Modelling and Analysis of Regulatory Interventions for Sustainable Public Wi-Fi Programs

The Case of India

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Abstract: Public Wi-Fi is a suitable technology alternative to mobile broadband for affordable Internet access. With a 2.6 billion population globally yet to be connected, many countries are formulating policies around public Wi-Fi to bridge the digital divide. India lags considerably, where only 44% of rural residents have broadband Internet access. Public Wi-Fi penetration in India is meagre compared to global deployments. The Indian Government launched the Wi-Fi Access Network Interface (WANI) as an approved public Wi-Fi infrastructure project in December 2020, with the dual objectives of encouraging local entrepreneurs to become Public Data Offices (PDOs) and offering citizens affordable high-speed Wi-Fi Internet service. However, the scheme has so far met with limited success due to factors such as high backhaul charges and price-based competition from existing service providers. The sustainability of these PDOs is critical for the success of the program. We developed an agent-based model of the WANI ecosystem by incorporating the Bass diffusion model for users' adoption of Internet data service offered by PDOs. Our simulations indicate that offering a one-time subsidy, capping the market share of individual PDOs, and mandating a lower Internet backhaul tariff for this project will lead to more sustainable and competitive Wi-Fi markets.

Keywords: public Wi-Fi, digital divide, Internet broadband, agent-based model, Internet backhaul

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Introduction

Wi-Fi networks complement cellular mobile broadband services offered by licensed telecommunications and Internet service providers (TISPs) through providing superior indoor coverage. The TISPs also benefit by offloading part of the traffic from the cellular network, thereby potentially reducing network congestion. The Wi-Fi hotspots are made available primarily by the Internet service providers (ISPs) in public places such as hotels, shopping areas, airports and railway stations, using subscription or advertisement-based business models. The total number of public Wi-Fi hotspots worldwide has increased from 100 million in 2016 to more than 550 million (Statista, 2024). For example, in India, RailTel a subsidiary of Indian Railways, provides Wi-Fi broadband access in over 6,000 railway stations across the country.

The WiFi4EU initiative promoted by the European Union (EU) has the goal of providing free access to Wi-Fi connectivity for citizens in public spaces, including parks, public buildings, libraries, health centres and museums in municipalities throughout Europe (Navío-Marco *et al.*, 2019; Van den Velden & Sadowski, 2023). Countries like the Philippines have initiatives such as 'Free Wi-Fi for All' with similar policy objectives of bridging the digital divide (Serafica *et al.*, 2023). The development of public Wi-Fi networks in the various states of the United States was primarily envisioned as a low-cost alternative to commercial offerings but rarely fulfilled social inclusion and development objectives (Fraser, 2009). These programs did not succeed due to regulatory complications of market distortion and the discouragement of private investment, especially in about 200 municipalities including Philadelphia, San Francisco and Chicago where the public Wi-Fi movement initially started (Chesley, 2009; Wilson, 2021).

The acute need for public Wi-Fi became apparent during COVID-19. Some school districts in the United States provided temporary Wi-Fi hotspots to students within 150 to 200 feet of buses to support distance learning (Lai & Widmar, 2021). Sieck *et al.* (2021) highlight the importance of public Wi-Fi hot spots for accessing health information in rural and remote areas. Pahlavan & Krishnamurthy (2021) document a detailed holistic overview of the evolution of Wi-Fi technology and its applications in our daily lives.

However, public Wi-Fi coverage in India is inferior. Public Wi-Fi hotspots per million people in the United Kingdom, the United States and China are respectively 175, 50 and 75 times that of India (Parbat, 2023). Noting the lack of public Wi-Fi infrastructure in India, the Telecom Regulatory Authority of India (TRAI) initiated discussions on an open Wi-Fi access protocol in 2016–17 and conducted many stakeholder meetings. The TRAI recommended an open standard specification referred to as Wi-Fi Access Network Interface (WANI) in 2017 (TRAI,

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2017). Subsequently, the government of India launched the Prime Minister WANI (PM-WANI) scheme, as approved by the Cabinet in December 2020, to improve affordable Wi-Fi access for the netizens of India (GoI, 2020).

By way of example, under the WiFi4EU initiative, municipalities received funding of up to approximately EUR 15,000 during 2018 to 2020 from the European Commission to defer the cost of Internet connectivity and equipment maintenance (European Commission, 2024). The WANI scheme, however, was designed to foster an entrepreneurial ecosystem to provide sustainable Internet access without any state subsidy, but the scheme was not successful. To date, there have been few successful business models for public Wi-Fi, and most remain experimental (Potts, 2014).

In this context, we analyse various factors that affect the deployment of such large-scale public Wi-Fi projects and characterise them using agent-based modelling (ABM). We simulate various scenarios and prescribe regulatory interventions for a sustainable public Wi-Fi initiative.

In the next section, we discuss the WANI project's specific technical architecture and economic characteristics. In Section 3, we develop an ABM and explain the model parameters. In Section 4, we present simulations of various scenarios and discuss findings. In the last section, we propose regulatory interventions based on our findings and indicate our research's limitations.

The Existing Framework of Public Wi-Fi Schemes

WANI is a technical and regulatory innovation that unbundles the Wi-Fi ecosystem to provide affordable and ubiquitous high-speed Internet access. Most Wi-Fi deployments, either enterprise or public, are provided by a single entity. In most cases, the ISP or TISP provides these functions. This may be due to existing telecommunications regulations where only licensed entities, such as ISPs and/or TISPs, can offer Wi-Fi services. Besides regulatory limitations, it is also driven by business cases where a single entity controls all network components, including backhaul and access. Such a controller is justified in cases where deployment is confined to an enterprise or small-scale deployment. However, large-scale deployments can only be achieved if the ecosystem is unbundled, where separate/independent functions are offered by different entities and integration/interoperability is taken care of by well-defined interface, application program interface (API), message flow and standards (Tatsumoto, 2021).

