Abstract

In developing countries like Namibia, data quality telephone lines are not available to over two thirds of the schools. Developments in wireless networking technologies have made connecting rural schools a practical and cost effective solution

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Introduction

Imagine walking into a school and being taken to a classroom. You can see the teacher working with a small group of kids on some computers near the back of the class. A closer look shows that they are researching ideas for a science fair project on gravity using the Internet. This could be a normal situation in many parts of the world. The difference is that this school is in northeastern Namibia, in a small village that has no phone lines, and no electricity. Using solar power, and a mix of wireless communication systems, *Schoolnet Namibia* has given this school access to current educational materials, a key for any school system to succeed in educating the people in their area via the Internet. Using the Internet can bring a world of information to a school, and open many new doors for both teachers and students. In countries like Namibia, where over 900 of the 1500 schools do not have some combination of electricity, data quality telephone lines, libraries, and even running water, accessing the Internet will need to make use of some innovative approaches. *Schoolnet Namibia* has a goal of connecting all schools in Namibia to the Internet by the end of 2005. This includes schools in some very remote areas. Combining different wireless communications technologies to match the different situations, two different wireless models have been developed by *Schoolnet Namibia*. These models will serve high-speed Internet access to areas with a low school density, and build on that system to supply areas with a higher density of schools.

Goals, and scope of the project

The cost of bringing communication wires to two thirds of the schools in Namibia is not affordable to any organization, especially when there would be little chance of ever recovering costs back on this infrastructure. The need for wireless communications was obvious; Schoolnet and other key organizations had never tried anything like this, and they needed to have a plan developed, tested, and proven. Some forms of wireless networking have been used in the developing world in the past, like wireless local loop (WLL) telephone services or radio based telephones. Many of the legacy WLL systems, commonly used in Namibia, cannot carry data traffic over speeds of 9.6k, far from the 64k speed goals of *Schoolnet Namibia*.

At the time the project began, a lot of developments were happening in the wireless networking industry. The 802.11b standard, defined by the Institute of Electrical and Electronic Engineers, was becoming widely used, and many new products were coming available with affordable pricing models. This was definitely an exciting time in the wireless industry.

From the beginning, the primary goal was to develop a model for data communications which will provide previously unreachable places access to stable and fast connections to the Internet. This was not limited to only Namibia, the models had to be applicable to other countries. The system had to be capable of point to multipoint (PtMP) connections, had to be affordable, stable, manageable, and supply at least equivalent bandwidth to a dial up modem connection. Range and the coverage area were included in the goals, but very loosely. Combining all of the goals together will actually dictate the effective range of this system.

Schoolnet Namibia is a very strong advocate of open source software, and uses it almost exclusively. All computer hardware donated to schools by *Schoolnet Namibia* uses Linux servers and workstations. The wireless equipment has to work with various operating systems, especially SuSE Linux. Legacy Windows and MacOS based systems would also need to be supported, as not all schools are using the Linux based thin client network, also developed by *Schoolnet Namibia*.

Schoolnet is an all-volunteer organization. A program called Kids on the Block encourages out of school, out-of-work people to come and volunteer their time to gain skills and experience in all of the areas Schoolnet that is involved. This will have to be true of the wireless program as well. Selected members of Schoolnet's technical team will have to be trained on the installation and maintenance of the wireless system. This is a large component of Schoolnet's sustainability plan, as knowledge is as important as money to the ongoing success of not only the wireless system, but also the entire Schoolnet organization.

A note on regulations

Regulations on using wireless technologies vary from country to country. Sending communications signals over your own property is fine, and does not require permission from a regulatory body. However, in Namibia and most other countries, sending communications signals over government property does require permission from the government's regulatory body. By the letter of the law, two people having a conversation, each standing on different sides of a road are violating the communications laws. The Namibian Communications Commission (NCC) is the regulatory body, responsible for licensing and maintaining radio spectrum usage in Namibia.

The Industrial, Scientific, and Medical (ISM) frequency bands are considered by many countries' regulatory agencies as exempt from licensing requirements providing the total power of the system is below a set limit. This means that no permission is needed for anyone to use these, interference caused by other people using these frequencies is to be expected, and is up to the operators, not the regulatory bodies, to make things work. The Federal Communications Commission of the United States and Industry Canada have set that power limit at 36 dBi, or one Watt. The NCC, and many other African countries do not consider any frequency bands, including the ISM bands, as license exempt. *Schoolnet Namibia* has built a strong partnership with Telecom Namibia, currently the only license holder for the frequencies in the ISM bands. As part of their commitment to education, Telecom Namibia is allowing the Schoolnet wireless system to operate under their license.

Technical Research Begins

The first step divided the wireless communications into two sections. The first was supplying a network connection to one remote school, and the second was to distribute that connection to the schools in the surrounding area. The majority of the research concentrated on distributing the connection; the choices for getting a broadband Internet connection to remote locations in Africa are much more limited than distributing that connection to the surrounding area. It was assumed that the connection would make use of very small aperture terminal (VSAT) satellite connections, or some hybrid satellite based system.

