International Network Generations Roadmap (INGR)

An IEEE 5G and Beyond Technology Roadmap

Connecting the Unconnected

1st Edition White Paper

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International Network Generations Roadmap (INGR)

Chapters:

- Applications and Services
- Edge Automation Platform
- Hardware
- Massive MIMO
- Satellite
- Standardization Building Blocks
- Millimeter Wave and Signal Processing
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- Connecting the Unconnected
- Deployment
- Energy Efficiency
- Systems Optimization

Table of Contents

ABSTRACT

Connecting the Unconnected or under-connected (CTU) is the holy grail of transforming the lives of over 3 billion people around the globe with wireless Internet who are yet to experience its value in multiple ways. If this could be accomplished, its impact on the society would be enormous. This white paper from the IEEE Future Networks CTU Working Group endeavors to highlight the need to consider the CTU requirements in 5G and B5G networks in the standardization process, in the development of the use cases, and affordable solutions. In its Vision 2030 SDG (Sustainability Development Goals) the United Nations has proclaimed access to Internet as basic human right and has said that these goals cannot be achieved without affordable access to Internet by everyone on this planet. While there are numerous projects and initiatives ongoing around the world, but these are fragmented and lack the critical mass and coordination to be able to impact the future standards, product development, and cost of deployment otherwise achievable by volume. It is the goal of the CTU group to create an open platform where the experts can bring their ideas, solutions, and potentially collaborate to create large global projects and influence the network service providers, manufacturers and their governments. This white paper defines the CTU working group's charter, scope, and provides a brief overview of the relevant stakeholders and linkages between them. Then the paper goes into the current status of the CTU landscape and where we want to reach to accomplish the vision of connecting everybody, especially those living in rural and remote areas. We present the various standards and industry fora and how they are interlinked. While technologies are available today, they need to be customized and optimized at the systems level to bring down the cost of network in order to be affordable. In addition, the content needs to be relevant and in local languages to be of useful, not to mention the need to offer innovative human computer interaction (HCI) solutions (that are not text based) so that people who are not literate or digitally disadvantaged can easily use the devices and consume services. Another important area is that of flexible spectrum allocation regime at the lower range of the spectrum to increase reach and coverage. Use of renewable energy sources will enable deployment in remote areas where there is lack of power grid or it is intermittent. Thus, this white paper identifies a number of technology gaps to be filled in 5G and B5G networks, such that access is affordable and content and services are actually consumed by the target set of users. Technology aside, need to develop innovative business models is a must to be commercially sustainable in the long-term. A number of such models, especially designed for the rural population, are proposed, such as Village Level Entrepreneur (VLE) Freemium (Free + Premium), revenue sharing among the chain of service providers, subsidized billing by USOF (Universal Service Obligation Funds). Finally, the white paper presents a 10-year roadmap starting from the current state to 3 years, 5 years and 10 years.

Key words:

Digital Divide, 5G, B5G, CTU, SDG, IEEE Future Networks, Rural and remote connectivity, United Nations, Societal impact of ICT, Network slicing, Spectrum management, content management, Business models, TV white space, Satellite, Community networks, VLE, InfoInternet, Internet Lite, Business models.

"CONNECTING THE UNCONNECTED" WHITE PAPER

1. INTRODUCTION

This initiative is new and innovative in that it addresses a humanitarian need by explicitly architecting future generations of networking to meet the needs of the unconnected and under-connected. The arrival of 5G mobile communications in 2020 is likely to accelerate the digitalization of economies and society; however, it is likely to miss over 3 billion users living in remote and rural areas, broadening the digital divide. The key objective of this working group is to enable everyone in the world to have access to Internet and participate in the Digital Society with technologies and systems level solutions that IEEE Future Networks Initiative (FNI) is driving toward with next generation of wireless technologies. Thus, the initiative's objective is to fine-tune 5G and beyond 5G (B5G) and start positioning 6G with a technical approach for secure, easy-to-use, affordable broadband internet access for digitally disadvantaged users. To meet this objective, the project collaborates with global entities and IEEE Standards Association (SA) to identify system concepts, architectures, standards, and public policies to achieve most of the sustainability goals defined by the United Nations SDG Goals for 2030. The proposal also accompanies a sustainable business model with potential revenue stream for the Initiative. In a nutshell, this Initiative and the work undertaken by this group are new and innovative in that they address a humanitarian need either by architecting future generations of networking or re-architecting the networks with existing technology to meet the needs of everyone in every region of the world.

As such, this WG addresses predominantly the topic of Information and Communication Technologies (ICT) for society in alignment with sustainable development goals (SDGs) defined by the United Nations' SDG Goals for 2030. Strategic focus on addressing parameters such as healthcare, quality education, sports, gender equality, and poverty eradication are crucial. Furthermore, it should be an important aspect of the project to explore unique community specific issues with consideration of stakeholders by employing co-design practices. The United Nation's Sustainable Development Goals (UN SDGs) in the Agenda 2030 [1], are framed to address global challenges including climate change, poverty and inequalities. The wireless technologies play an important role in societies and its linkage to UN SDGs is many-fold. Broadband wireless can significantly contribute to the achievement of the SDGs. The role of wireless/mobile communication to digital empowerment is very powerfully articulated by the United Nations High Level Panel on Digital Cooperation [2]. The panel report, presented in June 2019, addressed a set of recommendations, notable recommendations 1A, 1B and 5B (emphasis ours) [3]:

> *"1A: We recommend that by 2030, every adult should have affordable <u>access to digital networks</u>, as well as digitally-enabled financial and health services, as a means to make a substantial contribution to achieving the SDGs."*

> *"1B: We recommend that a broad, multi-stakeholder alliance, involving the UN, create a platform for sharing <u>digital public goods</u>, engaging talent*

and pooling data sets, in a manner that respects privacy, in areas related to attaining the SDGs."

"5B: We support a multi-stakeholder "systems" approach for cooperation and regulation that is adaptive, agile, inclusive and fit for purpose for the fast-changing digital age."

Addressing the issues of affordable wireless broadband Internet backhaul for rural and remote areas is challenging. Therefore, strategic longitudinal and cross-sectional research techniques will be important with respect to addressing real-world issues of innovative low-cost spectrum regime, useable privacy, cybersecurity, and human-computer interaction (HCI), etc.

This white paper gives a broad summary of what one can expect from the more in depth roadmap effort for this topic. It describes a high-level perspective and projection of the topic's technology status, in particular the challenges and gaps to be explored and reported in the 2020 edition of the IEEE INGR roadmap. The scope and stakeholders are summarized. Any expected linkages among the other INGR roadmap working groups are presented.

1.1. CHARTER

The world is connected through wired as well as wireless networks. In the access networks, wireless and mobile communication is playing a major role, whereas in core networks, the terrestrial and submarine optical fiber cables carry about 99% of the global Internet traffic [4]. Leveraging the existing ICT infrastructure, the 5G and B5G telecommunication networks will connect the unconnected to the Internet through wired-wireless network convergence. Cross-disciplinary research efforts will be required in the areas including mobile networks, photonics, artificial intelligence (AI), security protocols, chip-design, green technology, among others to develop B5G/6G networks. Moreover, future aspects such as quantum ICT should be researched up on to address issues like scalability, technology coexistence, technology migration in future. Innovative business models will be required to be affordable to meet the societal challenges. In short, connecting people, things, and access to broadband Internet is a lot cheaper and faster than building physical infrastructures to meet SDGs and, therefore, digital capacity building and digital access to information are critical to achieving the SDG goals and objectives by 2030. In short, the world is going to be hyper-connected with various networking technologies, and such an interconnected world (of people and things) must serve the societal needs, highlighted in the SDGs, to improve everyone's quality of life.

Thus, making systems human-centric enabled by community level intervention is the vision of this group. United nation's SDG Goals for 2030 explicitly acknowledge the role of ICT in human development. The purpose of the working group is to revisit 5G and B5G technologies to be cost effective for meeting the unique needs of those who have yet to experience the value of the internet, mainly those who are digitally disadvantaged or living in rural and remote areas. The key objectives of the working group are: (i) to increase the visibility of the need to connect the unconnected with affordable access as we usher into the era of 5G, (ii) develop, fine-tune and standardize the various technology components that would result in an open platform to meet global requirements of those still not connected to the Internet, and (iii) collaborate with the industry to help develop solutions for the unconnected in various parts of the world.

1.2. Scope of Working Group Effort

Internet is an important platform for ICT-based interventions in the remote and rural areas of the society. Internet network and services are key foundations for the emergence of digital economy across the world. Digital transactions and access to information will only be possible if there is reliable and safe technological infrastructure. Therefore, achieving universal connectivity is a critical aspect in pursuing sustainable development goals. Nomadic devices, particularly mobile phones represent the most pervasive personalized devices that have the potential to establish interconnections between users and services and among users in their community settings. Public-private cooperation is imperative to be successful, such that the innovations are aligned with local needs at various levels of interactions - institutional, national and international. Determining local needs and involving local people would mean promoting crowd-based technologies and empowerment of vulnerable communities, making systems human-centric with community-level interventions. It is also important to determine the types of applications that these users would like to support on their devices. An architecture will be customized based on the Key Performance Indicators (KPIs) supported by these applications. These KPIs could include bandwidth, latency, system control, system reliability among others. To define a specific architecture, it is important to map the KPIs desired by these applications with the 5G enablers that can provide these types of KPIs. For example, in order to provide low latency applications such as remote surgery, it is important to guarantee high throughput, minimal delay, unacceptable packet loss, to enable edge cloud and New Radio (NR) type access network.

First and foremost, the WG gathers the present state-of-the-art (i.e., a status overview) of the major CTU initiatives) around the globe and their drivers, such as the unique requirements of those regions. From this, we derive an open framework architecture, supported by the standards work that would need to be done, such that they are packaged turn-key solutions capable of being rolled out in different regions of the world. This would give IEEE the scale to be cost-effective and endorse platforms that take away the difficulties of choosing a solution from many different options. This architecture will be micro-service-based and will be adaptable to the requirements of the end-users. Thus, these architectures will be able to create services dynamically and will have the ability to do dynamic service chaining.

More specifically, the technologies of 5G and B5G will form the foundation to meet the overall objective of connecting the unconnected with low cost and usable (i.e., easy to connect and use) broadband wireless networks. Aside from developing an open systems architecture and platform, a tentative list of technical areas of focus are: (i) Least cost wireless front-haul and backhaul through beamforming and Multiple input, multiple output (MIMO) in reframed spectrum, (ii) use of RF spectrum white spaces including the TV bands, in addition to other access technologies, (iii) Trust, security and privacy that meets the capabilities of the user community, (iv) Simplified and intuitive human computer interfaces (HCI), (v) Micro-operator eco-system to encourage local coverage and enablement of the rollout of sustainable services, (vi) Regulatory and policy reforms that would be needed, and (vii) A dedicated 5G network slice for the CTU use case. Last but not the least, some key industry verticals would be selected and use cases developed, such as in healthcare, employment generation, education, agriculture and women empowerment.

1.3. LINKAGES AND STAKEHOLDERS

The economic value created by the mobile ecosystem is $1.1 trillion in 2018, while additional indirect and productivity benefits brought the total contribution of the mobile industry to $3.9 trillion (representing 4.6% of total global GDP) [5]. In addition, there is a strong correlation or linkage between high GDP per capita and mobile telephone penetration (see Figure 7 in the reference) [6].Looking further ahead, 5G alone is forecast to contribute $2.2 trillion to the global economy over the next 15 years. A fundamental role by the governments is imperative for the adoption of national policy measures to encourage long-term heavy investment in 5G and B5G networks. Motivating new business models, breaking down the total cost of ownership of mobile networks and creating new opportunities via assigning spectrum for vertical industries with a focus to improve rural services are the other catalysts. Similar to the current 3GPP collaboration, Figure 1 shows an example of the potential organizations to collaborate with to meet the objectives of this white paper.

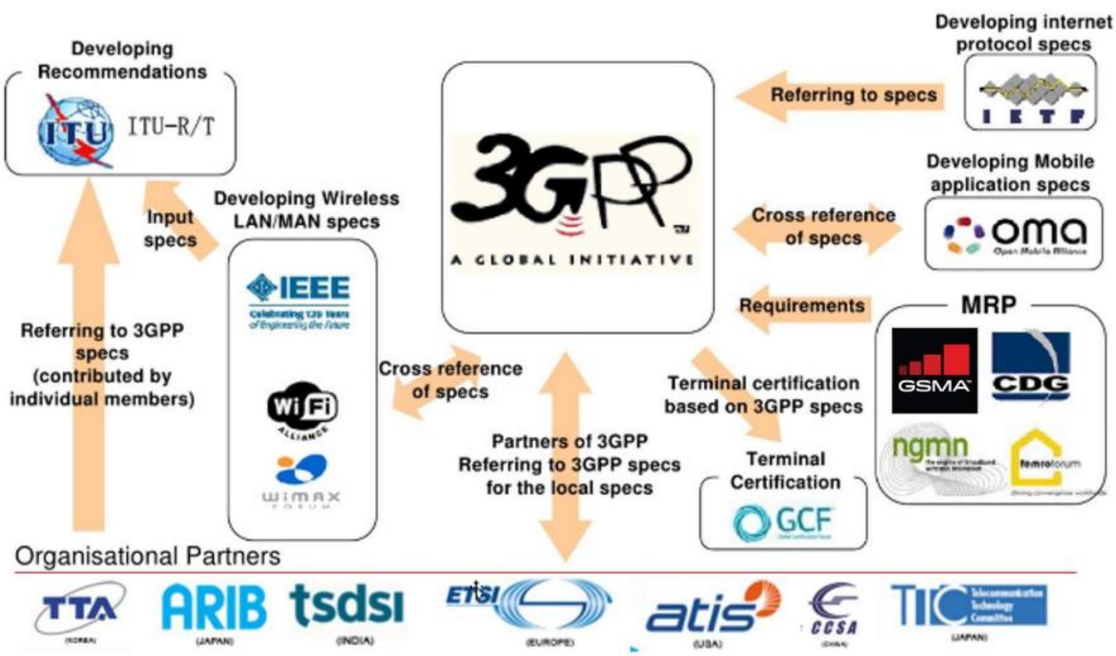

Figure 1. Types of organizations to collaborate with to create critical mass and consensus outcome [7].

In an inter-dependent world where diverse partners and stakeholders play an important role, it is important that we identify those relationships and dependencies to achieve the goals of the CTU WG. These are: governments who drive the policies and strategies to encourage deployment and adaptation of Internet access; various social and international organizations, such as the United Nations, GSMA, ITU, World Bank, European Commission, USAID, various Foundations, such as the Basic Internet Foundation [8]; standards organizations, such as the IEEE, ITU, ETSI, and national SDOs; manufacturers who develop the products and solutions; service providers who roll-out applications and content; users; and various industries who want to increase their revenues from those living in rural and remote communities. Another key driver is the recognition that the increase in Internet adoption increases economic activity and thus positively impacts the national GDP (see Figure 2 below) [9].

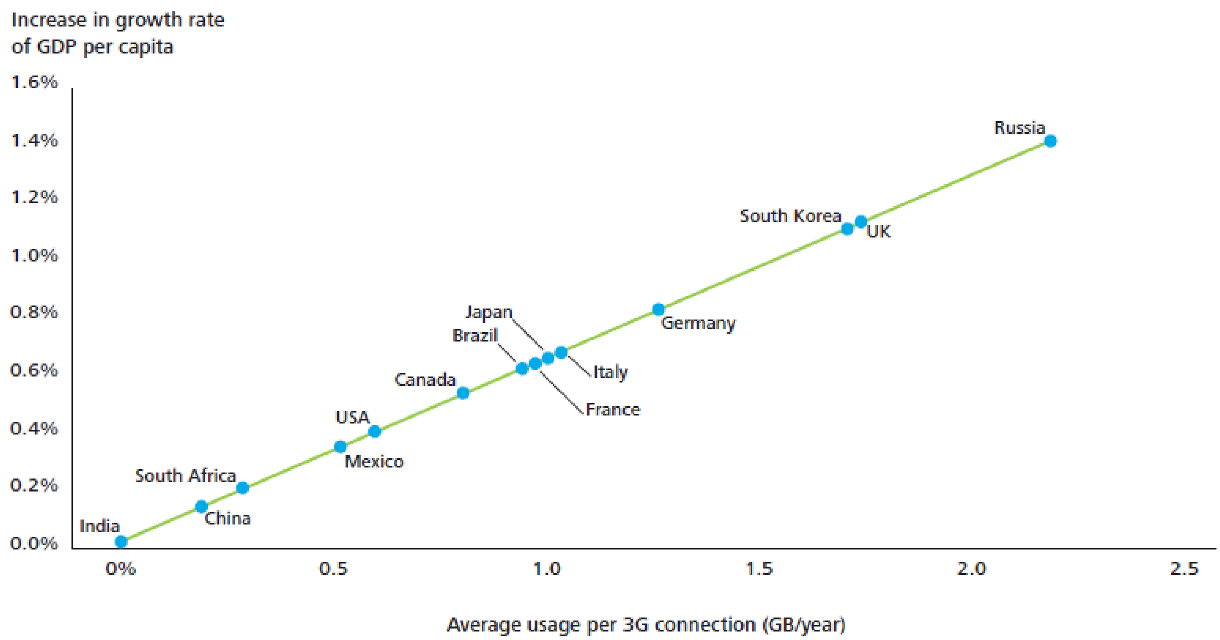

Figure 2. Effect of doubling data usage per 3G connection on GDP per capita growth.

