Mitigation of Rain-Induced Ka-Band Attenuation and Enhancement of Communications Resiliency in Sub-Saharan Africa

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Paper Category: Research-in-progress

Main Document format outlined on next page

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ABSTRACT

Despite tremendous growth in the area of mobile telephony, Africa continues to lag behind other developing regions in Internet access. The business opportunity to capitalize upon this Internet Protocol (IP) traffic need has not gone unnoticed. Major communications service providers have been investing heavily in Ka-band communications (the Ka-band is part of the K band of the electromagnetic spectrum) — which can carry more data than lower frequencies and offers additional frequency ranges at already occupied satellite positions — such that next generation Ka-band satellites can be responsive to the burgeoning IP traffic market. However, these Ka-band systems have disadvantages compared to lower frequency solutions; Ka-band systems are much more susceptible to weather due to signal absorption by moisture in the air and by wetness on antenna surfaces. These inherent limitations of the Ka-band hold a special significance for communications in Africa since almost a third of the continent is tropical in climate, and weather patterns across the continent are expected to further increase in variability, including increases in the frequency of extreme events, such as storms. The Paper further explores how the use of TV White Spaces, in addition to the availability of real-time weather information via the notion of "humans of sensors," could be particularly useful for observing, anticipating, and mitigating disruptions to communications services.

Keywords:

Access, Satellite Telecommunications, Ka-Band, Climate Change, TVWS, TV White Spaces, Sensor Networks

INTRODUCTION

Despite continued technological advancement in the arena of mobile telephony, Africa continues to lag behind other developing regions in the availability and bandwidth capacity of Internet access. Market forces are in motion to capitalize upon the business opportunity to meet this growing IP traffic need. Inmarsat, one of the major satellite communications service providers (along with, e.g., Hughes and Eutelsat), announced in June 2010 that it would invest "US$1.2 billion in Ka-band communications, via satellites" so as to capture the growing African IP traffic market [1]. On June 20, 2013 Astrium Services, a leader in end-to-end satellite solutions that has long been engaged in Africa, announced that it expects to sign a bulk-purchase agreement with Inmarsat to secure Ka-band capacity [2].

Mobile phones in African rural regions do not have easy access to terrestrial communication networks. This lack of access is driving this a market demand for expanding satellite-based Ka-band communications on the continent. The rapid roll-out of coverage into rural areas and minor cities by mobile operators is also producing a growth in the market of satellite-based cellular backhaul services[1] [3]. In fact, in 2006, it was noted that "29 out of 55 African countries and territories get more than 80% of their total international Internet bandwidth by satellite, and many fixed and mobile operators in the region are also becoming increasingly dependent on satellite for their domestic communications services as well [4]."

Both the operational costs and the price for service are very high in Africa. The operational costs of satellite-based mobile backhauls up to 40% of overall costs for service providers [5].]. Services costs in Africa are about 500% higher than in Europe. The cost for a German university is approximately $4000 per month for 1 gigabit per second of bandwidth (Gbps), a Kenyan School would pay $200,000 for the same service. In 2011, the total bandwidth capacity between African countries and the rest of the world was at 801 Gbps, a 60% increase compared to 2010. This is about one-seventieth of Europe's international bandwidth capacity. Africa's current low frequency bands lack sufficient bandwidth to convey large amounts of data per second. Exacerbating the limited bandwidth is the fact that, both low and very high frequency signals are heavily absorbed by the atmosphere.

[1] In a telecommunications network, the backhaul portion of the network consists of the

Ka-band allows for increased bandwidth at a lower price per bit and well meets the demand for bandwidth consuming venues, such as video.[2] The rapid growth of Ka-band capacity is significant. Ka-band is resilient, indeed, satellite-based communication mitigates risks associated with terrestrial-based network infrastructure. Satellite-based Internet networks serving an earthquake or conflict zone are not subject to failure or destruction during a catastrophic event. Furthermore, Ka-band has a higher data throughput than lower frequencies (e.g. C and Ku-band) [7], and it represents an additional frequency range at already occupied satellite positions [8]. The use of both satellite-based communications and traditional land-based communications creates a robustness and resiliency to technology failures and network interference. Dr. Steve New of the University of Oxford's Saïd Business School asserts that network resilience is a function of *dynamic interdependence* between the actors of a network; therefore, enhanced communications resiliency will ensure that a region's communications service has low response time even under peak load. Lower latency is significant Consider that millions of phone messages during an event, such as an earthquake can produce approximately 30 Terabytes of accelerometer (a sensor that measures the magnitude as well as direction of acceleration; the sensor can also be used to sense the orientation of the device containing it) data [9].

A diverse Internet infrastructure, that includes Ka-band, allows satellite operators such as Inmarsat to achieve higher data rates at a much lower price per bit. If the cost decrease is transferred to the end-user, it can result in lowered cellular technology adoption costs and an increase in market size and adoption (please refer to Figure 1).

