Re-assessing Long Distance Wireless for West Africa

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Abstract

In this paper, we describe our experiences deploying long distance, point-to-point WiFi links in Ghana and Guinea Bissau, focusing on several challenges that are somewhat unique to these countries and this region of the world. In particular, the high cost of transportation, lack of locally produced materials and goods, shortage of technically trained labor, and poor power infrastructure all contribute to an abnormally high cost of building terrestrial networks, especially with comparison to other developing countries such as India. In addition, the highly regulated and monopolized telecommunications sector in Ghana results in market failures even when good infrastructure such as fiber optic backhaul networks exists.

These challenges mean that low cost equipment is not enough to catalyze rural telecommunications deployments. Besides technologies for lowering capital costs, mechanisms for increasing reliability (to reduce transportation related maintenance costs), training and documentation tools (to increase local technical autonomy), low cost, reliable power systems, and rational spectrum and communications licensing policies all become especially critical in this particularly challenging environment. We underscore the significance of local context in planning and understanding the ecologies around information technology deployments with specific examples from West Africa.

I. Introduction

WiFi Long Distance (WiLD) networks have gained significant popularity recently, with software improvements allowing regular WiFi hardware to be used as point to point networking links over long distances, even over hundreds of kilometers. The Aravind network in Tamil Nadu, Southern India, uses the long distance wireless links to enable videoconferencing between doctors in Aravind Eye Hospitals and patients in rural eye clinics [9], [10]. These local intranet solutions are largely independent of existing local communications infrastructure. However, as such, they have been able to take advantage of low cost equipment and an ample supply of labor to effect a relatively large-scale networked systems deployment for use as an effective communications network.

A number of factors have contributed to our success with WiLD networks in India. However, the question remains as to whether the findings in [10] hold in other regions of India or the world, and scale to larger infrastructure deployments, and if they can integrate more thoroughly with national communications infrastructures. Does long distance WiFi have a role to play in building out transit infrastructure for remote areas? How does its suitability play out differently in different geographic regions?

We argue in this paper that many of problems entailed in building long distance wireless networks for transit backhaul, in which multiple remote repeaters are often used to transmit data over long distances, are *fundamentally different* than the problems we encountered in the Aravind deployment. Differences in capital and labor costs dwarf the costs of the communications equipment – meaning that lowering the cost of the equipment is not enough to enable the deployment of long distance wireless networks in the less densely populated rural areas of Africa. In addition, different telecommunications policy regimes (spectrum licensing, import policies, competition, VoIP policies) result in a different range of cost structures and technologies that can be deployed in each country. Indeed, the often severe gap between telecommunications policy (competition and cooperation) and implementation (monopolistic business practices) often discourages the deployment of large-scale network infrastructure in many African countries.

In this paper we share our experiences in working with local organizations and ISPs to deploy WiFi Long Distance (WiLD) networks as low cost infrastructure for enabling telecommunications in Ghana and Guinea Bissau. While most of the challenges we have encountered are common to many developing countries, transportation, the availability of local resources, and power infrastructure all contribute to a significantly different economics environment for building terrestrial networks than in many places in India or China, for example.

Our project in Ghana focuses on building backhaul networks, rather than last hop or distribution networks. This also entails a fundamental difference in the structure of the network itself, further affected by the relative population densities between Tamil Nadu and Ghana. Our network in Ghana necessarily require longer links and higher towers. The Ghanaian network has several links of more than 60kms, with a 90km link planned. The Guinea Bissau network has several 60km links planned as well. The goal is to develop a stable, low cost platform with which to penetrate very rural environments which are otherwise unsustainable telecommunications markets. Our experiences revealed some interesting insights into the telecommunication space in these countries as well as some hard lessons to be learned when considering future wireless infrastructure deployments and other ICTD projects.

In the remainder of the paper we will first go over our two projects in Ghana and Guinea Bissau in Section II, discussing their context, and the scope of the individual deployments. From there we will identify some key issues to be considered in infrastructure, specifically addressing technical challenges in Section III and administrative challenges in Section IV. We conclude with a discussion of our experiences and our own recommendations for future research and policy changes.

