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Connected OFCity Challenge: Addressing the Digital Divide in the Developing World

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Solving digital divide in the developing world

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***Abstract*—The development of Information and Communications Technology has provided over the past 50 years unprecedented support to the steady economic growth of developed countries. In recent years, some of the largest growths have been reported in emerging economies, which however often lack adequate telecommunications infrastructure to further sustain their development. Although a number of service and vendor providers have started to address the issue, the challenges they encounter are substantially different from those in the developed world, including unreliable electricity grid, poor fibre infrastructure, low revenue expectations and harsh climate environment.**

This paper reports use cases and solutions pertinent to the development of networking infrastructure in emerging economies, provided by organisations directly involved in such activities. After providing some background information on the current state of network infrastructure and main challenges for Africa and rural China, the paper provides details on two solutions proposed by the Alibaba infrastructure group and ZTE, respectively. The first is focused around the provisioning of services and network infrastructure through the development of low-cost Data Centers, while the second proposes cost-effective adaptation of both fibre and hybrid copper-fibre technology to rural areas. Finally the article is concluded with a brief discussion on the complementarity of the two approaches proposed.

***Index Terms*—Network architecture, Developing world, NREN, rural broadband, Data center, fibre access.**

I. Introduction

Networks and telecommunications are one of the pillars of today's' economy, which is strongly based on digital services. While the first application that comes to mind when thinking about network infrastructure is broadband delivery, Information Technology is pervasive in any field and industry and progressively covering larger and larger parts of our world. Typically, network architectures and deployment practices tend to be designed for the developed world, for example around deployment in high-revenue locations, so focus is on high-density population areas and where several other commodities are given for granted, e.g., electricity and other communication infrastructure (e.g. roads, etc.). This approach is not directly applicable to some of the developing regions, where challenges are different, due to lack of infrastructure and 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]. However, over 440 such 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 at the Optical Fiber Communications Conference (OFC), named Connected OFCity Challenge. This event can be seen as 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 organisers decided to move the focus on broadband technologies for the developing world. This paper delivers thus a story derived from work carried out in preparation for the OFCity event held in March 2018 in San Diego. 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, have come together to build up 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 to 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 the developed countries and call for 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 a specific use cases and emphasizing how the current situation is linked to the evolution of the region over the past century. Then it provides insight, from two large companies, on how development of new infrastructure can be adopted, through cost-effective solutions, to improve the delivery of digital services in developing regions. A first solution, provided by the Alibaba Infrastructure group, focuses on the development of Internet infrastructure and services around the deployment of new data centers. A second solution, provided by the ZTE group, proposes architecting passive optical network access fibre deployment to suit the economic constraints of rural regions. Finally, we conclude the article.

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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 centuries. By the early 20th century, much of Africa had been colonized by European powers which led to large movement of wealth and resources to Europe as well as large discrepancies in resources distribution between the people who remained in these regions. Such depletion of resources and social inequality carried on over the years and is still the main reason behind the weakness of their economy. African countries gained independence at different times, but most gained their freedom from colonizers 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 “employment, especially for the youth, urban planning, urban management, social services (health, education, transportation, energy, and culture), infrastructure, food security, public participation as well as the issues of violence, urban poverty and pollution" [4]. Similar challenges exist in the Information and Communication 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 17,000km. Since then many more fibre connections have been put in place, as shown in Fig. 1, helping enormously the development of broadband in 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 fibre, have tumbled bandwidth costs “from about US$5,000 to under US$100 per Mbps 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]) is installing fiber in a number of regions, with a profound impact on pricing reduction and increase in available services in those areas. The last several years have seen investments in fiber infrastructure by many organizations, including power transmission companies [8], however, more investments are needed to reach underserved areas and continue to drive competition. Indeed, while the price reduction was exponential, Internet access pricing is still high in some areas when compared to developed regions, with the average cost of 1GB at 9.3% of a citizen’s average income. In addition, in some cases, the average cost of monthly broadband packages is nearly double the national minimum wage [9].