There are some interdependencies and overlap among the working groups within the Future Network Roadmap working groups. The INGR WGs with which the CTU WG would be collaborating with are: Applications and services, Deployment, Massive MIMO, Edge Automation Platform, Satellite, Security, Standardization building blocks, System optimization and Testbed. Specific requirements of the CTU WG will be shared with the above WGs and their recommendations will be incorporated in the future releases of the white paper.

It is anticipated that in the future, the CTU WG will have close working relationships and MoUs with the ITU, 3GPP (and its associated SDOs), GSMA, WWRF, DSA (Dynamic Spectrum Alliance), and 5G Americas.

The enabling technologies that would play a major role in the CTU work are: Microwave, HAPS (high altitude platform systems), Balloons, Satellite Technology (Non-Terrestrial Networks), Fiber optic Technology, NLOS (non-line-of–site) backhaul, cognitive radio, DSA (Dynamic Spectrum

Access), cloud computing and virtualization, and renewable energy sources. For the vision of connecting the unconnected and bridging the digital divide, the governments, and the concerned regulatory bodies will need to play an active role in setting the policies in areas such as spectrum allocation, licensing (embracing technology neutral licensing frameworks), Universal Service Obligation Fund (USOF), rights of way, tariffs and to encourage mobile operators and ISPs to engage with the rural infrastructure and the local micro-operators and entrepreneurs.

2. CURRENT STATE

Accordingly, with the current technologies, there almost exist everything available to make CTU happen today; but, since these technologies are optimized for the high-end applications, such as fast mobility, high user density, multi-media AV applications, and loads of bandwidths to users, they are either an overkill or too expensive for rural and remote users. Contrary to the prevailing views, virtualization, cloud and edge technologies can deliver significant cost savings while improving the Quality of Service (QoS) by way of reducing capital expenditure (CAPEX) and operational expenditure (OPEX). It would seem that mmWave part of the spectrum is not the right approach for rural connectivity while lower bands of the spectrum are suitable for connecting the villages as this can cover a large distance over a sparsely populated area. On the business front, an aggressive freemium model, with a long-tail of profitability, would be a lot preferable approach to encourage the users to experience what Internet can do for them and what value it adds to their daily lives and businesses. Over the time, most Internet users would migrate toward full paying subscribers. Universal Service Obligation Fund (USOF) should play an important role to subsidize the local operators and methods developed to virally spread the adoption of internet access by the majority of the population.

Some of the most significant challenges that exist today are lack of digital knowledge, fear of technology, changing the *status quo* in the village communities, trust, lack of information about Electromagnetic Field (EMF) and health, ease of user authentication and secured access (single sign-on), ease of use in terms of HCI (i.e, need to increase use of speech, video and gestures), affordability of smart devices (smartphones, tablets), and lack of content is local languages. These and other challenges are described in detail in [4][10]. In some countries, rugged landscapes make it difficult for the deployment of technologies that require physical infrastructure. More so, modalities such as acquisition procedures for lease of buildings to host antennas and availability of spectrum also pose a major challenge. From the business perspective, most rural communities do not have the purchasing capacity to enable tech companies to achieve a return on investment. This makes them reluctant to invest in rural communities.

Although there are numerous worldwide initiatives on CTU, but due to lack of coordination and consensus, standards are missing and there is not a consensus on a few deployment models and platforms. This is resulting in lack of critical mass to drive the standards to develop low cost network architectures and business models. This is one critical mission of the CTU WG to bring all the CTU actors on a single platform to discuss, promote, standardize, and develop a few dominant solutions for different use case scenarios to bring about a massive impact on those still not benefitting from the available web-based digital knowledge. One enabling area that is most dominant is the allocation of spectrum for rural connectivity. Some others are low-cost beamforming, intelligent reflective passive surfaces as repeaters, and MIMO antennas that would work in NLOS scenarios. These would bring down the cost of backhaul to reach remote villages.

To achieve the goal of CTU, the expertise needed is in many *different areas but these need to be driven with the passion to bring down cost with newer technologies* and build solutions that are scalable from tens of users to thousands of users. To better understand the local needs and requirements, it is essential to include experts from the developing world where the Internet penetration is still very low. From a technical and business perspective, it is important to involve academic and industry professionals on a single discussion platform, such as the CTU in the IEEE FNI, to discuss and deliberate, and they all should be implementation driven.

The 5G upgrade ensures that mobile products continue to remain relevant to consumers, enterprises, governments, and society in general. The current state of 5G network is boosting three key capabilities: Enhanced Mobile Broadband, Ultra Reliable Low Latency, and Massive IoT, promoting services and products for urban areas. Thus, the WRC-19 has harmonized the spectrum for mobile services within the 26 GHz, 40 GHz, and 66 GHz bands and made it possible for countries to start assigning spectrum within the 50 GHz range for 5G. To bring the 5G benefits to rural areas, the mobile industry is supporting efforts to identify more spectrum below 1 GHz at WRC-23. Low-frequency spectrum is the ideal spectrum to use for improving coverage and boosting signal range. Additionally, WRC-23 will look at mid-frequency spectrum in the 3 GHz range (from 3.3-4.2 GHz), as increasing the amount of globally harmonized spectrum within this range would help boost the 5G network performance and bring down deployment costs. There are a relatively small number of trials in frequencies below 3GHz, but a large number in the mid-level bands at the 3-6 GHz range and also in the higher bands from 6 to 35 GHz. At present, there are also a few tests happening in unconfirmed bands as per GSMA Intelligence, Sept 2018 [11]. In April 2020, the FCC opened up 1200 MHz spectrum in the 6 GHz band (5.925–7.125 GHz) for Wi-Fi and other unlicensed use cases [12]. It is envisioned that this additional spectrum will also help improve rural connectivity.

The new 5G core network is a Service-Based Architecture that mostly resides in the cloud and is a virtualization-based platform that can coordinate a diverse range of networking technologies, allowing very flexible development of new services, as components can be connected without the need for specific new interfaces. Additionally, it allows for the decomposition of functions and the separation of signaling and data. It is a hugely flexible and powerful approach for CTU as well.

The current state of mobile networks introduces challenges, such as the investment cycle of mobile technology which lasts approximately 20 years and as the next generation technology is generally developed and introduced at around 10 years. 4G is in the last stage of deployment in the developing countries where most of the uncovered rural areas are located delaying the 5G and B5G deployment. Another delay for 5G and B5G deployment is the wide use of legacy 2G and 3G mobile networking technologies which use low frequencies because of the improved coverage and the low-cost of terminals. Both these characteristics are attractive for rural areas. As the spectrum is scarce mainly in low frequencies, rationalizing the 2G/3G spectrum to newer technologies, such as 4G and 5G, is desirable for the public good and to switch to the technologies that make the best use of it for CTU.

The Table below compiles a list of organizations active in bridging the digital divide, what they are doing and what their objectives are**. Note:** In future releases of this document, this table will continue to be updated with new information. This table is only qualitative at present and more quantitative and detailed information will be collected in the future.

Organizations	Activities	Targets/Locations
USOF (Universal Service Obligation Fund)	Many countries around the world have taken the initiative to ensure that communication as a universal right is accessible to its entire population; the Fund was established to facilitate access to communication services. While it is the responsibility of private entities to provide communication services, the Government came to realize that not all areas in the country could be economically viable for provision of communication services, the Fund came to existence to ensure that even those areas which are economically unviable have access to communication services (ICT, Postal and Broadcasting)	Adopted by the countries of Australia, Chile, India, Pakistan, Taiwan, Tanzania, among others.
UNICEF (Project Connect)	Project Connect started out of a need that was expressed by many UNICEF partners and UNICEF Country Offices, which was the need to know where schools are and how connected they are to inform programs around education, health and emergencies	Schools (Africa)
Internet Society	The Internet Society is a global cause-driven organization governed by a diverse Board of Trustees that is dedicated to ensuring that the Internet stays open, transparent and defined by all for all	Global
International Telecommunication Union (ITU)	Digital Transformation Centers (DTCs) https://academy.itu.int/main-activities/digital-transformation-centres-initiative - Project GIGA connecting schools - https://news.itu.int/mapping-schools-worldwide-to-bring-internet-connectivity-the-giga-initiative-gets-going/ - ITU-D Study Group SG1 - https://www.itu.int/ITU-D/study_groups/SGP_2006-2010/SG1/SG1-index.html - ITU-D Study Group SG2 - https://www.itu.int/ITU-D/study_groups/SGP_2006-2010/SG2/SG2-index.html	Global
United Nations	17 Goals, 169 targets, 244 indicators (232 individual indicators)	Global
GSMA	Focus on digital technologies to reduce inequalities around the world, https://www.gsma.com/mobilefordevelopment/.	Global
Linux4Africa: Bridging the Digital Divide	Linux4Africa bridges the digital divide between the North and South. Schools in Africa are provided with computers and open source software. Modern communication technologies create opportunities for social and economic development. https://en.reset.org/project/linux4africa	Africa with a focus on Tanzania and Mozambique
Basic Internet Foundation	Internet Lite for Freemium Access, School/Community connectivity, Digital Health, Sustainable Business for Connectivity to Digital Public Goods - https://docs.google.com/document/d/1wm5YE_XLQfJsi_aJUpPoIsRwc7k5GVl4vv_c_pUSbfw/edit?usp=sharing ; http://BasicInternet.org https://basicinternet.org/internet-lite-to-the-migoli-high-school/ https://migoli.yeboo.com/health_information_dashboard.php	Global
Arusha Women School of Internet Governance	Arusha Women School of Internet Governance (AruWSIG) is a premier program whose overarching aim is to mentor girls and women in Arusha (Tanzania) and its environs, through professional digital rights outreach symposiums and hackathons on the topic of Internet Governance	Women (Tanzania)
Habari Node	Habari Node Public Limited Company (Habari Node PLC) is an Internet Service Provider with its head office in Arusha, Tanzania providing standard Internet services and a range of other ICT based business solutions. Habari Node was jointly founded in 2010 by Afam (T) Limited and Arusha Node Marie to take over the Internet service activities of Arusha Node Marie, a society that has been operational since 1994.	Internet service provider (Tanzania)

C-DOT (Centre for Development of Telematics) India	C-DOT is an autonomous telecom R&D center of DoT, Govt. of India which is at the forefront of revolution in rural India. C-DOT has indigenously designed and developed Solar Wi-Fi, Long Range Wi-Fi, Public Data Office (PDO), C-Sat-fi (C-DOT Satellite Wi-Fi), Gyansetu etc. Solution for efficient and affordable rural broadband by utilizing BharatNet (NOFN) infrastructure in the country. www.cdot.in	Sustainable and affordable rural broadband in India
Caribbean Regional Communications Infrastructure Program (CARCIP)	The Project Development Objective is to increase access to regional broadband networks (rural and urban areas), and advance the development of an Information Technology (IT)/IT Enabled Service (ITES) industry in Nicaragua and the Caribbean Region. https://projects.worldbank.org/en/projects-operations/procurement-detail/OP00067970	Nicaragua
Google Loon Project https://loon.com/technology	Billions of people around the world are still without internet access. Loon is a network of balloons traveling on the edge of space, delivering connectivity to people in unserved and underserved communities around the world.	Rural locations around the world
Facebook Connectivity Project https://connectivity.fb.com/	Overcoming the global internet connectivity challenges of accessibility, affordability, and relevance requires a multi-faceted approach.	Rural and Urban connectivity

2.1. Connecting the Unconnected Population using Television White Space and Community Networks

Internet Access

A study from Research ICT Africa (RIA) reported that 86% of Tanzanian rural dwellers have no access to Internet services compared to 44.6% in urban areas (Research ICT Africa, 2017). Also, RIA reported that when Internet access is compared between men and women, significantly fewer women have access to and use of the Internet compared to men. Furthermore, RIA published a comparative report that indicated that Mozambique and Tanzania have the lowest household Internet use of 1% as well as Uganda which has only 2% among the 10 African countries involved in their study (Alison & Mothobi, 2019). This indicates that more effort is required to bring Internet to the remaining unconnected population. To address the issue of Internet access and gender gap in Tanzania, an investigation on affordable and reliable Internet access solution to connect the unconnected population in rural area was conducted. The investigation employed different approaches in order to address these twin issues of lack of Internet access and gender gap in Tanzania. These approaches included: (i) use of Ultra-High Frequency (UHF) spectrum band for wireless broadband communication in rural Tanzania, and (ii) use of bottom up approach to bring Internet connectivity in a rural area. The latter approach is commonly known as community network (CN) approach whereby community members are empowered to own and operate the installed network infrastructure in their locality. Based on the above investigation, it could be deduced that these twin approaches are applicable in other regions of the world as well.

TV White Space and Community Networks

In the literature, television white space is defined as the licensed but unused spectrum allocated for the primary user. It is generally observed that UHF spectrum is currently under-utilized due to the use of static spectrum allocation and also because most of the digital terrestrial television industry does not see value in investing in these areas because of the lack of business outcome. For example, in Tanzania, digital terrestrial television uses UHF spectrum band ranging from 470 MHz to 694 MHz after a successful migration from analog to digital terrestrial television. The University of Dodoma engaged its staff to conduct studies on how television white space technology can be used to address the Internet connectivity challenge facing most of rural and underserved areas in Tanzania. The researcher designed and implemented a television white space testbed network in Kondoa and it was able to connect three educational institutions in Kondoa, namely Kondoa Girls High School, Ula Secondary School, and Bustani Teachers College. Similarly, in India, television is mostly delivered over satellite using DBS technology and similar is the case in Latin America and other regions in Asia. This trend has left the television broadcast spectrum mostly unused or under-utilized, which could be put to good use for Internet connectivity in rural areas.

Community network approach is defined as a bottom-up approach that brings together local community members to establish wireless networks that address Internet connectivity challenges in a specific community.

Community Network Approach

Community network approach is defined as a bottom-up approach that brings together local community members to establish wireless networks that address Internet connectivity challenges in a specific community. This brings down the CAPEX and OPEX of the Internet access, while also ensuring that the infrastructure is not vandalized. For example, Kondoa Community Network (KCN) in Tanzania is the first community network to pilot the use of Television White Space (TVWS) in a rural area to address the issue of Internet access and gender gap in Tanzania. KCN was designed to bring together various stakeholders operating in Kondoa to design, operate, and support the installed network infrastructure. Members of the Kondoa Community Network are responsible in deciding the price of Internet access and hence create business viability in rural area. In its first phase, community members agreed to deploy network infrastructure that connected three public education institutions as described earlier and in its second phase one more private education institution offering ICT training in Kondoa was connected. Thus, four educational institutions are connected to high-speed Internet access in Kondoa. KCN has steering committee members representing stakeholders from government, political leaders, religious leaders, education institutions, private sector and community-based organization such as KIWAJAKO. The participation of all of these players was deemed important to have a sense of ownership of the project and to ensure its future sustainability.

Figures 3 and 4 show the Internet speed that was achieved in various education institutions in Kondoa. KCN subscribed for the 4 Mbps dedicated link from Halotel as its backhauling solution provider costing a monthly fee amounting to TZS 1,689,854.4 (about USD 730) for bandwidth and TZS 706,820 (about USD 305) for co-location fee.

