Broadband Internet and Access Technology for Rural Connectivity

Kishore Kumar Thakur, FIETE
Bharat Sanchar Nigam Limited, ARTTC Campus, Hazaribagh Road, Ranchi 835 217 Jharkhand India
cgm_jhk@bsnl.co.in

Abstract – **Wireless backhaul is increasingly recognized as an option for combating the expenditures involved in providing fiber based backbone for rural connectivity. Wireless backhaul solutions can take the form of point-to-point or point-to-multipoint wireless Ethernet bridges or wireless mesh networks. They can use licensed or unlicensed spectrum band. With throughput from as low as 10 Mbps up to Gbps, full duplex, a licensed microwave link or wireless bridge can provide sufficient capacity for many rural applications.**

Aspects of rural connectivity are explained that provide inputs for proposed solutions and policy formulation. Limitations of cellular, the need to focus on non-mobile endpoints, the use of unlicensed spectrum, and wireless links as an alternative for fibre are pointed out.

Keywords: Rural connectivity, Wireless internet, Access technology, Broadband internet, High-speed internet, Backhaul network, Very small aperture terminals

I. INTRODUCTION

RURAL areas especially those of the developing countries provide challenging environment to implement communication infrastructure for data and Internet based services. The main challenges are the high cost of network implementation and lack of customer base, as rural areas are characterized by low income, highly scattered and low population density. This situation drives network operators to establish network infrastructures in urban/city centres leaving rural areas as underserved community.

To achieve country-wide Internet access is an important goal to sustain the progress of our societies. Nevertheless, there is important gap between the urban and rural areas in terms of Internet Connectivity that is mainly due to a lack of interest by Internet Service Providers (ISPs) in deploying a wired infrastructure in these areas; such lack of interest is expected to be maintained since the estimated Return of Investment (ROI) is not attractive.

It is widely accepted that new information and telecommunication technology are needed to alleviate a wide range of obstacles for economic and social development in rural areas. This is particularly true for Internet accessibility, since it offers a global platform for retrieving and sharing information.

During past few years, there has been a remarkable progress in the most developed countries in terms of telecommunications facilities. However, outside the main urban areas, there are significant handicaps that make Internet connectivity a complex and costly task.

New wireless technologies offer effective and inexpensive solution to bring wireless Internet to rural areas. In fact, the promise of wireless Internet technologies led to increased interest of international development community. This synergy has driven by wireless standards recently ratified by IEEE, namely IEEE 802.11 standard [Ieee99] for wireless local area networking (also known as Wi-Fi), and the IEEE 802.16 [1] standard for long distance point-to-point connectivity (also known as WiMax) targeting MANs [2].

Wireless Internet will offer significant applications such as e-education, e-health, e-business or e-agriculture to remote users. However, additional efforts are required to extend the deployment of wireless infrastructures from urban centres and laboratories to low density population areas.

II. EXISTING AND EXPECTED RURAL CONNECTIVITY TECHNOLOGIES

Currently, a number of wireless technologies are either available or will be available soon which will bring high-speed internet access to most of the villages. The wireless technologies have progressed over the last few years like WiMAX (802.16d), 802.20 or Wi-Fi Mesh etc. These should soon allow the introduction of countrywide low cost rural broadband services. A list of present and expected connectivity technologies that can be used at present or in near future is listed below:

- Fixed Lines
- Cell Phones
- Cable Modems
- VoIP / VOB
- VSAT
- Wi-Fi
- WiMAX [3]
- Wi-Fi Mesh [4].

Providing connectivity to the rural areas may be possible through VSAT link or an Optical Fibre Cable (OFC) feed leased from an Alternative Telecommunication Network (ATN), this feed can be used in combination with Wi-Fi Technology like Bharat Sanchar Nigam Limited is doing in rural and remote areas under the Bharat Net Initiative**.** It can, therefore, be assumed that, countrywide low cost rural Broadband services shall be made available.

III. TECHNOLOGY ALTERNATIVES FOR ACCESS, BACKHAUL AND DEVICES

Technology options are always a function of type of locations, geography and terrain. Though there are various geographies that may exist, the terrains in most likely scenarios are likely to be the following:

i. Flat Open Space
ii. Valley
iii. Rugged Mountain Terrain
iv. Deserts
v. Islands.

The technology choice for a broadband network in rural areas has to be made mainly keeping into account the type of terrains which generally are difficult geographically, to select the most appropriate solution while keeping the cost low.

Normally, a broadband network can be divided in two main components, namely Access network and Backhaul network [5] as shown in Figure 1.

Access network provides last mile connectivity between subscriber/premises and nearest node of the service provider or point of presence (POP), whereas the Backhaul network connects all POPs of the service provider for carrying aggregated traffic of subscribers [6] to other service providers, International Gateway/Content Delivery Network (CDN). Different technologies both based on wireline and wireless are available for access and backhaul networks to provide end to end broadband services. Some of the technologies can be used both for access as well as backhaul [7].

Generally, the Access network is deployed by the licensed service providers or their franchises (MHSP) using various Wireline and wireless technologies. This network extends right up to subscriber premises/handset and must be designed and dimensioned on the basis of the services and applications that each customer may require, today and in future.

While selecting a particular technology option both speed and availability are important considerations. It is important to increase throughput (data rate) by deploying efficient IP based next-generation networks so that emerging applications and services that will play important roles in improving quality of life and boosting economic growth are supported.

