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Techno-Economic Study of 5G Network Slicing to Improve Rural Connectivity in India

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ABSTRACT Around 40% of the world's population is currently without access to the Internet. The digital divide is due to the high cost of provisioning these services and the low return on investment for network operators. We propose using 5G network slicing with multi-tenancy (also known as neutral host networks (NHN)) for macro-cells and small cells in rural areas to reduce the costs. This paper investigates the techno-economic feasibility of using rural 5G NHN to minimise the digital divide. A generic model is developed to analyse the techno-economic analysis of 5G NHN deployment around the world, with a special focus on rural areas where no MNO is interested in providing services. To understand the application, it is applied to the Indian scenario. First, a discussion on existing infrastructure, competition and statistics for Indian telecommunications is presented. Next, the technical requirements are analysed using the key performance indicators (KPI) required for the rural 5G NHN for the Indian scenario. The study also analyses the relationship between coverage, investment in the network, the number of subscribers, investment time, demand, the investment per user and sensitivity analysis to understand the feasibility of the proposed solution for Indian villages with different input conditions. Later, a case study is carried out based on the proposed approach, along with coverage modelling for a few Indian villages having different topologies. The results show that 5G NHN using network slicing can significantly reduce the total investment required for providing 5G services in rural areas. Furthermore, the study shows that rural 5G NHN is a viable investment and a key enabler for Internet connectivity for villages with 10-year investment, having a subscribers' base as low as 100 with a customer growth rate of 7%.

INDEX TERMS 5G mobile communication, multi-tenancy, network slicing, rural connectivity, techno-economic analysis.

I. INTRODUCTION

TODAY, around 60% of the world's population is connected to the Internet [1]. However, the rest of them are not, and most of these people live in rural areas. Rural connectivity is critical for the development of the country as well as the people. Rural connectivity is not only important, mainly for economic growth but also for educational development, social welfare, employment opportunities, and community engagement [2].

Access to mobile technologies and corresponding devices has increased exponentially in the last 20 years. Currently, 5G is being researched, tested, and deployed around the world. The main 5G use cases are enhanced mobile broadband (eMBB), ultra-reliable & low-latency communications (uRLLC) and massive machine-type communications (mMTC) [3]. 5G also allows remote monitoring of the network. One of the network architectures supported by 5G is network slicing which allows multi-tenancy [4]. This means a single network deployed by an infrastructure provider (InP), can be shared by multiple operators and this is known as a neutral host network (NHN) [4]–[6]. Network slicing creates virtual networks to support different applications, and slice tenants such as operators, industry verticals and small-scale businesses, to operate their 5G services easily, quickly and at affordable prices.

Rural connectivity has been a key issue that is yet to be solved by governments around the world. In [7]–[9], the research proposed using TV white space (TVWS) and renewable energy to connect rural areas, but the solution is not feasible for a large-scale network due to spectrum allocation challenges, power level restriction, technological compatibility with existing customer devices, and the spectrum license duration. Also, achieving roaming agreements with the mobile network operators (MNOs) is a challenge. To understand policy implications and the feasibility of a 5G nationwide network, the study in [10], [11] performed the techno-economic analysis of 5G deployment in the U.K. and Netherlands. The research concluded the need for supportive policy to encourage 100% coverage, especially bringing spectrum cost to zero in rural areas. One of the main reasons is the cost of provisioning 5G services using traditional deployment methods is very expensive in rural areas. This highlights the need for innovative solutions in rural areas to improve rural connectivity. The research in [12] which examined for an urban scenario, shows that using open-source technologies for deploying 5G with multi-MNO radio access networks (MORAN) sharing reduces cost by at least 50%. Unlike, [7]–[12], this paper focuses on 5G NHN for rural connectivity using network slicing.

There has been some literature on using 5G NHN to provide Internet connectivity in rural and urban settings [4], [6], [13]–[18]. The survey on the evolution paths of NHN, its strategies and business models is presented in [4]. The research also highlights the use of NHN to revolutionise telecommunication business models, especially rural and in-building connectivity. In [6], a community-industry driven ecosystem for rural 5G NHN for a wide-area network is explored using value network configurations and business models. This research explores the deployments of rural 5G NHN to reduce the digital divide. The research in [13], highlights the need for supportive 5G policies by eliminating spectrum licensing costs to deliver 6G for rural connectivity with application to the Indian scenario. The research also presents the exorbitant cost of 5G networks in traditional deployment, which leads to the need for friendly policies in rural areas to reduce the digital divide. As per the research, the cost-effective way of connecting rural areas is through wireless technologies. In [14], multi-tenancy within fibre broadband for Government and non-Government organisations in Tonga is explored to reduce the digital divide. A combination of technologies is studied, for a discussion with stakeholders to tackle the digital divide. In [15], a single network slice is used to provide basic but free Internet connectivity in the Democratic Republic of Congo (DRC) for people who cannot afford it, while the remaining slices are used for commercial operations. In [16], 5G NHN is tested in a pilot study for a densely populated urban city such as Barcelona, where the city council is the InP. 5G NHN is shared by network operators. Similarly, in [17], 5G NHN is studied for a campus-wide network where the university acts as an InP and MNOs lease slices from the network. The research in [18] presents the 5G RuralFirst pilot study on the Orkney Islands, Scotland, the U.K., which uses rural 5G network slicing for different industry verticals applications, especially wired broadband services for each home and broadcasting application. The research focuses on providing connectivity for remote rural areas as well.

In this paper, the techno-economic feasibility of a 5G NHN deployment is investigated. The research mostly focuses on areas with absolutely no connectivity or poor coverage, where no MNO is generally interested in providing services. Our paper is the first to investigate the use of 5G network slicing with NHN for rural connectivity, with a focus on the Indian context. By using rural 5G NHN, different MNOs could actively participate in providing 5G services to rural areas, especially those with low populations. The specific contributions of the paper are:

- A general model was developed for a techno-economic study of 5G NHN in rural areas. The model includes population distribution, demography, coverage models, market demand estimates, and the number of operators.
- An overview of the state-of-the-art presented for Indian telecommunication helps to understand the network requirement for the Indian setting.
- Key performance indicators (KPI) requirements for a rural network with a special focus on the Indian scenario is presented.
- The proposed model estimates the feasibility of rural 5G NHN by modifying the techno-economic parameters such as capital expenditure (CAPEX) and operational expenditure (OPEX), the average total cost of ownership (TCO), the minimum number of subscribers, break-even time, average revenue per user (ARPU), and the sensitivity analysis which presents an overview of input parameters that significantly impact the feasibility of the network.
- To understand the application of the results obtained, we perform an analysis of trends for different villages. The study on the feasibility of rural 5G NHN in an Indian context employs the proposed techno-economic model for a few Indian villages; Dhanushkodi, Lempia, Bandholi and Muddunoor, located in different parts of the country with unique topography.

Unlike in [4], [6], in this paper, we perform the techno-economic feasibility of 5G NHN in the rural setting. The focus of research in [13] is to understand the policy that is required to support rural connectivity in 6G whereas, our research on rural 5G NHN focuses on transforming the rural connectivity business to technologically and economically feasible in the rural parts, for example in India. Although multi-tenancy is explored [14]–[18], our research focuses on using network slicing with NHN in rural scenarios where MNOs serve the end-users using slices of InP.

