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Infrastructure Sharing Strategies for Wireless Broadband

Shruthi Koratagere Anantha Kumar, *University of Strathclyde*, Edward J Oughton, *George Mason University*

***Abstract*—There is a growing need to provide high-speed wireless broadband to deliver mobility for an increasing number of global Internet users. However, there are a variety of engineering-economic challenges associated with this endeavor. Therefore, an emerging zeitgeist of the modern telecommunications era is the concept of *infrastructure sharing*. While this approach has existed for many decades, there has recently been growing interest by both network operators and governments, who share the joint aspiration of reducing costs and increasing broadband coverage. In this article, we firstly explore *where* infrastructure sharing can take place, *how* these strategies can be implemented in practice, and *who* are the key enablers. Next, we report on a techno-economic viability assessment of rural 5G infrastructure sharing strategies for four major approaches, which include Business-as-Usual (No Sharing), Passive Sharing, Active Sharing, and a Neutral Host Network (NHN). The findings suggest that any network sharing strategy has a higher Net Present Value (NPV) of between 20-90% compared to the baseline (*No Sharing*). In particular, an NHN approach can help reduce deployment costs by 10-50% compared to other strategies to provide rural wireless broadband.**

***Index Terms*—Infrastructure sharing, broadband, wireless broadband, 5G, neutral host.**

I. Introduction

INTERNET connectivity has become a pervasive need across society and the economy, driving demand for reliable, high-speed wireless broadband services. For example, it is now commonplace for many consumers to use wireless broadband to access a wide range of online services, from finance and virtual education, to video calling and remote working. The traditional approach to the deployment of wireless broadband infrastructure involves each network operator deploying and managing their own independent networks to provide broadband connectivity in a region. For example, mobile network operators (MNOs) and Internet service providers (ISPs) sell their services to retail customers, businesses, and the wholesale market. However, this traditional deployment method is expensive, both in terms of capital expenditure (CAPEX) (e.g., equipment, assets, licenses, etc.), and operation expenditure (OPEX) (e.g., maintenance and repair) [1].

Regardless of broadband being crucial for economic development, it is unfortunately not always economically viable for operators to deploy the necessary infrastructure via market-based methods [2]. The consequence of these techno-economic difficulties means that there is a ‘digital divide’ where some communities are disproportionately affected by these infrastructure disparities [2]. Indeed, the United Nations’ Sustainable Development Goals (SDGs) Target 9.1 aims to ensure affordable access to universal broadband infrastructure by 2030, which is therefore a pressing global policy priority.

Although there are many factors that affect the ‘digital divide’, including demand-side adoption aspects, the lack of supply-side infrastructure is a major contributor to this phenomenon. Indeed, disparities in broadband infrastructure often result from low population density and/or weak adoption. Thus, these (usually rural and remote) areas represent a low priority for economically rational network operators to deliver new infrastructure or upgrades. These major factors can also be compounded by low fiber point of presence (PoP) density, challenging terrain, and the ongoing operational cost of network maintenance in these environments.

While there are many wireless broadband connectivity issues in rural and remote locations [3], there are also challenges in other settlement locations. For example, in dense urban and suburban areas, connectivity can often still be poor, especially when existing infrastructure is operating at or near maximum capacity constraints [4]. Indeed, as adoption rates and data consumption per user increase, existing wireless infrastructure assets become saturated.

Major engineering-economic factors in the telecommunications industry are now calling into question the traditional infrastructure deployment model. Consequently, there is renewed interest in cost-reducing strategies [5]. Currently, to overcome capacity constraints in wireless broadband networks, regardless of urban or rural locations, a network operator has to choose from three capacity expansion upgrade strategies - increase spectrum bandwidth, upgrade existing technologies (e.g., from 4G to 5G, or Wi-Fi 5 to Wi-Fi 6), or increase site density. However, if none of these options are economically viable, then operators may need to consider other business model approaches, such as *infrastructure sharing*.

The content described in this article is part of ongoing research studying the viability of infrastructure sharing strategies, exploring the impacts of various deployment scenarios, capacity targets, and realistic factors affecting investment [6]. A large focus is placed on how different sharing strategies affect the economic viability of new 5G infrastructure upgrades in rural areas. Existing deployment models may perform poorly in these situations, highlighting the need for new technology and business model innovation. The key contribution of this article is to explore the various benefits and limitations of different wireless broadband infrastructure sharing strategies.

