Evaluation of a single radio rural mesh network in South Africa

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***Abstract*— This paper evaluates the ability of a low cost wireless mesh network to provide Internet access to a rural area in South Africa with limited broadband connectivity. The network was installed in a mountainous area with a wide range of distances between nodes ranging from long range 5.5km links to short hops between buildings of only 30 to 50m. Due to this combination of distances, a mix of unplanned node placement with omni-directional antennas and planned nodes using directional antennas was used. The current network consists of 9 nodes spread over an area of about 15 square kilometers. There is electricity at all the sites but power outages are common, occurring at average intervals of one outage in 7 days, lasting between 3 and 24 hours. The network provides a good service to the satellite based Internet with throughput rates ranging between 300 kbps for 4 hops and 11000 kbps for 1 hop and an average throughput rate of 2324 kbps. The paper evaluates the throughput and delay performance of the OLSR routing protocol being used in the mesh network as well as giving an overview of usage patterns and social behavioural patterns of the users. The users range from first time users in poorer areas of the network to fairly accustomed Internet users in wealthier farming areas.**

I. Introduction

Community wireless networks in rural areas are starting to emerge in developing regions around the globe. Some examples of these networks are: ”The Dharamsala Community Wireless Mesh Network [1], mesh networks being set up by CUWin in Ghana [2] and long distance wireless networks being set up in Rwanda, Ghana and Guinea Bissau by the TIER group at University of California, Berkeley [3]. Some of the key issues that make rural wireless networks unique are long distances between nodes, single, low bandwidth gateways to the Internet, high cost of Internet connectivity, lack of reliable power and low technical skill levels of people in the area who need to maintain the network. Often what might not be an acceptable level of service in an urban area is considered a good level of service in a rural area.

There are currently two approaches to the construction of community wireless networks. The first consists of a highly planned network with some nodes having multiple radios, carefully chosen antenna configurations and IP addressing structures to engineer high-quality links with good throughput. The second approach makes use of single radio nodes, omni-directional and directional antennas and flat IP addressing schemes. The first approach is what one commonly finds occurring in urban areas where there is a high degree of ownership and skill level at each installation. The second approach is more ideally suited to rural areas where simplicity and cost take precedence over service quality. One of the key challenges for researchers, in the field of wireless networking protocol design, is the ability to carry out reliable performance measurements on their protocol. They will want to test features such as scalability, delay and throughput, network convergence in the presence rapidly changing link quality and route optimization.

Unfortunately most of the work done so far makes use of simulations which over simplify the physical layer and even aspects of the Medium Access Control layer. There is also a lack of consistency between the results of the same protocol being run on different simulation packages [**?**].

Mathematical models are another useful tool when trying to understand the effects of various network parameters on performance. For example Gupta and Kumar have created an equation which models the best and worst case data rate in a network with shared channel access, as the number of hops increases [7]. However recent work [13] done by the same author using a real test bed, using laptops equipped with 802.11 based radios, revealed that 802.11 multi hop throughput is still far from even the worst case theoretical data rate predictions.

After 6 hops, the mathematical model shows a 30% decrease in throughput whereas the test bed showed a 95% decrease in throughput. This highlights the importance of verification using real world test beds.

A recent Network Test beds workshop report [**?**] highlighted the importance of wireless test bed facilities for the research community in view of the limitations of available simulation methodologies. This was the motivation for the ORBIT project [**?**] which created a wireless grid similar to the one that will be discussed in this paper.

The ORBIT mesh lab has an 8x8 grid and a 20x20 grid which makes use of 802.11 wireless equipment based on the same Atheros chip-set that our lab uses. A key difference between the ORBIT lab and ours is that it makes use of Additive White Gaussian Noise (AWGN) to raise the noise floor instead of using attenuators. It allows researchers anywhere in the world to run an experiment on the lab by making using of a scheduler. Researchers can change everything from the routing protocol to the entire operating system that will be run on the nodes.

These mini scale wireless grids can emulate real world networks due to the inverse square law of radio propagation, which states that a radio wave will be attenuated by 6.02 dB if the distance is doubled no matter what the distances involved.

Most of the indoor test beds, such as the one used by Microsoft's Research lab [**?**], have been created by placing computers with wireless cards in offices and relying on walls to attenuate the signal enough to create a multi hop environment. Although these have been useful, they generate results that will be very difficult to repeat and verify due to the chaotic nature of signal prorogation in an office environment. .

There are many publications evaluating the performance of ad-hoc protocols with mobility, for example Di Caro's evaluation of AntHocNet in a city environment with pedestrian and vehicular based moving nodes [4]. There are also some evaluations of mesh networks in urban areas, for example the Roofnet project at MIT which provides broadband Internet to an area in the city of Cambridge [5]. Few results have, however, been published analysing the performance of rural mesh networks. One of the best reference works which looks at the challenges of placing technology in developing regions is a paper by the TIER group [6]. They highlight issues that most researchers would commonly overlook like equipment failures, power failures, transportation issues, tampering and theft. These are all issues that have been experienced in our own projects in rural areas.

