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MASTER'S THESIS

SOLUTIONS FOR WIRELESS INTERNET CONNECTIVITY IN REMOTE AND RURAL AREAS

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ABSTRACT

These days internet connectivity is listed in the basic needs of human habitat. Internet provides inevitable support in getting knowledge, professional and social connectivity, entertainment media, and in running majority of businesses. Human dependency on internet for efficient, proficient and time saving work has increased the demand of internet connectivity worldwide. The global index shows a percentage increase in internet users from 16% to 48% (of the world population) from 2005 to 2019. The users are accessing internet via different media, inclusive of fixed lines and wireless connectivity. In wireless connectivity by 2019, 86% of the world population is using mobile broadband services offered by different telecom operators in different regions. Around 44.7% of the world population lives in rural areas as projected in 2018. Telecom operators are now seeking to cover all urban and rural, segregated, and dense, plateaus and hills, small and big geographical areas for internet connectivity. The majority of challenges faced by operators for deployment of internet connectivity services are in rural areas. Internet users cited in rural areas experience poor coverage and bad quality of service (QoS) in wireless internet access. This thesis covers the rural area internet connectivity challenges, existing deployable solutions against the challenges, and provides example solutions to overcome these challenges, to provide wireless network coverage in rural areas of Finland.

Many of the existing wireless communication services are directly deployable or adjustable to the remote or rural areas almost the same way as for the urban areas. The major challenge is the low annual revenue per unit and segregated population densities of rural areas, which increase the return of investment time of network service providers. There are other challenges like ease of assembly, technology, backhaul connectivity, and electricity discussed in the thesis. The possible wireless network solutions deployable for wide area network regions and local area network regions are presented in this thesis. Thesis presents all emerging wireless technologies like small cell base station, super tower, balloon Loon project, power line Airgig project, satellite Viasat service, fixed wireless internet, and signal booster. Two possible network solutions for wireless network coverage in rural areas of Finland are analysed in the thesis. Huawei's RuralStar small cell base station is presented as the first network solution from the viewpoint of network service provider. Hajakaista network services to individual user are presented as the second network solution from the viewpoint of end user. An addition of outdoor router in Hajakaista network architecture is presented as an additional advantage of outdoor Wi-Fi service together with indoor Wi-Fi. The limitations of the network solutions and future work scope are discussed in the discussion part of the thesis.

Key words: Internet connectivity, Wireless connectivity, Mobile broadband service, Telecom operator, Quality of service, Network service providers, Backhaul, RuralStar HajaKaista, Fixed wireless internet, Airgig project, Wi-Fi, Loon project.

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TIIVISTELMÄ

Nykyisin internetyhteys nähdään perustarpeeksi koska se antaa pääsyn tietoon, mahdollistaa ammatilliset ja sosiaaliset yhteydet sekä toimii viihdeväylänä ja tärkeänä osana liiketoimintaa. Tämän vuoksi tarve internetyhteydelle on kasvanut maailmanlaajuisesti. Vuonna 2005 maailman ihmisistä 16 % oli yhteys internettiin ja 2019 48 %. Internetyhteys voidaan saada usealla eri tavalla kuten valokuidulla ja langatonta yhteyttä käyttäen. Vuonna 2019 maailman ihmisistä 86 % käytti langatonta tekniikkaa. Vuonna 2018 44,7 % ihmisistä asui maaseutualueilla. Teleoperaattorit yrittävät kattaa kaikki kaupunki- ja maaseutualueet; eristyneet, tasaiset, kukkulaiset, isot ja pienet maantieteelliset alueet. Suurimmat haasteet ovat maaseudulla, jossa ihmiset kokevat huonoa yhteyspeittoa ja yhteyden laatua. Tämä diplomityö tarkastelee, miten nykyisiä langattomia järjestelmiä voitaisiin käyttää maaseudulla toimivien yhteyksien luomiseksi. Työ esittää kaksi esimerkkiratkaisua Suomen olosuhteisiin.

Monet nykyisin kaupungeissa käytettävät ratkaisut ovat suoraan tai lähes suoraan sovellettavissa maaseudulle. Päähaasteet ovat matala vuosittainen yksikkötuotto ja hajallaan olevat alueet, jotka syyt kasvattavat investoinnin kuoletusaikaa. Muita haasteita ovat asennus, teknologia, siirtoyhteydet (tukiasemasta verkkoon) ja sähkön saanti, joita tarkastellaan työssä. Mahdollisia langattomia ratkaisuja ovat laajan alueen ja paikalliset ratkaisut, kuten työssä tuodaan esille. Työ tarkastelee solukkoverkkoja, supertornia, palloprojekti Loonia, sähkölinjoihin pohjautuvaa Airgig-projektia, Viasat-satelliittiratkaisua, kiinteää solukkoyhteyttä ja signaalin passiivista vahvistamista. Työ esittää kaksi ratkaisumallia Suomen olosuhteisiin. Toinen perustuu Huawein RuralStar-kevyttukiasemaan, jolla voi jatkaa operaattorin verkkoa. Toinen ratkaisu on kuluttajalähtöinen ja se perustuu Hajakaista Oy:n ratkaisuun. Siinä lisätään Hajakaista Oy:n perusratkaisun eli talon sisäisen Wi-Fi-verkon rinnalle ulkoinen Wi-Fi-verkko. Ratkaisujen rajoitteita tarkastellaan työn keskusteluosuudessa.

Avaisanat: Internetyhteys, langaton yhteys, liikkuva laajakaistapalvelu, teleliikenneoperaattori, palvelunlaatu, verkon palveluntuottaja, RuralStar, Hajakaista, kiinteä langaton internet, Airgig-projekti, Wi-Fi, Loon-projekti.

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FOREWORD

It is often said that character is the lighthouse of success, making small numbers formidable and procuring success and excellence in all orders. Succeeding in completing the thesis would not have been possible without the sheer cooperation, encouragement, and support from people at all stages of this formative journey. It was a tough job to study and simultaneously work for a living, but I never gave up instead climbed up to reach my objective. I am so thankful to Finland for this excellent opportunity to enjoy Finnish nature and experience a top-notch education system.

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Md Junayedur Rahman Bhuiyan

LIST OF ABBREVIATIONS AND SYMBOLS

ARPU	Annual revenue per user
ASN	Access service network
BS	Base station
BPL	Broadband over power line
CSN	Connectivity service network
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GBT	Ground-based tower
GBM	Ground base mast
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of things
ITU	International Telecommunication Union
ISPs	Internet service providers
LoS	Line of sight
LTE	Long term evolution
LAN	Local area network
MNOs	Mobile network operators
NLoS	Non-line of sight
PoE	Power over ethernet
PTP	Point to point
PLC	Power line communication
PLI	Power line internet
PLT	Power line telecom
PTMP	Point to multipoint
QoS	Quality of service
RSSI	Received signal strength intensity
RTT	Roof top tower
RRN	Relay remote node
RF	Radio frequency
RV	Recreational vehicle
SIM	Subscriber identity module
SS	Subscriber station
SUV	Sport utility vehicle
TIER	Technology and infrastructure for emerging regions
UE	User equipment
VoIP	Voice over internet protocol
WAN	Wide area network
WLAN	Wireless local area network
WMAN	Wireless metropolitan area network
WWAN	Wireless wide area network
Wi-Fi	Wireless fidelity
Wi-Fi-Aps	Wi-Fi access points

L_{FS}	Free space path loss in
L_{M}	Miscellaneous losses or other losses in dB
L_{RX}	Feeder loss in dB
L_{TX}	Transmitter loss in dB
G_{RX}	Received antenna gain in dBi
G_{TX}	Transmitted gain in dBi
P_{RX}	Received power in dBm
P_{TX}	Transmitted power in dBm

3GPP	Third Generation Partnership Project

1 INTRODUCTION

It is well known that the internet has brought a revolutionary development to form this modern and digital world. In the current era of emerging technology and science, people cannot imagine a single day without the internet. The internet became a part of our everyday life, and it plays a vital role in growing the knowledge by sharing information. However, nearly half of the world does not have access to the internet [1]. More than 700 million people in rural areas around the world still do not have facilities to access the internet or make phone calls [2]. Nearly 400,000 villages around the world cannot connect or reach any network services [2]. It is visible that a communication gap is spearing between cities and countryside, as well as the network connectivity gab between remote areas and urban areas is widening.

The internet has its significance in various aspects. It is essential for education, business, entertainment, career development training, marketing, and so on [3]. The internet is connecting users through different devices and equipment, like phones, computers, laptops, tablets etc. Nowadays, due to technology development, the internet is not limited to just connecting computers. The demand for the internet is higher and use in almost every infrastructure in many homes. It has created new wings of opportunities for people. The internet is useful for businesses, and personal needs. It brings a source of information, a social platform, and a business network. The most notable advantage of the internet is that it makes things more comfortable and more accessible [3]. Internet importance is undoubted because it is the internet through which one can gain and share information, knowledge, education, etc. In totality, the fact is the internet accelerates our lives and forms the modern society.

People, who are disconnected from internet, might suffer from a lack of communication as they have a lack of information, knowledge, present issues, business tips, medical facilities, banking facilities, entertainment, etc. The scenario is visible in rural and remote areas where internet facility is not available, or the internet is not reachable. It is essential to overcome the problems mentioned above and connect the rural area with the internet. The importance of internet connectivity is shown in the next segment for understanding the necessity of internet in rural areas.

1.1 The importance of internet connectivity

The internet has an impact in various ways on human beings. Nowadays, internet has become a part of our life. The internet has its significance in the field of education. The area of education spreads because the internet allows people to access from any location to learn whatever they want. Education via the internet can be free or paid. The internet brings facilities in the traditional education system by adding technology and features. Online portals, servers, pdf books, and notes make education more accessible, and one can earn vast knowledge. The internet is a platform with a wide range of information that both teachers and students can access at any time. The traditional system generally allows communication during working hours, whereas, with the internet's help, one can communicate whenever they want. Different scholarly domains, such as personal, organizational, and government domains, are easily available to find information. A student can have access to the published resources because of their availability through the internet. Internet can provide facilities over education by making it accessible to all connected people. Many organizations and companies can give their specific courses and career-oriented via online platform through internet. The internet brings us new methods of learning. These new methods are alternative to traditional learning and study materials, including crash course videos, images, animated videos, and educational games. Students and teachers can communicate with each other in a timely manner using internet platforms. A student no longer needs to wait until the next class to communicate with the desired teacher. An individual can easily communicate with others through online platforms. Additionally, most schools can have online platforms which are responsible for the discussions on various topics and assignments to facilitate students [4].

The internet has an impact on modern business. The process is to connect the buyer and the seller or the supplier with the manufacturer. Modern technology and system provide advantages in the business world. In business, marketing plays an important role. The application of internet in marketing, allows suppliers to reach market, provide customer service, or advertise the product with a press of a button. The way of choosing products has changed, and new service schemes are introduced in the modern world. Business organizations can communicate from a variety of platforms to position their products and services. Internet marketing is probably the most efficient and flexible procedure by which business organization can reach to the customers. Business organizations can find ways to interact with customers for

- Comprehensive consumer needs;
- Creating a good relationship;
- Conducting research.

The internet gives the interfaces between the business organization and customers. This interaction ensures customer's feedback by which the betterment of products and services can be done and, in return, increase revenue for the company. Internet offers communication with the organizations and companies, having offices in different geographical regions. For organization with offices at different location are connected throw the internet for their complete operation. Nowadays, email has taken the position of the primary method of communication in many organizations. The internet is used to create a preferred reputation through various platforms. Many businesses primarily use social media platforms and websites. It is visible that the presence of business pages on Facebook, LinkedIn, Instagram, and Twitter are increasing day by day [5]. These platforms allow the organization to establish an online introduction by portraying the firm's values and beliefs. Internet is used for online stores like Amazon and eBay. The online stores encouraged other companies to step on online platforms. The concept or business policy online created a revolution and introduced e-commerce/ e-business. These have become increasingly successful because of the growing number of people who prefer to purchase online. The online business can utilize by other trends like online and mobile banking, which may usefully contribute to the success of online businesses.

The diverse communication platforms assure that every single user may have a preferred network. Social media is becoming even more popular way of communication. Social media is a platform by which both formal and informal communication can be done. Businesses tend to prefer formal platforms like LinkedIn or emails. In contrast, young casual communications prefer less formal chatting sites such as WhatsApp, Facebook, Twitter, etc. A cellular phone with an internet connection can make this form of communication more flexible. The traditional way of getting information from books or newspapers is replaced by the internet. Nowadays, people browse Google or other search engines to solve their problems. Various online platforms are available, aiming to provide tutorials through which people solve problems like fixing a flat tire of a car. The internet is useful for choosing products with basic information like product ratings and historical events. The evolution of technology and the concept of database management makes it easier to maintain public services. Government organizations now have websites from where the public can acquire services and perform transactions such as electricity bill payment, tax payment, etc. Government platforms can also store and secure critical information like the progress of different projects and public records [4].

The health sector is also facilitated by the internet. Doctors and other health practitioners can attend various internet platforms like webpages, social media, or websites where they can provide quality medical information. This information plays a significant role in medical students and the public. A patient might find help with the knowledge or information about their disease and can take primary precautions. In the case of simple and necessary conditions like migraines, stomach aches, and menstrual period pain cure can be suggested by online platforms. An online hospital can be an effective level of giving service for those people who experience complexity to move or cannot manage time for visiting hospitals. A patient can communicate with doctors beyond the traditional consultation. The doctor would then be able to provide a diagnosis and prescribed treatment. These platforms may also be effective for recovering from addiction or seeking help, like sessions from psychiatrists. The internet is essential to bring solutions in the medical sector by applying telemedicine. Doctors now share experiences and can guide each other during surgery with the help of the internet and the 3-dimension technologies. The necessity is a clear line of communication and an internet connection during the surgery and can save both money and time [3].

The importance of the internet in the sector of media and journalism is undeniable. The internet can facilitate by timely reporting of news. People can get daily or hourly based news through online news portals on the internet. The presence of online media platforms makes it easy to access factual news [6]. Traditional newspapers take at least a day due to the printing process, where e-newspapers or online magazines can provide the news much quicker or even in a real-time manner. Though internet can provide news as much easier way then traditional way, one may get harassed by the fake or false news. Thus, it is recommended to pursue the authenticate sites. Internet replaces the traditional source of entertainment. Platforms like Netflix, Amazon Prime, and YouTube readily provide entertainment as they save a vast number of movies or series. These sources of entertainment consume low subscription fee, or even free contents are available. Physical barriers to communication are not a problem anymore [7]. The internet allows communicating with virtual reality. It is undoubtedly not equivalent compared to face-to-face communication. However, the internet allows people to maintain valuable relationships. The internet allows people to create new friendships and partnerships.

While the internet is essential in every aspect of our life, it is essential to maintain security and privacy. Maintaining internet security and privacy ensures that an individual hides his/her details and information's from fraudsters. A user's private information can be used to commit a severe crime, like uninformed purchase, and illegal transactions [8]. An innocent person can be a victim of other person’s crime. Damages caused by viruses and hacking can be prevented by internet security, and privacy setups such as a password, to limit the use of computers and private network to authentic users only. Antivirus has the features to detect and protect the computer against harmful software and viruses. A reliable security system can help in saving money by providing security to the valuable information. Businesses are often facing problems through data theft. The organization may have risks of losing important information and confidential documents that could harm the company. Competitor organizations can take advantage of stealing or destroying effective information. Prevention from losing important data is important for keeping a project running securely and may require the establishment of new strategies. Internet security and privacy can prevent interception. Research allows us to say that anyone could access private conversations and information. Standard security can reduce the risk of this interception and prevent one from enjoying other people privacy online [9]. Undoubtedly, the internet runs over our lives, and therefore the importance of the internet cannot be ignored. We should, therefore, take the necessary steps to avoid risks discussed above to use the internet in an appropriate manner to protect ourselves from things such as cyberbullying.