II. Background

A. Ghana: Wireless Inter-University Network

Our project in Ghana is an academic research network, initially intended to interlink the electronic libraries at each university in Ghana, and permit sharing of journal subscriptions. The network is also intended to interlink a group of hospitals as part of a telemedicine network. In prior trips we had demonstrated the utility of long distance wireless [9] by linking University of Ghana Legon to their remote workers college and medical school. We had also demonstrated a 70km link, the first hop of a wireless backbone linking Cape Coast to the capital city Accra, indicated as the link between Weija and Dego in Figure 1

The purpose of the Ghanaian network is to provide universities in Ghana with a dedicated wide area network (WAN). This WAN will initially facilitate inter-library communication for card catalog sharing, electronic resource and database sharing, and an inter-library loan system. Eventually, the network will also enable other capabilities such as video conferencing.

The network offers a significant opportunity for cost sharing between the university libraries. The libraries' licensing agreements for databases and other resources would permit them to share resources on their network, potentially saving tens of thousands of dollars per year. This potential for cost savings provides a concrete sustainability plan for the network.

We commissioned our local partner to build out the WiLDnet-based backbone between Takoradi and Accra, connecting Cape Coast University, University of Education at Winneba, and University of Ghana at Legon, in addition to two universities in Accra.

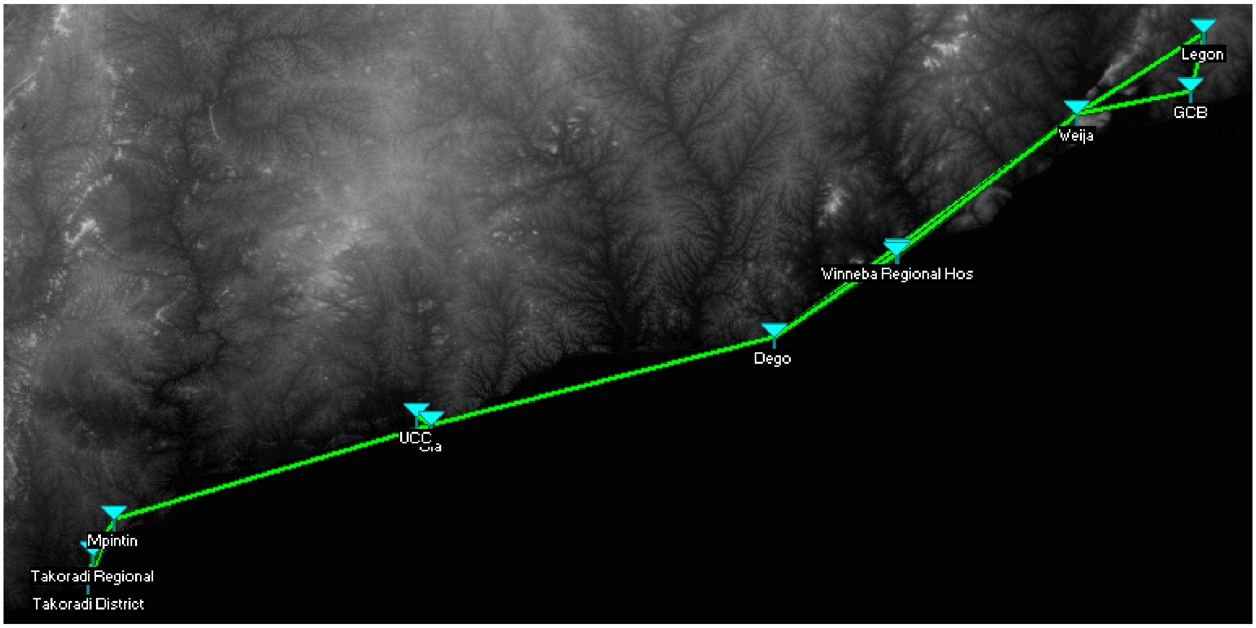

Fig. 1. Projected university and hospital network.