Although the performance of multi-hop single radio mesh networks is severely degraded by multiple hops as defined by Gupta's scaling law [7], this paper will show that users accessing a low bandwidth Internet service over satellite in a rural area can get a satisfactory service even over 7 hops. Improvements to the 802.11 MAC protocols for mesh configurations are being implemented in the 802.11s mesh standard and some work is being done by the TIER group and others to improve performance when long distances are used [8]. The author has found, however, that the current 802.11b/g standard is still sufficient for small scale rural mesh networking.

This paper evaluates the performance of a simple single radio mesh network running the Optimized Link State Routing (OLSR) protocol [9] consisting of 9 nodes in a rural area of approximately 15 square kilometers in South Africa.

II. Background

This section will help provide some background to wireless mesh networking and the Optimized Link State Routing protocol that is discussed in the rest of the paper

A. Ad-hoc networks

An Ad hoc network is the cooperative engagement of a collection of wireless nodes without the required intervention of any centralized access point or existing infrastructure. Ad hoc networks have the key features of being self-forming, self-healing and do not rely on the centralized services of any particular node. There is often confusion about the difference between a wireless ad-hoc network and a wireless mesh network (WMN).

A wireless ad-hoc network is a network in which client devices such as laptops, PDA's or sensors perform a routing function to forward data from themselves or for other nodes to form an arbitrary network topology. When these devices are mobile they form a class of networks known as a mobile ad-hoc network (MANET), where the wireless topology may change rapidly and unpredictably. Wireless sensor networks are a good example of a wireless ad-hoc network.

A wireless mesh network is characterized by: dedicated wireless routers which carry out the function of routing packets through the network, static or quasi-static nodes and client devices, without any routing functionality, connecting to the wireless routers. Broadband community wireless networks or municipal wireless networks are good examples of wireless mesh networks.

All these types of ad-hoc networks make use of ad-hoc networking routing protocols which are being standardized by the IETF MANET working group [10]. There is also work being done to standardize mesh networking in the 802.11s standard.

B. The Optimized Link State Routing (OLSR)

Pro-active or table-driven routing protocols maintain fresh lists of destinations and their routes by periodically distributing routing tables in the network. The advantage of these protocols is that a route to a particular destination is immediately available. The disadvantage is that unnecessary routing traffic is generated for routes that may never be used. Optimized Link State Routing (OLSR) is a popular pro-active routing protocol that is used in the Peebles valley mesh network. It reduces the overhead of flooding link state information by requiring fewer nodes to forward routing information. Figure 1 shows how a broadcast from node X is only forwarded by its multi point relays. Multi point relays of node X are its neighbours such that each two-hop neighbour of X is a one-hop neighbour of at least one multi point relay of X. Each node transmits its neighbour list in periodic beacons, so that all nodes can know their 2-hop neighbours, in order to choose the multi point relays (MPRs).

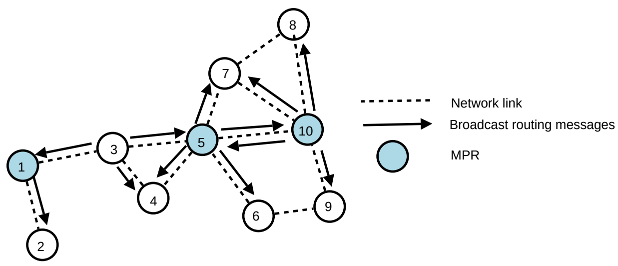

Fig. 1. *OLSR routing protocol showing selection of MPRs*

III. Peebles valley mesh design

The Peebles valley mesh network is deployed over an area of about 15 square kilometers in a rural area near the Kruger National Park in South Africa. The network was built to explore a least cost 802.11 network to supply Internet connectivity, being supplied to an aids Clinic. This connects to surrounding schools, homes, farms and other clinic infrastructure through the mesh network. The Aids clinic, which is a non-governmental organisation (NGO) funded by a pharmaceutical company social grant, has brought hope to over 700 patients in the area over the 4 years it has been running. The VSAT Internet connectivity, which is provided free of charge by a sponsor, is usually underutilized every month, with clinic users only using approximately 60% of the available bandwidth each month.

The satellite link provides 2GB per month at a download rate of 256 kbps and an upload rate of 64 kbps. Once the 2GB capacity limit is reach the Internet connection is cut off until the beginning of the following month and no spare capacity can be carried over to the following month. This spare capacity is shared to users in the mesh network, free of charge but has to be carefully managed by a firewall to ensure that their usage does not effect the clinic's Internet availability.

Figure 2 is a map showing the Peebles valley mesh. The area is mountainous and line of site is not always easy to achieve unless you have some good elevation. For example no link is achievable between D and E due to the mountainous terrain. A valley runs down the centre of the map which divides wealthier farming land on the left from a poorer tribal community on the right. Line of sight is usually possible across the valley and links tend to zig-zag between elevated points on either side of this valley. The dotted lines between the installations show the routes that the OLSR routing protocol has configured. A scale on the map is shown on the bottom left to give an idea of the distances involved.

