Towards Frugal 5G: A Case Study of Palghar Test-bed in India

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***Abstract*—There is an ongoing transition from the fourth generation (4G) cellular standard to the fifth generation (5G). Amidst this transition, addressing the connectivity needs of rural areas is still a distant dream. In this article, we discuss the connectivity requirements of rural areas and also present a network architecture based on these requirements. Low energy, low mobility, and large cell are the key aspects when designing a broadband network for rural areas. We refer to this network as the *Frugal 5G* network. We discuss two testbeds that we have deployed in India based on the Frugal 5G network architecture. The first testbed spanning 7 villages studies the feasibility of providing high-speed connectivity to rural areas via TV UHF band. The second testbed has been scaled up to 25 villages and studies the feasibility of connecting the rural areas by employing IEEE 802.11 (5.8 GHz) technology. Deploying such a large scale network requires efficient planning which has also been discussed in the paper. Sustainability of the rural broadband network is an important issue and has been addressed by proposing a multi-stakeholder partnership model. Insights obtained from these testbed deployments suggest that for connectivity to be sustainable, network planning, use of renewable energy, local support & community participation, and efficient business model are the cornerstones that should be adhered to.**

I. Introduction

The world's Information and Communication Technology (ICT) statistics presents a strange paradox. Even when 84% of the global population lives in areas which are covered by mobile wireless broadband, the adoption rate is only 48% [1]. Such low global adoption rate can be attributed to the lack of affordability and digital awareness. The developing countries have even lower adoption rate. Although India has made rapid progress in telecommunication and is currently amongst the largest telecommunication markets of the world, the broadband penetration is marginal. There are only 482 million broadband subscriptions in a population of about 1.34 billion [2]. Of these broadband subscriptions, only 32% belongs to the rural areas which inhabit 70% of the total Indian population.

The most promising method to provide broadband access to every household is via fiber deployment. However, most of the developing countries lack a pervasive fiber network. Thus, people access the Internet largely via cellular connectivity which is mostly available in urban and semi-urban areas. The cellular operators do not find it a viable business proposition to extend the network coverage in rural areas owing to the low Average Revenue Per User (ARPU), sparse population density, intermittent availability of electricity, and arduous terrain. Thus, to fill this expectation gap between cellular operators and end-users in rural areas, we need to rethink the requirements set for the next generation cellular systems. Since 5G is largely focused towards urban-centric requirements such as high mobility, very low latency, and very high data rate, it is unlikely that the 5G network will serve the rural areas.

Frugal 5G refers to the vision of providing affordable broadband access to rural areas overcoming the above-mentioned challenges. In order to realize this vision, three major aspects need to be considered that are i) analyzing the rural requirements, ii) developing a network framework alongside a planning tool, and iii) addressing sustainability of the proposed framework on the ground. In this paper, the above-mentioned aspects have been studied and validated on the field by deploying Frugal 5G testbeds in Palghar, Maharashtra, India. The paper also discusses various insights and learnings from the testbed deployment.

In the remainder of this article, we discuss how the Frugal 5G framework is developed. We discuss the results from the TV UHF band testbed and the unlicensed band testbed in Sections III and IV respectively. We have also developed a business model for the sustainability of the rural broadband network which is described in Section V. The testbeds provide valuable insights into the challenges while deploying a wireless broadband network in rural areas which are discussed in Section VI. Finally, we conclude our work in Section VII.

II. Frugal 5G Network Framework

The Frugal 5G network framework is focused on fulfilling the rural connectivity needs and thus it is imperative to first discuss these needs in detail.

