# Connected OFCity Challenge: addressing the digital divide in the developing world

Marco Ruffini, Kasandra Pillay, Chongjin Xie, Lei Shi, Dale Smith, Inder Monga, Xinsheng Wang and Shan Wey

***Abstract*—Over the past 50 years, the development of information and communications technology (ICT) has provided unprecedented support to the steady economic growth of developed countries. In recent years, some of the largest growth has been reported in emerging economies, which however often lack adequate telecommunications infrastructure to further sustain their development. Although a number of service providers and system vendors have started to address the issue, the challenges they encounter are substantially different from those in the developed world, including an unreliable electricity grid, poor fiber infrastructure, low revenue expectations, and often a harsh climate environment.**

**This paper reports use cases and solutions pertinent to the development of networking infrastructure in emerging economies, provided by organizations directly involved in such activities. After providing some background information on the current state of network infrastructure and the main challenges for Africa and rural China, the paper provides details on two proposed solutions. The first focuses on the provisioning of services and network infrastructure through the development of low-cost data centers, whereas the second proposes cost-effective adaptation of both fiber and hybrid copper-fiber technology to rural areas. The article is concluded with a brief discussion on the complementarity of the two approaches.**

***Index Terms*—Network architecture, developing world, NREN, OFCity, rural broadband, data center, fiber access.**

## I. Introduction

Networks and telecommunications are important pillars of today's economy, which is strongly based on digital services. A prime application associated with network infrastructure is broadband delivery; however, information technology is pervasive in any field and industry and is progressively covering larger parts of our world. Typically, network architectures and deployment practices are designed for the developed world, for example, in high-revenue locations; thus, the focus is on high-density population areas and regions where most other commodities (e.g., electricity, water, roads) are readily available. This approach is not directly applicable to some developing regions, where challenges are different, due to a lack of infrastructure and the diverse structure of the economy. However, the impact of developing regions to the global economy is changing rapidly. According to McKinsey, "the City 600 (i.e., the 600 cities making the largest contribution to the global Gross Domestic Product (GDP)) will generate 65 percent of world economic growth by 2025" [1]. Over 440 of these cities are in emerging economies, which by 2025 will account for close to half of overall growth. One billion people will enter the global consuming class by 2025. They will have incomes high enough to classify them as significant "consumers of goods and services and around 600 million of them will live in the Emerging 440".

The work behind this paper stems from an annual event held since 2016 at the Optical Fiber Communications Conference (OFC), named Connected OFCity Challenge. This event is a platform for industry experts and academic researchers to debate and create innovative solutions for future broadband network infrastructure and advanced services in a smart city. After focusing for two years on city models based on mid-size municipalities in the United States [2], [3], i.e., a well-funded modern city in a developed country, in 2018 the event organizers shifted the focus to broadband technologies for the developing world. This paper reports on work carried out in preparation for the OFCity event held in March 2018. Experts from the South African National Research Network (SANReN), the Network Startup Resource Center (NSRC) based at the University of Oregon, the Alibaba infrastructure group and ZTE built a case study on broadband connectivity for rural and developing regions both in Africa and China. They provided information on geographic and demographic composition of the regions and shared their insight on both the technological and business challenges faced by the general population. For example, the lack of fiber infrastructure and the often unreliable electricity grid pose challenges that are different from developed countries and require a different set of solutions.

This paper starts with an overview of the current network infrastructure in developing countries, adopting both East Africa and rural China as specific use cases. It emphasizes how their current state is linked to the evolution of the regions over the past century. Then it provides insight into how development of new infrastructure can be adopted, through cost-effective solutions, to improve the delivery of digital

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services in developing regions. The first solution focuses on the development of Internet infrastructure and services around the deployment of new data centers. The second solution proposes architecting Passive Optical Network (PON) access fiber deployments to suit the economic constraints of rural regions. A brief discussion on the complementarity of the two approaches concludes the paper.

## II. The use case for bringing Internet to developing and rural communities

### A. *The East Africa use case: from colonization to digitization*

In order to provide an understanding and insight into where some of the problems faced by developing regions in Africa originated, we look at its history over the past century. By the early 20th century, much of Africa had been colonized by European powers. African countries gained independence at different times, but most gained their freedom in the mid-1900s. At that time, the rate of urbanization was relatively weak and its consequences are still evident today with many issues related to basic services [4].