Early Research

Early research on distribution looked at using a few legacy technologies for wireless networking. The first major system considered was packet radio systems, formerly used by amateur radio operators to connect their computers. Information on hardware was found; modems that could transfer data at 56k in full duplex (can both send and receive at the same time) but availability became the challenge. The cost of conventional Internet access for home use dropped by over half in places like the United States and Canada, while the bandwidth increased by over 300%. This eliminated the demand for equipment, making the packet radio systems hard to find, too expensive, and too slow for users. Of all the manufacturers contacted, none are making their packet radio modems anymore. This type of system would also require too many people to learn an entirely new set of skills, which neither Schoolnet nor any of its existing partners had. The learning curves would not be steep enough to make this system work.

A hybrid system, combining cell phones with an incoming data feed from a satellite was another focus early on. This system receives all data from the satellite, and sends data via a cell phone. A satellite provider who was testing a new system was found, and a GSM cellular modem was purchased. The satellite feed uses the same equipment as satellite television, and luckily uses the same satellite. A SIM card was all that was needed for the modem to work. Technically speaking this worked, and was readily available… but cell phone airtime is expensive, and a quick look at a coverage map from MTC, Namibia's monopoly cell phone service provider, showed that there was no coverage in most of the rural areas. This could have been an option for some areas, but the high costs and small service area for the most part make this an impractical solution. A better way had to be out there.

One last early system called wireless bridging was tried. The bridges took very little time to set up and install. They worked first try. Granted we were using short-range antennas, and the maximum distance tried was around 100 meters. Longer-range antennas were easily available, a network plan was made for the schools in Windhoek. Then the quote came in. The sectoral antennas quoted for the base station bridge cost more then the bridge itself, and we needed four of them, and four bridges at the base station. Because this is a bridging system, the only difference between the base station and the customer premise equipment (CPE) radios are the antennas. While this system would have worked, and a secure supply of the bridges is available in South Africa, the cost was too high for our budget. There had to be a solution out there with a robust base station, and smaller, less expensive CPE radios.

A brief look was taken at “any point to multipoint systems,” also called “mesh systems.” In this scenario a main radio connects the wireless network to the wired network, however the CPE radios also work as repeaters, routers, and bridges. As long as one client could see another, then it would be connected. This is an excellent system, with great redundancy and range, but it is designed for telecom operators and carriers, making it far beyond the budgetary constraints of Schoolnet.

While none of our early ideas are being used as a whole, lessons learned during the initial research helped open minds, and build a network of contacts as well as a long list of web sites that became invaluable for the models that will actually be used. Some of the ideas and technologies have been changed slightly, and will be used to a lesser degree.

Things Begin to Take Shape

A stolen notebook computer helped change the direction of research; unfortunately it was my notebook that was stolen, with most of the research notes with it. Even the CD backups were taken when my home was robbed. After some time to see if there was anything I could recover somehow, research started once again almost from scratch. During this time, Schoolnet itself had changed its entire infrastructure at this point, and was now an Internet Service Provider (ISP). The network core was now dedicated to Schoolnet, and support for the wireless connections was included in the design. One of the big changes was my new notebook computer; at least it was new to me. This notebook had for the most part, survived a lightning strike. Everything except the Ethernet port worked, forcing me to look for alternative connectivity answers for me to connect to my server, ten meters away. Apple Airports got me connected but, I asked, could this be built up to connect schools much further away from the base station then the 10 meters separating me from the Apple base station?

Shorter range, small office/home office (SOHO) based wireless networking, like the Apple Airports, is becoming more commonly used over conventional wiring in offices everywhere. The cost is a little higher, but savings in time and hassle of running cables, are much more protected from power surges, and give the freedom of moving a computer without having to run a new cable. The basic system includes a small radio in the computer that connects to a more robust base station radio that is connected to the wired network. The range varies from manufacturer to manufacturer, but indoors a range of 100 meters, and outdoors a range of almost 300 meters can be reached without compromising stability. Some of these base stations and cards have external antenna ports, meaning that a high gain antenna can be added, extending the range. The initial math looked good for range, and the equipment was well priced. An option of even building our own antennas was even looked at. We even looked at plans to build an antenna housed in a Pringles can. However, the stability of this system at longer distances was not good, the base stations were not designed for this type of application. It would work for a small number of connections within three to four kilometers of the base station, but not the 8km to 10km range that is needed. Finding cards that are compatible with the Linux based servers was also a large concern. The cards are out there, but hard to find especially through African supply channels. Questionable stability at medium ranges meant that it would not work for mass distribution. Some of the concepts from this idea did carry on, and helped shape the eventual distribution model. This idea does have a roll to play, it will be seen again later in this report.

The idea of connecting people and places to the Internet at longer ranges couldn't be a new one. If there were these SOHO solutions, there had to be to a more powerful system out being used, that didn't require using the expensive bridges. While surfing a bridge manufacturers web site, two key things were suddenly right in front of me. First the term, WISP, short for wireless Internet service provider. Other people were doing what I was trying to do! There was also a picture of the sought after robust base station, and smaller CPE radios that worked at ranges over 10km, some even up to 20km! Now knowing that one company was making the radio solution I was looking to use, the search began for more. Contact was made with many WISP operators from all over the world through a very busy mailing list. Thoughts and ideas now had help to get into a working model, lots of radio suppliers were found, and contacted. The options were almost endless. Using the original criteria of range, cost, reliability, and ease of use the choices were narrowed down, and a request for quotation was called for. Prices came in, and for the most part were close together, and less then what we were expecting. For the most part, the models were developed to allow for any radio equipment to be used, the geographic layout, existing radio spectrum usage, regulations, and level of urbanization will be the main factors in radio selection in an area.