A. Analyzing the rural connectivity needs

The connectivity requirements of rural areas are very different from those of urban areas. Unlike urban areas, the low purchasing power in rural areas calls for a low-cost solution both in terms of the device as well as the network. One way to reduce the overall cost is to lower the spectrum usage cost by exploring opportunities like unlicensed spectrum or white spaces. In addition to this, decreasing the energy cost of radio equipment is critical for a low-cost solution. Currently, a

Long Term Evolution (LTE) system deployed in a macro cell consumes approximately 1.3 kW of power [3]. It is important to reduce power consumption to enable the usage of renewable energy such as solar power in a cost-effective way. Moreover, electricity is intermittent in rural areas which necessitate the installation of Diesel Generators, thereby increasing the operational cost [4]. To further reduce the capital and operational cost, next-generation cellular standards should consider large coverage area as an important requirement. Another distinctive aspect of rural connectivity is that high-speed mobility is non-essential. The key requirement is a primary fixed connectivity. In a nutshell, low energy, low mobility, and the large cell will lead to an affordable solution which we refer to as the Frugal 5G.

B. Envisioned Frugal 5G Architecture

One of the possible instances of the Frugal 5G network is shown in Fig. 1. Low-Cost broadband access to the end users can be provided via installing Wi-Fi Access Points (APs) in the villages. These Wi-Fi APs are wirelessly backhauled to connect to the fiber Point of Presence (PoP) which may be located several kilometers away from the villages. This wireless backhaul connecting the Wi-Fi APs to the PoP is referred to as the middle mile network [5]. A middle mile network can be based on the unlicensed band (5.8 GHz, 2.4 GHz), TV White Spaces or unlicensed mmWave (such as V-Band) mesh network. Depending on the scenario, a single frequency band or a combination of frequency bands can be selected. The middle mile network may form various topologies such as i) point to point, ii) point to multi-point and iii) multi-hop mesh topology. The topology is determined by the location of PoP, the locations of villages (where connectivity is needed) and the environment between them. The point to point and point to multi-point networks are easy to deploy. On the other hand, the multi-hop mesh networks aid in increasing the coverage and robustness of the network.

In order to validate the above-mentioned architecture, we have setup testbeds in Palghar district in the state of Maharashtra in India. Firstly, we discuss the Frugal 5G testbed based on TV White Spaces i.e TV UHF Band (470-585 MHz) in India. Next, we discuss the unlicensed band (5.8 GHz) testbed in the subsequent section.

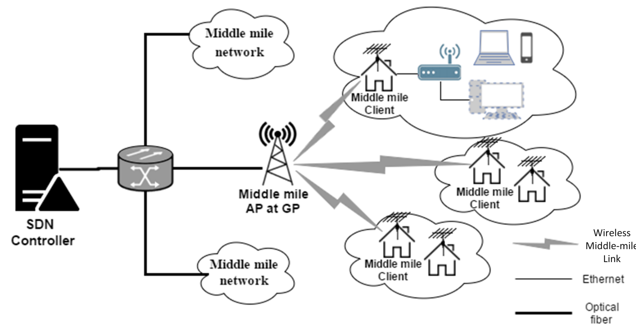

Fig. 1: An example of Frugal 5G architecture.

III. TV UHF Band Testbed

The purpose of setting up a TV UHF band testbed was to check the feasibility of using TV UHF middle mile for providing high-speed broadband access in the villages. This objective was motivated by the fact that the TV UHF band has good propagation characteristics and is highly underutilized in India. Around 12 out of 15 channels in the TV UHF band (470-585 MHz) are available at any given location in India [6]. The TV UHF band testbed spanned an area of about 25 sq. km and covered 7 villages in Palghar. The testbed sites were selected according to the following criteria: i) Distance between the Base Station (BS) (with PoP) and any other tower should be large, ii) Some government building like school/hospital must be present in the vicinity to provide services and iii) Availability of suitable space to install antenna and radio equipment. To operate the testbed in TV UHF Band, an experimental license was issued by the Government of India.

The implementation and performance analysis of the testbed are discussed in detail in [7]. The important observation from this testbed is that long distance Non-Line of Sight (NLoS) links can be easily formed via TV UHF band. The longest NLoS link installed in the testbed was 2.2 km long. The longest Line of Sight (LoS) link installed in the testbed was 7.2 km long. Based on these observations, we conclude that the TV UHF band can effectively address the wireless backhaul challenge for rural broadband. In spite of these benefits, an important factor regarding the TV UHF band is that there is no regulation in India for its usage. Moreover, when a large percentage of rural area is still not connected, relying on one method of connectivity is not efficient. This motivated us to explore the unlicensed band (5.8 GHz) for rural broadband which is discussed next.

