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Television White Space Based Broadband Network's Coverage and CAPEX Performance for Rural Areas Connectivity in Tanzania

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ABSTRACT

This study compared the CAPEX requirements for a television white space (TVWS) based broadband network and that of deploying the UMTS based mobile broadband networks to deliver broadband connectivity in areas with sparse population which characterize most of Tanzania rural. Like many developing countries, Tanzania has low Internet penetration, with penetration of just over 46% when multiple subscriptions are taken into account. The affected communities are mostly rural due to low population densities which make deployment of the mobile broadband to be much expensive in terms of costs. This limits the economic development potential in these areas given that the broadband connectivity and services is a key driver for the Fourth Industrial Revolution (4IR or Industry 4.0) and modern digital economy. Comparative between the coverage capability of the TVWS and UMTS family of standards by considering the number of base transceiver stations (BTS) is conducted to cover a specific geographic area for three different radio operating environments namely hilly, undulating and flat terrain landscapes. The broadband connectivity data rate is defined at the receiver rate of 2 Mbps or above, and used to determine the number of BTS required for the two technologies. Results show that introducing the TVWS as a middle mile solution, cuts the number of UMTS BTS required to serve the same population by 68%, 66.7%, and 75% for the three canonical environments respectively.

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INTRODUCTION

Broadband connectivity is increasingly becoming an important resource with the modern digital economy and the Fourth Industrial Revolution (4IR) relying on it as a key driver. 4IR for instance has brought a new era of technology innovation that enhances human-machine relationships, unlocking new market opportunities and fueling growth across the global economy (Xu et al., 2018). However, the Internet penetration for sub-Saharan Africa is at 24%, very low for a region which accounts for 40% of the global population not covered by a mobile broadband network (GSMA, 2019). Tanzania, in particular, has an Internet penetration of just under 50% without accounting for unique subscriptions (TCRA, 2021).

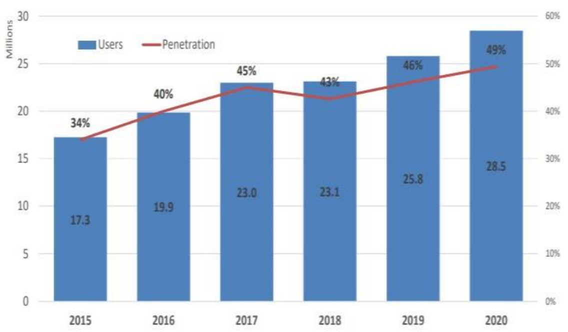

Figure 1: Tanzania Internet penetration (TCRA, 2021)

Figure 1 shows the number of Internet users and the extent of Internet penetration in

Tanzania by 2020. It is suggested that the Internet access gap would require around $100 billion to achieve universal access to broadband connectivity in Africa by 2030. To achieve the target connectivity goal, nearly 250,000 new 4G base stations and at least 250,000 kilometers of new fiber across the Sub-Saharan Africa region would be required (Bannerman, 2020). This is a formidable challenge, with three-quarter of the population remaining out of reach of mobile broadband signals in Sub-Saharan Africa. One solution to achieve 100% population coverage for mobile broadband is to establish backhaul networks with a mixture of 3G and 4G sites which is currently a predominant solution in the market (Nyanyuma et al., 2017). However, this solution requires high investment and operational costs for mobile broadband infrastructure and is more attractive in areas with high population density and hence adopted in urban areas. For countries with challenging population distribution, such as Tanzania, where most 70% of the population is sparsely distributed, it is difficult to deploy broadband infrastructures. As a result, the broadband is mostly found in cities and major towns where both operational costs (OPEX) and capital expenditure (CAPEX) per connected broadband subscriber can be attained by the commercial network operators (Massawe & Chitamu, 2022). The government of Tanzania aims to achieve the 80% Internet penetration by 2025. This represents about 60% rise in Internet penetration in under five years. It is estimated that up to 86% of the excluded population hails in rural areas compared with 44.6% in urban areas (Telecompaper, 2021). Given the challenge in delivering mobile broadband connectivity to sparsely populated and low-income rural population, connecting the unconnected in these areas will require innovative approaches. One such approach is opportunistically utilizing the unused digital television terrestrial television channels also known as TV white spaces to backhaul broadband networks for hard-to-reach areas (Khalil et al., 2017; Kumbhkar et al., 2015). This paper analyses the potential CAPEX reduction in deploying TVWS based broadband network in rural areas in comparison to the existing UMTS standards. I also propose specific network deployment models useful to provide broadband services in the rural areas.

