Rural Wireless Connectivity in Kenya

Abstract

The topic that was discussed was to provide rural connectivity, mainly voice but also including data communication, in Kenya. The most economical and logical method was to start connecting people locally through 802.11n with a base station in the center and then connected by landline to a router in each house. Regionally, hot air balloons would provide service at a low price with large coverage. Internationally, fiber optic cables will be the most viable way to connect Kenya to other countries.

This project will help Kenya's social infrastructure, economy, and development.

Introduction

In thinking of technologies to use in Kenya, many factors have to be taken into account. One of the major obstacles is Kenya's geography. Kenya is an east African country that lies on the equator and shares a border the Indian Ocean. Along with the Great Rift Valley, there are several mountains and vast plains. In the southwest region of the country is the Lake Victoria Basin. The western highlands are separated from the low plains that rise to the highlands by the Great Rift Valley. There are low-lying plains to the east which lead to the coastal region. These different geographical areas require different technologies to provide efficient service.

Kenya's people are just as diverse as the natural features. With about forty different ethnic groups, a reliable telecommunications system is greatly needed. While some groups of people remain stationary, some nomadic tribes still exist. The four major tribes include the Kikuyu people, the Maasai tribe, the Samburu tribe, and the Turkana tribe. The Kikuyu people reside near Mount Kenya and are known for their farming. The Maasai tribe is more traditional than the Kikuyu people. They are nomadic herdsmen that do not believe an education is important. They continue to farm for the sake of trading crops since they have no cash currency. The Samburu tribe is related to the Maasai tribe. They are semi-nomadic and live between Mount Kenya and the desert. The Turkana tribe is a group of nomadic pastoralists. They live in northern Kenya. A better telecommunications system would allow these different types of people to communicate with each other more readily.

Since the 1990's, Kenya has had a telecommunications system in place. Back then, the Kenya Posts and Telecommunications Corporation (KPTC) controlled all service for cellular phones. Private companies established full internet services in 1995, with strong objections from KPTC. In 1997, along with Vodafone, KPTC launched Safaricom, a Global System for Mobile Communications (GSM). Safaricom, as well as Enhanced Total Access Communications (ETACs), continues to cover the most populated areas in Kenya.

Choosing to help Kenya become connected was a logical choice. Kenya's people are clearly interested in using a telecommunications system because there is already one in place that is widely used. There are so many barriers with using this system, one of which is the tax that is placed on it. Most people cannot afford this because 50% of the population is below the poverty line. Their current system is inadequate and unreliable, and it is only available in densely populated areas. A better telecommunications system may help Kenya's struggling economy.

Rural connectivity will greatly improve the lives of Kenyans. Through the entire population being connected, instead of just those in densely populated areas, the entire nation will be connected to the rest of the world. Connectivity will allow the people to better educate themselves, foster economic growth, and cultivate related infrastructure growth.

Local

The initial part of connecting rural people is to connect the community and unite it as a whole. The purpose of people-to-people connectivity is to facilitate the transfer of information across a tribe and to provide information readily to every home. By connecting at a small-scale and then working up to a larger scale connection will be easier to handle and organize. The central idea of local-to-local connection is by having a base-station that will be connected by landlines to a router in each home. Each person in the home will then be able to connect to the router through a voice over Internet protocol (VoIP) phone.

The various technologies that will be considered are 802.11 (WiFi), 802.16 (WiMax), 802.20, Bluetooth, and 3G networks.

802.11 is currently used in common routers for internet connectivity such as Linksys, D-Net, and Netgear. It uses orthogonal frequency-division multiplexing (OFDM), dividing frequencies and arranging them orthogonal to each other or at right angles to eliminate interference. By using this type of coding system, it can operate at high frequencies without too much noise. Within the 802.11 or WiFi technology there are different frequencies or versions. The earliest was the relatively primitive 802.11 legacy. The two other main frequencies used are 802.11b and g and 802.11a.

802.11a was first introduced in 1999. It uses the 5 GHz frequencies at a realistic rate of 25

Mbit/sec and a maximum rate of 54 Mbit/sec. Because of the high frequency wavelengths, less interference occurs but the range is also greatly reduced, only about ten meters. A great technology for homes and offices where there is little distance to span and many technologies also emitting wavelengths that could interfere, it is not viable for rural local connectivity in Kenya. The distance is too short and can be unreliable at longer distances.