The WANI architecture is designed to be highly scalable and distributed across different telecommunications layers. It is interoperable at each layer and provides end users with a seamless and secure Wi-Fi experience. Another objective of WANI is to create an abundance of last-mile Wi-Fi access providers in the form of micro-entrepreneurs so that the proliferation of the Wi-Fi network is fast and easy (GoI, 2020). The WANI architecture, by design, enables the layered approach where a separate player supports each function of the Wi-Fi ecosystem. This renders the architecture scalable from a technical point of view and low cost from an economic point of view. The model envisioned setting up public Wi-Fi hotspots in Public Data Offices (PDOs) by local entrepreneurs with methods for monetising Internet services, at the same time providing affordable Internet access to users. The ISPs and TISPs viewed this as a threat to their existing broadband businesses and resorted to strategies such as fixing high backhaul charges to make this initiative unsustainable for the local entrepreneurs. The WANI ecosystem consists of the following:

1. **PDO**, which is established across the country by local entrepreneurs to maintain and operate WANI-compliant Wi-Fi access points (APs) and deliver broadband services to subscribers.
2. **Public Data Office aggregator** (PDOA), who with local knowledge, acts as an aggregator of PDOs and performs the functions relating to authorisation, accounting and security as built in the WANI architecture.
3. **App providers**, who develop applications to register users and discover WANI-compliant Wi-Fi hotspots in the nearby area and display the same within the app for accessing the Internet service.
4. **Central Registry**, that maintains, by the WANI architecture and specifications, the details of app providers, PDOAs and PDOs and enables interoperability among these independent entities of an ecosystem based on open WANI standard.

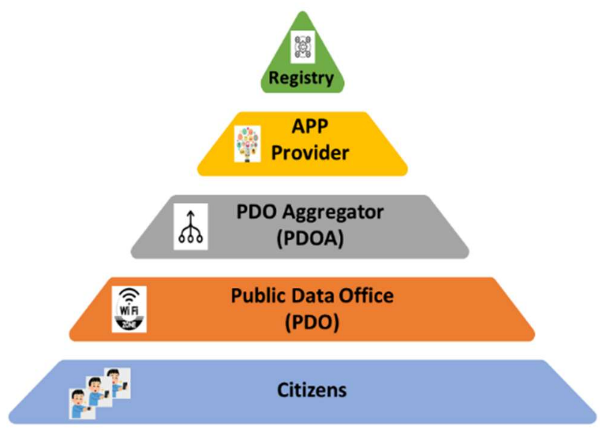

Figure 1. The schematics of the WANI ecosystem. (Source: authors' own)

Figure 1 schematically illustrates how the players listed above stack up in the WANI ecosystem. The WANI network consists of a Wi-Fi access point maintained by the PDO that is connected to the Internet backhaul provided by an ISP. A user sees the service set identifier (SSID) on the WANI application installed on the user's device, which is broadcast by the access point, clicks it and gets connected to access the Internet.

The total number of WANI hotspots in India is around 250,000 and increasing (Figure 2). However, this falls very much short of the envisioned target of 10 million hotspots in the Indian National Digital Communications Policy 2018 (GoI, 2018). As of October 2024, the number of PDOAs is around 201, out of which the state-owned TISP (namely, Bharath Sanchar Nigam Limited) accounts for about 20% of the commissioned WANI hotspots. Close to 50% of the PDOs are with a single private firm, indicating PDO market concentration.

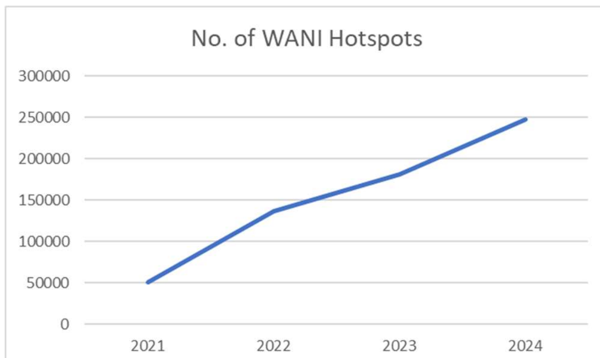

Figure 2. Growth of WANI hotspots over the years. (Source: authors' own)

Reasons for market failure

The PDOs, usually owned and operated by local entrepreneurs, install the Wi-Fi network using Wi-Fi APs to provide Wi-Fi connectivity within their premises (indoor) or limited outdoor surrounding areas. They procure Internet backhaul from the ISPs. There are two types of Internet backhaul services available from the ISPs: (a) Fibre to the home (FTTH) and (b) Internet leased line (ILL). The FTTH provides a shared connection to the ISP's Internet point of presence (PoP), while the ILL provides a direct logical/physical link to the PoP. Hence, ILL typically provides reliable downlink and uplink speeds compared to FTTH. The link speeds of FTTH and ILL in India typically range from 100 to 500 Mbps, respectively. The FTTH is designated as a retail service; hence, there are regulatory restrictions on the resale of bandwidth, whereas the ILL is a wholesale service. The TISPs provide affordable retail Wi-Fi access through FTTH, which competes with the WANI service.