This paper is organised as follows. Section II presents the 5G NHN background, methodology, modelling scenario, background of Indian rural connectivity, KPIs, and system modelling. Section III presents the main research outputs of

TABLE 1. Network sharing technologies.

Technologies	Features
Access point network (ACP)	RF, eNB, MME, and SGW is common but PGW is different [21].
Gateway core network (GWCN)	RF, eNB and MME is common but SGW and PGW are different [22].
Multiple operators core network (MOCN)	RF, eNB is shared and core is dedicated to each operator and service [22].
Multiple operators radio access network (MORAN)	Except eNB, rest of the components are shared. The traffic is routed to the corresponding operators using the eNB [3], [22].
National roaming	This refers to roaming agreements in the national context. But the complexity lies while deciding when the network should prefer home operator's network to other operator's network [22], [23].
Network slicing	End-to-end components of the 5G system, including the spectrum, and each slice has virtual units on the radio, core, and transport levels, are shared. The packets are routed by the InP network's core to the corresponding operators' core [3], [4], [19].

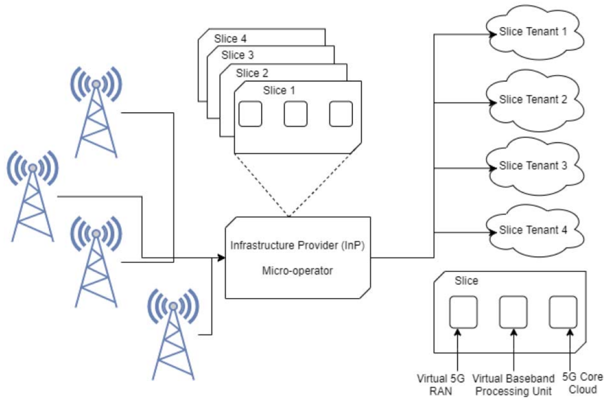

FIGURE 1. 5G multi-tenancy network slicing - A neutral host approach.

the study: coverage simulations, TCO, minimum subscribers, break-even time, minimum ARPU, sensitivity analysis and trends analysis of actual villages. Finally, conclusions are drawn in Section IV.

II. SYSTEM MODEL

A. TECHNOLOGY AND NHN BACKGROUND

Network slicing is one of the architectures of 5G, which is supported using software defined networking (SDN) and network function virtualisation (NFV). Network slicing enables the construction of virtual slices on the same physical resources to support a greater number of UEs, on-demand resource allocation, remote resource management for UEs, increased spectral efficiency, reduced costs, tailored services, and isolated operations of slice tenants. [19], [20]. Network slicing allows increased resource utilisation as the hardware resources are shared among the slice tenants, and allocated as per demand. In 5G network slicing, the baseband processing as well as the network upgradation is mostly performed in the cloud. Furthermore, the independent operations of tenant's services on the slice are one of the most interesting features of 5G network slicing.

The architecture of end-to-end 5G network slicing is as shown in Fig. 1. Each slice tenant on the network would have their own virtual 5G RAN, virtual baseband processing unit and a connection to the InP's 5G core. The InP core connects to the slice tenant's network 5G core. The InP could be either a third-party company, MNO, Internet service providers (ISPs), or a community-run company. Similarly, the tenants on the network could be MNOs, ISPs, media service providers (MSPs), vertical industry, event organisers, over-the-top (OTT) service providers and emergency services. The slice tenants would provide use-cases supported by 5G such as eMBB, uRLLC and mMTC. The network could operate on one of the tenant's spectrum or shared spectrum bands, depending upon the legal requirements of national regulator's policies. All data processing is done in the cloud, and data is encrypted as it travels from the InP network to the slice tenant's network. The network could change resource requirements as per demand using virtual resources.

There are different technologies of network sharing, and network slicing is the most advanced among them. A summary of network sharing technologies is shown in Table 1 [3], [4], [22], [24]. The key terms used in Table 1 are radio frequency (RF), evolved Node B (eNB), mobility management entity (MME), service gateway (SGW) and packet gateway (PGW). It's worth noting that while 4G technologies offer some sort of network sharing, they don't support end-to-end network sharing as 5G network slicing does [3], [4], [19].

In 5G network slicing, the slice can be created, connected and terminated as per the demand of tenants. Service provisioning on an ad-hoc basis is not possible in any other network sharing technologies. In 5G network slicing supporting NHN, multiple operators can co-exist without a direct agreement with other operators co-existing on the same InP network. The operators would have an agreement only with the InP. According to the service level agreement (SLA), the InP would allocate resources and provide minimum guaranteed resources to the slice tenants. Network slicing facilitates the co-existence of multiple slice tenants ranging from short to long term duration on the same physical network [3], [25]. The concept of NHN has been explored for a few years but requires policies to encourage investments and deployments by new entrants [4]. 5G NHN using network slicing would play a crucial role in reducing rural Internet connectivity costs as each operator could lease slices from a single physical infrastructure. Each operator can compete in terms of their service quality to end-users instead of infrastructure deployment-based competition.

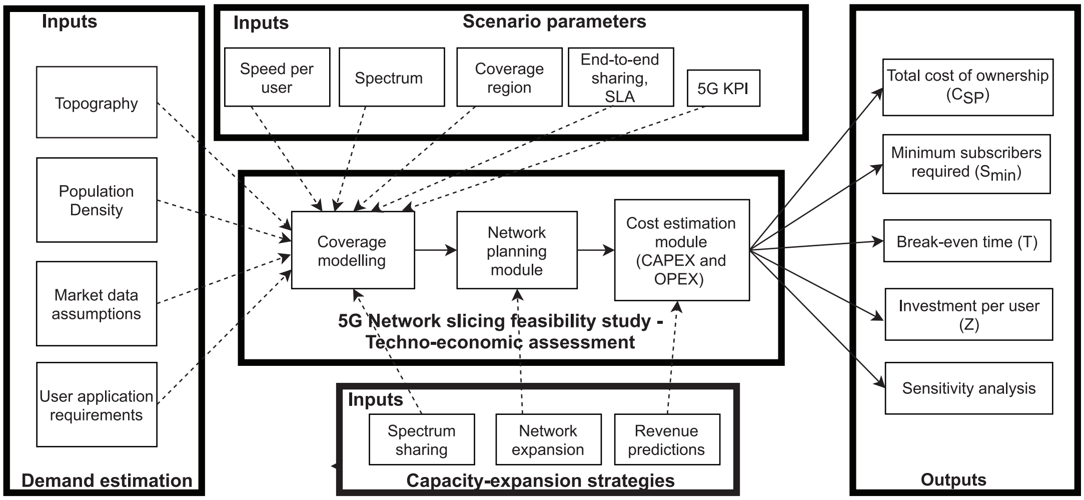

FIGURE 2. Modelling methodology.

B. METHODOLOGY

Demand for the village can be estimated using input, such as topography, population density, use-cases, market data assumptions and user application requirements. Next, network equipment is determined based on scenario parameters, such as speed per user, spectrum frequencies, desired region to be covered, end-to-end sharing, KPI requirements, and the SLA. These also estimate requirements of the number of antenna types and directions, base stations (BSs), servers, processing units and backhaul capacity. Furthermore, proper planning should also account for network capacity expansion strategies. When using spectrum sharing technologies, minimise the interference with other licensed users on the same band. Another input is revenue prediction parameters such as network uptake, population, and expected subscriber growth, which determines the feasibility of the network. The model outputs such as CAPEX to OPEX ratio, TCO, minimum subscribers' requirement, break-even time, and investment per user assess whether the network is sustainable in the assessed area and also the sensitivity analysis.

