TV White Space Solution for Affordable Internet in India

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1 Introduction

In the modern digital age, 'Right to Ubiquitous Connectivity' is a basic human right of individuals irrespective of where they live, their socio-economic status and gender. Internet has played a major role in the connectivity revolution by enabling maximum number of people through its benefits of usage. In spite of this spectacular growth in Internet usage, a staggering 47% of the global population is still unconnected. Furthermore, the percentage of unconnected population in developed countries is merely 10-15% which is significantly lower than that of the developing countries where 60-70% population is still unconnected [1].

The unconnected population in developing countries is divided across gender, education levels and place of residence. The major barriers that give rise to these divides in the developing countries are i) lack of digital awareness ii) unavailability of content in local language iii) unaffordability and iv) lack of Internet infrastructure. Digital awareness refers to the knowledge about Internet and the benefits that it can bring about. Even if people are aware about Internet and its benefits, the unavailability of contents and services in local language discourages them to adopt Internet. Assuming the availability of relevant content and awareness of Internet usage, the other two barriers of affordability and lack of Internet infrastructure can be addressed with new innovations in technology. This chapter does not deal with providing solutions for content generation and awareness creation but discusses possible technology solution for connecting the unconnected in an affordable manner.

Global connectivity map is incomplete without taking the Indian scenario into consideration. The current population of India is 1.34 billion of which only 159 million people are broadband subscribers [2]. Internet usage statistics suggest that approximately 317 million people access the Internet at least once a month. The urban rural divide in India is even larger where in only 34% of the users belong to rural areas even though 70% of the total population of India lives in these areas [3]. The Government of India, under its Digital India programme, has taken several initiatives to build an information highway connecting every part of the country. One such initiative called BharatNet aims at providing Points of Presence (PoPs) with optical connectivity to local self-government offices at village level called Gram Panchayats (GPs) in India. There are $250,000$ GP in India serving about $640,000$ villages. Thus, each GP serves around 2-3 villages on an average. These villages are generally located within a few kilometers of the GP office and will remain unconnected if fiber connectivity reaches only to GP office. In most of the developing countries, the fiber connectivity reaches only at designated points in the vicinity of the rural areas leaving a large part still unserved. Taking optical fiber to each and every village is very time consuming and expensive. Thus, there is a need to look for alternative wireless solutions so as to efficiently connect these villages. In this chapter, we discuss wireless solution based on TV White Space as a potential option to provide connectivity in the unserved rural areas.

In addition to providing an efficient technology solution, it is important to ensure that there is a sustainable return-on-investment for the service provider and an affordable subscription price for the end user. This drives the need for a sustainable economic model. We propose a model which ensures active involvement of GPs who will eventually promote and sustain the broadband. Such a model is referred to as the 4P model, i.e., Panchayat-Public-Private-Partnership model, which is a self-sustainable model.

The organization of the chapter is as follows. Section 2 introduces the barriers in connecting the rural population. Section 3 discusses the TV White space as a potential option to connect the rural areas. The architecture of wireless broadband network for rural areas is described in Section 4. In Section 5, we discuss the policy aspects for the usage of Television (TV) White Space. Section 6 presents an economic model which can be employed in the Indian context thus making it affordable and sustainable.

2 Barriers in Connecting Rural India

A World Bank study suggests that a 10% increase in broadband penetration would accelerate economic growth by 1.38% [5]. Given that 70% of India's population resides in rural areas, enabling connectivity has a potential of significantly enhancing the economic growth. However, rural broadband needs to address many challenging barriers some of which are enumerated below:

1. **Lack of fiber infrastructure**: Fiber cable is the most viable medium to support increased data capacity. China and United States of America have installed around 1 billion kilometres and 600 million kilometres of fiber respectively. In contrast, the fiber connectivity in India is very limited with only 60-70 million kilometres of fiber deployed till date. Currently, the rate of fiber deployment is around 15 million kilometres of fiber every year [6]. The current demand indicates the need of at least 50 million kilometres of fiber to be deployed every year. Some of the obstacles that have slowed down the process of fiber deployment are difficulties like obtaining Right of Way, uneven terrain and cost of deployment amongst others.