The Internet broadband market in India is dominated by licensed TISPs, who also control the resale of backhaul bandwidth required by the PDOs for their WANI networks. The significant costs of setting up the WANI are due to the Internet backhaul charges. The WANI policy mandates that the PDOs enter into a commercial agreement with the TISPs regarding backhaul (GoI, 2020). The TISPs offer the ILL services at a commercial tariff, 30 to 40 times

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more than their retail FTTH tariff, as shown in Table 2. Hence, the PDOs are forced to pay very high charges for their ILL backhaul connections on the supply side while at the same time facing the competitive home broadband service offered by the same TISPs on the demand side.

Further, India is a 'mobile first' market, with more than one billion users accessing mobile broadband services (Venkatesh & Sridhar, 2014). In addition, TISPs have been aggressively pricing their data plans, with India ranked seventh worldwide in terms of the lowest tariff for mobile broadband at an average of USD 0.16 per gigabyte (GB) (Cable.co.uk, 2025). This poses substantial demand uncertainty for public Wi-Fi operators, especially in urban areas.

Therefore, it has become difficult for PDOs to scale up due to high fixed and recurring costs and competition from the TISPs. The moot question is whether a scheme like WANI requires regulatory interventions such as state subsidies, tariff capping, capping on market share etc. to provide momentum for the growth of public Wi-Fi schemes across the country. Fraser (2009) well documents the failure of public Wi-Fi in US cities, mainly due to the high set-up costs of Wi-Fi networks by the municipalities and the availability of economical home broadband and mobile broadband from the TISPs. In the case of WANI, regulatory interventions shall enable not only economical broadband Internet to a price-sensitive population, but also the promotion of local entrepreneurship in the form of PDOs.

Regulatory Options for the Sustainable Public Wi-Fi Scheme

Although the public Wi-Fi scheme's intention is to nurture local entrepreneurship in setting up PDOs to provide sustainable low-price service as an effective alternative to a mobile broadband service, opposing forces such as restricted competition and high costs have hindered its penetration. The next section reviews three regulatory interventions that can alter the scenario.

Price cap regulation

Since price cap regulation (PCR) was introduced in the United Kingdom in 1984, price caps that set the ceiling price for retail services have been used by telecommunications regulators around the world to check price increases. It has been observed that PCR has been effective in containing prices in non-competitive markets (Xavier, 1995). However, some studies indicate that PCR has an adverse effect on quality of services (Façanha & Resende, 2004). Although PCR in the wholesale telecommunications market is scarce, recent studies in wholesale electricity markets indicate that temporary price caps tend to prevent higher price mark-ups by firms and improve market outcomes (Sirin & Erten, 2022). A recent study highlights the effect of PCR for wholesale roaming arrangements in the EU and the effect of lobbying by various stakeholders on the level of price caps (Alves *et al.*, 2021).

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With regards to the WANI model, since the backhaul is provided by the incumbent TISPs to the PDOs, and there is limited competition in the wholesale backhaul market, there is a case of PCR to be applicable to the wholesale backhaul tariff. As indicated in the aforementioned literature, it might have the effect of reducing prices and orderly market outcome, at least in the short run. The cost-based regulation, under which the regulator defines the access price equal to the marginal cost of providing access plus a fraction of the cost of the investment undertaken by the incumbent firm as the basis for fixing tariff cap, though widely used has some limitations (Sarmento & Brandao, 2007). In this model, unless there is verifiable cost information, the tariff cap fixed by the regulator may be arbitrary and in some cases may be more than the cost structure of the service providers, thereby defeating the very purpose of such cost-based regulatory intervention. Hence, it is very important to estimate the tariff cap based on reliable audited cost estimates.

Subsidy models

When the market fails, especially when the private entities incur higher cost of services, state subsidy is typically considered to support a program (Kalish & Lilien, 1983). These subsidies become necessary to correct market failures such as demand uncertainty, high initial investment costs and information asymmetry (Potts, 2014). In most countries, including India, the licensed telecommunications operators pay a universal service levy (USL) as a percentage of revenue towards a Universal Service Obligation fund (USOF). The state compensates the operators through this fund for their high-cost rural and remote area connectivity (details of USOFs in India are provided in Sridhar (2012)). The USL reflects the belief that telecommunications licensees needed to give back to society for the privilege of being chosen to provide telecommunications services without being burdened with a universal service obligation in unviable areas. Based on the historical data of 223 high-tech enterprises in Japan, Koga (2005) proved that subsidies favourably impact enterprises' development.

However, there are several regulatory decisions to be made with subsidies: (i) how much to subsidise, (ii) how long to subsidise, and (iii) who to subsidise – consumers or service providers. Grants and subsidies lower the effective price for consumers, thereby stimulating demand. The economies of scale achieved reduce the average cost of the service, thereby making it sustainable. It also reduces the capital burden on suppliers and helps them to sustain their businesses due to demand uncertainty (Kalish & Lilien, 1983; Potts, 2014). Hence, the objective is to determine the optimal subsidy policy to attain the stated objective in an efficient manner.

The demand side of direct subsidy for broadband service enabled by the Affordable Connectivity Program (ACP) in the United States has been extensively studied by Horrigan *et* *al.* (2024). They point out that households' social and economic connectedness plays an important role in beneficiary enrolment. The effects of both supply-side and demand-side subsidies in the context of digital terrestrial television (DTT) in Indonesia are provided by Ariansyah (2022). They studied how subsidising the DTT decoders to households while increasing competition amongst the DTT device manufacturers has positively impacted this adoption. There have been many studies on demand-side subsidies of handset bundling. A detailed analysis of handset bundling with mobile telecommunications services and their effect on social welfare in the Korean market is illustrated in Lee & Park (2016). The effect of government subsidies on the telecommunications industry, modelled using a three-player oligarch game, in the Chinese market is studied by Ma *et al.* (2022).