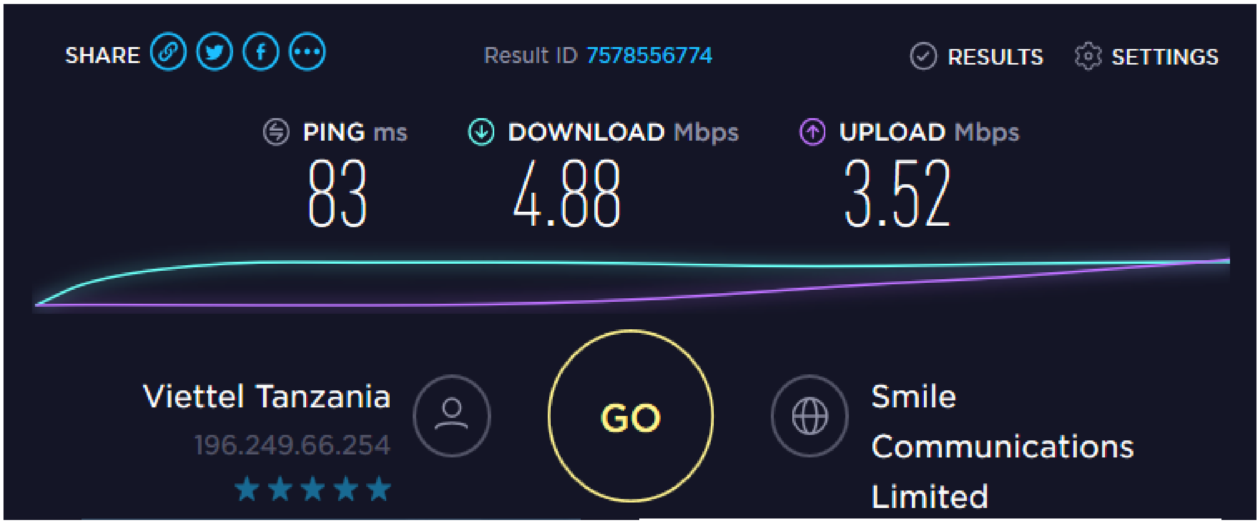

Figure 3. Internet Speed achieved at Bustani Teacher's College

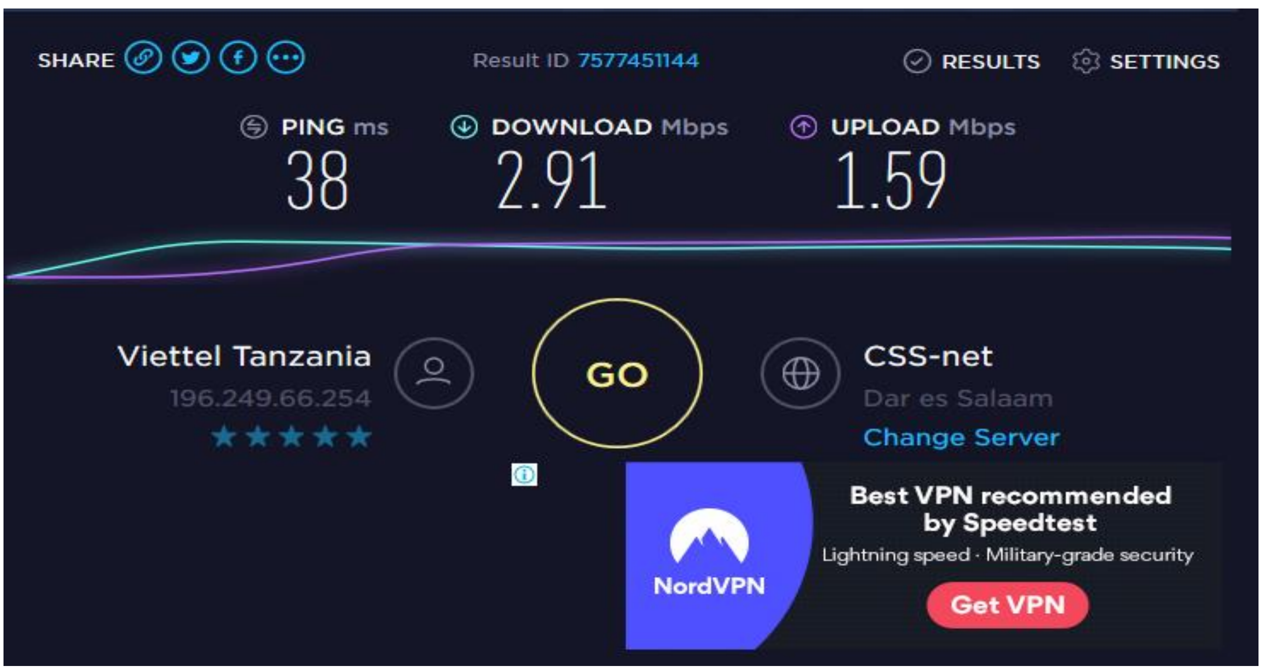

Figure 4. Internet Speed achieved at Ula Secondary School

Similarly, in Latin America, community networking is receiving a lot attention as an option to increase Internet connectivity to bridge the digital divide [13]. Some examples of this are: the Coolab, a Brazilian cooperative laboratory that aims to promote and fund such autonomous initiatives [14], and AlterMundi based in Argentina, an NGO, is supporting Wi-Fi networks in five villages in rural Córdoba.

3. Future State

The COVID-19 pandemic has changed everything we envisioned as normal and forced us to find the new meaning to everything for the first time and to see what a big part Internet has played during this crisis, such as the whole world is discussing online education for their people or parents signing their children up for online classes. With the service providers over pricing the Internet bundles due to high demand and lack of access in rural areas the challenges seem daunting. It is the foregone conclusion that the rural communities need Internet and it is not too late to change the narratives of rural communities and access. It is also imperative that this access be provided by mobile/wireless than by fixed access as also articulated by the FCC [15]. In addition, many developing countries badly need policy reforms keeping in mind such things as high taxation imposed on equipment, high cost of permit acquisition to establish the info spots. Support from the government as a major stakeholder is still minimal in making sure that the community sees value in this with safety and security of its people being a high priority. The local communities being able to create their own content is a dream come true for many but until that becomes a reality within the next 5-10 years, we will have to focus intensively on building digital capacity so that its availability/access is no longer an issue when technology does become available.

It is the vision of the CTU initiative to create a world where everyone on this planet has access to Internet at least for consuming basic services and providing gateway to other services, similar to having access to clean air, clean water, electricity and affordable healthcare. This access should be affordable and serve a user's daily needs in the local environment. By 2030, we envision to develop an affordable hierarchical network architecture which leverages the concept of edge clouds and fog computing such that most of the services and content is delivered from where the user community lives. This network will also enable other features such as programmability and scalability among others to dynamically adapt to the needs of the end users. We also envision that the users would play a dominant role to crowd source their content to the edge servers in their local languages and they themselves will curate it for its authenticity while meeting local cultural norms. In addition, they could potentially become players in the emerging global e-commerce and improve their quality of life with additional income. In short, the vision is to develop a network architecture and platform that is supported by the standards, is open and enables empowerment of the local community. It is only then that the solution would scale and virally spread on its own, thus minimizing the cost of network infrastructure and its operations for it to be truly affordable by everyone on this planet.

Providing free access to Digital Public Goods, as suggested by the United Nations' High-Level Panel on Digital Cooperation (https://www.un.org/en/digital-cooperation-panel/), is an economic challenge, as Internet access is costly in rural areas. One project "Non-discriminating access for Digital Inclusion" (DigI.BasicInternet.no) addresses this challenge head-on, and was established as part of the Vision2030 strategy of the Government of Norway at the Basic Internet Foundation (www.basicinternet.org) to address the provision of health information in rural areas. The DigI project, as well as all community networks, was faced with the enormous costs of Internet access, e.g. a provision of 4 Mbit/s Internet connection would cost USD 600 per month in rural Tanzania. Given that video takes 1-2 Mbit/s, such connectivity could provide 2-3 simultaneous video streams or other broadband services. As a result, providing broadband services of Digital Public Goods (DPGs) in a traditional, cloud based model is economically nonviable. The suggestion is to split the architecture and the access of DPGs into two parts [16]*:* (i) **Lite Bandwidth**: Content being text and pictures (L-DPG), and (ii) **Heavy Bandwidth**: Content being videos and streaming services (H-DPG). Separating *lite* and *heavy* content of the DPGs is a fundamentally new approach, which answers the demand for a cost-effective access to the DPGs. As L-DPGs only take 2-3% of the available bandwidth, they can use the Internet, and H-DPGs are stored on a local server, the DPGs can be delivered free of charge. Everything else is delivered as a premium service in the present day data plans. This Freemium (Free + premium) model is conceived to ensure that the Internet access service is commercially viable.

Lite parts of DPGs can easily be provided through a mobile network, even on thin 3G mobile links, as only basic information such as text and pictures are communicated. *Heavy* parts of DPGS are provided through a local representation at information spots, as indicated in Figure 5.

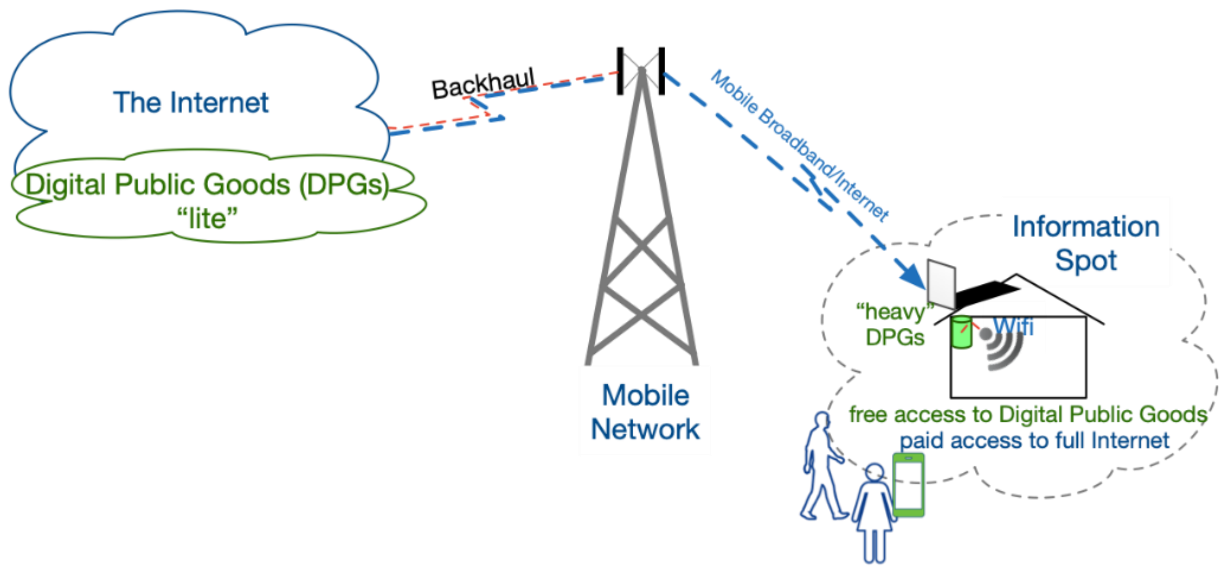

Figure 5. Architectural Model for free access to Digital Public Goods (DPG).

The result of such a separation of lite and heavy content would result in a cost-effective model for access to DPGs and any other educational content. The architecture will allow end-users a free access to DPGs, with minimum costs for public authorities. A typical wireless deployment in a village is shown in Figure 3, which costs less than USD 300 to deploy. This architecture has already been tested as part of the Digital Inclusion (DigI) project, running from 2017 – 2020. Information and Internet access has been proved using this model in Tanzania, Kenya, Ethiopia and Mali. The pilots have shown multiple success stories in: *(i)* Starting local businesses around InfoInternet, *(ii)* Self-sustainable ICT and communication infrastructure for digital inclusion, *(iii)* Access to health-related information to help control diseases, and *(iv)* Increase in the number of Internet users joining the world of digital information.

The DigI project built Information Hot Spots with the following main objectives: *(i)* Bridging the digital divide by providing non-discriminating access through the InfoInternet infrastructure (Figure 6), *(ii)* Provision of customized content for education and health purposes, thus creating the basis for jobs, as well as financial and social inclusion, *(iii)* A cost-effective, open and scalable Wi-Fi extension of the mobile network for the low-income group, enabling (mobile) operators to provide digital services, and *(iv)* Education, health and entrepreneurship for women and youth empowerment as representatives of the vulnerable society groups. DigI has created a locally-deployed infrastructure, compute, and economic solution using user authentication, pre-paid voucher-based payment system and community involvement. Local content is cached from the servers in the village to improve the quality of service and minimize backhaul access. This hybrid model ensures sustainability of the internet service [17].

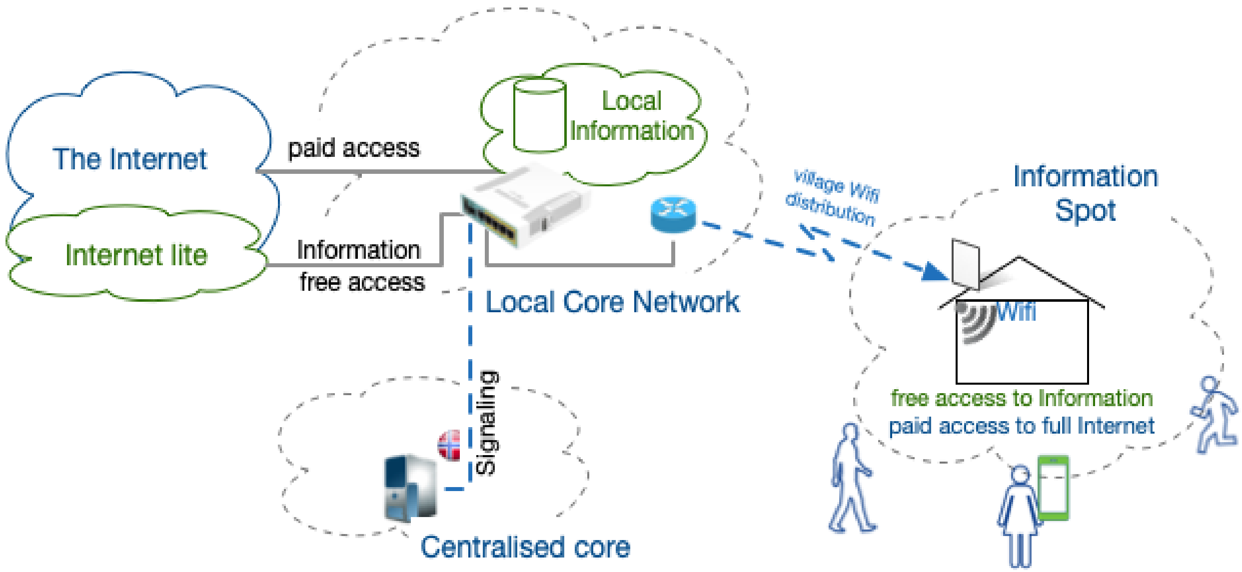

Figure 6: InfoInternet deployment in rural areas.

Figure 7 illustrates how villages could be connected by a distributed architecture where local servers serve several villages and are not solely dependent on the backhaul connectivity.

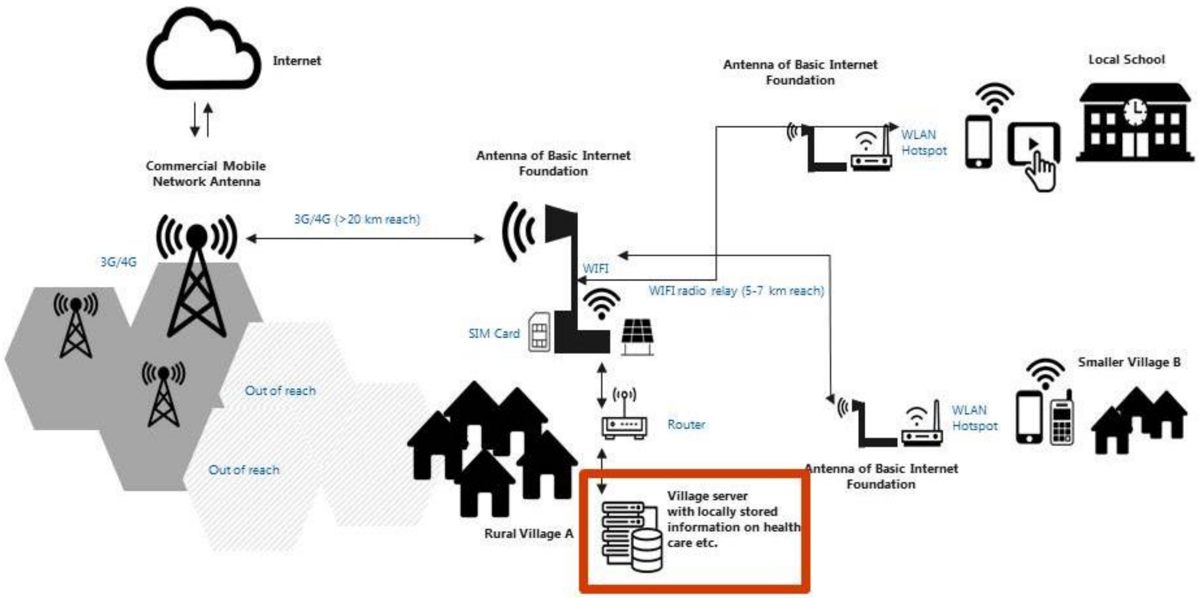

Figure 7. An architectural model for distributed deployment of Internet access.