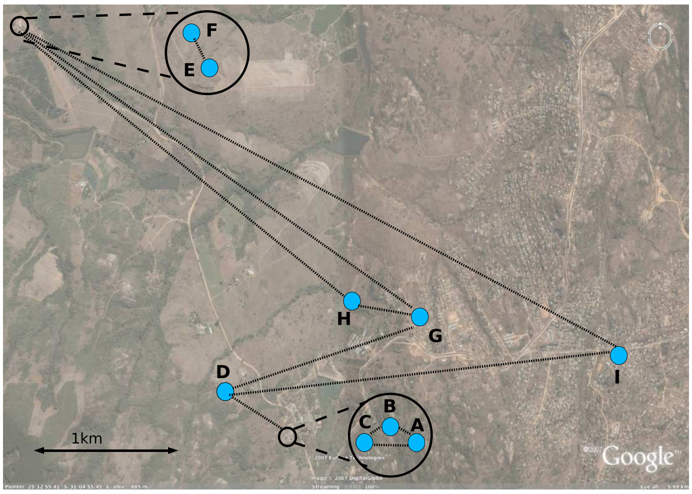

Fig. 2. *A map of the Peebles valley mesh. Each solid dot represents a wireless node. An empty dot represents a close cluster of nodes shown in the circles. The area on the left is wealthy farm land and the area on the right is poorer tribal land.*

TABLE I

Description of features of each mesh node. The node labels correspond with those on the map. The H column shows the number of hops to the Internet gateway, 'Path length to GW' column describes the total path distance along the OLSR selected route to the GW

N	Description	Type	Antenna	H	Path length to GW	OLSR Route to GW
A	ACTS Clinic (GW)	Outdoor	12dBi Yagi	0	50m	-
B	ACTS Accommodation	Indoor	2.14dBi Dipoles	1	50m	BA
C	ACTS Flats	Outdoor	8dBi Omni	1	90m	CA
D	USAID Farm	Outdoor	8dBi Flat Panel	1	620m	DA
E	Nut Farm	Outdoor	24dBi Grid	3	7.66km	EGDA
F	Nut Farm office	Indoor	2.14dBi Dipoles	4	7.76km	FEGDA
G	SAKHILE School	Outdoor	8dBi Flat panel	2	3.02km	GDA
H	Nurse Home	Outdoor	Cantenna	3	3.33km	HGDA
I	ACTS Hospice	Outdoor	24dBi Grid	2	3.94km	IDA

A. Hardware

The key decision criteria when choosing hardware for the project was cost. The cheapest off the shelf items that were available at the time where the Linksys WRT54G wireless routers. These are single radio 802.11 b/g routers which are capable of being re-flashed with a completely new operating system. They have a 200MHz CPU on board and use flash based memory with no fans or other moving parts. These devices are designed for indoor use and the first issue was to re-package the electronics so that it can be mounted on an outside mast.

An open enclosure is shown in Figure 3 mounted on a house on one of the farms. Power was injected over the Ethernet cable using a Power over Ethernet (POE) injector device. This helped simplify the installation as only a single cable needed to be run between the outdoor unit and the power source and PC which are normally located in the same place. The type of outdoor antenna that was used depended on the range and radiation pattern needed to reach other nodes in the mesh. A Cantenna installation was also tested in the mesh at one of the house installations, this is also shown in Figure 3. Cantennas are low cost antennas which use tins cans as a waveguide to boost the antenna gain. Table I gives some detail about the features of each node which includes their antenna characteristics, whether they were indoor or outdoor nodes and the paths they typically use to get to the gateway node.

B. Software

A standard Linksys WRT54G does not come with any mesh functionality. In order to turn the device into a mesh router, a new operating system and the mesh routing software

Fig. 3. *Outdoor mesh node with repackaged Linksys WRT54G electronics in a waterproof aluminium case. The picture on the left shows an installation at node D is using a commercial 8dBi flat panel, the picture on the right shows an installation at node H which is using a home made Cantenna*

needs to be installed on the unit. Freifunk, a group of open source wireless developers in Berlin, have developed a piece of firmware which packages a tiny version of Linux called OpenWRT, the OLSR routing protocol and some web based user interfaces. This firmware was used in the project with some modifications to enable remote traffic monitoring and bandwidth management.

C. Gateway

The mesh node which acts as a gateway to the Internet needs to be able to control the amount of bandwidth each user on the mesh is allowed to use. To fulfil this function some byte counting functionality was installed on this node using some scripting and standard Linux iptables rules. Each user was allocated a set amount of bandwidth per month and once this was used up they needed to wait until the beginning of the following month before they could access the Internet again. The clinic agreed to make 400MB available to the mesh network and this was then shared between all 10 nodes in the mesh network, giving each user about 40 MB per month on average. A default route to the VSAT Internet link was advertised to the entire network using the OLSR protocol's dynamic gateway feature.

