taken as on July08.

for 45 MHz spectrum was kept at US \$ 100M. In all 4 licenses were auctioned, allowing usage of the following frequency packages:

- 2G FDD: 2x10 MHz
- 3G FDD: 2x10 MHz
- 3G TDD: 5 MHz (for 3 packages only).

The price/MHz/population comes out to be 0.312 US\$¹⁹.

Switzerland

3.30 In Switzerland, the Swiss federal communications commission “ComCom” has launched the public tender for mobile frequencies in the 800 MHz, 900 MHz, 1.8 GHz, 2.1 GHz and 2.6 GHz ranges. The auction will take place during the first half of 2011. Along with other frequency blocks, one block of 2010-2025 MHz (1x15MHz) will also be auctioned. The license for this block will be valid until 31 December 2028 with a minimal price of CHF 12.45 million.

3.31 Some countries have auctioned 2010-2025 MHz band along with 2GHz band (1920-1980 paired with 2110-2170 MHz band) and the reserve price was set for the entire package which generally, included both FDD and TDD spectrum.

¹⁹ Taking population as on July08.

Chapter-IV

Summary of the Issues

Issues for consultation:-

- Q1. Whether there is a need to define a particular user equipment or architecture to be used by the vendors or this may be left to the market forces?
- Q2. Whether there is a minimal set of performance characteristics the UE has to meet before it is permitted to enter a network? These characteristics are over and above the inter-operability, protocol conformance and emission tests which presumably the UE has already passed.
- Q3. In addition to what has been described above, what can be the other security issues in IMT-Advanced services? How these security issues can be addressed?
- Q4. What basic security frameworks should be mandated in all networks to protect customer?
- Q5. Which spectrum bands should be identified for the IMT-Services in India?
- Q6. What should be the block size of spectrum to be put on auction? How many blocks of spectrum should be allocated/ auctioned per service area?
- Q7. What is the minimum spectrum block size for effective use of 4G technologies?
- Q8. What should be the maximum amount of spectrum which a service provider can be allocated through auction?
- Q9. Whether there is a need to specify the use of particular duplexing scheme based on the band in which spectrum allocation is done? If yes, in the case of TDD, is it required to specify further the frame

duration, mandate frame synchronization using one of a specified set of timing sources and a permissible set of Uplink/Downlink sub-frame schemes compatible with the IMT-A standards?

- Q10. What should be the reserve price per MHz in different spectrum bands?
- Q11. What should be the eligibility conditions for bidding for spectrum?
- Q12. Should there be any roll out obligations for spectrum given through auction? Should it be different in different bands?
- Q13. Whether there should be any specific rollout obligations in respect of rural areas?
- Q14. What should be the spectrum usages charges? Should it be based on revenue share or be a fixed charge?
- Q15. Using MIMO technology what can be the possible infrastructure sharing issues and what can be the probable solutions.
- Q16. What regulatory mechanisms are to be provided for delivery of voice services over IMT-A systems?
- Q17. Should the interoperability of services to legacy 2G/3G systems be left to market forces?
- Q18. What are the QoS measurements that can be reported on IMT-A systems? Suggest the appropriate KPI for data and voice services to guarantee customer satisfaction.
- Q19. In view of the likely deployment of scenarios where the cell radius is scalable to much smaller levels using the concepts of femto and pico cells:
- a. What will be the impact of femto cells/SoN architecture on KPI?
 - b. What will be the impact of Relays/femto cells on spectrum policy?

- c. What will be the impact on infrastructure sharing?
- d. What policy guidelines are required to encourage low emission low energy and high capacity architecture like femto cells overlaid over macro cells?