A Rural Implementation of a 52 Node Mixed Wireless Mesh Network in Macha, Zambia

Jonathan Backens[1], Gregory Mweemba[2], and Gertjan van Stam[3]

[1] Old Dominion University, Norfolk VA 23529, USA
jback006@odu.edu
[2] LinkNet, Macha, Zambia
gregory.mweemba@link.net.zm
www.link.net.zm
[3] Macha Works, Macha, Zambia
gertjan.vanstam@machaworks.org
www.machaworks.org

Abstract. In spite of increasing international and academic attention, there remains many challenges facing real world implementations of developing technologies. There has been considerable hype behind Wireless Mesh Networking as the ubiquitous solution for rural ICT in the developing world. In this paper, we present the real world rural mesh network implementation in the village of Macha, Zambia and draw both performance conclusions as well as overall experiential conclusions. The purpose of this paper is to introduce and analyze our low cost solution and extrapolate future trends for rural ICT implementations in Zambia.

Keywords: Wireless Mesh Network, Rural ICT, Implementation Test Case.

1 Introduction

The community owned and run LinkNet Multipurpose Cooperative Society services the rural community of Macha, Zambia with innovative communication technology and locally trained talent [8]. Since inception its model for connecting rural Zambia with ICT services has been to empower the local community to run and maintain a locally built, locally maintained and locally managed internet infrastructure based on wireless communication technologies. Utilizing only local talent and supplies, the Macha Network has provided not only a powerful and inspiring local ICT project, but has laid the foundation for a comprehensive test bed for other rural implementations. This real world solution consisting of a network of 52 Mesh Nodes and 99 total active wireless service providing devices remains one of the largest locally run rural networks in Africa.

In order to understand the conditions of Macha Zambia and a bit of the demands for ICT, it is important to consider the overall environment. Zambia as a country is the 17th lowest country on the UNDP's Human Development Index [3]. It consists primarily of agricultural workers with an average income

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of about $1USD/Day. The village of Macha is located in the Choma District of Southern Zambia, in a semi arid flat farming area. It remains 70 km from the nearest tarred road or landline phone. Currently there is a population of $\geq$ 135.000 persons within an 35 km radius[13]. As far as traditional mobile communications, GSM service arrived in December 2006 but as with much of rural Africa outages are common. Currently internet connectivity is available via VSAT, GSM EDGE and Short Wave although all are subject to cost, weather and power fluctuations(see Section 2.3 for more on challenges).

The main feature of Macha is the Macha Mission Hospital(MMH) and Malaria Institute at Macha(MIAM)[4]. These institutions provide health care for the greater Macha area as well as being the primary employer of educated professionals and medical researchers.

LinkNet(currently structured under Macha Works) began providing broadband internet service in 2006 to hospital professionals' residences, the MIAM clinic/lab and the local community center for an internet cafe. The motivation behind the Macha Network is nearly as diverse as its client base. The MIAM research laboratory and offices use the network for research, correspondence and data management, the Macha Mission Hospital utilizes similar resources in addition to e-health advances such as the Zambian Ministry of Health SmartCare program for digital health records. In addition, the local community exploits the Internet for e-learning with several community members attending online university courses [15]. Also, local farmers are discovering the power of the internet in understanding crop diversification[17].

This paper provides an overview of the entire Macha Network, benchmark testing of one of it implemented mesh networks, analysis of the viability of our current open source WIFI based mesh solutions in rural environments and conclusions about our implementation including challenges This paper builds on the foundational work by Matthee et al. in [14] where the Macha Network and vision for rural ICT development was first published. In this paper we illustrate the progress that has been made in the development and management of a large rural wireless network. In addition we extend conclusions drawn by the technical discussion of the Macha Network by Backens et al. in [9] to draw some conclusions on the feasibility of our solution in other deployments.

The paper is organized as follows, In Section II the overall technical implementation of the Macha Network is presented with a focus on the Wireless Mesh Network performance. Then in Section III we look at the challenges and lessons learned from our approach. Section IV we will discuss the future of our rural ICT development model expansion. Finally, Section V will draw conclusions about our rural ICT implementation model and subsequent 52 Node Wireless Mesh Network.

2 Network Description

The Macha Network employs a diverse group of low cost and readily available equipment for providing network coverage to the 100-150 daily network users.