1.2 Orientation of the thesis

There are significant reasons behind the unavailability of the internet in rural and remote areas, such as geographical position/location, rigid transportation system, scattered population, low income, number of subscribers, etc. that shallow the interest of companies to investment in these locations. The thesis is focused on finding solutions for internet connectivity in rural areas. It first introduces the internet and its importance, which is focused on Chapter 1. It also concerns the usage of internet in rural areas and its consequences in Chapter 2, the thesis points the challenges faced by the network service providers in connecting the rural areas. Chapter 3 is decorated with finding of the possible solutions to overcome the challenges marked in Chapter 2. Thus, in Chapter 3, it first separated the technology into classes for simplification and then provided the explanation of possible solutions according to the classes. The advantages and disadvantages of possible solutions are also given for understanding the most suitable solution. After that, the study provides proposed network solutions that can be implemented in rural areas of Finland and are denominated in Chapter 4. Theoretically, the proposed solutions are good for overcoming the existing challenges, to connect the rural areas with internet, but a practical demonstration may provide more efficient and authentic information. Chapter 5 holds the discussion of the whole work. A conclusion with necessary statements is given in Chapter 6, and lastly, Chapter 7 contains the necessary references.

2 RURAL AREA CONNECTIVITY PROBLEMS AND CHALLENGES

In countryside regions, internet service providers (ISPs) and mobile network operators (MNOs) have low internet subscription demands compared to city and towns [10], because of low population densities. The low demand together with other network deployment issues, like geographical challenges, weather conditions, infrastructure cost makes it challenging for ISPs and MNOs to provide internet access in these remote and rural areas. In Finland MNOs like DNA has average annual revenue per user (ARPU) of 18.9€ [11]. In rural regions ISPs and MNOs ARPU is generally low compare to average ARPUs [12], that makes it difficult, to deploy hardware infrastructure and services in the remote and rural areas for sufficient coverage. ISPs and MNOs count Erlang (unit of cellular traffic) and data utilization per cell-site for their financial-budget planning, for running and maintaining the existing network infrastructure and services and for further network expansion rollouts. The ISPs and MNOs focused on quality of service (QoS), which includes the tree main parameters associated with the communication system. These parameters are data packet loss (which happens due to weak signal), jitter (this happens due to network congestion and degrade voice and video quality and latency which represents the time taken by a packet to reach destination from the source and is expected to be zero) [13]. The ISPs knowingly limit their wireless radio frequency (RF) coverage from the base station, to decrease RF overshooting and to improve QoS [14] for users in the nearest regions [15]. This decreased coverage produces coverage holes mostly in remote and rural areas, because these locations have limited number of base stations. These coverage holes are blanket by deployment of new base stations. These deployments are part of ISPs and MNOs network expansion plans. Financial budget of these network expansions is directly linked to the ARPUs of the region which is currently the biggest challenge to provide connectivity of internet in rural areas [12]. Network deployment challenges in rural and remote areas are based on the location geographical conditions, weather conditions, link budget, technological challenges, and other aspects, and are reviewed in detail in this chapter. Challenges faced by the end user in remote and rural areas for deployment of personal coverage solution for signal strength and quality of service improvement, are also detailed in this chapter [16].

2.1 Rural area network deployment challenges faced by the ISPs

2.1.1 Technological challenges

Present wireless and wired internet services are served with different infrastructure, architecture, and equipment. The wired network in rural areas is always a challenge, in terms of infrastructure cost, where it is difficult to recover investments and earn revenue, because of low ARPUs and low population densities [12]. Multiple solutions for wireless internet connectivity are now available based on the coverage and capacity requirements.

Remote and rural areas were always seeking for coverage solutions, but current technologies, such as, long term evolution (LTE) and availability of 4K video streaming content, voice over internet protocol (VoIP) calling and Internet of Things (IoT) has raised the capacity issues with equal challenges. For coverage solution, a ground-based tower (GBT) is the most common tower type used in base station deployment in rural areas to provide long distance coverage. Base station with GBT towers can provide coverage up to 40 km [17]. MNOs base station use omni-directional antennas, to provide coverage in 360 degree or 270-degree area [18]. GBTs are heavy infrastructural elements and are limited in deployment to plane regions and connected areas. GBTs are deployed on top of hills for better coverage, but MNOs and ISPs face hug challenges in initial deployment and regular maintenance of these base stations, because of access and connectivity problems to these locations. The Figure 1 shows the field images of the deployed base station with GBT in regions of Finland.

Figure 1 The field images of the deployed base station with GBT in regions of Finland.

Roof top tower (RTT) [17] is another type of tower used by the base stations. RTT towers are planned on top of the infrastructure, buildings, warehouse, and take advantage of building heights, and provide (reduced tower infrastructure) cost benefits. Base station with RRT towers is common in urban areas, because of availability of buildings. In major areas of remote and rural regions, RTT bases station is not deployable, because of un-availability of building heights. The Figure 2 portrays the field images of the deployed RTT cell site in urban areas of Finland.

Figure 2 The field images of the deployed RTT cell site in urban areas of Finland.

In rural areas MNOs and ISPs face challenges in connecting backhaul using optical fiber cable, to connect base station to the core network and internet. The reason behind fiber backhaul connectivity challenges is large fiber length requirements, because base stations are located very far from each other in rural areas. The increase in fiber length increases the deployment cost. Backhaul connectivity in rural areas is generally obtained with point to point (PTP) and point to multipoint (PTMP) hops using line of sight (LoS) and non-line of sight (NLoS) communication with microwave antennas. LoS communication refers to the direct communication without any obstacle between transmitter and receiver whereas NLoS refers to the communication which places relays at additional location to overcome obstructions between transmitter and receiver [19]. In rural areas hop length vary from 5 to 35 km, depending upon the data rate requirements. Another possible solution to long hop is to use multiple hops of short length as relay, but these are challenging on part of cost in rural regions, as number of hops sites and infrastructure increases just for the purpose of backhaul connectivity. The Figure 3 describes the possibilities of backhaul connectivity with single long-distance hop and Figure 4 describes the possibilities of backhaul connectivity with multiple hops.

Figure 3 Possibilities of backhauling connectivity with single long-distance hop.

Figure 4 Possibilities of backhauling connectivity with multiple hops.

2.1.2 Financial Challenges

MNOs and ISPs make financial budget for network services, maintenance, deployment, and network-expansion based on the revenue obtained from the users. Users in rural areas are segregated in small regions with very low population. These regions are very far from each other and single base station cannot cover multiple regions; MNOs and ISPs require dedicated base stations to blanket these regions. MNOs and ISPs revenue from the base station in these low population density regions may not recover the investment and operational cost. Low population densities of these regions and makes it financially challenging to deploy dedicated base stations [12]. The deployment of network in these regions of rural areas would be having huge subscription rentals for users, to recover infrastructure cost. These rentals are unaffordable for the users, which makes MNOs and ISPs less interested in rural network expansion compared to urban areas.

In RF optimization, a coverage hole is blanket by nearby base stations, by increasing their coverage. The coverage is increased by increasing signal power and other directional antenna adjudgments of the base stations, as presented below.

- Increasing height of antenna improves cell coverage [20].
- Antenna mechanical tilt arrangements are done as per the geographical conditions of the location to improve network coverage [21].
- Antenna electrical tilt [21] this changes the antenna-main lobe settings and is adjusted to provide improvement in signal power. This is also termed as antenna beam steering.

RF optimization and beam steering are challenging in filling coverage issues in rural areas because of scattered housing densities and limited number of base stations. Majority of MNOs and ISPs seeking revenue has found challenges in deploying dedicated cell sites for internet connectivity in the rural areas and at first glance try to cover the rural areas with limited number of base station as per their financial budget.

2.1.3 Geographical location challenges

In plain rural regions network infrastructure deployment is easy, but network coverage and backhaul microwave hops, face signal blocking challenges, due to the presence of heavy vegetation. Vegetation with big trees and dense plantation, degrade the hops quality of service and deviate LoS, by blocking the radio signals, this breaks the backhaul connectivity. In the same way, network signals are blocked and users experience poor coverage. These challenges offer re-planning of the base station to other nearby location where vegetation is less, and they can cover the region. Re-planning needs LoS clearance for backhaul connectivity of the base station and is challenging at some locations.

Received signal strength intensity (RSSI) deteriorates with increase in vegetation [22]. Losses in received signal at user end due to vegetation, are studied in detail in link-budget calculations. The losses in dB due to vegetation are considered under other loses in link budget calculations.

In hilly regions radio waves are blocked by the hills and make coverage blackspot [23]. These occur due to shadowing of signal in hilly terrains [23]. Due to the presence of blackspot, user experience the following issues

- Highly variable signal;
- Slow mobile internet;
- Internet timeouts;
- Increased battery usage.

Hills offer another challenge of deployment and maintenance of base station infrastructure.

2.1.4 Challenges due to weather conditions

Weather is an important aspect for wireless internet performance and challenging for both wired and wireless network infrastructure deployment and are stated below-

- Rural areas with tough weather conditions such as heavy snow and rains, makes it challenging for network deployment activities year around.
- Some rural terrains with heavy vegetation, hills, and permanent snow, makes it challenging for MNOs and ISPs to deploy network infrastructures for internet connectivity.
- MNOs and ISPs make special arrangements at base station according to the region weather conditions, like extra power-bank for power cuts, heavy shelter of network equipment and other arrangements. These arrangements encounter for additional financial investments and are deployed only in special regions of urban areas.
- In rural areas base station has no special arrangements, and user faces sudden signal drops, poor internet speed, and complete network connectivity failures due to sudden change in weather.
- In poor weather conditions, power failure of hub site, which provides backhaul connectivity to multiple base stations, cause network failure of wide area network (WAN) region.

2.1.5 Link budget challenges

In deployment of the wireless network communication by the ISPs, link budget plays a vital role. In radio frequency planning of any geographical area, link budget calculations are conducted at the first glance, for prediction of possibilities in providing services, technological requirements, financial requirements, geographical requirements, Infrastructure requirements, power requirements, RF coverage maps, RF QoS to end user.

With use of network planning tool, path loss is predicted and is used in link budget calculation. Path loss is directly linked to the geographical regions, whether conditions and are explained above.

Equation 1 below provide a general view of link budget calculations [24].

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX} \quad (1)$$

P_{RX} is the received power in dBm, by the end user UE (3G/4G/5G) and in technical terms represented by the term RSSI (received signal strength indicator).
P_{TX} is the transmitted power in dBm, from the base station antenna (3G/4G/5G).
G_{TX} is the gain in dBi of the base station antenna towards UE.
L_{TX} is the transmitter loss in dB of the coaxial cable (feeder) connected between the antenna and the base station transmission equipment.
L_{FS} is the free space path loss in dB offered by the free space to the propagation of radio frequency signal.
L_M are the miscellaneous losses or other losses in dB, due to RF fading, scattering and absorption.
G_{RX} is the received antenna gain in dBi, in UE towards the BS.
$L_{RX,}$ is the feeder loss in dB at the user end.

Figure 5 describe the general block diagram description of different parameters of interest in calculating link budget.

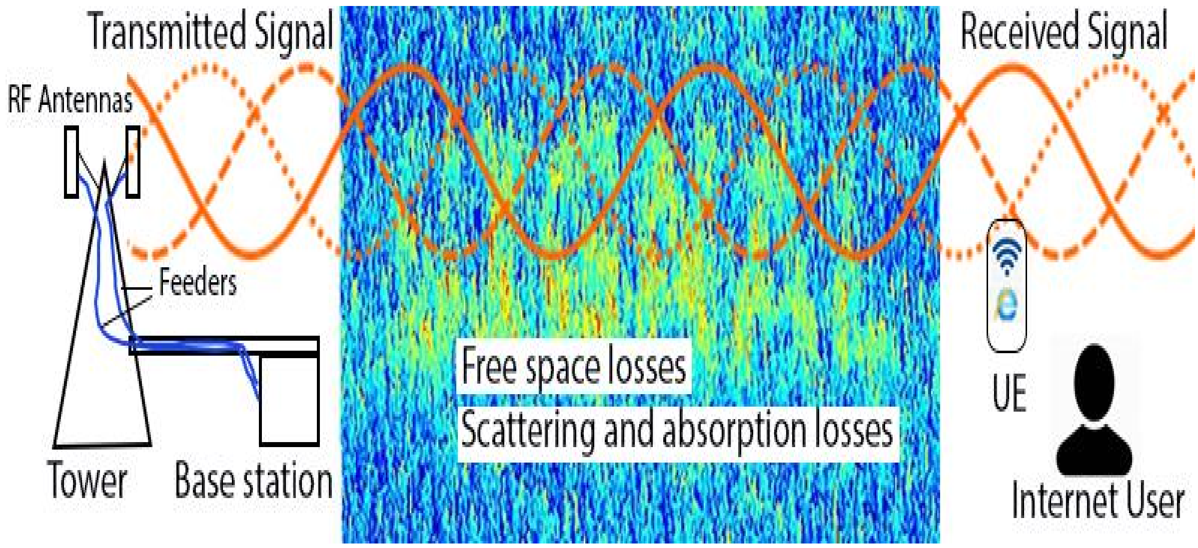

Figure 5 The wireless internet services base station architecture.

The RSSI level defines the coverage quality and QoS experience by the end user. Following Table 1 define the RSSI indexing of the 3G and 4G services.

Table 1 The RSSI indexing of the 3G and 4G services [25].

3G network RSSI index table.

RSSI		
RSSI	Signal strength	Description
>=-70 dBm	Excellent	Strong signal with maximum data speeds
-70 dBm to -85 dBm	Good	Strong signal with good data speeds
-86 dBm to -100 dBm	Fair	Fair but useful, fast and reliable data speeds may be attained, but marginal data will drop-outs is possible
< -100 dBm	Poor	Performance will drop drastically
-110 dBm	No signal	Disconnection

4G network RSSI index table.

RSSI		
RSSI	Signal strength	Description
>=-65 dBm	Excellent	Strong signal with maximum data speeds
-65 dBm to -75 dBm	Good	Strong signal with good data speeds
-75 dBm to -85 dBm	Fair	Fair but useful, fast and reliable data speeds may be attained, but marginal data will drop-outs is possible
-85 dBm to -95 dBm	Poor	Performance will drop drastically
<= -95 dBm	No signal	Disconnection

For good RSSI levels, path loss has to be minimized or gain has to be maximized as per link budget equation [24]. To increase RSSI levels high gain antennas, with power extenders to overcome all lose are required. MNOs and ISPs face cost challenges in deployment of the additional infrastructure and equipment.

2.2 Coverage and connectivity challenges faced by end user

2.2.1 Coverage enhancement challenges

Some ready solutions, including a repeater, booster and other active and passive equipment are available in market for RF coverage (RSSI level) enhancement. These solutions are specially designed for coverage enhancement in urban and rural areas. The RSSI requirements of these solutions is limited to certain RSSI level, below that it becomes challenging to enhance the signal power.

Some regions of rural areas are without dedicated base station or other coverage solution from the ISPs end. These regions have no coverage or poor scattered coverage from nearby base stations. Users in these regions experience very low RSSI level, and make it challenges for them, to make their own arrangements for coverage enhancement, by using coverage solution.

The equipment size and cost of coverage solutions increase with increase in their ability to capture low RSSI signals; both cost and size makes it challenge for end users to deploy the solution.

2.2.2 ISP's promoted solutions access

Some MNOs and ISP's propose special coverage solutions, based on number of users in the region. These solutions are also available for individuals, on heavy rentals. The solution is proposed to the location with high number of users, so that ISPs can maintain their ARPUs.

Location with limited number of users must bear heavy rentals for dedicated coverage solution services, which is challenge for some user to afford.

2.2.3 Affordability challenges

Affordability is always an important aspect. Users seeking for internet access are unable to pay high rentals for the internet services. In some regions of rural areas, users generate low ARPUs and make it challenging for MNOs and ISPs to provide dedicated base station or coverage solution for these regions. 13% of the world population is unconnected [26] because, they cannot afford rentals for internet services, and situation becomes more challenging in rural areas where deployment of coverage solution, needs extra investment.

According to a published report [27], Finland government has subsidize MNOs and ISPs for both wired (fiber-optic) and wireless (4G with 800 MHz band), internet connectivity in rural areas including least dense areas of Eastern and Northern Finland. For broadband (wired) and fixed wireless network services in Finland rural areas, a national project called "Broadband for all 2015" was launched for internet connectivity in rural areas. But the coverage remained below the European Union average because the government had to relax the subsidizing conditions since the number of received projects did not cover for the deployment targets [27]. MNOs and ISPs charged little high rentals due to low user densities in these regions to maintain their ARPU, and users faces affordability challenges in obtaining these services.