IV. OPTIONS FOR ACCESS NETWORK

Wireline Technologies: Wireline technologies are capable to support high speed data transfer with reliability [8]. Some of these technologies are:

- xDSL (Digital Subscriber line) over copper
- Passive Optical Network (PON) over Fibre (FTTX)
- Data Over Cable Service Interface Specification (DOCSIS)
- Ethernet-over-Coax (EoC)
- Power Line Communication (PLC).

Digital Subscriber Line (xDSL): DSL or xDSL is a family of technologies which uses the conventional telephone lines (copper cable) [9] for transmitting the digital data at higher frequency than the frequency used for voice communication. Different type of DSL technologies are:

(i) *HDSL:* High bit rate Digital Subscriber Line (HDSL) [10] is a bidirectional and symmetrical transmission system

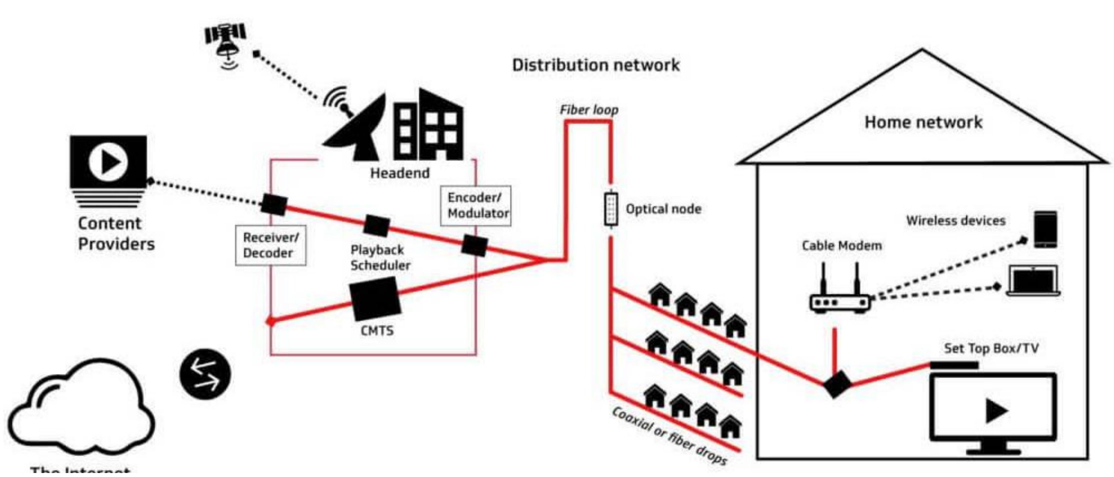

Figure 1: A typical broadband network.

that allows the transport of signals with a bit rate of 1544 Kbit/s or 2048 Kbit/s on the copper twisted pairs [11]. In this type of DSL bandwidth allocation in upstream and downstream is same. It works upto about 3 km delivering maximum speed upto 4 Mbps in each direction.

(ii) *Asymmetric DSL:* ADSL is a form of DSL where more bandwidth can be allocated to download than to upload. It provides maximum speed of 8-10 Mbps downstream and about 1 Mbps upstream. ADSL can provide satisfactory services upto about 3-4 km from the local exchange depending on quality of copper pair. It is suited to residential use as it shares a single twisted copper pair with voice, allowing users to use the telephone and surf the Internet simultaneously on the same physical copper pair line [12].

(iii) *ADSL2, ADSL2 plus* – ADSL2 is sequel to the original ADSL recommendation, enabling improved speed, longer reach and low power consumption. ADSL2 can deliver 8-12 Mbps download speed while further extending the distance coverage. Further, the voice channels are realigned and often provide the ability to combine multiple ADSL2 lines for higher bandwidth to certain customers. ADSL 2 plus (ADSL2+) builds further on ADSL2 by increasing the bandwidth throughput extending the usable frequencies on the line [13]. These increase download speed from 8 Mbps with ADSL2 to 16 Mbps with ADSL 2 plus, at the cost of coverage which is reduced to approximately 1.5 km [14].

(iv) *Very-High-Data-Rate DSL* (Very high speed Digital Subscriber Line) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. VDSL2 is an enhancement that supports asymmetric and symmetric transmission at a bidirectional net data rate up to 200 Mbit/s on twisted pairs using a bandwidth up to 30 MHz. VDSL connects to neighborhood optical network units (FTTN), which then extends connectivity to the telephone company's central office (CO) main fiber network backbone.

(v) In spite of continuous technological progress, physical limitations inherent to DSL technologies make them unusable in scarcely populated areas with long distances between the end users and the nearest telephone exchanges, or in regions where most houses are not connected to the telephone infrastructure. Therefore, these are not considered for a business case for rural broadband.

Passive Optical Network (PON) over Fiber

(i) PON is an Optical Access Network (OAN) with the capability of transporting various services between the customer premises and the Service provides node over optical fibber.

(ii) The optical section of a local Access network system could be either an active point-to-point or passive point-to-multipoint architecture. Figure 2 shows the architectures which range from Fibre to the Home (FTTH) [15], Fibre to the Building/Curb (FTTB/C) and Fibre to the Cabinet (FTTCab). The Optical Access Network (OAN) is common to all architectures shown in Figure 3; hence commonality to support various options in this system has the potential to generate large world-wide volumes. The FTTB/C and FTTCab network options are predominantly different from point of view of implementation [16].

