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ORIGINAL RESEARCH ARTICLE

UNLOCKING RURAL AND REMOTE COVERAGE WITH SMALL CELLS AND SATELLITE

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ABSTRACT

According to the Global System for Mobile Alliance (GSMA), in 2017, there were around 3.3 billion people connected to the mobile Internet. This represented an upward surge in global coverage compared to previous years. However, more than one billion people are still not covered by mobile broadband networks, representing what is termed "the coverage gap". Uncovered populations typically live in rural locations with low population densities, low per-capita income levels and weak or non-existent enabling infrastructure, and thus, closing the mobile coverage gap seems to be more of an economic challenge, than a pure technical one. This paper presents an overview of the need for rural and remote coverage, both from an operator and consumer as well as government perspective. It then presents the major challenges, and necessary actions to be taken by industry, Government and other stake-holders to drive rural and remote coverage by significantly lowering the cost of network roll-out and increase incentives for such deployments. The paper therefore, presents a technical and business case for the use of "Small Cells" in conjunction with satellites with a view to opening up huge markets via collaboration between the mobile operators and satellite system owners, while offering significant improvements in the coverage and capacity needs of remote, rural or underserved end-users in a cost-effective and scalable manner. Detailed insights to these two technologies are presented, including the innovations to overcome technical and regulatory challenges. Lastly, some real-life deployments are given and the paper concludes with some recommendations for Government and network operators presented

1.0 Introduction

Data usage on the mobile network is growing exponentially with emergence of affordable smart phones/portable devices, and the demand of data-hungry services and applications such as intelligent transport systems, smart grid communications, and other advanced systems based on machine-to-machine communications etc. Cisco has recently forecasted an 18-fold traffic increase (10.8 Exabytes per month) by 2016 with about 10 billion mobile devices by end of 2018, while other predictions indicate that mobile data will grow at 108% compound annual growth rate (CAGR) (Mogensen et al., 2007) with over a thousand fold increase over the next 10 years.

However, as data demand continues to rise, operator revenues are lagging behind as illustrated in Figure 1 (Ray Le Maistre, 2010). This trend is further worsened by advent of over-the-top (OTT) services, which rely on traditional network operator equipment, but gulp a major share of the revenues. Hence, urgent measures are required by industry to close this cost-revenue gap by minimizing the cost/bit through innovative technical and operational processes/services (Infrastructure sharing, optimized/small base stations) and reaching uncovered markets to unlock revenue growth. On the side of Government, effective, investor-friendly regulatory frameworks are important to ease network rollout to rural and remote areas in order to drive digital inclusion and derive more economic benefits. These regulatory processes include efficient and transparent spectrum policies, taxation, administrative efficiency etc.

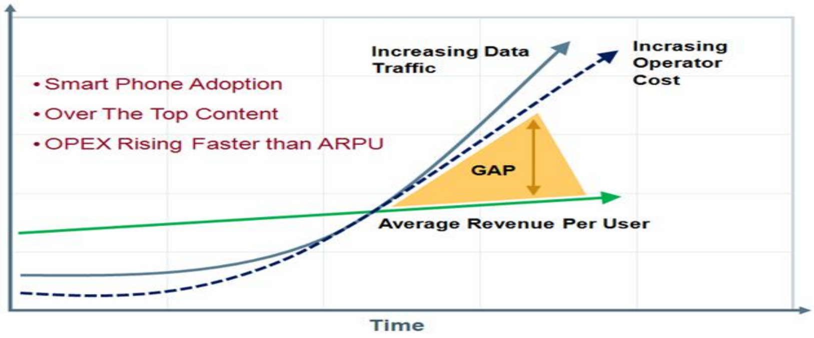

Figure 1: Cost-Revenue Gap (Source: Ray Le Maistre, 2010)

The question thus remains, how can this enormous data capacity be realized, consistent with delivering a customer experience for speed and continuous coverage, which exceeds today's levels and yet continues to be economically sustainable for operators. Over the years, researchers have investigated a lot of techniques to increase capacity, coverage and quality of service in wireless communications using the available limited resources. The Table 1 below is a result of such studies, which shows different strategies employed and their effect on capacity gain.

Table 1: Technique versus Capacity Gain

Technique	Capacity Gain
Frequency Division	5
Modulation Technique	5
Access to wider range of frequency spectrum	5
Frequency reuse through more cell sites	1600

[Source: Khawar et al., 2015]

It is very evident from Table 1, that use of frequency re-use by roll out of greater number of cells has yielded the highest capacity growth over years, and will continue to do so. However, deploying dense number of traditional base stations (macro base stations) to increase network capacity and coverage is not only cost prohibitive, but also operationally complex due to their huge sizes, high power consumption, cooling requirements and long set-up times.

One alternative approach is to deploy small, low-range, low-power base-stations to increase the data rate and/or coverage of mobile wireless systems in place of (or in conjunction with) traditional macro base stations. This achieves the same capacity-increasing effect, but with far less budgetary and operational requirements and complexity as in the case of macro-only

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deployments. Such a paradigm shift is steadily gaining lots of attraction in the mobile industry, and is referred to as a Heterogeneous Network (or Hetnet), where small cells are deployed alongside traditional macro base stations for coverage extensions to remote, rural areas or capacity enhancement to hot-spots. Whatever the intended motivation for their deployment, small cells provide operators with practical solutions to the data crisis and coverage issue in a cost-effective, flexible and scalable manner (Astely et al., 2009).

In this paper, the need for rural and remote coverage is analysed, both from an industry and government perspective, to close the digital divide and increase economic benefits, especially in developing nations. The business and technical case for rural coverage is therefore investigated, where coverage and usage gaps are identified worldwide, with peculiarities of emerging economies. Some key challenges MNOs face in bridging these gaps are also presented, including the regulatory role of government. A combination of small cells and satellite backhaul is identified as an innovative and effective solution to address the coverage gap in a sustainable way. For the scope of this paper, our priority is the use of small cells and satellite for coverage extension to rural or remote areas, including provision of voice and data services to under-served villages and towns, for emergency and disaster relief situations, oil-rigs, to aircraft, vessels, trains etc. Some practical solutions to the challenges are then offered, owing largely to recent advancements in both mobile and satellite technologies. Finally, some real-life deployments are showcased, and recommendations provided for practical implementation of such hybrid system in Nigeria.