The other branch of 802.11 are b and g. B was first introduced in 1999. It uses complementary code keying (CCK), a form of code division multiple access (CDMA). Operating using the 2.4 GHz wavelength, it has a realistic rate of 6.5 Mbit/sec and a maximum rate of 11 Mbit/sec and a range of approximately 30m. In June of 2003, a newer version named 802.11g tried to make improvements upon 802.11b. It can now operate at a realistic rate of 25 Mbit/sec and a maximum rate of 54Mbit/sec. However, using the 2.4 GHz frequency creates interference with other technologies. Microwave ovens, Bluetooth technology, and cordless phones currently use the same frequency band.

The newest 802.11 connection is 802.11n. It is currently being developed and will be available in 2007 with a range of up to 50m. Using multiple-input multiple-output (MIMO), 802.11n will have a realistic speed of 200 Mbit/sec and a maximum speed of 540 Mbit/sec. The disadvantages to this new technology are that it still operates in the 2.4 GHz frequency and could potentially be expensive because it will be a newer technology.

Overall 802.11a, b, and g are inexpensive and can be bought in mass quantities for less than 10 USD apiece, but the range of each and the speed is not great enough. 802.11n is the best candidate of all the 802.11 technologies but it may cost too much.

802.16 or WiMax was first introduced in 2001. This technology includes 802.16a, b, and c that operate on frequencies of 10-66 GHz. Using time division multiple access (TDMA), it has a range of up to 31 miles. The new 802.16e will be similar to the 802.20, another project undertaken by the IEEE. It can go up to 120 Mb/sec but the cost of each base-station on top of the individual router cost is between 10,000-20,000 USD.

802.20 is another new technology under development by the IEEE. The ballot was approved in January of 2006 but will be under suspension from June 8th, 2006 to October 1st, 2006 due to certain group reasons of competition and unfair research. It will operate on frequency bands below 3.5 GHz at a maximum rate of 1 Mb/sec. Using OFDM, it will have a range of up to 15 miles and withstand speeds of up to 250 km/hour. This is probably the best technology on the market for rural connectivity in Kenya, but because of the suspension of further research and the cost of new technologies, it could be an expensive and time-consuming venture.

Bluetooth technology has already been widely used by simple household device such as for hands-free cell phones. It uses the 2.45 GHz bandwidth at a low signal strength of only 1 miliwatt to prevent interference with other household appliances. The disadvantage is that this technology has a very short range, a few rooms apart or approximately 10m. This is the cheapest technology available, but, because of its limited range and signal strength, it cannot be used in Kenya.

3G refers to the next generation of cell phone technology. Unlike the 802 protocols, the main purpose of 3G is voice communication. However, because of the better data rates it is possible to transmit other types of information as well. Data rates for 3G range from 100 kbps to 384 kbps. One of the main applications being promoted by 3G providers is video capabilities. Like previous cellular technology 3G uses frequency bands from the licensed spectrum, frequencies purchased by the provider. WiFi (802.11) and its related technologies operate on unlicensed spectrums. Another important thing to note is that 3G allows the user to be mobile. WiFi (802.11) requires a stationary access point, as does WiMax (802.16). A mobile version of WiMax (802.16e) and 802.20 are being developed to support mobile access. The range of 3G is 1-3 kilometers depending on terrain and line of sight.

4G, a successor of 3G, is not projected to be available until at least 2008-2010. However, it would offer greatly improved date rates of up to 1 Mb/s while moving and up to 20 Mb/s stationary.

It is important to remember that 3G and 802 are different types of technologies. 802 protocols are used primarily for data transfer and 3G is used for voice communication. 3G technology is not suited for rural connectivity in Africa. The overhead cost and needed capital for base stations and infrastructure would outweigh the return.

Overall, 802.20 would be the best option in terms of technology to use. However, because of its suspension and possibly high projected cost, 802.11n when available will provide sufficient service at an affordable cost.

Regional

Another solution to rural connectivity involves a new form of wireless communication technology concerning floating aerial devices. These devices revolve around aircraft, balloons, and airships suspended in the air at an altitude of approximately 100,000 feet. Instead of relaying signals between orbital satellites and their receivers

600 to 1200 miles apart, wireless transmitters attached to floating balloons will act as a relay point. These high altitude platforms will act as a "low flying satellite" and relay transmissions.