This model shares similar features but differs from the models used in [12], [13], [26]. Techno-economic models, such as this one, are used for assessing the costs of mobile networks considering multiple parameters. Our model is in a way derived from [12] which is for 5G MORAN NHN but is modified to suit a single site deployment using 5G network slicing with NHN and spectrum sharing. The focus of the study using our model is to study the viability of 5G NHN in rural areas with a low population where there is plenty of under-utilised spectrum. Hence, this research does not focus on spectral efficiency as in [13]. Unlike in [26], the network congestion is already accounted for as InP provides a minimum guaranteed resource block to each slice tenant in case of congestion. The model considers analysis using network slicing. Also, this model focuses on rural areas.

In this paper, a single site typically can cater to all the demands in remote and rural areas with a low population.

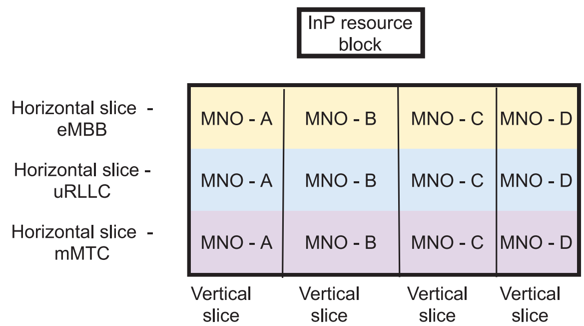

FIGURE 3. Rural 5G NHN with horizontal and vertical network slicing.

Hence, only per site analysis is performed. The fR1 frequency bands (less than 6 GHz) of 5G has coverage up to a few nearby villages within a radius of 5 km. The research on network slicing suggests 5G NHN will be able to support a higher number of users, and the network is scalable as per demand [3], [16], [21].

Coverage modelling aids in understanding the parameters for network planning such as frequency planning, the best location to place the BSs, antenna directivity, path loss, cell-edge, clutter, topographical challenges, signal to interference and noise ratio (SINR), KPIs, interference, and locating the blind spots of the coverage. In this study, coverage plots for the village of interest were simulated using MATLAB - antenna wave propagation toolbox, Radio Mobile and CloudRF. Based on the discussions with the MNO and verifying on cloudRF and MATLAB software, it is known that a single site deployment at 700 MHz and 3.8 GHz would be sufficient to meet all the capacity requirements of the applications in the generic village with coverage of up to 8 km and up to 3 km radius in an unobstructed environment and an environment with obstructions respectively.

C. MODELLING SCENARIO

Fig. 3 shows the 5G architecture for end-to-end network slicing supporting NHN using horizontal and vertical slices.

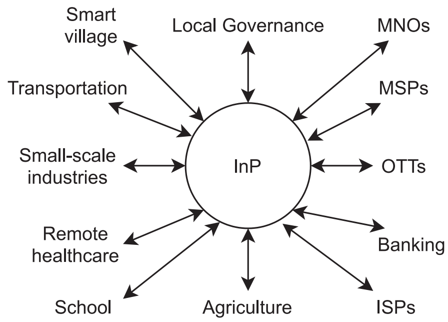

FIGURE 4. Rural 5G NHN use-cases.

TABLE 2. Rural population distribution in India.

Population range	Number of villages
Less than 100	45,276
100 - 199	46,276
200 - 499	127,511
500 - 1,999	129,977
2,000 - 4,999	80,413
5,000 - 9,999	14,799
10,000 +	3,961

The horizontal slicing supports different use-cases, whereas vertical slicing allows multiple MNOs who require a particular use-case from the horizontal slicing [25]. The InP deploys the 5G NHN in rural areas, and MNOs lease slices from the InP. Each MNO could provide services for multiple use-cases in the same village using the common physical infrastructure. The InP deploys and manages the rural 5G NHN for its entire life cycle. Previous research has established that 5G network slicing with multi-tenancy reduces the CAPEX by at least 30% and OPEX by at least 20% [12], [27], [28]. There could be tenants other than MNOs, such as agriculture, ISPs, MSPs, OTT, local governance, agricultural applications, schools, hospitals, small scale industries, transportation, smart village applications and banking. Local governance, broadband services, OTTs, e-banking, online education, TV broadcasting, healthcare, industrial applications, transportation, online education, and smart villages are some of the possible use-cases, as shown in Fig. 4. These applications could have an impact on network feasibility; future work can address this.

D. INDIAN SCENARIO

In India, around 70% of the population lives in rural areas. Most of these places have poor or no Internet coverage. The number of villages in India and their population distribution range is shown in Table 2 [29]. The 5G NHN has various use-cases in the Indian rural scenario, shown in Fig. 4. It includes healthcare, communication, smart farming, smart village, smart lighting, e-banking, e-governance, online education, small-scale industry applications, smart grids, broadcasting, spectrum management, and transportation [30]. During the COVID-19 pandemic, people preferred to live and work from remote areas. A good Internet connection in rural areas would help encourage the economic growth of the country as well.

In rural parts of India, the competition is weak among the MNOs due to the high cost of network deployment. There are more than 4 MNOs providing service in the country. The industry is heavily in debt. Therefore, MNOs are not keen on providing telecommunication services in rural areas. Generally, not all MNOs can secure spectrum licenses and receive approvals to provide services in the entire country using their infrastructure. Hence, there is some form of roaming agreement and infrastructure sharing between the MNOs to provide service to each other's subscribers in different parts of the country [31]. However, this is different from NHN using 5G network slicing that reduces the dependencies of MNOs on each and allows easier expansion of their services using slices discussed in Table 1. There is a need for lowering the cost of telecommunication service provisioning for MNOs in India to increase competition, encourage new entrants and improve the network performance [13]. The reduction could be in terms of cost for factors such as spectrum, equipment, site rental, power and license approvals.

The latest survey of rural connectivity in India, with a detailed study on emerging use-cases, government initiatives, as well as projects for rural connectivity, challenges and possible rural technologies for reducing the digital divide, is presented in [30], [31]. The study highlights the need for an innovative solution for last-mile connections using different technologies. As per a report by the various survey companies based on inputs from the Telecom Regulatory Authority of India (TRAI), there is a 93% broadband penetration in urban India versus a mere 29.3% in rural India [32], [33]. BharatNet initiative would provide 100 Mbps backhaul services to the gram panchayats (GPs) in India [34]. As of today, there are 1,65,082 GPs to which optical fibre cable and necessary equipment are provisioned [35]. According to the case studies part of BharatNet, generally, villages are located around 2 to 10 km away from the GPs [30], [35]. Therefore, for minimising the TCO per site in rural areas, a wireless backhaul connection is preferred, either point-to-point (PTP), point-to-multipoint (PTMP) or relay networks to the point-of-presence located at the GP office.

Following a discussion with Indian MNOs, a commercial-grade BS can support just over 2000 and 20,000 active users simultaneously, at any one time on LTE and 5G spectrum bands, respectively. The take-up of the network in India is about 35% [36], [37]. The average ARPU in India for mobile connectivity is INR 200, whereas the bundle inclusive of mobile, broadband and TV services is INR 1,300 in urban areas [15], [32], [38], [39]. However, in rural parts of India, the ARPU for mobile connectivity is INR 68 and for the bundle inclusive of mobile, broadband and TV services is INR 240 [33], [40]. MNOs offering a package is the latest trend.