3 SOLUTIONS FOR WIRELESS INTERNET CONNECTIVITY IN REMOTE AND RURAL AREAS

In the previous chapter, challenges faced by ISPs in deployment of wireless network services, and challenges faced by end user in deployment of coverage enhancement solutions were discussed. This chapter aims to provide solution for these challenges and, covers existing solutions available for coverage extension in remote and rural areas. These solutions are deployable by the ISPs, MNOs, as well as by the end users. Network architectures, equipment, and infrastructures of different wireless technological services, suitable for rural area internet connectivity are detailed in this chapter.

All wireless internet services offered by telecom-operators with 3G, 4G, 5G wireless connectivity and Wi-Fi, and fixed wireless services offered by the ISPs are discussed in detail in this chapter. The wireless connectivity services can be divided into different classes shown in Figure 6 [28].

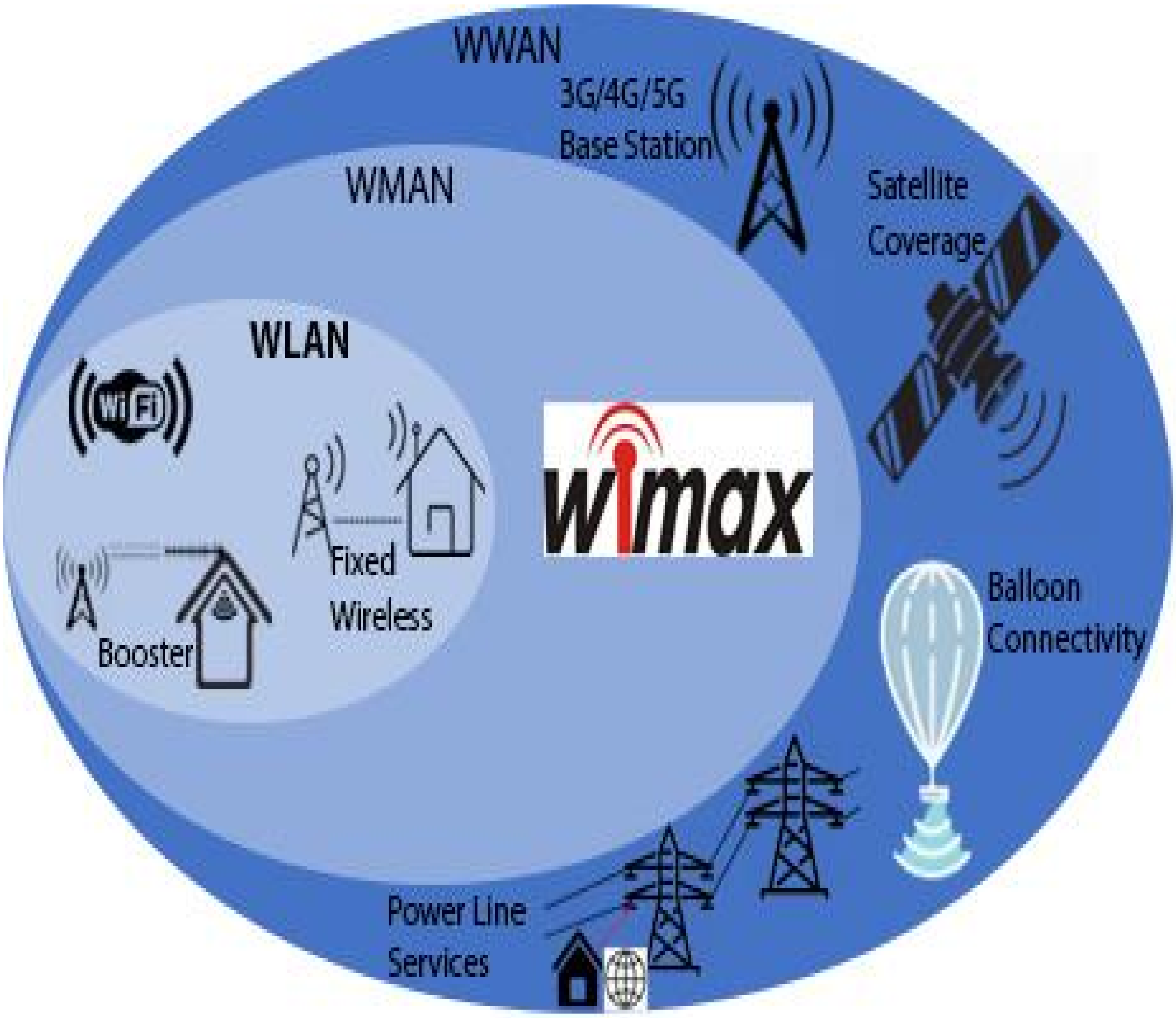

Figure 6 The wireless classes with respect to coverage size.

3.1 Wireless connectivity and their classes

Wireless network classes are differentiated based on their geographical coverage sizes. These classes inclusive of (WWAN) wireless wide area network, wireless metropolitan area network (WMAN), and wireless local area network (WLAN). WWAN covers all rural and majority of urban areas, WMAN covers metropolitan and urban areas (WLAN) provides separate connectivity to each user or multiple users in small area [29]. The wireless network classes and topologies in Figure 7 describes the wireless classes in detail.

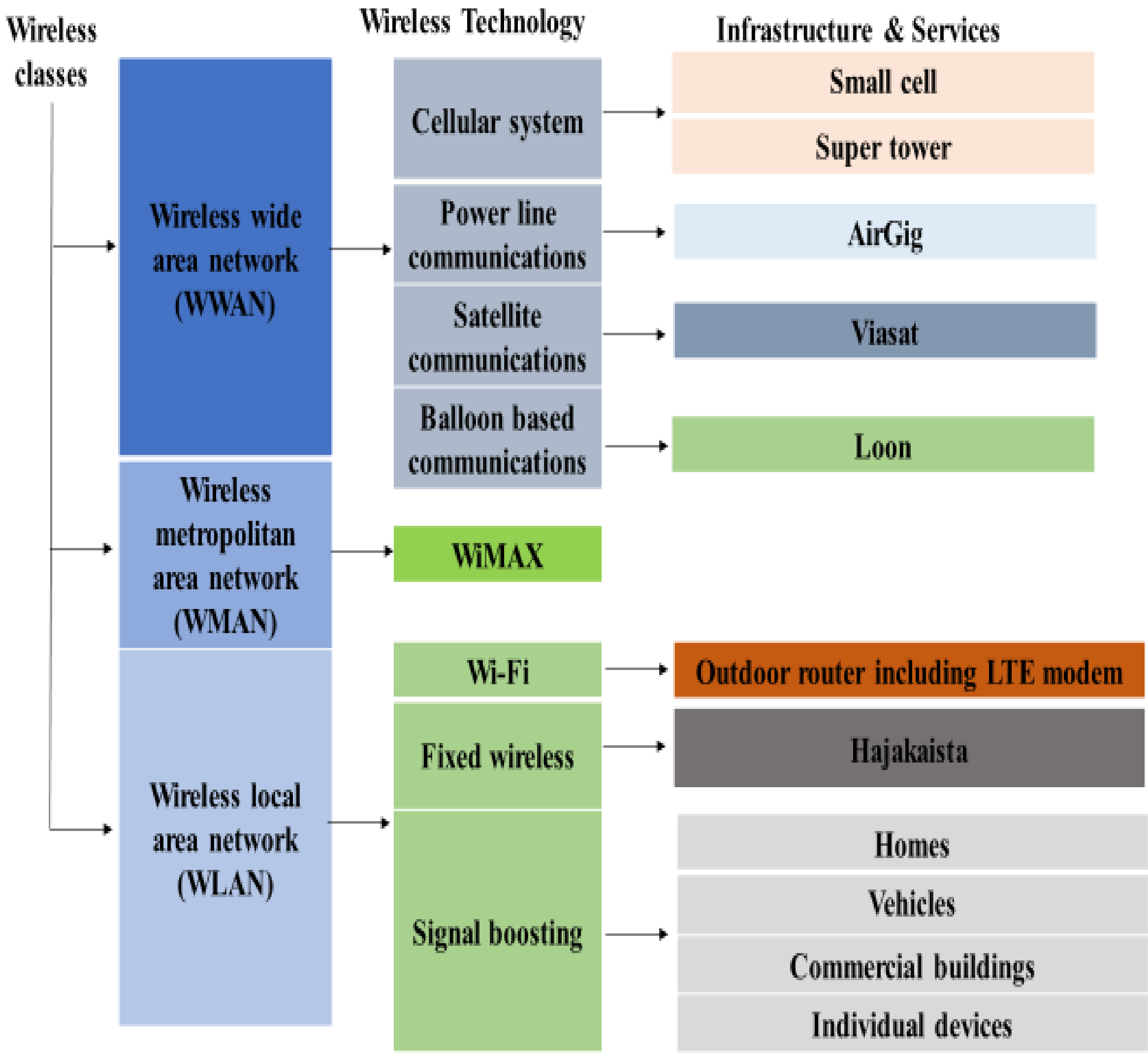

Figure 7 The wireless network classes and topologies.

WWAN class of wireless coverage provides wireless connectivity in big geographical areas. WMAN provides services with technology like WiMAX and are deployed in the urban metropolitan areas. For wireless connectivity in small areas, like buildings, offices, WLAN are deployed.

3.1.1 Backhaul connectivity

Backhaul is a major part of infrastructure of all wireless technologies. In cellular systems backhaul provides link to connect the base stations to the core-network [30]. Backhaul connectivity types are presented in the following Figure 8, that contains wired (optical-fiber) connectivity, point to point wireless microwave line of sight (LoS) links, and satellite relay connectivity [30].

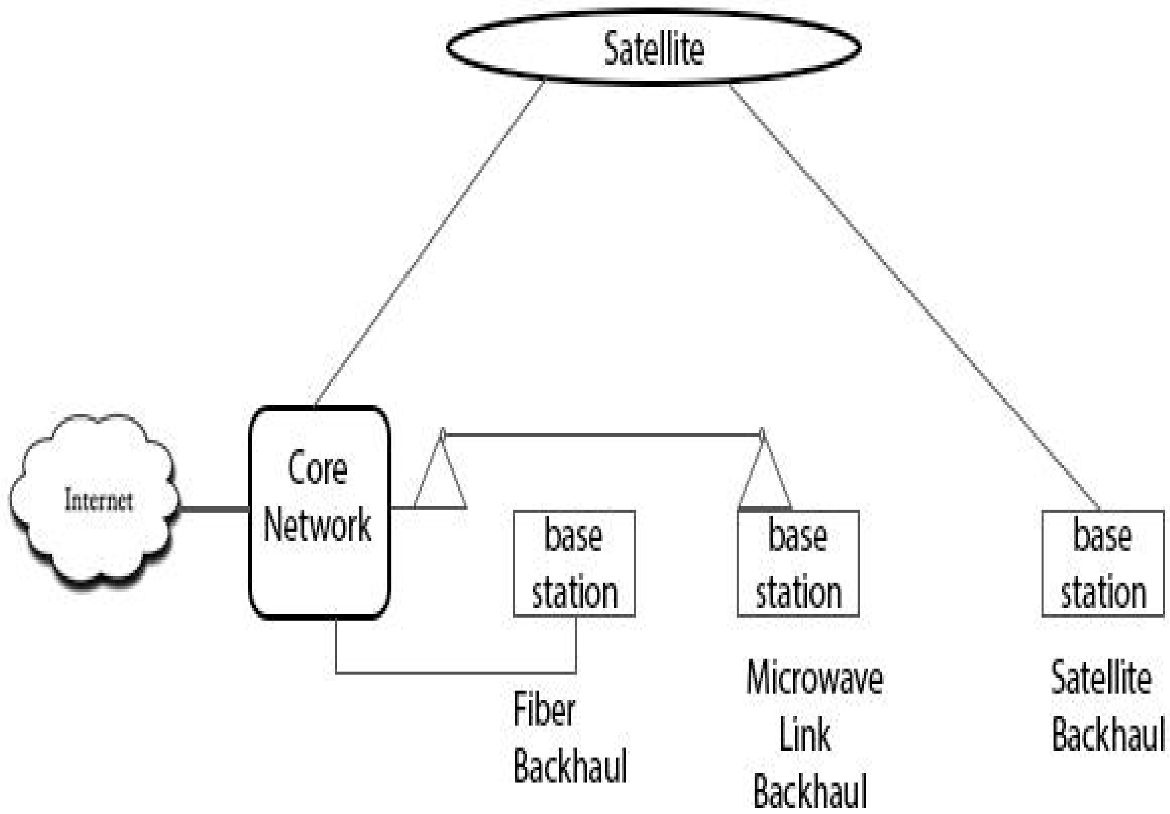

Figure 8 Block-diagram presenting backhaul connectivity topologies.

Wired backhaul using optical fiber is the latest technology in use and it has the highest data-bandwidth. In rural areas with difficult terrains, backhaul connectivity is often obtained with microwave links and satellite relay. Backhaul connectivity through power line infra, using additional fiber is another model, deployed in some regions [31].

3.2 WWAN connectivity solutions with examples

WWAN is a class of wireless technology, which provides coverage to the large geographical regions. A major part of WWAN network is covered by mobile network operators (MNOs) and some regions are covered by local Internet service providers (ISPs). International alliance and local government agencies (such as Finnish Communications Regulatory Authority) provide frequency allocation and network standards to MNOs and ISP for WWAN networks [31]. These international alliance and telecom bodies are International Telecommunication union (ITU), Federal Communications Commission (FCC), European Telecommunications Standards Institute (ETSI), Third Generation Participation Project (3GPP) [31].

3.2.1 Cellular system

A cellular base station consists of a tower and a shelter on ground. Tower contains the directional antennas to provide 2G, 3G, 4G-LTE coverage to the users on ground; and for the backhaul connectivity to the core network through fiber, microwave antenna or satellite link. The ground shelter contains all the network equipment and baseband units [17]. Base stations owned by MNOs are called as cellular towers, cellular base station, or cell sites [32]. . Cell sites in rural WAN regions are often connected to backhaul network using microwave links and satellite relays.

For rural and remote locations, base stations or cell sites are the usually deployable solution. The base station has different classes based on technology, equipment, size, and infrastructure. All base stations deployed for WWAN coverage include structural towers to deploy antennas on heights for wider coverage. Some common tower structure used by MNOs and ISPs include ground base tower (GBT), ground base mast (GBM) [29] ground base mast, roof top tower (RTT), pole site and wall mount [17]. Some common classes of base station include cellular tower, small cell [17], integrated radio devices and super towers; these are explained in detail in this chapter. Cellular tower is the most common used class of base stations. Cellular tower with GBT and GBM sites are deployed in rural and remote areas to provide maximum coverage. Base station with GBT and GBM towers can provide coverage in the vicinity of 10 to 40 km [17].

MNOs' cell sites coverage is considered in the form of hexagonal cells [33]. In planning the cellular network for WWAN areas, the geographical regions with human habitat are divided into the cells and RF planning tools are used to obtain minimum number of base stations, to blanket these cells [17]. An illustration of the geographical area division with cells is presented in Figure 9. Hexagonal cells in the Figure 9 represents the wireless coverage provided by the two base stations.

Currently, the biggest network manufacturers include Nokia, Ericsson, Samsung, and Huawei.