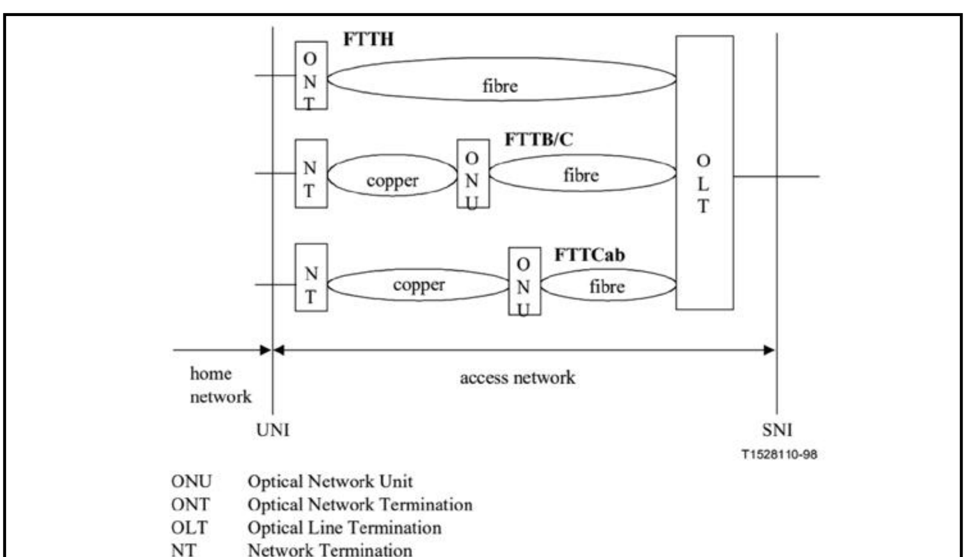

Figure 2. Network Architecture of Access Optical Network (Source: ITU-T G.983.1).

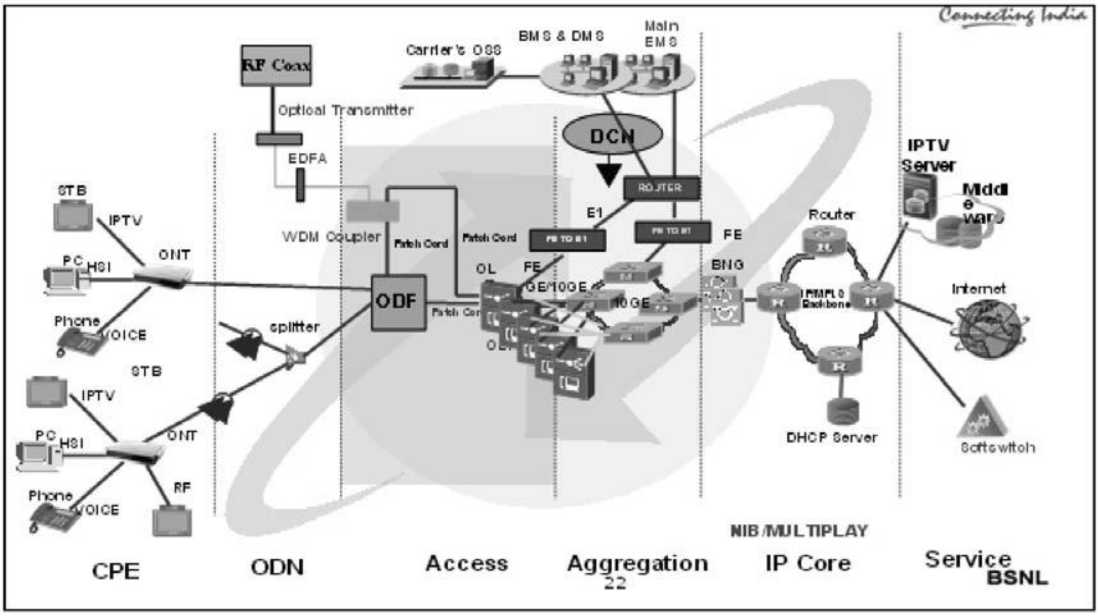

Figure 3. BSNL FTTH Architecture.

Data over Cable Service Interface Specification (DOCSIS): Data over Cable Service Interface Specification (DOCSIS) defines interface requirements for cable modems involved in high-speed data distribution over cable television system networks which enable provision for bidirectional data over coaxial and hybrid fibre-coax cables for interactive services [17].

Ethernet-over-Coax (EoC): Another technology used over cable TV networks is Ethernet-over-Coax (EoC). Standards used in this technology are Multimedia over Cable Alliance (MoCA) and Home Phone Networking Alliance (HPNA). MoCA has been designed for local in-building distribution using frequency range above 862 MHz, which limits its use mainly in HFC plants. HPNA in its latest version 3.1 uses the frequency range of 4 to 52 MHz and can therefore bridge greater distance due to low loss in coaxial cables in this frequency range.

Power Line Communication (PLC): Power line communication (PLC) is the term used to describe several systems using electric power lines to carry radio signals for communication purposes. Power line communication technology can use the household electrical power wiring as a transmission medium. Telecommunications services can be provided over power line through the modems and injectors. Access to Internet or other telecommunication services can then be provided by a leased line/wireless/satellite link attached at the Broadband over Power Line (BPL) devices [Fig. 4]. In future, it is expected that systems will be capable to offer upto 200 Mbps speed commercially [18].