Literature Survey

Tanzania like the rest of the sub-Saharan Africa region face a dire connectivity challenge that sees the Internet penetration at under 50% when multiple subscriptions are taken into account. In sub-Saharan Africa, mobile technology has evolved rapidly, but this has not happened to Internet access. With 170 million users, Internet penetration in Africa is 42%, significantly lower than the global average of 60% (Faria, 2021). One major challenge that faces operators in providing broadband coverage in rural areas, especially in developing countries, is a poor return on investment (ROI) contributed by the inhabitants' low population density and low disposable income (Smith, 2000). In Tanzania, for instance, it is estimated that under 30% of the population hails in the urban areas while over 70% of the population is in the rural areas with an average population density of 57 people per square km.

In order to connect the sparsely populated areas, innovative approaches are needed. Studies have proposed various approaches to cater to the environment types and the sparse population distribution. One approach uses low-level traffic over large coverage areas (coverage limited network design). A typical example of this is the provision of 3G coverage over the 2G networks. In Tanzania, the Universal Communication Access Fund (UCSAF) has employed this approach to provide data connectivity to remote areas. While this ensures that the wide-area is covered, the capacity is small since the 2G networks were planned for the coverage and the data rate deterioration would require a new deployment strategy over just swapping the 2G sites with the 3G sites (Massawe & Chitamu, 2022).

Another approach is the robust last mile for macro sites for low-density areas or small cells for hotspots for high-density areas. While macrocells are limited coverage, small cells are capacity limited both aimed to provide good data rates in their operating environments (Alsharif et al., 2019). Our previous study demonstrated how the distance distribution deployment approach for the TVWS based networks using macrocells achieved good coverage and capacity for sparsely populated areas (Ismail et al., 2021). With average revenue generated per user (ARPU) higher for urban areas than rural areas, small cells are economically viable for urban areas, while macro cells suit rural areas as the number of deployed sites is reduced. Figure 2 depicts the macrocells, and small cells overlay to extend the connectivity range for the served areas (Alam et al., 2018).

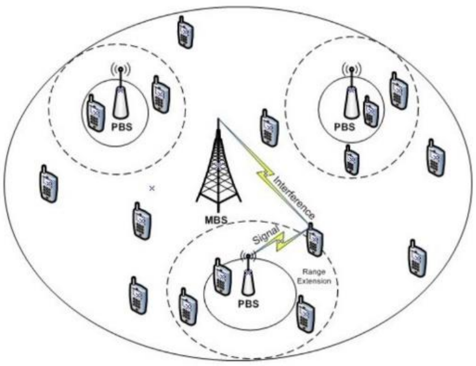

Figure 2: Layout of a macro cell overlaid with small cells (Alam et al., 2018)

Various strategies can also be combined to provide a reliable and optimally economic backhaul for end-users in the distributed backhaul. This may be a combination of macro and small cells alongside wired technologies such as optical fiber. In some scenarios, the use of the satellite is also included depending on how remote the population is (Sahu & Pawar, 2020). Distributed backhaul is considered promising for ultra-dense networks such as 5G to meet the explosive data demand. In this case, a reliable, gigahertz (GHz) bandwidth and cost-effective backhaul network connecting ultra-dense small-cell BSs (SBS) and macrocell BS (MBS) are pre-requisite. This backhauling strategy may not be cost-effective for sparsely populated areas with low disposable income.

Other approaches for broadband connectivity in rural areas include satellite connectivity which aims to cover rural areas currently out of reach of traditional cellular mobile networks. For instance, the aerospace manufacturer SpaceX has announced its intention to offer the Starlink satellite broadband service starting in 2020 – with eventual plans to expand to Africa (*Starlink*, n.d.). Facebook's Aquila, using solar-powered drones as wireless Internet relays, and Google sister company X's Project Loon, using large hot-air balloons, are testing drones and balloons to expand access in an innovative way (Internet Society, n.d.). Figure 3(a) shows the Aquila architecture, which employs free space optic (FSO) links to connect ground access points that serve ground users using either Wi-Fi or LTE technology. In Figure 3(b), the Google Loon balloons relay signals from the ground station to users on the hard-to-reach areas. Both Aquila and Google Loons support coverage for users up to 20 km away but they are relatively expensive compared to terrestrial solutions (Fotouhi et al., 2019).