2. **Low Average Revenue Per user (ARPU)**: One of the major obstacles in enabling rural broadband connectivity is the absence of mobile network operators in these areas. The operators are disinterested to serve in these areas because it is not economically viable owing to low to medium subscriber base. The Capital Expenditure (CAPEX) is significant which includes the cost of Base Transceiver System (BTS), fiber deployment and passive infrastructure. A considerable part of the Operational expenditure (OPEX) includes fuel and energy cost. Since the rural areas have low to medium subscriber density and Average Revenue Per User (ARPU) is also low, the operators are unable to get return on their investments which discourages them from investing in these areas.

3. **Difficult Terrain**: The difficult terrain poses a major difficulty in India where almost 80% of the mainland is hilly [7]. Hence, providing fiber connectivity is an arduous task in these areas. Alternate solutions like setting up a Point to Point wireless link (including unlicensed band radios) have been explored. However, high foliage loss and requirement of expensive tall towers limit the feasibility of a wireless link.

4. **Scarcity of Electricity**: To provide a reliable broadband access, the most important aspect is availability of electricity. In spite of being electrified, the availability of grid electricity in rural areas is unreliable and periodic, with power outages of 8-12 hours per day on an average. Since the Internet connectivity requires a continuous power supply, employing back-up power sources such as battery or diesel generator are necessary. This not only increases the energy cost but also leads to environmental pollution. Renewable energy options such as solar energy have been explored but have been found to be uneconomical when the power requirement of a Base Station site is high.

3 TV White Space: A Potential Solution

With the advancement in technology, multiple technology solutions, wired and wireless, are available to provide broadband connectivity. As discussed in the previous section, providing wired connectivity in sparsely populated rural areas is an expensive solution. Wireless technologies such as IEEE 802.11 (popularly known as Wi-Fi) [10], IEEE 802.11ad or WiGig [11] etc can be suitable options. However, due to difficult terrain in India and requirement of tall towers, these solutions will only be able to connect limited areas. In order to provide ubiquitous connectivity in such areas, a shift is required from traditional technology to a more affordable, efficient and robust technology. Wireless solutions based on TV White Space precisely suits such a scenario. In India, there is a significant amount of available spectrum in this band. In addition to this, it also has several unique advantages such as non line of sight propagation characteristics and ease of deployment. In this section, we describe in detail, the availability of TV White Space spectrum in India and the TV White Space standards suitable for rural areas.

3.1 TV White Space availability in India and its usage

To quantify the amount of TV White Space available and the capacity that can be achieved using the available spectrum, several studies have been carried out in various countries. In US, only 5 channels per person are available on an average in the UHF band (470-692 MHz) [14]. In Europe, around 18% of the UHF band (474-786 MHz) is available per person [15]. Similar studies have also been carried out in UK and Japan [12,13]. These studies suggest that the availability of white space is limited with only a handful number of channels available per person or at any location.

The scenario in developing countries is much more surprising with very poor spectrum utilization of the TV band. Unlike in US and UK, there is only one terrestrial TV broadcaster in India - *Doordarshan*. Doordarshan transmits only two channels at any location in the country each channel occupying a bandwidth of 7 MHz in VHF band or 8 MHz in UHF band. A detailed quantitative assessment of TV White Space in India reveals that 12 out of 15 channels of UHF Band IV (470-585 MHz) are available at any location [9]. Digital switchover of terrestrial TV is in progress for most of the developing countries. After digital switchover in India, the terrestrial TV broadcasting needs to shift to 585-698 MHz band. Hence, the 470-590 MHz band will be completely vacant [16]. This unused band may prove to be very effective in connecting the rural and remote parts of the country.

Currently, there are no regulations for the usage of TV White Spaces in India. India lies in Region 3 of the International Telecommunication Union (ITU) terrestrial spectrum allocations in which ITU permits fixed, mobile, and broadcasting services in TV UHF Band [16]. As per the National Frequency Allocation Plan (NFAP) of 2011, India Remarks 36 and 37, fixed and mobile services in 470-585 MHz band can be permitted on case by case basis. Therefore, this band can be used to provide fixed wireless broadband in rural areas. This is in contrast to Europe which lies in Region 1 where only broadcasting services are allowed in this band. In US, which belongs to Region 2, fixed services can be permitted in 470-512 MHz band.