IV. Unlicensed Band Testbed

The unlicensed band testbed is based on IEEE 802.11 (5.8 GHz) technology. In order to get a detailed insight into developing a large scale solution for rural broadband, we envisioned an even larger scale testbed as compared to TV UHF band testbed deployed in Palghar. This necessitated the development of a software-based planning tool to efficiently plan the network. Next, we discuss this planning tool after which the deployment and performance analysis are discussed.

A. Network Planning Tool

It is necessary to select the villages that need to be connected based on detailed demographic and geographic survey. Large scale deployment of wireless networks in these villages require detailed planning. Reliance on computer-based tools predicting radio frequency planning does not give a real estimate of the on-ground scenario for deployment due to which there are undue delays and cost of deployment becomes high. Thus, a planning tool has been developed which takes into account the bandwidth availability, availability of tower and throughput requirement based on population size. Based on these parameters, the tool determines detailed wireless link

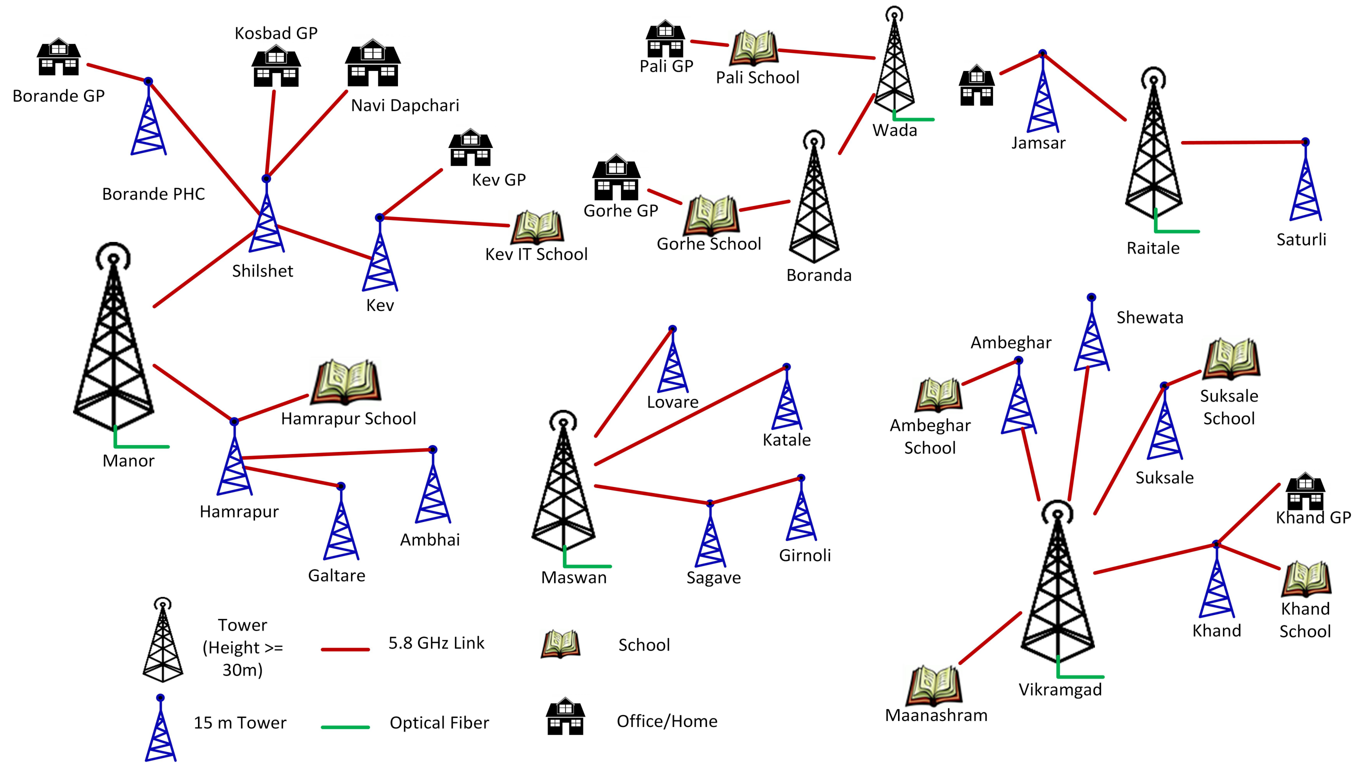

Fig. 2: Unlicensed Band Testbed

feasibility which acts as a foundation to plan the complete network. To successfully install a long distance point to point link using 5.8 GHz, LoS between transmitter and receiver is a critical requirement. Therefore, all the links in the unlicensed band testbed are the point to point LoS links. The output of the tool is the maximum transmitter and receiver height along with the maximum throughput supported by each link in the network. Additionally, a detailed bill of material is also suggested by the output. The planning tool is discussed in detail in [8]. The web-based Graphical User Interface (GUI) for the planning tool is available at [9]. Employing such a tool has an immense impact on the overall cost of setting up the network, time saved for deployment and less frequent field visits. In the subsequent section, we elaborate on the deployment based on the outputs from the planning tool.

B. Deployment

