# Broadband Communication Standards and Rural India

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The deployment of telephone networks in India started soon after its invention by Dr Alexander Graham Bell in 1876. The first telephone exchange was established in the country in 1882 during the British rule. Notwithstanding the early start, the growth of telecom infrastructure in the country was dismal for the next hundred years. The tele-density (No. of subscriptions/total population in %), which was ~0.03% at the time of India's Independence in 1947, barely went up to 0.3% in 1984 [1]. During the next decade, the situation improved marginally with urban tele-density touching 4.0% in March 1996. However, this small growth was observed mainly in urban areas as the tele-density in rural areas still languished at less than 0.3% [2].

Year 1995 can be considered an inflection point in the evolution of telecom industry in India, when the cellular telephony services were launched in the country. India observed considerable growth in telecom industry thereafter, so much so that from a low 1.3% in 1996 [2] the tele-density in the country stands at an impressive 88% today [6], comprising mostly of cellular subscribers.

Though there has been significant growth of cellular infrastructure in India, comparable in many ways to the developed economies of the western world [3], there is a fundamental difference between how cellular networks are used across these two regions. When cellular telephony was deployed in the west during late 1980s, wireline connectivity was already available to most of the people and cellular networks were used primarily to provide connectivity to mobile users. In contrast, when cellular networks were deployed in India in 1990s, landline infrastructure was hardly existent in the country [2]. In the prevailing circumstances, cellular network became the primary vehicle for basic voice connectivity. For example, today the tele-density in rural India is ~60% with almost all subscribers using cellular infrastructure for telephony services [4][6]. Mobility is an advantage, but not really the necessity in many scenarios.

The situation concerning the broadband connectivity is similar. Most of the developed economies have been using wired infrastructure along with access technologies like Wi-Fi to provide broadband connectivity to people. However broadband connectivity in India is primarily enabled through cellular network. In a country of over 1300 million people, there are only 20 million wireline subscribers [4]. The situation is worse in rural India with only 2.37 million wireline subscriptions in a population of ~900 million [6]. In such a scenario, cellular network remains the only viable option to provide broadband connectivity to people. Unfortunately, even cellular broadband eludes a significant chunk (~70%) of rural population today [4]. Relatively lower usage of cellular broadband in rural India raises the question of suitability of the existing cellular broadband technologies/standards to Indian rural landscape; it appears that these standards may not have been designed to cater to some of the specific challenges presented by rural India.

To analyse these aspects in detail, we first review the cellular technology standards, especially the popular cellular broadband technology standards. Thereafter, we discuss some important traits that characterize rural India. We also identify a few key requirements that may need to be supported by wireless broadband technologies in order to be successful in Indian rural settings. In the end, we discuss two important standardization efforts, which may prove useful in increasing the penetration and usage of wireless broadband networks in rural India.

# Evolution of Cellular Technology Standards

The decades of 1960s & 70s witnessed the development of what is known as the first-generation of cellular standards & systems. These were analog systems and provided basic telephony services to mobile users. Towards the end of 1980s, the second generation (2G) cellular standards came into existence. 2G systems were digital communication systems supporting voice calls and narrowband data services. The Global System for Mobile Communication (GSM) became the most successful of all 2G cellular standards. The Third Generation Partnership Project (3GGP) to develop cellular wireless standards was launched by Standards Development Organizations (SDOs) of Europe, USA, Korea, Japan and China. India being a late entrant to wireless standards, its SDO-Telecommunications Standards Development Society India (TSDSI), became an organizational partner of 3GPP only in 2015.

Considerable success of the GSM system motivated the development of IMT-2000 standards, the first standard for cellular wideband technology. IMT-2000 was standardized by International Telecommunication Union (ITU) in 1990s. 3$^{rd}$ Generation Universal Mobile Telecommunications System (3G UMTS) developed by 3GPP is a key component of the IMT-2000 standards. 3G UMTS paved the way for the next generation cellular standards, known as the “IMT-Advanced” or (4$^{th}$ Generation (4G)) in the first decade of the 21$^{st}$ century. 4G is the first truly broadband cellular technology standards. 3GPP Long Term Evolution (LTE) & LTE Advanced (LTE-A) are the most popular representatives of these standards. LTE/LTE-A have seen considerable deployment world-wide and are being used in a large number of countries to provide cellular broadband services. Even though India is no exception in this regard with sizeable LTE presence [5], a large % of rural population in the country is still not using broadband data services via 4G [4].

## IMT-2020 (5G) Standards

Around the year 2014-15, ITU started outlining its vision and requirements for the next-generation mobile broadband standards, IMT-2020 popularly called the 5G [16] [17] [18]. Here we take a detailed look at the 5G standards as originally specified by ITU and its suitability towards providing broadband connectivity in rural India.

Some of the key performance indicators (KPIs) for IMT-2020 as originally identified have very stringent requirements, such as, “Peak downlink data rate” of 20 Gbps, “User experienced data rate” of 100 Mbps, “Over the air latency” of 1 ms, “Connection density” of $10^6$ devices/square km, “Spectral efficiency” of 30 bit/s/Hz, and also enabling “high speed vehicles” with speeds of up to 500 km/h. With these KPIs, the focus of 5G cellular standards, seems to be on the use cases & requirements of urban areas in economically developed countries [21].