3.2 TV White Space Standards

Several TV White Space standards have been developed such as IEEE 802.22, IEEE 802.11af, IEEE 802.19.1, IEEE 802.15.4m, IEEE 1900.7 and ECMA 392 [21]. Of all these standards, the two most relevant standards in providing rural connectivity are IEEE 802.22 and IEEE 802.11af. IEEE 802.19.1 is relevant in terms of coexistence of IEEE 802 family operating in TV White Space.

- **IEEE 802.22:** IEEE 802.22 was the first standard based on Cognitive techniques that has been developed to access the TV White Spaces [17]. The most important application of this standard is to provide wireless broadband access in rural and remote areas. The standard specifies that a large range of 33 km can be achieved with only 4 W of Effective Isotropically Radiated Power (EIRP). The standard uses both geo-location database and sensing based techniques to access the TV White Spaces. As, the Indian scenario is almost static, the use of geo-location database can suffice. This standard is capable of working in any regulatory regime (e.g. US, Japan, UK, Canada, etc.). The operational range of this band is 54-862 MHz and can work with various TV channel bandwidths i.e. 6, 7 and 8 MHz.

  IEEE 802.22 follows a Point to Multi-Point (PMP) topology with a Base Station (BS) and its associated Customer Premise Equipments (CPEs). To protect the incumbents, it follows a strict master-slave relation where BS is a master and the CPEs are its slaves. No CPE can transmit before receiving an authorization from the BS.

- **IEEE 802.11af:** IEEE 802.11af standard or the White-Fi was formulated to adapt the existing IEEE 802.11 for TV band operation [18]. IEEE 802.11af systems operate on frequencies below 1 GHz and uses geo-location database to access the TV band. This standard was designed due to the congestion in unlicensed band i.e. 2.4 GHz and 5 GHz spectrum. There are two operating scenarios of IEEE 802.11af viz. indoor and outdoor. The indoor scenario has a range of up to 100 m similar to Wi-Fi. The outdoor scenario has a range of about few kilometres and is more suited for the rural setting. As TV channels may have varying bandwidths of 6, 7 or 8 MHz, it is required to aggregate the bandwidth. This standard works with the bandwidth of 5, 10, 20 and 40 MHz and hence depending on the availability of the channel, this bandwidth can be adapted.

4 A Wireless Broadband Network for Rural India

4.1 Technology Requirements in Rural Areas

The current developments in the cellular technology mostly focus on the requirements of high mobility. The need to support high throughput with very high speed mobility is driven by applications like Ultra High Definition (UHD) video streaming for users onboard of fast moving vehicles such as high speed trains etc. These applications are not important in rural areas when even primary connectivity is missing. The connectivity requirements for rural areas are quite different and are listed below.

- **Low cost solution:** The average monthly income of the highest earning member of a household in a typical rural area of India is around $75 [19]. Note that a household in India comprises of 5 members on an average [20]. Given this fact, people in rural areas may not be willing to invest $3 monthly (average cost of a monthly broadband subscription with 1 GB data limit) to subscribe to broadband services. Thus we need to develop cost effective solutions for providing connectivity in rural areas.

- **Limited mobility support:** In a typical semi-urban or rural Indian setting, most of the end users will either be nomadic or travel at a speed of around 30-50 km/hr. Hence, broadband connectivity at high mobility is not a major requirement in Indian context. It is more important to focus on providing fixed broadband services with limited or low mobility in the rural parts of the country.

- **Robust and Energy efficient technology:** In general, the developed countries have a very stable electricity grid and hence its availability is not a major concern. On the contrary, the availability of electricity in rural India is highly unreliable as described in Section III. This necessitates the development of an energy efficient and robust solution which can easily work with alternate renewable sources of energy like solar energy in a cost effective manner.
- **Support for large coverage area:** In general, rural areas are very sparsely populated. To provide ubiquitous connectivity in these areas, a huge investment in terms of Internet infrastructure is needed. If Base Stations with large coverage areas are deployed, the investment can be significantly amortized, thus making the solution more affordable.