As shown in Fig. 2, the testbed spans 25 villages over an area of about 350 sq. km. There are 6 clusters across 25 villages where each cluster comprises of 4-5 villages. The clusters are as follows: i) Hamrapur, ii) Maswan, iii) Vikramgad, iv) Wada, v) Raitale and vi) Shilshet. Based on planning tool output, if the villages are within a radius of 5 km from the PoP, they can be directly connected from the tower co-located with the PoP. However, if there is no PoP within this range, the tool selects the nearest village where backhaul can be extended. This is illustrated in the Shilshet and Hamrapur cluster. Since Hamrapur cluster could not be provided with a PoP, so it has been backhauled via PoP in Shilshet Cluster. As shown in Fig. 2, the network comprises of six towers (approx. 30 m tall) which are used as the BSs. The clients are mounted on a tower not more than 15 m tall. This significantly reduces the overall cost of the network as the towers of height 30 m or more are quite expensive. We have installed Ubiquiti PowerBeam (PBE-5AC-500) [10] and LigoWave (LigoDLB 5-20) [11] devices in the network. The Effective Isotropic Radiated Power (EIRP) of all the devices installed in the testbed is limited to 4 W and their operating frequency band is 5825 – 5875 MHz. Some images of the device installation in various villages is shown in Fig 3.

A total of 116 Mbps bandwidth has been provided for this testbed. 65 Wi-Fi APs have been deployed at various locations in villages like village offices called Gram Panchayat (GP), Primary Health Organization (PHO) centers, community centers, and schools. These Wi-Fi APs have been backhauled using 5.8 GHz middle-mile links which extend the PoP to the APs. The testbed is monitored using an open source Network Management System (NMS) tool called Zabbix.

C. Performance Analysis

The throughput performance of some links is shown in Table I. According to these results, a 5.8 GHz point to point link can be formed using towers of height 15 m and it can cover up to 2-3 km of distance. We have been able to successfully connect a maximum distance of 2.3 km while working with 15 m tall towers. Also, a long distance link of 12 km has been installed by mounting the radio equipment at a height of 35 m at both the transmitter and the receiver. These