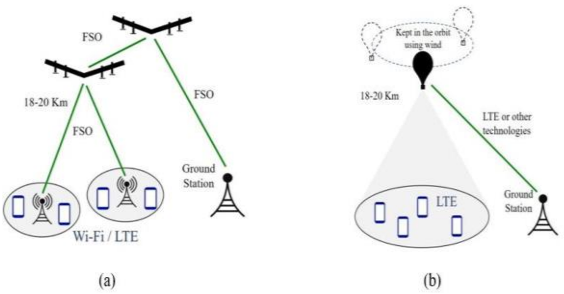

Figure 3: Aquila (a): is unmanned autonomous aircraft for relaying signals from the Ground Station. Google Loon (b): are stratospheric balloons to relay radio signals to remote users (Fotouhi et al., 2019)

One of the recent technologies for middle-mile broadband connectivity trialed is the television white space (TVWS). TVWS are portions of licensed television spectrum bands, either not utilized or sporadically utilized at a given time in a given geographical location. The migration from analogue to digital broadcasting service made the Digital Terrestrial Television Broadcasting (DTTB) efficiently utilize the TV spectrum, creating spectrum gaps that could be opportunistically utilized for other secondary uses. The trials of TVWS networks have shown great promise in delivering broadband connectivity. Some use cases were described by Ismail et al., (2019). The TVWS spectrum has superior radio propagation characteristics and its longer coverage range and robustness in building penetration can hugely contribute to enabling provision of affordable broadband connectivity services particularly in rural communities across Tanzania. This paper focuses on coverage capability of the TVWS based secondary network to deliver the broadband connectivity in comparison to the UMTS standards of mobile broadband.

Problem definition

Current mobile broadband connectivity technologies are not suited to sparsely populated areas. To provide a broadband connection of 2 Mbps as stated in the Tanzania National ICT Policy 2016 requires relatively high received power for as compared to voice service, which typically requires a 10-kbps connection and is an error tolerant service which would require a power ratio of about 8 dB compared to about 23 dB for Internet using 256 QAM radios. This power ratio difference makes it relatively difficult to cover large coverage areas for internet and consequently a lot more expensive to cover sparsely populated rural areas with mobile broadband compared to urban areas with relatively high population density. TVWS has emerged as a suitable innovative strategy to provide broadband network for rural areas, but how good is it in providing a better coverage while achieving the minimum required broadband data rate?

METHODS AND MATERIALS

The study analyses the achievable data rates in different propagation environments based on propagation measurements carried out in different parts of Tanzania and considering 3G UMTS networks Releases 4, 5, 6 and 7 operating in the 900 MHz band as proposed by Massawe and Chitamu (2022). The downlink is considered due to its high broadband data rates requirement. The transmit power for the TVWS and UMTS radios are 36 dBm and 24 dBm respectively and cell edge range limited by data rate rather than normal receiver sensitivities on the downlink (BTS to MS). The received power at the edge of the cell can be calculated as:

$$P_r = P_T + G_T + G_R - P_L(d)\ [dB] \quad (1)$$

where P_T, P_L , G_T and G_R and are transmitter power, pathloss, transmitter and receiver gains respectively.

The pathloss models for the channels propagation environment used in this investigation are based on results from propagation measurements carried out in different parts of Tanzania by Chitamu and Braithwaite (1996). The three pathloss Equations derived from the study are presented in Equations (2) to (4) representing hilly, undulating and flat terrain respectively. d is the BTS distance from the receiver.

$$P_L = 107 + 72\log(d) \quad (2)$$

$$P_L = 101 + 53\log(d) \quad (3)$$

$$P_L = 95 + 42\log(d) \quad (4)$$

The impact of the received power attenuation as it goes through the propagation environment and the Additive White Gaussian Noise (AWGN) at the receiver is measured by analyzing the figure of merit E_b/N_o (bit energy to noise ratio) at any particular location on the link, thus giving a radio link power budget.

$$\frac{E_b}{N_o} = \frac{P_r / R}{N / W} = \frac{P_r W}{NR} = \frac{P_r 1}{N_o R} \quad (5a)$$

$$R = \frac{P_r}{N_o} \frac{1}{\frac{E_b}{N_o}} \quad (5b)$$

$$P_r = \frac{E_b}{N_o} N_o R \quad (5c)$$

W is the system bandwidth.

Analyzing the received E_b/N_o to achieve the target data rate of 2 Mbps at the edge of the cell, we can calculate the coverage of the base stations (BTS), hence the number of BTS to cover the required population. The cell-edge radius will depend on the type of service being considered as services have different characteristics and requirements from the network. The study analyses BTS coverage to achieve the target data rate for specific rural areas characterized by three different radio operating environments namely hilly, undulating and flat terrain landscapes. These represents rural areas in Tanzania such as Ngudu in Mwanza (flat terrain), Njombe and Mafinga (undulating landscape); and Amani, Lushoto, Moshi and Usa River (hilly landscape) (Chitamu & Braithwaite, 1996).