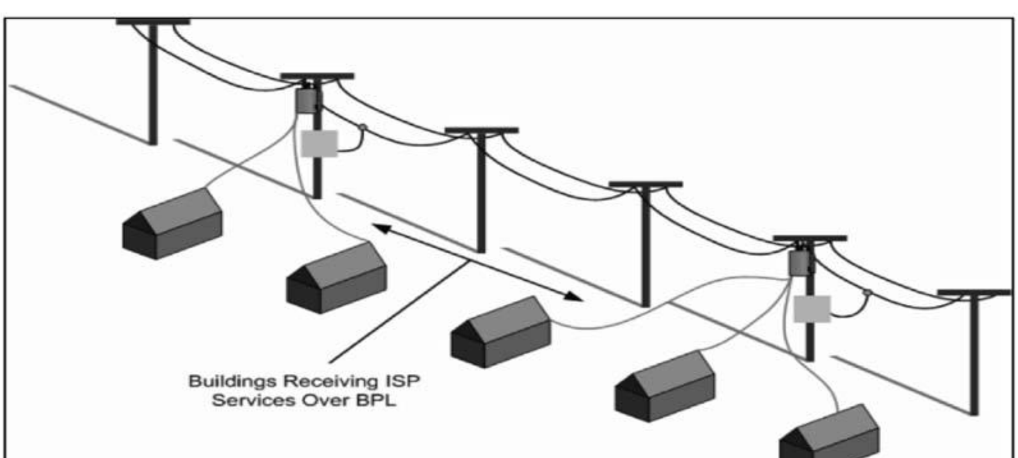

Figure 4: Broadband over power line.

Wireless Access Technologies: Wireless based technologies for Broadband access are emerging rapidly due to technological innovations. Wi-Fi as one of the wireless access technology can play very important role especially in the geographies like India. To substantiate this statement some statistics are provided below.

Various wireless technologies capable of providing Broadband are described next.

The unlicensed spectrum based Wi-Fi: The unlicensed spectrum in sub 6 GHz bands like 2.4 GHz, 5.1 GHz and 5.7 GHz can be utilized in rural areas where interferences are unlikely to occur. This technology is a low-cost option for creating the Access Points (Hotspot) in limited coverage areas. In addition; mid capacity radio links (50 Mbps) can serve as access connections to businesses, school campuses and government facilities. This option is low-cost, easy to install and can be used to provide adequate capacity for supporting Broadband services with a mix of legacy and Ethernet traffic. Due to its affordability, scalability and versatility, Wi-Fi Hotspot are spreading beyond urban to rural areas. Wi-Fi technologies can be configured into point-to-point and point-to-multipoint networks to improve range and provide last mile access for broadband.

Wi-Fi networks offer affordable, scalable and versatile technologies that can facilitate the spread of Internet access in rural and urban areas alike. Modern technology also makes it possible to integrate a server with high storage capacity with the Wi-Fi hotspot equipment. As the cost of such servers has come

TABLE 1 – INTERNET SUBSCRIBER BASE TRENDS

Segment	Mode of Access								Total Subscribers (in million)	
			Wireless Subscribers (in million)							
	Wired Subscribers (in million)		Fixed Wireless (Wi-Fi, Wi-Max, Radio & VSAT)		Mobile Wireless (Phone + Dongle)		Total Wireless			
	Dec-17	Mar-18	Dec-17	Mar-18	Dec-17	Mar-18	Dec-17	Mar-18	Dec-17	Mar-18
Broadband	17.86	17.95	0.441	0.457	344.57	394.19	345.01	394.65	362.87	412.60
Narrowband	3.43	3.28	0.013	0.014	79.65	78.06	79.66	78.07	83.09	81.35
Total	21.28	21.24	0.455	0.471	424.22	472.25	424.67	472.72	445.96	493.96

[*Source*: TRAI]

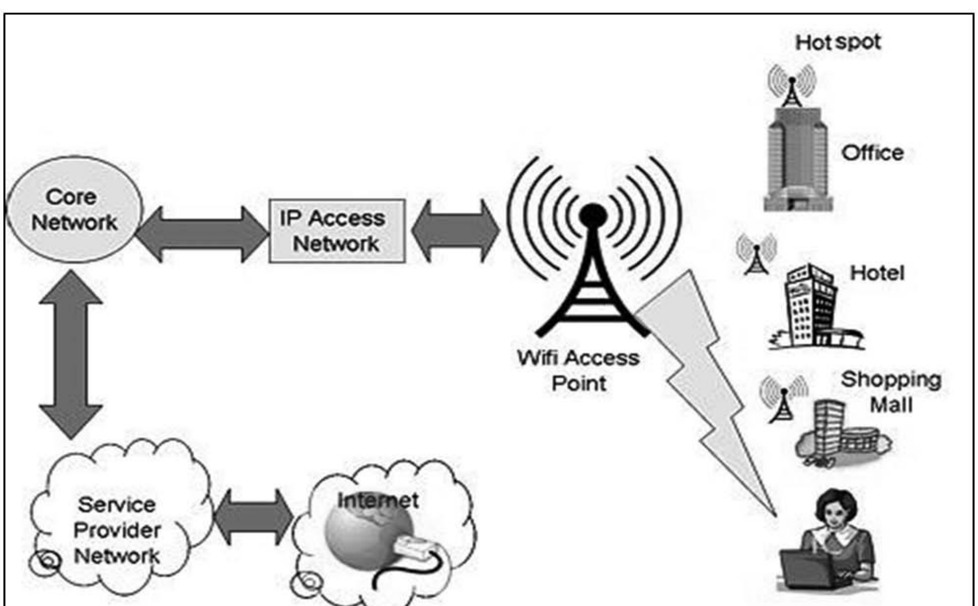

Figure 5. Wi-Fi Access through Wi-Fi Hotspot.

down significantly, along with the cost of storage, and the form factors of such devices are very small, it should be possible to cache or download content for easy browsing even when the backhaul connectivity is not available. Such an arrangement can find great application in storing children's study materials, educational data, agricultural and health related information, as well as movies and entertainment content, for the benefit of Wi-Fi users in areas with irregular connectivity, such as rural areas.