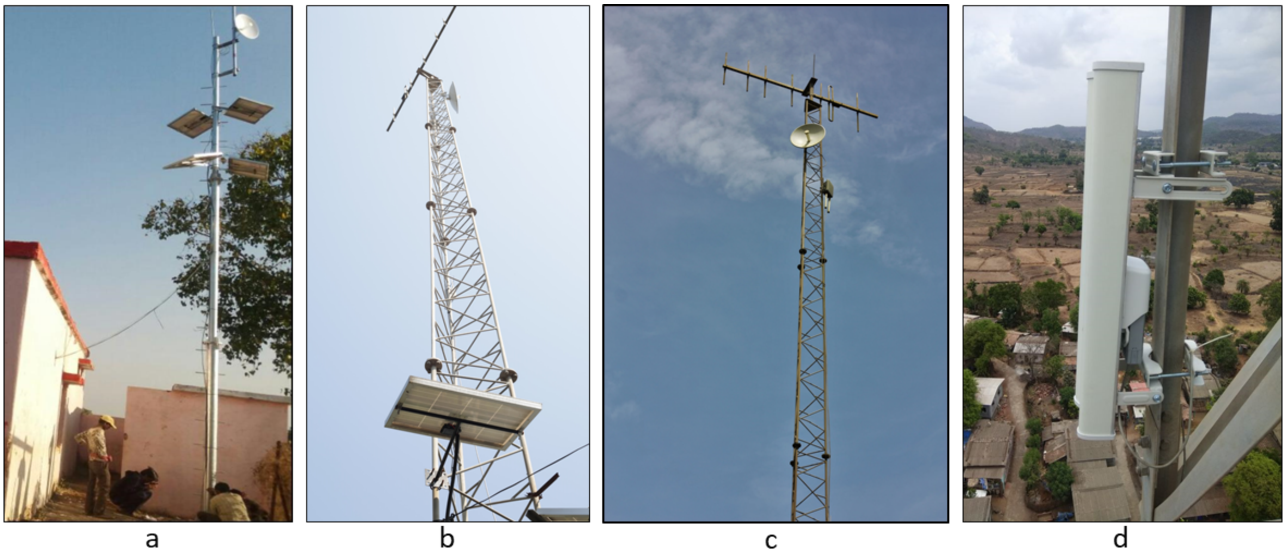

Fig. 3: The pictures show the devices installed at various villages in Unlicensed Band testbed. a) PBE-5AC-500 installed at Kev along with 48 V solar panels, b) PBE-5AC-500 installed at Shilshet along with 48 V solar panels, c) PBE-5AC-500 installed at Girnoli and d) LigoDLB 5-20 mounted on Maswan tower.

results suggest that unlicensed band can be effectively used to complement the TV UHF band. Depending on the availability of towers and the environment, a trade-off between the usage of the unlicensed band and TV UHF band can be made. Those links which can be easily formed using 5.8 GHz in a given scenario, using TV UHF band will result in wasteful use of valuable spectrum. The TV UHF band can be reserved for those links which are otherwise very difficult to be feasible using 5.8 GHz band with a tower of height less than 15 m.

The testbed went live in October 2017 and connectivity was enabled for a total of 8 months. During the initial 3 months, the connectivity was available free of cost after which it was on a chargeable basis. The GPs, PHOs, community centers and schools accessed the Internet on desktops while the villagers largely accessed the Internet from their mobile phones. The percentage of downloads were greater than uploads. Usage data suggests that most of the bandwidth was used for accessing windows update, Youtube, Hotstar, Facebook and channels in order of significance. The number of users and data usage increased progressively month after month after the connectivity was enabled as shown in Fig. 4. Smartphone ownership in the villages increased with the availability of the Internet.

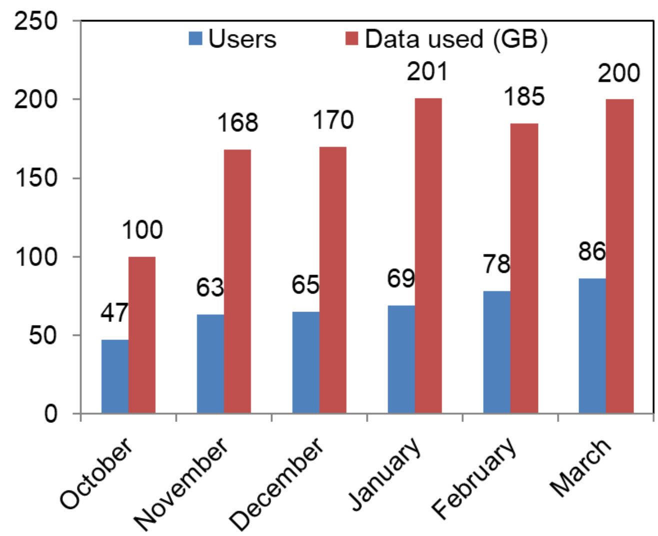

Fig. 4: Average number of active users and data usage pattern as observed in the Unlicensed band testbed from October 2017 - March 2018.