To achieve the CTU objectives, it is imperative that countries of the world adopt a unified approach towards technology. One of the most important resources needed to drive technology is spectrum availability. Efforts have been made by the ITU to achieve this by ensuring that all countries use the same spectrum bands for the same applications. By doing this, equipment manufactures will develop devices that can be used anywhere around the globe thus achieving economies of scale. Most regions of the world have identified similar spectrum bands for the deployment of 5G. This will make it easier for 5G technologies to become affordable due to economies of scale. Spectrum sharing is increasingly being appreciated and could be an enabler to CTU by 2030. Technologies such as Dynamic Spectrum Access will be deployed in rural areas to utilize the unutilized spectrum in the V/UHF band (Digital Terrestrial TV band) which is suitable for rural mobile broadband. On the business side, there is a need to innovate novel business models, such as the Freemium model to allow free + paid components of the data plans, community shared model, micro-finance with guaranteed return-on-investment, among others. Such a Freemium model is akin to people being able to walk free on the roadways and streets, where people can also walk on the Internet for free for basic content and services.

4. Requirements and Technology Gaps

It may be observed that certain specific traits characterize the rural areas, especially in developing countries. Some of the traits, though by no means exhaustive, are as follows:

- Low population density
- Sparse and clustered settlements
- Comparatively lower income levels

- Remote and difficult to access regions
- Inadequate grid-based power supply
- Price-benefit comparison with urban/suburban areas

One or more of these traits are likely to be present in almost all rural regions in developing countries and therefore any solution to rural connectivity should take these factors into account. Some of the consequences of these characteristics are as follows:

- Cost effectiveness of the network is an important requirement and both CAPEX and OPEX should satisfy this.

  i. From the perspective of cost effectiveness, softwarization of network elements and functions may be an important architectural need. The proposed architecture should allow selection and usage of those technologies, which enable greater softwarization of networks. This implies increased use of cloud, virtualization and service delivery from the edge
  ii. Technologies which are inherently simpler may be more cost effective. For example, Wi-Fi technologies with simpler authentication and access control mechanisms may be a more cost-effective option than the full-fledged 3GPP 5G network and hence it should be possible to integrate such options in the architectural framework. Other possibilities include trading fixed cost, e.g., subscriptions, to variable costs, such as pay per use of data rates and/or services This may help with the utilization based on disposable financial resources and levels of business services for market creation
  iii. Usage of content caching solutions through cheap commercial off-the-shelf (COTS) platforms may reduce the need for expensive backhaul in some scenarios and it should be possible to use them wherever necessary
  iv. The architecture should also emphasize reuse. Reuse of existing elements, like towers, buildings, backhauls, servers, which may have been installed for other purposes may be quite helpful in this regard.

- Protocols and architectures with inherent flexibility, allowing for a tradeoff between different parameters, e.g., between QoS and "affordability" (e.g., GAIA Project - https://irtf.org/gaia, IRTF) may also help and support some of the above-mentioned requirements
- To reduce the cost further, the architecture may also support innovative solutions such as direct Internet connectivity from the access network without involving the Mobile Core, such as utilizing satellites for backhaul
- The architecture should be such that it supports easy maintainability. Such architectures would reduce the expense of the operation and be useful in remote and difficult to access regions.

Next, we describe the key requirements and technology gaps.

4.1. Cost-optimized network architecture and open platform for services and development

One of the major impediments towards providing internet connectivity in rural areas is the lack of robust and affordable backhaul.

Backhaul

There are three types of scenarios in rural areas with respect to the availability of the backhaul**.**

i. ***Fiber backhaul:*** In this case, either fiber backhaul is available in each village or it is only available in one of the villages in an area (a cluster of villages).
ii. ***Microwave or other wireless terrestrial backhauls:*** Technologies of microwave, long-range WLAN or free space optics (FSO) are some of the possibilities.
iii. ***Satellite backhaul:*** If laying fiber is not possible due to difficult terrain and geography, only possible option is satellite based backhaul.

In order to provide broadband connectivity to people living in rural areas in India, Government of India is laying out optical fiber cables across the country connecting the village offices (also called the Gram Panchayats (GPs) in India). This is being undertaken as part of the project “BharatNet” by the Government. Rural India has about 250,000 GPs. Each GP serves roughly about 2.56 villages on an average, thus totaling approximately 640,000 villages. Typically, a cluster of 5-6 villages has one GP. There are around 40 to 50k villages without voice as primary service. Further, every village may deploy a wireless cluster based on the Wi-Fi technology to provide cost effective broadband connectivity to people living there. However, the connectivity from the GP to the nearby villages needs to be established so that the wireless cluster inside these villages may be connected to the nearest Village Office. In general, other nearby villages are typically located within 2 to 10 km radius of the Village Office, where the fiber Point of Presence (PoP) is expected to be available. As of today, more than 100 thousand Village Offices (GPs) (~138,000) are connected with fiber under BharatNet Phase 1 Program and plans are afoot to connect the remaining Village Offices (GPs) in BharatNet Phase 2 Program. There are around 6,000 locations which can only be served with satellite backhaul.

Middle-mile network

Often, a wireless middle mile network is required to bridge the access network in the village with fiber backhaul in a nearby main location. There are mainly two middle-mile technologies used for middle mile connectivity.

i. ***Long Range Wi-Fi:*** Wireless microwave links are created in the range of 2 to 10 km (this requires line of sight) using IEEE 802.11n or ac technology in 5.8 GHz unlicensed band. Link capacity of up to 400 Mbps can be achieved with such long-range links. Since Wi-Fi is used for access technology in the village, single multi radio hardware platform with suitable antennas can act as a hotspot as well as backhaul. Both point-to-point and multi-point configurations are possible as per the geography of the village to be connected. The system can work on solar power. The CAPEX and OPEX are low.

ii. ***TV White space (TVWS):*** TVWS works in sub 1 GHz frequency band of 470 to 698 MHz. This band is licensed in many countries and is used for TV broadcasting. This band is also made unlicensed for rural broadband in multiple countries. The link capacity is low (56 Mbps in FDD and 28 Mbps in TDD) with IEEE 802.22 technology. Multiple channels can be aggregated to enhance the capacity. The link can work in non-line-of-sight scenario and can provide very good range. One of the projects, undertaken at Indian Institute of Technology (IIT) Bombay, Mumbai, India on how to enable broadband connectivity in rural areas, explored the feasibility of deploying a wireless backhaul (middle-mile network) from these Village Offices to the nearby villages so that the Wi-Fi cluster in each village could be connected to the Fiber PoP at the nearest Village office. The study at IIT Bombay discovered that a significantly large portion of UHF band (TV whitespaces) is available in India as compared to the developed world [18] and could be used to provide the backhaul (middle-mile network) connectivity between the GP and the village Wi-Fi clusters. TV whitespaces are further beneficial to use due to the excellent propagation characteristics of the TV UHF band. The study also suggested that different radio access technologies, such IEEE 802.22, IEEE 802.11 and LTE-Advanced can be used to support the wireless middle-mile [18,19,20], which could utilize point to multipoint links or wireless mesh network architecture.

Redundancy in the middle mile is a major requirement of the architecture.

In case of backhaul as fiber and access as Wi-Fi, the middle mile technology is very crucial in the complete architecture as it will limit the total internet speed/capacity which can be made available to the village. The requirement varies from country to country depending on the definition of minimum broadband speed. In case of India, 2 Mbps is the recommended broadband speed. Number of total users, simultaneous users, contention ratio in the village along with minimum broadband speed defines total end-to-end speed/capacity required. An example connectivity architecture that includes access, mid-mile, and backhaul is shown in Figure 8.

Access Technology in the village to provide Internet to the people in the area:

To provide affordable broadband in the rural area/village, Wi-Fi is the most suitable access technology. User devices (e.g., mobile, tablet, laptop, desktop) come with Wi-Fi radio support. It is very easy to create Wi-Fi hotspot. The CAPEX and OPEX are very low due to its operation in an unlicensed band, low powered hardware, less dependency on the core network, etc. Wi-Fi also supports multiple configurations such as hotspot, mesh, point-to-point and multipoint, etc, which are suitable to provide coverage in rural areas. Wi-Fi technology is also future proof in the sense new standards are being developed to meet growing data demand and new use cases, and it maintains backward compatibility so that user device with older Wi-Fi technology keep working on new Wi-Fi technology hotspots. IEEE 802.11 b/g/n in 2.4 GHz mode is suitable for rural broadband as it provides higher coverage and all low cost user devices support 2.4 GHz Wi-Fi Radio.

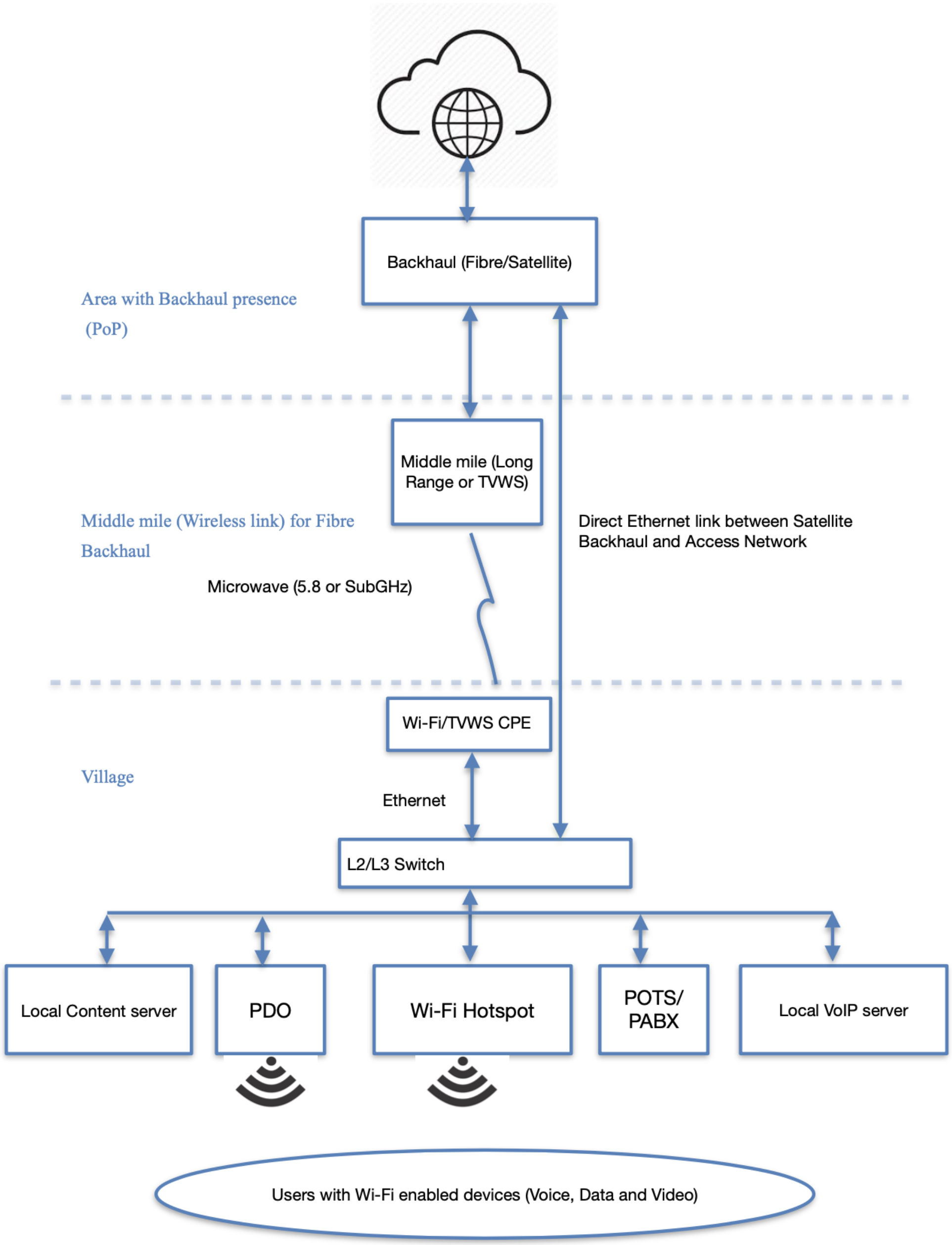

Figure 8. Connectivity architecture.

Apart from access, middle mile and backhaul technologies, rural broadband architecture also requires following network elements to support:

1. *Local Content Server:* To cache and host relevant content in regional languages locally. This has multiple advantages in rural scenarios.

i. The relevant content (agricultural videos, documents, news, educational content, government promoted schemes, awareness programs, etc.) in regional languages help people access useful information for free
ii. It increases the utility of the ICT Infrastructure. Due to frequent fiber cuts, the internet service may be down for days, weeks or even months. In such situations, making content available locally will help people to use the service even when Internet is not working
iii. It also helps in reducing the usage of Internet speed so that Internet can be used for other important purposes. Generally, Internet speed is low in rural areas. Video generally consumes a lot of internet bandwidth. Architecture should support caching of most used content locally in local content servers for general usage.

2. *VOIP Calling:* Voice is a primary requirement in rural area along with data. It allows people to communicate with their friends and family who are working in cities or nearby villages. This also helps them to reach for emergency services such as police, ambulance, etc, available in nearby village/town. There are many areas which do not even have voice facility (e.g., in India there are more than 40K such villages). VOIP is also a very low cost voice solution, and offers the following other advantages.

i. PABX facility on single VOIP channel in school and hospital helps teachers, nurses, etc, to build a community for themselves
ii. Local calling provision also helps in reducing usage of Internet bandwidth.
iii. POTs phone provision in the architecture helps people to make calls even if they do not own mobile phones.

The architecture should support community calling facilities such as PCO (Public Call Office) to make voice calls over Internet (even where cellular signals are not available). A VLE (Village Level Entrepreneur) can start an Internet kiosk also called Public Data Office (PDO) and provide voice calling facility.

3. *Voucher-Based Internet Access:* Due to very low income levels, affordable Internet is a major requirement. Everyone doesn't require a dedicated monthly plan for accessing Internet as their requirement is limited to their daily and immediate need. In such cases, vouchers with very low denominations is most suitable. The architecture should allow voucher generation, distribution and management locally so that people can access the Internet as per their need. This will also allow a VLE to establish Internet kiosk also called PDO and resell the internet.
4. *Emergency Alert in Disaster Situations*: The architecture should support broadcasting emergency alerts (such as heavy rains, fire, earthquake, emergency evacuation, etc.) to the people in rural area.
5. *Renewable Energy:* The architecture should support functioning of the systems on renewable power source such as solar, wind. The Hardware should consume least power.
6. *Maintainability:* The architecture should support remote maintenance of each network node including the power source. The health status of each node shall be available on the remote node. The redundancy provision in the network is required but overall cost implications of this requirement should be kept in mind. SDN based architecture is useful in such scenarios and important nodes should be identified for such provisions rather than a blanket SDN provisioning.

7. *Rural Requirement Specific Network Slice:* Depending on the usage, various network slices may be required to be configured in the network to provide required resources to different kinds of services. For example,

    i. For community telephone service, a network slice that can support low latency with fixed speed and data may be required to be defined.
    ii. For e-health checkup facility, a dedicated network slice of high data rate is required to support upload of reports, images, etc.
    iii. For interactive e-education, a dedicated high data rate and low latency slice support is required.
    iv. For soil sensors on agricultural land, such IoT related use cases, low aggregate data rate with massive simultaneous connections slice is required.
    v. For access to non-video content (i.e., static content), a slice that is free to access may be provided to allow consumption of useful information, such as cashless transactions, health, agriculture, education, safety and security.