Overall, there is still very limited availability of terrestrial fibre and the network availability is much lower than the developed countries average, as fiber cuts are common due to lack of centralized planning and ownership and there is no “call before you dig” service to prevent this. 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

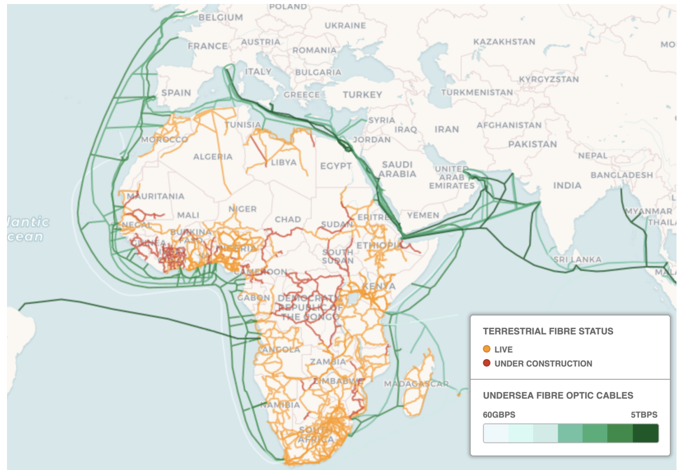

Fig. 1: Known Terrestrial and Undersea Fibre in Africa (2018) (courtesy of NSRC[5])

to fibre cables. When considering data center deployments, these regions are faced with unique environmental challenges such as extreme heat, heavy rains, flooding and lightning, in addition to the unreliable power mentioned above. As a result, there is a lack of large data centers, which translates into poorer services to the end users and increased reliance on international bandwidth to get to Internet resources. Business related issues include limited financial support, challenges with navigating internet administrative processes and affordability to end-users (public subsidy for lower income population). From a network operation perspective, most operators are faced with lack of training for network engineers to sustain its operation and difficult regulatory environments and regulatory barriers. 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, lack of national and/or regional cooperation and lack of strong national leadership driving open access Internet policies.

B. *The use case of rural Chinese communities*

Even though China is the 2nd largest economy in the world and has had tremendous growth in broadband coverage in recent years, the majority of the country is still constituted by poor, 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). Although higher than the global average of 10.25%, it was far below the values for West European (32.54%) and Asia-Pacific Asia-Pacific (APAC) regions (13.48%). During the same time, the average broadband speed was 1.4 Mbps, ranked 90th in the world, 10th in APAC. By comparison, the average broadband speed was 2.7 Mbps globally, 16.7 Mbps in Korea and 6.1 Mbps in the US. The rural villages were even lower than the 1.4 Mbps 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 generates new and higher income for the residents. In recent years, the income growth in rural villages is well over 11% annually, exceeding that of city dwellers. Higher disposable income is spent to improve business communication, e-commerce, entertainment, remote education and healthcare, etc. However, the broadband infrastructure lags behind the growing needs. In the Broadband China strategy, the Chinese government outlines the strategy to greatly increase the broadband population penetration rate, increase broadband subscribers and the average data rate, with a special emphasis of reaching remote towns and villages. By2020, the target is to reach 70% fixed broadband population penetration rate and 12 Mbps average fixed broadband speed in remote villages. Table I summarises the historic data in 2015, and projections for 2020.

Year	2015	2020
Fixed broadband penetration rate in remote villages	50%	70%
Number of fixed broadband subscribers	270M (8.1M in villages)	400M (12M in villages)
Wireless broadband penetration rate	32.5% (3G/LTE)	85%
Number of wireless broadband subscribers	450M	1.2B
Average fixed broadband speed (urban)	20 Mbps	50 Mbps
Average fixed broadband speed (remote villages)	4 Mbps	12 Mbps

TABLE I: Broadband penetration statistics for rural China

C. *The role that National Research Networks plays for broadband development*

One sector that deserves specific 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 which promote the AfREN concept of NRENs such as the UbuntuNet Alliance. 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 organisations, the average bandwidth provided to member institutions can be as low as 1–10 Mbps, with an average of 100 Mbps [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 1Gbps or 10Gbps. There are also plans to upgrade its national backbone from 10 Gbps to 100 Gbps 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.

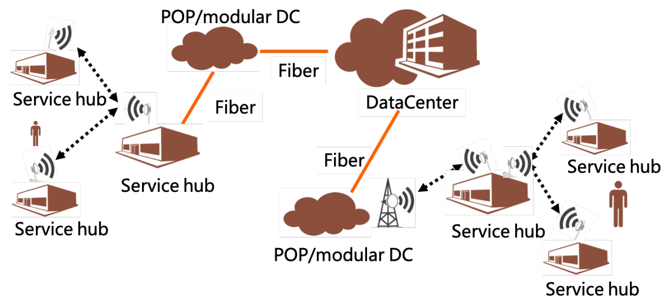

Fig. 2: Architecture of information infrastructure for connecting communities based on data centers

III. Technology for tackling the digital divide

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

One of the solutions to provide digital services and networks in areas without much legacy network infrastructure, is to build up a new network infrastructure focusing around data centers deployment. Figure 2 shows an example of 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 will 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 service, i.e. edge computing services. This approach also provides a solution for areas without fiber connections to 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-Gbps bit rates can be achieved for less than 5-km links.