ITU has also defined a set of test environments corresponding to important usage scenarios and the associated performance metrics. Currently, ITU defines five test environments, namely ‘Indoor Hotspot - enhanced Mobile Broadband (eMBB)’, ‘Dense Urban - eMBB’, ‘Rural - eMBB’, ‘Urban Macro - Massive Machine Type Communications’ (MMTC) and ‘Urban Macro - Ultra Reliable Low Latency Communication’ (URLLC). ‘Indoor hotspot’ and ‘Dense urban’ test environments target very high data rates. MMTC targets ‘Internet of Things’ (IoT) applications and URLLC focuses on low latency reliable applications [19]. All these four test environments are focussed on urban use cases. The 'Rural - eMBB' test environment of IMT-2020 is the only one pertaining to the use cases of rural area.

### IMT-2020 (5G) - Support for Rural Broadband Communication

'Rural - eMBB Test Environment of IMT-2020' has been defined by ITU as "a rural environment with larger and continuous wide area coverage, supporting pedestrian, vehicular and high-speed vehicular users" [19]. The salient parameters (configuration) of the **'original'** ITU 'Rural eMBB' test environment is provided in Table 1. In this original test environment, two different configurations were identified for rural scenario. Both these configurations utilize a cell radius of about 1 km and cater to high-speed vehicles (120 km/h). As one can see, the configurations typically model the high-speed vehicular traffic and are focused on providing connectivity to these vehicles passing through rural areas via high speed roads (highways). The test configuration also defines a "Mobility KPI", which strives to maintain connectivity for high-speed vehicular traffic, up to 500 km/h.

| IMT-2020 – Original Rural – eMBB Test Configuration used in ITU | | |
|---|---|---|
| **Parameters** | Config A | Config B |
| **Carrier Frequency** | 700 MHz | 4GHz |
| **Inter-Site Distance (ISD)** | 1732 meters | 1732 meters |
| **Bandwidth** | 20 MHz (DL+UL) | Up to 200 MHz (DL+UL) |
| **BS Tx power** | 49 dBm | |
| **BS Antenna Height** | 35 meters | |
| **User Equipment (Device) Distribution** | 50% outdoor vehicles (120km/h) and 50% indoor (3km/h)<br>500 km/h for evaluation of mobility in high-speed cases<br>Uniform User distribution | |

**Table 1: IMT 2020 Rural - eMBB Test Configurations (courtesy [19])**

Apparently, this 'Rural - eMBB' test configuration is a model of highway connectivity in economically developed countries and does not really reflect the broadband requirements for rural households in a developing country like India.

## Challenges to Broadband Connectivity in Rural India

The reasons behind the deficient broadband infrastructure in rural India including the cellular one, lie in some of the specific traits that characterize the Indian rural landscape. These have been identified below:

- Lower population density

Rural areas have lower population density as compared to the urban areas. As per the last census, conducted in 2011[7], the rural population density is 279 per square Kilometre as compared to 3,685 in urban areas.

- Sparse Population Distribution and Clustered Settlements

In general, rural areas are characterised by sparsity of population everywhere and India is no exception in this regard. Rural India comprises of villages, which may be far apart from each other with vast open spaces in between, as has been shown in Figure 1 (a). The distance between two adjacent villages may be anything between a few hundred meters to a few kilometres. Each of these villages may be home to a small population of a few hundred to a few thousand people.

- Remote and difficult to access regions

Many areas of the country, e.g., the hilly regions of Himalayas in the north, the deserts in the west or forests in large parts of central and north-eastern India, are quite remote from the urban centres of the country. Villages lying in these areas suffer from poor transportation infrastructure and may not be reachable easily.

- Comparatively lower income levels

Per capita income of people living in rural areas in India is much lower than that in urban areas [10]. With lower income levels, a large percentage of rural population may not have enough financial resources to pay for the broadband services and the poor Return on Investment (RoI) may not justify the investment in costly telecom infrastructure by private industry.

- Inadequate grid-based power supply

At many places in rural India, the availability of electricity from the grid may be inadequate and irregular [8]. In such a situation, it may be difficult to guarantee a continuous broadband connectivity if the network equipment is solely dependent on the supply of electricity from the grid. In order to provide 24/7 broadband connectivity, other power sources, such as, diesel-based generators may be required. However, usage of these additional power sources may increase the operational expenditure (OPEX) and make it even more difficult for people to pay for broadband services.

- Shortage of trained manpower

Rural areas present fewer economic opportunities both in terms of numbers as well as type of work; technically qualified people therefore migrate to towns and cities in search of better job opportunities [9]. Hence, skilled manpower capable of supporting and maintaining the network infrastructure, may not be available locally and may need to be brought from other places on temporary basis. This increases the cost of maintenance (OPEX) further.

- Barrier of language and literacy

Today, over 80% of online content (on Internet) is available in the following 10 languages only: English, Chinese, Spanish, Japanese, Arabic, Portuguese, German, French, Russian and Korean. These are understood/spoken worldwide by 3 billion people only [11] and rural population in India hardly read & write any one of these languages. Therefore, bulk of the online content may have little relevance for Indian rural population.