4.2 Rural Broadband Network Architecture

We now discuss a possible network architecture which can exploit the TV White Spaces to address the above requirements. As described in Section I, the Government of India is deploying optical fiber to connect $250,000$ GPs under the BharatNet project. There are around 2-3 villages under each GP which are generally situated within a few kilometres of the GP office. Even after the completion of BharatNet project, these villages will still remain unconnected as the optical fiber will terminate at the GP office. To extend the optical fiber to each and every village will be an expensive and infeasible solution. A low cost broadband access to the villages can be provided by deploying Wi-Fi Access Points (APs) as the access nodes. We need to address the issue of connecting these Wi-Fi APs to the optical PoP at the GP via TV White Space and this network will be hereinafter referred to as *middle mile network*.

Depending on the location of a GP and the villages under that GP, the middle mile network can form different topologies i.e. i) Point to point ii) Point to multi-point and iii) Multihop mesh network. In Figure 1, the middle mile AP locally connects to the optical PoP at the GP and the middle mile clients locally connect to the Wi-Fi APs in the villages. The end users in the villages access the Internet through Wi-Fi APs. The middle mile AP is connected to multiple middle mile clients in the villages through TV White Space thus forming a point to multi-point topology. Various standards like IEEE 802.22 and IEEE 802.11af suit the requirements of rural areas as discussed in Section 3.2 and technologies based on these standards can be effectively used in the middle mile. A middle mile Long Term Evolution Advanced (LTE-A) network operating in TV White Space can be explored to improve spectral efficiency over the above-mentioned technologies in this band. In [22], the feasibility of using LTE-A in middle mile has been discussed. The authors in [22], propose a proportionally fair radio resource allocation over the middle-mile network which uses Coordinated Multipoint (CoMP) approach offered by Long Term Evolution - Advanced (LTE-A) to satisfy the broadband requirement of rural areas.

To cover a large area, the middle mile topology can take complex form including a mesh topology. A new paradigm in networking, Software Defined Network (SDN), can address the above problem effectively. In SDN, the control plane and data plane are separate. The control logic is completely implemented in the central controller and the network devices are simple packet forwarding devices. Therefore, it becomes much easier to manage a large scale network such as the proposed rural broadband network.

There are several benefits attached to the proposed network architecture which are enumerated below:

1. **Reduction in Infrastructure cost:** The TV White Space has good long distance propagation characteristics thereby providing a good coverage. The coverage area of this band can be large (in kms) even with transmit power as low as 1 W. Due to the reduced power consumption,