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 is cost effective and scalable in 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 (summarised in Table II):

- 500 servers, each of 2 RU size consuming 350W, 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 one single power grid if not possible to get 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 the small data center, whose aggregate server and networking consumption is 190KW, 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 larger outer 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, built by Alibaba [9]. Zhengbei is an impoverished county but is very rich in renewable energy resources. It produces 5 billion kWh of renewable wind and solar energy each year, while annual consumption of the whole county is less than 400 million kWh. In Zhangbei, besides providing internet services for the local community, the data centers have become the biggest consumer of the local wind and solar energy, providing significant amount of revenue, which greatly helps the local economy. In addition, the natural energy resources significantly reduce data center operating cost for Alibaba.

Unit Name	Size of containers	Configuration	Number of containers
Computation and storage unit	40 feet	250 servers	2
Power supply unit	40 feet	200 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

TABLE II: Configuration of the container data center

B. Fibre deployment in rural areas

In terms of connectivity, even the solutions adopting small local data centers will require large data exchange towards 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., in the order of 1 to 20 Tb/s) is fiber-optic communications. In order for the data center and the whole network in the area to operate properly, new fibre connections need to be provisioned, typically over three independent fibre routes to provide adequate resiliency. Deploying fibre cost effectively can be challenging, depending on the specific region. In areas with existing pole infrastructure, which can be from 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 will 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, highly cold or hot environments. For these reasons, many data center providers prefer their fiber cables to 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, as fiber needs to be buried deep in the ground to protect it from accidental damage. If a buried direct cable is broken, it is also more expensive to repair.

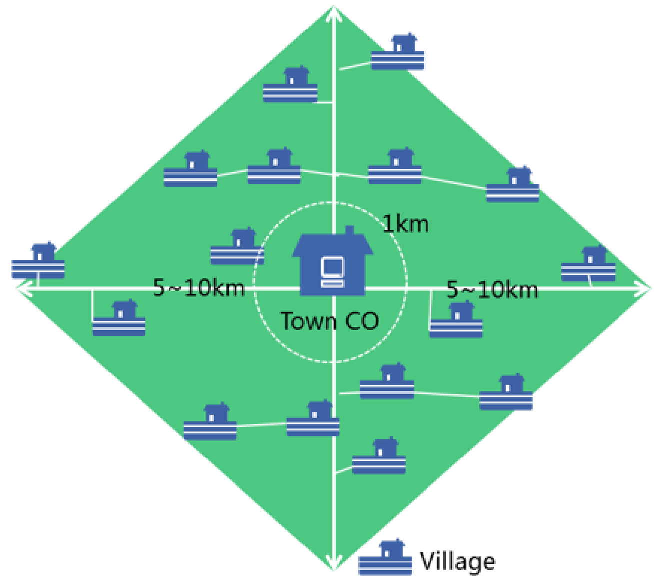

Fig. 3: Typical topology of a town central office providing broadband access to about twenty villages

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 to more than 300 km without any inline amplifiers, and longer distances can be achieved with some sacrifice in capacity [10], [11]. Such capacity is sufficient for example for a small data center. As