B. Guinea Bissau: Community Radio Syndication Network

In Guinea Bissau we are working in collaboration with US-AID and Eguitel, a locally owned and operated ISP, to network together 15 community radio stations. The network will allow live syndication of radio content from across the country. The network will also run a delay tolerant network (DTN), which allows recorded broadcasts to be stored in a centralized repository and then shared with the other radio stations in the network. Because the system is based on an asynchronous store- and-forward architecture overlaid on the wireless network, it will be tolerant of network outages, power outages, and other problems intrinsic to networking in a country like Guinea Bissau.

The recent history of Guinea Bissau has had a significant impact on our project. A war with neighboring Senegal in 1998-9 left the countrys infrastructure in shambles, including the telecommunications systems. After a brief dictatorship, the country returned to democracy in 2003, and as part of the reconstruction effort, Eguitel was granted a broad telecommunications license, enabling them to carry voice and Internet trafc, including VOIP trafc. Eguitel was also granted a broad spectrum license. This has dramatically reduced the administrative barriers for Eguitel to build a national terrestrial network, and also has made them an attractive partner for our research group. In particular, their broad spectrum license has raised several possibilities for innovative uses of WiFi equipment.

1) Community radio

After the war with Senegal, community radio activists installed radio stations throughout the country with the hopes of fostering open, independent communication, and supporting democracy. US-AID identified networking these radio stations together in order to provide national coverage as an important priority for supporting independent dialog about important domestic issues [7].

In conjunction with University of Western Cape (in South Africa), and their “African Virtual Open Initiative and Resources,” which provides funding and practical opportunities in open source development for academic departments throughout Africa, we designed a network architecture to address the communication needs of these radio stations. See Figures 3 and 4.

Our network architecture has two central components. For live national broadcast, we use low cost

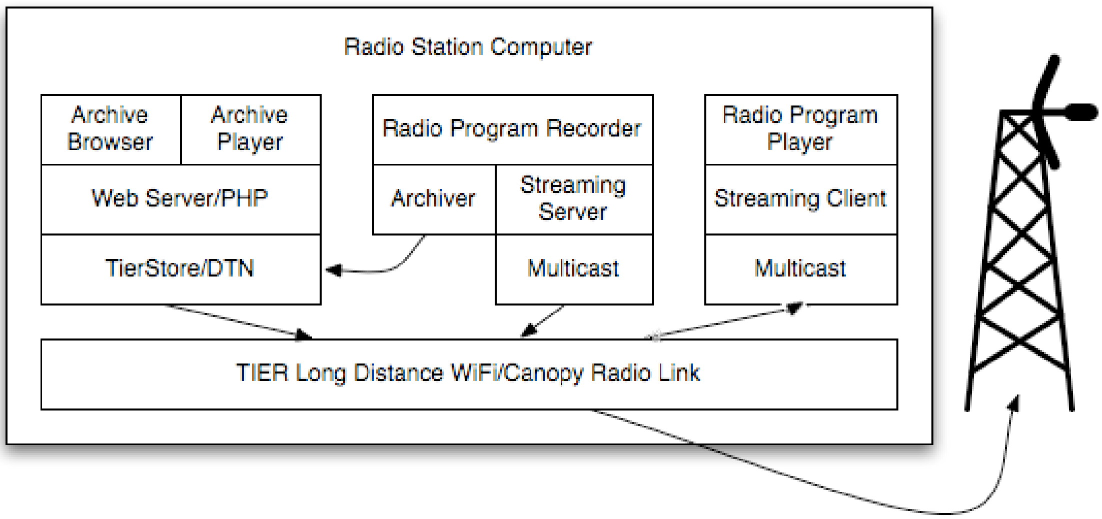

Fig. 2. The software architecture for the Guinea Bissau community radio platform

routers based on WiFi hardware running our proprietary, TDMA based MAC protocol [8]. The TDMA MAC enables the maximum theoretical throughput of the hardware over long distances, and also reduces "jitter," or variability in delivery delay for data. For rebroadcast and archival, we use TIERStore, a "Delay Tolerant Networking" (DTN) file system which is tolerant of disconnections. Using the DTN stack overlaid on the WiFi network allows us to provide robust syndication of content even when the low cost links are unreliable [3], [4].