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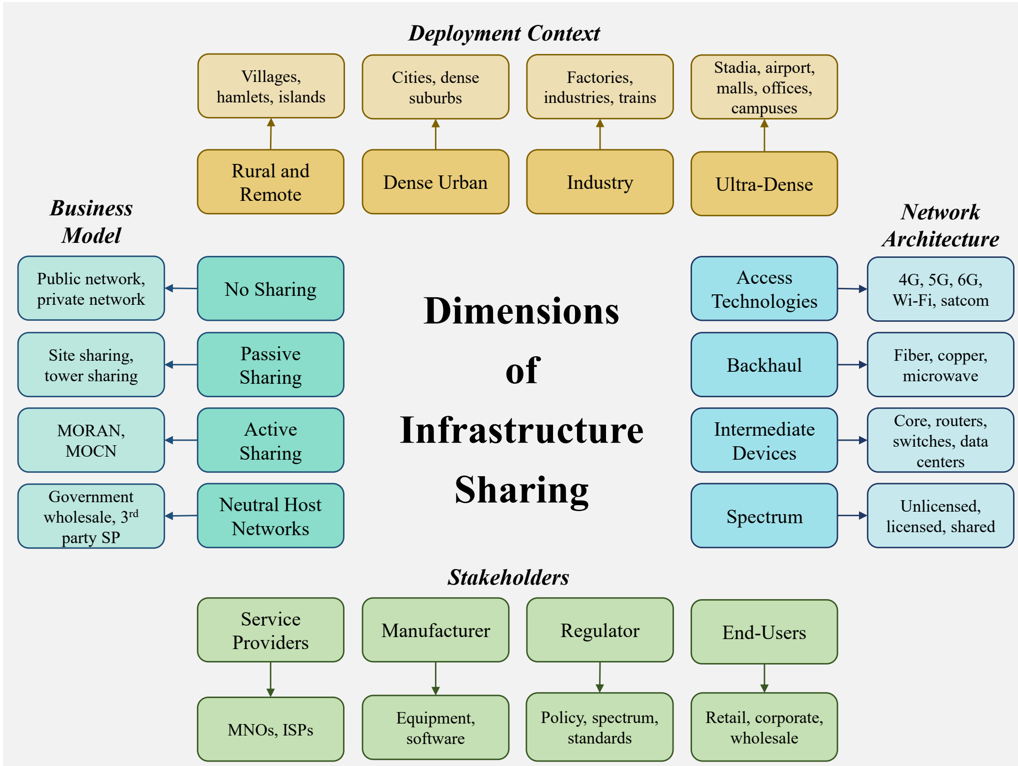

Fig. 1: Dimensions of infrastructure sharing strategies for wireless broadband

II. Dimensions of Infrastructure Sharing: Where, How and Who?

Wireless broadband infrastructure can be deployed and operated by a variety of entities. There is a wide range of motivating factors for these entities, from profit-seeking MNOs, ISPs, and other private companies to those with strong social objectives, such as community network providers and governments. Private network operators usually take a rational infrastructure investment approach and deploy network assets based on return on investment (ROI), given the level of demand in the area. In contrast, those deploying wireless broadband assets to achieve social objectives may take an antithetical approach, instead targeting only those areas which are not economically viable via rational market-based infrastructure delivery. Figure 1 shows the many dimensions of infrastructure sharing strategies for wireless broadband delivery. These include the following four interrelated factors:

A. *Stakeholders*

All entities associated with telecommunication networks are relevant stakeholders, including network operators, manufacturers (hardware and software), regulators, and the final end-users of any provided broadband service.

Firstly, service providers (SPs) operate network assets to deliver broadband services and may desire to participate in network sharing strategies. For example, MNOs, ISPs, or other SPs all have the key business of transporting user traffic to and from global Internet networks in return for revenue. Secondly, a manufacturer consist of any entity which builds hardware or software network components to enable network functions. This stakeholder is essential for ensuring that any assets produced are secure, stable, reliable, and provide high-speed services. Manufacturers have an important role in network sharing, as they are responsible for ensuring their components can be loosely coupled to support easy interfacing and compatibility between different vendor devices. Thirdly, regulators play a key role in formulating and delivering industrial policies that balance economic efficiency and equity considerations [2]. Therefore, they have a key leadership position in encouraging and enabling infrastructure sharing strategies. Indeed, regulators are also responsible for spectrum policy and ensuring the efficient allocation of this scarce resource (e.g., across licensed and unlicensed bands). Regulators also play an important role in the international spectrum and standardization bodies, including designing and developing technical standards that support infrastructure sharing.