E. SYSTEM REQUIREMENTS - KPIS

The network's performance in 4G and older technologies is determined by the network's equipment and QoS. On the

TABLE 3. KPIs for 5G networks in a rural Indian setting.

5G KPI	Category	Priority
Peak Data rates	eMBB	1
Peak Spectral Efficiency	eMBB	2
Data rate experienced by the user	eMBB	2
Area Traffic Capacity	eMBB	3
Latency (User Plane)	eMBB, uRLLC	1
Latency (Control Plane)	eMBB, uRLLC	1
Connection Density	mMTC	3
Energy Efficiency	eMBB	1
Reliability	uRLLC	1
Mobility	eMBB	3
Mobility interruption Time	eMBB, uRLLC	3
Bandwidth (Maximum aggregated bandwidth)	IMT-2020	min 20 MHz

other hand, the KPIs define 5G network features that need to be prioritised for the application of interest. The KPIs give a qualitative assessment of the 5G network's performance. The KPIs can be varied depending on the use-cases, application, load, demand, user density, virtualisation type, and other factors [41].

KPIs for the 5G rural networks listed in Table 3, where the values 1, 2, and 3 represent high, medium, and low priority levels of KPI for Indian rural scenario deployment. KPIs help the InP in determining the type of deployment needed to meet the requirements. Generally, in rural areas in the Indian scenario or any other country, the following factors are to be considered for rural 5G NHN.

- *Peak data rates:* The network should have downlink data rates of approximately 50 Mbps and uplink data rates of 25 Mbps [41], [42] for applications such as video calling, video streaming, surveillance, mobile health, online education, online consultation for farming related queries, and industrial automation. Applications such as IT education and services in rural areas help in improving rural area conditions [43].
- *Peak spectral efficiency:* This parameter could be a moderate priority to accommodate a maximum number of users in limited spectrum bands. Usually, the number of devices on the network is low in rural areas [42].
- *Data rate experienced by the user:* Data rate experienced by the user should be moderate and satisfy the minimum 5G requirements. However, the coverage should be high to focus more on providing connectivity to a larger area [42].
- *Area Traffic Capacity:* The data capacity per user in rural areas will increase by at least 10 - 20 Mbps compared to data capacity per urban user, due to reduced congestion on the network [10], [11], [26], [44].
- *Latency:* Typical delay is around 0.5 ms and 10 ms for the user and control plane respectively in 5G networks. The user plane allows commonly used user data to be cached at the edge to reduce delay for applications such as healthcare services, online education, industrial automation, cattle monitoring, and e-governance. The control plane is used to control the connection between the network and the user equipment.
- *Connection density:* Usually, the network can support up to a million devices per km^2. The number of devices in rural areas is relatively low. Therefore, this factor has a lower priority during initial deployments [42].
- *Energy efficiency:* Rural areas have energy issues and frequently interrupted power supply. Hence, the network needs to consume low energy compared to a traditional telecommunication network. The network should be highly energy efficient [9], [30].
- *Reliability:* The network should be highly reliable to support network slicing and predict outages to avoid network breakdown.
- *Mobility:* Generally, the roads in rural areas have lower speed limits. The number of high-speed moving vehicles in rural areas is low. The maximum speed of vehicles travelling on rural roads in India is around 80 kmph [42]. Consequently, mobility has a lower priority.
- *Mobility interruption time:* This parameter determines the handover time in very high-speed moving vehicles. It can be of low priority for rural applications due to the lack of high-speed vehicles.
- *Bandwidth:* To support 5G performance criteria for applications such as individual, small business, and industry, a minimum bandwidth of 20 MHz may be required. When network demand is modest, a 5 MHz bandwidth should suffice for a network serving individual end-users [42].

This description of KPI helps in the customisation of the network to suit rural needs. The system requirements and the constraints in rural areas are lower compared to the system requirements and the constraints in urban areas. KPIs help to estimate the cost of setting up a 5G network in rural parts of India.

F. FEASIBILITY MODELLING

A techno-economic model enables understanding of the scope, profitability and risk involved in the business. It takes into consideration most of the possible factors influencing the business and is used in different research projects [12], [13], [17], [26], [31], [45], [46]. In this research, the techno-economic model is used for studying the feasibility of 5G network slicing supporting NHN in rural parts of India.

The cost per site is estimated by calculating the CAPEX, OPEX and TCO for the investment duration of T (in years). The CAPEX C_c, includes installation of a new BS with a tower (C_{bs}), multi-carrier BS (C_{mbs}), fibre (C_f), backhaul (C_{bh}), 5G core (C_{co}), and other equipment such as batteries (C_{bt}) and backup generator support for power supply (C_{gt}), and technology licensing (C_{tech}), and is given:

$$C_c = C_{bs} + C_{mbs} + C_f + C_{bh} + C_{co} + C_{bt} + C_{gt} + C_{tech}. \quad (1)$$

The OPEX C_o per year, includes day-to-day maintenance such as BS OPEX (C_{bso}), site lease (C_l), network maintenance (C_m), backhaul (C_{bho}), spectrum (C_s) and rentals (C_{rent}), is given:

$$C_o = C_m + C_{bho} + C_{rent} + C_{bso} + C_l + C_s. \quad (2)$$

In this study, TCO for the InP (C_{Ti}) is given as follows:

$$C_{Ti} = C_c + TC_o. \quad (3)$$

Let 5G network slicing supporting NHN deployed by InP have parameters as: total number of slices, $\beta = \sum_{n=1}^{N} \beta_n$, and minimum required resource block per slice tenant be $\delta_{min} = [\delta_1, \ldots, \delta_N]$. Assume a 5G network has M KPI requirements, then KPI requirements of n^{th} MNO as $\rho_n = [k_1, \ldots, k_M]$. Hence, KPI for all the MNOs on the 5G rural NHN is $K = [\rho_1, \ldots, \rho_N]$. Expenditure of the InP will heavily depend upon the number of slices β, KPI requirements of the slice tenants K, slice size γ, type of virtualisation V, and the minimum guaranteed resource block δ_{min} [47]. In provisioning services for the slice tenants, there is a need to solve the complex dependency between various parameters, given by the incremental cost C_{inc} for the InP:

$$C_{inc} = E(K, \beta, \delta_{min}, \gamma, V), \quad (4)$$

where $E(.)$ is the standard expenditure function and can be explored more in detail from [47]. The values of K, β, δ_{min}, γ and V will vary depending on each situation and MNOs' requirements [20]. To simplify the analysis, we assume C_{inc} to be around 20% of C_{Ti} as C_{Ti} includes most of the cost involved in slicing technology as well as 5G infrastructure deployment. Typically, C_{inc} can range between 0 to 20% depending on the additional KPI requirements of the MNOs. Therefore, the modified TCO, C_T for the network is:

$$C_T = C_{Ti} + C_{inc}. \quad (5)$$

In our study, the TCO is computed for a greenfield deployment, i.e., no presence of existing telecommunication infrastructure. The lifetime of the equipment is generally around 10-years but can be functional for 20 years with minimal upgradation.