2. Rural and Remote Coverage

2.1 Why Bother About Rural Coverage?

The Coverage Gap: More than 2.5 billion people – over 40% of the planet's population – live in rural and remote areas of developing countries according to an ITU report [Small Cell Forum, Dec 2013] of the small fraction that has any access to telecommunications, radio broadcasts and voice telephony have traditionally been the main services provided. However, with increasing proliferation of cheap and affordable smart phones and other portable devices, mobile operators globally are now working hard to grow their networks in terms of: higher subscriber base, increased ARPU (Average Revenue per User), and improved coverage. This is driving them to expand connectivity into rural/remote areas, and also ensure ubiquitous coverage even during disasters and emergency situations (Williams et al. 2012).

For the purpose of this paper, the expression "Rural and Remote" (or just "Rural") refers to rural, isolated and poorly served areas by telecommunication facilities, where various factors interact to make the establishment of telecommunication services difficult. A rural area may consist of scattered settlements, villages or small towns, and may be located several hundreds of kilometres away from an urban or city centre (Bright et al., 2012). However, in some cases a suburban area may also be considered as rural. A rural area exhibits one or more of the following characteristics:

Scarcity or absence of public facilities such as reliable electricity supply, water, access roads and regular transport;

Scarcity of technical personnel;

Difficult topographical conditions, e.g. lakes, rivers, hills, mountains or deserts, which render the construction of wire telecommunication networks very costly;

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Severe climatic conditions that make critical demands on the equipment;

Low level of economic activity mainly based on agriculture, fishing, handicrafts, etc.;

Low per capita income; Low population density;

Under-developed social infrastructures (health, education, etc.)

Very high calling rates per telephone line, reflecting the scarcity of telephone service and the fact that large numbers of people rely on a single telephone line.

Nigeria's population is about 190 Million people according to a 2017 World Bank study with about half of this population (51%) residing in rural areas (Qiang et al., 2009). There has been a giant surge recently in mobile penetration, from 54% in 2016 to more than 84 % currently with mobile Internet standing at around 51% (Kolawole, 2018). However, there is still obviously a lot more to do to bridge the divide between urban and rural areas for the country to reap even more benefits across the ecosystem.

Currently, the GSMA estimates that the coverage gap is equivalent to about 1.2 billion people globally, with sub-Saharan Africa being the largest by a huge margin as shown in Figure 2. Coverage gap is simply defined as the lack of supply of mobile services, while the usage gap, on the other hand, is a lack of demand for mobile services where coverage is already available (Buckwell et al., 2018). This may be due to poor digital literacy, high cost of mobile devices, etc. As can be seen from Figure 2, only sub-Saharan Africa has the coverage gap being higher than the usage gap affirming the huge digital divide across many African states.

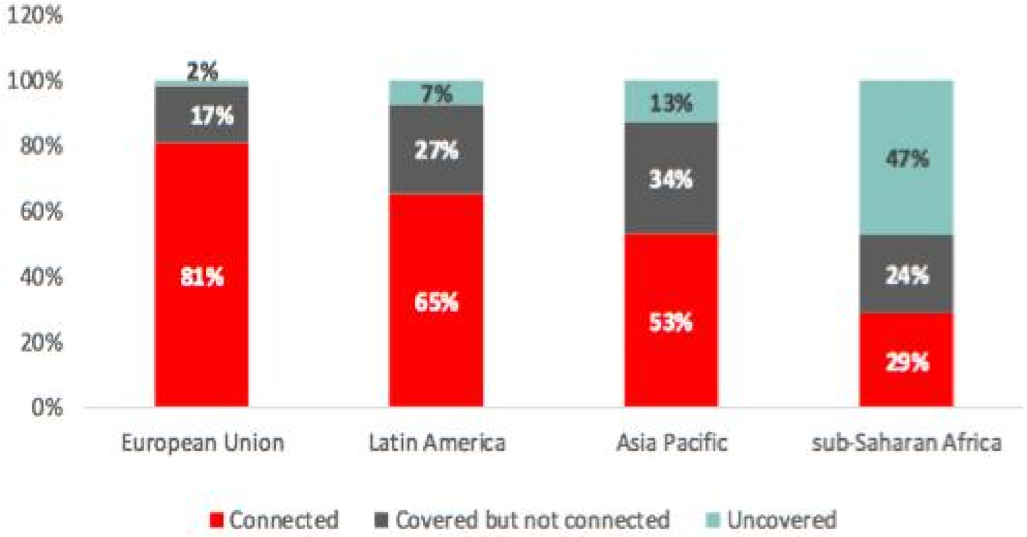

Figure 2: Global Mobile Coverage Gap (Source: Buckwell et al., 2018)

Economic Potentials: A recent study found that in countries such as Nigeria, a 10% increase in mobile penetration increases total factor of productivity, a measure of an economy's long-term technological dynamism, by 4.2 percentage points in the long run (Williams et al., 2012). Furthermore, a World Bank report estimates that a 10% increase in mobile broadband adoption leads to 1.4% GDP growth for developing economies (Qiang et al., 2009). Improved access to mobile voice services and broadband will also have great impacts on key sectors such as healthcare, education, and agriculture as well as enhance growth of SME's. It is therefore in the economic interest of Governments to do all they can to drive mobile and digital adoption across the nation.