Finally, end-users are the final paying consumers of broadband services, including retail customers, businesses, local and national governments, and other industry verticals. One important requirement for end-users is network and data security, as confidential information is transmitted over any shared network. Users are often agnostic as to how operators provide broadband services, providing they receive their desired quality of service, securely.

B. *Business Model Approaches*

As highlighted in the introduction, the various economic challenges in the telecommunications industry are forcing network operators to explore new business models. Here, we summarize and highlight the main approaches for infrastruc-

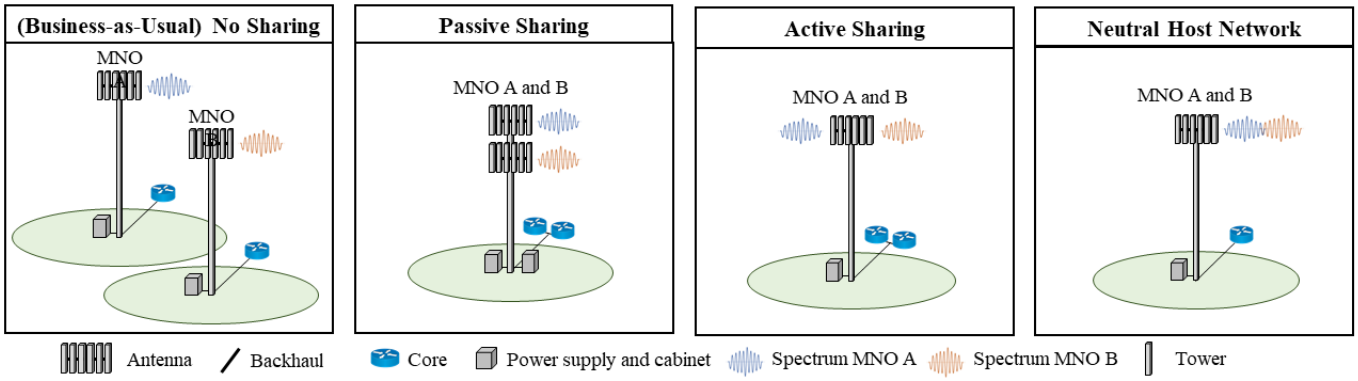

Fig. 2: Infrastructure Sharing strategies

ture sharing, as visualized in Figure 1. Moreover, Figure 2 provides a detailed architectural example of the differences in sharing strategies in the case of cellular technologies (e.g., for 5G).

The ***Business-as-Usual (No Sharing)*** context has each operator deploying either a public or private independent network that is operated and owned by this entity. In many markets, such an approach represents the status quo and is popular with network operators in high demand locations because it provides 100% control over any built assets. Moreover, operators have the opportunity to retain all of the generated revenue and profit. In contrast, governments may favor this approach for public broadband networks when infrastructure asset construction is necessary to expand coverage and achieve infrastructure-based competition.

In a ***Passive Sharing*** approach, at least two operators share non-electronic components, such as the site compound, and tower structure. Typically, a joint venture company is created to legally manage shared assets, with each operator having a proportional shareholding. This infrastructure sharing strategy is already prevalent in many telecommunication markets and is a proven way for operators to collaboratively reduce costs.

When utilizing ***Active Sharing***, at least two operators share both passive and active electronic components, such as antennas, radios, and baseband units (BBU) (while excluding spectrum resources and the network core). The two popular methods for *Active sharing* are multi-operator radio access network (MORAN) and multi-operator core network (MOCN). In addition, a joint venture company may be employed to manage the operation of the assets. To maintain infrastructure-based market competition, regulators may limit the number of operators participating in active sharing. Roaming agreements are a more basic form of this strategy, where operators allow their national or international competitors' customers to roam on their network, to extend service coverage.