Advancements in Wi-Fi technology: Wi-Fi uses radio waves that run at a specific frequency, generally 2.4 GHz and 5 GHz, to create wireless networks. The widespread adoption of Wi-Fi technology is attributable both to technological advancements in standards as well as the fact that most jurisdictions have fully or partially de-licensed the radio frequencies on which it operates, hence drastically bringing down the cost of delivering Wi-Fi services [19].

Wi-Fi technology has gone through significant advancements in the years since 1997, when the 802.11 standard was first adopted by the IEEE [20]. These subsequent improvements to the technology have enabled better speed, reliability and security in the usage of Wi-Fi networks. Table 2 summarises the Wi-Fi generations currently in use.

TABLE 2 – CURRENT WI-FI GENERATIONS [21]

Standard	Year of introduction	Frequency	Maximum connection speed
802.11a	1999	5 GHz	54 Mbps
802.11b	2000	2.4 GHz	11 Mbps
802.11g	2003	2.4 GHz	54 Mbps
802.11n	2007	2.4/5 GHz	450 Mbps
802.11ac	2014	5 GHz	1.3 Gbps

IMT standard based Cellular Access technologies using Licensed Spectrum: New wireless technologies are capable to provide faster data communications services along with voice. These are based on the International Telecommunication Union (ITU) family of standards under the International Mobile Telecommunications (IMT) programme and commonly known as 4G and beyond (5G) technologies [22].

However due to cost considerations for network which works in licensed spectrum band as well as high smart devices these are yet to proliferate in rural areas and are not likely support the business case for rural and remote areas yet [23].

Both wireline and wireless technologies have their advantages and disadvantages. One fact is very vital that wireline technologies are having much greater capacity as compared to wireless technologies. However, there are many developments in wireless technologies based on Wi-Fi and players have started using this technology for access in a cost-effective manner.

Satellite Based Communication for Broadband Access: VSATs offer opportunities for achieving universal broadband coverage through the large areas achievable via a single footprint, and the fact that satellite technologies can be deployed as soon as the satellite is operational, regardless of terrain, distance or any availability of 'last mile' infrastructure [24].

Use of satellite technology for broadband access offers significant advantages in terms of ubiquitous coverage, simplicity in network design, reliability and rapid deployment and is very effective to serve rural and inaccessible hilly areas where wired access as well as terrestrial wireless is cumbersome to install and maintain. Though the perception is that today's satellite solutions lag behind fiber and wireless technologies in latency, mass throughput, and cost per bit, however, in future satellites are becoming very advanced in terms of reliability, speed of deployment, and security. Indeed, the next generation of satellites have started delivering higher transmission speeds, potentially competing with other types of Broadband connectivity both in terms of speeds and costs (Broadband Commission, ITU).

Advantages of using VSAT for broadband access: VSAT based services can be deployed anywhere. It provides Broadband access independent of the local terrestrial/ wireline infrastructure, which is particularly important for backup or disaster recovery services as well as in accessible areas.

- The services can be deployed quickly - within a few hours.
- VSAT enables customers to get the same speeds and SLAs at all locations across their entire network regardless of location.
- Current VSAT systems use a broadcast download scheme which enables them to deliver the same content to tens or thousands of locations simultaneously at no additional cost [25].

Limitations of VSATs: Latency (delayed response) is generally experienced by VSAT links. As in case of GSO signals relay from a satellite 22,300 miles above the Earth, a minimum latency of approximately 500 milliseconds for a roundtrip appears. They are subject to signal disturbances due to the weather; the effect is typically far less than that experienced by one-way TV systems that use smaller dishes. VSAT services require an outdoor antenna installation with a clear view. This may make installation in skyscraper urban environments or locations where a customer does not have roof rights problematic [26].

V. SELECTION OF TECHNOLOGY FOR BROADBAND ACCESS

A host of many factors influence the optimal choice of technologies [27]. Among the most important are:

- Type of terrain
- Speed of deployment
- Data handling capability to the customer
- The existing footprint and quality of the fixed telephone network
- The availability of spectrum suitable for fixed and mobile voice and data services
- Cost of service provision
- Capacity of the masses to pay.

The technology options for delivering wired local loop broadband connectivity include the rollout of xDSL, DOCSIS cable, and fiber to the home infrastructure. All these suffer from the high cost of deployment as well as cumbersome and time-consuming process for installation. Wireless options include the rollout of mobile (2G, 3G, 4G), wireless broadband (Wi-Fi, WLAN), and VSAT infrastructure. Within cell-based (mobile) wireless standards, all users connect to a single base station, and the transmission bandwidth has to be shared among all users in the cell's coverage area. Most of these technologies suffer from the high cost of deployment except those making use of unlicensed spectrum to avoid high spectrum-oriented costs.