2) Local partners, local infrastructure

Eguitel gets a significant benefit from providing this service to the community radio stations. They can piggyback on the infrastructure of the local radio stations, including the mast, power and some minor local technical expertise. Furthermore, because the local radio stations are invested in the network's success, they are more likely to identify and help troubleshoot problems than a passive partner who does not use the network themselves.

Eguitel can also use this network to provide VOIP and other Internet services to remote areas of the country without investing the significant capital and maintenance outlays that would be necessary for a virgin deployment. Also, since the radio stations often have line of sight to their neighbors, the network does not need many remote repeaters.

This combination of invested local partners, relative network density and reused infrastructure tilt the economics of Eguitel's network in favor of success.

III. Technical Challenges

Our network in Ghana has several relay points which are not also endpoints. This presents both technical and administrative challenges. Technically, relays without a support engineer on site require "truck-rolls" for maintenance. Truck rolls are notoriously expensive in any network, but much more so in Ghana. This is caused by two main factors.

First, transportation infrastructure is poor, particularly in remote rural areas. This means that more time, wear and tear on vehicles and more fuel per truck roll. Secondly, a scarcity of well trained engineers means that an engineer will probably need to travel further to reach the remote location, and will probably charge a high rate for their time. In fact, we found that well trained engineers in Ghana were paid hourly rates similar to engineers in industrialized countries. These two factors make reliability of paramount importance to the sustainability of a large scale network in Ghana with remote repeaters.