The advantages of high altitude platforms are numerous. Located 20 miles above ground, these devices have direct lines of transmission. While normal tower stations are built to be high above ground, they are nowhere near the 20 miles altitude of the floating platforms. This difference in altitude allows the floating balloons to send and receive data signals in straight lines. For example, if a tower is overshadowed by a building or skyscraper taller than it is, its broadcast potential would be significantly diminished. Furthermore, because the device is at an altitude lower than that of satellites, it can transmit more efficiently. While a satellite has to send and receive signals at a distance of 600 to 1200 miles above Earth, a floating aerial device only has to perform the task at a distance of 20 miles above ground, allowing these platforms to have higher bandwidths than their satellite counterparts.

These devices are also cost effective. Floating balloons, running $300 a piece, are significantly less expensive than their satellite counterparts which can incur costs of $100 million and tower stations which cost $12,000 and higher. According to Marc Weingarten in "Up, Up and Away," "a carrier could activate dead zones at $300 per SkySite. For $15 million, 50,000 sites could cover 90% of the country. It would take $60 million to construct 5000 towers to cover 20% of the United States."

In addition, each device also has an impressive 350 mile range radius. This range easily outclasses its WiFi competitors. WiMax, also known as 802.16, has a maximum range of 50 miles in line of sight and 15 miles in non-line of sight transmissions.

Though aerial devices provide many advantages to rural connectivity, there are several drawbacks to this technology. Currently aerial devices depend upon battery supply as its energy source. The balloon requires redeployment every twenty-four hours to renew its energy supply. Prospective engineers have envisioned running the device upon solar energy, but current solar cells are unable to generate enough solar energy to run the platforms. Power will be especially weak during the winter, as solar energy collection is difficult. The aerial device is still unfinished and is currently in development. In addition, the aerial device must be stationary to function at its full potential. Therefore, mechanisms are required to prevent the balloon from drifting with air currents and during storms. Nevertheless, floating aerial devices are a viable and efficient technology.

The deployment of the Balloons is still in its developing stages. While recovery is relatively simple, with the balloon simply ejecting a parachute and slowly descending to the ground, and with tracking through an onboard GPS, launching is still an issue. Currently, Space Data Corp, a pioneer in floating aerial devices, is attempting to secure a contract with the National Weather Service. The proposition will ask the NWS to launch the balloons, with SDC recovering the launched devices.

From both an economic and engineering standpoint, floating aerial devices is a viable option. "A recent trial run in Phoenix, Arizona provided data that a 2 watt transmitter on a high altitude platform was as effective as a 500-watt tower," says David Wu, President of Space Data Corp. These balloons would offer companies an inexpensive option to provide network service compared to building expensive towers. This technology would not replace existing towers but be implemented as a supplement to existing stations. With the advent of these high altitude platforms in the not too distant future, a solution to rural connectivity is in the horizon.

International

In terms of international connectivity, there are several options. Falling under the category of guided media, international communications can be carried by copper wire or optical fiber. In the category of unguided media, the communications can be made by microwave radiation through satellite networks or directly through terrestrial microwave antennas.

Optical fiber is a guided communications medium where data is transmitted by pulses of light through a glass or plastic cable. The type of fiber that is applicable for large applications is single mode fiber, or fiber with a core diameter of less than 10μm. Using single mode fiber, a transmission can be sent up to 140 km without the use of an amplifier or repeater. The cost of fiber is approximately $1000 per kilometer. This figure, however, does not account for the cost of the intricate multiplexing equipment needed at either end; neither does it account for the expensive repeaters needed at the end of each interval. This need for expensive equipment represents one of the huge disadvantages of optical fiber. Moreover, this equipment is difficult to maintain.

The older technology of data transmission over copper wires does not suffer as extensively from these disadvantages. Although copper wire does experience signal attenuation, and therefore needs amplifier equipment, the amplifier equipment is cheap. Multiplexing technology is also cheap, and the construction and maintenance of copper wire systems is simple and inexpensive.