[2] It should be noted video services, such as Netflix, accounts for one-third of all North American bandwidth, and YouTube accounts for a significant portion of the European bandwidth [6].

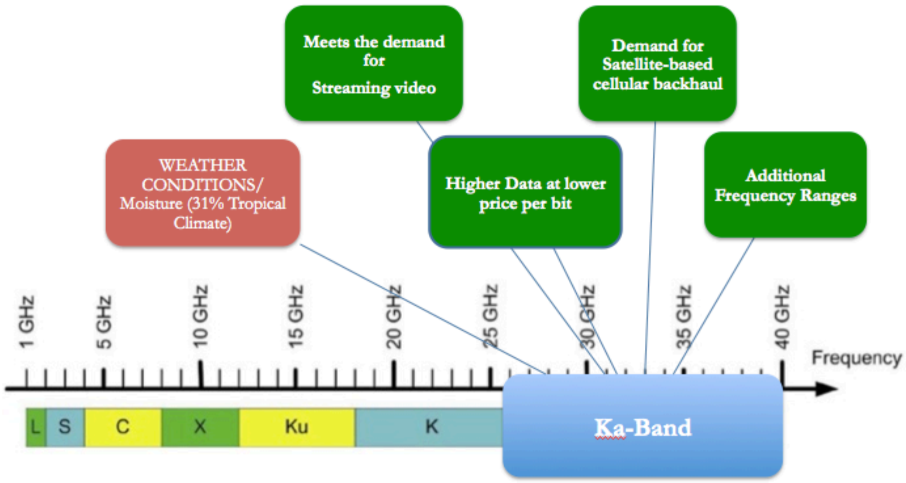

Figure 1 Ka-Band Advantages and Disadvantages.

Higher transmission frequencies have several disadvantages compared to lower frequency solutions. Higher frequency Ka-band systems (26 GHz – 40 GHz) are much more susceptible to weather conditions than Ku-band (12 GHz – 18 GHz) and C-Band (4 GHz – 8 GHz) systems due to “rain fade,” signal absorption by air moisture and by wetness on antenna surfaces [10]. The loss of data from normal atmospheric moisture makes Ka-band poorly suited for applications, such as classical satellite TV. In contrast, IP traffic applications, can withstand some degree of routine data packet loss — a receiving device knows to request the missing data again and again until the entire transmission can be reassembled — and the delay of a split second or even longer usually does not pose a problem for Internet -based communication. IP traffic on the Ka-band will degrade under conditions of heavy precipitation (e.g., a rainstorm), especially during peak traffic times [11].

Telecommunications plays a tremendous role in the fostering of economic growth and human development in Sub-Saharan Africa. The need to improve telecommunications resilience in the region emerges is pivotal to empowering communities living in rural and remote areas. While satellite service still provides a fundamental telecommunications infrastructure, we believe that Ka-Band - will play a prominent role by further expanding telecommunications capacity.

Since the importance of weather-induced data loss particularly relevant for telecommunications resilience in Sub-Saharan Africa, the following sections will provide an overview of the linkages between Ka-Band satellite telecommunications and weather susceptibility. It will also identify Internet expansion suitable strategies. In particular, we will explore the potential of TV White Spaces (TVWS), as well methods that exploit the *humans as sensors* concept, taking advantage of data generated by mobile phones and social media.

KA-BAND TELECOMMUNICATIONS IN SUB-SAHARAN AFRICA

Satellite coverage and proper satellite functioning are important aspects of African communications resiliency. A case in point regarding regional communications network resiliency, it is interesting to note that when Inmarsat repositioned its satellites (the Inmarsat-4, a.k.a. I-4 satellites) in stages between August 2008 and February 2009, to comply with U.S. regulatory requirements and to optimize its network,[3] the net result was outages of coverage in many areas of the continent.

In addition to its commercial services, Inmarsat provides *gratis* global maritime distress and safety services (GMDSS) to ships and aircraft. The above service outage created gaps in the GMDSS; the significant gaps caused a stir within the humanitarian aid community. The sensitivity to regional communication to satellite availability has pushed emergency planners to tackle new and difficult questions about the possible effects of satellite communication outages as well as preparation and mitigation options. The scheduled I-4 outage in Broadband Global Area Network (BGAN) services (i.e. the service of connecting remotely located laptop computers to Internet networks) that lasted from January 7 to February 6, 2009 was anxiously monitored by those whose region of interest was West Africa (including Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, Sierra Leone, etc). The loss of situational awareness during this outage was compounded by torrential rains in regions of Namibia. The rains destroyed the livelihoods of at least 350,000, or 16% of Namibia's population [12]. The specter of reduced satellite coverage in regions of extreme regional climate change had shown its shadow and

[3] So as to avoid interference with other satellite systems operating across mainland North America and ensuring that two of the Inmarsat-4 (I-4) satellites were within sight of the Inmarsat Satellite Access Station in Hawaii.

prompted many organizations, such as the UNDP (United Nations Development Program) and its disaster risk reduction (DRR) practitioners and academic partners, to carefully think about the future of communications resiliency [13].