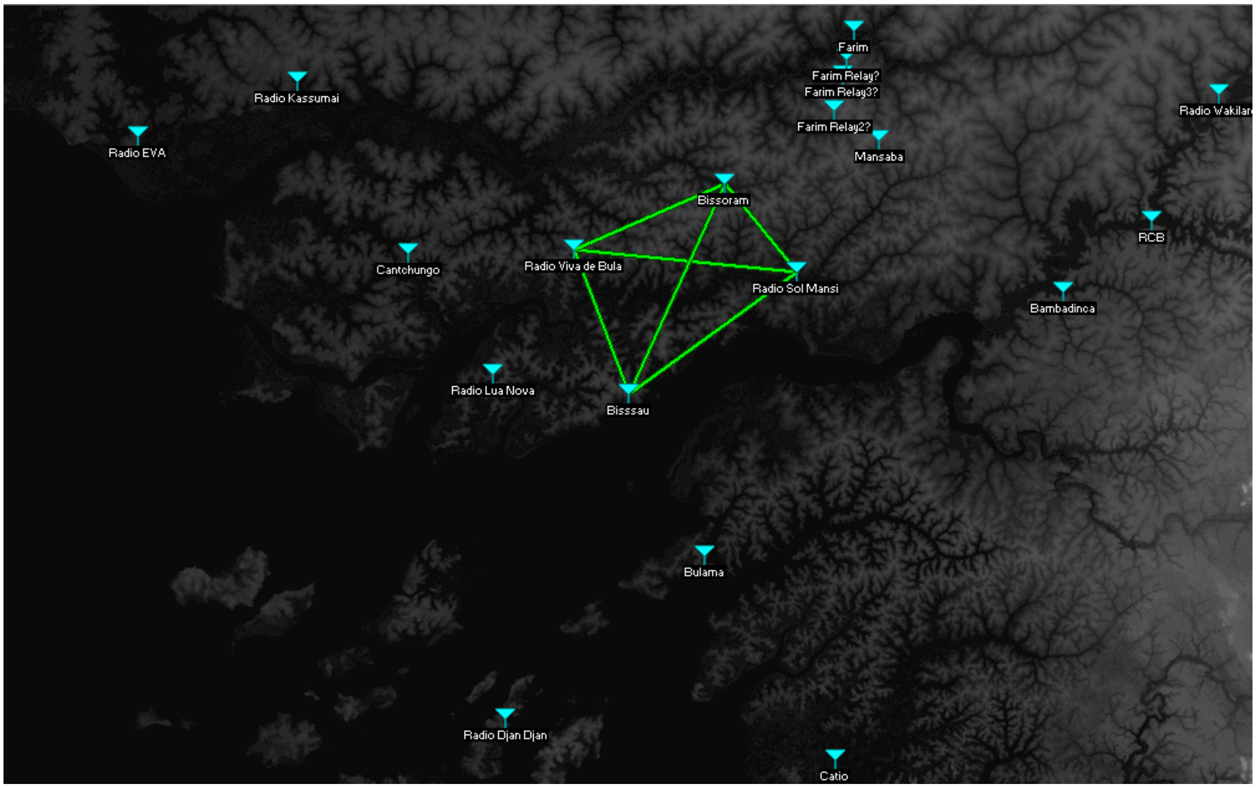

Fig. 3. The Guinea Bissau network in operation

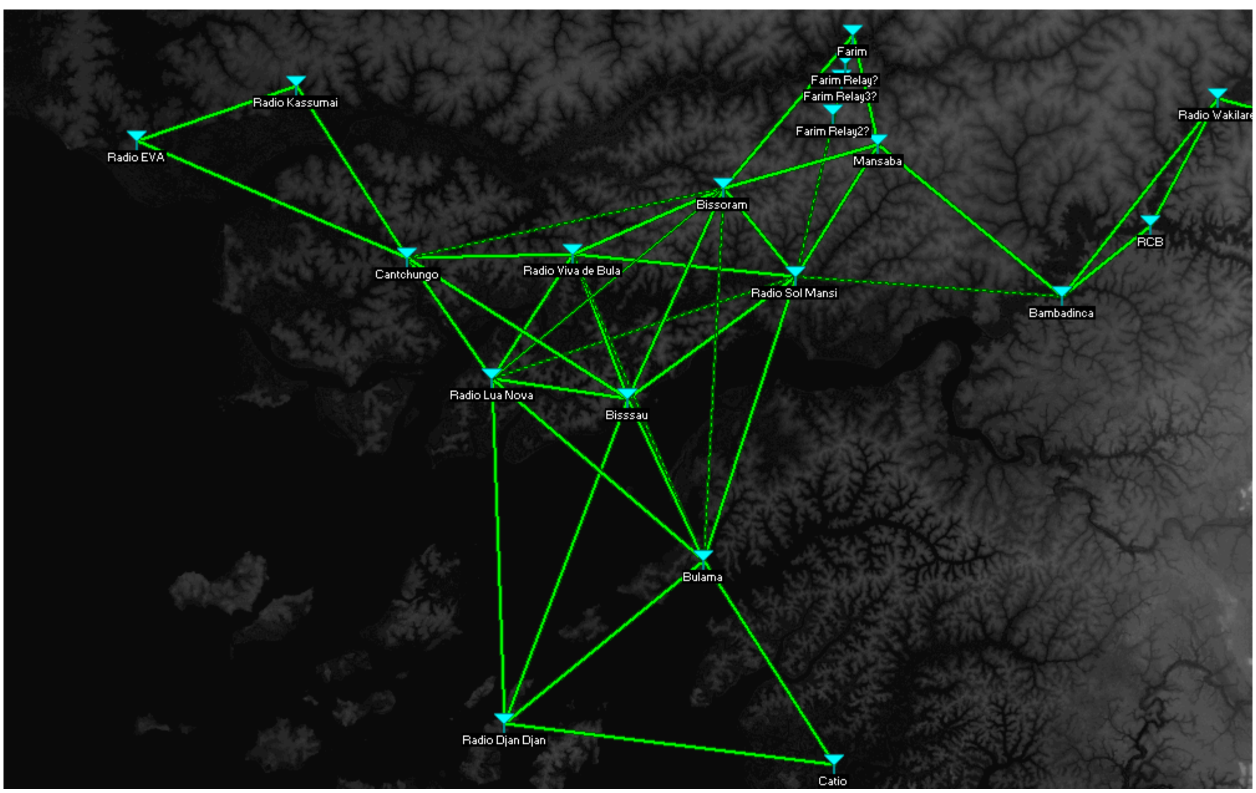

Fig. 4. The Guinea Bissau network as planned

Fig. 5. An unanticipated technical challenge. Our router, located about 10m from the base (now the top) of the mast, was no longer functioning when we returned to our site 6 months later.