Table 1. Wireless Devices in Macha Network

	MIAM	MMH	Other
Freifunk Mesh Nodes	11	0	14
Open-Mesh Nodes	0	27	0
Open WRT APs	8	17	4
Linksys Firmware APs	10	2	0
X-lin (directional)	0	0	6
TOTAL MESH NODES	**52**		
TOTAL APs	41		
TOTAL Linksys WRT54Gx	66		
TOTAL WIRELESS DEVICES	**99**		

These users and the subsequently associated networks are broken up into three basic groups: MIAM Campus, MMH residential housing and everyone else. As shown in Table 1, the Macha Network utilizes mostly Linksys WRT54GL wireless routers flashed with OpenWrt [6] based firmware (Freifunk[2] for Mesh and DD-WRT[1] for Access Points). An Open Mesh network is deployed within the hospital staff housing and consists of 27 Open-Mesh Mini-Router[5] nodes running its own firmware. In contrast, the hybrid mesh nodes consist of two WRT54GL boxes wired together with one serving as a mesh backbone node and the other as an Access Point (AP). These hybrid nodes can be seen in Fig. 1. The combination nodes are employed within the MIAM campus and are placed inside each residence in a unique indoor-to-indoor deployment method to provide coverage for the entire complex. Thus each house within the MIAM campus is outfitted with a hybrid mesh node and each house in the MMH campus is outfitted with an Open Mesh box. These nodes are deployed regardless of usage by the household so that overall coverage can be achieved. This also has the benefit of allowing easy connection of new users if at a later time the need arises.

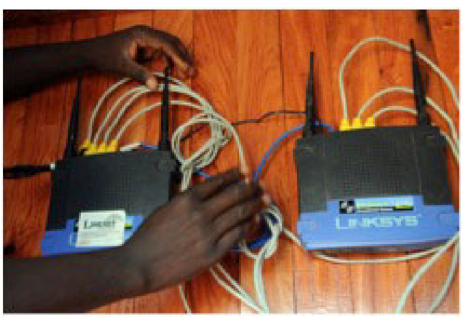


Fig. 1. MIAM Hybrid Node: WMN + AP

Each of the three primary networks are fed from a central tower within in the MIAM complex. This central tower is located next to the IT Room which monitors and manages the network as well as maintains the gateway connection to the internet via VSAT. The gateway is connected via C-Band VSAT with CIR of 128 kbps burstable to 1 Mbps and a Ku-Band VSAT with 32 kbps burstable to 256 kbps.

It should also be noted that in addition to the WRT54GL boxes, the Macha Networks also utilizes locally available X-Lin outdoor wireless APs with directional antennas to feed the different networks from the central mast. Although readily available in Lusaka, these devices are imported into Zambia cheaply and have no known English benchmarks or technical data sheets.

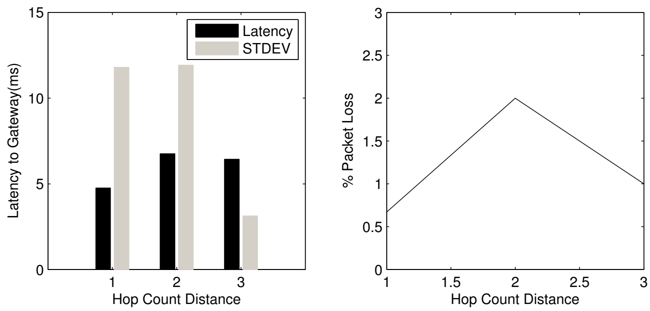
2.1 Performance Conclusions

The Macha Mesh Network at MIAM represents a very typical 11 node Wireless Mesh Network deployment following the Meraka DIY guide [7] and the previously listed hardware. The primary concerns of the network was behavior in terms of latency and overall throughput. Since nodes were supplying the primary means of communications to many of these points it was essential that a adequate throughput and latency be maintained across all nodes in order to assure some level of QoS. Initial testing show in Figure 2. revealed that the overall latency was not affected in a great deal by the hop count from the gateway. In fact nearly all nodes experienced between 5-10ms of delay: a value well within the required QoS for most applications. It should be noted however that occasionally nodes would experience severe latency increases for brief periods. These were attributed to both the dynamic nature of the spectrum as well as the overall inefficiency of the OLSR routing of the Freifunk nodes.

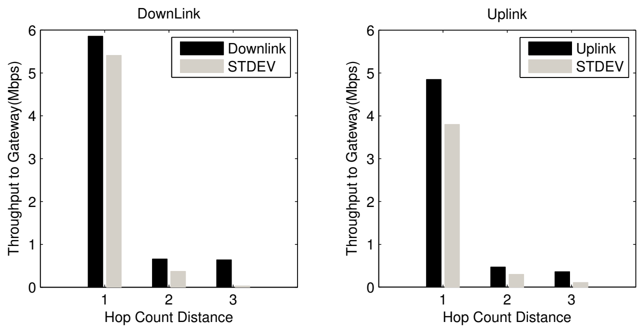
In contrast to relatively promising latency performance, the MIAM network's throughput was shown to decrease at a better than linear rate inversely proportional to the number of hops away from the gateway(as seen in figure 2(b)). Although testing was done in a saturated worst-case network and typical performance can be markedly better, these results clearly show the limitations of our current wireless mesh network solutions in terms of network size per gateway. Although there have been better performances shown in laboratory tests with OLSR based wireless mesh networks in [11], the harsh real world conditions in rural Zambia have proved a limiting factor for our indoor to indoor approach.