8. Data plane and control plane separation is required to reduce the failure points and flexibility in network configuration. This also helps with data offloading in the edge networks to support ultra-low latency type applications.

IEEE P 2061 Frugal 5G Network: IEEE P 2061 (or Frugal 5G Networks) [21], an IEEE standardization project that aims to design an architecture to enable rural broadband communication adopts a holistic approach to address the problem of broadband connectivity in rural areas. It suggests a novel wireless network architecture, taking into consideration the needs and the characteristics specific to rural areas. As part of the proposed "Frugal 5G Network" architecture, a heterogeneous access network is being defined where macro cells provide coverage in a large but sparsely populated area, while Wireless Local Area Networks (WLANs) support broadband connectivity in village clusters (possibly densely populated). This approach is closely aligned with the architectural approach defined in the 5G standards. Data from/to WLANs in village clusters are carried over wireless backhaul (or middle-mile). Software Defined Networking (SDN) and Network Function Virtualization (NFV) paradigms are used to define a flexible and scalable network architecture, which integrates the three different access technologies, i.e., WLANs, Wireless backhaul and the macro cell technology, under a unified architectural framework. The concept of Edge Computing has also been used in order to bring intelligence to the edge, which enables services like local content storage and delivery. The proposed network architecture is being developed independently of the 3GPP 5G technology standards but it can very well be integrated with the 3GPP 5G network. It can also augment the 3GPP 5G network and serve as a cost-effective architectural solution to support broadband connectivity in rural areas.

4.2. NLOS BACKHAUL SOLUTIONS, INCLUDING LONG RANGE WI-FI AND TV WHITE SPACE TO REACH RURAL AND REMOTE AREAS

In order to connect the unconnected, currently there are solutions based on Wi-Fi, TVWS and/or by UAV/Satellite technologies.

In this sense, Wi-Fi technology in conformance with standard IEEE 802.11 has celebrated its 20 years of appearance in 2019. Most countries allow deployment of this technology by using the unlicensed Industrial, Scientific, and Medical (ISM) bands with no cost for home/office; however in other countries, these networks must be at least registered in case the communicating sites are located in different places, and, in the worst case scenario, must be paid an amount of money determined by the number of sites and the number of subscribers the network has.

Apart from mobile handset, multiple other devices such as laptops and tablets generally support only Wi-Fi. Desktops (in schools or homes) can be made Wi-Fi enabled with very low cost USB dongles costing less than $5, hence it is ubiquitous. Therefore, overall device ecosystem in rural areas is predominantly Wi-Fi enabled in conjunction with feature phones with 2G. For this, access technology could be either GSM or Wi-Fi. GSM being cellular though has the advantage of a large coverage area, but comes with high CAPEX and OPEX, high power requirement and higher cost in licensed spectrum. Meanwhile, Wi-Fi requires low CAPEX and OPEX, can operate on renewable power sources such as solar, does not require a complicated core network, and is better suited to provide decent coverage in rural areas. Looking at the geography and distribution of population in a village, most of the time, the broadband users are sparsely distributed in pockets (such as vegetable market, fish market, schools, government buildings, post office, residential area, etc). Such a sparsely distributed population does not require a complete village level coverage but requires hotspot type of coverage in clusters of the target areas.

However, Wi-Fi suffers from low coverage in both LOS and NLOS regions. The LOS range can possibly be extended by using Wi-Fi repeaters (cooperative networks using relays). For NLOS coverage, one of the offerings could be to connect through relays as for LOS. Another option could be to use reflecting surfaces, which could be strategically placed based on the topology. In addition, Wi-Fi technology from 1 to 3 in conformance with IEEE 802.11a/b/g/ has a low throughput efficiency (around 40-60%), and with respect to delay and jitter, these parameters do not allow real-time applications. Meanwhile, Wi-Fi 4 in conformance with IEEE 802.11n has better throughput efficiency, which could reach up to 80%, with proper parameters of delay and jitter, allowing real-time applications to run smoothly. Wi-Fi 5 in conformance with IEEE 802.11ac is even better with 90% of throughput efficiency and delay and jitter are minimum, allowing applications as video on demand, 4k video transmissions, etc. This technology is much affected in NLOS scenarios, due to its operation in the 5GHz band and the presence of Co-Channel Interference (CCI), resulting in the average throughput efficiency of about 30% with delay and jitter increasing to several seconds in worst case situations.

Wi-Fi for long range backhaul

Unlicensed band operation (2.4 & 5 GHz), with Line of Sight operation (LoS) at medium range require high mast to achieve Line of Sight. IEEE 802.11 g/n/ac SISO or MIMO operation, operating at 20, 40 or 80 MHz (depending on country regulation), can deliver up to 400 Mbps Link speed (e.g. 40 MHz in India), which is better link capacity than TVWS in P2P operation with patch or grid antenna & P2MP operation with sector antenna (45/60/90/120-degree antenna configuration). The longest link has been deployed to reach 381 km in Venezuela with a throughput of 3 Mbps; another network has been deployed in Ecuador to connect San Cristóbal and Santa Cruz belonging to Galápagos Islands, where the link is 92km long over the sea, with a throughput of 4 Mbps, jitter of 2 ms and delay of 0.3s. The main problem in reaching these distances is at MAC level, because ACK timeout must be modified. The LOS range can be extended by using Wi-Fi repeaters (cooperative networks using relays). For NLOS coverage, one of the offerings could be to connect through relays as for LOS.

Since same Wi-Fi technology is used for access as well as in middle mile, a single AP hardware platform with multi radios and selection of appropriate antennas can function for both for access as well as for backhaul/middle mile. This helps to lower power consumption of overall network, ease to maintain with single hardware (rather than one hardware for Wi-Fi and another for TVWS) and easy to operate on renewable power source such as solar.

All things considered, Wi-Fi is still the most suitable access technology to provide hotspot coverage in the clusters at a very low cost and low maintenance fashion. With the use of Wi-Fi mesh, point-to-point or multi-point configuration, all important and required locations can be covered with Wi-Fi. Figure 9 illustrates extension of rural broadband via Wi-Fi, middle-mile and fiber backhaul networks.

Optical fiber backhaul

Many countries are creating optical fiber backbones to provide digital connectivity to rural areas. However, rural geography presents some unique challenges of cost and maintenance. For example, in India, there are around 250,000 GPs (main business hubs) typically serving 2-3 adjoining villages within a radius of about 2-10 km. Wireless backhauls to extend the fiber backbone reach to the nearby 2-3 villages is a low cost solution compared to laying fiber beyond GPs. There are several options of wireless backhaul, call it middle mile links, to connect Wi-Fi AP in nearby villages with fiber backbone termination in the GP. Long range Wi-Fi and TVWS are two good wireless technologies for this purpose. Both have their own advantages and disadvantages.

TVWS

Another solution is the Wireless Regional Area Networks (WRANs) for which IEEE 802.22 is one of the standards that has been developed and is expected to operate primarily in low population density areas in order to provide broadband access to data networks. The WRAN systems will use vacant channels in the VHF and UHF bands allocated to television broadcasting in the frequency range between 54 MHz and 862 MHz while avoiding interference to the broadcast incumbents in these bands. Interference from other users and devices is a major concern and challenge for the development of the IEEE 802.22 receiver. There are several research challenges as well. These are, for example, statistical characterization of the channel, noise and interference for the considered communication channel, and subsequent design of transmitters and receivers. The research in these areas will pave way for increasing capacity and improving the performance of the communication receivers, and should help the policy makers and standards bodies to make TVWS a reality. Thus, there is a need for research in powerful signal processing techniques which can enhance and improve BER throughputs. Since IEEE 802.22 has suggested use of cognitive radio, it potentially enables spectrum reuse and/or use by others as primary or secondary service providers. Moreover, the current TV transmission infrastructure can also be used to provide connectivity in the rural areas. IEEE 802.22 offers 56 Mbps data rate (FDD), 28 Mbps (TDD), NLOS operation, 6/7/8 MHz channel capacity, channel aggregation, and database query to protect incumbent links. Protection of incumbent providers is quite important because TV/DTH broadcast is a widely used service in rural areas for entertainment and news.

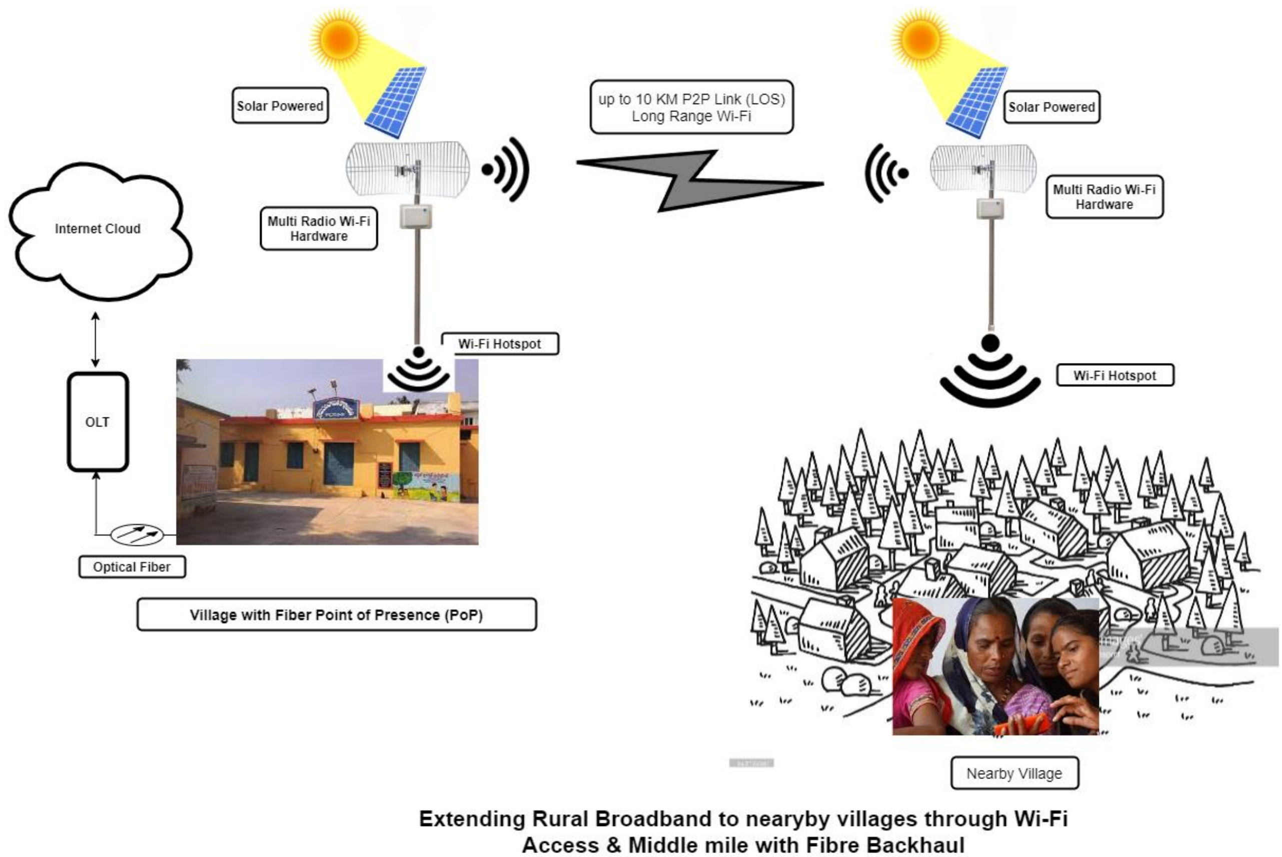

Figure 9. Extension of rural broadband to nearby villages through Wi-Fi access and middle mile with fiber backhaul.

4.3. LOS Backhaul Solutions Using Microwave, High Altitude Platforms (HAPS), and Free Space Optics (FSO)

LOS backhaul can be viewed as a special case of NLOS backhaul, but typically it can be classified as terrestrial and non-terrestrial. Excluding fiber technology which is wired, terrestrial LOS wireless is typically land-based and point-to-point, such as microwave, and free space optics (FSO).

Microwave point-to-point backhaul is widely used in 3G, 4G/LTE and 5G networks for distances of about 50 miles, and offers the advantage of small-sized antennas due to small wavelength allowing them to transmit/receive in narrow beams. Another advantage is that because of narrow beam the same frequencies can be reused without interference. Typical operating frequencies are between 300 MHz and 300 GHz, and can deliver data rates of up to several Gbits per second depending on the modulation technique and operational frequency used.

Microwave frequencies are also used in satellite communication between ground stations and satellites. FSO is a potential technology that can be used for backhaul between village office and the ISP point-of-presence (PoP) in a nearby urban town or in mid mile network at a distance of up to 2 km, connected via optical transceivers on towers or high-rise buildings in line of sight. While the achievable speed could range from 10 Mbps to 10 Gbps, the disadvantage of FSO is that the optical signal quality and data rate are often dependent on the atmospheric conditions.

With an era of micro-satellite beginning to take shape, it is prudent that standardization of the satellite communications takes place in the optical bands too. NASA, NICT, and others are taking this as the new frontier for communications, and in fact early trials and deployment plans in 2025-time frame have also taken place for the same. There are three possible ways we foresee connections could be established using optical satellites as below:

Satellite to satellite: In satellite to satellite communication an optical connection can provide an ultra-high speed connectivity. This could be used for communication, control, navigation and sharing other data between the satellites.

Satellite as a relay: In this scenario, one or more satellites act as an optical relay to connect and provide connectivity between satellites which are not in line of sight or between earth-satellite-earth stations. The communication could be established between two or more satellites through an intermediary satellite in a cooperative fashion. Here, the relay action is performed at the satellite which can be done in all optical domain itself.

Satellite to ground: It is expected that broadband satellite communication systems will use higher frequency radio waves (e.g. millimeter waves) or optical lasers for the feeder link from the geostationary data relay satellite to the ground station and for a direct downlink from the earth-observation satellite. However, millimeter waves and optical lasers are both susceptible to attenuation by rain and clouds, which can interfere with communications. For optical satellite to ground communication, if site diversity is constructed among two or more ground stations connected with a terrestrial network, it can be assumed that a link should be established with one of the ground stations. Research on weather relevant to optical satellite communication, such as the extent of clear sky regions has been conducted in Japan. Adaptive optics and other techniques could be developed to provide over 1 TBs high speed communication link between the satellite and the ground station using optical wireless technologies.

The main drawback of using satellite-based communication is the latency; otherwise, it is perfect for broadcast purposes and is quite economical. Nevertheless, to achieve seamless connectivity in the remote regions, heterogeneous networks leveraging wired, wireless, terrestrial, and non-terrestrial networks will be required. The optical fiber cables deployed around the globe aggregates the traffic generated by mobile end users in the metro and access networks into the core network. Thus, the vastly deployed and increasing optical fiber infrastructure must be leveraged for high-speed mobile broadband connectivity in remote regions using wireless optical broadband networks (WOBAN) [22]. For hilly and terrain regions, wireless network solutions including satellite communication may be deployed. Along with satellite communication, the densely deployed submarine fiber cable infrastructure may be explored to improve connectivity in seas and islands by constructing cable landing stations on islands for optical signal regeneration, where macro cells may be deployed for improving wireless connectivity. It goes without saying that there is a variety of deployment scenarios and each scenario will call for a specific solution to meet local needs while being cost effective.

Mesh, Including ad hoc for D2D, communication for local coverage

The effectiveness of D2D cooperation depends on a wide range of decision-making processes that include cluster formation, resource allocation, in addition to connection and mobility management. These differentiating factors are shown to enhance the overall network reliability compared to standard techniques and to facilitate dynamic operation which is essential for practical implementation for local coverage in rural areas. It is also considered as one of the promising techniques for the 5G wireless communications system and used in so many different fields such as network traffic offloading, public safety, and social services. On the other hand, Wireless Mesh Network (WMN) arises from this context of development and brings with it great advantages due to its mesh topology that results in an easy implementation, flexibility, self-forming, and adaptability in different scenarios including rural areas. While D2D seems to be an interesting technology for rural communities, it would probably need to wait until after the traditional methods to extend Internet to those unconnected are implemented.