Our equipment offers high performance at ranges that other low cost WiFi based solutions are unable to achieve because of our custom software. Because we are a research team, however, reliability of our equipment and software has not been a primary focus of our efforts. In the Aravind network our partners have been able to overcome this difficulty because of the relatively low cost of labor, the relatively short distance between the endpoints, the relative lack of repeaters in the network architecture, and because of the superior organization and dedication of our technical partners. Our partners were able to develop protocols to deal with outages quickly.

In Ghana, on the other hand, our technical partners are overworked and inundated with other priorities. This means that failures in repeaters are not only expensive to deal with, but also that repairs are subject to our partners' busy schedules. Outages can last for days, seriously undermining the usefulness of the network. In the Ghanaian network, reliability of equipment is critical to the success of the network, and the cost of more expensive, reliable equipment will be quickly recovered in maintenance savings and usability.

The Guinea Bissau network, in some respects, is similar to the Aravind network. Most of the radios in the network are endpoints at FM radio stations (even when they also function as repeaters). This means that there is a person already on site who is responsible for power, and equipment maintenance, and who can be trained to do basic trouble-shooting.

Another technical challenge is that of locating the routers themselves, mounting them on masts sufficiently high to clear local foliage while still being accessible for power and maintenance. While there are many local and cultural issues attached to this task [1], we specifically note that in our experience the cost of building towers in Ghana have been several times the cost of building the same towers in India. Table I indicates the costs of building towers in Ghana. As a point of comparison, for the price of a single 30m tower (about 6000USD), we were able to negotiate the installation and maintenance of three such towers for the Aravind project. While some of this can be attributed to good negotiation, a lot of this price difference is due to the difference in the costs of raw materials and labor in the respective locations.

In addition to this cost difference, however, the typical lifetime of a tower in Ghana is shorter, at

[1]Our technical collaborators in Ghana typically provide Internet access to local schools in exchange for permission to build towers on nearby hills, and at one point specifically had to secure permission from the local hill god to do so.

approximately five years, and the tower must be taken down and replaced at intervals, adding to the ongoing cost of maintenance. In practice, towers are not built well, or are not taken down in time, and both towers and equipment are lost, in addition to the potential damage and injury to surrounding buildings and people. This happened to us twice in Ghana, with two separate collaborators. In the first instance (Figure 5) the tower was not well constructed. In the second instance, weather conditions had conspired against our infrastructure partner, and the tower at Dego collapsed a month before they had scheduled a contractor to come to replace it. As a result, upon our arrival, they were scrambling to replace all of the lost equipment, and to re-establish all of their links on a temporary mast while waiting for the new mast to be completed, delaying our own deployment by an additional three months. The equipment we had already installed on the towers was, of course, sunk cost, and we were required to acquire new equipment for the replacement tower.

IV. Administrative Challenges

As we mentioned above, remote repeaters can present an administrative problem for wireless networks, particularly community based wireless networks. For endpoints with an on-site engineer or technical liaison, failures are pretty clearly the responsibility of that engineer. For repeaters, however, a central entity or third party needs to take responsibility for the failure.

In the Ghanaian network, we initially took responsibility for the maintenance of the repeaters, and the backbone network. We agreed that after one year of operation, the GARNET2 consortium would take over financial responsibility for the network operation, with engineering done by our technical partner. This, however, has proven to be a difficult proposition. Administrators have been hesitant to take on the responsibility of maintenance, because of the instability of the network. This is compounded by the bureaucratic problem of getting several different university administrative units to agree to a maintenance protocol. As our financial ability to maintain the network has diminished, so has the operation of the network.