Wi-Fi is proving to be an ideal option for Broadband access in rural areas because of its cost advantage and ubiquity of the Wi-Fi compatible access devices. The advantages and disadvantages of Wi-Fi based wireless versus Wireline Broadband access have been analyzed and listed in Table 3.

TABLE 3 – WI-FI V/S WIRELINE

	Advantages	Disadvantages
Wi-fi based access	• Low Capex • Unlicensed Spectrum • Quick & easy deployment • Ubiquitous availability of affordable devices due to economies of scale • Low Opex	• Distance Limitation • Unable to serve very dense population areas.
Wireline broadband	• High capacity broadband • Very high data rate • Evolution to extremely high throughput	• Expensive (capex) to deploy new network • High opex

Considering the lower cost of deployment and also its usage in unlicensed band, Wi-Fi emerges as a compelling technology sweet-spot for access in rural areas, especially when the inexpensive devices which are Wi-Fi enabled are widely available.

VI. OPTIONS FOR BACKHAUL TECHNOLOGIES

Another pillar for Broadband network infrastructure is the backhaul network. Regardless of the technology selected for the Access, the main requirement of broadband services in rural areas is how to transport data capacity to and from the Access node and centralized node of core network. This backhaul connection to the access node should be able to carry at least to the order of 100 Mbps to the nearby point of presence (PoP), and sometime even more.

Terrestrial Microwave Based Backhaul: The microwave transmission in licensed spectrum band is separated into two low and high frequency groups. The low frequency group uses the spectrum between 6 and 11 GHz and is more focused on long haul, high capacity transport to rural access nodes. The high frequency group utilizes the 13-38 GHz spectrum and is more oriented towards medium and short haul applications.

Taking advantage of low frequency group radios operators can easily build long haul links that span over 30 km per hop and may reach up to 130 km with more sophisticated planning. Such high capacity links can be cascaded together to create radio trunks for networks spanning thousands of miles over virtually any terrain. Long haul radio technology is already tested and proven having been in service for years carrying real-time traffic in applications ranging from broadcast TV, to controlling and monitor of gas pipes, water systems and power grids, to military applications [28].

Today, radio solutions offer operators a reliable technology for long haul transport. Accompanied by new high capacity techniques, microwave radios can now be utilized as a cost-efficient alternative to fiber and serve the growing need for Broadband services in rural communities.

Satellite Based Backhaul: Satellites have been successfully serving the traditional markets *i.e.* telephony and broadcasting, covering large geographical areas using single beam/transmission. For satellite operators, their footprint is virtually limitless. Demand for two-way Broadband Access over large geographical areas not served by telecommunication infrastructure is ever increasing.

Satellite telecommunications technology has the potential to accelerate the availability of high-speed Internet services in developing countries, including the least-developed countries, the land-locked and island nations, and economies in transition.

Though satellites are generally designed for a 15-year life they often provide service for periods of 18 years or longer. Satellites are inherently highly reliable and provide a very high availability (up-time) compared with terrestrial solutions like fiber/copper cable or terrestrial wireless – particularly in developing countries where long sparse distances need to be covered.

Meanwhile, there are inherent latency (the time it takes to send and receive a message, 540 ms to 800 ms for a geostationary satellite in a typical environment) issues associated with the delivery of broadband using geostationary satellites. Latency is however not a problem for many applications like basic email access and web browsing. Since latency is due to the distance between the satellites and the earth, satellites in lower earth orbits have less latency than geostationary satellite networks [29].

Besides there are frequency dependent atmospheric/rain-attenuation problems for satellite signals especially in tropical areas – which creates issues primarily for higher frequencies like Ka-band. However, with improved technology in place to mitigate latency and attenuation issues, the underlying advantage of true global Broadband Access availability of satellite Broadband (*i.e.* data and web-based applications) is unmatched. One issue is that of the data capacities of the satellite bases Backhaul, which is not up to the mark yet [30].

Optical Fiber Based Backhaul: As the optical fiber based transmission system has enormous capacity, they are ideally suited for the backhaul segment for broadband specially taking into account the futuristic high-speed broadband applications. Even though wireless is accepted as an economical option for delivering "last mile" connectivity, backhaul traffic is usually carried via fiber-optic networks because of their high capacity. That is why optical fiber systems are forming the integral part of National Broadband Backbones. Issues with optical fiber systems are high CAPEX which needs funding from public agencies and also the time it takes to create the network.

VII. SELECTION OF TECHNOLOGY FOR BACKHAUL NETWORK

Comparison of three dominant backhaul technologies is given in the Table 4.