Directional and MIMO for rural backhaul

The major issue in providing low-cost broadband to rural areas is to provide reliable backhaul connections that spread over tens or even hundreds of miles, connecting villages to the nearest service provider. To support mobile operators through the implementation of policies and regulations that enhance incentives to invest in rural networks. Such policies should eliminate unnecessary deployment costs, enhance operational flexibility, and increase investor confidence [23]. With massive MIMO we can compensate for that effect by adding more antenna elements, effectively keeping the antenna size constant as we move to higher frequency bands. The second major benefit 5G New Radio (NR) provides over LTE is the lean design which can significantly reduce network energy consumption, especially in rural areas with low average traffic [24].

With NR efficiently supporting lean-design and massive MIMO, we now have the right tools to deploy long-range systems supporting high data rates with low average network energy consumption. It is possible that combining NR 3.5 GHz and LTE 800 MHz on a GSM grid can provide vastly superior capacity compared to an LTE 800 MHz standalone networks, the reason being that in higher bands we can get access to more spectrum, and the lower band can provide the coverage for cell-edge users at the same time.

It is evident from R&D that MIMO is a key technology to increase the throughput. In 5G, massive-MIMO has taken shape for downlink channels, where hundreds of antennas could be serving one user with a few tens of antennas, the same would probably increase on both the base station and device side in future. For rural connectivity, the need for directional antennas or beamforming using MIMO antennas is really necessary. There may not be a need for a massive-MIMO; however, MIMO beamforming is critical for delivering improved transmission than single antenna and with no directional transmission. This would increase energy efficiency and also increase the usage of spectrum in other sectors of the same cellular area.

Spectrum allocation

Below is the popular range of spectrum bands for mobile and wireless communications.

- Unlicensed Band 5 GHz spectrum: In India, 50 MHz frequency allocated for fixed point-to-point configuration in 5.8 GHz band. It requires at least 80 MHz contiguous band in 5 GHz for the outdoor fixed point-to-point operation to provide adequate capacity for long-range Wi-Fi Backhaul/middle mile connectivity
- V (57 to 64 GHz and 65 to 71 GHz) & E (71 to 76 GHz and 81 to 85 GHz) bands should be made unlicensed to promote low cost high capacity backhaul links to meet evolving bandwidth need in rural area. It is simple to use with database mechanism to allow reuse of the band with adequate geographical separation. Some of these bands are also utilized in point-to-point fixed microwave backhaul links
- 5 GHz band: UNII-2B (5.350 to 5.470 GHz), UNII-3 (5.825 to 5.850 GHz) & UNII-4 (5.850 to 5.925 GHz) bands in 5 GHz are under discussions for unlicensed such that these coexist with the incumbent technology
- 6 GHz band for unlicensed use: FCC has just allocated the complete 1200 MHz band from 5.925 to 7.125 GHz for unlicensed usage. Depending on the incumbent fixed and satellite communication, the band can be segmented for very low power indoor use (100 or 250 mW) and middle power outdoor use (1W). Due to the present COVID-19 situation, the indoor Wi-Fi consumption has increased many folds due to continuous presence of children and adults inside home. Work from home requires connection for at least 8-10 hours each day over video conferencing facility, real-time access to code servers for development and debugging, children using Wi-Fi for e-education, gaming, adults using OTT services such as Netflix, movies, etc, and elderly people watching programs of their interest
- 470 to 698 MHz UHF Band: Predominantly used by terrestrial TV broadcasters across the world. This band has unique capability of very long range transmission in non-line of sight scenario. It is very useful for rural broadband. Multiple countries are utilizing this band with TVWS technology to provide microwave middle mile/backhaul connectivity. Sufficient bandwidth requires to be identified through segmentation and harmonization approach by adequately protecting terrestrial TV broadcasting. This band is also identified as IMT-2020 band in Region 1 & 2 (not in Region 3 - where India operates) as per WRC-19
- C Band (3300 to 3400 MHz) and Extended C Band (3400 to 3600 MHz): Widespread satellites operating in C-Band. This band is mid-band and suitable for IMT-2020 usage. In India, 200 to 400 MHz of contiguous bandwidth can be recommended for mobile use (IMT-2020).

In many countries, the spectrum auction process of the 3.5 GHz band (3.4 to 3.8 GHz) is in the starting blocks with Licensed Shared Access (LSA) in mind. With respect to spectrum policy, the basic idea of LSA is extended by coordinating licensed and unlicensed spectrum usage in a centralized Spectrum Access System (SAS), including the need to coordinate for local spectrum licenses for rural hot spot coverage. In Latin America region, a network comprising of two bands is proposed, one on 800 MHz (for existing GSM/LTE compatibility) and another on 3.5 GHz for 5G NR that can provide low cost and/or subsidized high rate and high capacity mobile broadband services in rural areas.

Sub-GHz bands (e.g., 600 or 700 MHz) which can be used to support a large coverage area may be used for providing connectivity in rural areas. These bands may be supplemented with newer waveforms to further increase the coverage. One such example has been proposed by Telecom Standards Development Society of India (TSDSI) to ITU for IMT-2020 under Rural MBB use case. This is called the Low Mobility Large Coverage (LMLC) solution and supports the rural eMBB scenario. High speed mobility support is a much lower requirement for the CTU use cases in rural areas. Such solutions shall be especially useful in areas with low population density. Another important solution component is to enable people and companies located in rural areas to have access to the local spectrum (e.g., property-based licensing) to enable private network deployments.

A CTU network slice in B5G networks to meet basic user needs at lowest cost

Network slices comprising of cheaper non-3GPP access technology along with COTS and Open Source based Core Network elements can be used for rural connectivity. The Core Network entities may support relatively simple packet forwarding functionality with limited QoS differentiation between different traffic flows.

So far, the 5G mobile systems are mostly known for their superiority in terms of performance, flexibility and cost efficiency but are less known for their social benefit. However, the huge social benefit of 5G is demonstrated through the realization of the Internet Light CTU network slice. The Internet Light is aiming at providing free access to Internet information for all and can be implemented by an Internet Light Network Slice (ILNS) available and accessible to everyone. A proof-of-concept is described in [25]. Potentially, because 5G network is a network of networks and with the possibilities of creating slices, new/multiple stakeholders/investors can become players in infrastructure deployment and network operations.

Content management, including crowd-sourced content creation, and delivery optimized for non tech-savvy users

Local content creation, storage and delivery capability may be an important requirement for the rural connectivity. As indicated above, local content storage and delivery may help in reduced backhaul usage and improved service quality by reducing the response time. Even with a small backhaul capacity, local content storage may help in the delivery of services with reasonably good quality.

One study [26] has shown that 80% of the content on Internet is available in only 10 different languages. These languages are spoken by roughly 3 billion people, less than half of the world's population. A significant number of languages in the world are spoken/used by only a small number of users, who may be inhabitants of specific regions. There may not be enough useful content on Internet in these regional languages and for such people. Content creation facility may help such languages and people.

The whole point of creating digital infrastructure in rural area is to bring the population at the bottom of the pyramid in main stream digital economy. What is next after providing Internet access to the people in the rural area? What will the people do with broadband? There are many ways people in rural areas can utilize broadband to improve their income, their lifestyle, etc.

Today, major consumption of broadband is watching videos. In urban areas, people spend most of their Internet bandwidth to watch videos on OTT platforms such as Netflix, etc, in addition to chatting with their friends and family, accessing their emails, being active on social media, e-commerce, paying their bills, doing financial transactions, making phone calls, playing games, etc. This section of society is digitally aware.

But same is not the case for people living in rural areas. Due to limited education, it is very difficult for them to search the Internet. For example, a farmer may be interested in watching videos related to farming, crops, soil, insecticides, seeds, etc. Children may be interested in watching educational content, community may be interested in listening government promoted schemes and other awareness programs (such as agriculture produce prices in nearby markets). Also, they will like the content to be in their local language. On the other hand, new opportunities may emerge for entrepreneurs, including translating /subtitling larger Internet content into local languages.

At least applications (Android based) have made it comparatively easy for people to access services. For example, if they know after clicking a particular app they can listen to the news in their language, they simply tap the app and listen. If they have to search the same thing on web, it is next to impossible. Installing of the apps is one-time work which can be done with the help of VLE or someone who knows where to find the application and how to install and configure it.

Another aspect is the frequent disruption in the connectivity to the Internet. The frequent fiber cuts leave the system not working for long periods of time. The repair work is time consuming and bureaucratic in nature. If the ICT infrastructure allows hosting the relevant content local to the village, it will improve the utility of the network. Though it may not be possible to access the Internet, people can still watch the locally relevant content in their local language. It is also useful for students to access educational content at any time they want.

Third challenge is the Internet speed in the rural area. In such a scenario, accessing the video content directly from the Internet is bandwidth consuming, and affects the QoS of other low bandwidth services. In addition, if the relevant content in local language can be pushed to the local content server in the village, it will help reduce the Internet bandwidth consumption. The locally hosted content can be made free, such as government promoted videos, awareness videos, national database of educational content, health related videos, agricultural videos, video on how to use government promoted schemes through mobile phones, how to pay electricity bills, how to book train tickets, how to file RTI - Right to Information, emergency and disaster alerts. There can also be chargeable content such as movies, music, games, which can also provide revenue to the VLE (Village Level Entrepreneur) who is the local service provider. Other innovative and creative content can be pushed from the server in the cloud to the edge/local server to provide new and interesting content to the users, possibly free of charge.

The system can subscribe the feeds of various national programs (e.g., NKN - National Knowledge Network in India) to make content available.

With Wi-Fi as access technology, there is abundance of bandwidth available for accessing video content by many people simultaneously if it is stored in a local server.

Intuitive and simple user authentication and network security solutions

A major barrier to onboarding is user authentication before s/he can access the Internet. Every access network comes with its own authentication mechanism. In rural areas, the network onboarding must be with ease and minimum human interaction.

Wi-Fi access points or cellular access are generally used to access the Internet. FTTH service is another technology for access in homes, schools, offices, and hospitals for fixed devices. It becomes very difficult for someone in rural area to enter username/password in the captive portal page in English to access the Wi-Fi due to various constraints such as fear of technology, English as the primary language for authentication, digitally illiteracy, and being physically challenged. Remembering the SSID and password in English is another challenge.

With cellular access, once SIM is inserted in the mobile handset, there is no need for any further authentication. Cellular access is not always available in the rural area due to very low ARPU and lack of viable business and ROI for mobile operators.

For Wi-Fi access, such dedicated SIM provisioning is not in use so far. Requiring SIM also poses limitations on non-SIM based devices such as laptops or desktops. SIMs are typically used for cellular devices and are specified by 3GPP. WiFi alternatives may include MAC addresses but this is device specific and would not have the same precision as subscriber (including IMSI) based identification.

Single click signup with minimum human interaction is the most important requirement in connecting the unconnected; otherwise, people would find it very difficult to use the broadband services offered to them.

One-time authentication with the help of VLE (Village Level Entrepreneur) is one option so that people do not need to authenticate again and again. A backend database is required to identify the user and associated voucher/plan for the data access. Below we present some selected authentication mechanisms that may be preferred for the digitally disadvantaged section of the society.

APP based authentication: enables one-time configuration, where a dedicated APP is installed on the device and configured with relevant information. Every time one wants to access the Internet through Wi-Fi, he/she just needs to click the APP and authentication is automatic. APP is something which is easy to click and remember (distinct icon of the APP with some image which is easy to understand with wording in local language). These applications can be multi-functional such as prompting for online payment when a voucher amount is running low and/or when it is about to expire. Money can be paid through wallet or digital ID already stored into the APP during the configuration process itself.

QR code, voice, face, biometrics, etc, can be additional modes of authentication through APP.

QR code based voucher which contains user credentials to connect with the Wi-Fi is another method. User will get his/her access credential in the form of a QR code printed on a voucher. Camera based user device is required to read QR code. APP on the mobile phone can read the QR code and connect the device to the Wi-Fi network.

Audio driven authentication: Authentication based on voice inputs and identifying unique voice pattern can be another mechanism. The recognition algorithm can run locally by the APP on the user device or remotely in a central database. The audio sample is captured during one-time configuration initially preferably by the VLE who is hosting the Wi-Fi infrastructure.

Face recognition driven authentication: The facial features are captured during one-time configuration which is used to authenticate the user. The recognition process can either run locally by the APP on the user device or remotely in a central database.

Biometric (finger print or retina) authentication: The biometrics are captured during one-time configuration which is used to authenticate the user. Again, the recognition process can either run locally by the APP on the user device or remotely in a central database.

Numeric key driven authentication: It is relatively easy to enter numbers (username and password can be based on numbers). Numbers can also be pressed over audio instruction similar to IVR menu. Numeric interaction can be in local language and the phone keyboard could easily support the local language.

MAC address based authentication: For multiple devices at the same time, this method can also be used for user authentication. Due to randomization/changing of MAC address in new Android devices (for better user privacy), this method is not recommended at least not presently. But it will work with old mobile handsets. Multiple MAC addresses (in mobile, laptop, desktop, etc.) can be configured at once so that accessing Internet by all these devices becomes seamless with single configuration.

Mobile number + OTP based authentication: Many countries use a mobile number in combination with OTP as username/password for authentication. Authentication based on mobile + OTP is not a viable option at all locations, especially in rural areas. Many rural areas are not served with cellular coverage. Or many people do not have SIM cards due to lack of coverage. Laptops/desktops usually do not provide option to install and use a SIM card.

Information/videos on how to use Wi-Fi, what is SSID, how to enter the username, password, etc, need to be made available in local language to educate and train the potential users.

Security: During internet access is most critical. Nowadays, people prefer to make all types of financial transactions (for paying utility bills, insurance premium, hospital bills, e-commerce payment, etc.) through their mobile/laptop/desktop by connecting to the Wi-Fi. There are chances of password, banking information, private chats, photos, etc, over wireless network to be stolen, which prevents people in the rural areas to use wireless method of Internet access. Adequate security mechanisms such as password protected Wi-Fi configuration are required. Mechanisms to detect and eliminate man in the middle attacks are required to be implemented. The websites/apps which involve transactions of sensitive and financial nature must be https protected to allow end-to-end security. Building security by design in the network is essential.

Non-text HCI which assumes that users are not proficient in typing and reading

HCI primarily refers to how the content and applications are presented on the user device and how a user interacts with it. Both must be adapted to match the skill-level of the user, especially those who are illiterate or digitally disadvantaged. On the output side, the applications should be represented by visual icons and widgets, and possibly augment them with voice instructions which may be silenced by the user when s/he becomes comfortable with technology. Similarly, web pages may be augmented with widgets and audio instructions. Rather than text-based output, the applications should output information in speech, images or video, or combinations thereof. For inputting instructions or specifying parameter values, one or more of the following input mechanisms can be employed: touch, speech, gestures, handwritten instructions on paper, or simply gaze.

Therefore, CTU requires removing barriers associated with a variety of factors related to interface design. It is important to make interfaces that will provide an intuitive experience for the users in preforming tasks relevant to their day-to-day activities (e.g., tasks ranging from accessing government services to sending money, checking price list in the market, using tele-health services, reporting emergencies). If intended users are facing an overwhelming complexity pertaining to an interface, handling ICT devices will be intimidating for them and may impede the acceptance and adoption of new technologies made available to them. This, in turn, may negatively affect the efforts of diversifying the socio-demographic range of users in rural settings.

An intuitive interface requires minimal efforts from a user in task performance and gaining proficiency. Interface needs to be guided by the idea of natural engagement in developing familiarity with an ICT device. The idea hinges upon a user's interaction aligning with natural and general instinctive understanding and successful use of the interactive system (having previous experiences or not having any relevant experience). Adopting the approach of intuitive interface will benefit the rural users in terms of increase in speed (while reducing trade-off in accuracy), higher level of confidence and efficiency, faster adoption of technology, and reduced requirement of training. Another major barrier is when a user has to authenticate oneself before s/he can access the Internet. Every access network comes with its own authentication mechanism. In rural areas, the network onboarding must be with ease and minimum human interaction.

Key features [27]

- There is a shift from dominance of 2-D to broadening of interface paradigm by adoption of dynamic 3-D interaction, multimodality of information input and output for interaction such as combined gesture and speech input, including translation of texts and special input devices (laser pointer, personal digital assistant). Intuitive interface calls for the favorable integration of features, e.g., intelligent, active functionality and more natural modalities such as language and speech need to be well coupled with direct manipulation features.
- Interface that is easy to learn and understand for inexperienced users is key to intuitivity of an interface. The interfaces should be designed to make it easy for the user to predict the

outcomes of actions. If users are made aware of errors appropriately, they will seek corrective action using feedback provided to them. Such lenient learning environment will enhance the positive experience of the users.