In Guinea Bissau, on the other hand, the staff at the few endpoints that have been installed so far are enthusiastic participants. In conjunction with a technical partner who views it as in their own best interest to maintain this network for their own use, the operation of the network has been more reliable.

Another important administrative issue that has had a significant financial and operational impact on the respective networks is spectrum. In Ghana operation of 2.4Ghz equipment for outdoor networking requires a 500USD annual fee. While this is a relatively low barrier to entry, it creates unnecessary bureaucracy. More concerning is the 5000USD annual fee per site per channel fee for 5.x Ghz licenses. This is prohibitively expensive for any operator except for large scale operators, and basically prices small projects out of the market.

This licensing requirement means that the 2.4Ghz bands are heavily over-subscribed in urban areas, and effective performance of 2.4Ghz point to point radios varies dramatically based on uncontrollable factors.

As mentioned previously, Eguitel has a broad spectrum license which enables them to choose equipment based on its technical properties. Most of the radios in the Guinea Bissau network are 5.x Ghz radios because of the smaller antenna size needed for 5.x Ghz radios with comparison to 2.4Ghz radios.

In Table I, we see a summary of the major cost factors the remote relay stations we built or utilized in Ghana. Clearly, the radio itself is dwarfed by other costs. The cost of spectrum means that spectral efficiency is a primary concern, and the cost of truck rolls means that reliability is much more important than low capital cost for the radio. Any time these exogenous cost factors can be eliminated creatively, even at the expense of a slightly more expensive radio, that should be done.

V. Technical directions

In this section, we summarize the issues we have touched on in the previous sections, and describe technical solutions that can begin to address the practical challenges of low cost backhaul networking.

Radio equipment		$500
Mast	up to 30m	$200/m
(non-galvanized)	up to 80m	$300/m
	installation	$200/m
	Maintenance	$1000/year
	road	$15,000/km
	road maint.	$5,000/year
Power	Batteries	$350
	Solar (100w)	$900
	Grid power	varies
	Wire instl.	$+++
Security		$500/year (approx)
Spectrum	2.4 Ghz regist.	$500/year
	5.x Ghz license	$5,000/year/channel/site
Field Engineering	Hotel	$50/night/engineer
	Daily rate	$110/day/engineer
Transportation	Petrol	$0.50/km
	Vehicle	$0.50/km
Truck Rolls		$50-500/roll

TABLE I

MAJOR COST FACTORS FOR A REMOTE RELAY STATION. MANY COSTS ARE HIGHLY DEPENDENT ON LOCATION AND OTHER FACTORS. "TRUCK ROLLS" FOLDS SEVERAL COSTS INTO ONE FIGURE

For backhaul networking, in which endpoints do not have line-of-sight or near-line-of-sight, radio equipment costs are marginal compared to other costs in the system. Therefore, research in low cost backhaul telecommunications needs to focus on innovations that extend the range or effective LOS for WiLD networks, increase reliability or robustness of the system to point failures, allow for mounting on less stable masts, and can be installed and configured by relatively untrained technicians. Rational spectrum policy should be researched and lobbied as well.

When considering ways to reduce the cost of equipment, often the dominant cost in building a remote repeater is in building a mast. In cases where an existing building can be used, with perhaps a pole or short mast on the roof, obviously this should be done. Not only does this result in a shorter mast, but will also provide extra security and possibly an existing power source. This is something that has been implemented in many of the Aravind links. In the case of the Ghana deployment, this was possible for several of the end points, but the unavailability of intermediate relay points between routers along the backbone required mounting our antennas on taller masts.

In lieu of an existing structure, trees, particularly tall stable trees (such as Kapok trees, Figure 6) on the crests of hills present an interesting opportunity. While not as rigid as a steel mast, trees often grow on crests, have withstood the test of time (often better than steel masts do (see image)), and do not require roads for installation and maintenance. Building masts on remote peaks often requires building roads to reach them, a cost which can easily reach many tens of thousands of dollars, and which requires significant maintenance.