Finally, The Models

At long last, the final models began to take shape. Ideas started to be proven, and become plans. Knowing that math and theory can only prove so much, the models were sent to various people in the wireless industry to see how they compare with actual fieldwork done in various places around the world. They were adapted slightly from the feedback received, and made ready for implementation. These are conceptual models, and are not designed with any specific equipment manufacturer in mind. The idea was to create a connectivity model; all efforts were made to stay with standardized hardware to allow for flexibility, and easier expansion in the future. Both models have been built to allow for choices of hardware, software and service providers.

Low School Density Areas

The first and simplest model designed for areas where no two schools are close enough for a radio based connection. This model has not changed from day one. Low density areas are defined as places that do not have another school close enough to it to connect via radio. This model uses only a very small aperture terminal (VSAT) satellite based system for connectivity. VSATs can both send and receive data via satellite, and can be placed almost anywhere in the world. Although initial hardware costs are relatively low, the schools will require Schoolnet to subsidize the monthly operating costs.

Essentially there are two ways VSAT providers charge for services. The first is a subscription is paid for each VSAT installed. In this situation, each VSAT works independently of all other VSAT stations installed. The bandwidth has a higher committed information rate (CIR), and is generally the faster option. The second is sold as a shared amount for a network. For example, a one megabit connection can be bought, and then every VSAT installed on the network shares that connection. If one VSAT is using the Internet then it will have access to the full bandwidth. If 15 are using the Internet, then they will share the bandwidth among them. This is usually the more cost effective solution. Which of the two options to use depends largely on bandwidth expectations, budget, local regulatory rules, and of course availability.

A VSAT station sends and receives its signals from a geostationary satellite, orbiting more then 35,000km above the earth. The Internet connection does not come from the satellite itself, but from an earth station somewhere in the world. This means that the signals must travel over 70,000km before they get to the Internet, and the requested data will travel back the same distance. Radio waves do travel at the speed of light, but because of the distances traveled there is some unavoidable latency involved with satellite-based solutions. As there is no high speed Internet earth station in Namibia, *Schoolnet Namibia* is looking for an overseas provider to handle our connections. This does mean that the VSAT supplied areas will function totally independently of the wire supplied areas of the country. This will help keep the wired bandwidth costs down. However services offered by Schoolnet, pornography filters, will need to be supplied to be the VSAT provider, or installed at each VSAT location, adding to the maintenance of the system.

High School Density Areas

The second model is for areas with a high density of schools. These areas are defined as having schools close enough together to link via a radio based solution. Like the first model a VSAT is installed at a central location. Added to that are radio base stations, an antenna, and a transmission tower to get the antenna higher. Remote schools then connect to the base station using the smaller CPE radios, and directional antennas.

Depending on the desired range, and the density of schools will determine the specifications of the antennas used at both the schools, and at the base station. Places that have a smaller number of connections inside approximately a 10km radius can use omni directional antennas. These antennas cover all 360 degrees around them, but are limited in power. Places that have higher school density then that will use sectoral antennas, which cover a section of the compass circle. Sectoral antennas focus their power on a smaller section of the compass circle, allowing for longer range, and larger number of connections within the coverage area. Sectoral antennas split the load of the compass circle, and focusing the power to a limited area increases the range from the base station. Sectoral antennas commonly cover from 60 degrees to 180 degrees. The cost is higher because of the added hardware, but the number of connections, increased range and the greatly improved stability does justify the added expense. The height of the base station antenna will also play a large roll in determining the range. How far away from the base station the school is will determine the minimum antenna strength needed to connect the schools. Larger gain antennas can be used, but are more expensive then the smaller gain antennas.

The initial hope of a single radio solution that will work everywhere unfortunately was not going to work. There are just too many types of unique situations in Schoolnet's wireless network to pick a single type of radio system, and only use that throughout the network. Traditionally, a WISP will set up an infrastructure, and that will become their service area. Schoolnet is in the opposite situation, where the service area is already defined, and the infrastructure needs to be built to fit. This means that a school that is out of range from all points, still needs to be connected somehow. Some radios require radio line of sight (LOS) conditions, meaning that the path of the radio wave takes from both the sending and receiving radios must be free of obstructions like buildings and trees. Other radios are designed to work in non line of sight conditions (NLOS). Trees and buildings do not affect the radio as much with these radios, allowing for better installations in urban areas, and lowering the height of antenna towers in treed areas. A radio solution can be figured out to match specific situations. Urban areas, with tall buildings can block the LOS between two sites, leaving two options. Ether a taller tower is needed, or a radio solution that does not depend on LOS can be purchased. In some cases, both LOS base stations, and NLOS base stations are mounted on the same tower, as NLOS equipment tends to be more expensive then LOS equipment.