In a ***Neutral Host Network*** (NHN) approach, two or more operators agree on end-to-end network sharing for all passive and active components, which may also include the sharing of any spectrum resources and the network core. The 5G NHN sharing strategy is different compared to those offered by earlier technologies such as 2G/3G/4G, as many stakeholders can co-exist for multiple use-cases. The infrastructure provider deploys and maintains the NHN infrastructure, while other operators become virtual tenants on the incumbent network [4]. This type of sharing is growing in popularity. For example, this method is being tested and trialed for many contexts, including hospitals, densely populated city centers, rural and remote areas, indoor spaces, seaports, airports, and university campuses [4], [6], [7]. Finally, a government driven national wholesale network is also a basic version of the well-established NHN, either by playing an active role in deploying new broadband infrastructure or by regulating an incumbent to offer services based on set prices [2].

C. Deployment Context

There are many contexts where infrastructure sharing is an attractive strategy. Cost sharing helps in reducing network operator risk and exposure to demand uncertainty in situations where adoption and average revenue per user (ARPU) are weak. Indeed, in a challenging rural and remote deployment context, the ability to share costs helps network operators improve the economic viability of their investments [2].

In contrast, dense urban areas have high demand, adoption, and ARPU. However, the challenge lies in the cost-efficient deployment of infrastructure. For example, in high-rise buildings, there may not be enough physical space to deploy multiple networks, therefore sharing can help to avoid in-building resource duplication [4], [7]. Moreover, serving indoor spaces using an outdoor-to-indoor approach is challenging, and can lead to poor user experience. Indeed, newer high-rise buildings in urban centers are increasingly built from reinforced concrete and steel, with large quantities of insulation making propagation by higher frequencies difficult. Sharing can boost indoor coverage and enhance user Quality of Experience (QoE).

There are many deployment contexts that require advanced connectivity across industry verticals, however these can be specific to each business model, for example, in agriculture, transportation, mining, smart cities, utilities, health, education, and government. Additionally, in the case of transportation infrastructure, such as highways or railway lines, there is also a strong justification to be made for network sharing on safety management grounds. For example, this might be especially true in very high-risk situations, such as along high-speed railway lines. While broadband connectivity is essential for business commuters, high-speed trains can travel at speeds of more than 250 km/h, where signaling requires very high reliability [8].

Although there is a strong business case for deploying multiple independent networks in ultra-dense areas, sharing is often a sensible option. For example, in shopping malls and stadia, the benefits of a shared network include improved interference control, resource utilization, and more efficient management of deployed civil engineering assets (as only a single infrastructure owner needs to coordinate with the city government or real estate management company) [7].

D. Network Architecture

There is a wide range of wireless communication technologies and architectures that are amenable to infrastructure sharing. Indeed, we formally divide this area into four main groupings, which include access networks, backhaul connectivity, intermediate devices, and spectrum resources.

Cellular, Wi-Fi, and satellite technologies broadly comprise wireless broadband access technologies. Currently, infrastructure sharing is growing in all three access domains [4]. For example, in cellular networks, infrastructure sharing can range from *No Sharing* to a fully NHN architecture to provide coverage. In contrast, Wi-Fi access networks are often subcontracted to third parties when deployed to both outdoor and in-building environments (e.g., offices). This provides a single designed and managed connectivity platform for all building users to connect to, historically offering both Internet access and Wi-Fi calling when cellular coverage is poor [9]. Satellites are also being researched to support different levels of infrastructure sharing for different industry verticals along with retail customers [1].

However, access networks are only one network architecture component. Indeed, a variety of fixed and wireless backhaul technologies are in use, which may be shared to enable packet transport to and from a shared access location, to another infrastructure location, such as a fiber PoP [3]. For example, in high-income countries, backhaul for cellular sites is most commonly a fiber optic link or a legacy copper/coaxial cable. Meanwhile, in low- and middle-income countries, a wireless microwave backhaul link (point-to-point or point-to-multipoint) is the most commonly used site backhaul option available for sharing [2].

In less common cases, network operators may decide to share an intermediate device, including servers and routers, as well as their own licensed spectrum resources. This may depend on an operator's ad hoc desire given a particular deployment context. Unlicensed spectrum resources are already widely shared by network operators, but this is usually for highly localized delivery (e.g., Wi-Fi) or by niche wireless ISPs operating in rural and remote areas (where the quality of service is delivered on a best-effort basis). The degree to which components across the four network segments are shared (or not) differentiates how the main infrastructure sharing strategies are implemented in practice.