By using lightweight, passively cooled, low power equipment, we have the opportunity to exploit these pre-existing structures. Lightweight equipment will be less prone to damage on a tree, and low power means that solar rather than mains or diesel power can be used. Lightweight radio and solar equipment can easily be packed in and maintained on foot.

Unfortunately, less rigid trees will threaten to disrupt a network's reliability, especially in storms. In

Fig. 6. A dead kapok tree, approximately 30m tall, with a similarly sized live tree in the background

Fig. 7. A gratuitous picture of the authors installing a router at the University of Ghana

order to tolerate swaying during high winds, a network can employ electronically steerable (as opposed to mechanically steerable) antennas, such as phase-array or switched parasitic antennas. Various low cost electronically steerable antennas are currently under research at Berkeley and Intel Research [5], [1]. These technologies will open the door for very low cost repeater stations.

Regardless of whether repeaters are installed on rigid steel masts, or other structures such as trees or poles, truck rolls to remote sites are extremely expensive due to poor roads, and expensive fuel. Technologies that can increase reliability or robustness to failure will significantly impact the operating cost of a networking in much of Africa. Truck rolls to remote sites often mean paying not only for transportation, but expensive per-diem for RF engineers (see Table I).

In addition to using passively cooled equipment, robustness in the power system can be helped by using power-conditioners , and significant battery backup. Battery systems, however, have their own costs, with operational lifetimes of about three years. Charge controllers which can monitor battery health can allow for scheduled truckrolls for preventative maintenance, rather than emergency replacement runs. Good charge controllers also extend the life of a battery system by changing in a way that reduces memory effect in the batteries. Peak power tracking chargers can also increase the effective output of a solar or wind generator, reducing capitol and maintenance costs for those devices. The charge controller we have developed has all these features [10].

In some cases, for some applications, asynchrony can be used to significantly reduce the cost of communications. Because asynchrony allows a system designer to build for average rather than peak demand [6], power and bandwidth requirements can often be significantly reduced. Also, asynchrony can be used to mask intermittent failures, making the system much more robust. Transaction processing and some communication can sometimes be made asynchronous (even voice communication such as broadcasting like in our FM radio network, and voice messaging [6]) with enormous cost implications. Research on delay tolerant networking attempts to create a rich and flexible framework for developing applications which operate in challenging environments and intermittent networks [4].

Another major cost factor for network deployment in Africa is human resources. Trained engineers are difficult to find in many parts of Africa. Technologies which either allow engineers to work more efficiently, or allow less trained staff to do work that an engineer would normally have to do will significantly impact the HR cost of a network. Meraki routers have gained significant popularity in building “roofnets” both in the developing world and the developed world, because of their relative ease of configuration [2]. While Meraki routers prove useful in locations where Internet access is reliable, the software is unusable in locations where Internet access is intermittent or entirely inaccessible. Similar technology for long distance point-to-point links would probably enjoy similar popularity.

Surana et. al. [10] have begun to investigate the root causes of failures in wireless routers in India. Their findings point towards robust power systems and software for remote diagnosis and maintenance, and expert-system style troubleshooting tools for field engineers.

Electronically steerable antennas which can automatically align themselves might also increase the efficiency of deployment engineers, decrease the amount of training they need, and decrease the likelihood of antenna misalignment.

VI. Conclusions

While WiLD has made significant strides forward in connecting rural communities in developing regions around the world, there is still much to be understood about how well this technology replicates to other types of deployments and in other geographies. With these two case studies in Guinea Bissau and Ghana we have shown how some of our assumptions about what has made WiLD successful in the Aravind network break down for deployments of long distance WiFi in the context of rural backhaul. Each project put forth differences in the costs of maintenance, installation, spectrum licensing, and even administrative challenges that suggest that low cost equipment alone is not sufficient to address the needs of these projects.

To help address some of these challenges, we have put forth suggestions for further research in this direction, attempting to highlight both existing and projected research that might better enable us to use wireless technologies for long distance backhaul in more sparsely populated areas.

In future work we hope to be able to generalize some of our findings, building a more complete model of how the cost factors and partnerships contribute to the failure or success of a wireless network.

VII. ACKNOWLEDGMENTS

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