Selecting the right radio equipment for specific situations is definitely a key to the success of Schoolnet's wireless network. This is also the part with the most variables, and options. Almost all wireless networking equipment uses some sort of spread spectrum technology, either frequency hopping, or direct sequence. Direct sequence spread spectrum (DSSS) is the most common, and also the cheaper of the two solutions. However, the frequency changing pattern is standardized over 11 channels for all equipment, limiting the number of DSSS that be on one tower, and increases the chance of interference from other systems in the same area. Of the 11 channels, only three are orthogonal, meaning they do not overlap; the other eight can actually interfere with each other. This interference limits the number of DSSS that can be put on one tower or high site. Frequency hopping spread spectrum (FHSS) allows the frequencies used and the hopping pattern to be configured on an individual basis. This removes the limitations for equipment on individual towers, and greatly reduces the chance of interference from neighbouring systems. This equipment is slightly more expensive, and there are fewer manufacturers producing it.

Plan B

The centrepiece of the wireless models in Namibia is the VSAT hardware. Throughout this report, it has been assumed that the main base stations will have their connection to the main network supplied by a two-way satellite system. In Namibia there are currently no national providers of broadband satellite based Internet systems, and it is against the NCC regulations to use foreign providers. Unless either the regulations change, or a Namibian provider starts soon, Schoolnet will need a non-satellite base solution to get to as many schools as possible. Unfortunately, this may not be a solution for low-density schools. We decided to find solutions using long-range antennas. Using tall radio transmission towers, and high frequency radio equipment with very directional high gain antennas, an internet connection can be made up to 100km away, still using off the shelf hardware. The 2.4 GHz and 5.8 GHz frequency band has a much smaller clearance zone required, and adding a signal amplifier between the radio and the antenna will make up for the free space loss over the extended range. One advantage of this solution is the reduction of monthly costs, however the initial capital outlay is very high. The available bandwidth will have to be managed a little more closely as there will now be a lot more demand on the point where the wireless network meets the wired network. Remember that only four DSSS in the same frequency range can be placed on one tower. Using FHSS base stations will help increase the number of DSSS bridges that can be used to extend the range covered by one VSAT.

One thing that has recently become available in Namibia is a one-way satellite connection. These can only receive data; however, when strategically placed they can greatly reduce the demand on the bandwidth of the entire system. Since the satellites receive speed is approximately 2 MB, sending data and requests can still be done by the wireless Ethernet connections. These satellites will definitely be used throughout the system, as a reliable and cost effective way of increasing the total bandwidth of the system. The drawback again lies in some of the local services offered by Schoolnet. Filter rules for example are applied to incoming packets, not the request packets. This means that filter based services, like pornography filtering, will need to be implemented at every point where a satellite connects to the network, again increasing system maintenance.

Increasing the Range…

With base stations covering a radius between 10km and 20km, it would take a lot of VSATs to connect all of the base stations. Early research with bridges showed that two places could be linked together with one of these bridges. Using a 2.4 GHz or 5.8 GHz bridge from the satellite to a school approximately 40km away can supply the connection another base station, increasing the radius served by the VSAT to 60km. Depending on the number of schools covered in the total radius, another layer of bridges could be installed. Just keep in mind the use of bandwidth… If the central hub site has an 8 megabit connection, and the goal is to provide a 64 kilobit connection, approximately 160 schools can be covered and still maintain the connection speed goals, assuming all schools are using all of their bandwidth. The chances of having all schools using all of their bandwidth, combined with the downloading nature of the web will make it a rare occasion when all schools will be using their full bandwidth at the same time. This actually inflates the 160 school figure to over 300, meaning that more schools can be connected to the same channel, reducing the needed bandwidth and costs.

…Without Sacrificing Speed

One word keeps being said in this report, without a whole lot of explanation behind it. That nine letter word is constantly on the minds of every ISP worldwide. The word is “bandwidth.” It is used to describe the speed of a network connection, and how much data can be transferred over a period of time. Bandwidth is not plentiful in Namibia. Between UUNet Namibia, and Telecom Namibia, the two Internet bandwidth providers, there is currently less then 10 megabits of bandwidth for the whole country. This total is even less then the capacity of our wireless bridges.

Needless to say, the fastest radios are not going to be an issue in Namibia quite yet. Connecting over 1500 schools to the Internet with that little bandwidth will take a creative management plan. This is not a report on either network management or bandwidth management, so I will keep this part short too. We hope to reduce the demand on bandwidth using caching. Caching servers will be implemented at both the main ISP servers, and at every point where the radio network meets either the wired network or a satellite connection. This will save downloading the same web pages many times in the same day, saving bandwidth importantly on our connection to the Internet, and also on Schoolnet's virtual private network (VPN) established within Namibia. Caching servers are starting to lose their effectiveness, as they cannot save post form data, or dynamically produced web pages. Web designers are using these types of pages more often, reducing the effectiveness that caching servers. While they will not save 50% of the bandwidth any longer, even a savings between 15% and 20% still will make a noticeable difference in speed for the end user, on demand on the available system bandwidth.

Places that have satellite connections can also take advantage of datacasting caching services offered through some satellite partners. Datacasting allows for commonly used web pages to be put into the cache before a user requests them. Imagine the difference in a class if the teacher has requested the relevant web pages for a class the day before, and they are sitting waiting for his class. No demand is put on either the VPN, or the Internet connection during the peak usage hours of the Schoolnet system. The learners looking at the pages do not have to wait for the information they need for their lesson either. Again, the same dynamic data issues on caching do apply, but selecting web sites that are not dynamic or post form can easily work around this problem.