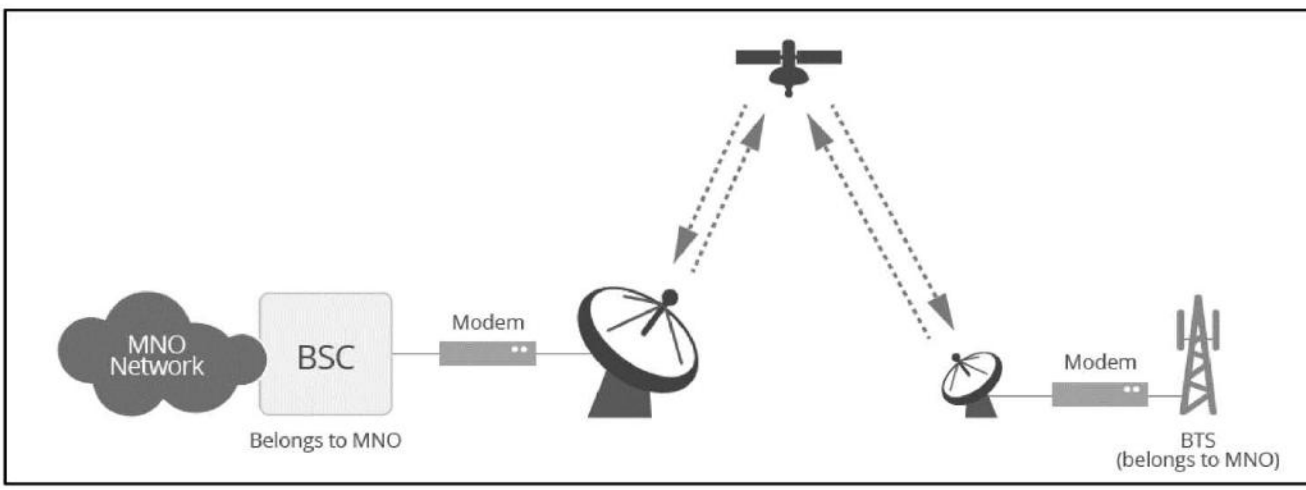

Figure 6. Satellite based backhaul services.

TABLE 4 – TECHNOLOGIES FOR BACKHAUL IN RURAL AREAS

	Terrestrial Microwave	*Fiber*	*Satellite*
Capacity	Limited	No limit	Limited
Distance	Cost per link. Some incremental cost with the distance	Directly dependent	No Dependence
Terrain	Any line of sight required	Becomes costly when trenched in mountains, desert, rocky plains or jungles	Any. Ideal for remote and difficult to Access terrain.
Climate	Sometime might need to select protected all indoor installation for the active equipment	Limits on Aerial fiber optic cable installation	Suffers from rain attenuation/ atmospheric conditions
Accessibility	Need Access only to the end points – two base stations for example	Trenching can be tricky if there is no Access for vehicles along the path	No issue
Time frame	Time taken in site acquisitions and towers erections	Right of way, and construction works may take a while and increase linearly with distance	Instant

While fiber has an obvious advantage in terms of capacity, it often does not fit the bill for rural deployment being too costly and too time consuming to deploy. Microwave on the other hand offers shorter setup cycles after obtaining the spectrum license. Satellite is suitable for providing Backhaul connectivity to remote and hilly areas which are difficult to access, otherwise.

Backhaul connectivity is often limited by the availability of the fiber-based network. The delivery of backhaul connectivity to rural areas lacking fiber-based network involves balancing of concerns about broadband access, connection quality, and the expenditures and delays entailed in rolling out supporting infrastructure. The benefits of terrestrial wireless backhaul technologies specially in unlicensed spectrum bands are worth considering in such cases.

Wireless backhaul is increasingly recognized as an option for combating the expenditures involved in providing fiber based backbone for rural connectivity. Wireless backhaul solutions can take the form of point-to-point or point-to-multipoint wireless Ethernet bridges or wireless mesh networks. They can use licensed or unlicensed spectrum band. With throughput from as low as 10 Mbps up to Gbps, full duplex, a licensed microwave link or wireless bridge can provide sufficient capacity for many rural applications [31].

VIII. CONCLUSION

Four aspects of rural connectivity that are inadequately understood were explained. The discussion would affect both proposed solutions and policy formulation. Limitations of cellular, the need to focus on non-mobile endpoints, the use of unlicensed spectrum, and wireless links as an alternative for fiber were pointed out.

Rural connectivity is poised to be a powerful new rural infrastructure that nurtures local economies and leads to education, social development, and other kinds of infrastructure. In the best case, rural connectivity will bring new options to these regions, produce a visible improvement in the quality of life, and reduce the pressure towards urbanization (with its associated societal costs). Besides reviewing the candidate technologies, finer points of wireless connectivity that need to be understood were covered to make this vision happen.

REFERENCES

[1] D. Johnsto and J. Walker, "Overview of IEEE 802.16 security," IEEE Security and Privacy, v 2, n 3,2004, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1306971.

[2] S. Nedevschi, J. Pal, R. Patra and E. Brewer, "A Multi-disciplinary Approach to Studying Village Internet Kiosk Initiatives: The case of Akshaya." *Policy Options and Models for Bridging Digital Divides,* Tampere, Finland, March 2005.

[3] J.D. Saunders, C.R. McClure and L.H. Mandel, "Broadband applications: categories, requirement and future frameworks" Peer Reviewed Journal on internet", vol.17, no. 11, 5 November 2012.

[4] S. Sen. *Topology Planning for Long Distance Wireless Mesh Networks,* Master's thesis, IIT-Kanpur, May 2006. *with Bhaskaran Raman*.

[5] World Economic Forum. *The Global Information Technology Report*. http://www.weforum.org/gitr.

[6] B. Raman and K. Chebrolu. "Design and Evaluation of a new MAC Protocol for Long-Distance 802.11 MeshNetworks." Proc. *11th Annual International Conference on Mobile Computing and Networking paper*, Aug/Sep 2005.

[7] Wireless Internet Institute, *The Wireless Internet Opportunity for Developing Countries*, ISBN-0-9747607-0-6. www.w2i.org. November 2003.