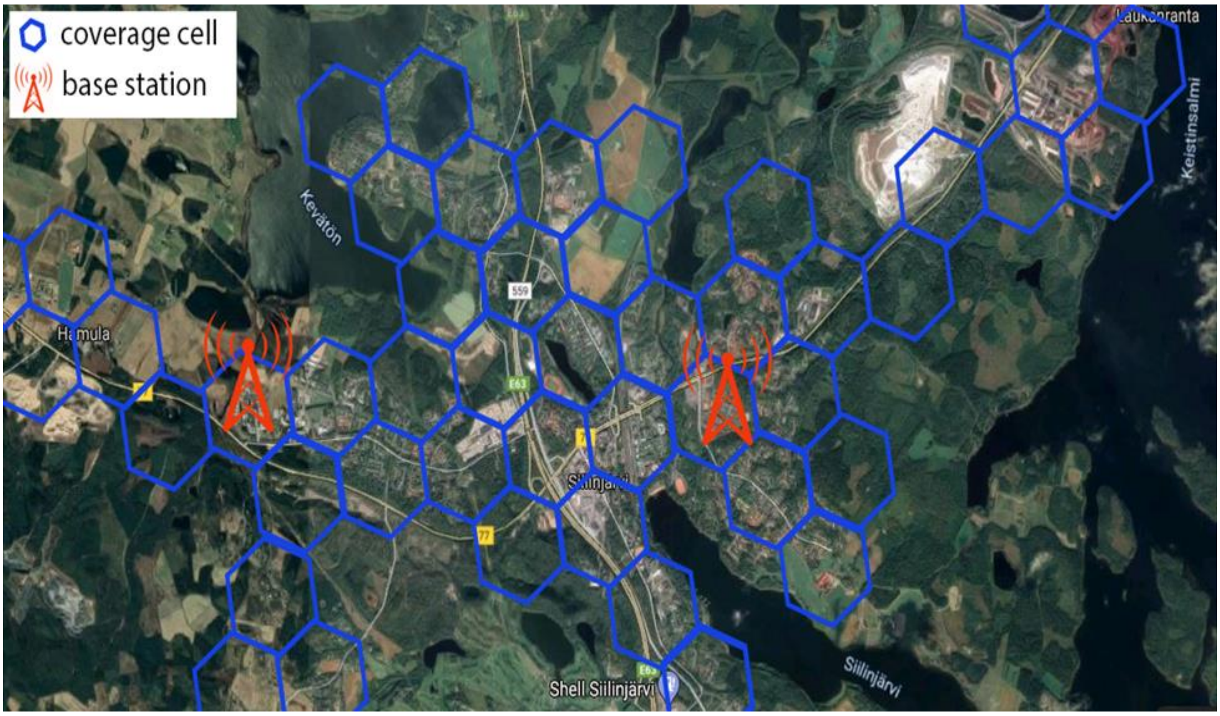

Figure 9 MNOs Base station planning model (Satellite view).

3.2.1.1 Small cell

Small cells are base stations, which are connected by both NLoS and LoS backhaul and provide outdoor coverage in the nearby vicinity of up to 5 km [33]. Small cell deployment does not required towers and reduces installation time and cost. These advantages of small cell base stations over macro base stations make them most cost effective and technically viable solution for coverage in rural areas. Figure 10 presents the small cell backhaul connectivity and coverage model. Macro Base station connects to the small cells with NLoS and LoS connection and provide backhaul connectivity. These small cells provide network coverage to the nearby UEs [35].

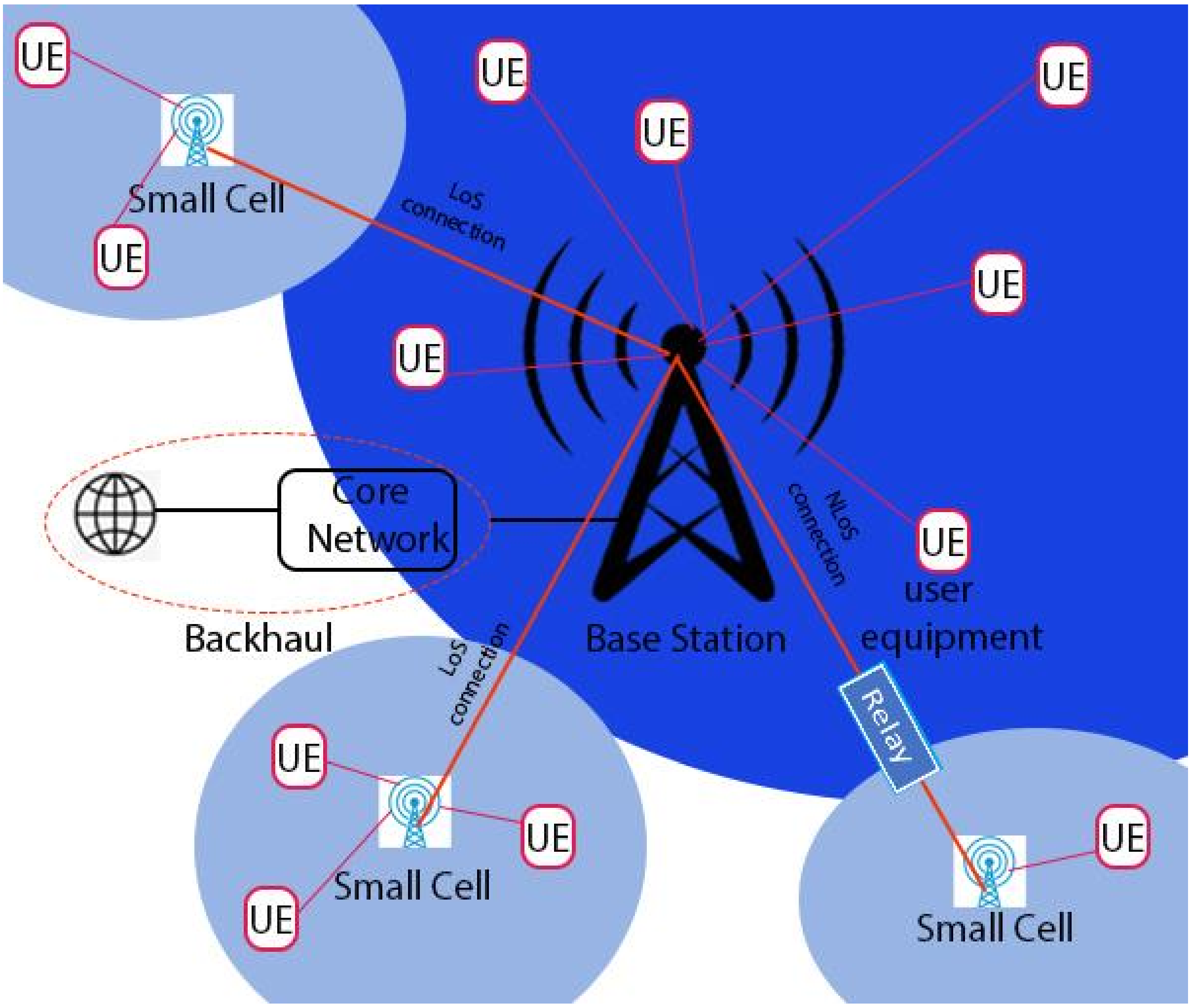

Figure 10 The small cell connectivity and coverage model.

Huawei's RuralStar is the small cell base station that is specially designed for network coverage in rural areas. Ruralstar is explained in detail in Chapter 4 with its advantages and limitation. Ruralstar is a cost-effective solution for sparsely populated rural areas in comparison to macro base stations as stated in [2].

3.2.1.2 Super tower

The super tower [36] solution is Altaeros tethered aerostatic blimp, which is filled by helium. It provides wide-area coverage from a height of approximately 240 meters that allows fully autonomous cell site deployment. Electricity for high capacity radio is provided by the tethers. The tether of each aerostat contains integrated fiber optics and a power conductor, which enables the tether to provide electricity. The super tower can incorporate any number of radio systems to integrate into existing networks. It contains high gain antennas, including 4G and 5G technology base stations. It does not have 2G or 3G, to provide minimum connectivity in rural areas where 4G and 5G is not available [37].

The super tower is designed for wide-area coverage that could be a replacement for satellite deployments. A single super tower could replace nearly sixteen regular cell towers at a 60% lower cost [36] as shown in the example. Figure 11 presented the geographical coverage offered by the super tower and base station as a comparison. Users are not sharing one signal because of multiple radio units and thus making internet speeds high enough for video streaming or other high data rate requirements. The super tower is sustainable even in winds up to 160 kilometers per hour and lower-category hurricanes [38]. It has features to monitor weather conditions and automatically returns to the ground if extreme weather events are detected. It starts flying automatically once the weather becomes friendly again [36], [37].

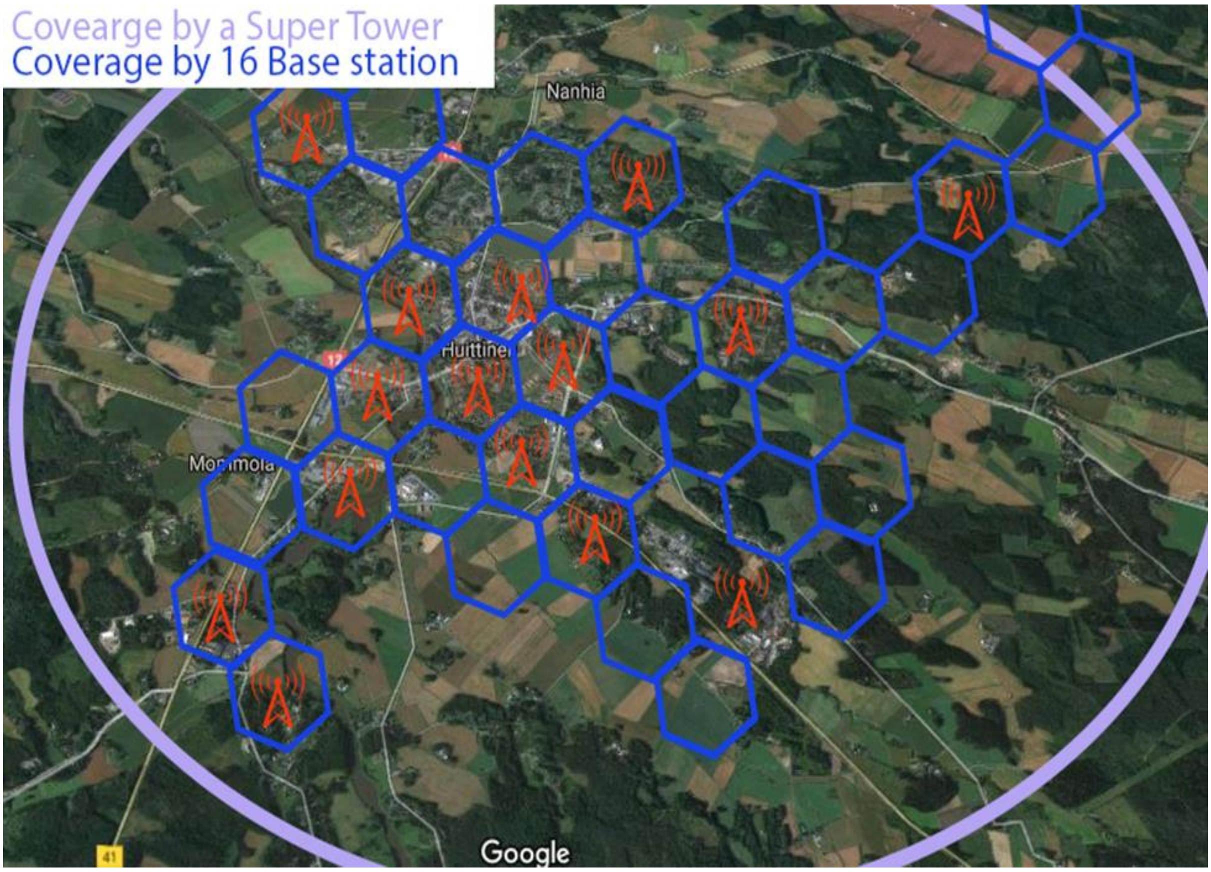

Figure 11 Coverage comparison of super tower and base station (Satellite view).

3.2.2 Power line communications

Power line communication (PLC) technology makes use of the existing electrical power transmission architecture to make end-user connected to internet [31]. Electricity is an essential need of the human habitat, and is accessible to the majority of world population living in remote and rural areas [39]. Electrical power transmission with overhead towers, underground powerlines, is accessed by the end user with physical wired connectivity, for use of electricity. This existing infrastructure provides favorable conditions for technology to be built to access internet using these power lines in addition to the electricity. PLC network is limited to the areas with power grid and may provide wireless backhaul connectivity to the nearby cellular base stations.

Figure 12 shows internet connectivity via power line infrastructure. Research is ongoing for PLC or broadband over power line (BPL) for commercial use. PLC may become a future part for gigabit internet service for WAN regions such as remote and rural areas [31].

PLC will be the most cost-effective solution for ISPs and MNOs to provide internet access to remote and rural areas, by utilizing existing power line infrastructure. PLC will be used as backhaul connectivity for segregated regions of remote and rural areas and provide broad bandwidth for deployment of multiple WAN and LAN solutions. MNOs will make use of PLC as backhaul connectivity to provide power line telecom (PLT) services and ISPs will use PLC for power line Internet (PLI) services [40], both will deploy multiple small cell base-stations and APs (Wi-Fi) for WWAN and WLAN coverage. Project Airgig is one available technology in research for commercial PLC, by AT&T [41].

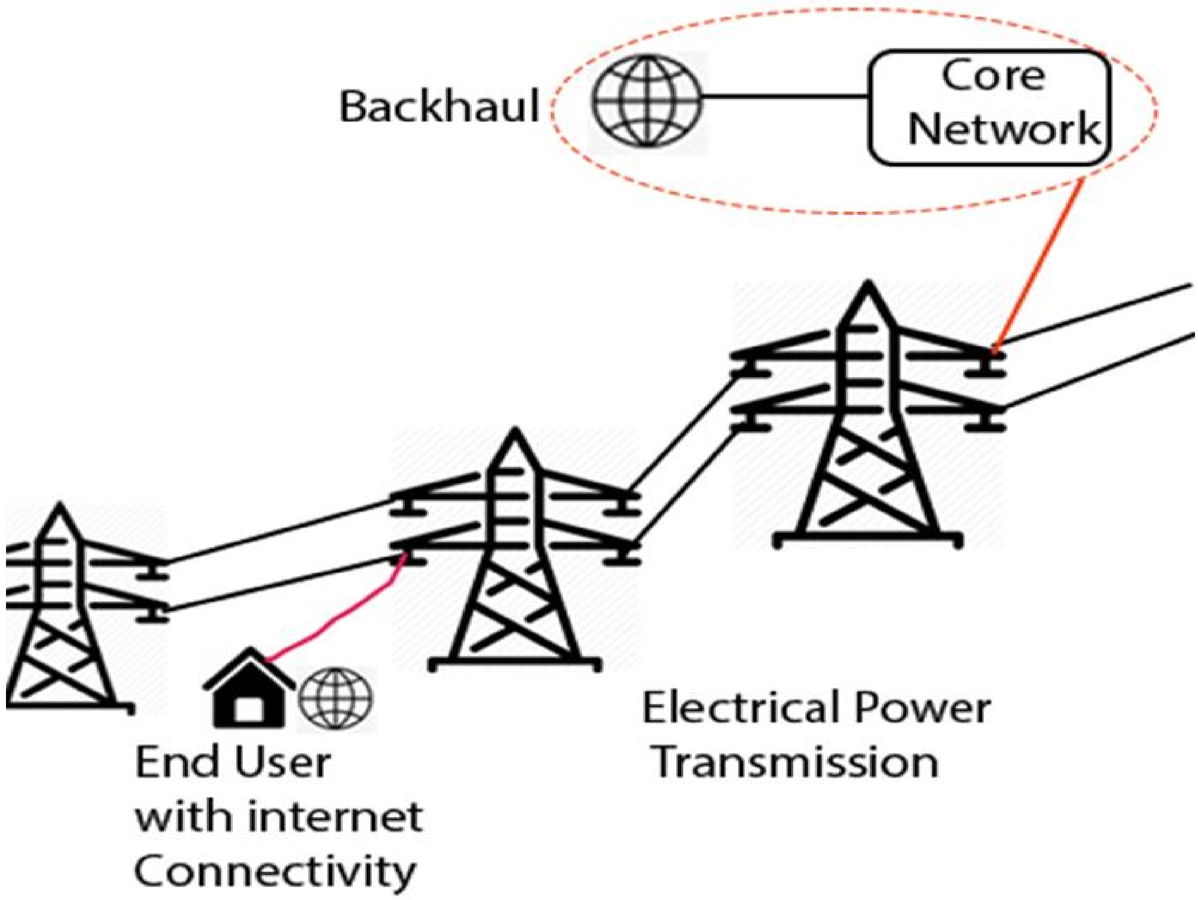

Figure 12 PLC network infrastructure.