Some Quick, but Serious Talk

While the long-term use of radio-based systems will save a lot of money, the equipment is expensive to buy. The system needs to be designed for the specific needs of the area it will be covering, comply with local regulatory rules, be configured properly, handled properly, and installed according to manufacturers specifications. Talk to many suppliers, and try to stay with people whom you feel comfortable with. Talk with other people who use wireless technologies, see who they deal with. The landscape, like trees and hills, will be the largest factors in what type of radio solution is used. Have experienced site surveyors both plan and work on the high sites. Find an equipment supplier that can be trusted and work closely with them throughout the entire project. This is their job, and they know what equipment works best in the various situations. Throughout the final planning and the early implementation phases, daily contact with the two different suppliers used by *Schoolnet Namibia* was made. Make arrangements to get staff trained in the proper methods of configuring and installing the CPE radios, and getting the schools working. Then start training on how to configure the base stations. Most manufacturers offer certification courses, a small investment in training for your staff will save a lot of headaches later.

Some REALLY Serious Safety Talk

Base station antennas need to be mounted high on towers. Climbing towers is very dangerous! This is something that should be left to experienced tower climbers. With the exception of the harnesses, climbing towers is not like rock climbing. When climbing up a cliff, you are looking at something solid, and in most cases have something solid to hold on to. Climbing a tower is nothing like that. There is no solid object in front of you… only a ladder if you are lucky. The most common direction to look is down. Towers also sway in the wind, and move around if there is more then one person on them. An inexperienced climber may freeze on the tower, creating a really dangerous situation. Now another inexperienced climber has to go up and try to talk the person down. Remember, the climber will also be carrying that expensive sectoral antenna that took a long time to get shipped in and cleared through customs. It has to be mounted properly or it will not work properly, meaning the system will have less coverage, not cover the planned area, or not work at all. Tower climbing is the only part of the entire *Schoolnet Namibia* operation that is not taught to the volunteers. This is not a matter of putting on a harness, and starting to climb. **This is one job that is left for the professionals.**

A Few Sustainability Ideas

Making effective use of donor funding must include a plan to allow for continued operation after the donor funding runs out. Again, this is all throughout the plans of *Schoolnet Namibia*. The wireless network plays a large role in this. Keeping the usage of VSATs limited, and relying on radio based technology for the bulk of the schools will be a great start to minimizing the monthly costs, since the main cost involved with the radio based network is the installation costs. Ongoing monthly costs are very low on a per school basis. This can allow for the monthly costs to be in a range that schools can afford, and can keep Internet in the classroom.

Local phone calls are not free in Namibia, and the same is true in most African countries. The Ministry of Basic Education, Sports and Culture in Namibia have limited the amount schools can spend on telephone bills. That limit translates to two and a half hours of Internet time per month, assuming they make no other phone calls for any reason. Installing wireless technology will allow those schools will allow unlimited Internet use, and still stay within the ministry limits.

There are income-generating opportunities with this equipment, that can still allow non-profit organizations like *Schoolnet Namibia* to stay within their mandates. Connecting education related groups and initiatives other than schools can be charged for, and connected wirelessly instead of telco based leased lines. For example, one of the first ten CPE radios bought, two will be used for income generation, connecting a teacher training college, and an "E-Learning" initiative in one of the government ministries. This will raise enough money to purchase the other 47 CPE radios needed for all other schools in

Windhoek in just over one year, and still save both other organizations on the cost of a commercially available connection.

Other options are there as well. Renting tower space to other groups, like TV stations, FM radio stations and GSM cell phone providers can generate funds to help cover the cost of the towers, or work as a bargaining tool with other tower owners to trade tower access. Choosing a radio solution that is voice over IP (VoIP) compatible, and then installing a gateway will allow for schools, or anyone else in the coverage area to get a radio base telephone line, making them accessible to the whole world. Income can be generated collecting cross connection fees from the local telephone company.

A Final Reality Check

Unfortunately there is not one set-in-stone solution that can be duplicated everywhere, that will be exactly the same and work in all situations. Wireless equipment needs to be selected based on the specific situation and needs of the area, and the bandwidth goals of the system. The theory behind the models does not change. An Internet connection is brought to a location, and then distributed to the surrounding area. Radio high sites have one or more robust base stations that schools connect to by a smaller radio that is connected to their computers. Point the antennas so they line up, and there’s now Internet in some of the more remote places in Namibia.

There are still many hurdles left to cross before the digital divide is bridged, or better yet, disappears completely. These connectivity models give not only *Schoolnet Namibia*, but also other Schoolnet like organizations all over Africa the initial direction needed to connect previously out of reach schools.

Appendix A – Towers and Masts

The difference between towers and masts is minimal, but a combination of both will play a very key role in any wireless system. Both are structures designed to hold antennas high above ground level (AGL). The difference between the two is that towers are free standing, and masts use guy wires, or stay wires to help support it. Masts are less expensive to purchase, however they have a much larger footprint because of the stay wires. Towers are more expensive to purchase and use more aggregate materials, but take a lot less land and usually have a higher windload rating. There are two key numbers with towers and masts, total weight and windloading. These are two numbers not to be exceeded.