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Figure 3 shows the value chain of economic benefits derived through increased mobile coverage in a country as contained in (Qiang et al., 2009) – increasing mobile broadband leads to increased services and opportunities for consumers and businesses, which brings higher revenues to MNOs through increased subscriptions and payments, who then pay taxes and fees to Government. At the same time, ripple effects of increased consumer spending and booming businesses leads to higher GDP and better economy for the nation.

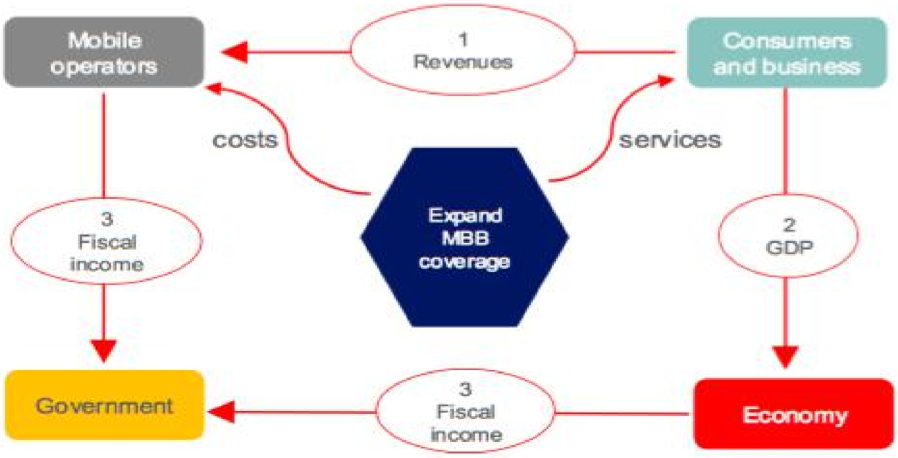

Figure 3: Economic Impacts of Mobile Broadband (Qiang et al., 2009)

2.2. Barriers to Rural Coverage Expansion

Rural and Remote areas are generally sparsely populated and hard-to reach, thus associated with some challenges and misconceptions by MNO's. Figures 4 and 5 present some interesting results from studies on such challenges hindering MNOs from investing in rural coverage (Bright et al., 2012). Key amongst these include:

High CAPEX - Rolling out traditional Macro BS's to such sites is costly and difficult - towers, shelter, power, cooling.

High OPEX for the MNO's – powering BS's (fuel, generators), maintenance, ease of installation

First Operator that penetrates market takes it all.

ARPU presumed to be low by MNO's, insufficient to justify network roll out or creating very difficult business model.

Due to remoteness and distance from urban centers, often MNO's assume security level is not adequate enough.

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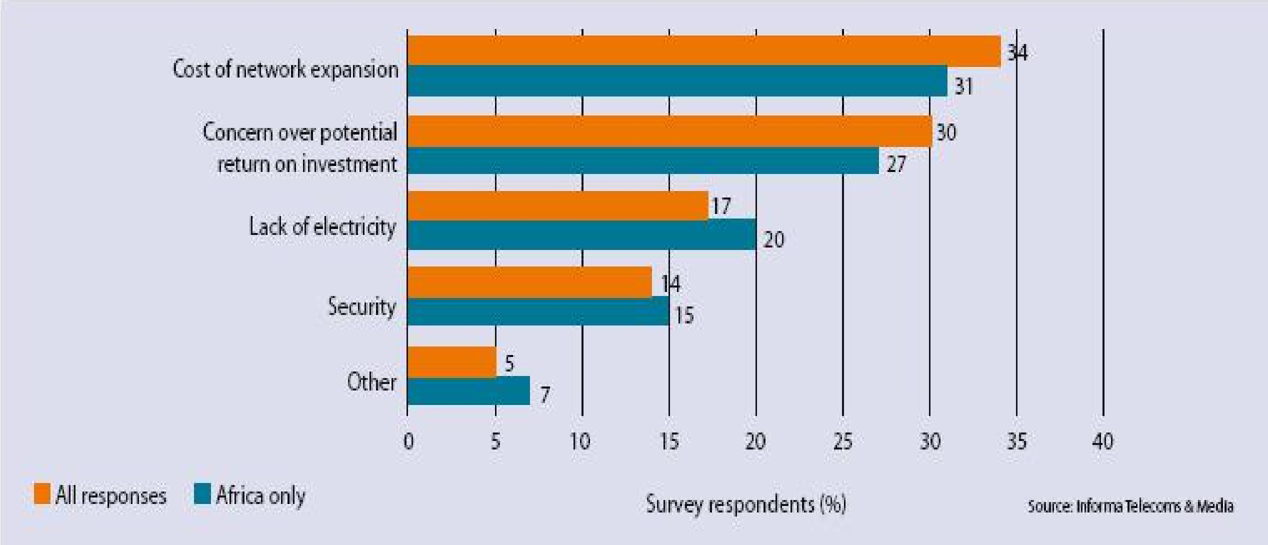

Figure 4: Survey on MNOs' biggest barriers to Infrastructure Expansion into Rural Areas (Source: Bright et al., 2012.)

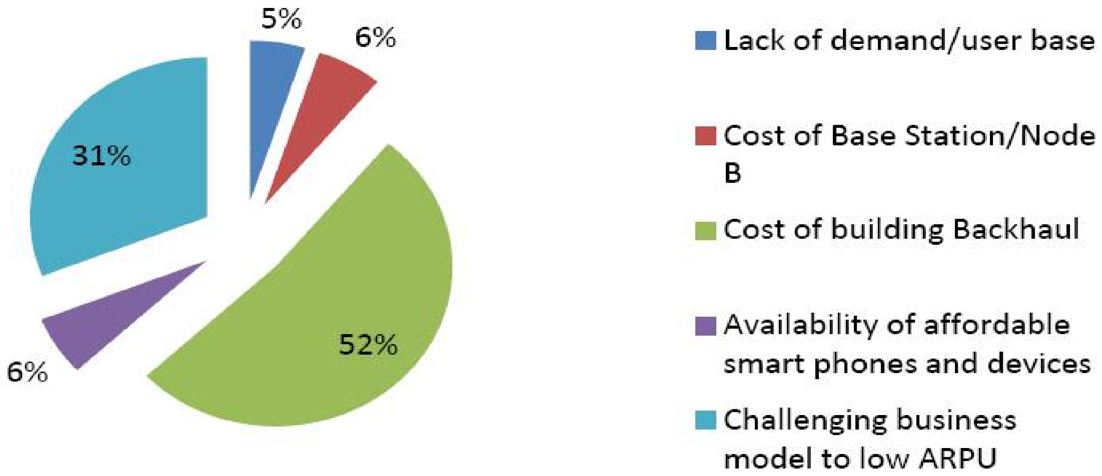

Figure 5: Operators Perceptions on Different Factors hindering Rural Connectivity (Source: Bright et al., 2012.)