InP can provide service in the village using the localised spectrum bands. Generally, if InP used shared spectrum bands for rural 5G NHN, then the spectrum license is for 3, 5, or 10 years [48]. Otherwise, the licensed spectrum band for 25 years is auctioned, for commercial mobile communication used by MNOs. If InP is spectrum trading, then the spectrum duration depends on the agreement between the incumbent of the spectrum band and the secondary user.

The following four criteria have been analysed for 5G NHN to understand the techno-economic feasibility of the network by varying the following parameters: cost modelling, the number of subscribers, investment time, and minimum investment cost per user.

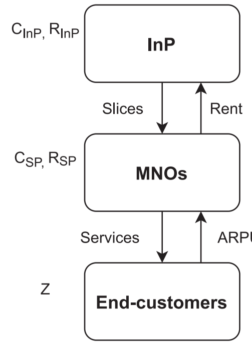

FIGURE 5. Cost and revenue relationship among InP, MNO, and end customers.

1) COST MODELLING

The cost and revenue relationship between InP, MNOs and end-users with their corresponding parameters, shown in Fig. 5. A cost model is a tool used by businesses to determine the best values to produce a product. Business owners can understand how to make goods at the lowest possible cost when using this technology. The cost and revenue streams for InP and MNOs are:

- *InP:* The cost for the InP C_{InP}, is the same as the TCO for the network plus the incremental cost for slice provisioning, C_T.

$$C_{InP} = C_T. \quad (6)$$

The revenue R_{InP} is calculated,

$$\begin{aligned} R_{InP} &= P + C_T, \\ &= xC_T, \\ &= \sum_{n=1}^{N} r_n, \end{aligned} \quad (7)$$

where P is the InP's expected profit for the network, the InP's expected profit (in percentage) from the network is represented as $x \in (1, 2]$ which is a constant, N is the number of service providers on the InP network, and r_n is the rent paid by the n^{th} service provider on the network to the InP. The cost per tenant/service provider towards the slices depends on the individual KPIs required for their applications. However, the expected revenue of the InP, R_{InP} is equal to the summation of all rents paid by the tenants towards the 5G NHN network.

- *MNOs:* Similarly, the cost (C_{sp}^n) and revenue (R_{sp}^n) for the n^{th} service provider, is calculated,

$$\begin{aligned} C_{sp}^n &= r_n, \\ R_{sp}^n &= \sum_{j=1}^{T} 12 Z_n^j S_n^j T, \end{aligned} \quad (8)$$

where S_n^j is the number of subscribers, and Z_n^j is the APRU per month for n^{th} slice tenant for j^{th} year.

For streamlining the analysis, the combined cost (C_{sp}), revenue (R_{sp}) and subscribers (S) of all the service providers on the network in the village of interest are given by,

$$\begin{aligned} C_{sp} &= R_{InP}, \\ &= \sum_{n=1}^{N} r_n, \\ R_{sp} &= \sum_{n=1}^{N} R_{sp}^{n}, \\ S &= \sum_{n=1}^{N} S_n. \end{aligned} \tag{9}$$

2) MINIMUM SUBSCRIBERS

To demonstrate the use of 5G NHN in rural areas, the InP is assumed to cater only to MNOs, each with the same KPI requirements, because they would be serving end-users having similar demand. Hence, the rent is equally divided among the MNOs who only serve individual subscribers S with an ARPU of Z throughout the investment duration. The potential subscribers from private LTE and other vertical industries on the network could be future works of this study. While calculating the minimum subscribers required for all MNOs on the network, assume the growth rate r_g for the number of individual subscribers during the life cycle of the network to be zero. Hence, the minimum subscribers, S_{min}, required to achieve the expected TCO at ARPU, Z using (8) and (9), is calculated as,

$$S_{min} = \frac{1}{12}\frac{C_{sp}}{ZT}. \tag{10}$$

3) BREAK-EVEN TIME

Break-even time (T_{be}, in years) is the time required for total profits to be zero with S subscribers at Z ARPU, and calculated as follows:

$$T_{be} = \frac{1}{12}\frac{C_{sp}}{SZ}. \tag{11}$$

4) INVESTMENT COST PER USER

The combined cost C_{sp}^{a} and revenue R_{sp}^{a} for all the service providers together, considering depreciation of CAPEX r_{dc} and appreciation of OPEX r_{do}, the cost-of-service provisioning, and a customer growth rate of r_g is given:

$$\begin{aligned} C_{sp}^{a} &= \sum_{j=1}^{T}\Big(C_{spc}^{j}(1+r_{dc})^{j} + C_{spo}^{j}(1+r_{do})^{j} + C_{inc}\Big) \\ R_{sp}^{a} &= \sum_{j=1}^{T} 12S(1+r_g)^{j} ZT, \end{aligned} \tag{12}$$

where C_{spc}^{j} and C_{spo}^{j} is the overall combined CAPEX and OPEX cost for the service providers in the j^{th} year, which is rent for the InP.

The cash flow for the j^{th} year in InP-MNO business is calculated by $F_j = R_{sp,j}^{a} - C_{sp,j}^{a}$, i.e., revenue minus cost for that year, and the overall cash flow, F, for the business is given by,

$$F = \sum_{j=1}^{T} F_j. \tag{13}$$

The net present value (NPV) (ζ) is used to estimate whether the business is lucrative ($\zeta > 0$) or not ($\zeta < 0$) by calculating the discounted present value at the targeted rate of returns r of future cash flows (13) during the investment duration T. NPV takes into account the time value of money and can be used to compare similar investment options. The NPV estimated as,

$$\zeta = \sum_{j=1}^{T} \frac{F_j}{(1+r)^{j}}. \tag{14}$$

Financial break-even occurs when the cash flows equal the initial investments; this is only possible when the NPV is zero at the end of the study period [11], [44], [49], [50]. As a result, a company tries to figure out the number of sales that will result in zero NPVs and a break-even condition. To calculate the minimum investment cost per user (Z_{min}) (also known as minimal viable ARPU) such that the network is feasible, for a varying number of subscribers in the village is estimated using 15. This value would let the stakeholders decide whether the network would earn any profit at a price that people would be willing to pay. In this particular study, the analysis is for 10 year investment period. The following optimisation equation with its constraints, is solved to calculate the minimum viable ARPU using (12), (13) and (14).

$$\begin{aligned} \min_{S, r_g, C_{sp}^{a}, r} \quad & Z = \frac{C_{sp}^{a}}{\sum_{i=1}^{T} 12S(1+r_g)^{i} T} \\ \text{s.t.} \quad & \zeta = 0 \\ & Z > 0. \end{aligned} \tag{15}$$

III. RESULTS

In this section, we will discuss the techno-economic feasibility of 5G NHN in rural areas, with a focus on India.

A. COST ESTIMATIONS OF THE NETWORK

Based on the study done by researchers in [13], [46], the various costs of the LTE/5G non-standalone (NSA) network components in making broadband services affordable are as shown in Table 4. In general, on average, the telecommunication circles use a cell threshold of 500 inhabitants per km^2 [13]. This study uses a conversion of \$ 1 (USD) = INR 75.

In India, there are four major nation-level MNOs. All four operators would ideally like to operate everywhere in the country. In rural parts of India, the number of potential subscribers per village is high. The TCO for single-cell

TABLE 4. Unit cost of 5G components.