The minimum required number of BS depends on both the area to be covered and the served traffic. To cover a target area A_T (km^2), the minimum required number of BS N can be defined as a function of the maximal BS coverage range R (km), obtained from Equation (6) as:

$$N = A_T/\pi R^2 \quad (6)$$

RESULTS AND DISCUSSIONS

First, the pattern of the received signal strength corresponding to the different canonical areas (Equations 1, 2, and 3) with G_T and Gr set equal to 0 dBi for normalization purposes and of 24/36 dBm (UMTS/TVWS) are shown in Figure 4. The TVWS data threshold is set at -90 dBm and that of UMTS at -80 dBm to correspond to BER of 10^{-3}.

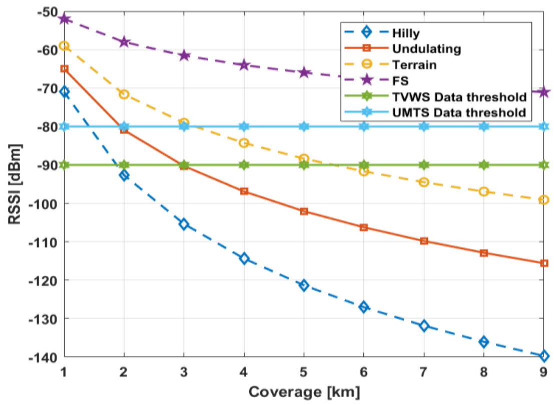

Figure 4: Received signal power in different environments

It can be noted that the TVWS network achieves more coverage at the same terrain due to its low receive sensitivity (RSS) compared to that of UMTS. Figure 5 shows that for the same coverage range, the TVWS achieves a better Eb/No performance than the UMTS network. At a target Eb/No threshold of 20 dB, TVWS/UMTS BTS coverages are 1.5 km/0.8 km, 2 km/1.2 km, and 3.2 km /1.5 km for hilly, undulating and flat terrain respectively. Figure 6 confirms the BTS coverage performances obtained in Figure 5 when a data rate of 2 Mbps is fixed at Eb/No = 20 dB. Using Equation (6), the number of BTS to cover a rural area of 50 km^2 is shown in Table 1.

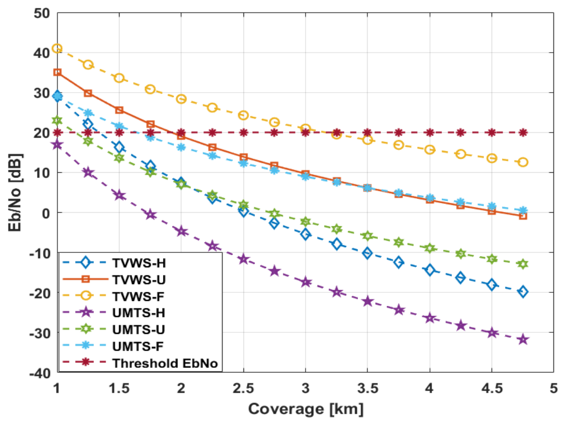

Figure 5: Eb/No performance for UMTS and TVWS

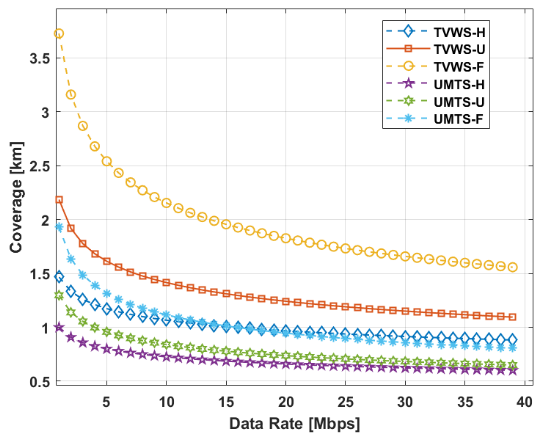

Figure 6: Coverage vs data rate for Eb/No=20 dB.

Table 1: Number of BTS to cover a target area of 50 km^2

Canonical area	Hilly	Undulating	Flat
UMTS	25	12	8
TVWS	8	4	2

It can be observed that there is 3-fold BTS reduction when TVWS is used over UMTS to cover a target area of 50 km^2 at a target data rate of 2 Mbps. Assuming equal investment cost per BTS for the two technologies, this reduction represents a 68%, 66.7%, and 75% investment reduction for the three canonical environments respectively. This represents a good CAPEX for network deployment. For Tanzania, which has vast sparsely populated rural areas, this could be a good solution to achieve rural connectivity and reduce digital divide.

CONCLUSION

This study analysed the coverage and hence CAPEX performance of the TVWS based broadband network in comparison to the UMTS family of standards which are predominantly deployed in areas with high population density due to their high OPEX and CAPEX. It has been demonstrated that for sparsely populated areas such as rural areas in Tanzania, the TVWS based deployment of broadband network could be the best strategy to reduce the deployment costs.

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