Similar challenges exist in the ICT sectors. For example, East Africa has only recently gained access to undersea optical fiber cables, when, in 2009, the first cable linked South Africa to Europe via the East Coast of Africa, over a distance of 17,000 km. Since then, many more fiber connections have been put in place, as shown in Fig. 1, helping enormously the development of broadband on the East and West coasts of Africa. In only a handful of years, the move from a telecommunications infrastructure based on satellite communications towards one based on optical fiber has slashed bandwidth costs "from about US$5,000 to under US$100 per Mb/s per month" [6].

As the number and capacity of undersea fiber cables have grown, there has been a corresponding increase in the level of investments in terrestrial capacity (also shown in Fig. 1). Projects such as Google's Project Link (transformed in 2017 into CSquared [7]) are installing fiber in a number of regions, with a profound impact on price reduction and an increase in available services in those areas [8]. The last several years have seen investments in fiber infrastructure by many organizations, including power transmission companies [9]; however, more investments are needed to reach underserved areas and to continue to drive competition. Indeed, while the price reduction has been exponential, Internet access pricing is still high in some areas as compared to developed regions, with the average cost of purchasing 1 GB of mobile data at 9.3% of a citizen's average income [10]. In addition, in some cases, the average cost of monthly broadband packages is nearly double the national minimum wage [11].

Overall, there is still very limited availability of terrestrial fiber and network availability is much lower than in a typical developed country, as fiber cuts are common due to a lack of centralized planning and ownership. Many regions often have an incomplete and unreliable power grid and Internet connections and outages are common. Additional challenges include theft and Ultra-Violet (UV) degradation to fiber cables. When considering data center deployments, these regions are faced with unique environmental challenges such as extreme heat, heavy rains and flooding, in addition to the unreliable power grid. As a result, there is a lack of large data centers, which translates into poorer services to end users and increased reliance on international bandwidth to access Internet resources.

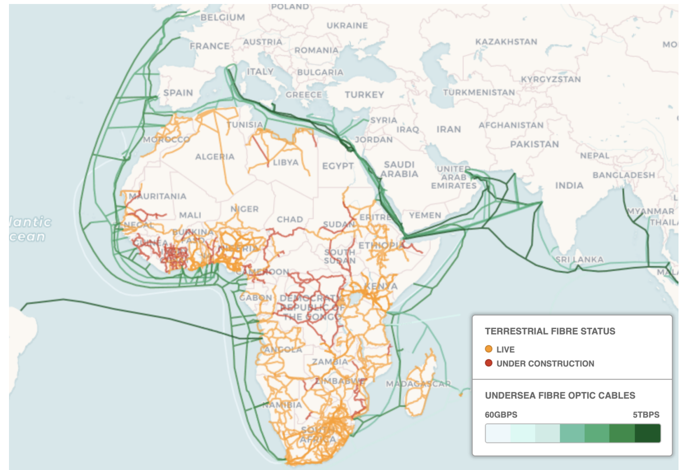


Fig. 1: Known terrestrial and undersea fiber in Africa (2018) (courtesy of NSRC [5])

Business related issues include limited financial support, challenges with navigating Internet administrative processes and end-user affordability (e.g., public subsidies for lower-income population). From a network operation perspective, most operators are faced with lack of training for network engineers to sustain their operation and difficult regulatory environments. These add to the lack of viable business models in rural areas, excessive dependence on external funding sources, lack of sustainable funding models for operational expenses, as well as the need for national and/or regional cooperation and the need for a strong drive towards open access Internet policies.

### B. *The use case of rural Chinese communities*

Even though China is the 2nd largest economy in the world [12] and has had tremendous growth in broadband coverage in recent years, the majority of the country is still constituted by rural remote villages and farm land with relatively low population density. In 2011, the broadband population penetration rate in China was 12.23% according to a report from China Academy of Information and Communications Technology (CAICT) [13]. Although higher than the global average of 10.25%, it was far below the values for Western Europe (32.54%) and Asia-Pacific (APAC) (13.48%). At that time, the average broadband speed was 1.4 Mb/s, ranked 90th in the world, 10th in APAC. By comparison, the average broadband speed was 2.7 Mb/s globally, with 16.7 Mb/s in Korea and 6.1 Mb/s in the United States. The rural villages of China were even lower than the 1.4 Mb/s national rate, while some areas had no coverage at all.