III. 5G: Technology, enablers and impact

The latest cellular technology standard is 3GPP 5G-Advanced (Release 18), with earlier releases already being globally deployed. Compared to 4G, the key performance indicators (KPIs) of 5G include 10-100x data rates, 100x devices, and 10x lower energy consumption [10]. A key 5G architecture which supports NHN multi-tenancy is 'slicing', in which virtual networks are created to serve specific use-cases by allocating appropriate isolated resources within an optimized topology [11]. Furthermore, the end-to-end NHN KPI for the 5G network supports improvements in terms of accessibility, integrity, utilization, mobility, and energy efficiency [12]. This is achieved by implementing many of the main technological requirements for a 5G standalone network based on 3GPP Release 18 and earlier, including secure slice creation capabilities to enable independent and isolated usage, spectrum aggregation, and dynamic spectrum sharing by multiple operators [12], [13].

Moreover, 3GPP Release 18 also includes a range of features to support hyperconnectivity, including (i) the usage of artificial intelligence and machine learning (AI/ML) to improve network performance, automation, and the air interface, (ii) extended reality (XR) for cloud gaming, (iii) high-accuracy positioning of users and devices, (iv) beamforming for personalized coverage, and (v) network power savings [13]. Furthermore, this release also supports use-cases for connecting the unconnected, including 5G satellite integration to provide coverage in remote areas, RedCap to support a device with reduced capabilities, and a personal Internet of things (IoT) network to support out-of-coverage relays [13].

The sharing of infrastructure in 5G and future generations is highly dependent on a range of technology enabling institutions including governments, investment firms, regulatory agencies, standardization organizations, and funding bodies. Furthermore, there is also a range of techno-economic drivers which affect sharing strategies based on the business value present, the economic feasibility of each technology, associated pricing, market competition, the degree of cooperation among competitors, and the likelihood of future revenue opportunities.

IV. Techno economic assessment for infrastructure sharing strategies

Techno-economic assessment (TEA) is a key tool to help network operators and other stakeholders in the telecommunication market assess the suitability of proposed new technologies, business models and policies [14]. The success of infrastructure sharing in practice is dependent on operators having adequate market incentives. Therefore, understanding the techno-economic viability of any strategy is essential. This includes the potential return on investment. Here we report the findings of a techno-economic model that evaluates various infrastructure sharing strategies [6]. The input-output structure of the TEA model used in this study is illustrated for reference in Figure 3.

The evaluation focuses on upgrading brownfield rural cellular infrastructure to target a number of 5G KPIs. Consider a