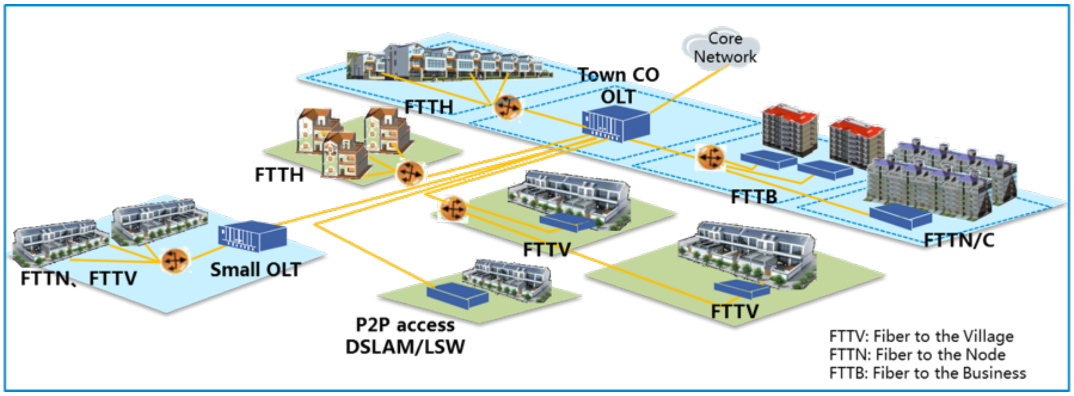

Fig. 4: FTTx architecture to connect remote villages

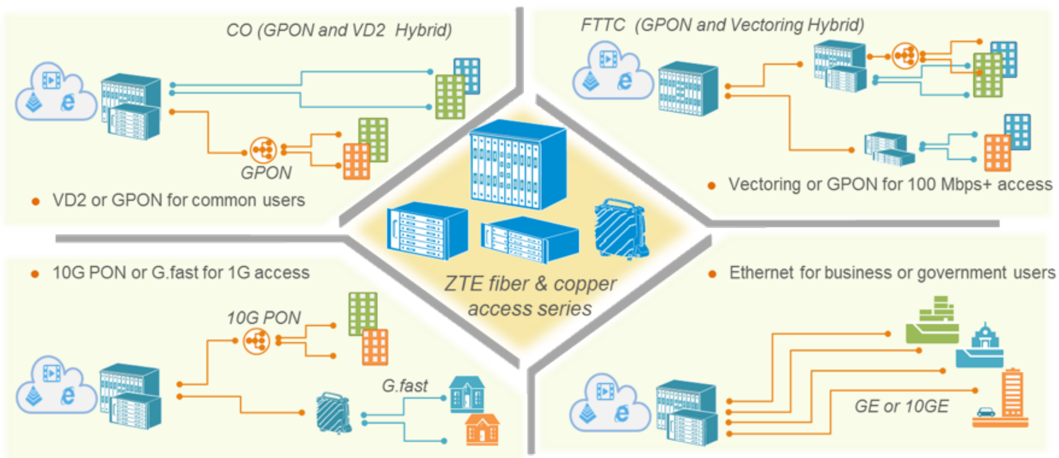

Fig. 5: Hybrid fiber-copper solutions

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 fibre deployment strategies based on Passive Optical Networks

Bringing the focus back to the access network, a second solution, designed by ZTE, 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 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. Once reached the village, twisted-pairs are used to make the final connection to each household. A typical example for a Chinese town-village is reported 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 fibre to the rural areas is shown in Fig. 4. The PtP copper trunk cable form the town to the villages is replaced by PtP trunk fiber. This is typically followed by shared PON fibre to another set of nodes in the village. From there on, twisted-pair cables, with typical distance of less than 800m, are left 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 improve the broadband connectivity, replacing copper with fibre also solves the issue of theft, which is a prevalent problem causing loss of millions of dollars annually.

Overall, while the Advancing Fiber Retreating Copper strategy is under development, it is expected that fiber and copper will coexist for a long time to come. Fiber access faces several challenges such as high cost in civil works and regulatory restrictions, while copper technology continues its advance from 100 Mbps with Very-high-bit-rate Digital Subscriber Line V2 (VDSL2) to 1 Gbps with G.fast. Furthermore, NG.fast is expected to deliver an astonishing 5Gbps+ to the end user albeit at a reduced distance. Thus, many major equipment vendors have hybrid fiber-copper solutions in the market place. Four examples 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 provide services to separate customers. Case 2 (top right-hand side of the figure) is also a hybrid GPON and VDSL2 (with vectoring) solution. However in this case, PtP fibers connect a Town CO to village COs followed by either GPON or Asymmetric Digital Subscriber Line V2 (ADSL2) to subscribers. Case 3 uses 10G-PON to increase both data rates and the number of subscribers, and PtP fiber followed by G.fast to user. Case 4 describes a scenario of direct PtP fiber to the premises, which is typically applicable for government agencies and large business users.

IV. Conclusions

There are many unique challenges to the developing world. Despite this, in the last century information and communications technology (ICT) infrastructure and solutions have improved significantly as the number and capacity of undersea fiber cables have recently grown in Africa. This has also spurred a corresponding increase in investments for terrestrial fibre capacity. Indeed, for example, this has led Africa to experience the most significant cost reductions in Internet connectivity than any other region.

The solutions proposed address connectivity both in the metro/core area and in the access, where two different approaches were discussed. These were rather complementary as they addressed two diverse but equally common situations. The solution proposed by ZTE for example is based on the existence of old copper infrastructure, thus it can assume the reuse of existing ducts. For this reason it proposes solutions that can make use of fixed network infrastructure, providing more reliable and higher capacity connectivity. The solution proposed by Alibaba is instead optimal for green field developments, where no existing infrastructure exists and is thus heavily based on the use of mobile infrastructure both for end user connectivity and backhaul.

Finally, we would like to conclude the paper by noticing that in the past few years there has been an 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.

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