Over the past few years, the changing economic structure has stimulated strong economic growth in remote villages, which has generated new and higher income for the residents. In recent years, the income growth in rural villages has exceeded that of city dwellers. In the first quarter of 2019, the income growth in rural villages was 8.8% compared to 7.9% in cities [14]. Higher disposable income has led to more spending on business communication, e-commerce, entertainment, remote education and healthcare, etc. However, the broadband infrastructure still lags behind the growing needs.

In the Broadband China strategy, the Chinese government has outlined a plan to greatly increase the broadband population penetration rate, increase broadband subscribers and the average data rate, with a special emphasis on reaching remote towns and villages [15]. By 2020, the target is to attain a 70% fixed broadband population penetration rate and a 12 Mb/s average fixed broadband speed in remote villages. Table I summarizes the historic data from 2013 and the projections for 2020 [15].

TABLE I: Broadband penetration statistics for rural China

| Year | 2013 | 2020 |
|---|---|---|
| Fixed broadband penetration rate | 40% | 70% |
| Number of fixed broadband subscribers | 210 M (50 M rural) | 400 M |
| Wireless broadband penetration rate | 25% (3G/LTE) | 85% (3G/LTE) |
| Number of wireless broadband subscribers | 330 M | 1.2 B |
| Average fixed broadband speed (urban) | 20 Mb/s (available to 80% of users) | 50 Mb/s |
| Average fixed broadband speed (remote villages) | 4 Mb/s (available to 85% of users) | 12 Mb/s |

### C. The role of National Research Networks

One sector that deserves special attention is that of research and education institutions, as they are typically provided with state-funded infrastructure, organised by National Research and Education Network (NREN). In a few African countries, significant effort was carried out by pioneering academics who, with the help of the Association of African Universities (AAU) and its Regional Education Network (REN), promoted the idea that African countries needed to establish their own NRENs. In addition, they promoted the idea to have them linked together in a continent-wide network through an initiative called the African Research and Education Network (AfREN) [4]. The AfREN initiative has since spurred the development of other regional associations that promote the AfREN concept of NRENs such as the UbuntuNet Alliance [16]. The NSRC also plays a significant role in helping to develop and deploy Internet infrastructure and services for NRENs.

According to Foley (2016) [6], as of June 2016 there were fourteen operating NRENs in Sub-Saharan Africa and four in North Africa. Twelve more are in advanced planning in other African countries. This is out of a total of fifty-four African countries and "coincides with a transformation in the telecom infrastructure and services on the continent as fiber optic connectivity, both undersea and on land, is expanding at a rapid pace" [6]. However, even with these dedicated organizations, the average bandwidth provided to member institutions can be as low as 1-10 Mb/s, with an average of 100 Mb/s [6].

An example of a more mature NREN in Africa is the South African National Research and Education Network (SA NREN). This is a joint effort between the SANReN and the Tertiary Education Research Network (TENET) of South Africa. This NREN currently connects its sites at 1 Gb/s or 10 Gb/s. There are also plans to upgrade its national backbone from 10 Gb/s to 100 Gb/s technology in the near future, with growing international capacity off the East and West coasts of the country. The NREN also offers its research and education community value-added services such as trust and identity services, video conferencing, data transfer and cyber-security services.

## III. Technology for tackling the digital divide

This section provides two complementary solutions, which have already been deployed in the field, to improve connectivity in rural areas of developing nations. The first is based on the use of distributed data centers close to the end users, while the second focuses on adaptation of broadband access transmission technologies to rural areas. In section III.D we then propose a design that attempts to bring together pros and cons of the two strategies to provide an end-to-end design solution.

### A. A Broadband development approach based on data centers

One of the solutions to provide digital services and networks in areas with little legacy network infrastructure is to build up a new network infrastructure focused on data-center deployment. Figure 2 shows an example of an architecture for a data-center-based information infrastructure that can be used to provide Internet services to local communities. One data center is sufficient to cover an area of a thousand square km, which in these regions could provide services to about one million users. A second data center might be considered for additional resilience, depending on available resources.