Extreme Climate change, Telecommunication resilience and 'Humans as sensors' approach

Climate is defined as the average state of the atmosphere for a given time scale and a specified geographical region [14]. The Intergovernmental Panel on Climate Change (IPCC) defined climate change as "any change in climate over time caused by natural variability or human activities" [15], while climate variability "refers to variations in mean state of climate on temporal and spatial scales beyond that of individual weather events". Typical examples of climate variability are torrential rainfall, floods, and prolonged drought.

Africa is predicted to be one of the regions most affected by extreme climate change, even the nature and extent of such change is still far from being determined. Lack of adequate historical climate data on Africa [16, 17, 18] is one of the foremost reasons for such uncertainty, making the downscaling of climate change scenarios at the sub-regional level extremely complex [19]. Wide differences are expected in rainfall events at the regional level. While an increase in annual mean East African rainfall is expected, a decrease in much of the winter rainfall region and on western margins of southern Africa is likely. Still uncertain is the impact of climate change on rainfall events in the Sahel, the Guinean Coast and the southern Sahara [20]. In addition, patterns across the continent are expected to further increase in variability, including increases in the frequency of extreme events, such as storms. "Many African regions are coming to be recognized as having climates that are among the most variable in the world on intra-seasonal and decadal timescales; in fact, all these climates exhibit differing degrees of temporal variability, particularly with regard to rainfall [21]." A significant increase in heavy rainfall events has been already observed in various parts of southern Africa [22].

Because of the expected heavy rainfall events, the limitations of the Ka-band hold a special significance for communications in Africa for both disaster management and longer-term sustainable development. In order to observe, anticipate, and mitigate climate-induced disruptions to communications services the availability of real-time weather information is key, as well as accurate predictions of precipitation in the near and medium term. Ka-band technological infrastructure would otherwise be at risk during peak traffic times, such as during crises. However, African country climate data is frequently neither collected nor shared. Columbia University, the Bill and Melinda Gates Foundation, and Google's philanthropic team are negotiating with African meteorological organizations to make weather data more freely available[4].

The identification of innovative ways to collect and disseminate data about weather and climate is thus critical to improve climate monitoring and enable African institutions to anticipate and mitigate telecommunication service disruptions. The notion of using "humans of sensors" [23] has emerged as a new approach to gather and synthesize data and information on weather, network telecommunications and energy. Indeed, not only traditional (e.g. weather) sensor networks could support the development of scalable and distributed monitoring solutions, but sensor networks composed by mobile devices could be extended by treating each "human as a sensor". This approach can take advantage of the cell phone and social media communications, aggregate both private and publicly available data in real-time with quasi-real-time data gathered deliberately or inadvertently by many hundreds or thousands or millions of individuals. Such contribution could be pivotal to improve observation, anticipation, and mitigation of climate-induced telecommunications disruptions, as well as to gather weather and climate to fill the gap undermining the study of climate change. The "humans as sensors" approach would thus not be instrumental in improving connectivity per se, but rather it could serve as a key proxy to (early) warning about network quality of service.

TV WHITE SPACES (TVWS) AS A SOLUTION TO EXPAND ACCESS IN REMOTE AREAS OF SUB-SAHARAN AFRICA

As previously discussed, operational costs and the price for satellite telecommunications are particularly high in Africa, and alternatives have been explored to promote the expansion of telecommunications services across the continent. Recently TVWS have received a lot of attention as a possible alternative. In 2013, three TVWS trials have begun in Africa. A Google-sponsored trial of TV White Spaces in the Western Cape of South Africa began in March 2013 to

[4] See http://goo.gl/GyUPM for further reference.

connect ten primary and secondary schools to the Internet. In Kenya a local Internet Service Provider (Indigo Telecoms), has partnered with Microsoft and the Government of Kenya to build a TVWS pilot in the Nanyuki region. The pilot connects a health care clinic, a library and three local schools. In Malawi, a network was setup by the University of Malawi to connect a school, a hospital and a seismological research center to the Internet. Among the reasons why TVWS received so much attention by governmental institutions as well as corporations is that they primarily offer a solution to the spectrum shortage that has resulted from the explosive growth of wireless technologies.

In most developing countries, microwave links are used for point-to-point communications to extend the backhaul up to the edge of the network. The small wavelength (from 30 cm to 1 cm) allows small size antennas to direct them in narrow beams. The high frequency gives the microwave band a very large data capacity. A disadvantage of microwaves is that they are limited to line of sight propagation; they cannot pass around hills or mountains as lower frequency radio waves can.