D. Impact Assessment

It was observed that connectivity has greatly impacted the lives of the villagers served by the testbed. There have been economic impacts such as saving money, time and effort by using the Internet service available in the village. Moreover, the connectivity has also impacted the quality of life of the villagers through awareness. Connectivity has also brought about employment opportunities for the local youth in the form of entrepreneurship, network maintenance and selling Internet coupons. The impact assessment studies are still ongoing based on which suitable connectivity interventions can be developed.

V. Development of Sustainable Business Model

Sustainability of the connectivity is also an important question that needs to be answered to develop an effective solution. In the unlicensed band Palghar testbed we have addressed this question by developing and validating a sustainable business model based on Public-Private-Panchayat Partnership model (4-P model) [12], [13]. In the field of telecommunications, the most widely used business models are public-private

TABLE I: Experimental Results of Unlicensed Band Testbed

Link	**Distance**	**Tx Height**	**Rx Height**	**Throughput**	**Device**
Shilshet-Kev	2.1 km	15 m	9 m	180 Mbps	PBE-5AC-500
Shilshet-Boranda	1.5 km	15 m	15 m	160 Mbps	PBE-5AC-500
Ondhe-Khand	2.3 km	15 m	9 m	60 Mbps	LigoDLB 5-20
Vikramgarh-Manashram	1.5 km	15 m	9 m	110 Mbps	LigoDLB 5-20
Wada-Borande	12 km	35 m	35 m	76 Mbps	PBE-5AC-500

partnership (PPP) models. These models largely use a top-down approach and in most of the cases, the partnerships fail due to their disadvantages such as funding gaps, inadequate monitoring, maintenance delays etc. For developing a business model for rural areas a bottom-up approach needs to be followed that focuses mostly on local needs and involvement of the people in the villages who use the connectivity. This also makes way for the sustainability of the connectivity in the village. PPP models usually do not take heed to the local needs, which could be one of the reasons for their failure in remote, rural areas. For instance, in villages with high mortality rates, located in remote areas with harsh terrain conditions, e-health facilities and suitable infrastructure for these services need to be set up.

At the village level in India, the local self-government called Gram Panchayat (GP) is the administrative body. The GP acts as the representative of the local people and their needs. The state government funds the GP and the GP is the local authority for financing development activities in the village. Thus, the Panchayat becomes an indispensable entity in the partnership model alongside Public and Private. Based on this, the 4-P model has been developed and validated on the ground for its viability and sustainability, with Panchayat being at the core of the model as both the end user as well as the financier for sustainable connectivity.

The model validates the existing ground scenario in the Palghar testbed, where the capital expenditure investment for the Internet connectivity infrastructure has been set up from the academic project funding and the grant from Tata Trusts. This funding has enabled connectivity at the GP offices. The important role of the revenue model is to i) recover the operational expenditure and ii) generate revenue by the GP. Based on an 8-months' usage of bandwidth by the GP office, the average bandwidth used per month is approximately 1 to 2 Mbps. However, the GP office purchases 2 or 4 Mbps bandwidth (costing \$14 and \$24 respectively) from the local Internet Service Provider (ISP) which is the monthly operational expenditure for each GP. The GP exercises its financial authority to pay for the bandwidth to the local ISP. Usage statistics at the GP office suggests that the connectivity is used solely for eGovernance services and limited mailing services. Thus the entire bandwidth is not used by the GP and the unused bandwidth is sold to the villagers in the form of 'pay as you use' daily and monthly coupons of $\$0.14$ and $\$1.4$ respectively through Wi-Fi AP at the GP office. In this way, the GP generates revenue for itself.

The GP office pays $\$14$ per month as the cost of bandwidth to the local ISP and collects $\$14$ by selling the unused bandwidth to the villagers (approx 10 villagers paying $\$1.4$ as monthly coupon charge). Thus $\$1.4$ is the monthly Return on Investment (RoI). Thus accumulated yearly, the GP is able to use the earned revenue for development activities in the village. A detailed cost-benefit analysis study of the connectivity reveals that the 4-P model is an economically viable and sustainable model in providing connectivity to the remote rural villages of India.