# Rural Wireless Broadband Communication System - Requirements

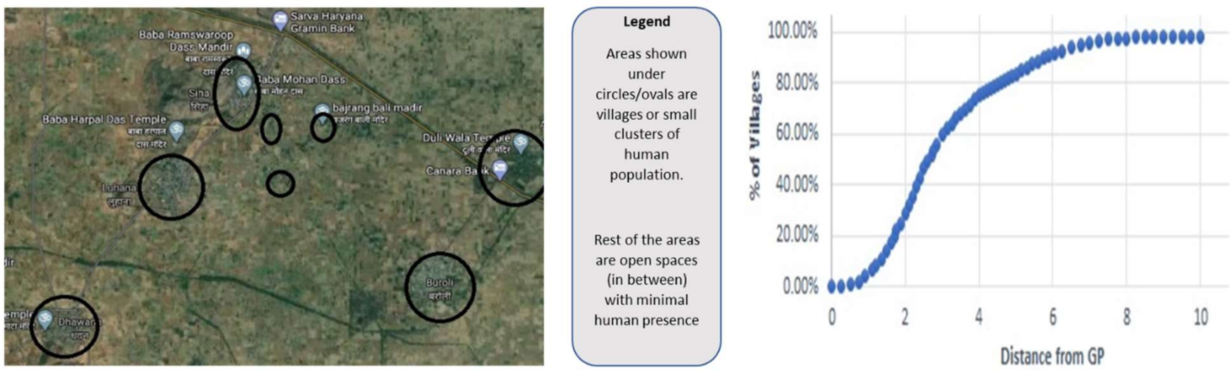
Wireless communication technology and its variants, e.g., cellular technology can be used to provide broadband connectivity to rural population In India. However, the specific characteristics/challenges identified above impact their deployment and usage. Any broadband wireless technology, to be deployed in rural India needs to address these challenges. Considering these challenges, we can identify a set of requirements to be supported by the wireless communication technology in order to be successfully deployed in rural India.

**Affordability of Solution/Technology**

Affordability of the technology is one of the most important requirements. In view of the factors, such as, lower income levels and lower population density in rural areas, it is imperative that the technology is affordable and the cost of delivering the service to users is low. Lower Capital Expenditures (CAPEX) and OPEX may need to be enabled through appropriate technology choices. For example, spectrum cost is one of the key parameters to impact the CAPEX and usage of unlicensed spectrum may help reduce CAPEX. Similarly, if part of the backhaul connectivity, generally provided through fiber or Digital Subscriber Line (DSL), can also be based on wireless technology, it may reduce the CAPEX further. This may particularly be true for areas, which are remote and suffer from poor accessibility.

**Alignment with Geographical Distribution of Population**

In order to provide communication service to users, a base station (BS) in a cellular system typically broadcasts radio signals (electromagnetic waves) uniformly over a wide geographical area also called a ‘cell’. In contrast, population in rural areas is unevenly distributed; people live in small clusters with vast open spaces in between. Due to this characteristic distribution of population, providing similar level of service in a ‘cell’, i.e., broadcasting radio signals over a large geographical area uniformly may neither be required nor efficient. For efficient usage of radio resources, bulk of the radio signal energy should be directed to pockets of highly populated areas [22] while open areas with small number of people present should do with smaller amount of radio energy transmission. In nutshell, the deployment of wireless technology should be aligned to efficiently cater to the characteristic distribution of population in rural areas.




(a): Example Rural Landscape

(b): Distance between a village and its GP office

**Figure 1: Rural Landscape in India – Village Distribution (Courtesy – Google Earth, [12][13])**

**No Need for High Speed Mobility Support**

One of the most important requirements for cellular technology is the support for user mobility. The technology was primarily developed to support the communication needs of mobile users. Each successive generation of cellular technology has been designed to support communication at higher vehicular speeds than that of the earlier one. IMT-Advanced (4G) technology supports communication needs of users moving at a speed of up to 375 km/hour [15], and IMT-2020 (5G) technology has been designed to support the speed of 500 km/hour[18]. Support for high speed mobility poses multiple challenges for the design of cellular systems, such as, the need to develop highly complex channel estimation and synchronization techniques [31] and makes it costlier.

Interestingly, high-speed mobility use cases are not needed for rural India. Most of the users in rural India are pedestrian or moving at speeds lower than ~40 km/hour [25]. Therefore, wireless or cellular systems to be deployed in rural areas may be w/o the support for high speed mobility. It may reduce the complexity as well as the cost of the system.

**Reduced Energy Consumption**

As indicated above, power available from the grid may be inadequate and in order to support the operation, conventional cellular systems may need other sources of power, such as, diesel-based generators. Usage of diesel-based generators increases the OPEX of the system and the affordability of the system goes down [23][24]. Usage of technologies, that consumes lesser amount of power and is capable of running on renewable energy sources is preferable in this scenario.

**Ease of Manageability**

Ease of Manageability is quite important due to cost and access constraints. The network equipment and the technology should be such that the equipment can be managed with ease and these should be plug and play, wherever possible. The maintainability of the network equipment deployed in remote regions is of even higher concern.

**Support for Local Content Generation and Storage**

As mentioned earlier, bulk of the content available on Internet today are not in Indian languages, and it reduces the attraction of Internet for people in many parts of rural India. India is home to a large number of local languages and has immense language and cultural diversity. Therefore, the support for local content generation, upload and storage may be beneficial.

# Wireless Broadband Communication Standards for Rural India

All technical standards are driven by a set of requirements. Unfortunately, the requirements identified above, do not form part of the basic requirement set of IMT Advanced [15] and IMT-2020 standards [16] [17], the leading standards for cellular broadband technology. However, for better suitability to rural India, wireless broadband standards may need to cater to these requirements. It should also be observed that these requirements are not specific to India. Many of these are applicable to rural areas in other developing countries and in parts of the developed countries too [14]. Therefore, any technical standard, catering to these requirements, would be useful in a large number of geographies world-wide.