D. Services

In order to make a rural mesh network a rich user experience, a wide array of local services were installed on a server in the mesh. As Internet traffic is expensive and limited, creating a high degree of localised traffic is a key strategy for any rural mesh network designer. Here are some of the services that were made available:

1) *DNS Server:* In order to make finding nodes on the mesh simpler, a DNS server was installed and each mesh node was given a host name. In the future a distributed DNS service could be explored which can potentially run on each mesh router and can start up when parts of the mesh are isolated due to link failures.
2) *Proxy server:* There are a number of reasons to run a proxy server. Firstly saving on expensive Internet traffic is vital, secondly there are a number of automated updates that run on windows machines in particular and these can quickly use up a users bandwidth quota without their awareness. A proxy can also be used to block these automated updates. The proxy was setup in transparent proxy mode so that all port 80 traffic was automatically routed to the server and the user didn't need to enter any proxy settings on their web browser.
3) *Local Ubuntu Linux repository:* Updating Linux based machines or installing new applications over the Internet is a bandwidth costly exercise. The latest release of Ubuntu Linux is mirrored on the server every 6 months by manually bringing a copy on a hard drive to the site and copying it over to the server.
4) *Asterisk server:* VoIP is a key applications on rural mesh networks which can save a large amount of money due to the high cost of mobile phone calls. Asterisk, which is a open source/free software implementation of a telephone private branch exchange (PBX), was installed and two VoIP phones were installed to connect the clinic and the hospice. In the future any user on the network can use a software/hardware based VoIP phone anywhere on the mesh to communicate with each other for free. The Asterisk PBX is also being used to connect all new phones being installed on the clinic premises.
5) *Samba server:* Samba is a useful service to allow users to share files amongst each other. For example if someone downloads a particular service pack they can put it on the samba file server for other users to access and avoid duplicating the download.
6) *Local school Wikipedia:* Wikipedia has become an invaluable reference tool for finding basic information on topics of interest. The school can use this as a resource for their teachers and learners. This is particularly vital for them, as school learners often don't have access to proper text books or reference books. A local sanitised Wikipedia which has content aimed at school learners was installed on the server for this purpose.

E. Configuration

1) Addressing: All the nodes in the mesh network were given static IP addresses for their Wireless and LAN ports. The following scheme was followed: Wireless IP address were 10.1.1.x and the LAN IP addresses were 10.2.x.1. A DHCP server is run on each node which hands out a block of addresses to clients connecting to the mesh node. All wireless nodes and client devices are reachable from anywhere on the mesh due to OLSR's Host Network Address (HNA) advertising mechanism which adds the LAN side IP address block in the routing table of all other nodes.

2) 802.11 and OLSR Settings: The Linksys WRT54G's are capable of 802.11b or 802.11g mode of operation. The nodes were all set to auto select between b/g mode based on the signal quality available. The signal strength varied greatly in the mesh which meant that some nodes were switching down to 802.11b 2 Mbps and others were using 802.11g mode at 24 Mbps data rates. Signal strength was set to 100 mW which is the legal limit in South Africa in the 2.4 GHz ISM band. The OLSR routing protocol was set to use RFC recommended values other than the routing metric which was set to ETX.

F. Routing metric

The OLSR RFC specifies "Link Hysteresis" as the official metric to use to determine link quality between nodes. However an improved alternative metric, Expected Transmission Count (ETX) [11], calculates the expected number of retransmission that are required for a packet to travel to and from a destination. The link quality, LQ, is the fraction of successful packets that were received by us from a neighbour within a window period. The neighbour link quality, NLQ, is the fraction of successful packets that were received by a neighbour node from us within a window period. Equation 1 shows how ETX is calculated.

$$ETX = \frac{1}{LQxNLQ} \tag{1}$$

In a multi-hop link the ETX values of each hop are added together to calculate the ETX for the complete link including all the hops.

Figure 4 shows the ETX values for 7 consecutive successful packets followed by 7 consecutive unsuccessful packets assuming a perfectly symmetrical link and a link quality window size of 7.

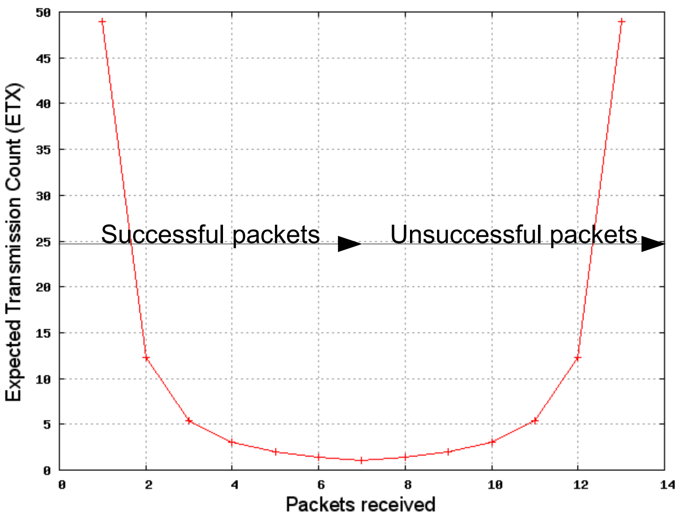

Fig. 4. *ETX Path metric values for successive successful and unsuccessful packets*

A perfect link is achieved when ETX is equal to 1. ETX has the added advantage of being able to account for asymmetry in a link as it calculates the quality of the link in both directions. Unlike Hysteresis ETX improves and degrades at the same rate when successful and unsuccessful packets are received respectively. OLSR with ETX will always choose a route with the lowest ETX value.