In general, users expect Wi-Fi offerings in public places to be charged at lower prices, and more often for free, as it complements mobile broadband. However, as indicated earlier, the wholesale backhaul bandwidth prices, as fixed by the TISPs, are high enough for public Wi-Fi operators to provide their services at affordable, lower prices. Studies were conducted on the regulator's trade-off of reducing the wholesale price for third-party providers (TPP). While this decreases retail price, promotes the entry of more TPPs and increases consumer welfare, it is likely to decrease the revenue of the incumbent TISPs and hence the incentive for TISPs to invest in networks (Ross, 2024). Further, a counterargument states that any investment in networks is considered as a sunk cost and therefore does not depend on the revenue earned by the TISPs (Alleman & Rappoport, 2006).

In reality, the Internet data market is highly competitive due to existing ISPs and TISPs and follow competition-based pricing rather than cost-based pricing, which is derived by taking into consideration the price levels defined by existing competition in the market (Mikail, 2019). Hence, PDOs are forced to charge a competitive price to the user for data volumes while incurring heavy costs to build and run the PDO business. This has been cited as one of the reasons for the failure of WANI. Per GB data pricing per day in the range of INR 1–3 is derived by comparing prevalent pricing of 4G cellular data (~INR 10 per GB) as per latest TRAI performance data (TRAI, 2024a), and FTTH home broadband and discounting to get competitive advantage.

Outlined below are selected subsidy models and the associated challenges:

1) Subsidy to cover the loss of PDOs: Since the program's objective is to create a financially sustainable business model for local entrepreneurs, a subsidy to offset the losses incurred during the initial stages of operations may be an option. However, the subsidy may deter the PDOs, either by growing subscriber revenue or reducing the

costs of their services. Estimating the expected losses and encouraging the PDOs to become profitable in the future are this model's challenges.

2) Subsidy as a percentage of revenue earned: The subsidy is provided as a percentage of earned revenue and given to all PDOs, as there is no exclusion criterion. However, in this case, the efficient and profitable PDOs can scale up quickly with the given subsidy, resulting in possible monopolisation of the market.

3) One-time subsidy to cover the fixed cost: In this method, a portion of the fixed cost of deploying the access points, cabling, antenna, enclosure and fixtures is provided to all PDOs to reduce the average cost of operation. This method gives the PDOs almost the same subsidy amount. The efficient PDOs will be able to sustain themselves during the initial stages. Leveraging on the network effect, the few PDOs who sustain themselves during the initial period will be able to subsequently gain market share. The market is expected to be an oligopoly, with a few PDOs dominating the market.

Researchers have analysed the above models in the context of telecommunications and technology industries. In their recent paper, Ma *et al.* (2022) indicate that a one-time lump sum subsidy has the needed effect on regulatory impact. Hence, in this paper, we analyse the effect of a one-time lump sum subsidy as it is administratively easier and promotes a relatively more efficient PDO market.

Capping the number of users

In the WANI scheme, the objective is to introduce as many PDOs as possible to encourage local entrepreneurship while providing Internet access to a large user base. At the same time, price capping as a regulatory intervention has been studied in detail (Rey & Tirole, 2019). There have been many studies on data capping for broadband use and its effect on competition and consumer welfare (Dai *et al.*, 2014). It must be noted that capping on broadband data or speed by the service providers is to enable better management of traffic prioritisation and congestion. Although uncommon, any cap on the number of users is likely to promote competition in service provisioning.

The mapping of users to each service provider enables equitable distribution of the users to available PDOs, thereby improving competition in the market. However, a lower cap may reduce the number of users of each PDO to a level at which the PDO will not be able to recover costs and make a profit. At the same time, a higher cap may result in non-optimal use of PDO resources, such as Wi-Fi hotspots and the leased backhaul capacity. Hence, it is important to design an optimal capping so that the stated objectives can be realised and the market is stable with sufficient competition.

For example, one Wi-Fi Access point connected to an Internet backhaul with 100 Mbps speed and 3,000 GB of data volume in a month can serve up to 50 users with up to 2 GB of data per day to utilise its network capacity to the maximum. If the PDO serves a smaller number of users than its maximum utilisation, the revenue earned will not be sufficient to recover the fixed cost. Further, the fixed cost is a step function of the number of users. For example, in the case mentioned, if the number of users is more than 50 then the capacity upgrade is available only in discrete quantities, requiring additional fixed cost.

Agent-Based Modelling of the WANI Scheme

We use ABM to understand the impact of the regulatory interventions on the financial sustainability of the WANI scheme. ABM enables the simulation of heterogeneous agents such as PDOs and Wi-Fi users. The interaction between the agents and the system's resultant behaviour form the patterns operating in the real world (Hamill & Gilbert, 2015). As a deductive approach, ABM enables modellers to define rational agents' behaviour using well-defined mathematical equations. On the other hand, the abductive approach in ABM enables the emergent behaviour of systems with multiple agents and their interactions over many iterations (Schinckus, 2019).