Clearly broadband over indoor-to-indoor deployed mesh networks is not possible under our current technology constraints in the rural environment. However reasonable data rates are achievable for basic network usage by local users. This conclusion is pivotal in the argument for continued use of these hybrid mesh nodes in indoor to indoor deployments. In addition we are spurred on by the promising developments in mesh technology such as the development of better routing protocols such as B.A.T.M.A.N. which in lab tests have shown marked improvement over our OLSR approach [10].

In addition to overall performance, a more thorough analysis was conducted to compare the traditionally used 802.11b with DSSS to the 802.11g with OFDM to perhaps gain insight into additional throughput and latency factors. The initial testing was a simple comparison of 802.11b and 802.11g modes of operation based on similar static data rates. It was clear that although 802.11g employs the



(a) MIAM Mesh Latency



(b) MIAM Mesh throughput w/ default settings

Fig. 2. MAIM Mesh Performance

interference reducing OFDM modulation scheme and higher possible bit rates, that in a mesh environment these techniques were ineffective. In fact the 802.11b's DSSS modulation was shown to be far more stable and have a higher throughput with lower jitter than 802.11g OFDM in a Freifunk mesh deployment. 802.11gs higher throughput rates of 54Mbps were unachievable due to unacceptably high interference. (SNR too low to achieve connection in mesh configuration) A more detailed analysis is presented by Backens et al. in [9].

Although these performance conclusions highlight the considerable room for improvement in current mesh techniques, practically the limiting factor in network remains the Gateway connection under current conditions. The prohibitively high cost of our limited bandwidth(1Mbps connection) and its unavoidable latency ($\geq$400ms) remain the dominating characteristic of our network. However, from a user perspective the results of the Macha Network implementation and testing was encouraging. The network provides a usable and easily deployable solution for rural implementations. For small to medium sized mesh networks, the indoor to indoor model is possible, but can be greatly improved with better routing techniques, multiple gateways and adaptive modulation schemes.

2.2 Training

One of the surprising conclusions discovered throughout the LinkNet implementation in Macha is that installation and configuration of the initial wireless mesh technology is the smallest effort in developing a sustainable rural wireless network both in terms of cost and time. The dynamic nature of the wireless spectrum, the inconsistent performance of low cost hardware and difficulties of remote management combine to make create continual technical attention. However the greatest time and cost consumer remains in the training of local talent to undertake these tasks.

Simply stated, rural environments in underdeveloped countries by their very nature have little or no locally knowledgeable talent in the areas of wireless communication and networking. Rural talent almost universally has challenges with advanced topics such as protocol stacks, wireless propagation and troubleshooting processes. Topics that take time to understand and master even in developed countries. These same challenges have been faced in similar rural wireless mesh projects in India [16] and South Africa [12]. Therefore holistic training in Macha has been implemented though both the development of LinkNet Information Technology Academy and extensive self-motivated study. Originally LinkNet employed exclusively self-motivated study by providing apt future technicians and engineers free internet access and refurbished hardware to learn on. The initial results were very promising as exposure to the vast learning resources of the Internet and a few helpful practice parts produced 4 well qualified computer technicians. However as more wireless networking was introduced into Macha and specifically mesh networking, it became obvious that formal training would be required to fill in the holes in self-study education.

LinkNet takes advantage of a bevy of interim knowledge as scholars and IT experts visit Macha to supplement the core networking and computer maintenance coursework. This education has drastically increased the numbers of qualified technicians and helped improve the wireless expertise of the local talent. In addition now only occasional technical issues arise that are beyond the knowledge of local talent.

Our experience has shown that clearly, a locally trained workforce capable of managing a substantial wireless mesh network is possible but may require months of training and experience.

2.3 Challenges

The Macha implementation has faced many challenges with both equipment and environment. One of the most detrimental obstacles in rural Zambia remains the prohibitive cost of VSAT internet. Current LinkNet allocates nearly 2.000 USD/Month for its VSAT connections which are almost constantly saturated with traffic. Increasingly difficulties are foreseeable in the near future as regardless of funding, there is becoming a shortage of available channels and bandwidth on existing satellites. Thus the most expensive Internet in the world is becoming even more so.