In order to develop a technical standard for rural wireless broadband, the standards development community in India took two separate approaches. One of them is called the 'Low Mobility Large Coverage Area Cell (LMLC)', and the other one, 'Frugal 5G Networks'. Both these have been developed to provide last mile broadband access through wireless technology in rural areas.

## LMLC – Augmentation of IMT-2020 for Rural Broadband

Capacity increase has been one of the key focus areas for the cellular industry and the upcoming 5G standards is no exception, as demonstrated by the key KPIs identified by ITU. Enhanced capacity translates to higher throughput as well as improved user experience. Reduction of cell sizes is one of the techniques used in cellular networks to achieve higher capacity. A cell with reduced size serves a smaller number of users and can therefore provide higher per-user throughput. Dense urban areas with high user density, need smaller cells to maintain reasonable user experience. For example, an Inter-Site Distance (ISD) of 200 meters for the 'Dense Urban - eMBB' scenario and an ISD of 500 meters for the 'Urban Macro' scenario has been discussed in the 5G standards [19]. Over the years, both academic & industrial research have spent significant amount of efforts to understand the intricacies of smaller cell sizes [20]. This may also be due to the fact that urban areas have more users with higher paying capacity. Numerous interference management algorithms and Multiple Input Multiple Output (MIMO) techniques have been developed for interference-limited macro cells of smaller size. However, cellular systems with very large cells have not received much attention all this while. LMLC is an attempt towards understanding the characteristics of very large cells and how they can be used to support broadband connectivity in rural landscape with lower population density.

In order to appreciate LMLC better, we may need to understand the organization of villages in rural India. Villages in India are organized around an administrative unit called 'Gram Panchayat (GP)'. A group of a few nearby villages constitute a GP. Depending on the size & the population of the constituent villages, total number of villages in a GP typically varies between 1 to 5, covering a geographical area of ~10-20 square kilometres [7]. Every Gram Panchayat has one office (GP office), used for administrative purposes. There are around 600 thousand villages and 250 thousand GPs in India [7] [12].

In order to provide broadband connectivity to villages in India, the Government of India has embarked upon an ambitious project, called BharatNet [13]. It is one of world's largest rural broadband projects, expected to provide fiber connectivity to all GPs in India by connecting each GP office via fiber, i.e., it will cover the whole of rural India with fiber, with one fiber 'Point of Presence' (PoP) in every ~10-20 square kilometre area. However, fiber connectivity may not be provided to individual homes in the villages. Therefore, once the fiber PoPs are deployed, there will be a need to extend the broadband connectivity from the PoPs to individual homes. One of the ways to extend the last mile from the fiber PoP is to install a cell-site at each fiber PoP. A Base Station (BS) tower at the cell-site can serve the neighbouring areas through wireless medium and provide broadband connectivity to the villages around the GP office. The backhaul connectivity between the cell-site and the Core/Internet is taken care of by the fiber PoP, reducing the CAPEX. If the wireless technology can cover a large area and support the connectivity needs of all villages inside a GP, CAPEX would further decrease as a small number of BSs, typically one BS per GP, can cover the rural India.

In Figure 1(b), distribution of the distance between the villages and the corresponding GP office has been illustrated. One can observe from the figure that a radius of 3 km from the cell-site (the fiber PoP in GPs) can cover 60% of the villages, a radius of 6 km from the cell-site can cover >90% of the villages, and a radius of 10 km can cover almost all villages. Therefore, a wireless technology that can support a cell radius of ~6 km, and provide high speed data in the covered area, would solve the problem of broadband access for >90% villages. 4G LTE technology can support large coverage area cells [34] but as shown in Table 3, it may not be able to provide the required date rates.

Cell sizes with ~1 km radius, the main focus of the **original** "Rural – eMBB" test configuration in ITU, may cover only a small area around a cell-site. It would be insufficient to serve all villages inside a GP [Figure 1]. Cells with such small sizes would need a base station to be deployed in every village. This would increase the backhaul and cell-site infrastructure requirements, inflate the deployment cost and result in an unviable solution with a huge gap between the expenditure (CAPEX+OPEX) and the RoI. Moreover, per village cell-site might solve the problem of broadband connectivity inside the villages, but it may not enable connectivity to devices/users in the open spaces/farms around the villages. There might be a small number of users in these areas but they would remain unserved. IoT devices deployed in the farms to support farming related IoT use cases may also remain unserved.

### LMLC Configuration

Some members of TSDSI led by researchers of IIT Madras, IIT Hyderabad and CeWiT Chennai [20] pioneered the concept of LMLC. India introduced LMLC as a new sub-configuration of the Rural eMBB test environment in ITU toward IMT-2020 evaluation methodology [19]. LMLC configuration focuses on low mobility users (a mix of pedestrian <= 3 kmph and vehicles <= 30 kmph) and an ISD of 6 km. Unlike other rural broadband use cases of IMT-2020 and the earlier IMT-Advanced system, LMLC does not focus on high-speed mobility. The salient features of the LMLC test configuration is shown in Table 2 below.