3.2.2.1 AirGig

Project AirGig [42] is a technology introduced by AT&T Labs that can provide multi-gigabit wireless internet speeds in the future by using power lines. It could be used as a backhaul technology for MNOs and ISPs. It can provide last-mile wireless connectivity to homes without fiber-line. With this technology, multi-gigabit connections are possible without building new cellular towers or fiber infrastructure. Low-cost plastic transceiver is prototyped under this technology for transmission over the power line and provide 4G LTE and 5G multi-gigabit communications [43]. The technology is flexible to configure and easier to deploy than fiber-lines. Project AirGig could also help utility companies to detect power line issues quickly by pinpointing specific locations [43].

3.2.3 Satellite communications

In order to connect the rural area with internet, the use of satellites for carrying wireless signals is a solution to consider. Topographic limitations are not applicable for satellite communication, and it can provide a good solution for long-distance links and links over difficult terrain. Satellite communication works under the most challenging geographical and climatic conditions. Satellite communication service works both as a backhaul connectivity to connect base station to core network and as a direct network service to provide internet access to the end user. MNOs and ISPs face cost challenges in deployment of satellite for backhaul connectivity, compared to microwave links and fiber lines. They also face cost challenges for satellite direct network services compared to base station.

Satellite internet services provides data rate of 506 Mb/s to individual users using K_u (1 GHz to 170 GHz) band through geostationary satellite [44]. Figure 13 presents the basic architecture of the satellite internet services using communication satellite. This comprises of a wireless router or a modem installed at the user premises, connected to a dish antenna via a short coaxial cable. The antenna is mounted outside the home, with clear access to the communication satellite. The communication satellite is linked to satellite ground terminal containing satellite receiver by satellite network operator and from there the signal is linked to MNO’s core network. A single satellite network can serve different regions of rural and urban areas. Service providers can provide their services to a larger population by using geostationary satellite [45].

By sharing satellite infrastructure reduces cost of services, but still initial deployment of satellite is very expensive. Other than cost, there are some significant challenges in deployment of satellite internet service in rural areas, including bad or poor signal levels from satellite due to heavy vegetation [46]. These challenges can be overcome by high gain antennas and power extenders.

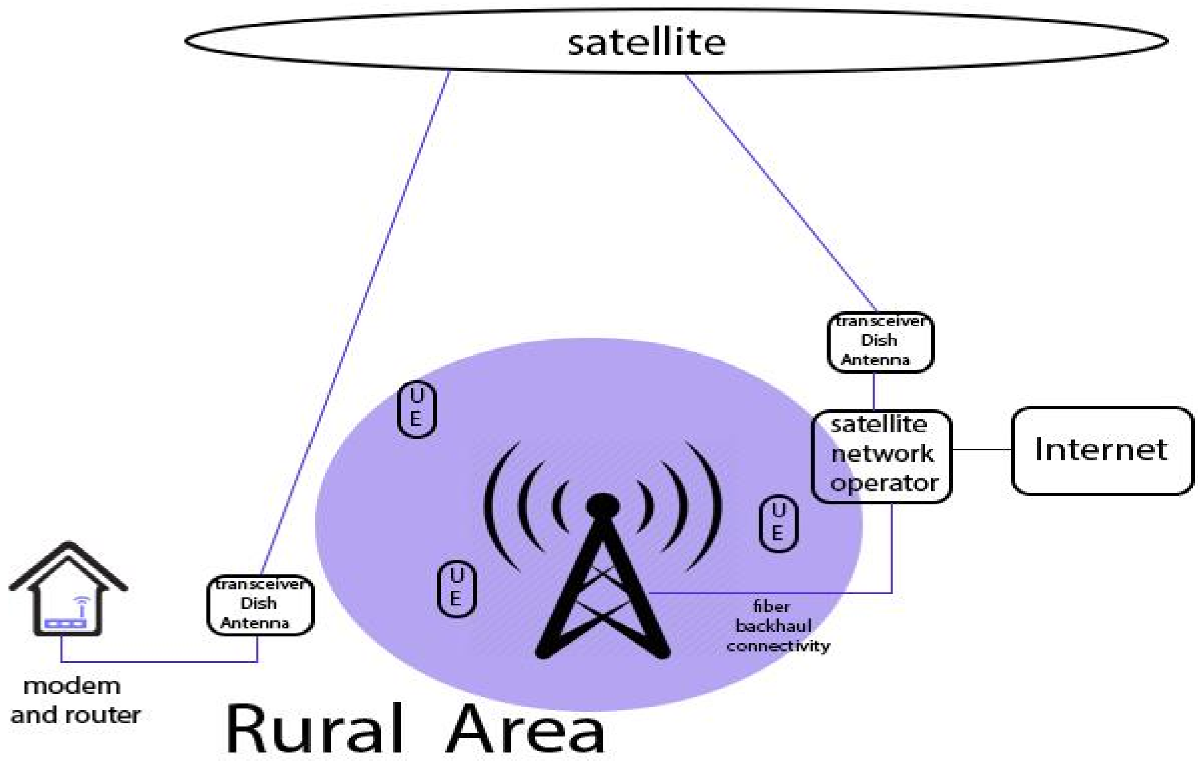

Figure 13 Satellite network topologies.

3.2.3.1 Viasat

Viasat [44] is one of the service-provider, of residential satellite internet services in United States. Viasat also provides satellite internet services for corporate and government clients. These services include providing in-flight Wi-Fi; have tie-ups with majority of airlines such as JetBlue, United Airlines and Virgin America. These services include an internet option for people living in countryside, remote and rural areas [47].

3.2.4 Balloon based communications

Another high-altitude solution for wireless communication is based on balloons [45]. Instead of using satellite communications, which is expensive; balloons with communication equipment (inclusive of compact base station), are lifted above the Earth and they act as a separate cellular site or wireless broadband station. Carrying equipment balloons would float up to the edge of space to transmit and receive wireless signals [38]. The balloon infrastructure allows MNOs to deploy 3G/4G LTE services over the wide area, where each balloon is representing a "relay" in the overall network. The balloons can work as a backhaul component and as a network base station for cellular and broadband coverage. The cycle of Balloon with equipment releases and recovery in Figure 14 presents the cycle of using balloons to be equipped with hardware and its lift off to space. The autonomous infrastructure allows balloons to carry up the equipment once a day, and with completion of the day cycle the equipment drifts back to the ground, carried by the parachutes. And with the start of cycle balloons are refilled and released again with the equipment.

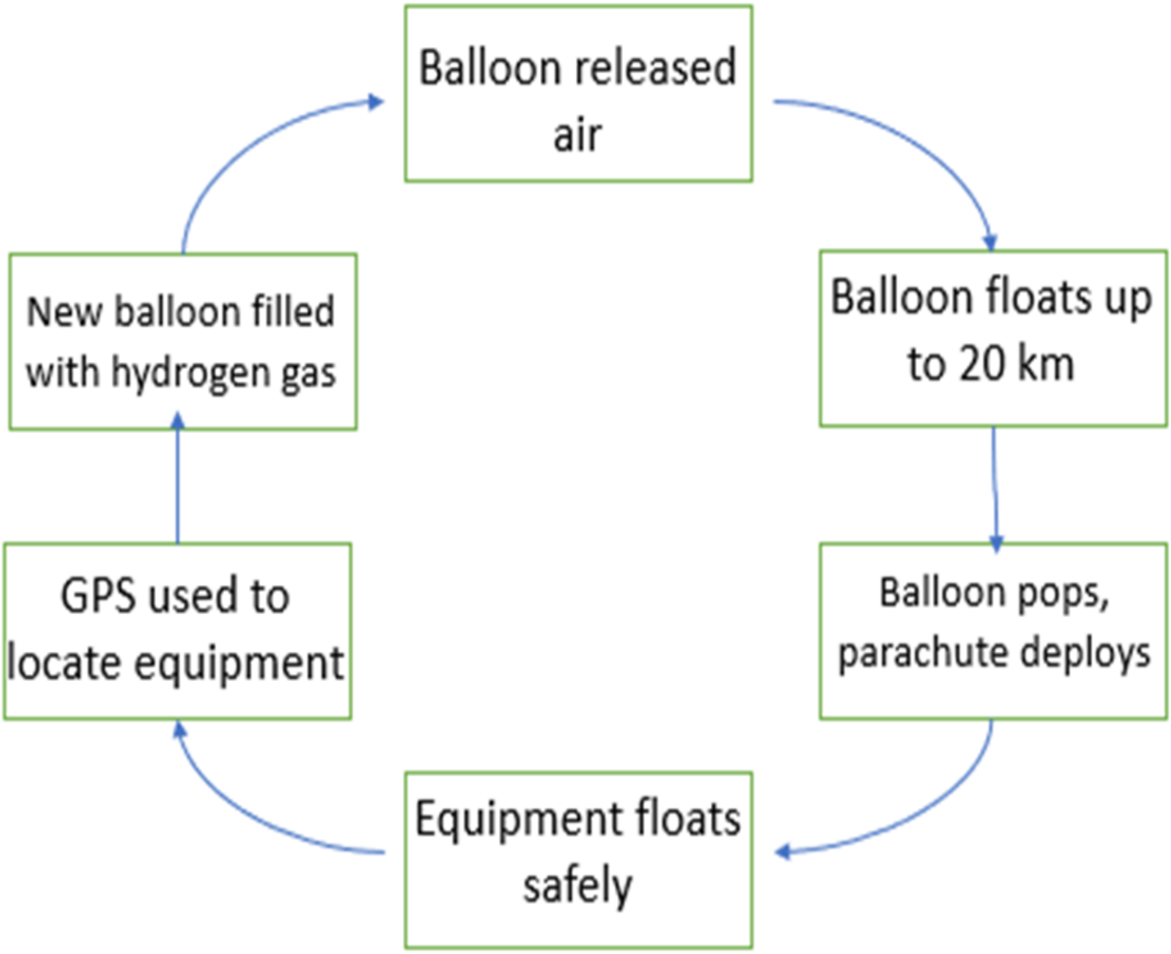

Figure 14 The cycle of Balloon with equipment releases and recovery (Adopted from [45]).

3.2.4.1 Loon

Project Loon was carried out by Google X labs in 2013 [48]. Loon has taken essential components of a cellular site, and replaced them with durable, light weight, easily transportable equipment, to be carried by a balloon for up to 20 km in space. Loon balloons are manufactured and designed to endure the harsh conditions of the stratosphere, where temperatures drop to -90° C and winds blows over 100 km/hr. Each balloon is built to stay in stratosphere for 100 days before landing back on Earth in a controlled way [48]. Items carried by the Loon Balloon while on flight are:

- **Solar panels:** During sunlight solar panels powers the equipment and charge the onboard batteries for power requirements during night operation.
- **Antennas:** Balloon is equipped with antenna for backhaul and antennas for providing 3G 4G LTE coverage.
- **Flight capsule:** The flight capsule comprises of electronic equipment for flight control of Loon system.
- **Parachute:** A parachute is deployed for safe landing of all equipment of Loon, back to Earth, after completion of flight cycle [48].

3.3 WMAN equipment

A wireless metropolitan area network (WMAN) is intended to provide network coverage in big regions with area of approximately the size of a town [49]. WMAN provides wireless services through point to point (PTP) and point to multipoint (PTMP) connectivity and covers last mile connectivity in metropolitan regions. The PTP and PTMP networks can expand to 50 km for backhaul connectivity [49]. ISPs provide WMAN services with deployment of big network infrastructure. WMAN standards are governed by the IEEE association, and define protocols for WMAN services. WiMAX is the most popular service under WMAN. WMAN network architecture is presented in the Figure 15 [45].

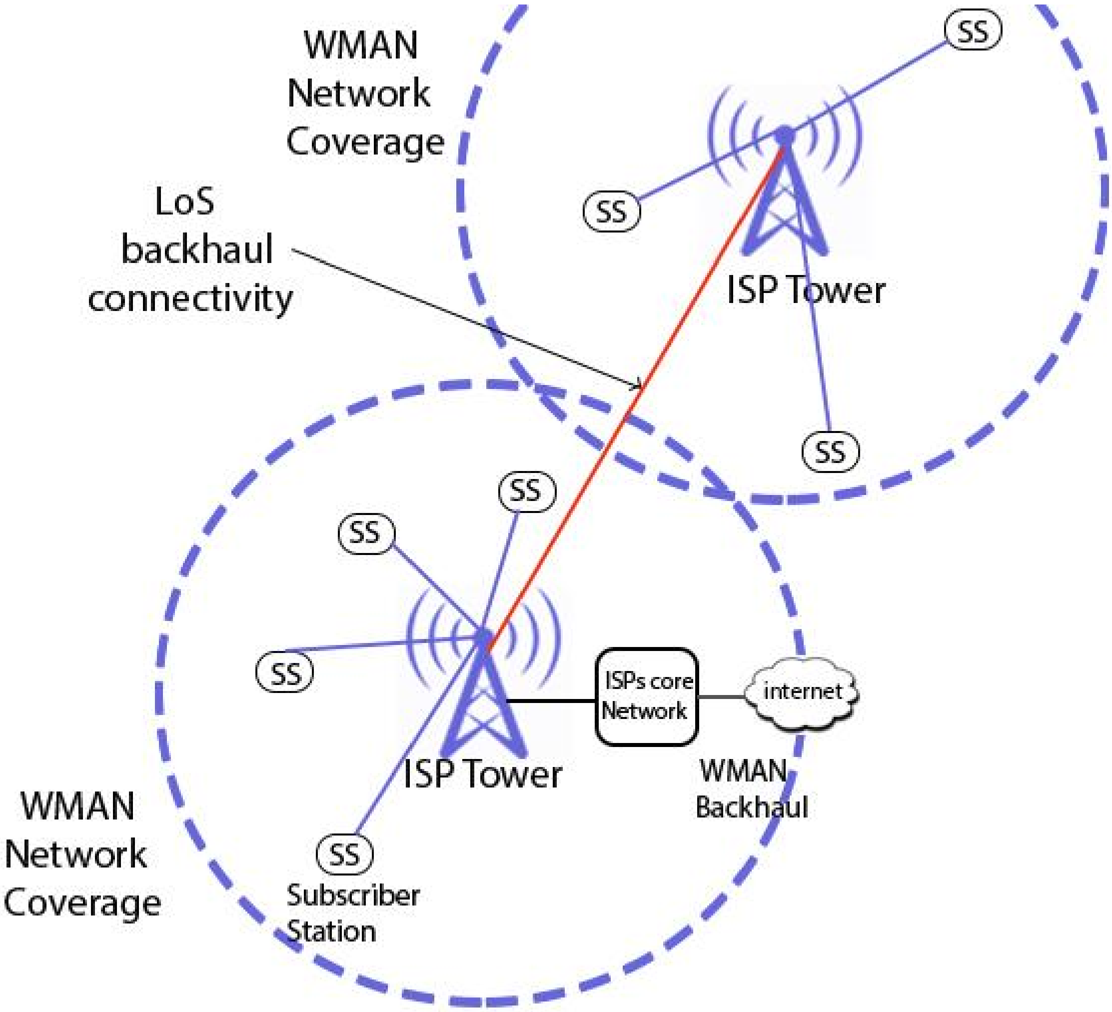

Figure 15 WMAN network architecture.

3.3.1 WiMAX

WiMAX is an standard which is introduced in April 2001, by leading communication companies to promote WMAN broadband wireless access equipment that citifies the IEEE 802.16 and ETSI HIPERMAN standards [50]. WiMAX technology is standardized by IEEE 802.16, to provide wireless broadband internet services in Wireless Metropolitan Area Networks. IEEE 802.16 has standardized use of 10 to 66 GHz frequency band for WMAN services [50] and after that IEEE 802.16a has published use of 2 to 11 GHz band [49].

WiMAX base station can provide coverage in the radius of 50 km, as per IEEE 802.16 standard. The offered internet speed varies with distance, and the maximum 30 Mbps speed is obtained by the user near to the base station. Average speed is 25 Mbps [49]. WiMAX network architecture comprises of three major parts [51]:

- Subscriber station (SS): It is a WiMAX interface equipment used by users in WiMAX network to access WiMAX services.
- Access service network (ASN): This is the coverage of the WiMAX network that provides radio network access formed by the base stations.
- Connectivity service network (CSN); This is the backhaul network of the WiMAX network that provides IP connectivity and performs core network functions.