Total weight is the maximum amount of mass that can be added to the structure. Most antennas used in wireless networks like this are not that heavy, commonly used antennas rarely weigh more then 15kg. However, one cannot forget to add the mass of all antennas, plus the weight of anyone climbing the tower or mast. Exceeding this limit can either damage the tower, or cause it to collapse.

Windloading is how much force caused by wind can be applied to the tower without it moving enough to cause signal problems. Every antenna has a windload rating, and the tower has a maximum windload. If the tower limit is exceeded, the tower can move enough to disrupt communications; the tower can be damaged or in the worst-case scenario, get blown completely over by the wind.

When planning for towers or masts, it is very important to look into the future to look at what else might need to be added to the tower. It is much more cost effective to build a stronger tower in the beginning, then to have to either replace a tower, or build an additional tower near by. This does include other organization's antennas if co-locating equipment is a consideration. Check with radio suppliers to get average windloading of other wireless applications, like FM radio, cellular phones, and TV broadcasting.

If building towers is necessary, hire a professional tower rigging company to do the building. Not only will they have the proper tools to make the job go smoothly, they have the engineering background to insure that all civil work is done to specifications, and guy wires are positioned properly and use the proper cables. All masts and towers must be inspected by an qualified engineer immediately after construction to

Appendix B – Equipment Used in Testing the Models

Equipment from two different radio manufacturers was installed and tested. These radios were not installed to 'compete' with each other to see which one would be used as a whole. Considerable research was done on specific radio manufacturers before orders were placed. One LOS solution, and one NLOS solution was installed.

The NLOS Solution

This was the first order placed by *Schoolnet Namibia*. Since Namibia is not exactly the most treed country; the majority of NLOS conditions are in the urban areas. Equipment from Waverider Communications Inc, base in Toronto, Canada was chosen. Products from the LMS3000 range were selected. These radios operate in the 902 to 928 MHz section of the ISM bands. There currently is not a local Waverider agent, so the first order was placed directly with Waverider.

Base Station: CCU3000, 50 user
Base Station Antenna: Antel 10 dBi Omni Directional

CPE: EUM3000
CPE Antenna 1: 6 dBi Waverider Diversity Antenna. Used for clients up to 2km from the base station
CPE Antenna 2: 9.1 dBi Yagi. Used for clients over 2km, and up to approximately 10km.

Expected range: 4km NLOS, 10km LOS

Website: www.waverider.com
Email contact: sales@waverider.com

Our testing system, designed for use in Windhoek, had one base station, and ten CPE radios. The omni directional antenna was mounted at the top of a 15m mast, which is on top of Schoolnet's 10m building. The connected schools were between 2km and 9km away from the mast.

Waverider was chosen in part for the NLOS capacity, but another large factor was the great pre-sales support. Reading some independent reviews of Waverider equipment and post sales support finished the deal, and the order was sent for one CCU3000, and ten EUM3000 units. So far, the quality of the equipment has been great, and their service has more then lived up to their reputation. There is a little more configuration required with Waverider equipment compared to some other manufacturers, but the documentation is well written, and training courses are also available. Schoolnet is planning on continued use of Waverider equipment; care will have to be taken not to interfere with GSM cell phone providers working near the same frequency.

The LOS Solution

The very first wireless equipment found on the web during this project that was the robust base station, and smaller CPE radios was made by Alvarion, formerly known as BreezeCom. Almost a year later, the first order for Alvarion equipment was placed through a reseller, Satellite Wireless Networking (SWN) based in South Africa.

Base Station: BreezeAccess II AU-E HP-2.4
Base Station Antenna: 10.5 dBi 120 degree sectoral
(*Schoolnet Namibia's* LOS towers will use two base station radios, each connected to two sectoral antennas)

CPE 1: SU-I-D 1D Breezecom Radio (Low Power, up to 5km)
CPE 2: SU-R-D 1D Breezecom Radio (Medium Power, up to 12km)
CPE 3: SU-E-D 1D Breezecom Radio (High Power, up to 20km)

CPE Antenna 1: 22 dBi flat panel antenna
CPE Antenna 2: 25 dBi grid antenna

Expected range: 20km LOS

Alvarion website: www.alvarion.com
Alvarion email contact: africa-sales@alvarion.com

SWN website: www.swn.co.za
SWN email contact: lofty@swn.co.za

The Alvarion solution tested consisted of two BreezeAccess II AU-E HP-2.4, four 10.5 dBi 120 degree sectoral antennas. Two antennas were connected to each base station, using a splitter. The first system was installed in Ondangwa, and a second installed in Oshikati. These two high sites will cover an area with one of the highest density of schools in the country. Using the sectoral antennas splits the load that each base station handles, maintaining a higher connection quality, at the greater ranges. Schools connected started at 1km from the high site, and went up to 20km away.