Some Technical Challenges

From a technical perspective, the most critical barriers to rural coverage as verified by both Figures 4 and 5 respectively are – base stations, backhaul and power.

Base Stations: The cost and complexity of deploying multiple macro base stations to rural/remote areas is quite significant, and often does not correspond to the revenue profile of these sparsely populated areas. Also, absence of complementing network equipment and facilities in close proximity means MNOs would be isolated from gateways, switches, fibre networks etc. for long distances. Innovative RAN solutions are therefore essential for MNOs to operate in such environments. These are presented in latter sections of the paper (Xiaolu et al., 2013).

Backhaul and Installation Cost: According to Bright et al. (2012), as shown in Figure 5, the most critical issue when deploying multiple cells for extended coverage is the choice of backhaul. Due

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to the shrinking of the cell sizes, the numbers of radio access points increase significantly, leading to huge increases in backhaul cost and real estate cost of installing access points. Diverse backhaul strategies are needed to accommodate dense base stations, and this is discussed in subsequent sections of this paper.

Power: The power consumption of multiple macro base stations is quite enormous, and even more so for developing nations such as Nigeria, where MNOs mostly rely on diesel generators for reliability. Renewable sources are becoming attractive, and shall be discussed in section 3 of this paper.

2.2.2 Government and Regulatory Bottlenecks

Aside technical barriers, there are also some critical issues with government policies/regulatory implementation that hinder rural coverage. Government needs to provide regulatory friendly environment. Figure 6 shows the role Government should play through effective and efficient regulation and administration, spectrum and tax policies, drive infrastructure sharing by MNOs. This would help lower the risk perception by MNOs for rural coverage, increase return on investment (ROI) thereby leading to better incentives of MNOs to deploy and ultimately, lead to improved network coverage (Gernaro, 2018).

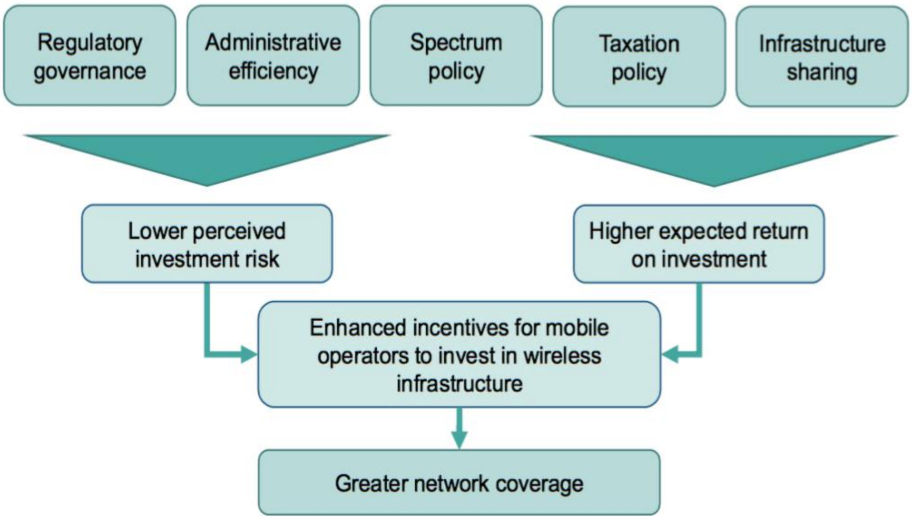

Figure 6: Role of Government in Closing Coverage Gap (Source: Gernaro, 2018)

2.3 Way Forward for Rural and Remote Coverage

According to the GSMA, bridging the mobile coverage gap is more of an economic challenge than a technical one (Kapovitis et al., 2018). Hence, for rural/remote coverage to be commercially sustainable, the demand and supply of mobile services should attain equilibrium as illustrated in Figure 7(a).

In Figure 7(a), the supply and demand curve for mobile services is illustrated. The supply curve represents the incremental cost of covering an additional 1% of the population, and is upward sloping due to the fact that costs get higher as population density reduces (such as rural areas). This may be due to poor economies of scale, difficult terrain for infrastructure deployment, security and other challenges for rural/remote areas as already stated earlier. On the other side, the demand curve represents the additional revenue accrued by additional 1% of the population covered. It is downward sloping because there are less revenues generated in less populated (rural) areas, mainly due to low income level (ARPU), poor digital literacy etc. The point where

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demand and supply meet is where MNOs would target so as to maximize revenue and provide optimal coverage (Guillaume, 2017).

According to industry reports, for rural areas to be commercially viable, significant cost reductions are needed by more than a factor 10 (Genaro et al. 2018). Innovations in both technology and operation are therefore essential to drive these costs down and shift the supply curve to the right as shown in Figure 7(b). Supply enhancing measures include – Improvements in Satellite backhaul leading to reduction in cost from $150K to $100K and coverage from 60% to 70% as shown in Figure 7(b). Another key measure is to deploy smaller base stations that have low power consumption, low-cost and very low maintenance –called Small Cells. Small Cells are compact, low-powered, fully integrated base stations that present MNO's with cost-effective solutions for coverage and capacity (Guillaume, 2017).