Similar to other rural African projects, Macha struggles with regular power issues. Weekly power outages, spikes, brownouts, sags and lightning strikes are infrequent in most developed areas, but are commonplace in rural Zambia. Often these can result in unusual network behavior as equipment put in unstable states as well as high rates of equipment failure. One such example is the 27 node Open-Mesh deployment which fails to recover from certain low power conditions and requires manual resetting each node. This is a labor intensive task during raining season since it can occur on a daily basis.

Another common problem is the lack of quality equipment. Since many commercial and high-end products are not available or affordable, the Macha network has been built with locally available products which have a wide range of quality and documentation. One example of this are the X-Lin WIFI directional APs which are non-upgradable and are non-interoperable with Linksys WRT54Gx's even though both claim IEEE 802.11 compliance.

3 Future Work

LinkNet under the Macha Works oversight is committed to expanding ICT deployments to over 10 rural communities in 2010. This requires significant standardizing of the design and large scale role out of hybrid mesh networks. We are moving beyond proof of concept and evaluation and into production. In addition, the focus is moving from multi-specialist research in wireless mesh networking (primarily expatriate initiated) into inter-disciplinary research. As we have discovered the broad extent of influence rural ICT and community networks have in Macha, we are left seeking to integrate multi-specialist research, with development truly out of local need.

The many obstacles in local talent training and the required time investment has lead LinkNet to attempt the deskilling of mesh network roll out and maintenance engineering. This simplification would allow for quicker deployments and correlate with our values of empowering locally trained rural talent. Furthermore we are partnering with national African research and education institutions to develop further research areas.

Lastly, we are joining in the development of rural community ICT business models. This is currently a hot topic of research within the development community and Macha Works is seeking to help provide a equal contribution funding model.

4 Conclusions

The Hybrid Macha Mesh Network can provide a significant contribution to the current knowledge base of rural wireless mesh implementations. Specifically we have shown that a locally talent driven solution can be found to meet basic internet needs using mesh technology. Although the mesh network does require considerable attention and care in setup and maintenance, it is a viable current solution for low-bandwidth networks. Simply put, rural indoor to indoor Hybrid

Wireless Mesh Network are a workable solution, but one has to be aware of its limitations under current technology. These technology constraints are a much needed area of current research and it is hoped that the lessons learned from the Macha Network Implementation will serve as a motivation for future research. Unfortunately, test bed solutions produced in laboratories and Universities are far too often not realized in real world rural African environments inundated with unique challenges. Thus there remains a great need for test cases like Macha to be included in the academic research community.

References

1. dd-wrt.com, `http://www.dd-wrt.com/site/index`
2. Freifunk, `http://start.freifunk.net/`
3. Human development indices: A statistical update (2008), `http://hdr.undp.org`
4. Malaria Institute at Macha, `http://www.machamalaria.org` (accessed 2009)
5. Open-mesh, `http://www.open-mesh.com`
6. Openwrt: Wireless freedom, `http://www.openwrt.org/`
7. D.I.Y. Mesh Guide (2007), `http://wirelessafrica.meraka.org.za`
8. LinkNet Multi-Purpose Co-operative Society Limited (2009), `http://www.link.net.zm`
9. Backens, J.D., Song, M., Engels, L.: Rural Wireless Mesh Networks in Africa: An Experiential Study. CATA, 128–133 (2009)
10. Johnson, D., Ntlatlapa, N., Aichele, C.: A simple pragmatic approach to mesh routing using BATMAN. In: 2nd IFIP International Symposium on Wireless Communications and Information Technology in Developing Countries, CSIR, Pretoria, South Africa, pp. 6–7 (2008)
11. Johnson, D., Hancke, G.: Comparison of two routing metrics in OLSR on a grid based mesh network. Ad Hoc Networks 7(2), 374–387 (2009)
12. Johnson, D.L., Roux, K.: Building rural wireless networks: Lessons learnt and future directions. In: Proceedings of the 2008 ACM workshop on Wireless networks and systems for developing regions, pp. 17–22. ACM, New York (2008)
13. LinkNet. LinkNet Masterplan: Communications for Rural Zambia (2007), `http://link.net.zm/?q=node/30`
14. Matthee, K.W., Mweemba, G., Pais, A.V., Van Stam, G., Rijken, M.: Bringing Internet connectivity to rural Zambia using a collaborative approach. In: Proc. 2nd IEEE/ACM ICTD (2007)
15. Pais, A.: eLearning for rural communities (2007), `http://www.link.net.zm`
16. Surana, S., Patra, R., Nedevschi, S., Ramos, M., Subramanian, L., Ben-David, Y., Brewer, E.: Beyond pilots: keeping rural wireless networks alive. In: NSDI 2008: Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation, Berkeley, CA, USA, pp. 119–132. USENIX Association (2008)
17. Van Stam, G.: Case: Sunflower farming. Internet changes Rural Africa (2007), `http://www.link.net.zm`