Modelling such an extensive socio-technical system with many stakeholders ought to provide insights into how micro-level changes impact emerging system behaviour (Vila *et al.*, 2004). Drawing on the extant literature on using ABM to derive macro policy decisions from micro behavioural characteristics, we build a model to simulate the working of the WANI scheme. Although the non-linearity of complex systems can be modelled using conventional analytical methods, it can be insufficient as interactions between variables are not captured in full (Schneider & Somers, 2006; Sterman, 2000). The simulation results from ABM can provide guidelines to regulators and policymakers for effective intervention.

The WANI ecosystem consists mainly of two agents/actors in the system: (i) users who consume the service and (ii) PDOs which provides the last mile of Wi-Fi connectivity and associated services to users. In the following subsections, the calibration and parameterisation of the ABM are provided.

Diffusion of innovation model

We use a diffusion of innovation theory pioneered by Rogers (2003) to model the growth of Wi-Fi users. The Bass diffusion model is a widely used mathematical model for technology diffusion and has been widely used by research to model Internet adoption and mobile services adoption (Bass, 1969; Jha & Saha, 2025) and is given by:

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$$n(t) = \frac{dN(t))}{dt} = \left(p + q\,\frac{N(t)}{M}\right)(M - N(t)) \quad (1)$$

The various parameters of the model in Equation 1 are provided in Table 1.

Table 1. Parameters of the Bass diffusion model

$N(t)$	Cumulative number of adopters at time t
$n(t)$	The number of adopters at the time t
M	Maximum number of potential adopters
$p \in \{0.1\}$	Innovation co-efficient
$q \in \{0.1\}$	Imitation co-efficient

(Source: authors' own)

The growth of the Wi-Fi user base depends on innovation and imitation factors. Innovators adopt an innovation independently without any other external influence, while imitators adopt an innovation based on others' feedback and experiences (Rogers, 2003). In our model, the values of p and q are set at two different levels to simulate a faster or slower diffusion process. Some researchers have empirically derived p and q from time series data (Jha & Saha, 2025). However, due to the unavailability of data on Wi-Fi users in India, we normalise the values of p and q with higher and lower p and q values, resulting in faster or slower adoption, respectively.

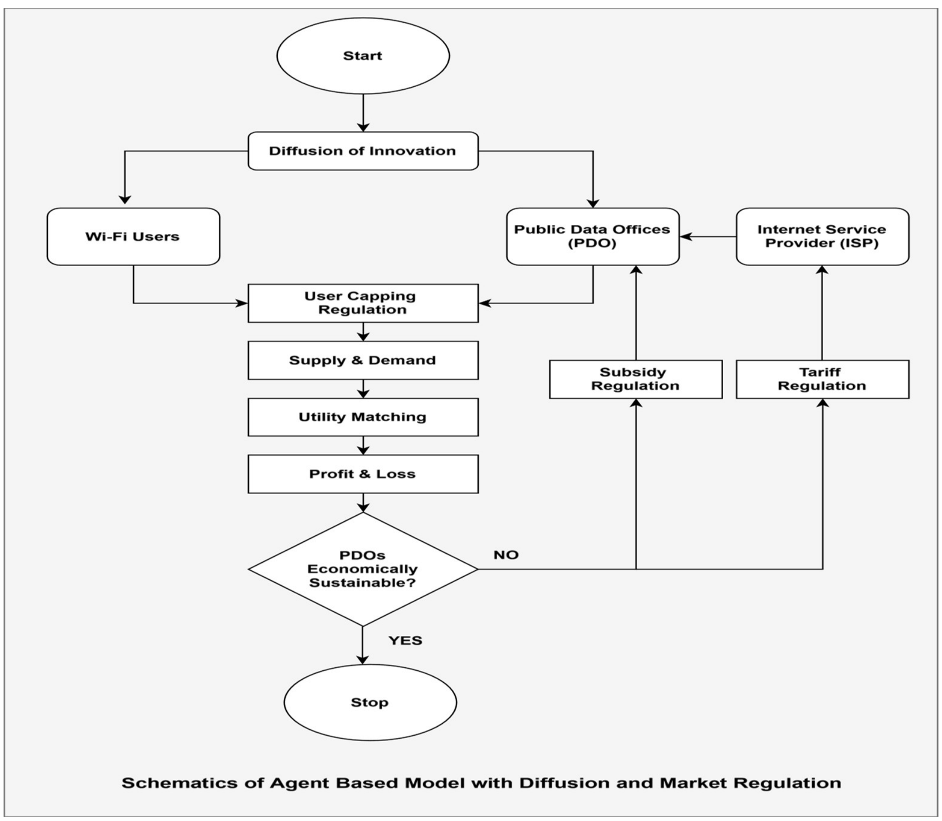


Figure 3. Schematics of the agent-based model simulations. (Source: authors' own)

We simulate high and low rates of diffusion of user base to understand the market equilibria in two extreme cases and derive the bounds. Figure 3 provides the schematics of our model.

Calibration of Internet backhaul models

The PDOS can provide the WANI services indoors within the premises (that is, Internet centre/cybercafé) or both indoors and outdoors with extended coverage. While one to two APs are required for indoor connectivity, more will be required to provide outdoor connectivity. However, outdoor connectivity is expected to draw more demand as users can be nearby and still access the Internet. Since the number of users and devices is expected to be more than indoor, the bandwidth required for Internet backhaul is also higher. We model various types of WANI deployment, and the corresponding cost estimates based on the price of APs and backhaul tariffs charged by the various ISPs are provided in Table 2.