Component	Cost ($USD)
Sector antenna	1,500
Remote radio unit	3,500
IO fronthaul	1,500
Processing	1,500
IO S1-X2	1,500
Control unit	2,000
Cooling fans	250
Power supply	250
Battery power system	10,000
Baseband unit cabinet	200
Tower	5,000
Civil materials	5,000
Transportation	5,000
Installation	5,000
Site rental (rural)	1,000
Router	2,000
Backhaul: Wireless link (small)	20,000
Backhaul: Wireless link (medium)	30,000
Spectrum (sub 1 GHz band)	$2.18/Hz/person [13]
Spectrum (over 1 GHz band)	$0.61/Hz/person [13]

TABLE 5. Deployment cost estimations.

Green Field Deployment	Cost per BS (in INR millions)	Changes per year
Installation of new BS with tower and other infrastructures such as batteries and backup generator support for supply + software (C_c)	3	-2%
Day-to-day maintenance per year (C_0)	0.15	3%
Core upgrade cost (included in the CAPEX)	10% on the markup of RAN deployment	
Incremental cost in provisioning of the slices as per the demands of the MNOs (C_{inc})	20% of the overall cost	

site deployment using 5G network slicing supporting NHN is estimated based on the information collected from the Indian census, Google Maps, journal articles, research papers, discussions with the Indian operator, and a few universities. The total cost of the 5G NHN network as per the Table 4 in the Indian scenario with assumptions as discussed in the previous section is around $ 66,000 per site. This study does not account for an incremental cost of slice provisioning. However, based on discussions with an Indian operator, the cost for the rural 5G NHN with KPI, shown in Table 2.5, are captured in Table 5. The average CAPEX for the InP is approximated to INR 3 million with r_{dc} depreciating at 2% per year, and the OPEX for the InP to INR 0.15 million per year with r_{do} appreciating at 3% per year.

The parameters used for the techno-economic study of Indian rural 5G NHN, shown in Table 6. It's interesting to note that the actual cost of spectrum in localised spectrum sharing technology isn't available for the Indian situation. But should be lower than the values presented in Table 4, which is for a nationwide spectrum license. Typically, the spectrum sharing license costs per area are negligible compared to obtaining a nationwide spectrum license. Generally, InP would prefer a localised spectrum license for providing services in the villages of their interest.

TABLE 6. Simulation parameters for the techno-economic analysis.

Parameter	Value
N	4
T	max 20
CAPEX r_{dc}	-2%
OPEX r_{do}	3%
r_g	7%
S	max 1500
Z	max INR 1200
r	8%
take-up	35%

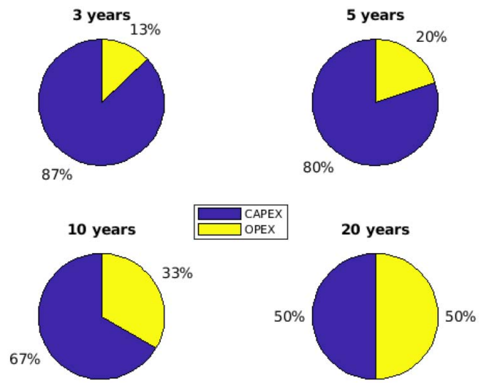

FIGURE 6. CAPEX to OPEX ratio with changing the investment years.

Fig. 6 presents the CAPEX to OPEX ratio per site for the InP as the duration of the network increases. Initially, the CAPEX is very high compared to the OPEX. Later, OPEX increases compared to CAPEX with time due to the wear and tear of the equipment. The investment in 5G services in rural areas could be 3, 5, 10 or 20 years, depending on the license duration obtained for spectrum and network operations. Using the data from Tables 4, 5 and 6, the cost for different investment durations is estimated using (3), (4) and (5), assuming the network wouldn't require any major upgrade during the lifetime of the investment.

The results of the techno-economic study discussed in the previous section are:

1) ESTIMATION OF TCO FOR THE RURAL 5G NHN

Fig. 7 shows the cumulative TCO per site for all MNOs using 5G with and without NHN for 3, 5, 10, and 20 years, respectively. The TCO for the InP is approximately INR 6 million ($ 81,600) and INR 7 million ($ 95,200) for 10 years and 20 years, respectively, inclusive of the miscellaneous expenditure towards supporting NHN.

Fig. 7 shows that the adoption of rural 5G NHN results in cost savings. Consider two scenarios for providing 5G services in the rural areas - case 1: 5G NHN with spectrum sharing and case 2: 5G networks without NHN or any form of network sharing, i.e., each operator deploying their own 5G networks. Consider the scenarios with 10 years of investment in the network for providing services in a rural area with a single site. The TCO per site for each MNO to deploy 5G without NHN is INR 4.75 million ($ 64,476), which combines the sums the cost for 4 MNOs around INR 18.5

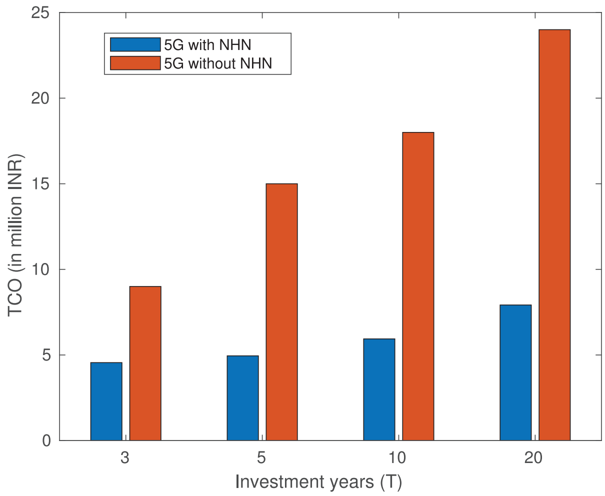

FIGURE 7. TCO for 5G networks with and without NHN.

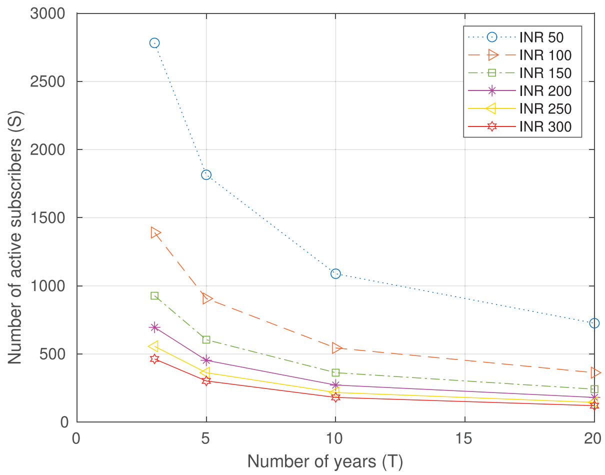

FIGURE 8. Minimum subscribers required on the network for break-even to be achieved.

million ($ 254,452). However, the cost for an InP deploying 5G NHN is INR 5.4 million ($ 73,960), where the TCO per MNO would be INR 1.35 million ($ 18,320) per MNO. This translates to a cost reduction of around 70% per MNO. The 5G NHN reduces the overall cost for the network per site and MNOs, by at least 65%.