| IMT-2020 – LMLC Test Configuration for Rural Broadband | | |
|---|---|---|
| Parameters | Config A (Original) | LMLC - Config C |
| Carrier Frequency | 700 MHz | 700 MHz |
| Inter-Site Distance (ISD) | 1732 meters | 6000 meters |
| User Equipment (Device) Distribution | 50% indoor, 50% outdoor (in-car) Randomly and uniformly distributed | 40% indoor, 40% outdoor (pedestrian), 20% outdoor (in-car) Randomly and uniformly distributed |
| BS Tx power | 49 dBm | |
| BS Antenna Height | 35 meters | |
| User Equipment (Device) Speeds of interest | 50% outdoor vehicles (120km/h) and 50% indoor (3km/h) 500 km/h for evaluation of mobility in high-speed cases | Indoor users: 3 km/h; Outdoor users (pedestrian): 3 km/h; Outdoor users (in-car): 30 km/h |

**Table 2: LMLC Configuration**

In addition to the test configuration, a new channel model was introduced for the LMLC rural scenario. This new channel model is valid for a cell radius of up to 20 km [35][36]. In the initial proposal for LMLC, a 12 km ISD was proposed, sufficient to cover more than 90% villages [Figure 1]b. However, after detailed discussion among the stakeholders, an ISD of 6 km was accepted. Also, the average spectral efficiency was accepted as a mandatory KPI for the LMLC test configuration that must be satisfied by all IMT-2020 technologies. While not sufficient for an exhaustive rural coverage, LMLC is a step in the right direction. LMLC deployment architecture is illustrated in Figure 2 below.

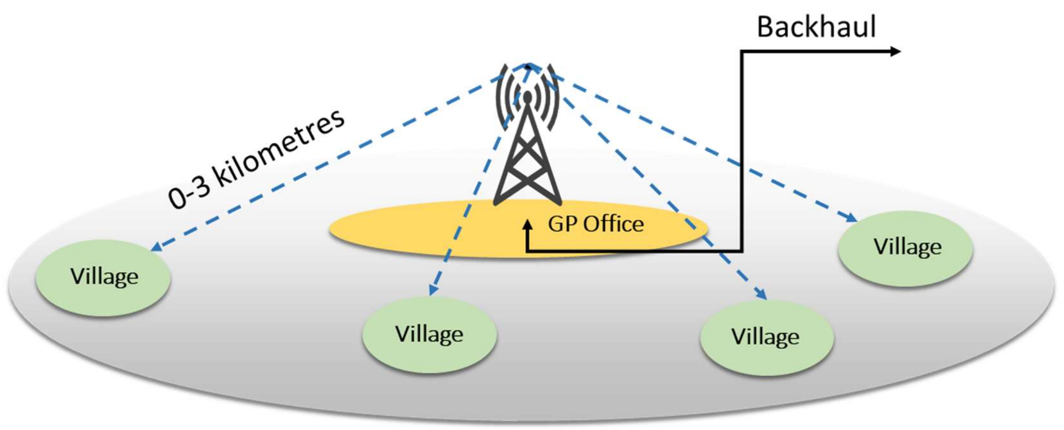



**Figure 2: LMLC Deployment Architecture (courtesy [20] )**

## Frugal 5G Network (IEEE P2061)

Frugal 5G network is a novel wireless access network architecture proposed by a group of researchers at IIT Bombay, India. It has been initiated as a technical standard, P2061 under Institute of Electrical and Electronics Engineers (IEEE) and is expected to be completed in year 2021[28]. The proposed standard has basis in some of the learnings from two large-scale testbeds deployed by the IIT Bombay team in the district of Palghar, near Mumbai, Maharashtra, India [27] [29].

The Network architecture has been developed after detailed consideration of requirements for rural wireless broadband, many of those have been identified above in section, ‘Rural Wireless Broadband Communication System - Requirements’. The architecture presents a framework, which can be realized by utilizing components (with suitable modifications) from the existing cellular standards including 5G and/or other existing wireless technology standards. It does not propose to develop any new wireless access technology.

### Frugal 5G Network Architecture

'Frugal 5G Network' is a heterogeneous access network (AN), comprising of macro cells and Wireless Local Area Networks (WLANs) brought together under a unified control and management framework with the help of Software Defined Networking (SDN) and Network Function Virtualization (NFV) technologies, two of the cornerstones of the emerging communication networks [32][33]. 'Frugal 5G Network' can be integrated with 3GPP 5G Core Network through 3GPP defined N2/N3 interfaces like any other access technology [38].

As shown in Figure 3, the Frugal 5G Network provides last mile connectivity to end-users with the help of either macro cells or WLANs. It enables connectivity to the external data network such as Internet, either via the Core Network or directly w/o the Core, unlike other cellular networks. In India, it can utilize the fiber backhaul, being deployed by the BharatNet project, to connect to the Core/Internet or any other backhaul, which is available.

As shown in Figure 3, a macro BS may be collocated with a PoP belonging to fiber, DSL or some other backhaul technology (can utilize the PoP in a GP deployed by BharatNet in India) and provides blanket coverage to users in a large area. It also provides the required Quality of Service (QoS) for the critical applications, if needed. Macro BS is expected to work in a lower frequency range, preferably in sub-GHz bands, to support a large coverage area. The standard does not restrict the macro cell to any particular technology. The key characteristics that the cellular broadband technology have to support are large coverage area and affordability. As will become clear later, it does not have to support very high throughput/capacity. 3GPP 4G LTE is capable of supporting large cells [34] and can be used as a component of the Frugal 5G Network. Depending on the requirements and the capabilities supported by different cellular technologies, any one of them can be used as a macro BS. The architecture also allows usage of different cellular technology at different locations.