Table 2. Wi-Fi access network cost structure

PDO configuration	Access network cost in INR	Backhaul cost in INR (yearly)	Total fixed cost (for one year) in INR
Indoor FTTH	5,000	20,000	25,000
Outdoor FTTH	10,000	40,000	50,000
Indoor ILL	5,000	4,00,000	405,000
Outdoor ILL	10,000	1,100,000	1,110,000

Note: These costs are derived by comparing data plans from leading ISPs in India. (Source: authors' own)

Supply demand matching process

The model's parameters are provided in Table 3. The users are generated using the diffusion model in Equation 1. Each user has a utility function, U_i, which is a function of price and quality. Since the PDOs are local entrepreneurs, the users are also aware of a PDO's reputation, which also affects their utility. The users select to attach themselves with the PDO, which provides maximum utility. Under the capping model, as the user base for a PDO reaches the ceiling N set by the regulator, then users are forced to shift to the next preferred PDO and so on. Under the subsidy model, each PDO receives a fixed subsidy S for a defined period to defray the cost of APs and backhaul connectivity. At the end of each planning period, the PDOs calculate their profit/loss. The profit-making PDOs remain in the market while the loss makers exit. The PDO who remains in the market, improves its network quality and reputation. It also reduces the price to attract more users, as long as profit threshold is met.

As indicated in Table 3, we assume a uniform distribution for users' affinity towards price, quality and reputation (Valera & Gomez-Rodrigue, 2015). The primary reason for choosing one uniform distribution over the others is that the set of users in a locality served by the PDOs is relatively homogenous. In order to simulate the heterogeneity of PDOs, the price, quality and reputation of services offered by the PDOs are drawn from a normal distribution. This provides a marketplace wherein each PDO offers differing {price, quality, reputation} to distinguish itself. The flow diagram of the simulation process is provided in Appendix 1.

Table 3. Simulation parameters of the model

I	Set of all users; |I| = M = 500
J	Set of all PDOs; |J| = 10
α_i	User i's affinity towards price; $\alpha_i \in U(0,1)$
β_i	User i's affinity towards quality; $\beta_i \in U(0,1)$
di	User i's data consumption per day; $d_i \in U(0.5, 2)$
γ_i	User i's affinity towards the reputation of the PDO; $\gamma_i \in U(0,1)$
p_j	Price charged by the PDO j for the Wi-Fi service; $p_i \sim N(2, 0.1)$ and is non-negative for revenue calculation
q_j	Quality of service offered by the PDO j; $q_i \sim N(2, 0.1)$
r_j	Reputation of the PDO as perceived by the users j; $r_i \sim N(2, 0.1)$
U_i	Utility derived by the User I from a PDO j; $U_i = \beta_i q_j + \gamma_i r_j - \alpha_i p_j$
N_j	Number of users matched to PDO j
TC_j	Total cost incurred by PDO j while serving N_j users = fixed cost (FC) + variable cost (VC) - S
FC	The cost of a Wi-Fi access point, antenna, last-mile cabling from the ISP PoP to the service point, and Internet backhaul cost of FTTH or ILL is shown in Table 2 for FC for different deployment scenarios
VC	INR 0.10 per day per user to PDOA for aggregation platform charges
TR_j	Total revenue of PDO_j while serving N_j users $=\sum_1^{N_j} p_j d_i$
π_j	Profit earned by PDO j while serving N_j users = $TR_j - TC_j$
Th	Profit threshold (INR 1,000)
n_j	Number of users matched to PDO j at each step
$\bar{N}$	Regulatory capping on the number of users to be matched to each PDO. Optimum capping = 50, no capping = 500
S	Regulatory subsidy to the PDO. Derived by calculating average loss of loss-making PDOs after one-year period (INR 10,000)
T	Policy period. Simulation step definition (for one year, step = 360; for two years, step = 720; for three years, step = 1,080)

Source: authors' own

Model Results and Discussions

We developed various scenarios of interest in the deployment of the WANI model as indicated below, by maintaining the wholesale backhaul price to PDOs equivalent to that of the retail FTTH pricing as indicated earlier.

We simulated the models shown in Figure 4 over a planning period of three years. Following are the significant interventions in the model:

1. The diffusion of adopters of the WANI scheme is as per Equation 1. The subscribers are assigned to the PDOs based on the utility value U_i calculated for each subscriber i across the set of all PDOs J as given by the equation for the same as given in Table 3.

2. In the case of scenario wherein no subsidy is provided by the government, loss-making PDOs exit the market.

3. In models where one-time subsidy is given, the subsidy amount is calculated based on the first-year cumulative loss incurred by the PDOs as in the case of the model without subsidy. This one-time subsidy is set to take care of the losses incurred by most of the PDOs in their first year of operation. If still some PDOs are at loss at the end of their first year, they exit. From the second year onwards, if any of the PDOs still make losses, they exit as shown in the flow diagram in Appendix 1.

Summary of the simulation results over a three-year planning period are shown in Table 4 and Figure 5a and Figure 5b.