[8] T. Starr, J. M. Cioffi and P. Silverman, *Understanding Digital Subscriber Line Technology*, Prentice-Hall, 1998.

[9] M. Andrews and L. Zhang, "The access network design problem," in *FOCS,* 1998, pp. 40–59.

[10] M. J. Miller and S. V. Ahamed, *Digital Transmission Systems and Networks*, Computer Science Press. 1987 & 1988.

[11] J. Beaubein, "Rwanda Looks to a Wired Future" National Public Radio audio broadcast on August 23, 2005. http://www.npr.org/templates/story/story.php?storyId=4811417.

[12] S. Ivezic, D. Celj, V. Mandaric and Z. Unkovic, "Information Technology, Strategy Planning for Telecommunication Company- an Experience", *ConTel*, 1997, Zagreb.

[13] *Asymmetric Digital Subscriber Line (ADSL) transceivers – Extended bandwidth ADSL2 (ADSL2+)* ITU-T Recommendation G.992.5.

[14] S. Ivezic, D. Celj, V. Mandaric and Z. Unkovic, Information Technology, Strategy Planning for Telecommunication Company- an Experience, ConTel, 1997, Zagreb.

[15] S.F. Shaukat, U. Ibrahim and S. Nazir, "Monte Carlo Analysis of Broadband Passive Optical Networks," *IDOSI*, vol. 12, no. 8, pp: 1156- 1164, 2011.

[16] F.J. Effenberger, H. Ichibangase and H. Yamashita, "Advances in Broadband Passive Optical Networking Technologies", *IEEE Communications Magazine*, pp. 118-124, Dec. 2001.

[17] J. Martin and M. Westall, "Validating an 'ns' Simulation Model of the DOCSIS Protocol", under submission. Available at http://www.cs.clemson.edu/~jmarty/docsis.html.

[18] S. Galli and L. Oleg, "Recent developments in the standardization of power line communications", *IEEE Communications Magazine,* pp. 64–71, July 2008.

[19] R. Tang, "Indoor Propagation in Cellular/PCS System Design", *Proc. Wireless Communications and Systems, IEEE 1999 Emerging Technologies Symposium,* pp 8.1 – 8.4, 1999.

[20] S. Ranvier, "Path Loss Models", S-72.333 Lectures Physical Layer Methods in Wireless Communication Systems, Radio Laboratory, HUT, 2004.

[21] J. Reynolds, "Going Wi-Fi: A Practical Guide to Planning and Building an 802.11 Network", *Focal Press*, 2003.

[22] 3GPP,"Long Term Evolution of the 3GPP radio technology" www.3gpp.org/Highlights/LTE/LTE.htm.

[23] ITU-R M.1645 "Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000" www.itu.int/rec/R-REC-M.1645/e.

[24] H. D. Clausen, H. Linder and B. Collini-Nocker, "Internet over Direct Broadcast Satellites," *IEEE Commun. Mag.*, pp. 146–51, June 1999.

[25] *VSAT Network*s, John Wiley & Sons Ltd, 2003.

[26] Dermot Ahern, "Vsat Very Small Aperture Terminal", *Marine and Natural Resources*, September 2003.

[27] J. Scott Marcus and Rekha Jain, "Fast Broadband Deployment in India - Role for cable television".

[28] D. Bojic, E. Sasaki, N. Cvijetic, W. Ting, J. Kuno, J. Lessmann, S. Schmid, H. Ishii and S. Nakamura, "Advanced wireless and optical technologies for small-cell mobile backhaul with dynamic software-defined management," *IEEE Commun. Mag*., vol. 51, no. 9, pp. 86–93, Sep. 2013.

[29] J. Owens, "Satellite Backhaul Viability," *Bechtel Telecommun. Technical J.*, vol. 1, no. 1, pp. 58–61, Dec. 2002.

[30] ITU Report: *Regulation of Global Broadband Satellite Communications.*

[31] World Bank: *ICT in agriculture.*

Kishore Kumar Thakur, FIETE (b.17.2.1960) is Chief General Manager Telecom, Jharkhand Circle since June2015 and Chairman, IETE Ranchi centre. Obtained B. Tech. (Electronics and Communications Engg.) from BIT Sindri in 1983 and MBA (Marketing) from BR Ambedkar Open University, Hyderabad in 2009. Currently pursuing PhD under the supervision of Ramjee Prasad, Professor, Future Technologies for Business Ecosystem Innovation, Aarhus University, Herning, Denmark. Possesses 35 years of work experience**.** Served as Assistant Computer Engineer in TISCO Jamshedpur.

Working in Bharat Sanchar Nigam Ltd, Department of Telecommunications for last 32 Years, mostly in Hyderabad Telephones. Worked with all technologies, namely manual exchanges, strowger, cross-bar, E10B (Local/ Tax), C-DOT, System-X, EWSD, OCB, 5ESS, LG (CDMA) and GSM. Associated with development works during the periods of major technological changes.

Worked for one year as DGM in Nagaland in2002-2003. Served as GMTD, at Cuddapah and Warangal, districts and as GM (Marketing), AP Circle Hyderabad in-charge of sales and distribution, franchisee management, marketing and PR activities. Also worked as GM (Mobile), J&K Circle for 2 years and as GM (Projects) Hyderabad for two years. Attended workshops, seminars and trainings on switching, transmission, mobile and management courses. Also attended comprehensive Lucent Technology training in USA on 5ESS switch. Leading balanced life with Sahaj Yoga Meditation and advise others also the same.