However, due to inherent limitations of the cellular technology and smaller bandwidth availability in sub-GHz band, a macro BS may not be able to serve all users inside a Gram Panchayat. Table 3 shows the estimated data rate requirements for a GP along with the capacity of a three sector Macro BS (LTE/5G) using a bandwidth of 20 MHz.

| Parameters | Value | Remarks |
|---|---|---|
| **Average Area under a Gram Panchayat (GP)** | ~15 | Estimated Area in square kms (derived from the total rural area of the country and total number of GPs) |
| **Average Population Density/Sq km** | 325 | Estimated for year 2020 (Value for Year 2011 - 279) |
| **Average Population of a Gram Panchayat** | 4875 | Estimated Value = (Population Density * Average Area of GP) |
| **Contention Ratio (1:10)** | 10 | No of users simultaneously sharing the data capacity |
| **Required Broadband Data Rate (per user)** | 2.0 | in Mbps |
| **Required Downlink (DL) Data Rate/GP** | 975 | In Mbps |
| **Average Spectral Efficiency DL (bit/s/Hz/TRxP)** | 3.3 | Rural eMBB - ITU M.2412 |
| **Carrier Frequency** | 700 | In MHz |

| | | |
|---|---|---|
| **Bandwidth** | 20 | In MHz - Total DL+UL BW(TDD) |
| **Radio Resource – DL/UL(Uplink) Ratio in TDD** | 1:1 | DL/UL Symmetric Configuration |
| **No of Antenna Elements at BS (TRxP)** | 2 | 2 TRxPs per Sector |
| **DL Throughput Capacity - Single Sector** | 66 | in Mbps |
| **No of Sectors/BS** | 3 | Three sectors per BS |
| **Macro BS Downlink Throughput Capacity** | 198 | in Mbps |

**Table 3: Macro BS – Capacity vs Requirements**

As can be seen from the table the "Required Downlink Data Rate/GP" is 975 Mbps while the achievable DL throughput with 3 sectors and 2 TRxPs/sector is just 198 Mbps. In reality, the achievable DL throughput may be even smaller due to lower spectral efficiency for edge users. In contrast, the required data rate is expected to increase in future, as has been envisaged in the recent 'National Digital Communications Policy' of the Government of India [39] .

Therefore, to augment the broadband connectivity provided by the macro BS, WLANs are deployed inside the villages. IEEE 802.11 based WLANs may be used for this purpose. It is an energy-efficient and cost-effective technology. It facilitates high-speed broadband connectivity to stationary (pedestrian mobility) users, and is aligned with the requirement that most rural users are low mobility users. Since WLAN is used to provide high speed connectivity inside villages, bulk of the users are covered through WLANs. Macro cells are essentially used to fill the coverage holes between the WLANs and therefore macro BS need not be an expensive high capacity system.

However, the major challenge in deploying WLAN Access Points (APs) inside villages is the required backhaul support as there will be a need to connect the APs in the villages to the nearest fiber/DSL PoP, which may be located in a GP office. Today, no mechanism is available for the same. As shown in Figure 1(b), the distance between the two may range from a few hundred meters to a few kms. Frugal 5G Network proposes to use a wireless backhaul to enable the connectivity between WLAN APs and the fiber PoP. This wireless backhaul is called the Wireless Middle Mile Network (WMMN). The standard allows the usage of other technologies, such as, DSL or Optical fiber too as the middle mile, wherever available. Usage of wireless technology as the middle-mile is not mandatory. For example, if tomorrow, fiber connectivity is extended till individual villages then that can be used as the middle-mile.

WMMN consists of two types of simple Layer 2 radio devices, Middle Mile APs and Middle Mile Clients. Just like the macro BS, the Middle Mile AP is collocated with the fiber PoP. Middle Mile Clients are located inside the villages, close to the WLAN APs. A Middle Mile AP communicates with Middle Mile Client devices over a point-to-point wireless link. WMMN can be based on technologies like long range Wi-Fi, IEEE 802.22 [26] [27] etc. however the standard keeps it flexible.

A Middle Mile Client and a WLAN AP can be a single device with two different radio interfaces, just like a relay. Alternatively, these may be two separate devices connected through a wire. WMMN supports optimized multi-hop mesh network topology to effectively address the network coverage [37]. WLAN APs, Middle Mile APs & Middle Mile Clients are low power radio nodes capable of running on renewable energy sources. As shown in Figure 3, the proposed architecture mirrors the rural population distribution, which helps in efficient delivery of services to the users.