Another viable way of connecting telecommunications networks over long distances is microwave communication. Microwave is a term used to refer to the band of electromagnetic radiation with frequencies between 300MHz and 300GHz. At frequencies above 300GHz, the attenuation caused by absorption by the atmosphere becomes so dramatic that those frequencies are unusable for telecommunications. However, higher frequencies lend themselves to simple, cheap construction of directional antennas. The microwave spectrum, therefore, is a good compromise for long distance radio communications; the frequencies are low enough to suffer only tolerable attenuation in the atmosphere but high enough to allow the construction of small, cheap antennas. Data can be sent between two antennas placed on top of towers, each with a parabolic dish focusing the electromagnetic radiation into a signal directed at the other antenna. The range of a typical terrestrial microwave antenna is approximately 50 km. Distances longer than this can be spanned by a chain of antennas.

A final option for long distance telecommunications utilizes satellites. Instead of using a microwave antenna to communicate directly with another terrestrial antenna, the signal is sent to a satellite. The equipment required for a system is the same as that for terrestrial microwave links (an antenna known as a VSAT, or very small aperture terminal), with the added necessity of satellites. Satellites used in telecommunications fall into two categories: geosynchronous satellites (known as GEO) and Low Earth orbit satellites (known as LEO). A geosynchronous satellite orbits the Earth at a distance of 35,786 km above the surface of the Earth; at this distance, the period of the satellite's orbit is equal to the period of rotation of the Earth. Since a GEO satellite stays fixed in the sky, a microwave antenna that communicates with it can have a directed signal. However, the disadvantage of GEO satellites is the distance between the satellite and the terrestrial antenna. Microwave radiation sent between an antenna on the ground and a geosynchronous satellite suffers dramatically from atmospheric attenuation; this necessitates expensive antennas that must have very powerful signals. The other option for satellite networks, the LEO satellite, does not experience this disadvantage. The period of orbit of a LEO satellite is between one and two hours; a network of LEO satellites is therefore required to provide continuous coverage to any particular region of the Earth. Because the radius of a Low Earth orbit is merely 200 to 1200 km above the surface of the earth, it is cheaper to launch LEO satellites and easier to build telecommunications equipment that can overcome the signal attenuation caused by the atmosphere between the surface of the Earth and a satellite in Low Earth orbit.

Communications between satellites and terrestrial networks are conducted through terrestrial antennas called very small aperture terminals (known as VSATs). When the satellite is in geosynchronous orbit, the VSAT is a directed antenna that points at the satellite; aside from atmospheric attenuation, this is an efficient solution. However, the motion of a Low Earth orbit satellite precludes the use of a directed antenna. Most current technologies that deals with LEO satellites use omnidirectional antennas; this is inefficient. New technology is emerging that uses phased array antennas, which would make the VSAT more efficient in terms of power consumption.

When analyzing the various technologies available for large-scale connectivity in Africa, both technical and economic activities must be taken into account. All four of the technologies mentioned are feasible technically. However, the use of terrestrial microwave antennas does not make sense when compared to the cost of optical fiber for long distances. Furthermore, optical fiber is technically superior, and quickly becoming economically superior, to copper wire for long distance telecommunications. For developing nations, launching a satellite into geosynchronous orbit is prohibitively expensive.

Low Earth orbit satellites are economically viable because any LEO satellite network is, of necessity, global; a network of LEO satellites developed in for use in the Americas, Europe and Asia would also provide coverage to Africa. Connection plans in this LEO network would be organized using demand assigned multiple access, as described in. This would allow major corporate users to access large amounts of bandwidth; however, it would also allow users in poorer areas to pay only for the limited amount of bandwidth that they use. Development would be easy even in the most remote areas given the presence of reliable electricity.

Optical fiber has advantages for large scale communications. Whereas a LEO network would be difficult to expand, optical fiber has enough bandwidth that expansion is easy. Optical fiber projects are already underway in Africa; one example is the East African Submarine Cable System.

The technical difficulties involved in large-scale telecommunications connectivity are essentially related to terrain. Flat areas are easily interconnected with optical fiber. Mountainous areas, however, may be better served by satellites.