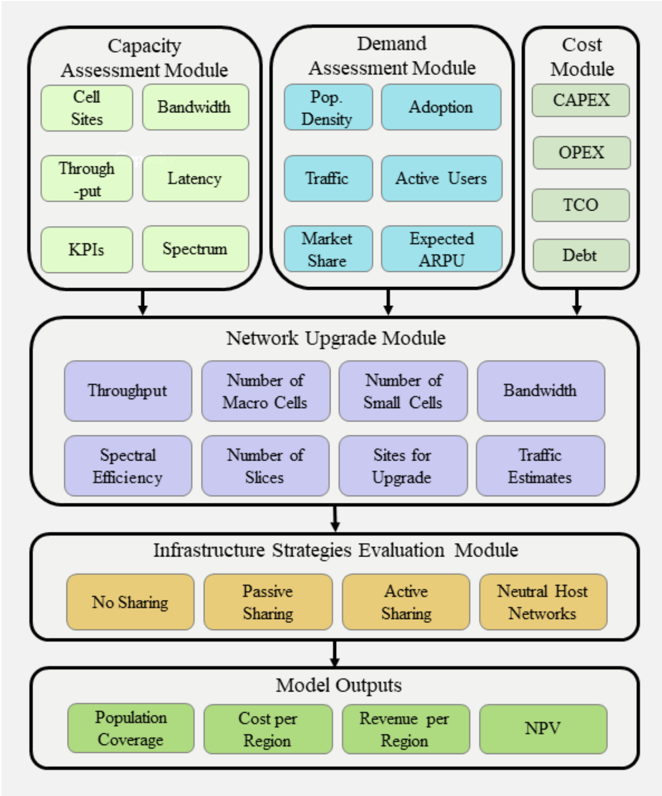

Fig. 3: Modeling methodology

rural area of approximately 500 km^2 with a population density of 36 people per km^2. The model estimates the realistic channel throughput at the cell edge to provide 30 Mbps per user at a 95% confidence level. The aim is to deliver a high quality of service (QoS) to ensure a satisfactory QoE for each user. Over an assessment period of 10 years (2023-2032), the brownfield macro-cells present are upgraded to 5G and small-cells are deployed to serve end-users with a mean monthly data usage of 50 GB. The model aims to estimate the number of sites and equipment needed for each upgrade strategy, which varies depending on the degree of infrastructure sharing, thus altering the cost of the supply-side deployment.

The main assessment metric used here, the net present value (NPV), represents the present value of all necessary investments and potential future revenue over the study period. Here, the cash outflow is the total cost of ownership (TCO), while potential future returns are calculated by finding the product of the number of subscribers (new and existing subscribers upgrading to 5G), ARPU per month, study period (in months), and subscriber growth rate [6]. Moreover, an NPV with a value exceeding zero represents a positive return on investment, whereas a negative value indicates a loss. In Figure 4, the NPV is illustrated for the four 5G network sharing strategies explored, along with a set of revenue scenarios that are relative to the baseline estimate of the future generated income. Future revenue is one of the most uncertain parameters, which justifies the exploration of the sensitivity of this parameter.

The results of the NPV analysis quantitatively demonstrate how economic viability varies for each infrastructure sharing strategy. In fact, in Figure 4 for a baseline ARPU of $30, the NPV is still negative for both the *No Sharing* and *Passive Sharing* strategies, indicating a negative return on investment. In contrast, the NPV is marginally positive in the case of *Active Sharing*, and then substantially positive when implementing a *NHN* strategy. Thus, infrastructure deployment approaches in challenging rural areas are well suited to using a neutral host. While this strategy provides the best business case based on these quantitative estimates, operators may also find this sharing option reduces their vulnerability to demand uncertainty in weak adoption and/or low ARPU locations. Equally, telecommunication regulators may favor that this strategy enables smaller, local operators to also provide broadband services, lowering the barriers to entry for entities with fewer capital resources.

Additionally, the results in Figure 4 illustrate that the business case for *Passive Sharing*, *Active Sharing* and a *NHN* approach, exhibit a higher NPV between 10-20%, 20-35%, and 35-50%, respectively, against the Business-as-Usual (*No Sharing*) strategy. Indeed, the findings suggest that sharing strategies outperform other non-sharing models by at least 15% when matched to comparative revenue and demand conditions. Furthermore, a sensitivity analysis of future revenue is presented in Figure 4, achieved by generating different scenarios relative to the estimated baseline future revenue. Based on the adopted model parameters, the results indicate that increasing ARPU by 33% results in a corresponding NPV increase of 2x when using *Passive Sharing*, 3.5x when using *Active Sharing*, and 4x when using a *NHN* strategy, versus the Business-as-Usual model (*No Sharing*). The wider ramifications of these results will now be discussed.

V. Discussion of Infrastructure Sharing Strategy Performance

This article identifies four main benefits offered by infrastructure sharing. While there is little doubt that such strategies enable cost savings, as this is one of the most fundamental reasons why network operators seek out sharing opportunities, it is important to identify this benefit first. Relating to this, the second benefit is that sharing strategies also enable operators to de-risk investments when moving into areas of unknown or uncertain demand, via syndication. Thirdly, a much higher QoS/QoE can potentially be delivered to users when network operators share infrastructure, in particular when applied to in-building networks. For example, the traditional outdoor-to-indoor method for providing service can perform poorly in certain deployment situations, especially in dense urban environments. Finally, there are a range of sustainability benefits from avoiding infrastructure duplication, as fewer emissions and environmental pollutants are released in both building and operating multiple broadband infrastructure networks.