2) ESTIMATION OF THE MINIMUM NUMBER OF SUBSCRIBERS

Fig. 8 shows the minimum number of subscribers required for monthly ARPU ranging between INR 50 and INR 300 and an investment duration of 3 to 20 years. The cost for provisioning service is equated to C_{sp}. The network has the lowest number of required active subscribers compared to the other scenarios when an investment duration of 20 years. Furthermore, with a monthly ARPU of INR 300 for a 20-year investment, the network would be feasible even with a minimum of 100 subscribers with 0 customer growth rate, as shown in Fig. 8. If the investment duration of 10 years, then the minimum subscribers required are around 1100,

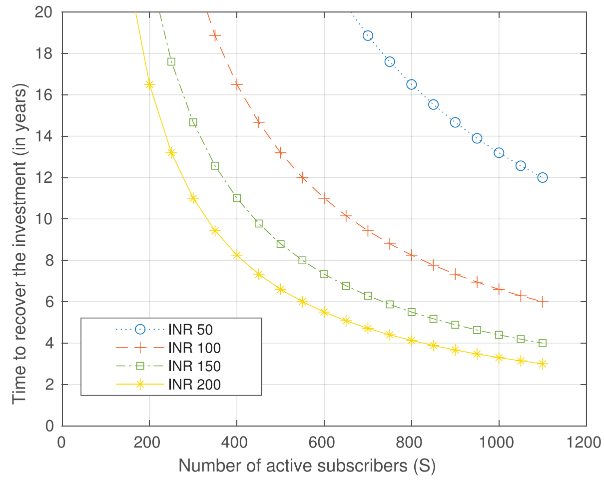

FIGURE 9. Time to reach the break-even point.

575, 400, 300, 275, and 250 at ARPU of INR 50, INR 100, INR 150, INR 200, INR 250 and INR 300, respectively.

As the ARPU increases, especially with an ARPU higher than INR 150, there is an exponential reduction in the number of subscribers required to reach the break-even point. For any investment duration with a higher ARPU, the network becomes feasible for less than 500 subscribers. It would need at least 500 subscribers with a subscription fee of INR 300 to 2350 subscribers with a subscription fee of INR 50 for a scenario involving a 3-year investment.

3) ESTIMATION OF TIME TO RECOVER THE INVESTMENT

Fig. 9 shows the time taken to reach the break-even point of the investment. The time to recover the investment depends on the TCO, network take-up, service demanded, ARPU, number of subscribers and service quality.

The break-even time with a monthly ARPU of INR 50, when the number of subscribers is between 1200 and 700, respectively, can be reached between 12 and 20 years for a rural site. With a 20-year investment, however, it becomes feasible with fewer than 200 subscribers on a network that has a monthly ARPU of 200. The break-even time would occur in 3 years with 1100 subscribers under the same scenario. The timescale that InP should invest depends on the village population, expected ARPU and network take-up rate. The network becomes feasible for more than 1000 subscribers for any duration with a monthly ARPU higher than INR 100.

4) ESTIMATION OF MINIMUM INVESTMENT PER USER WITH A USER GROWTH RATE

Fig. 10 shows the customer growth chart for a network having 100 subscribers in the first year with a subscriber growth rate, r_g of 7%.

Fig. 11 shows the minimum investment per user required to provide 5G NHN in a rural area to achieve a zero NPV at the end of the investment period. We assume that the customer growth rate r_g to be 7%, and the targeted rate

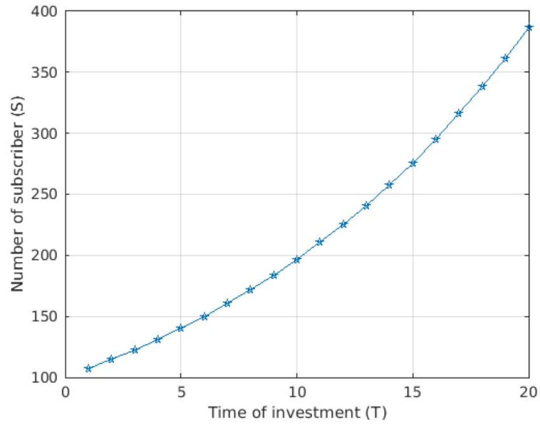

FIGURE 10. Customer growth chart over the number of investment years.

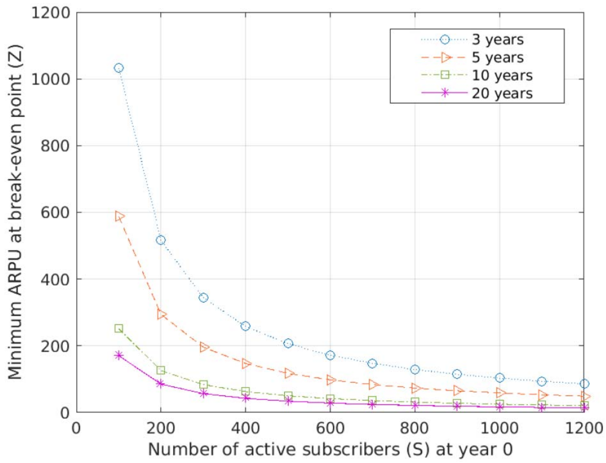

FIGURE 11. Minimum investment per customer towards the network to reach break-even point.

of returns r to be 8% (from other alternative investments). In rural areas where 100 active subscribers at year 0, the monthly ARPU is expected to be INR 1,100, INR 600, INR 250, and INR 180 for investment duration of 3, 5, 10 and 20 years, respectively. The minimum monthly ARPU exponentially reduces to less than INR 200 and 100 for any investment duration with more than 500 and 100 subscribers, respectively. Fig. 11 shows that 5G NHN is suitable for a village with a 3-year investment having less than 500 subscribers as well. By compromising a little on reliability, if the equipment is 2^{nd} or 3^{rd} grade, then the TCO would decrease exponentially, which reduces the minimum investment required per end-user further.

B. SENSITIVITY ANALYSIS

Sensitivity analysis helps investigate the impact of the dependent variables by changing the independent variables under the given set of assumptions. The study uses 'Visyond' [51] software for the estimations of factors impacting the NPV by varying each factor at a time by ±10% variations from the base case, in which, the input parameters results in NPV = 0 scenario and requires only wireless backhaul as discussed in Section III-A.

TABLE 7. Sensitivity analysis for rural 5G NHN.

Input	Input type	Influence on NPV
Take-up	Demand	22.34%
ARPU	Demand	22.34%
Population	Demand	22.34%
RANs, Tower and more	Economic	7.87%
Backhual	Economic	7.16%
Operations	Economic	7.16%
Investment duration	Economic	6.93%
Incremental cost (C_{inc})	Demand	3.73%
Spectrum	Economic	0.02%
Core	Economic	0.01%

TABLE 8. 5G network parameters.

5G KPI	Category
Downlink mean throughput per user	50 Mbps
Frequency band	700 MHz and 3.8 GHz
Carrier Bandwidth	10 MHz and 20 MHz
Antenna Technique	MIMO
Modulation	256 QAM
Cellular Layout	120° sectorial antenna
Propagation Model	Okumura-Hata, Longley-Rice
BS Power	46 dBm
Scenario	rural
Network Speed	100 - 400 Mbps
Tx Antenna Height	10 m and 30 m
BS Antenna Height	1.5 m
Network Slicing with Multi-Tenancy	Yes
Number of National level MNOs	4

Table 7 shows the sensitivity analysis for rural 5G NHN in the Indian scenario. Note that all values are normalised to a sum of 100%. Demand factors such as ARPU, take-up percentage, and population have a substantial influence on network feasibility with sensitivity of 22.34% each. CAPEX, such as RANs, masts, towers and more impact by 7.87%, whereas backhaul, and operations impact by 7.16% each on the overall sensitivity. Other parameters such as incremental slice cost (C_{inc}) and investment duration impact the sensitivity by 3.73% and 6.93% respectively, whereas factors such as spectrum, and core have negligible effect.