A number of Points of Presences (POPs) stations, which could be implemented as smaller modular micro data centers, are then distributed around the area and connected to the main data center with optical fibers. Each POP would provide coverage to end-user premises through several service hubs that use Wi-Fi or other wireless coverage technology. Service hubs can be located in office buildings, schools, stores and community centers, as edge nodes, which provide local computation, storage and wireless access, i.e., edge computing services. This approach also provides a solution for areas without fiber connections to the service hubs. As most data is processed and stored locally, the required bandwidth to connect to the other sites is significantly reduced. A mesh network to connect service hubs and POPs/modular data centers can be formed using 5 GHz WiFi technologies. With advanced antenna technologies, up to 1 Gb/s bit rates can be achieved for links less than 5 km. Higher speeds are attainable with wireless technology, typically operating in the millimeter wave range; however such techniques are mostly suitable for

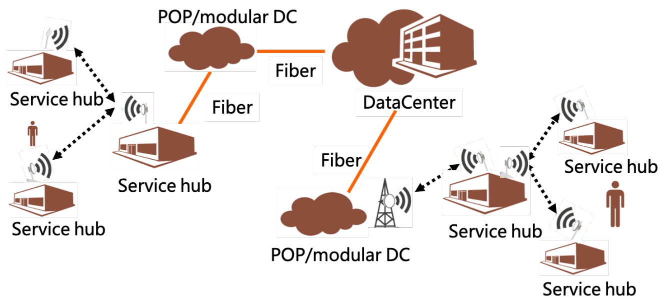


Fig. 2: Architecture of information infrastructure for connecting communities based on data centers

high-density scenarios with distances below 1 km [17]. For longer distances, e.g., for links between POPs and service hubs and between DCs and POPs, fiber transmission appears to be the most functional solution.

These local, small data centers are ideal for areas that do not have rich energy resources and can be in the form of containers, which are cost effective and scalable for the future. Multiple containers, consisting of computing and storage units, power supply units, cooling units, surveillance and maintenance units, and backup power units are deployed for each system. A sample data center might include the following items (summarized in Table II):

- 500 servers, each of 2 RU size consuming 350 W, generating a total power consumption of 175 kW.
- Networking equipment (switches, routers, optical transport) and surveillance systems (cameras and sensors), for a total consumption of 15 kW.
- Air cooled air-conditioning for cooling servers and networking equipment.
- 2 + 1 power supply architecture with UPS.

The two power supplies can come from a single power grid if it is not possible to connect to two independent power grids, with capacity no less than 300 kVA. The backup power is provided by generators. Assuming the Power Usage Effectiveness (PUE) is less than 1.3, the total power budget for a small data center, with an assumed aggregate server and networking power consumption of 190 kW, becomes about 250 kW.

In addition to this local data center solution, in areas that are rich with renewable energy resources, such as solar, wind or hydroelectric power, it is also possible to build mega data centers, which can provide Internet services for the greater region. More importantly, this is an efficient way to use local renewable energy resources and can bring revenue for local communities to help develop the local economy. One good example is the Zhangbei cloud data center in Zhangbei County, Hebei Province in China [18]. Zhangbei is very rich in renewable energy resources. It produces 5 billion kW of renewable wind and solar energy each year, while annual consumption of the whole county is less than 400 million kW [18]. In Zhangbei, besides providing Internet services for the local community, the data centers have become the biggest consumer of local wind and solar energy, providing a significant amount of revenue, which greatly helps the local economy. In addition, the natural energy resources significantly reduce data center operating costs.

TABLE II: Configuration of a typical container-based data center

| Unit Name | Size of containers | Configuration | Number of containers |
|---|---|---|---|
| Computation and storage unit | 40 feet | 250 servers | 2 |
| Power supply unit | 40 feet | 250 kW power system | 1 |
| Surveillance and maintenance unit | 40 feet | 2 people work space | 1 |
| Backup power unit | 20 feet | 300 kVA generator & diesel tank | 1 |

## B. *Fiber deployment in rural areas*

In terms of connectivity, even the solutions adopting small local data centers will require a large data exchange with the outside world (either to other data centers or network gateways). The most appropriate technology that can provide sufficient bandwidth to meet the large capacity data transmission requirement (e.g., on the order of 1 to 20 Tb/s) is fiber-optic communications. In order for the data center and the whole network to operate properly, new fiber connections need to be provisioned, and most data center operators require three independent fiber routes. Indeed, reliability has become one of the most pressing requirements for cloud computing services and most data center operators require design rules whereby the service is not affected by two simultaneous fiber cuts.