IV. Evaluation

The results that will be presented were derived from a set of various measurement processes that are outlined here, the methodology being used was strongly based on work done by MIT Roofnet [5].

1) The TCP throughput is the result of one-way bulk transfers of 100 source buffers of 8192 bytes each being sent between each pair of nodes in the mesh. A standard Linux tool called ttcp was used for this test and throughput is measured as the number of bytes that were delivered to the receiving node. This process is repeated 3 times and an average is finally recorded.
2) The latency is established by sending 84-byte pings once per second and the average round-trip time is recorded.
3) All tests are done with RTS/CTS disabled as this did not improve the performance of the mesh, other researchers have reported similar findings [12]
4) Hop count was recorded by examining the routing tables generated by OLSR on each node.
5) All radios were set to auto-select 802.11b or 802.11g mode as well as the data rate being used. This will be dependent on the signal strength being reported by the radio.
6) The Peebles valley mesh normally provides Internet access to users and this was not disabled during these experiments. However, as will be discussed later, the throughput of the satellite link compared to the throughput of the links in the mesh is significantly lower and so even if there were some Internet traffic, it would have had a small effect on the results.

A. Throughput and delay performance

Figure 5 shows the distribution of TCP throughput among all pairs of nodes in the mesh. The average throughput is 2324 kbps and the median is 1276 kbps. The distribution of throughput can be understood by hop count between pairs as well as other environmental factors such as distance or obstacles such as trees or buildings. Hop count plays the largest role in determining a drop in throughput and Table II illustrates this. Figure 6 shows the throughput with it's standard deviation as the number of hops increase. The high degree of standard deviation is due the wide range of distances as well as obstacles, such as trees, in node pairs with the same number of hops.

Throughput degradation due to hop count in packet based networks with single radios has been well studied by Gupta *et al* [7]. The theoretical best case and worst case throughput is given by Equations 2 and 3:

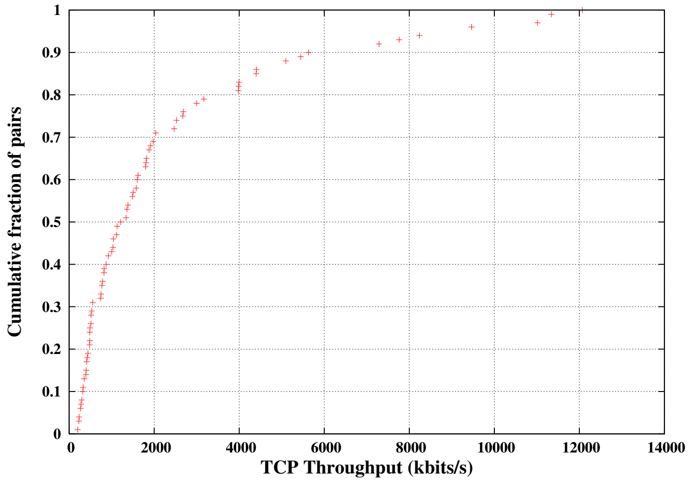

Fig. 5. *Cumulative distribution function*

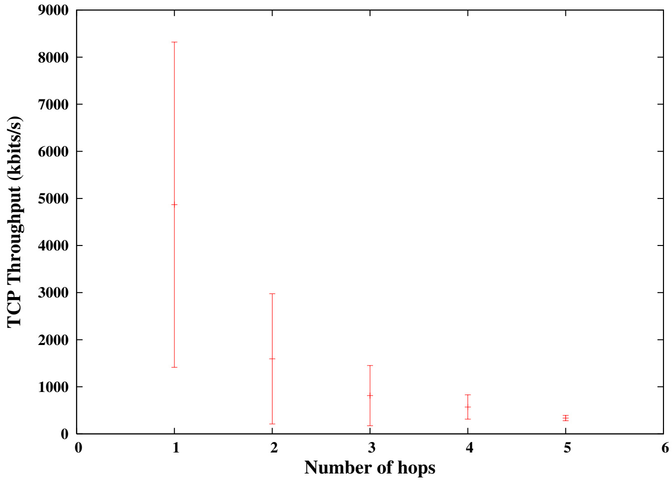

Fig. 6. *Effect of number of hops on throughput*

TABLE II

Average TCP throughput and round-trip ping latency between each pair in the network, arranged by the number of hops in route chosen by OLSR