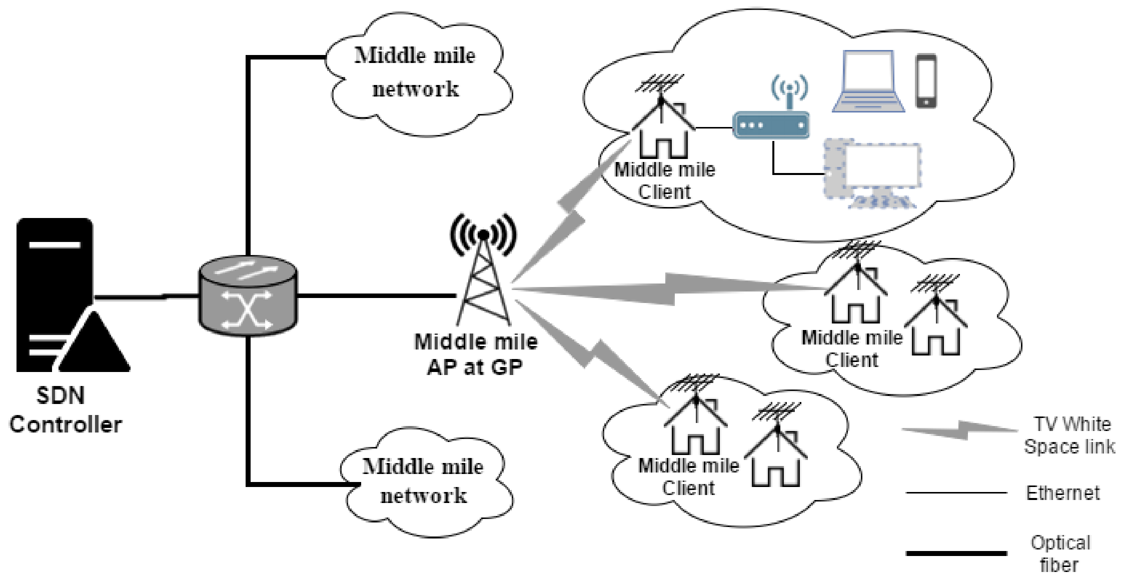

Figure 1: Rural broadband network architecture

the need for Diesel Generator (DG) sets, cooling equipments etc can be eliminated, leading to a cost effective solution. Another major advantage of this band is its non line of sight connectivity, which will minimize the need of tall towers required for Fresnel zone clearance. In the proposed network architecture, the end-users access the Internet via Wi-Fi APs which are not only affordable but also provide high speed broadband access.

2. **Ease of deployment:** When deploying Wi-Fi (5.8 GHz) APs to form a point to point link, antenna alignment poses a great challenge. Since the line of sight connectivity is not a crucial requirement with TV White Space, the installation of equipments becomes easy.

3. **Suitable for hilly terrain:** Difficult terrain in India with huge vegetation on majority of its land poses a challenge in providing good connectivity. TV White Space can address this challenge with its non line of sight propagation characteristics. Also, the foliage loss is lower in this band as compared to higher frequencies [24].

4. **Operation using Renewable Energy Sources:** India is a sunny region with around 250–300 clear and sunny days in a year [25]. The energy incident over India's land area is approximately 5000 trillion kWh per year with most parts receiving 4–7 kWh per sq. m per day [26]. As the power consumption of a typical TV White Space AP is less, solar power can be effectively used to power up the devices.

4.3 TV White Space Testbed in India

Based on the proposed rural broadband network architecture, a TV White Space testbed has been set up in the rural areas of Palghar district, Maharashtra, India [27]. The testbed is situated in Palghar district which is about 100 km away from Mumbai. It includes seven villages spanning an area of about 25 sq km. The successful testbed trial in Palghar emphasizes the feasibility of using TV White Space in the rural areas. Internet connectivity availed in three villages of Palghar district has provided an insight about how Internet can greatly enhance the life of the villagers.

In the next stage of this testbed, it is scaled from 7 villages to 25 villages in Palghar district. There are 5 clusters in the scaled testbed, each cluster consisting of 4-5 villages. One of the 5 clusters is illustrated in Figure 2. The PoP is located at Maswan village and is connected to TV White Space AP. The TV White Space AP connects to the TV White Space clients in the 4 villages in a point to multi-point manner. These TV White Space clients are locally connected to the Wi-Fi APs. Owing to the long distance propagation characteristics of the TV White Space band, we are able to connect villages which are around 4-5 kms away from the PoP. This would not have been possible if unlicensed band radios would have been used.

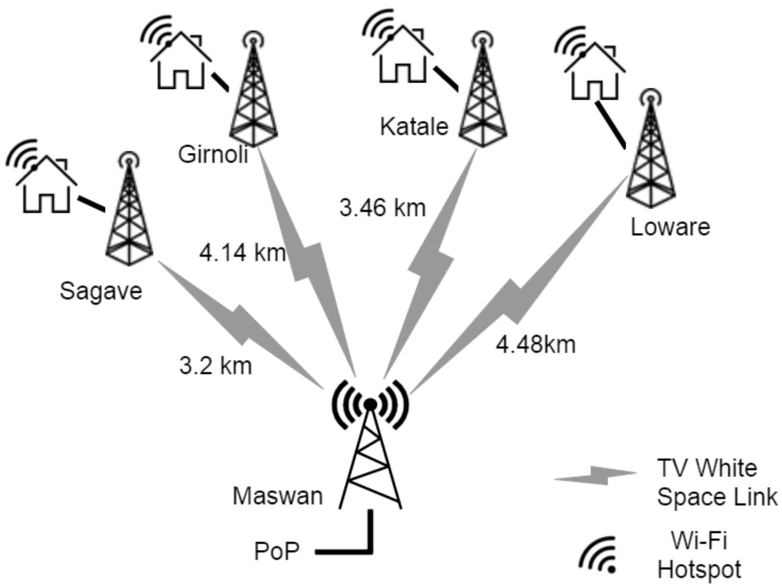

Figure 2: An example cluster in Palghar testbed of 25 villages

5 Regulatory Regimes to access TV White Space

It is important to note that the regulatory regimes for the use of TV White Space are not yet decided in India. The behaviour of primary users in the TV White Space band is static in India. Any harmful interference to primary can be easily avoided with the use of a geo-location database. However, the major challenge in the Indian scenario is to design a regulatory framework under which multiple operators having deployed their rural broadband network can share the spectrum efficiently to serve the rural areas.