3.4 WLAN equipment

A WLAN is a network that provides wireless internet access by established links between two or more devices using wireless communication. It uses 2.4 and 5 GHz radio frequency bands to form a local area network and provide coverage within a limited area [52]. WLAN provides network in small geographical regions, example schools, hospitals, builds and other small regions [53]. Wi-Fi is the most common technology used in deploying wireless local area network services in many region [54]. All technical standards for WLAN and its technologies are provided by IEEE association [53].

3.4.1 Wi-Fi

Wi-Fi is an alliance that certificates wireless devices for conformity of IEEE 802.11 standard. The alliance lists companies, such as, Apple, Comcast, Samsung, Sony, LG, Intel, Dell, Broadcom, Cisco, Qualcomm, Motorola, Microsoft, Texas Instruments, and T-Mobile [55].

Wi-Fi technology was introduced in 1997, allowing 1 or 2 Mbps data transfer speed and is not any longer employed by the wireless community. In year 1999, IEEE 802.11a and 802.11b were introduced, allowing data rates of 54 Mbps using a 5 GHz frequency band and, 11 Mbps using a 2.4 GHz frequency band, respectively [56]. IEEE Wi-Fi standards in Table 2 [57] presents the IEEE Wi-Fi standards with their respective year of release, frequency band and data rates.

Table 2 IEEE Wi-Fi standards.

IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ax
Year Released	1999	1999	2003	2009	2014	2019
Frequency	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz & 5 GHz	2.4 GHz & 5 GHz	2.4 GHz & 5 GHz
Maximum Data Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps	1.3 Gbps	10-12 Gbps

Wi-Fi alliance certified WLAN network contains Wi-Fi access points (Wi-Fi-APs), and Wi-Fi user devices. Wi-Fi-APs contains RF antenna and a radio transceiver which transmit radio signals (within the frequency band, defined by IEEE standards [57]), these signals are received by Wi-Fi receivers (e.g., computers equipped with Wi-Fi cards) [55]. Whenever a device with a Wi-Fi-card, receives the signals within the range of a Wi-Fi network, it initiate the connection request and on authentication, creates a connection with the Wi-Fi-AP [58].

Wi-Fi services are provided using Wi-Fi-APs to multiple users present in small regions and using Wi-Fi routers as an individual connection to a home, office, or other personal location. Wi-Fi router acts as a Wi-Fi hotspot, and creates wireless connection with Wi-Fi devices in range to provide internet access [59]. Wi-Fi-APs have stronger signal strength and long radio transmissions with a radius of 90 to 165 m generally for use in small public areas, whereas Wi-Fi routers are more competent for homes with radio transmissions of 30 to 50 m [60].

WLAN planning for a building or other infrastructure using Wi-Fi APs involves the below mentioned steps [60].

- Location survey: Initial survey is conducted to map the total area to be covered.
- Shape of area: For shapes, multiple photos are taken, and areas are divided into various shapes [60].
- Building or wall material: Material type provides the wireless signal penetration information. Walls of brick, cement, or cinderblock degrade network coverage and required more APs for better coverage [60].
- Number of users: Assumed number of users are important for calculating number of APs required on capacity basis.

Wi-Fi wireless LAN technology is extremely easy and cheap to deploy as compared to wired systems. Wi-Fi can, therefore, provide network access in rural and urban areas where it is challenging to run wired network. Additionally, a huge majority of laptops, cordless phones, cellular phones, cameras, and media players today have built-in Wi-Fi interface, which therefore enables easy connectivity. Wi-Fi has no mobility issues and user can roam around a building from one access point to other [60].

3.4.1.1 Long range Wi-Fi technology

The Technology and Infrastructure for Emerging Regions (TIER) project was started for low cost, unregulated, long-range Wi-Fi point-to-point connections, as an alternative to other fixed wireless, cellular networks or satellite Internet. TIER project has modified the standard IEEE 802.11 protocol implementations, to make them suitable for long distance, point-to-point usage [61]. The modifications in the standard cause risk of breaking interoperability with other Wi-Fi devices and suffering interference from transmitters located near the antenna [61].

TIER at University of California at Berkeley in collaboration with Intel uses a modified Wi-Fi setup to create long-distance point-to-point link of 4.8 to 16.0 km [61]. There are no commercial standards for long range Wi-Fi point to point standards. Research is ongoing to overcome the power and interference challenges in long-range Wi-Fi.

3.4.1.2 Outdoor router including LTE modem

An outdoor router is an ideal solution to provide internet access in outdoor area of remote areas. The outdoor router has a mobile modem and high-gain antenna to receive a stronger mobile signal and works with weak signal as well at locations far away from base stations. It receives mobile phone signals from the nearby base station, and then provides wireless internet access by Wi-Fi hotspot and wired internet access by local area network (LAN) ethernet connection. The device contains MNO's subscriber identity module (SIM) and offers MNO's internet plan and rentals. Figure 16 presenting outdoor router working topology. Table 3 presents EZR30 of company called OutdoorRouter as an example of an outdoor router for a rural area [62].

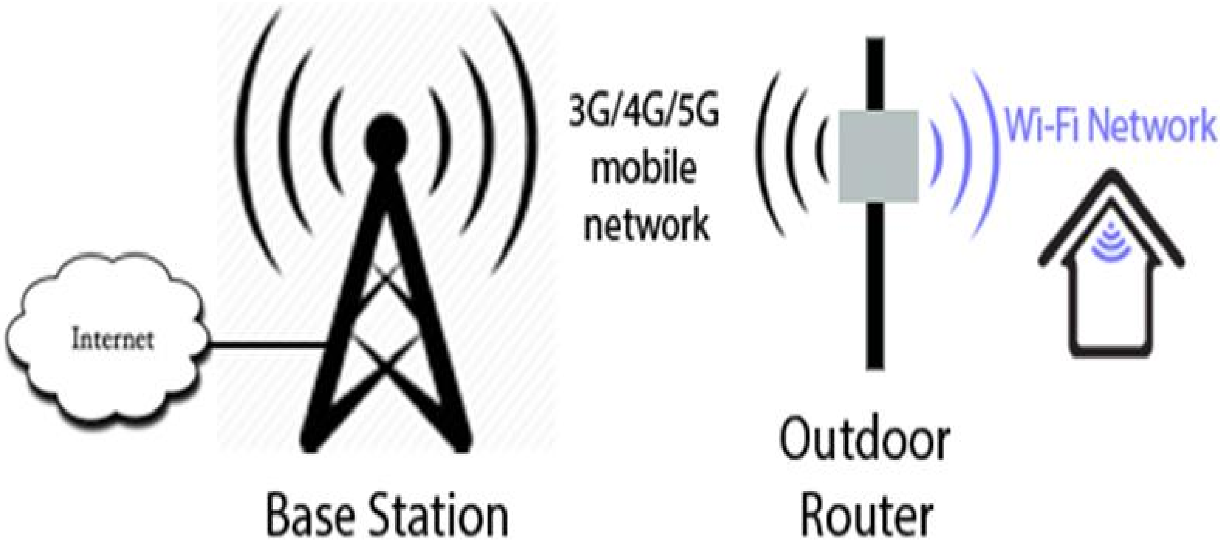

Figure 16 Outdoor router working topology.

Table 3 An example of an outdoor router for a rural area.

	Devices Name	Company name	Specification and features
Outdoor router	EZR30 Series	Outdoor Router	• Mobile modem (with international mobile equipment identity (IMEI) number). • Standard subscriber identification module (SIM) card slot. • Support 2G, 3G, 4G and even LTE-Advanced mobile networks. • Covers (150~300) m radius in the open area. • Sustainable for all weather conditions and rugged deployments.

3.4.2 Fixed wireless

Fixed wireless is a technology that is employed to supply internet connectivity over a specified range without wired connectivity. Fixed wireless internet is especially utilized in rural areas where fixing the infrastructure for internet services is prohibitively expensive. Transporting and burying cables within the ground and getting the required permits are challenging.

Fixed wireless internet service provides a high-speed internet access between 1 to 30 Mbps. The end user premises are connected to the ISPs using radio signals instead of fiber or wires. At users premises a high gain antenna with a radio transceiver module is fixed on top of roof, which communicates to the ISPs transmission towers and establish a fixed link. The transceiver equipment is connected to an indoor router or modem which provides Wi-Fi coverage in indoor [63]. Figure 17 presents topologies of fixed wireless internet services [64].

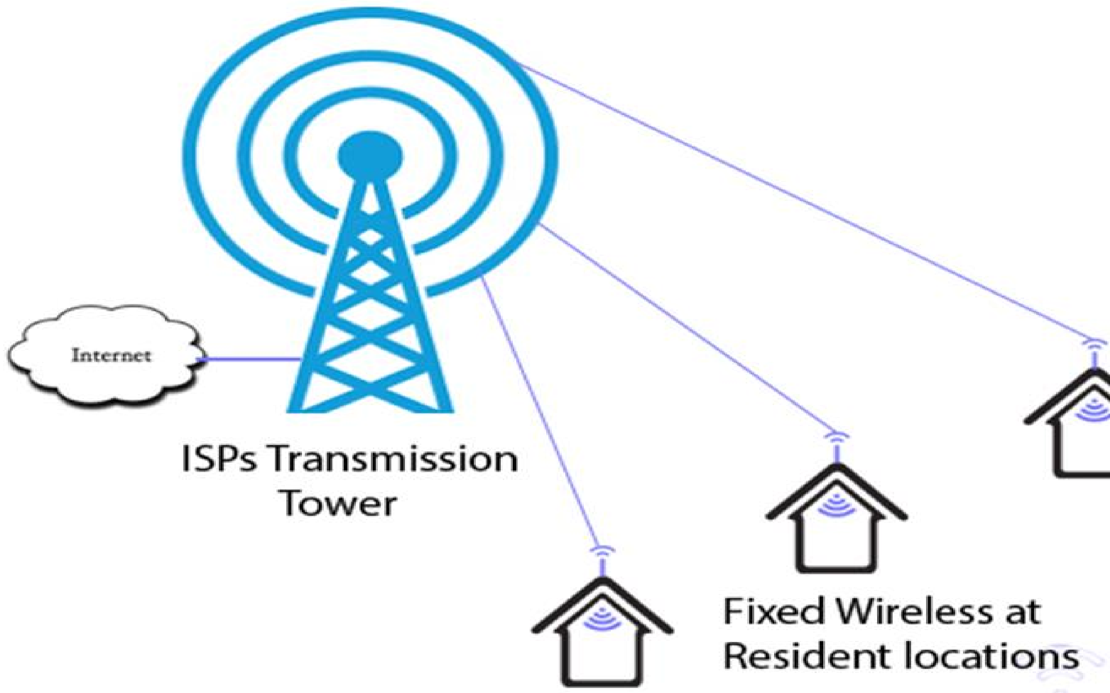

Figure 17 Topologies of fixed wireless internet services.

Fixed wireless deployment is carried by a licensed technician from the ISPs end. The technician first conducts the survey of the user residence for equipment requirements and wireless antenna location possibilities. In the next phase, antenna mounting on roof and equipment (including transceiver module and Wi-Fi modem) placement is conducted. In the end, installation and configuration is done and Wi-Fi services are enabled [65]. CenturyLink, AT&T, HajaKaista, etc. provide fixed wireless services.

3.4.2.1 HajaKaista

HajaKaista is a fixed wireless service provider in Finland. HajaKaista provides fixed wireless hardware as well as services. The hardware contains roof top and indoor equipment. Roof top equipment comprises of super-efficient, high-quality directional antenna and indoor contains high-quality indoor- unit, which converts the mobile network into WLAN (with Wi-Fi) and LAN (with Ethernet cable) connection. HajaKaista equipment is compatible with all MNO networks, and capture signals from long distance base stations. HajaKaista equipment is virtually deployable in all regions and gives 2 to 7 Mbps data rate on 3G networks and 5 to 30 Mbps on 4G networks [66].

HajaKaista fixed wireless product package includes [66]

- HajaKaista 3G 900 directional antenna;
- WLAN 3G/4G router.

HajaKaista's rental cost for 3G and 4G networks include all charges for seamless internet connectivity such as [66]

- operators' share of the subscription;
- equipment rental;
- equipment perpetual warranty;
- maintenance cost.

3.4.3 Signal boosting

Signal booster is a device that receives the week signal from the base station and amplifies it to make it useful for the user equipment (UE). It also amplifies the signal of UE, being sent to the base station. There are three main components of a booster device:

- **External antenna:** The external antenna (mainly a Yagi antenna [67]) is installed on the roof or outside of the house. The external antenna has its own gain, which provides amplification to the received and transmitted signal. For maximum amplification, the antenna is connected to an amplifier unit [67].
- **Amplifier:** The amplifier unit amplifies both signals coming from the base station to the UE and signal going back to the base station. The amplifier unit is connected to the external antenna and indoor antenna with a coaxial cable
- **Indoor antenna:** The indoor antennas distributes the signal to and receives the signal from UE.

The booster makes use of external power consumed by the amplifier unit to boost or extend the received and transmitted signal power. Signal booster has a drawback, it works on some minimum network signal power, due to this limitation these are not deployable to rural areas where signal power is under booster requirement. The complete booster deployment setup is presented in the Figure 18 [67] and a block diagram of different types of booster is given in Figure 19.

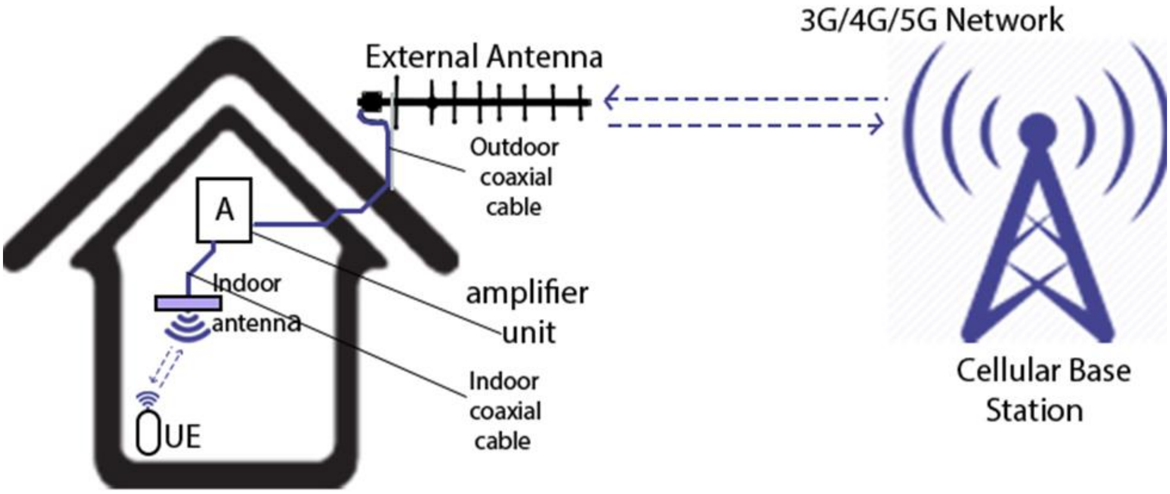

Figure 18 The booster deployment setup.

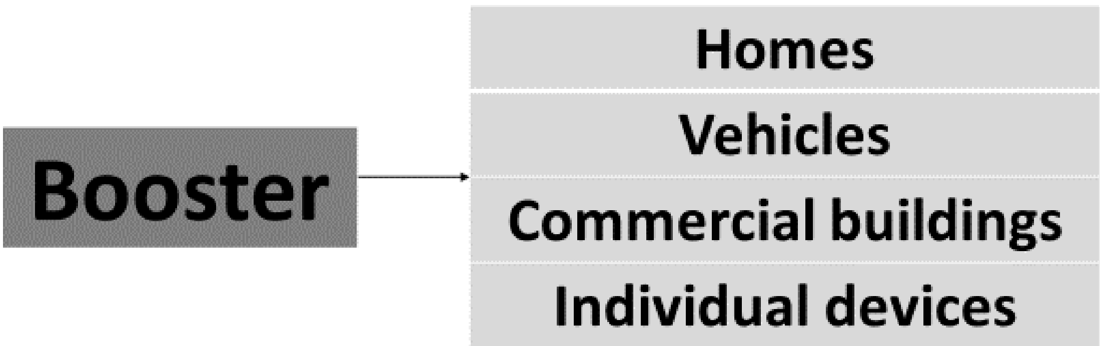

Figure 19 A block diagram of different types of booster.