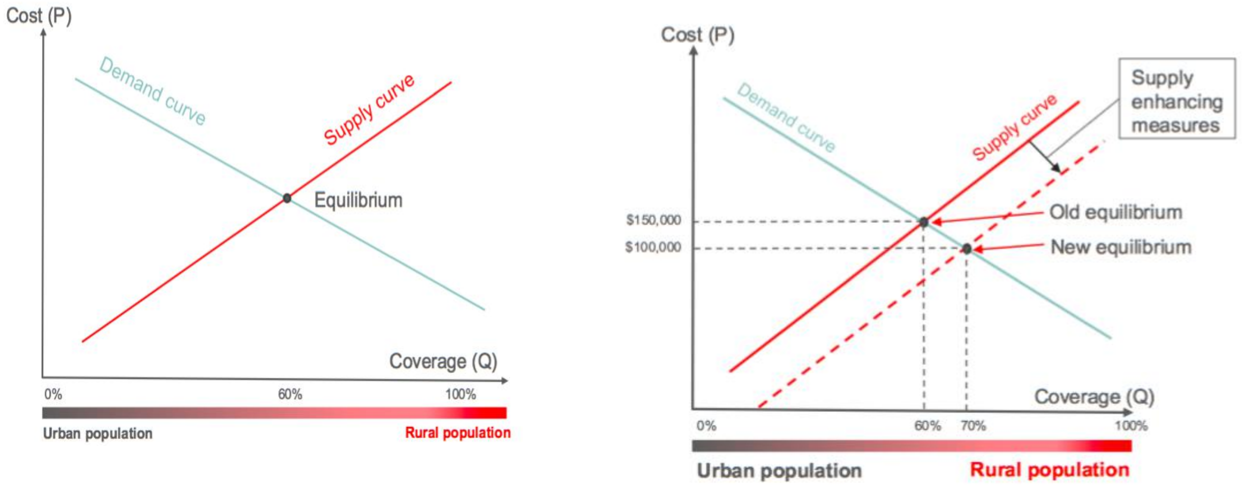

Figure 7: (a) Equilibrium Point for Sustainable Coverage (b) Shifting Equilibrium Points to Lower Costs (Source: Guillaume, T. 2017)

3. The Game Changer: Small Cells and Satellite

3.1 Demystifying Myths Around Rural and Remote Coverage

Recent developments in both mobile and satellite technologies have addressed some of the technical challenges and demystified some of the myths around rural and remote connectivity.

Base Stations: The advent of 'Small Cells' (small, low power Base Stations) as against power-hungry macro BSs supports a business case for rural and remote connectivity.

Power: As most of the small cells only require tens to 10 watts maximum, simple single-phase supply available at distribution level is what is needed without the need for complex three-phase systems. Where mains power supply is rarely available, as in many developing countries and isolated, remote areas of developed nations, equipment that operate with DC of 12/24V are sufficient and can be powered by solar, wind, fuel or other alternative power sources. Battery banks and efficient power systems need to be designed depending on the use environment.

Backhaul: Recent advancements in satellite technology, new modulation and coding schemes, efficient multiple access techniques etc. have now enabled effective and affordable satellite backhaul systems for coverage extension to rural/remote areas. Such a system meets various needs for operators and end-users when used to transport data between the small cells and the core network, such as - much wider coverage, availability anytime anywhere even with no prior physical infrastructure on ground (ideal for ships, aircraft), rapid deployment, security for military communications (Erik et al., 2011).

Figure 8 below summarises the solutions to the 3 key technical challenges mentioned earlier.

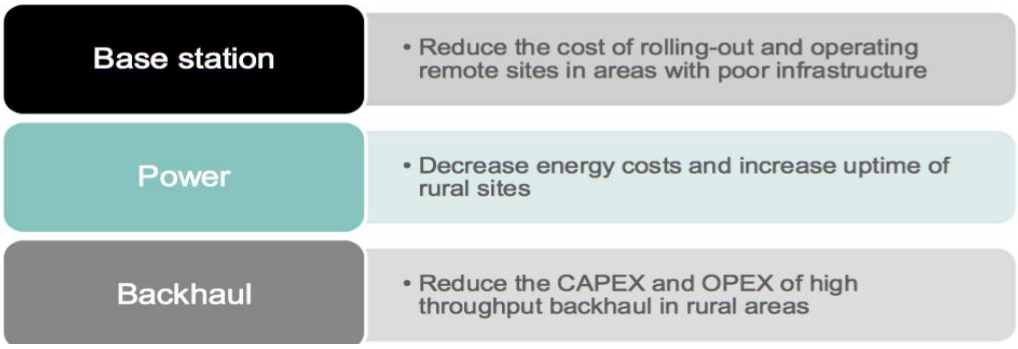

Figure 8: Key Technical Challenges to Rural and Remote Coverage
(Source: Erik et al., 2011)

Site acquisition and Maintenance: Due to their sizes, small cells are very easy to maintain with no requirements for cooling and complex debugging. They can be mounted on walls, street posts, roof tops, etc., but must withstand outdoor temperatures.

3.2 Solution in Radio Access Network (RAN): Small Cells

In order for MNOs to operate in a commercially sustainable way in rural/remote areas, there needs to be a paradigm shift in deployment architecture of the dense base stations required. One effective method is to rely on “Small Cells”, which are defined according to the Small Cell Forum, as operator-controlled, low-powered radio access nodes, including those in licensed spectrum and unlicensed carrier-grade WI-FI. They are small size, fully integrated base stations comprising of both the baseband processing and the radio module in one physical unit, and typically have a range from 10 metres to several hundred metres (1-2 km). They provide improved cellular coverage and capacity and are used in applications for homes and enterprises as well as metropolitan and rural public spaces (Khawar et al., 2015).