Hops	Pairs	Throughput (kbps)	Latency (ms)
1	23	4867	4.69
2	24	1593	4.98
3	14	812	5.78
4	9	571	5.8
5	2	336	7.3
Avg: 2.21	Total: 72	Avg: 2324	Avg: 5.71

$$\lambda_{WORST}(n) = \frac{W}{\sqrt{n\log(n)}} \quad (2)$$

$$\lambda_{BEST}(n) = \frac{W}{\sqrt{n}} \quad (3)$$

These equations do not take into account effects of the 802.11 MAC layer protocol or signal propagation and, as such, present an idealistic case. Other work, by the same authors, examined the throughput losses when using real 802.11 hardware in laptops communicating between offices [13]. Previous work, done by the Meraka Institute, calculated multi-hop effects on throughput in an indoor grid based testbed of 49 closely spaced nodes set to ideal conditions with no packet loss between them [14]. All these results are presented together in Figure 7.

The Peebles valley results are almost identical to those that Gupta experienced when carrying out multi-hop experiments with laptops between offices. This shows that the multi-hop throughput exponent index, shown in Equation 4 is dependent on the link budget between nodes. This link budget can be low because of distances between nodes, obstacles or because of lower gain antennas being employed. The 7x7 grid results, using ideal conditions, moves closer to the theoretical achievable maximum due to no packet losses being present in the network.

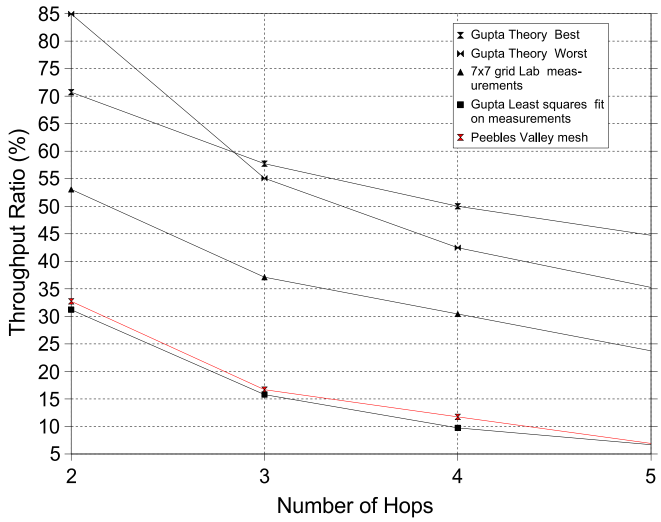

Fig. 7. *Comparison of theoretical, indoor and outdoor throughput*

A linear regression on the log of the x and y axis for the throughput in Peebles Valley was carried out using a least mean squares fit. This reveals a slope of 1.62 which is close to 1.68 discovered by Gupta in his indoor trials. The predicted throughput for this network is thus shown by Equation 4.

$$\lambda_{PEEBLES}(n) = \frac{W}{n^{1.62}} \quad (4)$$

This formula can now be used to extrapolate how many hops result in an average throughput which is less than the 256 kbps VSAT satellite link being used. If the average baseline throughput for one a single hop (W) is set to 4867, the predicted average throughput is 267 kbps after 6 hops and 208 kbps after 7 hops. The bottleneck to the Internet in this unloaded network being caused by the mesh network occurs only after 7 hops.

Tables II also shows round-trip latencies for 84-byte ping packets to estimate the delay on an idle network. Interactive latency is acceptable when there is a single user on the network. The average user will experience 5.71ms of latency between any pair of nodes. A VoIP phone has been set up at point A (ACTS clinic) and point I (ACTS Hospice) and no noticeable delay is experienced in this two hop link even when there is some Internet activity. Figure 8 shows the amount delay with standard deviation as the number of hops increases. What is noticeable is that each hop only introduces an average 0.5ms increase in latency whereas the application and the kernel stack appear to add about another 4ms of delay overhead. In a loaded network these figures would rise significantly due to queuing and interference in the network.

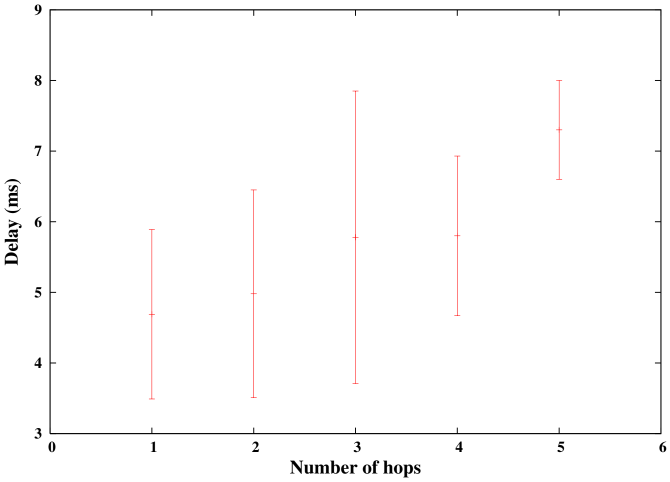

Fig. 8. *Effect of number of hops on delay*

B. Internet usage patterns

As described earlier, a small portion of Internet bandwidth was allocated each user and once this is used up it is was not available again until the following month. Users could however request to be allocated additional bandwidth and if the ACTS clinic usage was fairly low that particular month, more bandwidth could be allocated on a case by case basis by an administrator.