- It is important to emphasize on the instinctive nature of an interface in terms of flow of thoughts, intentions, and actions in contrast to effortful and conscious process of rational reflection in task performance (thus adaptive to the user context minimizing the cognitive burden of interaction).

While there is huge amount of information available on the Internet, unfortunately, the rural population can't benefit from it due to various limiting factors, such as fear of technology, computer illiteracy and linguistic challenges [28]. Existing websites are full of text mostly in English and need complex navigation to extract the needed data. It's further complicated by advertisement and personalization by Internet content providers. On the other hand, enabling technologies such as personal computer, laptop and even mobile to some extent lack human touch. It is also to be noted that existing technologies do not enable physically challenged people with vision issues and elderly population with reduced motor-ability, hearing aid & even illiteracy. Below, we identify some hardware and software requirement to make them HCI compliant.

Hardware requirements

1. CAPEX and OPEX

- Open source Operating System based specialized hardware to reduce the CAPEX.
- Low power consumption with possibility to run on solar power to reduce the OPEX.

2. Enabling digitally illiterate user

- Belonging-ness: Ensure that the models that are owned are only a limited types to assist learning from each other
- The hardware outlook should be innovative and user friendly.

3. Enabling illiterate person

- Numeric Keypad – It is assumed that almost everybody understands numbers 0-9, specifically as they deal with currency and mobile phones as a part of daily life
- Audio speaker – For announcement in local language for those who cannot read
- Large screen – Mini projector for larger display is cost effective and power efficient than large LCD screen.

4. Enabling visually impaired

- Braille keypad
- Audio speaker – For announcement in local language for those who cannot see.

5. Enabling Person with limited motor abilities

- Large numeric keypad buttons – makes it easy to tap large buttons.
- NFC based card for frequently needed services, e.g. latest news, live price of agricultural or other products, etc.

Software requirements

- Tie-up with content providers
- Navigation which is image and number driven
- Innovative GUI design that can adapt to the existing website and whenever it changes
- Add-on text in local language and automatic language translation
- Add-on announcement in local language
- Optimization of data usage due to limited bandwidth, viz. reuse content until updated, storing (licensed) frequently used data offline
- Subscription to various HCI ready content
- Authentication and localized customization
- Remote status monitoring and upgrade

Figures 10 and 11 illustrate a deployment scenario and the corresponding interaction flow, respectively, for a potential HCI system that is hardware and software compliant [29].

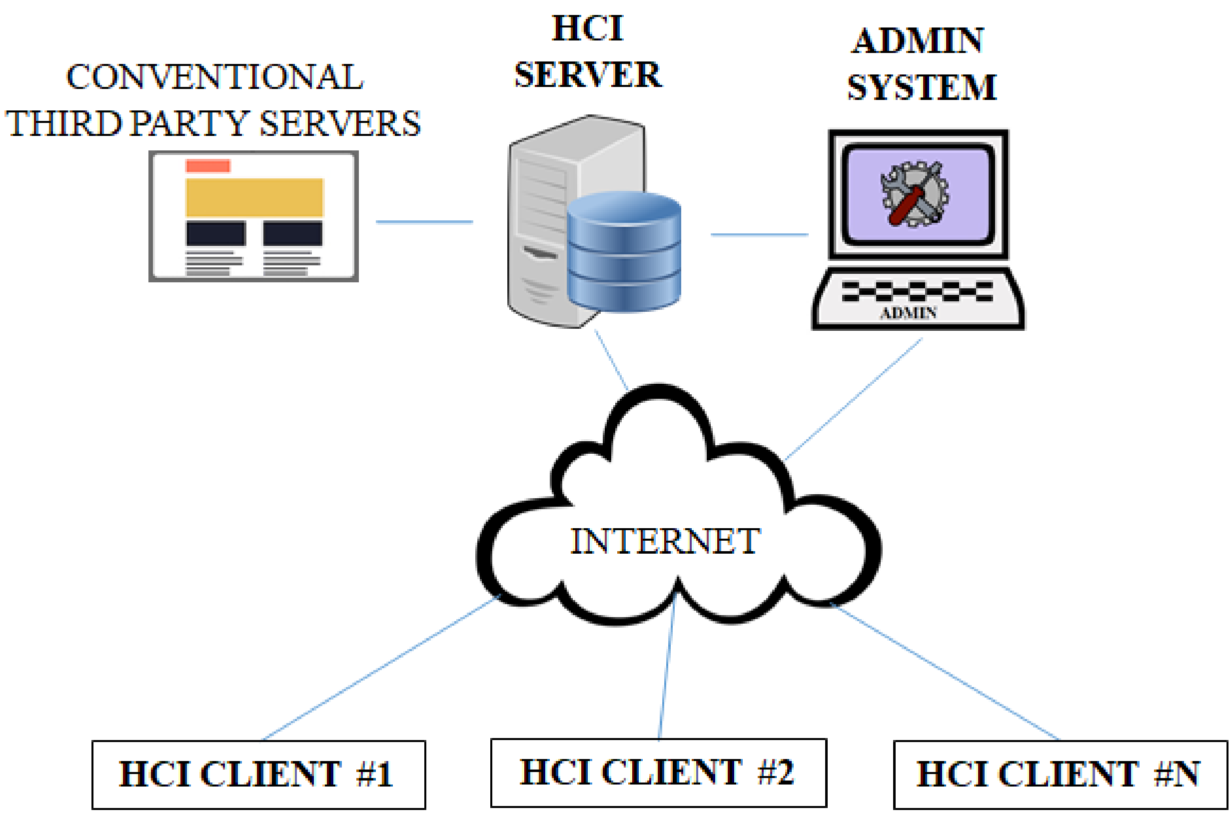

Figure 10. Deployment scenario of an HCI system compliant with hardware and software requirements.

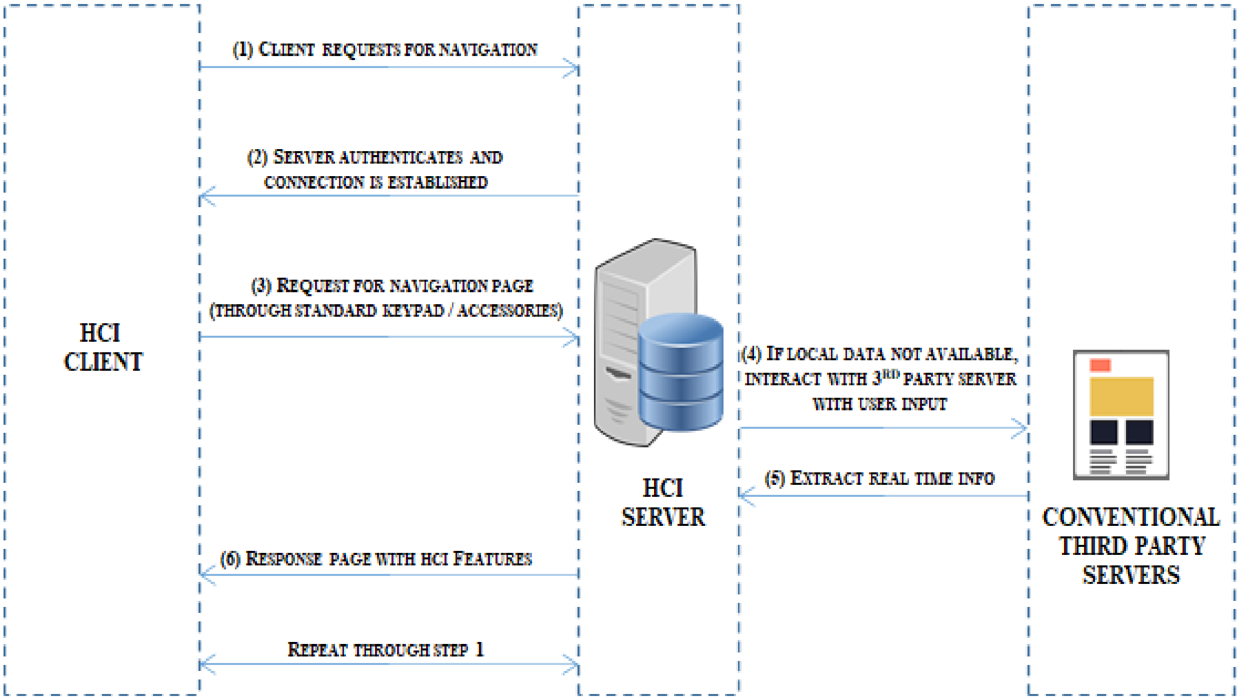

Figure 11. Operational flow of an HCI system.

Power management, including use of renewable energy, in scenarios where power grid is not available

This is very important, especially for remote areas because the communication equipment may not have or have limited (unreliable) access to the power grid. There is a need to explore energy harvesting from RF and/or renewable energy sources, such as solar, wind. Low power consumption is one of the major require for rural and remote areas further away from the grid [30]. Where power supply from the grid is unreliable, this calls for a new type of (joint) resource optimization in communication systems, renewable power source with energy storage and power grid. An INGR White Paper on energy efficiency is a good reference for more details on the need to be aware of this important topic, its current status, and linkages [31].

Sustainable business models and Key Performance Indicators (KPIs)

Sustainable business models that include non-quantifiable KPIs in pricing and service subsidies for those at the bottom of the pyramid is paramount for Internet access to be commercially viable. The definition of KPIs must be expanded to include social impact parameters as key value adds. These KPIs may be defined as: increase in agricultural productions, decrease in diseases, increase in employment, gender equality, increase in literacy rate, etc.

The concept of Village Level Entrepreneur (VLE)

VLE delivers various government and non-government services to the end user through ICT infrastructure owned by him/her, who is typically a local resident of the village and willing to invest, create and maintain the ICT infrastructure which is useful for the community. He or she earns money by offering affordable broadband and other ICT services. VLE is the owner of the ICT infrastructure. He/she also takes care of the backhaul such that it runs uninterrupted. VLE is equipped with some ICT skills (possibly after some training) to operate the ICT infrastructure in the village. VLE can also invest fully in CAPEX and OPEX and earn the profit or choose to earn commission where cost of ICT infrastructure is borne by the aggregators or implementing agencies or a hybrid arrangement where the VLE gets commission and a fixed salary. A VLE can also be recognized as a micro-operator.

Ownership is the key for building a sustainable business in rural areas. A hybrid model of small investment by VLE and a meaningful fixed income along with commission or profit sharing is a recommended model where VLE is always motivated to sustain the business and engages with the people in the community to address their real needs.

CSC (Common Service Centre) model can be adopted where VLE makes some investment and also gets a fixed salary/commission from implementing agency and offers a variety of G2C & B2C services. VLE can collaborate with many other institutions such as insurance companies, financial institutions, healthcare, agriculture, etc., and can become a content/service provider for them and potentially a financial point of contact. He/she can also serve as a proxy post-delivery person to deliver the parcels/letters to and from the nearby post office. He/she can collaborate with e-commerce players and become the Cash on Delivery point and manage delivery/return of the goods to/from the people. VLE can start other complementary businesses such as photocopying, printing, scanning, Internet kiosk, etc., to earn extra money. VLE can be encouraged to start the ICT infrastructure along with his/her existing business and later turn it into a full time business to minimize the risk in the new business venture.

Due to digital illiteracy, hand holding in the form of VLE is very important who would be the go to man/woman for any ICT needs. Since VLE is investing his/her time and money in the ICT business, he or she can sustain the business with his/her commitment to succeed. He also commands the respect and credibility in the community. He can also impart his skills to others to create pool of local people to maintain the ICT network. With maintenance being local, the cost associated with travel by experienced technicians from outside is eliminated or reduced. VLE also helps and educates the local people to use the Internet services. Government support in terms of subsidized loan is required to help VLE establish ICT infrastructure and get the business off the ground.

The Internet service offered should make a difference in the lives of people and meet their daily needs. Merely making Internet available in a rural area doesn't serve any purpose. Only watching songs/movies, playing games, etc, won't serve the purpose. Calling family and friends in other parts of the country or world is a compelling value proposition. Direct transfer of benefits to the people through ICT infrastructure is one of the main objectives of many governments, which reduces the leakage and corruption by the middlemen. Local people can also send their complaints to the concerned authorities. This helps in reducing/eradicating the corruption. Access to Internet and availing the government machinery is powerful to bring accountability and timely resolution of issues.

In addition to developing and promoting the VLE-based business models, other potential options are: (i) freemium (free + premium) content model, (ii) free access to Internet for certain amount of data consumed and then usage based, or (iii) Subsidizing data consumption above a certain threshold by the funds from the USOF (Universal Service Obligation Fund).

Another approach is to use the concept of Public Data Office (PDO), which is a concept similar to the PCO (Public Call Office) concept, where anyone can come and access the Internet after buying vouchers/coupons. Its features are as follows.

- Reselling of Internet bandwidth in the form of low denomination vouchers/coupons to rural populations to help them perform their immediate tasks
- A viable business model for local entrepreneurs is to buy Internet bandwidth in bulk and resell it in the form of voucher/coupon in small bundles with small profit margin is another potential approach. It generates extra business along with the existing business
- Single box solution which can plug and play with any available backhaul in the rural area using renewable power such as solar.

A potential PDO architecture to augment Internet resources in a village with a sustainable business model might look like as in Figure 12.

- Access: IEEE 802.11 based Wi-Fi or cellular
- Backhaul: Copper/optical, microwave, satellite, FSO, long-range Wi-Fi, cellular (as per availability in the rural Area)
- Modules
    - AAA functionality
    - Policy (bandwidth control, QoS, ACLs)
    - Voucher generation, distribution & management: GUI and Android APP
    - KYC (Know Your Customer Module) - Mobile OTP and ID card
    - User on-boarding: Captive Portal, APP, QR code, single click signup
    - Content Server: Local relevant static content and video in regional language (which is available even when backhaul is not working)
    - Computing Engine: Built-in computer removes requirement of external PC/laptop to operate Public Data Office or ICT Infrastructure
- External Interface: To connect keyboard, mouse, monitor, printer etc.
- Low power consumption: To operate on renewable power such as Solar.

There are significant benefits of the VLE model:

- VLE takes ownership of the system
- VLE perform local maintenance contributing to ICT skills development
- Some potential businesses around PDO are photocopying, printing, Internet kiosks, ticket booking, helping people to avail G2C services (allowed by the government), 3D printing.
- The same model can be extended to aggregator model where a PDO aggregator creates the ICT infrastructure for VLE and provides him bulk vouchers to resell and provide commission on every sale. This is similar to earlier recharging of mobile prepaid connection at any nook and corner shop.