Due to their low-power, size and easy installation feature, they present a cost-effective solution to bridge the gap between data demand and capacity, close coverage-holes and extend connectivity to rural, remote areas in a profitable way. Generally, small cells have the following features:

Low-cost, low power, small form factor solutions

Provide targeted local coverage and dedicated capacity

Comprise of both the baseband processing and the radio module in one physical unit

Delivering Cellular services with COTS standard based equipment – affordable, available

Easy installation and near-zero maintenance, rapid deployments and self-organizing features

Support a wide range of backhaul solutions

Can be easily mounted on any structure, without rigid, expensive framework or equipment, hence, less prone to vandalization and theft.

MNOs could deploy numerous small cells with significantly lower risks, and costs in terms of both CAPEX and OPEX. Small Cells could be targeted to specific locations where needed.

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3.2.1 Types of Small Cells

Table 2 highlights the types of small cells with their different characteristics. Typically, small cells range from indoor-based residential/enterprise femtocells to picocells/microcells, which are mostly deployed for capacity increase in urban host-pots or coverage extension to remote areas. Macrocells are the traditional base stations we see every day mounted on huge towers with high power consumption and cooling requirements (Xiaolu, 2013).

Table 2: Types of Small Cells

Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/Outdoor
Micro Cell	1 to 10	0.3 to 2.0	100 to 2000	Indoor/Outdoor
Macro Cell	10 to >50	8 to 30	>2000	Outdoor

3.2.2 Purpose

The main reasons for deploying small cells are for capacity enhancement and coverage extension, which can be generally classified but not limited to the following:

1. Providing additional capacity at a high-traffic location (hot-spot).
2. Offloading traffic from a congested macro-cell.
3. Providing higher capacity and performance at the edge of a macro-cell.
4. Extending coverage at the edge of the network and into isolated or remote areas.

Out interest in this paper is to consider the Case 4 above where Small Cells are deployed for extending coverage to under-served, remote, small or mobile communities, and explore how this can be done effectively in conjunction with Satellite as a backhaul option. Therefore, we will concentrate on use of pico and micro/metropolitan cells for outdoor use as against residential/home femtocells which have been widely studied for capacity enhancement indoors (Qiang et al., 2009, Khawar et al., 2015, Kapovitis et al., 2018).

Figure 9 below shows some of the scenarios where Small cells could be deployed with Satellite backhaul. Whether for extending coverage into rural/remote areas such as villages, islands, off-shore communication, or transportation (aircraft, ships, high-speed trains), small cells and satellites can provide ubiquitous connectivity.

Figure 9: Small cells and Satellite: Insensitive to distance and mobility (Source: Khawar et al., 2015)

3.3 Satellite Backhaul

Satellite as a backhaul option for coverage extension in such scenarios meets various needs for operators and end-users when used to transport data between the small cells and the core network, such as - much wider coverage, availability anytime anywhere even with no prior physical infrastructure on ground (ideal for ships, aircraft), rapid deployment, security for military communications etc. Services being provided to these areas by the small cells over satellite could be prioritized for voice in form of 2G only systems, or could provide more data support in forms of 3G and probably 4G systems, especially for more developed markets where the business case will support the appropriate network roll-out.

Traditionally, satellite backhaul was considered wasteful, expensive, cumbersome and 'old'. Recently however, advances in space sector, V-Sat and complementary terrestrial systems have revived the market for satellite backhaul and demystified certain myths around it. Common problems traditionally associated with satellite backhaul of IP data especially with 3G/4G small cells include: Latency and jitter, base station and Node B synchronization, space segment cost and weather conditions (especially in the bands with higher available bandwidth for broadband such as Ka and Ku bands). Also, eavesdropping and active intrusion used to be easier in satellite networks due to their broadcast nature compared to pure terrestrial systems. The long delays and burst errors could lead to loss of security synchronization as well, compromising the integrity and reliability of communication. Furthermore, the Round-trip time of around 540ms for satellite two-way communication is not ideal for effective operation of the Transmission Control Protocol (TCP) protocol since it requires three-way handshake to set up and maintain connections (Roddy, D. 2006).

3.3.1 Recent Advances in Satellite Technology

However, most of these problems have been adequately addressed with advances in satellite system technology. First among such advances is the shift to second generation DVB or DVB-S2, making the networks much faster and more efficient via introduction of Adaptive Coding and Modulation (ACM). Rain fade and bad weather is also better addressed by this innovation and capacity is not wasted in clear sky weather since system adapts to specific environment. Satellite launch costs have significantly been reduced due to improving technology, competition from new entrants such as Space X, and better economies of scale (Vince, 2015).

The introduction of Time Division Multiple Access (TDMA) systems has also been a major driver in the use of satellite for small cell backhaul because it allows for effective sharing a pool of bandwidth resources by many sites in a cost-effective manner as against Single-Channel per Carrier (SCPC) systems which allocates dedicated bandwidth to a single user irrespective of usage as illustrated in Figure 10 below. Lastly, advanced High Throughput Satellites (HTA) now enable frequency reuse via spot beams of Ku and Ka bands, offering very high capacity and spectral efficiency with significant cost reductions per MHz of capacity, also reducing the Space segment cost significantly. Examples of such satellite systems are Eutelsat's Ka satellite with multiple spot beams over Europe as captured in Figure 11 below. Others are ViaSat-1 and EchoStar XVII, which provide more than 100Gbps of capacity, more than 100 times the capacity of traditional Ku FSS Satellites (Kapovitis et al., 2018). Appropriate encryption and security measures have also been introduced to prevent Quality of Service (QoS) degradation due to security processing, such as IpSec, and other TCP/IP performance enhancement schemes (such as TCP acceleration protocol), have been developed to allow high data rate communications over Satellites (Maral et al., 2011).