It is well established that the supply and demand dynamics involved in upgrading an existing network to a new technology (e.g., 5G) can be challenging in both urban and rural areas. Therefore, the following evaluation explores the different aspects of the four main network sharing strategies. For example, a discussion is undertaken which identifies the deployment

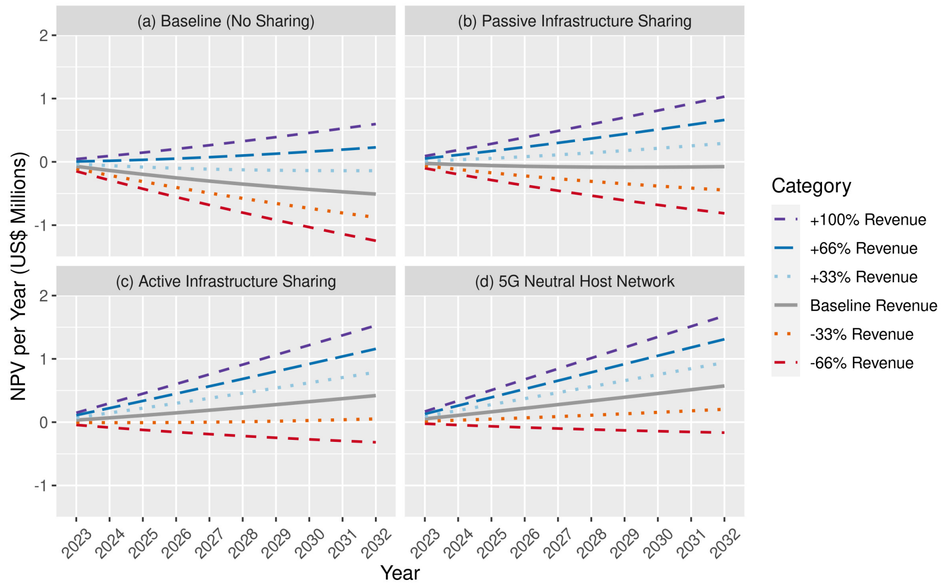

Fig. 4: NPV analysis for the various sharing strategies in rural scenario

contexts in which each model is potentially most suitable, as well as the challenges associated with each sharing strategy.

Business-As-Usual (No Sharing): When a rural area has high revenue potential, then a Business-as-Usual strategy may well be the best option for an operator to pursue. Indeed, if an operator does select this option then this may not necessarily lead to a detrimental effect on wider society. For example, in areas of high traffic demand, this may still support multiple networks being built or upgraded, and established benefits from infrastructure competition among operators. However, there can be high barriers to entry for smaller local operators to enter the market and successfully compete.

Passive Sharing: Such a sharing model is preferred when there is healthy competition among operators, but only moderate demand for services present. Typically, operators will negotiate how to carry this out in practice, but it may involve reciprocal site access agreements on a site-by-site basis or establishing a joint venture with equal ownership among the different participating companies. The network management of site assets over time may undergo significant changes, as less desirable site locations are decommissioned.

Active Sharing: In low-demand, difficult-to-serve places, the expense of infrastructure deployment may force operators to look at more extreme cost reducing measures, making an actively shared approach more desirable. However, a key challenge with this strategy lies in reaching agreement in the arrangements for network sharing with other incumbent operators (who are also usually competitors). In these challenging deployment contexts, operators may want to complement each other's coverage areas via an active approach by enabling user roaming. Unless the potential operator is a national-level operator, there are high barriers to entry for local operators.

NHN: This option is the most practical for areas with low or ultra-high user densities [6], [7], [9], [15]. Indeed, a *5G NHN* strategy offers superior engineering capabilities, and a high degree of flexibility can also be provided to operators, for example, by utilizing short slice leasing periods. Despite being the cost-effective option, operators who lease resources from the incumbent MNO must be able to do so at a fair price and have confidence in longer-term price projections. Moreover, there are also many issues that could arise in the legal governance of each site, especially in how the QoS agreements are maintained and enforced between end-users, slice tenants, and other operators.

Finally, one key caveat that requires careful consideration is the impact of network sharing on market competition. The level of infrastructure consolidation over the next decade could be significant and requires careful scrutiny by telecommunication regulators to ensure competitive markets are maintained. Certainly, operators (as rational market actors) will prefer the selection of network sharing models based on the most attractive techno-economic feasibility, reflecting both the cost and revenue streams of any infrastructure upgrades. However, there may not always be mutually aligned interests between operators and regulators. Therefore, it is important for public policy to consider the wider ramifications of increased infrastructure sharing, along with any potential negative impacts on infrastructure-based competition. These areas would need to be explored as future impactful research problems.