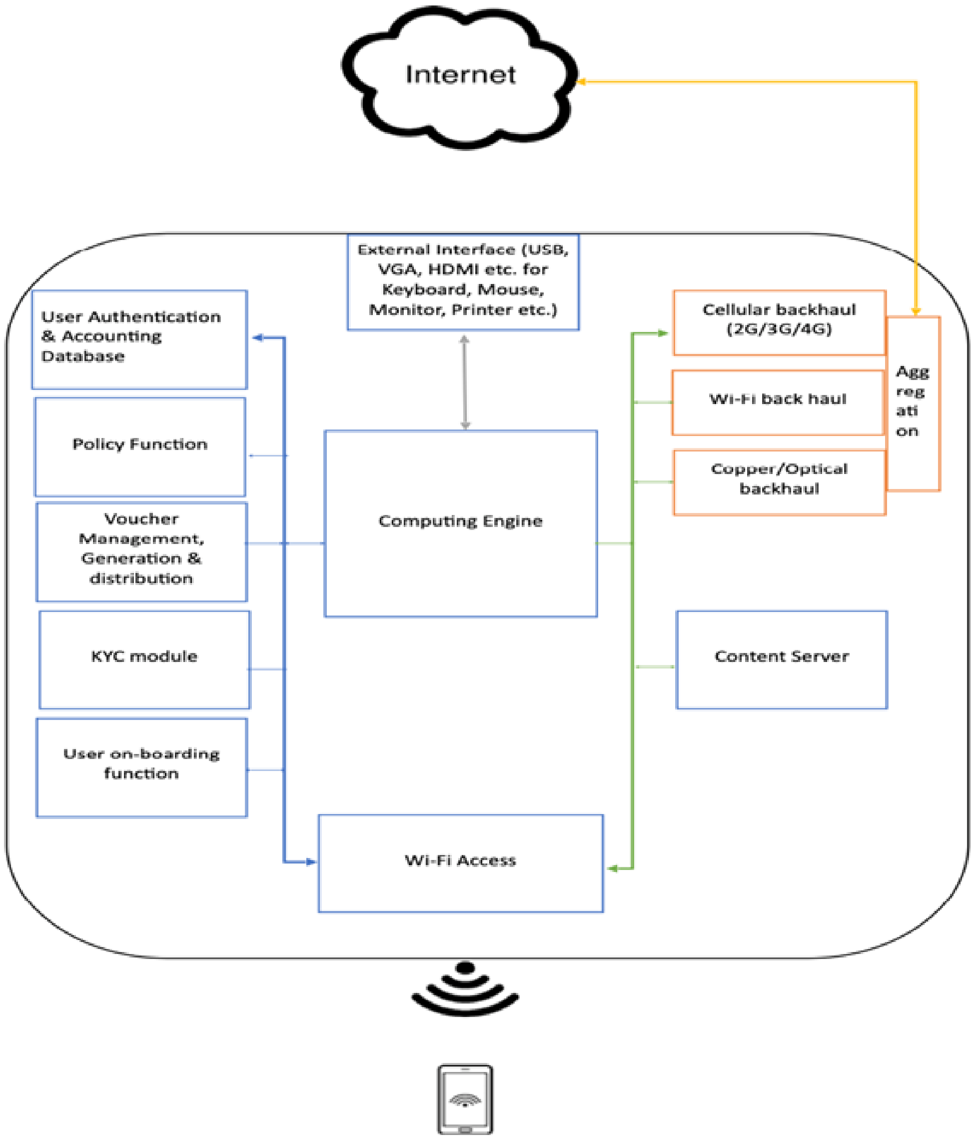

Figure 12. An illustration of a PDO architecture.

There are, of course, certain policy/regulatory requirements to enable a PDO architecture:

- Reselling of the Internet bandwidth through PDO module should be allowed by the regulator of the country. Existing VNO rules require to be amended
- KYC of the user to access Internet through PDO should not be based on cellular (mobile + OTP) authentication. Many people may not have mobile number/SIM and the rural area may not have cellular coverage. IP based KYC (such as an electronic ID) should be allowed for KYC of user to access PDO/Wi-Fi network.

Finally, collaboration with local players is a must to build trust and co-create solutions to local problems. Any small rural business model will require the ability to optimize resources within the suitable scope in the local community setting. Other aspects to be considered are: (i) Training, (ii) Service reliability and security, (iii) Risk management and performance optimization (capitalizing on complexity, re-aligning customer relationships, flexible cost structures and rapidly scaling up or down depending upon the local dynamics), (iv) Keeping the structure simple and easy for decision making, and (v) Economic sustainability (with payback to investors limited to investment amount, profit reinvestment, expansion, conglomerate discount, etc.).

5. ROADMAP TIMELINE CHART

Table 1 - Working Group Needs, Challenges, and Enablers and Potential Solutions

Name (be brief)	***Current State*** ***(2020)*** ***(details)***	***3 years*** ***(2023)*** ***(details)***	***5 years*** ***(2025)*** ***(details)***	***Future State*** ***10-years (2030)*** ***(details)***
(1) Cost-optimized open network architecture and platform for CTU use cases	A variety of solutions being offered without coordination – lack scale to benefit from volume	Architecture and platform defined with global consensus. Necessary standards in-place	Turnkey solutions available from equipment vendors and service providers	Global wireless broadband internet penetration reaches 85% of the population
Global collaboration among stake holders and public support				
One or more standard architectures to meet selected deployment scenarios				
(2) Backhaul solutions to meet selected use cases	Most technologies already available. However, HAPS and TVWS still not stable or in packaged form for roll-out	Technologies cost optimized for different scenarios assuming NLOS backhaul in most cases. Standards in-place for HAPS and TVWS.	Several large pilots done in different regions of the world	Solutions deployed to reach about 80% of the global population
A common platform for discussion and agreement, like IEEE FNI				
Several standard low cost solutions for selected deployment scenarios				

Name (be brief)	*Current State* *(2020)* *(details)*	*3 years* *(2023)* *(details)*	*5 years* *(2025)* *(details)*	*Future State* *10-years (2030)* *(details)*
(3) Cost-effective solutions for local coverage. This may include mesh and D2D technologies	Technologies already available. Standardized turn-key solutions that are low-cost needed	2-3 standardized deployment solutions capable of serving different scenarios and requirements	Validation of solutions with pilots and some deployments in commercial settings by the ISPs	Large-scale global deployments enabling most people to take advantage of the Internet
Cost reduction, ease of connectivity, multi-user login, biometric authentication energy-aware reconfigurations				
Ad hoc networking with mesh and automatic reconfiguration to balance load and to conserve power	Ad hoc and mesh networks are becoming an important link in creating so-called social Internet, to prevent Internet exclusion	Improvement of MAC layer protocols and optimal usage of the radio spectrum, and adaptability in different scenarios including rural areas	Wireless mesh routing protocol with hight compatibility with 5G technology to provide low latency, and reliable connectivity to all the mesh nodes.	Proven compatibility with 5G technology, and widespread implementation of ad hoc networking with mesh, and automatic reconfiguration for high-efficiency energy consumption
(4) Long range low power RF transceivers for backhaul	Technologies already available, but need to be evaluated, optimized, and tested for the CTU and remote reach use cases	Standardized few transceiver configurations for selected use cases	Global consensus on selected technologies. Some commercial rollouts worldwide	Widespread deployments throughout the world. Completed validation.
Customization of directional beam forming and MIMO for rural reach out and for remote areas. Collaboration among vendor and research communities. Vendor buy-in for volume production. Availability of power.				
Low-power directional antennas possibly utilizing split architecture of RH, BB and edge cloud to lower cost				

Name (be brief)	*Current State* *(2020)* *(details)*	*3 years* *(2023)* *(details)*	*5 years* *(2025)* *(details)*	*Future State* *10-years (2030)* *(details)*
(5) Spectrum refarming, especially when Wi-Fi space becomes crowded as more users/networks emerge	Sufficient research already done and extensive tests with some pilots already in place	Large number of governments and regulators allocating lower band of the spectrum for CTU. Eased transmit power limits.	Cognitive and dynamic spectrum use commercialized for CTU use cases	Optimized collaboration and interworking among the spectrum bands with minimal interference. Easy availability of network equipment and user devices.
Commitment of the regulators with updated policies. Availability of commercial grade equipment	Harmonizing allocation of spectrum for new technologies such as 5G. Setting up policies that enable spectrum refarming	Governments setting up policies that facilitate quick rollout of new technologies to replace obsolete ones such as 5G for WiMAX	Fully rolled out 5G technologies	Massive production of devices. Affordable 5G services that are easily available in both urban and rural areas. A connected world.
New spectrum regime and low or free disbursement of spectrum resource to promote lowest cost deployments and services	Governments studying pricing models for new spectrum identified for 5G	Assignment of spectrum to operators and deployment	Massive deployment of new technologies	Avail more spectrum to build capacity for availability of broadband services.
(6) CTU network slice in 5G and B5G networks	Concept and technology in early stage of definition and standardization	Sufficient thought leadership and critical mass to require that there be a network slice for CTU that is either free of cost or very low cost	Some laboratory and pilot implementations and validation of the concept	Limited commercialization of the slicing technology to CTU use cases.
Standards, availability of products, and lack of full understanding on how to actually build and deploy network slices				
Increased collaboration among the various stakeholders and strong participation in standards bodies				

Name (be brief)	*Current State* *(2020)* *(details)*	*3 years* *(2023)* *(details)*	*5 years* *(2025)* *(details)*	*Future State* *10-years (2030)* *(details)*
(7) Content management	Various solutions and technologies already known and available. These, however, need to be applied to CTU use cases and network architectures	Systems level architecture defined and standardized for commercialization	Pilots implanted and solutions validated through user feedback and how well the approach to crowd-sourcing is working and received	Numerous global deployments that engage the end users and communities in generating and managing content of local interest.
Edge-based content management architecture				
Develop a distributed architecture that promotes and enables local participation				
(8) Simplified user authentication and security	Technologies available, but not integrated and optimized for simplicity for the digitally illiterate/disadvantaged users	Architecture defined and open but secured authentication and security platform developed	Testbeds and pilots done with user feedback completed for large scale commercial rollout	Worldwide large-scale commercial deployment.
Lack of simple and useable biometric authentication for the CTU class of users				
Solutions available but need to be integrated in user devices				
(9) Intuitive human computer/device interaction (HCI) technologies adapted for the users who are digitally disadvantaged	Technologies generally available, but not integrated with devices with the CTU users in mind	HCI architecture defined	Implementation done by some vendors and laboratory and field trials completed	Successful roll-out of new HCI for the target CTU users.
Consensus among the developers on the HCI approach and architecture. Openness of the platform that enables authoring of tools and techniques by anyone				

Name (be brief)	*Current State* *(2020)* *(details)*	*3 years* *(2023)* *(details)*	*5 years* *(2025)* *(details)*	*Future State* *10-years (2030)* *(details)*
Integration of voice, video and gesture modalities with applications and the browsers with minimal use of text-based interaction				
(10) Availability of power and energy conservation where either there is no grid or power is intermittent	Technologies available, but not optimized for low cost	Architecture defined that use both grid and renewable energy sources for network equipment and user devices in CTU use cases	Selected field trials done and some commercial roll-outs	Turn-key solutions available worldwide.
Cost-optimized, safe and secured access to power				
Develop low-cost, integrated solution to power supply				
(11) Affordable but sustainable business models, leveraging the fact that the rural communities become engaged with the larger global communications and economic systems	Some theoretical models published but not adopted by the service providers since they only target the revenue with quantifiable KPIs	New model of social impact developed that are preferably also quantifiable	Large feedback on the success or failure of the newly developed business models gathered and evaluated	Potentially novel and disruptive business models have been rolled out in commercial networks making up the Internet.
Novel KPIs or innovative social impact measures of success. Lack of governments to drive new measures of success for social impact, and novel policies of spectrum bidding, taxing and industry subsidies				
Novel barter methods akin to freemium models of today.				

6. SUMMARY

The goal of connecting the unconnected or under-connected is well aligned with the United Nations Vision 2030 SDG goals. It is well recognized that these goals can only be met with the Internet becoming accessible to everybody on this planet because building the new physical infrastructure is both very expensive and time consuming. Unfortunately, about 3.5B people, mostly living in rural and remote areas, have yet to experience the value of the Internet. Although, there are numerous regional and global initiatives to bring Internet to the rural population, these efforts are neither coordinated nor create a critical mass to be able to influence product designs, solutions and standards. The IEEE FNI endeavors to bring all these efforts on a single platform for discussion to bring awareness and needed attention as 5G and B5G standards are being developed as one of the essential pillars of success of the future networks to be inclusive of all sections of the society. In order to give impetus to this effort, IEEE New Initiatives approved a project, "IEEE Connecting the Unconnected Challenge (CTU)," with the humanitarian goal of addressing the "digital divide." After identifying high priority humanitarian needs (such as healthcare, education, agriculture) the initiative will partner with relevant organizations to devise a program that can deliver services and applications to meet those needs through a competitive challenge. As one of the deliverables from the CTU working group in the IEEE FNI, in this white paper, we highlighted the current status, the future ambition and the requirements on 5G and B5G related technologies and networks to meet CTU requirements emanating from those users who these technologies are expected to serve. The white paper also discusses a number of novel business models for any CTU solutions to be commercially sustainable.

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9. ACRONYMS/ABBREVIATIONS

Term	Definition
1G-4G	First Generation to Fourth Generation
3GPP	Third Generation Partnership Project
5G	Fifth Generation
AAA	Authentication, authorization and accounting
ACK/NAK	Acknowledgment/negative acknowledgment
ACL	Access control list
AI	Artificial intelligence
AP	Access point
API	Application programming interface
APP	Application
AV	Audio visual
B2B	Business to business
B2C	Business to consumer
B5G	Beyond 5G
BS	Base station
BSS	Business support system
CAPEX	Capital expenditure
CCI	Co-channel interface
CDMA	Code division multiple access
CN	Core network
COTS	Commercial off-the-shelf
CP	Control plane
CTU	Connecting the unconnected
C/U	Control plane / User plane
D2D	Device to device
DevOps	Development and information technology operations
DFT-s-OFDM	Discrete Fourier transform spread orthogonal frequency division multiplexing
DL	Downlink

DPG	Digital public goods
DSA	Dynamic spectrum allocation
DTC	Digital transformation converegence
DTH	Direct to home
EAP	Edge automation platform
EMF	Electro magnetic frequency
eMBB	Enhanced mobile broadband
eNB	Evolved node B
EPC	Evolved packet core
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency-division duplex
FDMA	Frequency division multiple access
FNI	Future network initiative
FSO	Free space optics
FTTH	Fiber to the home
G2C	Government to consumer
GDP	Gross domestic product
GHz	Gigahertz
GP	Gram panchayat
GSMA	GSM (GroupeSpeciale Mobile) Association
GUI	Graphical user interface
HAP	High altitude platform
HCI	Human computer interface/interaction
H-DPG	High bandwidth-Digital public goods
HIR	Heterogeneous Integration Roadmap
ICT	Information and communications technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IIT	Indian Institute of Technology
ILNS	Internet Light Network Slice

IMS	IP multi-media subsystem
INGR	International networks generation roadmap
IoT	Internet of things
IP	Internet protocol
IRDS	International Roadmap for Devices and Systems
IRTF	Internet Research Task Force
ISG	Industrial specification group
ISM	Industrial, scientific and medical
ISP	Internet service provider
ITS	Intelligent transport system
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
KCN	Kondoa community network
KPI	Key performance indicator
KYC	Know your customer
LAA	Licensed assisted access
LCD	Liquid crystal display
LDPC	Low-density parity-check
LDPG	Low bandwidth-Digital public goods
LMLC	Large cell low mobility
LOS	Line of sight
LSA	Licensed shared access
LTE	Long-term evolution
M2M	Machine to machine
MAC	Medium access control
MANO	Management and orchestration
MEC	Multi-access edge cloud
MIMO	Multiple input, multiple output
ML	Machine learning
mMTC	Massive machine-type communication
mmWave	Millimeter wave

MR	Merged reality
MVNO	Mobile virtual network operators
NLOS	Non-line of sight
NaaS	Network as a service
NASA	National Aeronautics and Space Administration
NF	Network function
NFC	Near field communication
NFV	Network function virtualization
NGO	Non-governmental organization
NGMN	Next generation mobile networks
NGC	Next generation core
NICT	National Institute of Information and Communications Technology
NKN	National knowledge network
NLOS	Non-line of sight
NOMA	Non-orthogonal multiple accesses
NR	New radio
NS	Network slicing
NSA	Non-standalone
OEC	Open edge computing
OFDM	Orthogonal frequency-division multiplexing
OMEC	Open mobile edge cloud
OPEX	Operational expenditure
OPNFV	Open platform network virtualization
OSS	Operational support system
OTP	One-time password
OTT	Over the top
PGW	Packet gateway
PHY	Physical layer
PoC	Proof of concept
QoS	Quality of service
RAN	Radio access network

RE	Range extension
RIA	Research ICT Africa
RSRP	Reference signal received power
SAS	Spectrum access system
SDG	Sustainable Development Goals
SDN	Software defined network
SDO	Standards developing organization or standards development organization
SIM	Subscriber identification module
SISO	Single input and single output
SLA	Service level agreements
SON	Self-optimizing network
TDD	Time-division duplex
TDMA	Time division multiple access
TSDSI	Telecommunications Standards Development Society India
TTI	Transmission time interval
TVWS	TV white space
UAV	Autonomous aerial vehicles
UE	User equipment
UL	Uplink
UP	User plane
URLLC	Ultra-low reliability low latency connection
USAID	United States Agency for International Development
V2I	Vehicle to infrastructure
V2V	Vehicle to vehicle
vEPC	Virtual evolved packet core
VLE	Village level entrepreneur
VNF	Virtual network function
WOBAN	Wireless optical broadband access network
WMN	Wireless mobile network
WRAN	Wireless radio access network
WRC	World Radio-communication Conference

WG	Working group

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