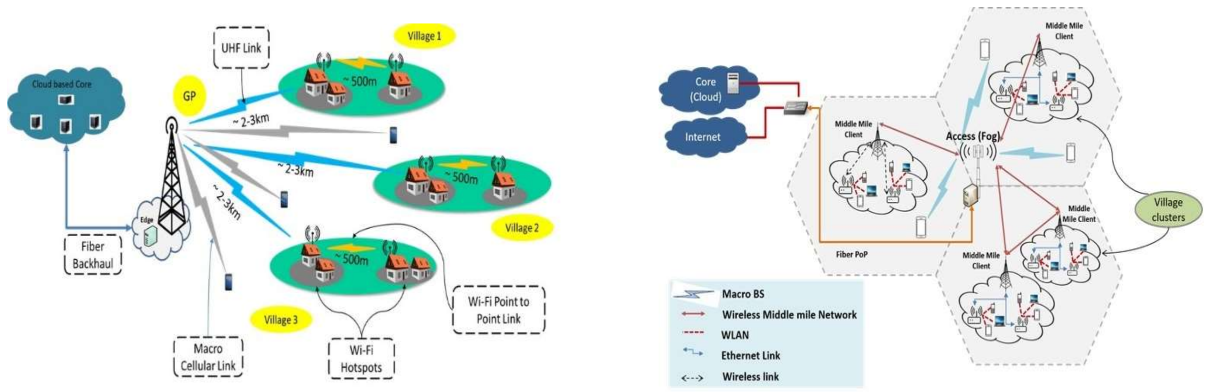



**Figure 3: Frugal 5G Network Architecture: (a) and (b) courtesy [30]**

Collocated with the PoP, there may be an Edge (Fog) cloud. The Edge cloud may contain an SDN Controller, a unified interworking function and a Content Delivery Network (CDN) for local content storage and delivery.

SDN Controller brings together all three access network components, the Macro BS, the MMN and the WLAN under a unified control and management framework. The unified interworking function in the edge cloud enables connectivity between the Frugal 5G Access Network and the Core/Internet. Irrespective of the access technology being used by the UE, WLAN or the macro BS, a single unified interworking function is used for connecting a UE to the Core. Edge cloud also supports direct connectivity to Internet and also to the local CDN.

The control and data plane elements in Frugal 5G network may be instantiated as virtual network functions capable of running on commercial off-the-shelf platforms. Typically, wireless networks are upgraded every few years to keep up with the technical advances. With the help of the virtualization, these upgrades can happen only in software and reduce the CAPEX. The table below shows how the rural broadband requirements maps to different features of the Frugal 5G Network.

| Requirements | Features | |
|---|---|---|
| **Affordability** | Low Cost & Low Power WLAN and Middle Mile Network Elements, Usage of Unlicensed Spectrum, Lesser No of Macro BSs | Usage of SDN/NFV, Usage of Commercial off-the-self Platform |
| **No need for High Speed Mobility Support** | Majority of the users served by WLAN | Possibly a simpler Macro BS |
| **Reduced Energy Consumption** | Usage of WLAN and Point-to-point Middle Mile Link | Sub-GHz band for longer reach by macro BS with lesser amount of power required |
| **Ease of Manageability** | Simpler Network Elements (IEEE 802.11, IEEE 802.22 devices) | |
| **Local Content Generation and Storage** | Local Storage in the Edge, Usage of SDN and NFV enabling local access | |
| **Sparse & Clustered Population Distribution** | Network Architecture aligned with the population distribution - Macro cell to cover a large area and WLANs to support village clusters | |

**Table 4: Rural Broadband Requirements to Features of Frugal 5G Network**

## Conclusion

Mobile devices are the most commonly used connectivity devices in rural India. It has transformed the rural landscape considerably and it appears that the wireless telecommunication standards are likely to have the most significant impact on the Indian rural society in future too.

However, we observe that the leading wireless broadband standards, especially the 4G/5G cellular technology standards, may not be very well aligned with the characteristic requirements of rural societies, especially those of developing countries like India. The focus of 4G and 5G cellular standards, as originally defined by ITU and 3GPP, has been on the use cases and requirements of urban societies. This may be one of the key reasons behind relatively lower penetration and usage of 4G cellular networks in rural India as compared to urban India. Realizing that a similar fate might await the 5G technology too, the Indian telecommunication standards development community initiated two separate standardization efforts to augment the 5G standards, the 'LMLC' and the 'Frugal 5G Networks'. LMLC has already been integrated in ITU's IMT-2020 (5G) standards successfully. The development of 'Frugal 5G Networks' standards is currently ongoing under IEEE as part of IEEE's 5G standardization portfolio. It is expected that these standards will pave the way for enhanced penetration and usage of future wireless broadband technology in rural India with pronounced impact on the lives of the people.

## References


[1] Colin Agur, "Re-imagining the Indian state: External forces and the transformation of telecommunications policy, 1947–present", Global Media and Communication, Sage Publications, 2018

[2] Telecom Regulatory Authority of India - Recommendations on Growth of Telecom services in rural India, The Way Forward, October 3, 2005

[3] https://www.gsma.com/coverage/

[4] Telecom Regulatory Authority of India - The Indian Telecom Services Performance Indicators, July – September, 2019

[5] "Mobile Network Coverage", Lok Sabha Q&A, Govt of India, Ministry of Communications, Department of Telecommunications, February 2020

[6] Highlights of Telecom Subscription Data as on 31st January, 2020, Telecom Regulatory Authority of India, Press Release No.29/2020

[7] Census of India 2011, https://censusindia.gov.in/

[8] Progress report of village electrification, Ministry of Power, Government of India, 2017, [Date accessed 25.05.2019]. [Online]. Available: https://data.gov.in/catalog/progress-report-village-electrification

[9] Migration data, Census of India 2011, https://censusindia.gov.in/2011census/migration.html

[10] "PER CAPITA INCOME IN RURAL AND URBAN AREAS", GOVERNMENT OF INDIA, "MINISTRY OF STATISTICS AND PROGRAMME IMPLEMENTATION", "UNSTARRED QUESTION NO. 2845 TO BE ANSWERED ON 12.12.2019" RAJYA SABHA, available on "https://rajyasabha.nic.in/"

[11] A. Marcus and A. Wong, "Internet for All: A Framework for Accelerating Internet Access and Adoption," in World Economic Forum, 2016,

[12] Census of India 2011, https://censusindia.gov.in/2011census/Listofvillagesandtowns.aspx

[13] Bharatnet (http://bbnl.nic.in/) : (A project to provide affordable rural connectivity in India)

[14] "A Rural Broadband Strategy, Connecting Rural America to New Opportunities", Microsoft

[15] Recommendation ITU-R M.2012-1 Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)

[16] ITU-R M.2083, "IMT Vision–Framework and overall objectives of the future development of IMT for 2020 and beyond" 2015.