The major challenge of international connectivity with Kenya is an economic one. Reliable telecommunications services of a reasonable quality cannot be provided without a good infrastructure. Major telecommunications providers will not invest in major infrastructure developments unless there is a clear demand. This demand is in the form of a large, multinational corporation; private use does not qualify as a justification for investment except in large, urban areas. Thus, many argue that development of large-scale telecommunications in rural Africa will be a slow process, with progress made only as Africa is slowly industrialized.

Other researchers, such as Parker in, argue that competitive development is a fundamentally flawed approach to rural development. Parker suggests that rural development must be facilitated by the government, since large corporations have no incentive to develop services in regions with relatively little demand. A good example of the success of this strategy is the deployment of telephone service to Alaska in the 1970's. Claiming that the minimum cost of a terrestrial antenna for a satellite connection was $500,000, the large telecommunications company announced that it could not supply connections to rural communities due to issues of economic feasibility. The state government found a different equipment vendor willing to supply the equipment for only $50,000 for each station and applied for a permit with the FCC to install the equipment. The commercial telecommunications company quickly submitted a competing proposal; the project ended up being very profitable for the telecommunications company. This case is support for government involvement in telecommunications development. While there is an argument that communications development is shaped by free market forces alone, analysts such as Parker contend that government intervention is necessary to facilitate rural communications development.

One facet of communications economics that is completely controlled by the government is the tax placed on telecommunications. In 1991, Kenya placed a value added tax on telecommunications. This was an effort to increase tax revenue and to create a tax system that would fluctuate with changes in national income. Many African nations treat telecommunications technology as a luxury item, and tax it accordingly. Kenya has lowered or waived many of its taxes on telecommunications technology, but remaining taxes still hamper infrastructure development. It is easy to suggest that states like Kenya should eliminate or cut drastically any taxes that are even minimally associated with development of telecommunications services. However, governments do need to balance the need for expansion with the immediate need for revenue; in general, taxes are affected by other factors and it is difficult to isolate their interaction with telecommunications development.

Conclusion

Rural connectivity can play a large role in a lesser-developed nation such as Kenya. This design for connecting the country achieves its goal by approaching the task one step at a time beginning with local connectivity.

Locally, people would be connected through 802.11n routers. There will be a router in each household, which will provide service to the phones at a range of about 50m, and each router is connected by copper wire or landline to a base station at the center of the village. Although 802.11n will not be available until 2007, it is the cheapest equipment that will provide enough speed and send enough amounts of information for a local village in Kenya. Pre-802.11n routers are available for 50 USD. 802.11n, because it is another improved technology, should cost approximately 30 USD when mass-produced. If there are 34 million people in Kenya and only 59% live out side of the city, routers will cost a total of 75 million USD. If there were to be a base station for each 10km2 at a rate of $1000 for each station, it would cost $58 million. This would be a total cost of about $133 million.

Regionally, an aerial balloon would cover each base station. Using microwaves, it has direct line of sight and is a high altitude platform. It can cover a large range, 350 miles radius at a time. However, this technology needs to be replaced every 24 hours and is not anchored anywhere, meaning it is mobile and can cut off service eventually. There is low fuel efficiency as well, but each balloon only costs $300. The actual technology can be sent up by the National Weather Service and later servicing costs will be cut. Given that Kenya has an area of 582, 650 km2, it would take only one balloon to cover the entire country Kenya. The main transmitter will be located on the ground in the capital of Kenya, Nairobi.

This main transmitter will be connected internationally via fiber optic cables. Copper wire has too little bandwidth and microwaves based on giant dishes are too expensive. Another option is to have the United States lend Kenya satellites, or to use them when they are not above the United States, for connectivity. However, this solution would not help Kenya in the future and can only offer a short-term temporary solution. There is already a fiber optic ring around Africa that has been installed but has not been used. Faster and spanning longer distances without a need of an amplifier or repeater, fiber optic cables can be laid for only $1000/km. Based on the fact that it took approximately $100 million to wire Rutgers onto the optic cable network, it is estimated that it will take upwards of $200 million to wire all of Kenya.

This brings the grand total of this design to approximately $333 million. Although this maybe a big price tag, this design is aimed to bring connectivity to all of Kenya and all the people in Kenya. The best way to approach this task is to make sure that if money and labor are to be sent to Kenya to build such a network, the highest-performance and more economical materials and technology should be used to ensure a rapid growth in social infrastructure, economy, and development.

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