3.4.3.1 Homes

A cell phone signal booster can improve 4G and 3G cellular signals to provide increased coverage within houses, apartments, home offices or workspaces. Cell phone signal booster provides quality of services, including better talk and text, faster internet, and consistent service [68]. The installation of today's signal booster systems is very simple and flexible. Anyone can do this who have basic "handyman" skills and familiarity with the use of simple hand tools. There are different booster systems that provide a variety of improved cell signal coverage area inside houses. Table 4 presents some commercial booster device solutions for different sizes of houses [68].

Table 4 Commercial booster device solutions for different sizes of home.

	Size of area	Devices Name	Company name	Specification and features
Homes	Large (Up to 700 square meters)	Installed Home Complete	WeBoost	• Boost signal strength up to 700 square meters. • Supports multiple simultaneous users. • Enhances cell coverage for an entire home. • Ability to target cell towers from any location. • Will work in a 5G world.
	Medium (Up to 460 square meters)	Home MultiRoom	WeBoost	• Multi-user cell signal booster for residential use. • Increase cellular connectivity and signal strength up to 460 square meters. • Simultaneously support multiple users. • Providing uninterrupted streaming capability, fewer dropped calls, better voice quality, faster internet speeds. • Will work in a 5G world.
	Small (Up to 250 square meters)	Flare	Surecall	• Boost signal strength up to 230 square meters. • Supports multiple simultaneous users. • Reduces missed and dropped calls and increases data speeds of 4G LTE. • Compatible for 5G Phone. • Boosts 4G LTE data signals on 5G phones and devices.

3.4.3.2 Vehicles

A vehicle signal booster is used in vehicles instead of home or offices. It works same as a cell phone booster, and improves cellular signal of 3G, 4G, LTE networks to provide increased coverage within a car, sport utility vehicle (SUV), truck, semi-truck, a recreational vehicle (RV), camper, boat and marine, yacht, or fleet vehicle [69]. These boosters are compact in size compared to commercial home boosters.

Vehicle cell boosters come in a wide variety of designs, for specific vehicle types. Table 5 shows the vehicle booster and their features [69].

Table 5 Vehicle booster features.

	Devices Name	Company name	Specification and features
Vehicles	Drive Reach	weboost	• Most powerful, in-vehicle cell signal booster. • Reach the farthest cell towers in rural areas. • Delivering coverage on the road. • Stops dropped calls while also improving data speeds, voice quality, and streaming capability. • Works on all United States (US) carrier networks. • It simultaneously supports multiple users.
	Fusion2Go 3.0	SureCall	• Maximum power and gain throughout the most remote areas of the road. • Supports multiple users simultaneously. • Works on all North American carriers • Compatible with all cellular devices. • Boosts 4G LTE data and voice signals on 5G phones and devices. • Reduces dropped and missed calls.

3.4.3.3 Commercial buildings

Commercial or enterprise signal boosters are deployed in commercial offices, buildings, warehouses, and construction sites. These locations have areas in thousands of square m [70] where it is difficult to provide strong wireless coverage at all locations. Commercial signal booster can provide solutions that can boost reception up to 9200 squares m [70]. Commercial signal boosters can be used in large homes or apartment buildings. Together with boosting coverage, these solutions improve signal quality, rapid call drops and improved data rates [70]. Table 6 gives an example of a booster for commercial buildings [70].

Table 6 An example of a booster for commercial buildings.

	Device Name	Company name	Specification and features
Commercial buildings	Enterprise 4300	WilsonPro	• Boosting innovations centered on its all-new multi-tower targeting technology. • An antenna is dedicated to a specific frequency band to collectively amplify signals from multiple towers. • Requiring a single outdoor antenna to deliver enhanced cell signal coverage to its indoor antennas.
	Force5 2.0 Industrial	SureCall	• Boosts signal for 4G LTE data, voice and text for all major North American carriers. • Boosts 4G LTE data and voice signals on 5G phones and devices. • Supports 100+ users simultaneously. • Reduces dropped and missed calls. • Improves data performance for large or enterprise buildings. • Up to 7400 sq. m coverage for commercial buildings.

3.4.3.4 Individual devices

In today's world, there exists devices which requires cellular coverage for their operation, without human involvement, these devices are also termed as smart devices. These individual devices are known as Internet of things (IoT) and machine to machine (M2M) devices. In some locations, cellular coverage is weak or no coverage and makes it challenging to deploy IoT and M2M devices. WilsonPro has developed an IoT device with an integrated cellular signal amplifier which works as a signal booster [71]. Example of booster for individual devices provided in the following Table 7 [71]. This device works as a direct connect booster.

Table 7 Example of booster for individual devices.

	Devices Name	Company name	Specification and features
Individual devices	IoT 5-Band	WilsonPro	• Ideal for custom designed IoT communication systems built within tightly constrained spaces. • The IoT 5-Band connects directly with cellular modems. • In the power failure, the passive radio frequency (RF) bypass failover feature allows cellular modem to proceed to help guarantee successful IoT data transfer. • The powerful antenna receives the cellular signal and delivers it to the booster. • The booster amplifies the weak signal and serves as a relay between the cellular modem and the cell tower. • The cellular modem performs efficiently as it feeds data to the booster and stays connected to the network.
	M2M 4G LTE	SureCall	• Machine-to-machine or IoT signal booster for 4G LTE cellular frequencies. • Increases 4G LTE signal strength for AT&T or Verizon. • Connects directly with cellular modems • The booster amplifies the weak signal and serves as a relay between the cellular modem and the cell tower.

4 POSSIBLE NETWORK SOLUTIONS IN FINLAND

The network deployment challenges faced by ISPs and MNOs were studied in Chapter 2, and in Chapter 3. Possible network solutions to overcome these challenges are discussed in this chapter. Possible network solutions are studied, as an example, for unconnected regions of Finland, located in the northern Europe. The country has surface area of 338432 km^2, including the land and inland water areas [72]. Finland has total population of 5.5 million and 14.6% of this population lives in rural areas [73], [72].

The Figure 20 presents the geographical segregation of Finland on the basis of inner urban areas, outer urban areas, peri-urban areas, local rural areas, rural heartland areas, rural areas close to urban areas, and sparsely populated rural areas. Finland has total 19 provinces. The geographical segregation of these provinces on map of Finland is presented in Figure 21.

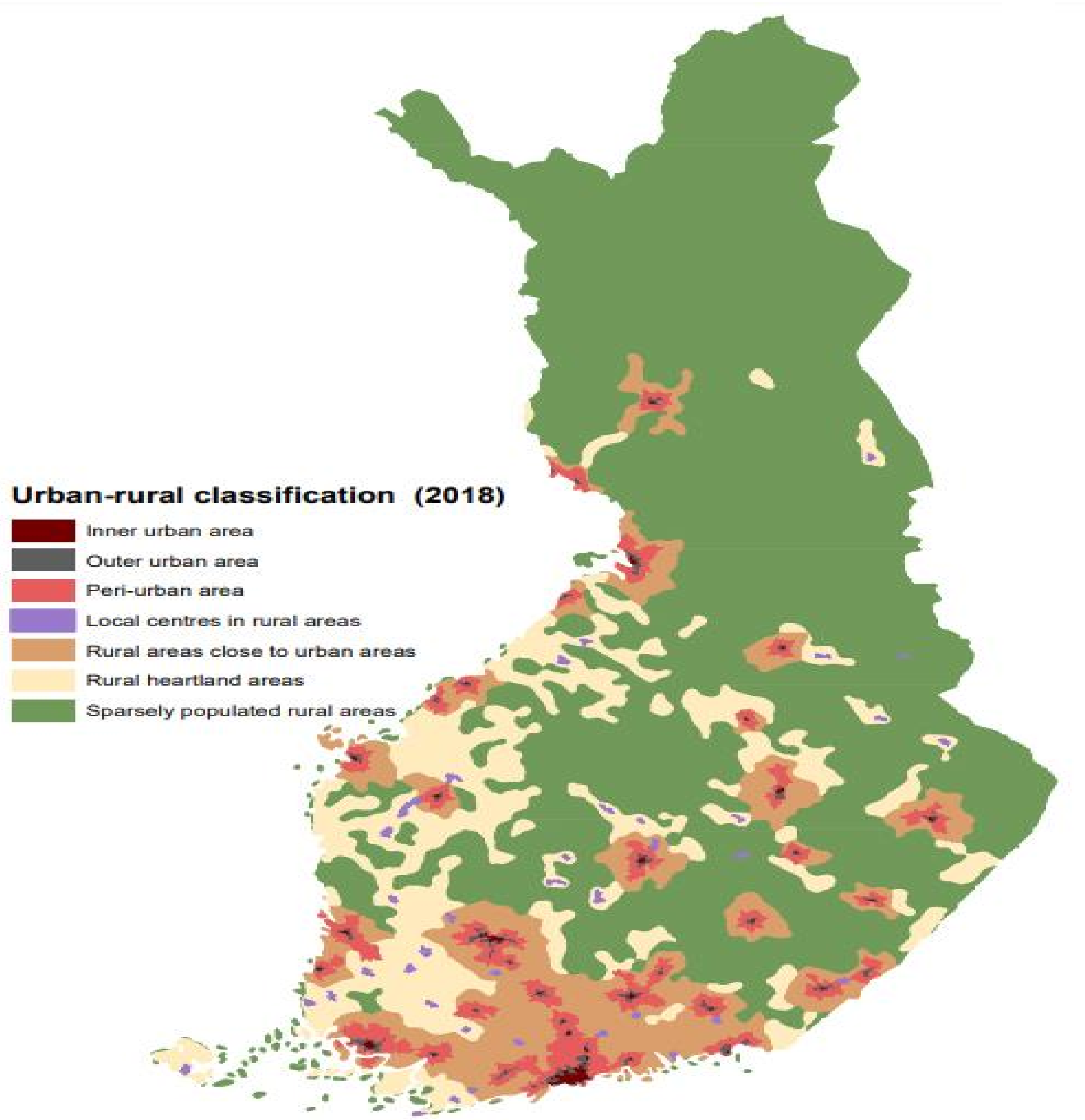

Figure 20 Urban and rural classification of Finland (Source: @SYKE 2018, CC BY 4.0) [74].

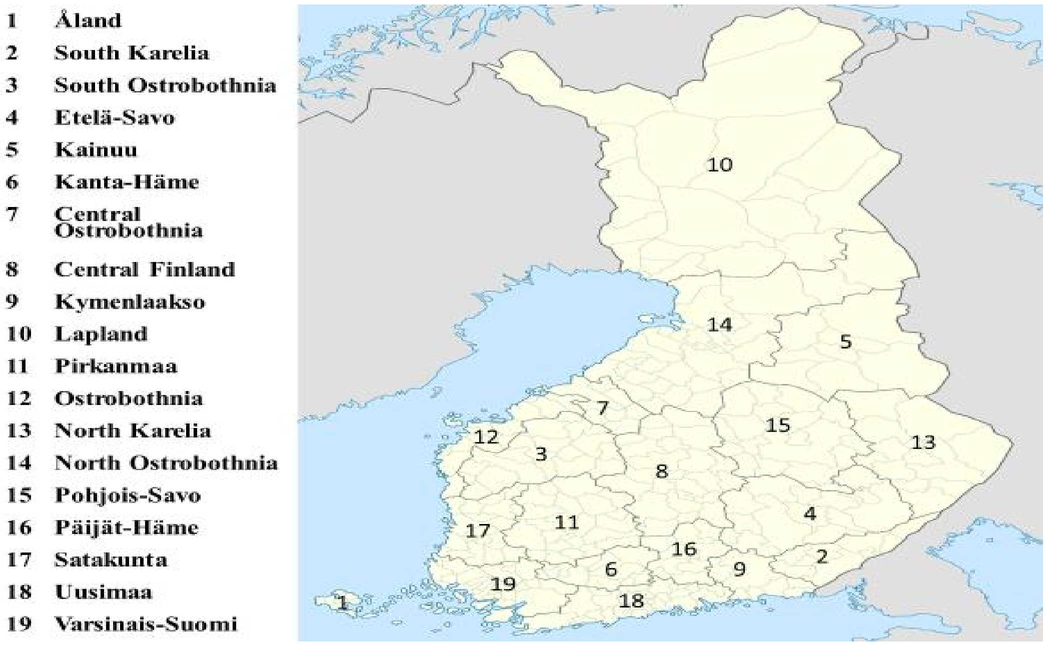

Figure 21 Province map of Finland (Source: @WIKIMEDIA 2020, CC BY-SA 4.0) [75].

Finland has total 4G network coverage of 89% based on geographical region [73]. Lapland and Kainuu are the two provinces with least coverage [76]. Lapland has 69% coverage and Kainuu has 83% coverage [73]. The Table 8 presents the 4G network coverage of all 19 province of Finland [73].

Table 8 4G network coverage in Finland provinces.

		4G Coverage
	Finland	**89 %**
	Provinces	
1	**Åland**	**100 %**
2	**South Karelia**	**98 %**
3	**South Ostrobothnia**	**100 %**
4	**Etelä-Savo**	**100 %**
5	**Kainuu**	**83 %**
6	**Kanta-Häme**	**100 %**
7	**Central Ostrobothnia**	**100 %**
8	**Central Finland**	**100 %**
9	**Kymenlaakso**	**100 %**
10	**Lapland**	**69 %**
11	**Pirkanmaa**	**100 %**
12	**Ostrobothnia**	**100 %**
13	**North Karelia**	**95 %**
14	**North Ostrobothnia**	**97 %**
15	**Pohjois-Savo**	**100 %**
16	**Päijät-Häme**	**100 %**
17	**Satakunta**	**100 %**
18	**Uusimaa**	**100 %**
19	**Varsinais-Suomi**	**100 %**

In this chapter two network solutions from Chapter 3, are provided and analyzed for expansion in network coverage, in these sparsely populated rural areas. The first network solution is for the service provider and the second solution is for the end user.

4.1 A network solution for a service provider

A local connectivity solution is provided which may effective to a single home or in a group of houses. The solution is provided by a local network with a backhaul solution.

A small cell base station is a good solution for sparsely populated rural areas, in respect of cost, ease of assembly, technology, backhaul connectivity, and power. Small cells provide coverage in a small area. RuralStar, a small cell base station designed especially for rural areas by Huawei [77] can be used as a solution for sparsely populated rural areas of Finland. RuralStar is analysed for all the network deployment challenges and are presented below.

Cost
Huawei's RuralStar recover its equipment and deployment cost in less than 5 years from date of integration, compared to traditional base station, which take more than 10 years [2]. This makes easily adoptable for service providers facing cost challenges for rural regions with low ARPUs.

Ease of assembly and deployment
RuralStar is deployable on poles with minimum space and takes few hours from installation to integration, in comparison to challenges in deploying traditional base stations including high rental fees, difficulty in finding appropriate sites and slow deployments, which can take at least one month [2].

Technology
RuralStar is compatible with 3G and 4G LTE technologies and provide data rate of up to 10 Mbit per second for the end user, in the vicinity of 5 km. RuralStar uses high gain omnidirectional antenna [2]. This will provide coverage to a group of houses in sparsely populated rural areas.

Backhaul connectivity
RuralStar captures 3G, 4G wireless backhaul connectivity from a macro base station in range of up to 60 km with NLoS connectivity [78]. This makes it an ideal network coverage solution for rural areas with LoS connectivity challenges as describe in Section 2.1.1.

Power
RuralStar power consumption is 85% less than the traditional base station and thus, lowers total costs by 70% [34]. This will provide long runtime on batteries, during power failure due to bad weather condition or other reasons [2].

RuralStar has been deployed commercially in many countries, including Nigeria, Thailand, Algeria, and Ghana [2]. Figure 22 presents RuralStar functional diagram and its hardware. Figure 23 presents the network solution for service provider using RuralStar.