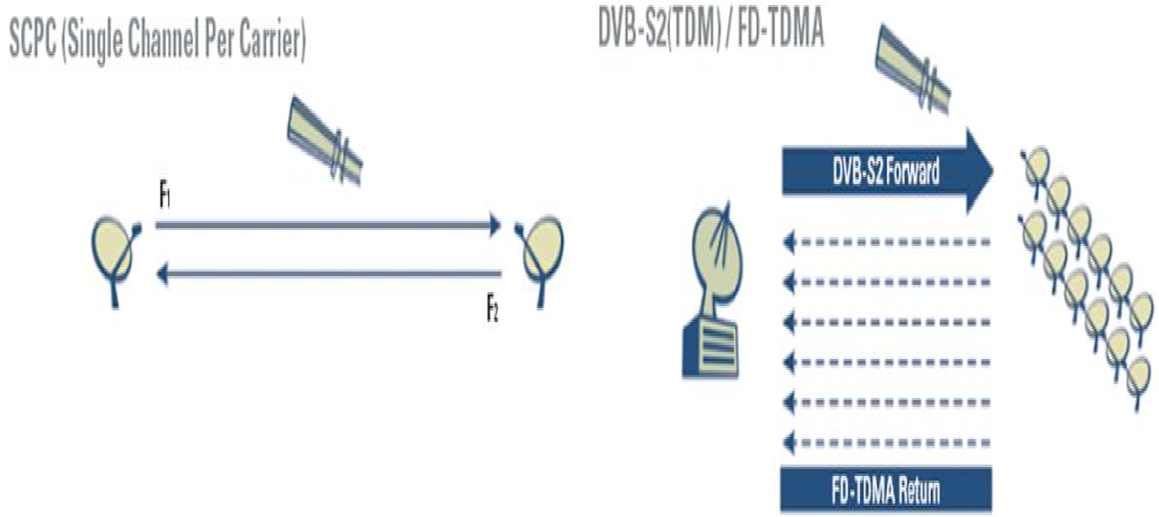

Figure 10: SCPC vs. TDMA (Maral et al., 2011)

As shown in Figure 10, SCPC allocates maximum bandwidth per site always –wasteful, static, while TDMA allocates bandwidth on-demand to each site – economical, dynamic

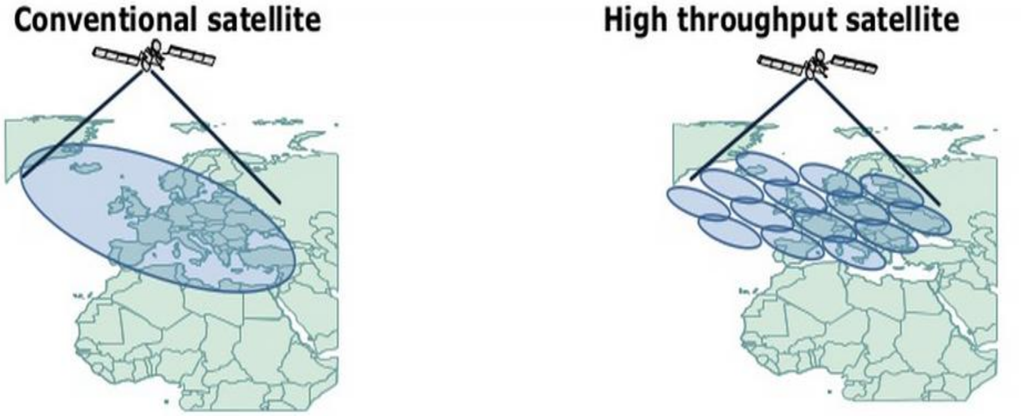

Figure 11: Footprint for Conventional and High Throughput Satellites (Source: Vince, 2015)

The Increased broadband capacity by HTS implies cheaper bandwidth, translating directly to reduce OPEX as presented in Figure 12 where the cost per bit of new generation HTS are compared with traditional satellites to show the significant reduction in cost by the newer generation systems.

Figure 12: Cost Reduction in Satellite Systems (Source: Vince, 2015)

3.4 Proposed Architecture of Small Cells and Satellite

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Figure 13 shows a typical architecture for the proposed small cells and satellite system. Numerous small cells provide connectivity to a rural/remote location, with their traffic aggregated at a V-sat for onward transmission to the core network (backhaul) through a High Throughput Satellite. The Teleport is required in connecting the satellite network to the rest of the terrestrial core network for IP connectivity (Khawar et al., 2015).

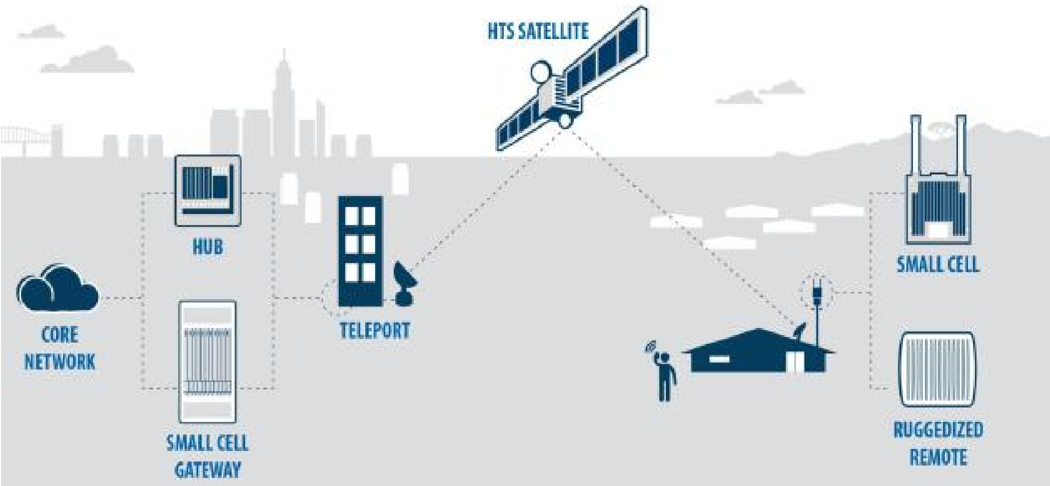

Figure 13: Typical Architecture of Small Cells with Satellite Backhaul (Source: Khawar et al., 2015)