VI. Conclusion

In this article, a general introduction to infrastructure sharing strategies was first presented that covered *where* infrastructure sharing may take place, *how* infrastructure sharing may take place, and *who* may enable infrastructure sharing to take place. Secondly, techno-economic results on the quantitative performance of four main strategies for rural 5G upgrades were presented, including Business-as-Usual (No Sharing), Passive Sharing, Active Sharing, and a NHN approach.

Indeed, the findings indicate that any network sharing strategy has a higher NPV of between 20-90% compared to the baseline strategy (No Sharing), which translates to a stronger business case for investment, and potentially higher profit margins. In particular, an NHN approach can help reduce deployment costs by 10-50% compared to other strategies to provide rural wireless broadband.

Importantly, this article identifies four main benefits of infrastructure sharing. While the first factor, cost savings, may be platitudinous it has large ramifications for the second factor, pertaining to uncertainty reduction. For example, network operators have the ability to move into locations with large demand uncertainty and share risk with other operators through a process of syndication. The only caveat is that while downside risks can be shared, operators may also have to share any upside revenue growth among syndicated competitors with whom they are sharing assets. Thirdly, there are strong benefits for boosting QoS/QoE, especially as network operators can provide better service in challenging environments. For example, this could be in rural and remote locations, or also through sharing in-building infrastructure in dense urban locations which are hard to serve using higher frequencies via outdoor-to-indoor methods. Finally, there are a range of sustainability benefits from sharing network assets, as avoiding infrastructure duplication reduces carbon and other environmental emissions produced in the construction and operation of new network assets.

While the content of this article has provided a timely primer for those interested in the implications of infrastructure sharing strategies, there are still many important future areas of research which require attention. Firstly, the large majority of studies in the literature have hitherto focused on only the cost savings associated with sharing strategies. Therefore, new quantitative analytics are required which consider broader impacts, beyond just cost. This research needs to therefore include the environmental emissions savings attained from avoiding infrastructure asset duplication, for example, from deploying a neutrally hosted 5G network. Secondly, future studies would also benefit from trying to better quantify the potential improvements in QoS/QoE which arise from network operators sharing infrastructure to improve the coverage of provided broadband services, for example via 5G. Such evidence would be particularly insightful if it quantified improvements in serving hard-to-reach locations, in rural and remote areas, and for providing improved in-building coverage.

Finally, one key caveat that requires careful consideration is the impact of network sharing on market competition. The level of infrastructure consolidation over the next decade could be significant and requires careful scrutiny by telecommunication regulators to ensure competitive markets are maintained. Certainly, operators (as rational market actors) will prefer the selection of network sharing models based on the most attractive techno-economic feasibility, reflecting both the cost and revenue streams of any infrastructure upgrades. However, there may not always be mutually aligned interests between operators and regulators. Therefore, it is important for researchers and policy analysts to consider the wider ramifications of increased infrastructure sharing, along with any potential negative impacts on infrastructure-based competition.

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Shruthi Koratagere Anantha Kumar ,aka, Shruthi K A graduated from GITAM University, Hyderabad, in 2016. She is currently pursuing a Ph.D. degree with the University of Strathclyde, Glasgow, UK. She is a Visiting Faculty with George Mason University, Fairfax, USA, and Researcher with the StrathSDR lab, Department of EEE, University of Strathclyde. She specializes in rural telecommunications, business models, pricing strategies, game theory, cost assessment, and business models for 5G networks, especially for rural areas and 5G verticals applications.

Edward J. Oughton received the M.Phil. and Ph.D. degrees from Clare College, at the University of Cambridge, UK, in 2010 and 2015, respectively. He later held research positions at both Cambridge and Oxford. He is currently an Assistant Professor in the College of Science at George Mason University, Fairfax, VA, USA, developing open-source research software to analyze digital infrastructure deployment strategies. He received the Pacific Telecommunication Council Young Scholars Award in 2019, Best Paper Award 2019 from the Society of Risk Analysis, and the TPRC48 Charles Benton Early Career Scholar Award 2021.