BreezeCom was one of the original wireless manufacturers, which now continues under the Alvarion name after merging with Floware. They make a quality product that is competitively priced. Having SWN, as a local agent will be a great help when it comes to supply, support and warranty work. SWN also has extensive knowledge and experience working with wireless communication all over Africa. The base stations used are FHSS, allowing for many base stations to be installed close to each other, and more importantly, avoiding other people using DSSS. Also in this solution, different CPE radios will be used in combination with different antennas to allow for a more cost effective solution to be found for each site. One option that has not been used within the testing system yet are the CPE units with built in voice over IP (VoIP) support. This can allow for a phone to be connected to the CPE itself, and used as an IP phone by itself, or as a regular phone if Schoolnet adds a gateway to the system.

VSATs

At the time this report was written, only the radio models had been installed, and tested. Schoolnet had not installed a VSAT system yet. Discussions with various suppliers have started, but there are some heavy regulatory issues in Namibia that also have to be dealt with before a system can be installed. One of be best monthly costs found is approximately US$300.00 per month, plus US$4000.00 for hardware. That is sustainable when the cost is spread out over many schools, however for low density school areas, it is still too expensive for either *Schoolnet Namibia* or a single school to carry the cost on their own.

Appendix C – Some of the Math

There is a lot of math involved in designing wireless systems. Luckily most equipment resellers and manufacturers have built spreadsheets that can do most of the work. Knowing, and understanding some of the formulas will help understand how the systems come together.

Converting from Watts to decibels (dBm).

Either Watts (W) or decibels (dBm) can be used to express power values of radio systems. In many cases, the decibel convention is much easier to work with, however Watts will still be common on many technical documents.

$$dBm = 10 \times \log P_{mW}$$

Where P_{mW} is the power measured in milliWatts

Wavelength

Wavelength is the distance a wave takes to complete one full cycle. The conventional symbol for wavelength is the Greek letter lambda or λ.

$$\lambda = v / f$$

Where λ is the wavelength, v is the velocity of the wave (this is a constant equal to 300,000,000 meters per second, also the speed of light) and f is the frequency.

Fresnel Zones

These zones make up the largest difference between radio line of sight, and visual line of sight. They are elliptical shaped zones around the direct line between the antennas. There are different zones, but it is mainly the first Fresnel zone that affects wireless networking systems. If more then 40% of the first Fresnel zone is blocked by some obstruction, then LOS systems may not work.

$$R_1 = \frac{1}{2} \times \sqrt{\lambda \times D}$$

Where R1 is the radius of the first Fresnel zone, λ is the wavelength, and D is the distance between sites.

Path Loss, or Free space loss

As radio waves travel from the transmitter to the receiver, the signals get attenuate, or get weaker. This formula is used to calculate the loss in signal strength, and will help insure the signal is strong enough for the receiver to collect and understand the transmission.

$L_p = 32.45 – (20\log(F_{MHz}) + 20\log(R))$

Where L_p is the path loss in dB, R is the radius, or distance in kilometers, and F is the frequency in MHz.

Equivalent Isotropic Radiated Power (EIRP)

EIRP measures the strength of a signal as it leaves the antenna. This is the place where the signal will be the strongest. Regulatory agencies that recognize license exempt frequency bands use EIRP values to set power limitations.

$EIRP = P_{out} + L_c + G_a$

Where P_{out} (dBm) is the output power from the radio, L_c (dBm) is the loss in signal due to the cable, and G_a (dBm) is the antenna gain. The EIRP is expressed in dBi.

Appendix D – Glossary of Terms

Every attempt was made to keep the main body of this report as conceptual as possible, without getting incredibly technical. Unfortunately it is next to impossible to keep new terminology out of a report of this nature. This glossary of terms has been included to help clarify terms used here, as well as other terms used in the wireless networking industry.

AP – Access Point. Another name for a radio base station. This is the central hub radio that the CPE radios connect to.

AU – Access Unit (Same as AP). Commonly used by Alvarion to describe their base stations

CAP – Communications Access Point. A Waverider term for a unit designed to hold three base stations, connected to three sectoral antennas, working on three different channels.

CCU – CAP Channel Unit (Same as AP). Commonly used by Waverider to describe their base stations.

CIR – Committed Information Rate. The guaranteed amount of bandwidth available for a connection

CPE – Customer premises equipment. These are the radios that will be installed at the schools

dB – Abbreviation for Decibels

dBi – Decibels Isotropic. Measures the dB gain in antennas.

dBm – A ratio (Log10) of Watts to one milliWatt, or the output power of a signal referenced to an input signal of 1 milliWatt.

Directional Antenna – An antenna which focuses its signal on only a section of the compass circle

DSSS – Direct Sequence Spread Spectrum. One of two spread spectrum modulation schemes, where the frequency used is set on a certain transmit and receive channel. The transmit and receive function will only happen in that set channel in a certain section of the Frequency band. The channel band is normally wider then FHSS.

EIRP – Effective Isotropic Radiated Power. This is the total system power. It includes the output power of the radio, the cable loss between the radio and the antenna, and the gain of the antenna.

EMI – Electro Magnetic Interference

ETSI – European Telecommunications Standards Institute. The ETSI is the governing body for frequency use in Europe.

EUM – End User Modem. The same a CPE, commonly used by Waverider. Short for end user modem.

Fade Margin – An allowance of signal strength that will help accommodate for unpredictable factors, like weather.