Most microwave links use the frequency bands that are being kept open for general unlicensed use. This region of the radio spectrum is called the ISM band, which stands for Industrial, Scientific, and Medical. Most other parts of the electromagnetic spectrum are tightly controlled by licensing legislation, with license costs being a huge economic factor. In most countries, the ISM bands have been reserved for unlicensed use and therefore do not have to be paid for when used.

While the focus of most researchers has been in protecting the incumbent user of the spectrum, the TV broadcasters, from the possible interference caused by the new entrants, we believe that rural areas in Developing Countries are ready for the deployment of white spaces radios that can be used to provide Community Network services and Internet access. It has been proven that the spectrum used by TV White Spaces is available in many African countries. In Senegal more than 90 MHz are available in Dakar alone, and more across the country [24]. This spectrum could be used for broadband. Our measurements in Malawi and Zambia confirm the same availability of free frequencies, with even emptier spectrum in rural areas. The reason of such availability is that TV broadcasters never had an economic incentive to serve sparsely populate areas especially using the UHF band. A recent decision of the FCC (Federal Communication Commission) in the

US to allow the nationwide deployment of TVWS band devices, has provided the incentive for several manufactures to invest in the production of equipment capable of providing links at a reasonable throughput operating in the 470 MHz to 690 MHz band.

The attributes of TV White Spaces make them attractive for use in rural areas. They have much better propagation characteristics that higher frequency which means that individual base stations can reach further. This reduces the total number of base stations required for a given area. UHF spectrum is that it doesn’t require direct line-of-sight between radios. This aspect will lower the cost of deployment by reducing the need for high towers and more complex network design. Finally, the market cost of TVWS devices will be closer to that of WiFi equipment than traditional wireless broadband equipment used in licensed spectrum. Unlike WiFi, TVWS represent a better solution to expand access to the Internet in Africa for two reasons. First, in most African cities the unlicensed spectrum used by WiFi is crowded and it is impractical for networking use. In rural areas the better propagation characteristics of TVWS means that fewer base stations and towers are required, thus reducing the overall costs. A further advantage relevant to the specific African climate is that rain fade is especially prevalent at frequencies above 11GHz, so TVWS networks will not be interrupted by bad weather.

An *ad hoc* evaluation mechanism should be developed to test the effectiveness of TVWS deployment, to determine the degree to which it can complement Ka-Band and can increase telecommunications resilience in Sub-Saharan Africa. Proposed evaluation criteria include: (a) throughput in normal weather conditions; (b) throughput in heavy rain conditions; (c) power consumption in idle and transmission modes; (d) latency and jitter in normal and rain conditions; and (e) physical resilience in normal and rain conditions.

CONCLUSIONS

This paper presented the main issues linked to weather susceptibility of Ka-Band satellite telecommunications, a communications mechanism whose capacity to carry more data than lower frequencies and offers additional frequency ranges can help expand Internet access in Sub-Saharan Africa. However, Ka-band telecommunications performance in Ka-band is indeed affected by moisture in the air and by wetness on antenna surfaces. The need to improve telecommunications resilience is particularly important in rural and remote areas, where the expanding penetration of mobile phones combined with the lack of terrestrial communication networks make satellite coverage pivotal.

TVWS represent a particularly promising solution to mitigate Ka-Band rain attenuation telecommunication gaps in rural areas of Sub-Saharan Africa for two reasons. First, TVWS is virtually unaffected by rainfall events. Second, TVWS free frequencies are particularly available in remote and rural areas because TV broadcasters never invest in coverage of these sparsely populate areas. TVWS technology should not be regarded as a solution in and of itself – as it would require a connection for its own backhaul (e.g. to fiber). A TVWS network could also be used to reach multiple uplinks, though the likely proximity of such uplinks would possibly decrease the overall quality of service offered via TVWS.

More broadly, it should be underlined that every technological solution to improve access in Sub-Saharan Africa will need to be context-wise, as the past decades proved that one-size-fits-all solutions were inappropriate within Africa. Moreover, being the expected impacts of climate change are still uncertain. With specific regards to heavy rainfall events- there is a need for policy makers to plan adequate (possibly redundant) solutions in order to strengthen telecommunications resilience across the region. To do so, we propose the further assessment of the deployment of complementary technology solutions and strategies, such as the combination of Ka-Band, mobile and TVWS linked with the involvement of African citizenship thanks to a 'humans as sensors' approach will be particularly interesting. Future research will be carried out to measure the specific extent of TVWS availability and the testing of integrated solutions linking Ka-Band and TVWS in areas of Sub-Saharan Africa prone to heavy rainfall.

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