VI. Learnings from the Testbeds

Deployment of two large scale testbeds in rural areas has provided us various insights which are helpful in developing guidelines or recommended practice for enabling rural broadband. These insights are discussed next.

A. Technical Insights

1) Ease of Installation: A successful link installation requires perfect antenna alignment between the transmitter and the receiver. As the network planning tool provides a reference network topology along with the antenna height and the required number of devices, the deployment process becomes significantly easier. The planning tool can also be effectively used for extending the available fiber PoPs for speedy connectivity to the villages in the vicinity.

2) Infrastructure reuse and sharing: To reduce the overall cost of a rural broadband network, infrastructure reuse and sharing is the key. We can reuse the already available infrastructure in the villages like small towers, government buildings etc, as well as share infrastructure such as solar panels for electricity backup, can make the deployment cost-effective. In our testbed site-survey of the villages revealed the presence of 10-12 m tall towers lying unused. As these already available towers were used for installing devices for the testbed, it significantly reduced the cost of deployment.

3) Use of Solar Power: The availability of electricity is intermittent in rural areas as discussed before. Therefore, usage of renewable energy sources such as solar power is essential. All the towers and poles in the testbed are equipped with solar panels and 48 hour battery backup. This ensures the continuous working of the links in the testbed and also reduces the operational cost of the network.

4) Regulatory Issues: As mentioned previously, the TV UHF band is highly underutilized in India with 100 MHz of band available at any location in India [6]. According to the National Frequency Allocation Plan (NFAP) 2011, the $470-890$ MHz band is allocated for the fixed, mobile and broadcasting services [14]. Although the fixed and mobile services are allowed in TV UHF band in India, the band is primarily assigned for broadcasting to Doordarshan. This is a primary obstacle in using this band for deploying an experimental testbed or providing commercial services in this band.

B. Social Insights

1) Local Support: After the testbed deployment, it is very important to train the local youth for its optimal maintenance security. During the deployment phase, we have taken the support from local youth, in various ways, for deploying the network.

2) Benefits to the villagers: The impact of providing the Internet to the villagers has also been studied. The impact assessment study suggests that if the Internet is provided to villagers, they are able to take benefits of the e-services such as e-governance and e-banking. They could also accomplish tasks such as paying their bills which helped them to save time and money. The readiness of the villagers to pay for the Internet has also been tested. Based on the savings that they were able to accomplish with the help of the Internet, they decided an amount of $2 per month which they can pay.

3) Need for community owned networks: The impact studies have also revealed the need for Community owned networks [12]. Community networks encourage the involvement of the villagers to whom the connectivity has been enabled and provides solutions to questions regarding the sustainability of the network in the last mile, maintenance, and upkeep of the network. This network is monitored by the local self-government in the village (Gram Panchayat) that prioritizes village needs to regional needs, finance for bandwidth, operation, and maintenance of the devices.

4) Need for sustainable business model: Sustainability should be addressed during the chalking out of the project plan for the network to thrive and grow even after the project funds are over. This principle has been implemented while planning the Unlicensed band testbed. The sustainable business model can serve as a foundation for making rural broadband to be financially self-dependent at the village level.

VII. Conclusion

Developing a broadband connectivity solution for rural areas involves many technical and business challenges. We have performed an analysis of these challenges and proposed Frugal 5G as a sustainable solution. We have also validated the Frugal 5G Network Architecture by successful deployment and testing of two testbeds. We have proposed a sustainable business model based on a multi-stakeholder partnership which ensures that connectivity once enabled is able to thrive and grow on its own. It is important to note that rural requirements may change from one village to another. An optimal solution will take these diverse requirements into account and generate a solution that is replicable and scalable. We have endeavored to propose such a solution in this paper.

To take these efforts further, we submitted a project request to IEEE which has been accepted and a working group, Frugal 5G Networks has been initiated by IEEE [15]. A standards development project P2061, under this working group, aims at designing a low mobility energy efficient network for affordable broadband access for rural areas.

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