In areas with existing pole infrastructure, which can be from the power lines of electricity companies, aerial fiber cables are one of the most cost effective methods of field fiber deployment as it avoids the need to dig up roads to bury fiber cables or ducts. However, aerial cables are fragile. They strain, sag and eventually break if they are exposed to extreme wind and large temperature variation. In addition, ice loading and UV degradation can occur in, respectively, extremely cold or hot environments. For these reasons, many data center providers prefer that their fiber cables be buried underground, as these are more reliable than aerial fibers, especially in areas where extreme weather is common. Buried fibers are not affected by excessive wind, UV radiation or ice damage, as, for example, they are buried below the layer where the soil freezes. However, buried fiber deployment costs much more than aerial fiber deployment, as the fiber needs to be buried deep in the ground. If a buried cable breaks, it is also more expensive to repair.

From a system-level perspective, connecting data centers in some remote areas can be achieved through unrepeatered fiber-optic transmission. It has been demonstrated that an unrepeatered system can carry 8 Tb/s capacity over more than 300 km without any inline amplifiers, and longer distances can be achieved with some sacrifice in capacity [19], [20]. Such capacity is sufficient for example for a small data center. As

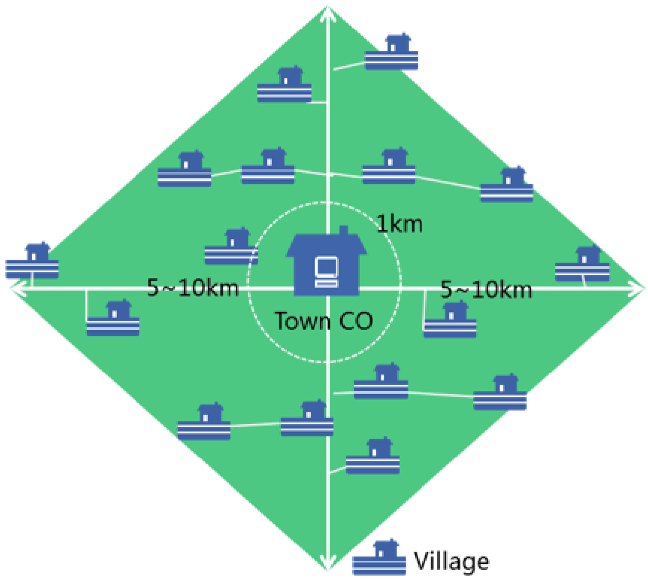


Fig. 3: Typical topology of a town central office providing broadband access to about twenty villages

an unrepeatered system does not need any inline repeaters, the entire fiber line is passive and only some specially designed optical amplifiers are required at each end of the line. This significantly reduces the CapEx and OpEx of the fiber-optic system, especially in areas with poor infrastructure.

### *C. Rural fiber deployment strategies based on Passive Optical Networks*

Bringing the focus back to the access network, a second solution, which is complementary to the development of data centers, is based on re-architecting multiple access technologies, both fixed and wireless around the constraints posed by rural areas. Indeed, a large array of broadband technologies must be considered to connect the many remote areas with diverse geographical challenges, such as coastal region/islands, desert, high humidity and high elevation areas. Technologies including fixed fiber/copper access, 3G/4G wireless access, coaxial cable, microwave and satellite have all been deployed.

In China, the broadband infrastructure plan for remote villages is the so-called Advancing Fiber Retreating Copper (AFRC) strategy, i.e., starting with a hybrid fiber-copper solution and phasing out copper wherever possible. Traditionally, broadband connectivity, if available at all, is provided by Point-to-Point (PtP) copper trunk cable from a town Central Office (CO) to a remote node covering villages that are 3 to 5 km away, using ADSL2+ technology with transmission rate up to 24 Mb/s. Once a village is reached, twisted-pair cable is used to make the final connection to each household. A typical example for a Chinese town-village is illustrated in Fig. 3, where a town CO would serve about 20 villages within a 5-10 km radius. Each village has typically tens to a few hundred households.