C. CASE STUDY - INDIA

This section outlines a case study performed for four Indian villages to verify the trends obtained. These villages have poor coverage or no coverage as per 'OpenSignal', making it suitable for studying the feasibility of the network. Consider a greenfield rural 5G NHN deployment with BS in the centre of the village for coverage modelling for the case study.

Table 8 shows the technical network parameters used for performing coverage analysis for the Indian scenario. The Okumura-Hata radio propagation model was used for simulations to understand the SINR values in the region of interest. From the simulations, in a rural area with a power level of 46 dBm, the coverage radius can be as high as 4 km from the BS at 3.6 GHz and greater than 10 km at 700 MHz. Usually, the location of a BS is selected such that 6 to 8 nearby villages are covered per site when using a frequency less than 1 GHz. Minimal obstruction to the signal path due to the lower height of buildings is one of the main reasons for high coverage in rural areas.

FIGURE 12. Coverage plots with 10 m antenna height at I - 700 MHz with bandwidth of 5 MHz and II -3800 MHz with bandwidth of 10 MHz: Dhanushkodi (I (a), II (b)), Lempia (I (c), II (d)), Bandholi (I (e), II (f)) and Muddunoor (I (g), II (h)).

From the coverage plots of these rural areas, that using either a 10 m antenna at a frequency of 700 MHz or 3800 MHz, it is possible to provide adequate coverage and speed in the assessed area as shown in Fig. 12. The cell coverage extends to nearby farms and villages that are present within a radius of 8 km from the location of the transmitter

TABLE 9. Case studies - India.

Location	Dhanushkodi, TamilNadu	Lempia, Arunachal Pradesh	Bandholi, Rajasthan	Muddunoor, Telangana
Topography	Sea-side	Mountain	Desert	Plain and rocky
Population	500	635	1357	3493
Initial Subscribers	175	222	474	1222
minimum investment per user	INR 185	INR 120	INR 70	INR 20

tower. If required, lower the power levels to focus the cell coverage only on the village of interest and its use-cases. This study focuses on one particular area where the transmitter is situated to understand the techno-economic feasibility of 5G NHN in communities with low subscribers.

The minimum investment is calculated for each village as shown in Table 9 using information from Fig. 11. For a 10-year investment plan at 7% customer growth rate and an initial number of subscribers at 35%, take up, the study examined. The coverage plots for different villages using these frequency bands as shown in Fig. 12. At 700 MHz, the coverage is higher while the speed is reasonable (300 Mbps). However, at 3800 MHz, the coverage is slightly lower but with very high data rates (700 Mbps). The InP could accordingly select the frequency bands based on the ease of licensing the spectrum bands.

In the coverage planning, consider an omni-directional antenna to support applications. Table 9 shows the case study on the suitability of network slicing for different villages, as described below.

- In Dhanushkodi, the initial number of subscribers is around 175. If InP deploys a rural 5G NHN on the shore, then coverage is uniformly present up to a radius of 9 km (254 km^2) at 700 MHz and 7 km (153 km^2) at 3800 MHz, from the tower location; and covers a few nearby islands as well. The main possible end-users of the network are fisherman and their families. This place is also a tourist spot, generating additional revenue for the InP by serving those roaming customers. In this scenario, unless the ARPU is higher with customer growth of 7% or greater, the network is not feasible.
- In Lempia, the initial number of subscribers is around 222. Similar to the previous case, it requires a higher ARPU or customer growth rate. However, one advantage for Lempia is the tourist who would be roaming on the network. It is close to a tourist location. But the network needs to minimise the blind spots created due to the topographical challenges, i.e., being surrounded by mountains. The site approximately covers a region of 100 km^2 at 700 MHz and around 40 km^2 at 3800 MHz from the transmission tower.
- In Bandholi, the initial number of subscribers is around 474 making the network feasible even with a zero-customer growth rate. At 7% customer growth rate, the network is viable with a minimum ARPU of INR 70. The network can earn revenue by supporting agricultural applications as well. The site approximately covers a region of 120 km^2 at 700 MHz and around 50 km^2 at 3800 MHz around the transmission tower.
- In Muddunoor, the initial number of subscribers is around 1222. In this scenario, the network is successful for both InP and MNOs, as the minimum ARPU required for a feasible network is around INR 20. Rural connectivity is an attractive option for more than 1000 active subscribers using 5G NHN. The site covers a region of 270 km^2 at 700 MHz and around 180 km^2 at 3800 MHz from the transmission tower.

From the above discussions, the feasibility of rural 5G NHN changes for varying inputs from different villages. The feasibility of the proposed solution depends on parameters such as topography, infrastructure requirements, demand, ARPU, expected end-users and duration of the investment. When the network is feasible for individual end-users, then the network would most likely be viable for additional business customers. Business customers from small-scale to large-scale would generally pay higher ARPU compared to individual end-users. The impact of business customers in rural areas could be a possible extension of this work.

D. DISCUSSIONS

The above techno-economic analysis concludes that 5G network slicing with NHN is a viable option. The proposed solution for rural connectivity is an attractive business option and would potentially solve the digital divide challenges.

In the Indian scenario, there is a decent number of subscribers at any given place, shown in Table 2. The challenge lies in providing 5G services in rural India at low ARPU. As discussed in Section II-D, the InP would have to focus on the last mile connectivity to the villages from the nearest PoP to serve the end-users using low-cost backhaul solutions. 5G NHN encourages rural connectivity even for subscribers as low as 100 for a 10+ year investment.

IV. CONCLUSION

In this paper, the study explores 5G network slicing with NHN for tackling the digital divide. A general model analyses the techno-economic feasibility of 5G NHN per site, with special focus on areas where no MNO is interested in providing services. 5G NHN is seen as a cost-effective solution compared to traditional network deployment for rural scenarios. Later, to understand the techno-economic feasibility, the proposed model was applied to the Indian setting. The discussion highlights the state-of-the-art of the Indian telecommunication sector and the need for innovative solutions in the rural market. Next, the description of system requirements and the corresponding KPIs for the 5G NHN in the Indian scenario. End-to-end 5G network slicing among the MNOs with InP provisioning a 5G network with required KPI and SLAs can reduce network cost by at least 50% compared to the traditional network in rural parts of India. The study explores the network parameter requirements to analyse the viability of rural 5G NHN deployed by InP. For example, the rural 5G NHN is sustainable within a 10-year duration, having a customer growth of 7%, even for a village with at least 100 subscribers on the network. As the number of subscribers increases, the network becomes feasible for a shorter investment time and lower ARPU. According to the sensitivity analysis for the rural 5G NHN for the India scenario, the most crucial parameters are demand inputs such as take-up rate, ARPU, and population. The rural areas could have a different pricing plan based on the 'investment per user' analysis. Later, the case study for a few Indian villages with different topography and inputs - 'Dhanushkodi', 'Lempia, 'Bandholi' and 'Muddunoor', helped in the usage of the model that developed. This model is versatile and applied to different scenarios in India and around the world. Thus, 5G NHN can be considered a strong contender for providing 5G solutions in rural communities.

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