[17] ITU-R M.2411. Requirements, evaluation criteria and submission templates for the development of IMT-2020

[18] ITU-R M.2410. Requirements related to technical performance for IMT-2020 radio interface(s)

[19] ITU-R M.2412. Guidelines for evaluation of radio interface technologies for IMT-2020

[20] Saidhiraj Amuru, Radha Krishna Ganti, Kiran Kuchi, J. Klutto Milleth and Bhaskar Ramamurthi, “A Case for Large Cells for Affordable Rural Cellular Coverage”, Journal of Indian Institute of Science, Volume 100:2, April 2020

[21] L. Chiaraviglio, N. Blefari-Melazzi, W. Liu, J. A. Gutierrez, J. Van De Beek, R. Birke, L. Chen, F. Idzikowski, D. Kilper, J. P. Monti, and J. Wu, “5G in rural and low-income areas: Are we ready?” in 2016 ITU Kaleidoscope: ICTs for a Sustainable World (ITU WT), Nov 2016, pp. 1–8.

[22] A. Karlsson, O. Al-Saadeh, A. Gusarov, R. V. R. Challa, S. Tombaz, and K. W. Sung, “Energy-efficient 5G deployment in rural areas,” in 2016 IEEE 12th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob). IEEE, 2016, pp. 1–7.

[23] “Typical Calculation of Running Cost per unit (kWH) for DG set”, “https://www.apollopowersystems.com/wp-content/uploads/2016/03/Typical-Calculation-of-Running-Cost-per-unit.pdf”

[24] https://economictimes.indiatimes.com/industry/energy/power/india-to-consider-ways-to-lower-hydropower-tariffs/articleshow/62599393.cms?from=mdr

[25] “TRANSFORMING INDIA’S MOBILITY A Perspective”, Niti Aayog, Govt of India

[26] M. Khalil, J. Qadir, O. Onireti, M. A. Imran, and S. Younis, “Feasibility, architecture and cost considerations of using TVWS for rural Internet access in 5G,” in 2017 20th Conference on Innovations in Clouds, Internet and Networks (ICIN), March 2017, pp. 23–30.

[27] A. Kumar, A. Karandikar, G. Naik, M. Khaturia, S. Saha, M. Arora, and J. Singh, “Toward enabling broadband for a billion plus population with TV white spaces,” IEEE Communications Magazine, vol. 54, no. 7, pp. 28–34, July 2016.

[28] P2061: Architecture for Low Mobility Energy Efficient Network for Affordable Broadband Access, 2018. [Online]. Available: https: //standards.ieee.org/project/2061.html

[29] M. Khaturia, S. B. Belur, and A. Karandikar, “Chapter 5 - TV White Space Technology for Affordable Internet Connectivity,” in TV White Space Communications and Networks, R. Stewart, D. Crawford, and A. Stirling, Eds., 2018, pp. 83 – 96.

[30] Meghna Khaturia, Pranav Jha and Abhay Karandikar, “Connecting the Unconnected: Towards Frugal 5G Network Architecture and Standardization”, IEEE Communication Standards Magazine, June 2020.

[31] P. Fan, J. Zhao, and C. I, “5G high mobility wireless communications: Challenges and solutions,” China Communications, vol. 13, pp. 1–13, N 2016.

[32] S. Denazis, E. Haleplidis, J. H. Salim, O. Koufopavlou, D. Meyer, and K. Pentikousis, “Software-Defined Networking (SDN): Layers and Architecture Terminology,” Tech. Rep. RFC 7426, 2015.

[33] ‘Network Function Virtualization’ ‘An Introduction, Benefits, Enablers, Challenges & Call for Action’, ETSI - “Network Functions Virtualisation – Introductory White Paper”

[34] LTE – The UMTS Long Term Evolution, From Theory to Practice, Second Edition, Stefania Sesia, Issam Toufik, Matthew Baker

[35] IITH et.al.. Comparison of _/2 BPSK with and without frequency domain pulse shaping: results with PA model. In: 3GPP TSG-RAN WG1 Ad-Hoc NR Meeting, R1-1701180, Spokane, WA, USA, Jan 16–20, 2017

[36] IITH et.al.. Low PAPR reference signals. In: 3GPP TSG RAN WG1 Ad-Hoc Meeting # 1901 , R1-1900215, Taipei, Taiwan, 21–25 Jan 2019

[37] Meghna Khaturia, Kumar Appaiah, and Abhay Karandikar, "On Efficient Wireless Backhaul Planning for the "Frugal 5G" Network", Proceedings of Workshop on Future Networking for 5G and Beyond Testbed and Trials, IEEE WCNC 2019

[38] 3rd Generation Partnership Project; TS 23.501 V15.6.0 (2019-06) System Architecture for the 5G System; Stage 2 (Release 15)

[39] National Digital Communications Policy – 2018, Department of Telecommunications, Govt of India