A typical set of solutions used to bring fiber to the rural areas is shown in Fig. 4. The PtP copper trunk cable from the town to the villages is replaced by PtP trunk fiber. This is typically followed by shared PON fiber to another set of nodes in the village. From there, twisted-pair cables, with typical distance of less than 800 m, are left in-place to cover the final connection to the households. A village can also serve as a center node hosting a small Optcal Line Terminal (OLT) to serve a few other smaller neighboring villages. By doing so, wider coverage and better services can be achieved with lower OpEx and potentially lower CapEx than its copper counterpart. In addition to improving the broadband connectivity, replacing copper with fiber also solves the issue of theft (motivated by the price of copper), which is a prevalent problem causing significant monetary loss annually.

Overall, while the AFRC strategy is under development, it is expected that fiber and copper will coexist for the foreseeable future. Fiber access faces several challenges such as high cost in civil work and regulatory restrictions, while copper technology continues its advance from 100 Mb/s with Very-high-bit-rate Digital Subscriber Line V2 (VDSL2) to 1 Gb/s with G.fast. Furthermore, NG.fast is expected to deliver an astonishing 5 Gb/s+ to the end-user. Clearly, for copper technology, an increase in capacity can only be achieved through a reduction of the transmission distance. (A shorter distance is required to increase the signal-to-noise ratio of the transmission channel, in accordance with the well-known Shannon-Hartley theorem, which specifies the maximum capacity of a communications channel.) Progressively reducing the copper distance by deploying optical fiber deeper into the network is however a popular strategy across operators worldwide. Depending on each operator's deployment scenario, four sample use cases of hybrid fiber-copper access and PtP Ethernet access are shown in Fig. 5.

Case 1 is a hybrid Gigabit-PON (GPON) and VDSL2 solution, in which the two technologies independently provide services up to 100 Mb/s. This case typically addresses areas with business buildings within a short distance (<1000 m) from the CO via VDSL2 and villages up to 20 km from the CO via G-PON. Case 2 is also a hybrid GPON and VDSL2 (with vectoring) solution providing 100 Mb/s services. However, in this case, PtP fibers are first used to connect a town CO to several village COs followed by either GPON or VDSL2 with Vectoring to subscribers. This case typically addresses villages in more remote areas. Case 3 increases the capacity provided to customers by either connecting them using 10G-PON technology or else providing 1Gb/s speed though G.fast. In the latter case, the copper distance is very short (up to 100 m) and the cabinet is connected to the village CO using PtP fibers. This case is typically suited for fast growing areas. For completeness, Case 4 describes a scenario of direct PtP fibers to the premises, such as local government agencies and large business users. This case does not apply to typical individual household subscribers.

### *D. End-to-end solution design*

The solutions proposed above are indeed complementary in that the first solution, based on the development of data centers, is optimal for green-field developments, where little