3.4.1 Some Real-Life Deployments

As given in [Small Cell Over Satellite, 2014] Gilat offers the Cell-Edge small cell over satellite solution, featuring the latest version of 3G – HSPA+, with data rates of up to 21Mbps in the downlink and 5Mbps in the uplink. Gilat is specialized in satellite backhaul, and have opened up access to rural areas with more than 2,000 cellular backhaul installations worldwide. The company offers the turnkey, Cell-Edge high-performance small cell over satellite solution, which features optimization of voice and data compression techniques, in addition to high bandwidth efficiency algorithms. This technology minimizes satellite space segment overhead, combined with satellite bandwidth allocation on demand, reducing satellite OPEX by as much as 80 %. The integrated Cell-Edge solution ensures an enhanced user experience, using TCP and HTTP acceleration to overcome the inherent satellite delay. Figure 14 shows the typical architecture of the Gilat Cell-Edge solution (Doreet, 2014).

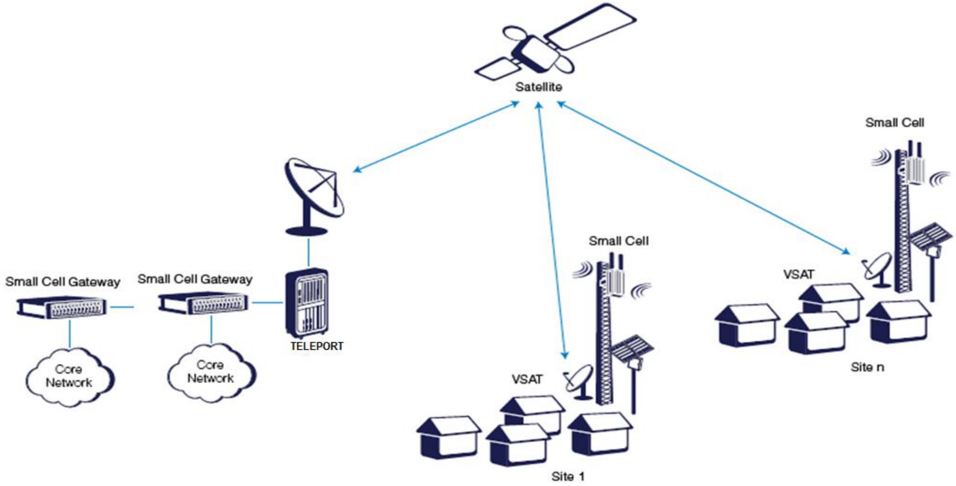

Figure 14: Gilat's Cell-Edge over Satellite Solution (Source: Doreet, 2014)

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Other Deployments

K-Net combines iDirect Satellite backhaul with Altobridge Small Cells to provide connectivity in rural and remote areas of West and Central Africa, supporting MTN, Vodafone, Tigo. It has lowered TCO by up to 65% compared to traditional backhaul service (Richard, 2014).

RuralStar: This is a Huwaei technology which enables three transformations: transforming microwave or satellite transmission in traditional solutions to Relay, substituting simple poles for towers, and enabling a move from diesel generators for power supply to solar power thereby shortening the return on investment (ROI) period for mobile communications in remote rural areas. Operators can then lower the threshold of profitability by 50%. The solution has been successfully deployed by 12 operators in eight counties, including Nigeria, Thailand, Ghana, Indonesia, and Mexico, examples of which are presented in Figures 15 and 16 respectively. It won the GSMA award for "Best Mobile Innovation for Emerging Markets" in year 2018 (Madeline et al., 2018).

Figure 15: Rural Star 2.0 Small Cell in Nigeria

Figure 16: Rural Star Small Cell in Ghana

(Source: Madeline et al., 2018)

As seen by the different examples, such combined solutions offer a unique cost-effective solution to serving rural, remote areas. The small cells allow MNO's expand networks without the high costs of installing and maintaining macro base stations. Satellite backhaul is insensitive to distance or terrain, allowing multiple sites to be connected quickly and without prior infrastructure. HTS and TDMA allow frequency re-use by spot beams and dynamic bandwidth allocation and sharing on-demand.

With such solution, MNO's are only paying for the satellite bandwidth that they need, and serving customers that they target, using infrastructure that is likely to pay for itself in weeks or months, rather than years (Madeline et al., 2018).

4. Conclusion

Rural and remote coverage is key to bridging the coverage gap, close imbalance and, increase operator revenues and subscriber base, and drive economic development across the nation. The industry has been skeptical in deploying systems to such sparsely populated areas, or for mobile platforms, dead-zones and disaster situations because the economics hardly justify the roll-out of expensive macro-base stations. With advent of low-power, low-range, small radio access points, the cost of deployment and maintenance is significantly reduced, and operators can strategically choose to engineer their networks to address target areas quickly and with ease. The impact of mobile on GDP and other sectors of the economy such – education, health,

Corresponding author's e-mail address: abdullahi.umar@cstd.nasrda.gov.ng commerce etc. are incentives for Governments to ensure effective and transparent policy and regulatory frameworks are established for boosting rural mobile coverage.

The small cells and satellite collaboration proves that the space industry and mobile sector can effectively complement each other for mutual benefits. Such a combination enables much wider coverage for many small cells, is very quick to deploy, provides dynamic and affordable bandwidth pooling capability so as to provide coverage only when and where needed, offers greater level of flexibility, power management and security for rural/remote cell sites. It could also proffer significant contribution towards Nigeria's target of 50% broadband penetration by 2020. Future communication satellites of Nigeria should be designed to be HTS and consider serving MNO's for cellular backhaul, mobile broadband and rural/remote coverage in Africa as a niche market.

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