FCC – Federal Communications Commission. The governing body for radio frequency use in the United States

FHSS – Frequency Hoping Spread Spectrum. The second spread spectrum modulation technique where the frequency that is used hops according to a hopping pattern configured in both the transmitting channel and the receiving channel in a certain piece of the band. The channel band is normally narrower then in DSSS.

Free Space Loss – Attenuation of the radio waves in space between the transmitter antenna and the receiving antenna.

Fresnel Zone – The elliptical shaped area around the visual line-of-sight path that radio waves spread out into after they leave the antenna. This area must be clear or else signal strength will weaken, creating a NLOS condition. The *s* in Fresnel is silent, it is pronounced *fru-nel.*

GHz – GigaHertz. 1 GHz = 1,000,000,000 Hz

GSM – Global System for Mobile Communications. A type of cell phone network used in over 100 countries. This has become a standard through most of Europe, Asia and Africa.

Hertz (Hz) – The unit of measure used for radio waves. It counts cycles per second of a wave.

IEEE – Institute of Electrical and Electronic Engineers. One of the worlds largest technical professional societies. It is a significant standards-making body for computer and telecommunications standards, the 802 standard for Ethernet.

IP – Internet Protocol

ISDN – Integrated Services Digital Network

ISM bands – Industrial, Scientific, and Medical frequency bands.

ISP – Internet Service Provider. An organization that provides access to the Internet for its clients.

Isotropic Antenna - A hypothetical, lossless antenna having equal radiation intensity in all directions. Used as a zero dB gain reference in directivity calculation (gain). The sun is often given as an example of an isotropic radiator.

ITU – International Telecommunications Union.

LOS – Line of sight. When the path the radio wave takes between two antennas is clear, with no obstructions. This is close to a visual line of sight, meaning that usually if you can see one antenna from the other, then the path is considered to have a clear line of sight.

MIR – Maximum Information Rate. The maximum amount of bandwidth available for a connection.

MHz – Mega Hertz. 1 MHz = 1,000,000 Hz

NLOS – Non Line of Sight. The path between two antennas is not clear, some obstructions block the path of the radio waves.

NOC – Network Operations Centre.

Omni-directional Antenna – An antenna that can both transmit and receive signals from anywhere in the compass circle.

PEBCAK – A mythical problem description used by technicians. Problem exists between chair and keyboard.

POTS – Plain Old Telephone Service. These are normal, wire based, phone lines.

PtP – Point to Point. A radio connection from one specific point to another specific point. A wireless bridge between two buildings is an example.

PtMP – Point to Multi Point. A radio connection from one point to more then one other point. A base station with 23 CPE radios connected to it is an example.

RF – Radio Frequency.

RSSI – Receive Signal Strength Index.

Rx – Abbreviation for receive

Tx – Abbreviation for transmit.

VoIP – Voice over IP. Transmitting voice conversations over data networks, like the Internet, using IP.

VPN – Virtual Private Network. A network which is not private, but very close. More clearly put, a VPN displays some characteristics of a private network, however it uses a publicly switched network, like the Internet, to connect different parts of the network.

VPDN – Virtual Private Dial-up Network. A VPN that connects dial-up hosts to a network.

VSAT – Very Small Aperture Terminal. Satellite systems that can both send and receive data.

WEP – Wired Equivalent Privacy. An encryption method used in wireless systems to insure security and privacy levels similar to wired LANs.

WISP – Wireless Internet Service Provider. An ISP who serves customers using wireless networking equipment instead of wire based connections like modems, or DSL connections.

WLL - Wireless Local Loop. A radio based telephone system. Can be more cost effective to install, especially in harsh environments and places where laying cable is difficult.

Appendix E – A Place to Start

Web Sites

General Information

www.wispfaq.com - Frequently Asked Questions

www.idrc.ca/acacia/03866/wireless/index.html - An IDRC/Acacia toolbox on wireless networking in Africa.

www.alvarion-usa.com/RunTime/KnowledgePool_10000.asp?tNodeParam=1 - A growing knowledge base put together by Alvarion on wireless networking.

Organizations

www.part-15.org - Part-15.org is an advocacy group attempting to further both the use of and education on effective use of license exempt frequencies for Internet usage.

www.wlana.org - The Wireless LAN Association is made of a group of wireless venders and manufacturers.

www.wirelessethernet.org - A group working towards interoperability between different manufacturers equipment.

Calculators

www.ydi.com/calculation/

www.wispfaq.com/calculators.html

The Mailing List

There are a number of great mailing lists on the Internet that can prove to be a great resource. However, the ISP-Wireless listserv hosted by Internet.com stands out above all else. This listserv has a large, and very active subscription base. There is a whole world of information available from the other subscribers, and answers are very helpful. Many contacts, and a lot of research for the *Schoolnet Namibia* wireless system came from this mailing list.

As with any other mailing list, it is a good idea to do some initial research to help form the questions better. Be specific when posting messages and questions, and try to give all details possible. Especially details like range, LOS or NOLS, bandwidth goals at the client's site, where the system will be installed, and if there is any existing wireless equipment working in that area. The more relevant information that can be given up front will give a huge return in the quality of answers.

To subscribe, send an email to: join-isp-wireless@isp-wireless.com