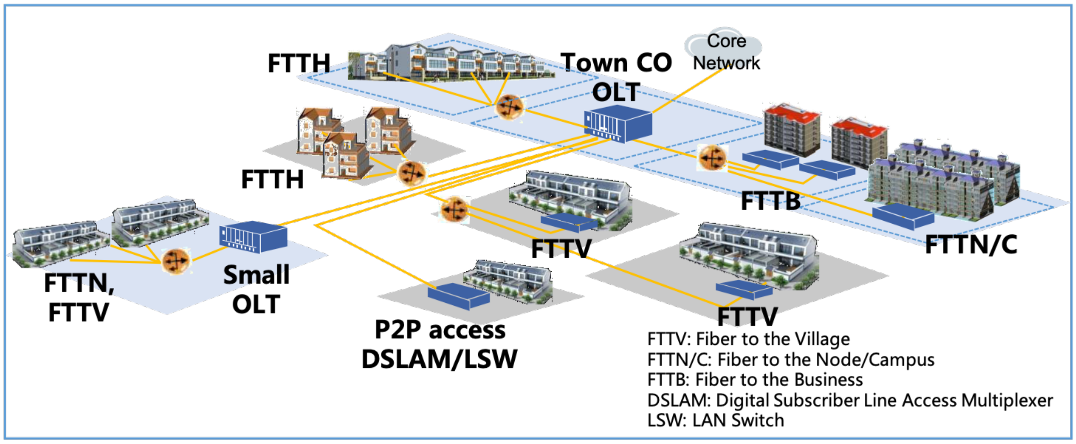


Fig. 4: FTTx architecture to connect remote villages

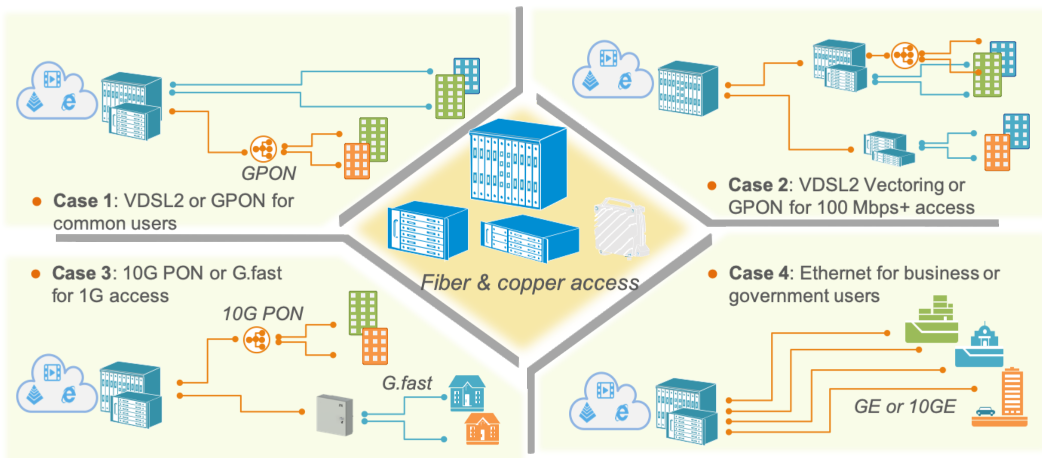


Fig. 5: Hybrid fiber-copper solutions

previous infrastructure exists and is thus heavily based on the use of mobile infrastructure, both for end-user connectivity and part of the backhaul. Conversely, the second proposed solution is based on the existence of old copper infrastructure, thus it can assume the reuse of existing ducts. For this reason it makes use of fixed network infrastructure, providing more reliable and higher capacity connectivity. In some cases, there can also be benefits in merging the two strategies together into an end-to-end solution.

For example, taking the FTTx architecture shown in Fig. 4 as reference, service hubs (shown in Fig. 2) could be located at small OLT sites, with micro DCs at the Town CO OLT site. This could secure higher capacity and more resilient connectivity in locations where fiber is already available or where there is a possibility to invest in fiber access infrastructure. The larger data centers would then be connected via the core network to multiple town COs.

In addition, as the telecommunications world is heading towards 5G type of applications, with low latency and high reliability requirements, it is natural to ask how will this architecture support such requirements in the future. An interesting proposition is to evolve the PON architectures to support communications across all end points. While typical PON architectures only allow traffic between OLT and Optical Network Units (ONUs) (i.e., North-South), a new design could support communication directly across the end points (i.e., East-West between ONUs). This would enable ultra-low latency communications across any end point in the system, including edge cloud computation sites [21], making the architecture ready to support the next generation of Internet applications. Another interesting future approach is the use of hybrid beamforming for massive Multiple Input Multiple Output (MIMO) communications [22], which could also be used to enable direct high-speed communications, dynamically between end points and edge cloud, possibly replacing part of the fiber access network.

## IV. Conclusions

There are many unique challenges in the developing world. The solutions proposed here address connectivity both in the metro/core area and in the access. Two different approaches were discussed. The solutions should be viewed as complementary as they address different parts of the network and different scenarios, i.e., legacy copper vs. greenfield, either of which may be encountered in developing regions.

In the past few years there has been increasing attention from service providers and equipment vendors in improving network connectivity and services in the developing world. The challenges are many, from economic to environmental, but innovative solutions have been proposed for adapting the architecture and technology to address these challenges.

## V. Acknowledgements

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