The existing regulatory regimes can be broadly classified as – *individual authorization* schemes and *general authorization* schemes. In individual authorization schemes, the right of access to the spectrum is granted to an operator on a licensed basis. The individual authorization schemes can be distinguished as *dedicated, co-primary* and *Licensed Shared Access (LSA).* For instance, mobile operators typically get a dedicated access to the spectrum. Through spectrum auctions, they pay a very high fee and can use the spectrum for a fixed duration. Co-primary and LSA regimes have been recently introduced as complementary methods to dedicated spectrum access. These methods not only increase the spectrum utility but operators can also ensure predictable Quality of Service (QoS) to the users. Under general authorization schemes, users are allowed to share the spectrum opportunistically but with equal priority. The cost of spectrum is either very low or zero. For example, the Industrial, Scientific and Medical (ISM) bands have been license exempt. Multiple technologies have been developed that work in these bands, e.g. Wi-Fi [10], Bluetooth [23] etc.

Given the Indian scenario where 100 MHz of TV White Space is available at any location [9], the main concern is to design a framework under which operators who are providing broadband service in rural areas can guarantee QoS to its users. The regulatory regimes under which operators can share the spectrum along with guaranteeing QoS to its users are co-primary and LSA schemes. The relevance of these schemes in the Indian scenario is discussed next:

- **Licensed/Authorized Shared Access**: In licensed shared access (LSA), the sharing takes place between primary users (e.g. TV broadcasters) and limited secondary users (e.g. MNOs). The former is referred to as the incumbent and the later is referred as the LSA licensees. The LSA licensees are responsible for protecting the incumbent users. The spectrum sharing among LSA licensees takes place according to the rules set by the regulator. As the LSA licenses are given in limited number and all the licensees are known, it provides higher level of guarantee for return on investment. Authorized Shared Access (ASA) is a specific case of LSA where the license holder is an MNO. ASA has been developed for International Mobile Telecommunication (IMT) band (e.g. 3.8 GHz in US) whereas LSA covers a much larger spectrum and is defined for heterogeneous users [28].

- **Co-primary Shared Access**: The co-primary shared access scheme allows sharing of the spectrum among the operators with the same regulatory status (e.g. Mobile Operators). The sharing can take place via mutual agreements among operators or enforced via requirements set by the National Regulatory Authority (NRA). Note that in this model the operators would have equal access rights without priorities being set by regulation. As the TV White Space band is highly unused in India, a part of this band under co-primary shared access scheme can be given to operators to provide broadband services in these areas.

  Co-primary sharing can be done by limited spectrum pooling [28] method in which NRA allocates a band to multiple license holders and refrains itself from partitioning the band. Although it is difficult to ensure instantaneous QoS guarantees, long term minimum QoS guarantee can be ensured via mutual agreements between operators. The mutual agreements and the number of participating licensees are known a-priori. This gives some predictability to the sharing licensees and they can get return on their investment. Generally, the limited spectrum pooling method is discussed in the context of mobile network operators (MNOs), however this concept can be extended in rural areas to share the spectrum among multiple operators in the middle mile network. This band can be lightly licensed under co-primary shared access which can further aid in developing an affordable broadband solution. Therefore, it is a much more preferable scheme in Indian rural setting.