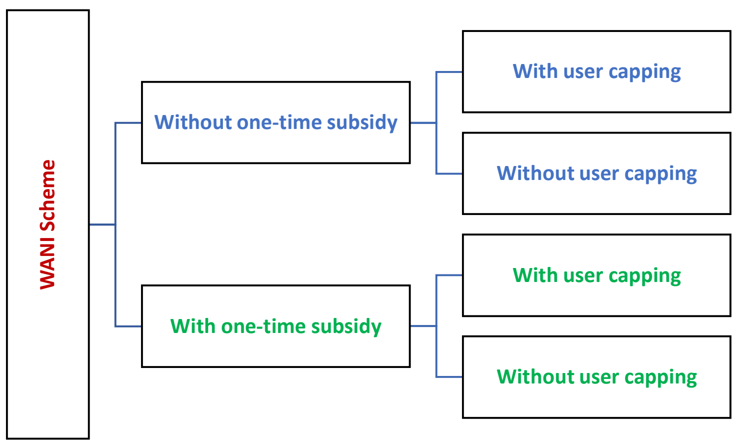


Figure 4. Simulation scenarios (Source: authors' own)

Table 4. Summary of simulation results for slow diffusion

	No. profitable PDOs			
	No. subsidy + no. user capping	No. subsidy + user capping	Subsidy + No. user capping	Subsidy + user capping
Year 1	2	7	2	8
Year 2	1	4	2	7
Year 3	1	1	2	5
	Average cumulative profit per PDO per month			
	No. subsidy + no user capping	No. subsidy + user capping	Subsidy + no. user capping	Subsidy + user capping
Year 1	1,429	836	1,697	1,453
Year 2	8,220	1,484	6,402	544
Year 3	5,99	2,499	767	264
Avg. over 3 years	3,416	1,606	2,955	754

(Source: authors' own)

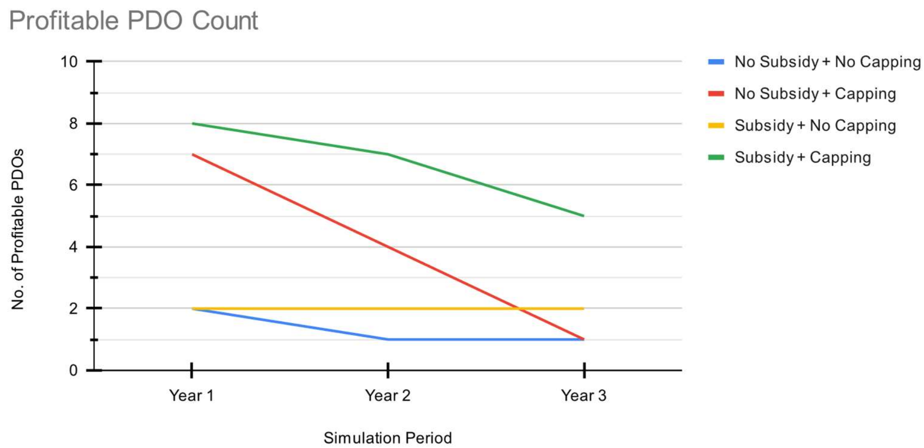


Figure 5a. Number of profitable PDOs year-wise. (Source: authors' own)

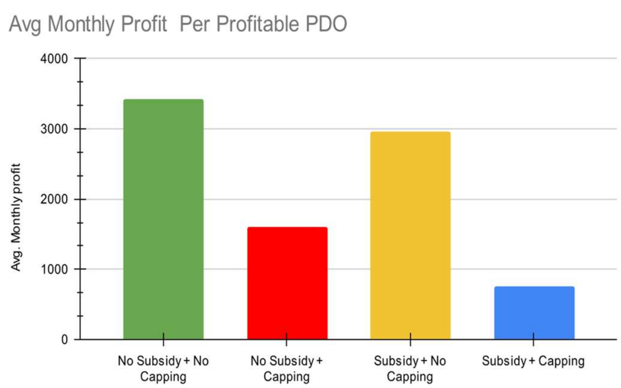


Figure 5b. Average monthly profit per profitable PDO over three years. (Source: authors' own)

Following are observations based on the simulation results:

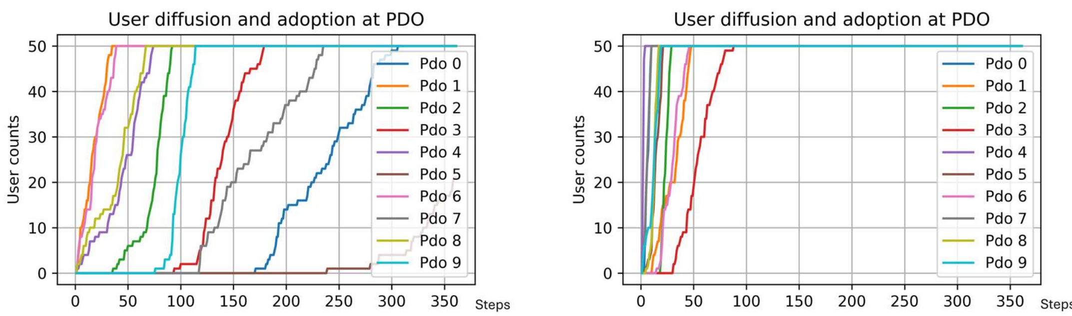
1. Without any one-time subsidy, the market tends to have a monopoly in the long run as most of the PDOs cannot sustain themselves due to the higher costs when increasingly more subscribers are onboarded. Due to the network effect and the economies of scale, it becomes feasible for one PDO to be profitable in the long run. With subscriber capping, although there are enough PDOs in the second year, it becomes a monopoly market from the third year onwards.

2. With subsidy, we witness a duopoly market without subscriber capping per PDO. This is due to the network and economies of scale effects.

3. However, the model with subsidy and subscriber capping results in a very competitive market with up to five PDOs existing with profitable businesses in the third year of operation. However, it is to be noted that under this scenario, the average profit reduces and is equitably distributed amongst the PDOs compared to the monopoly cases where the average profit is relatively much higher.