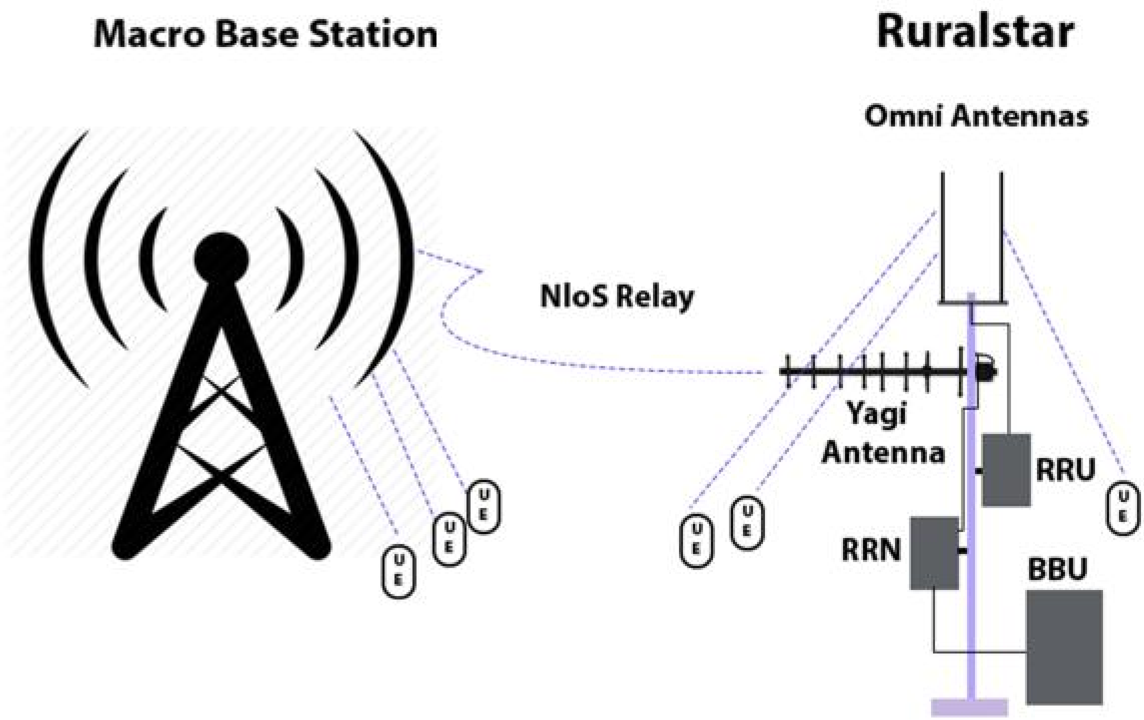

Figure 22 RuralStar functional diagram and hardware.

The RuralStar makes backhaul connectivity with NLoS signals coming from the nearby macro base station using a yagi antenna. The yagi antenna is connected to the relay remote node (RRN), which provides wireless backhaul connectivity, to the next RuralStar site. In this way multi hop network is established with multiple RuralStar sites [2]. The multiple hop network is presented in Figure 23. RuralStar provides network coverage using omnidirectional antenna, installed on top of pole for better coverage. Omni antenna is connected to remote radio unit (RRU) which works as a radio transceiver. RRU is connected to the ground base band unit (BBU) which performs the baseband processing functions.

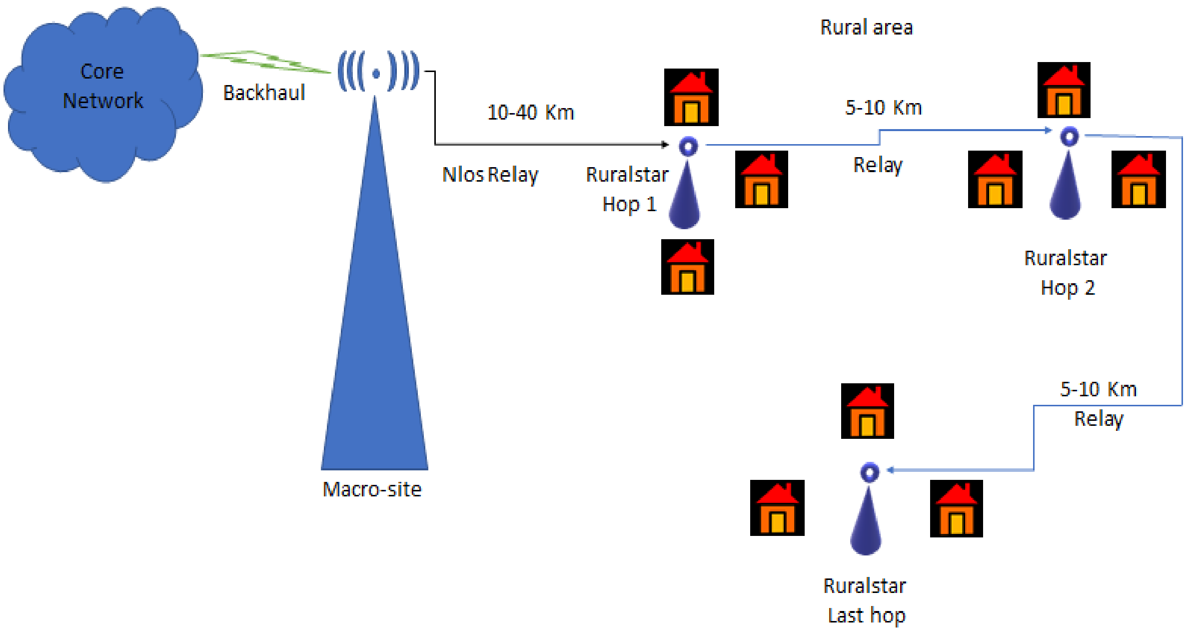

Figure 23 Wireless network solution for a service provider.

In multi hop RuralStar network, backhaul connectivity is done using relay node topologies, by relaying signals from one RuralStar site to other using RRN hardware with a yagi antenna. A single RuralStar site can provide multiple hops with single hop length of 5 to 10 km, under some limitations, like it is limited to relay only 2G and 3G services. This makes the second hop RuralStar site to provide only 2G and 3G services to its users. This makes the Rularstar users unconnected to the available 4G services available by the MNOs.

4.2 A network solution for the end-user

A network solution can be designed from the viewpoint of the end-user. As the rural areas are sparsely populated, it is not a good idea to cover up the whole area, which may cause wastes of investment. Instead of giving coverage to the whole area, it is more efficient to provide the services to limited area where people work and live. The concept is that the services should provide according to usage and maintain a way that it could be extended or can give wireless coverage to the whole area if necessary, in the future. Fixed wireless services for WLAN locations refers the individual connection service. Fixed wireless as discussed in Chapter 3, provides Wi-Fi services to the user residence or office for personal use. HajaKaista is the fixed wireless service already active in Finland [66] and is discussed in detail in Chapter 3.

HajaKaista fixed wireless services overcome all the deployment challenges, to provide network coverage in sparsely populated rural regions of Finland; these are presented below.

Cost and Usage
The hardware cost, deployment cost and service rental are bear by the end user, which makes it a good solution for ISPs in providing network coverage [66]. The deployment is done at user's location which cuts ISPs location-rentals.

Ease of assembly and deployment
A licensed technician from ISP, deploy the HajaKaista hardware and configure service. This takes less time in comparison to the deployment of a base station.

Technology
HajaKaista hardware is compatible with 3G and 4G LTE services offered by MNOs in Finland. HajaKaista fixed wireless services provide 2 to 7 Mbps on 3G network and 5 to 30 Mbps on 4G [66].

Backhaul connectivity
HajaKaista fixed wireless captures 3G/4G network signals and provide Wi-Fi service in indoor location [66]. The architecture does not require expenses for backhaul connectivity because the existing 3G/4G network works as backhaul, this make it cost-effective and easily deployable solution for network coverage.

Power
HajaKaista hardware consumes very little power and is connected to the user resident power supply. Users pay the power charges; this makes ISPs free from making power arrangements and backups, as required in base station deployment.

HajaKaista cannot be deployed at all places in rural areas, as it requires a minimum network signal power for its function. HajaKaista users face slow internet speed due to capacity issues in the connected macro base station. The base station has limited internet bandwidth to be distributed to the connected users; when the users are less, they experience good internet speed. The speed gets degraded with increase in number of users, because of the limited bandwidth. Users connected to the base station through HajaKaista faces same issues because HajaKaista has no additional contribution to the internet bandwidth, these limitations are discussed in next Chapter 5, even though HajaKaista is a good network solution for end user residing in sparsely populated rural areas of Finland.

A wireless network solution for end-user for fixed wireless service in outdoor and indoor location is presented in Figure 24 below.

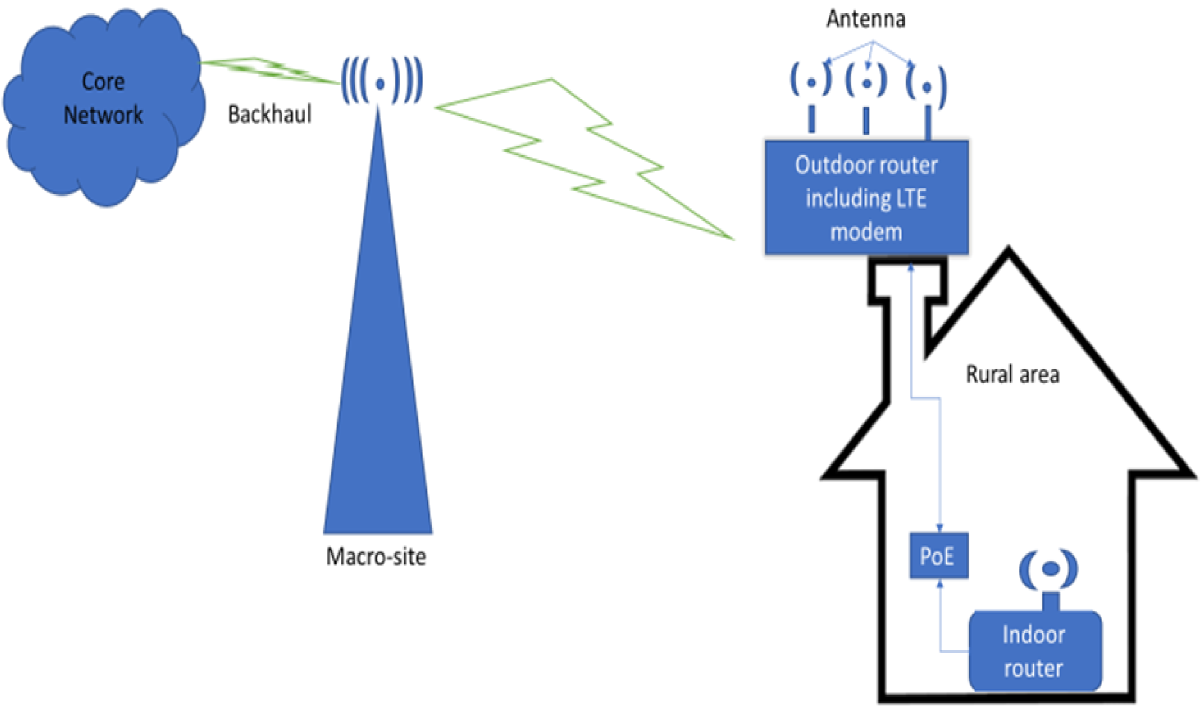

Figure 24 Wireless network solution for end-user.

The network solution has two major elements, an outdoor router, which contains an integrated LTE modem and an indoor router. The outdoor router with its antennas is installed on top of the roof [62]. The outdoor router has two omnidirectional antennas which capture 3G and 4G-LTE signals from the nearest macro base station and a Wi-Fi antenna for outdoor wireless coverage. The indoor router has an indoor Wi-Fi antenna for indoor wireless coverage. The outdoor router is connected to the indoor router with a power over ethernet (PoE) cable [62].

This solution has additional advantage of outdoor Wi-Fi coverage in comparison to HajaKaista. So, in a manner, this can be a complete solution for internet connectivity and its services for rural areas.

5 DISCUSSION

Internet access is an essential need for getting connected, for information, education, and work (see Chapter 1). In rural areas internet access is limited to poor connectivity or no connectivity. In rural areas of Finland, network service provides face many challenges (see Chapter 2), in deploying wireless network services (see Figure 22, Figure 23 and Figure 24). 11% of Finland geographical area is unconnected or has no wireless network coverage; Lapland and Kainuu provinces are the two sparsely populated rural areas of Finland with 69% and 83% coverage (see Table 8). Possible network deployment solutions for rural regions under wireless network classes, including wireless in wide area network, and wireless local area network are presented in Chapter 3. In this thesis two network solutions are presented. Among them one is for service provider and another is for end user. Those solutions can be deployed in sparsely populated rural areas of Finland (see Chapter 4). These network solutions are evaluated below with their limitation and future work approach.

5.1 Evaluation of the proposed solutions and future work

The first network solution is deployment of Huawei's small cell base station. Huawei's RuralStar solution specially builds for rural areas fulfil all rural requirements, and overcome all cost, ease of assembly, technology, backhaul connectivity, and power challenges faced by network operators (see Section 4.1). A single RuralStar site can connect from 60 km to the macro site, and capable of providing multiple hops with single hop length of 5 to 10 km. A RuralStar site is limited to relay only 2G and 3G services to the next RuralStar site. This makes the second hop RuralStar site to provide only 2G and 3G services to its users. Future work is required to make RuralStar site to relay 4G services to multiple hops. This enhancement would provide better data rate and good quality of service to the users under RuralStar coverage. RuralStar is still a good network solution for rural areas, to provide 2G, 3G services or minimum connectivity in location above 60 km from macro site by using multiple hops.

The second network solution is fixed wireless, designed from the viewpoint of the end-user. It provides services according to user demands and usage. HajaKaista provides fixed wireless services in sparsely populated rural areas of Finland. HajaKaista overcomes all cost, ease of assembly, technology, backhaul connectivity, and power challenges faced by network operators (see Section 4.2). HajaKaista provides indoor Wi-Fi internet services by capturing 3G or 4G signals from the macro base station from a distance up to 55 km. HajaKaista claims minimum data rate of 2Mbps. HajaKaista is a good network solution for individual connectivity in sparsely populated rural areas. There are limitations associated with HajaKaista services. A licensed technician conducts initial survey at the user's location to measure network signal strength and compare it with the minimum signal power requirements of HajaKaista equipment. Another limitation is associated with slow internet speed due to capacity issues. HajaKaista connection does not provide capacity enhancements, and the users are experience data rates offered by the macro base stations. Sometimes the capacity of base stations is simply not able to provide a satisfactory connection to all its users. HajaKaista is not able to solve the problem arising from the base stations. Future work is expected to make HajaKaista to connect to multiple macro base station for capacity improvement. And use of high gain antenna with power extenders in deployment of rooftop setup of HajaKaista can be conducted as a part of research to improve minimum signal power requirements.

6 SUMMARY

The thesis provides information about the importance of the internet in today's life. Use of the internet and its advantages, in education, medical, business, social connectivity and other areas are presented in Chapter 1. Majority of people in urban and suburban areas in world has access to the internet, but the scenarios are different for rural and remote areas. 700 million people in rural areas around the world do not have access to internet. The thesis aims to provide solution for wireless coverage in remote and rural areas of the Finland.

Network infrastructure and technology used in urban areas is deployable in remote areas and may require some additional infrastructure at some sparsely populated areas. Network deployment in rural areas faces different challenges, among these the major challenge is ARPU and is discussed in the thesis in Chapter 2, other are cost, easy of assembly, infrastructure, power, backhaul connectivity etc. The thesis elaborated these challenges faced by the network service provider.

Possible wireless network solutions with their classes (WWAN, WMAN and WLAN) are presented in the thesis in Chapter 3. The network solutions presented are small cell base station, super tower under WWAN; WiMAX under WMAN and Wi-Fi, fixed wireless, signal boosting under WLAN. These solutions are analysed in the thesis to overcome the challenges in connecting rural areas for wireless internet access.

For wireless network coverage in rural areas of Finland, small cell cellular base station and fixed wireless outdoor Wi-Fi coverage together with indoor Wi-Fi are proposed as two wireless network solutions. RuralStar small cell cellular site and HajaKaista fixed wireless internet service are presented in Chapter 4 as the two wireless network solution. These network solutions are designed to provide network coverage to a big sparsely populated rural area or internet access to an individual user. The limitations of the two demonstrated solutions are also discussed with scope of future work. Lastly, it can be said that the thesis presented work for understanding the circumstances that explain the necessity of the internet in rural areas and shows ways that can bring rural areas under a network.

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