6 Economic Model

In addition to providing an efficient technology solution which meets the needs of the rural areas, it is important to develop an economic model that will sustain the network and its services at the village level. This can be achieved through a sustainable economic model which is viable for both the end user and the investor. Such a model is the basis of financially self-dependent projects and its smooth running. The basic premise of an economic model is the demand supply dynamics. Unlike the urban areas where the demand for Internet connectivity and the supply by means of various technologies is at tandem, the rural areas suffer from a severe deficit. In rural areas, the demand for Internet connectivity is either nonexistent or it is underserved and unmet through no or minimalistic supply. This is because of various reasons such as low user rates, inefficient infrastructure, poor coverage and inadequate communication services. Communication network unlike road and water network is built on demand. With less demand in rural areas, the network building is slack and slow. Rural has also been associated with 'free' and 'subsidized'. It is for this reason, enabling connectivity in rural areas has not been aimed towards permanency. While the private operators are unsure of their customer base, the government operators are unsure of how to maintain and manage the networks.

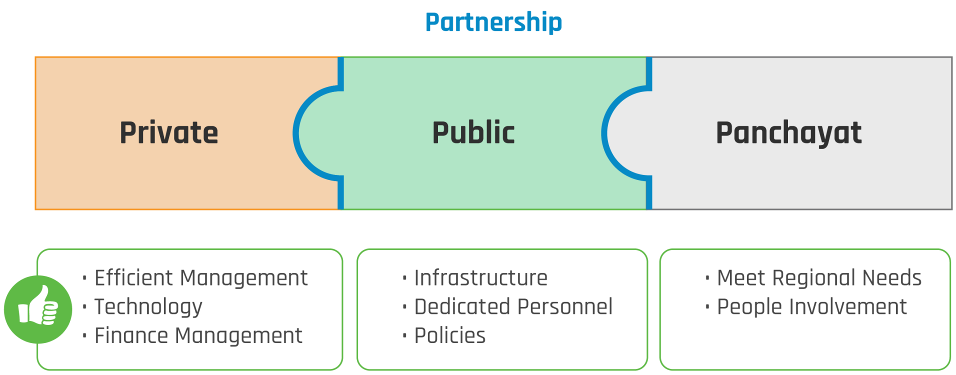

Figure 3: 4P Economic model

The sustainable model should take into consideration the expected growth in demand in the near future. This can be achieved by: (a) Using economic or cost-saving technology options so that the investment cost is low (b) having a partnership with the government so that some part of the operating expenditure can be borne (c) Partnering with the Gram Panchayats so that we involve the local people and train them to make this model self-sustainable.

There are several types of economic models such as i) private only, ii) public only and iii) private, public partnership models. There have been several types of public-private-partnership (PPP) models, such as Build Operate Transfer (BOT) model, Build Transfer Operate (BTO) model and Joint Venture model. [29] These models have their own advantages and disadvantages because of which they were unable to sustain themselves on field for a long duration. Some of the short comings of these models are: planning and maintenance delays, inadequate monitoring, funding gaps and improper risk management. A key feature that these models lacked was involvement of the local people for whom the network was set up and therefore did not cater to the regional needs. For example, in rural areas which suffer from maternal, child and infant deaths, the services should be oriented towards better healthcare facilities. Hence, we propose a 4P model: Private, Public, Panchayat Partnership model in which the Panchayat holds the responsibility of maintaining the network at the village level. In this scenario, the "private" could be, for instance, a private broadband service provider. "Public" could, for instance, a government-owned organization which sets up the infrastructure. Panchayat is the local name for a village-level organization which maintains and runs the network. The advantage of this model is that, since it is owned by the villagers themselves, they will be in a better position to decide and prioritize the services that cater to their regional needs.

This increases their responsibility towards maintaining and running the services in a sustainable manner. The model is depicted in Figure 3. One of the key features of the model is the creation of local Village level entrepreneurs (VLEs) who act as a bridge between the village and the government. They are responsible for making the people digitally aware and are responsible for running these activities on a daily basis. These activities thus become a source of revenue generation for the VLEs and hence is expected to sustain for a longer duration.

7 Conclusion

It is an important task to enable connectivity in the unserved and underserved rural areas of India. Most of the developing countries in the world also face similar problems of connecting the unconnected. In this chapter, we have proposed a wireless broadband network based on TV White Spaces along with a sustainable economic model which can not only provide connectivity but also enable successful operation of the network at the village level. However, there are a number of open problems that needs to be addressed such as – spectrum sharing, policy and regulation of TV White Space and universal replication of partnership business models on ground. The proposed vision of employing TV White Space in the middle mile has the potential to radically change the current connectivity scenario and bring about a connectivity revolution.

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