The cumulative bandwidth used at each node is shown in Figure 9. Users who had never been exposed to the Internet, such as the nurse's house and Sakhile school, found it difficult to understand how to control their bandwidth usage. More training is needed on how to use bandwidth sparingly, for example you will notice that the 40MB allocated to Sakhile school was used within 4 days.

The nurse's house makes use of a cantenna installation as shown in Figure 3. Her first daughter lives at home looking after her baby and doesn't have a job. As a result she is one of the most prolific users of the Internet. One of her other daughters made use of the Internet connectivity supplied by this project to find a job and is now in another part of the country. Her first daughter uses the Internet to for social networking, growing her IT skills and looking for jobs. As this site belongs to a staff member of the clinic, extra bandwidth has been allocated if spare capacity was available. You will notice the graph plateaus at some points and then ramps up again; this was usually when extra bandwidth was requested and there was a delay of a few days before it was actually allocated.

Some of the reasons for the lack of activity of other users is the availability of 3G in the area to the wealthier farmers such as the Nut Farm (node E and F) and USAID (node D). Convenience is a priority over cost for these users and the process of reconfiguring their computer to connect to the mesh is seen as a burden even though it can give them some free bandwidth. The sites are, however, important for connectivity to other areas in the mesh. Guests who visit the Nut Farm and USAID tend to be the main users and one of the business partners on the Nut Farm, who doesn't have a 3G account, is an occasional user of the network.

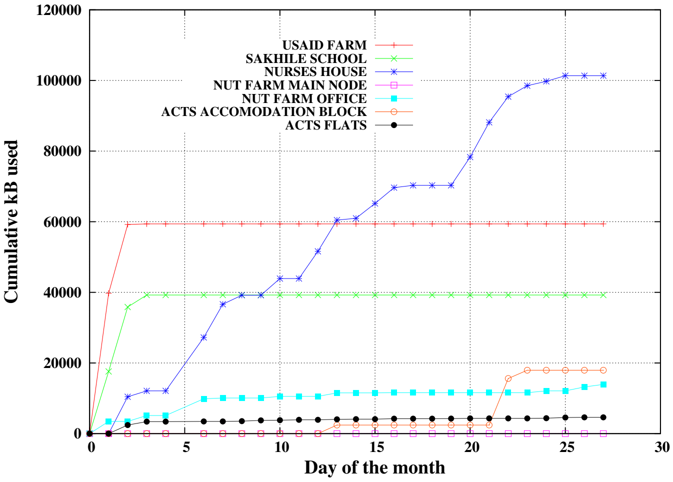

Fig. 9. *Internet usage pattern*

Another useful usage pattern to observe is the amount of outbound versus the amount of inbound traffic from the Internet. Table III shows these statistics for a month's usage as well as the percentage of the total traffic which was inbound. A high percentage of inbound traffic, as is the case at SAKHILE school, shows a typical asymmetric web usage pattern. When this approaches 50 percent, as is the case with ACTS Accommodation, the nurses home and USAID, it reveals a higher degree of social networking being carried out with applications like instant messaging and peer-to-peer VoIP. This correlates well with the type of users in question, for example the ACTS accommodation block is used by overseas visitors to the AIDS clinic and they use the network to correspond with friends back home. The nurse's first daughter, as described earlier, uses the network to correspond with friends around the country. The hospice node only has a VoIP phone to make internal calls to the clinic and so no Internet traffic was observed there. The Nut Farm main node is simply used as a repeater to the office node, so all Internet traffic is only observed coming from the office node's IP address, which is why no traffic is observed there either.

TABLE III

Internet usage pattern of users during the month of August 2007

N	Description	Inbound (KB)	Outbound (KB)	Total (KB)	% In
B	ACTS Accommodation	9945	7997	17942	55
C	ACTS Flats	3447	1171	4618	75
D	USAID Farm	26073	33308	59381	44
E	Nut Farm	0	0	0	0
F	Nut Farm office	10853	3074	13927	78
G	SAKHILE School	37491	1765	39256	96
H	Nurses Home	52123	49238	101361	51
I	Hospice	0	0	0	0

Windows machines connecting to the mesh network would often launch automatic updates without the users awareness. The transparent proxy service installed on the network allowed a rule to be configured on the proxy which blocked all access to these updates. Other updates that need to be blocked were virus update programs which also run without the users awareness. A better approach to automated updates, in bandwidth constrained environments, is to place all these service packs and virus updates on the shared server to prevent users duplicating common downloads.