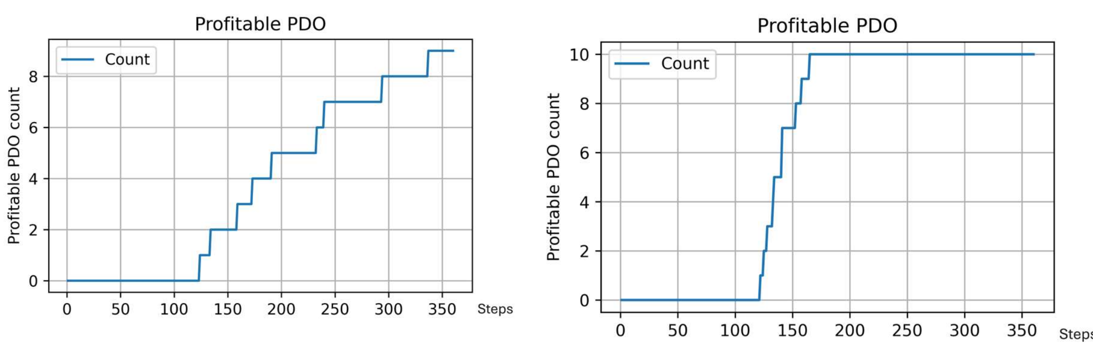
4. We also simulated a scenario with ILL backhaul at the existing prices and found that none of the PDOs are profitable, even in the long run. It must be noted that in most areas, especially in the rural parts of the country, ILL is provided by a monopoly TISP and hence the need for regulatory intervention on backhaul charges in such non-competitive markets.

We also simulated scenarios with slower and faster diffusion rates by changing the adoption and imitation coefficients in the Bass diffusion model. In general, with faster diffusion, Wi-Fi adoption reaches the maximum limits quickly, as shown in Figure 6 and Figure 7. This also results in a greater number of profitable PDOs compared to the case when the diffusion is slower. We find that the average profit per PDO with faster rates of diffusion is 30% to 40% more than that with a slower diffusion as shown in Figure 8. Research on diffusion models indicate that word of mouth and advertising will enable faster adoption.



(a) (b)

Figure 6. Adopter distribution across PDOs with (a) slow diffusion and (b) faster diffusion. (Source: authors' own)



(a) (b)

Figure 7. Profitable PDO count with (a) slow diffusion and (b) faster diffusion. (Source: authors' own)

Figure 8. Average monthly profit comparison for slow and fast diffusion. (Source: authors' own)

Conclusion

Our study indicates that public Wi-Fi projects such as WANI require an economic and regulatory analysis to create an ecosystem that is conducive for stakeholders to make it sustainable. A healthy, competitive market with a relatively larger number of profitable PDOs providing affordable Wi-Fi services is essential for the sustainability of such projects.

Tariff capping and its implications

Realising the need to reduce Internet backhaul costs, the telecommunications regulator in India (TRAI) has recently circulated a draft amendment of the ILL tariff for consultation. As per this draft proposal, the ceiling on the ILL tariff for PDOs, specifically for the WANI scheme, is proposed to be reduced to twice that of the home broadband FTTH connections (TRAI, 2024b; TRAI, 2025). This is expected to reduce the capex burden on the PDOs and, in turn, reduce the prices of Wi-Fi services offered by the PDOs. However, this tariff-capping proposal has been met with opposition from the TISPs. The TISPs argue that the drastic reduction in the wholesale ILL tariff will make their businesses unviable. Further, the reduction will also prompt many of their existing home broadband users to shift to the WANI scheme due to lower price options. However, it must be noted that while users with low data usage are likely to shift to the WANI networks, users who are data intensive and quality conscious are likely to retain their home broadband connections.

We also note that even with the FTTH pricing scheme, without subsidy we witness only two to three PDOs that become profitable in the short run and lean toward monopoly in long run. Such a scenario is acceptable in urban areas where the demand for Wi-Fi is relatively known and predictable. However, in semi-urban and rural areas, where the price elasticity of the users' demand is relatively high and there is demand uncertainty, a one-time subsidy is definitely required apart from a reduction in backhaul charges to make this project sustainable.

Regulatory recommendations

As indicated in our simulation study, the market will likely witness very few PDOs without capping the number of users per PDO. With optimal capping on the number of users to limit the market share in the short run, the market will likely tend towards more competition with a relatively larger number of PDOs. Similar situations have been witnessed in the digital payment sector in India, and limits on market share are being reviewed to prevent a duopoly market structure (*The Economic Times*, 2024).

Our simulation study indicates that some form of subsidy is needed to overcome the initial uncertainty and offset the fixed costs of setting up the PDOs. The entrepreneurial model without subsidies has not increased Wi-Fi penetration in the country. The USOF (also referred to as Digital Bharat Nidhi) is primarily intended to serve these types of requirements (Digital Bharat Nidhi, 2024). The existing USOF scheme that subsidises the telecommunications infrastructure in rural and remote areas of the country should be used for a one-time subsidy for all PDOs. As per our simulation, the acceleration of technology adoption also has a measurable impact on the sustainability of the PDOs. This can be done through mass awareness programs of the WANI scheme through traditional broadcasting and digital media by the government. Once the diffusion picks up and the user base starts increasing as per the Bass diffusion model, the economies of scale will enable the PDOs to generate revenue thereby making them sustainable. Infrastructure such as WANI has the potential to become a digital public infrastructure over which Internet services can be provided at minimal costs, both by businesses and governments, especially to netizens in the rural and remote areas of the country. With the above regulatory interventions, WANI can be self-sustainable, with many entrepreneurs venturing to become PDOs.

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Appendix

A1. Flow diagram of the simulation process. (Source: authors' own)