C. Behavioural patterns of users

Exposing the Internet for the first time to users, brings with it a certain amount of responsibility. Although the Internet brings people a wealth of information, it also brings with it many potentially harmful vulnerabilities. Keeping a community based mesh network running also requires a good level of stewardship by the users. Some of the key behavioural patterns we have observed are:

- First time Internet users were easily fooled into believing they had won huge sums of money by Internet scams which typically manifest themselves as pop up screens. Pop up blockers can partly prevent these kinds of problems but more importantly, educating users on not believing everything that the Internet presents to them is vital.
- Personal information, such as mobile phone numbers, was freely shared over the Internet. Identity theft and banking phishing schemes are rife on the Internet and users need to be made aware of these dangers.
- There was little conceptual understanding of what type of Internet usage consumes large amounts of bandwidth. A graph was available from a web site which showed what percentage they had consumed but wasn't viewed by users due to no understanding of graphs. A more tangible mechanism is needed on a PC which has a visible decreasing counter when bandwidth is consumed.
- Up time in the network was often severely hampered by users unplugging their equipment. Plugging mesh nodes into a wall socket might not always be the best solution as these might sometimes be needed for other electrical devices when the Internet is not being used.
- Viruses were very common on windows machines and these machines often needed to be formatted and windows reinstalled. Using Linux based systems protects users from virus attacks as well as being free. But users, such as teachers at the school, were afraid to embrace an unknown operating system as they saw this as an extra hurdle to an already difficult task of becoming IT literate in windows.
- Instant messaging tools such as Skype have proved to be a very valuable helpline for inexperienced users in the network. Users would often message more experienced users in the cities to find out how to fix a computer problem or set up a new application. It was even possible to remotely log into the mesh network and fix a problem on a PC while messaging a user. The social networking revolution that is taking place on the Internet at the moment could be the key solution to creating support structures for users in rural networks.

D. Environmental observations

Placing sensitive electronic equipment outdoors and exposing it to the elements brings with it its own set of challenges. Here are some of the environmental issues we have observed:

- Lightning in the area is very severe; the granite rocky outcrops tend to attract lightning particularly at the farms and clinic. Over the 2 years that the project has been running, 4 hubs, 2 PC Ethernet ports and 2 wireless router Ethernet ports were damaged by lightning. No wireless routers have been completely destroyed by lightning even though they are mounted on rooftops. The Wireless routers are supplied with 5 Ethernet ports and when one is damaged by lightning, it was found that another one could be used and the router would continue to function normally. A long length of Ethernet tends to be the main cause of problems, with EMF from lightning being induced in the copper and damaging equipment to which it is attached. At the clinic, Ethernet between buildings was replaced with fibre optic cable and this removed the problem completely. Ethernet from the wireless routers is kept as short as possible and is now routed through lightning protectors which are built into many UPS's, this has also removed the problem.
- The Peebles valley area has a subtropical climate with an average daily maximum temperature of 27 $^{\circ}C$ and an average daily minimum temperature of 13 $^{\circ}C$. The average yearly rainfall is 767 mm with an average of 100 days having more than 1 mm of rain. The aluminium outdoor enclosures that were used have proved to handle the elements very well; after 2 years no visible material fatigue was observed in the cases. The seals have also showed no signs of wear and the electronics inside the cases has been kept dry. The cantenna was severely rusted after 2 years but this has had no effect on its performance. The standard CAT5 Ethernet cable that is run from the outdoor unit down into the building has started to show signs of hardening and cracking where it is exposed to

the sun. In the future a higher grade UV resistant CAT5 cable will be used in sections which are exposed to the sun.

V. Conclusion

This trial rural mesh network has illustrated that single radio mesh networks based on low cost commodity wireless equipment is a viable means to provide Internet connectivity to an area with limited broadband connectivity. The mesh network provides a satisfactory grade of service for Internet access based on a best effort shared VSAT satellite Internet resource. Average throughput speeds of 2324 kbps and an average delay of 5.7ms was achieved between any two nodes on the unloaded mesh network with an average hop count of 2.21.

Training first time users of the Internet on how to use Internet and local server resources effectively is a difficult challenge. Installing voice and instant messaging applications to allow them to contact more experienced users in the city has helped at least create a lifeline when they need advice. Users also need to understand that each of their nodes forms a crucial point in the mesh network and the network depends on their node staying on all the time. There needs to be more awareness of what type of usage behaviour results in large amounts of bandwidth being consumed, a simple usage graph available on the local server hasn't been effective. Some innovation around a bandwidth usage application which uses graphical and audible alerts is needed.

VI. Future considerations

Ideally before first time users of the Internet visit their first web page, training programs should be given on the dangers of the Internet, such as scams, viruses, and protection of personal information. If training programs are not possible, a portal page which is always displayed before visiting the Internet could warn users of these dangers with up to date information on the latest scams.

Once local services such as video conferencing for Tele-health or Tele-education and local bandwidth intensive repositories are used, the single radio mesh network will be pushed to its technical limits and far more congestion will be observed. If these usage patterns begin emerging, some improvement to the mesh infrastructure might become necessary with multiple radio nodes being installed at strategic points.

Further analysis is also required on understanding the performance of these networks under severe load conditions which will help answer basic questions like how many VoIP calls can be supported for a mesh network with a specific average hop count.

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