Planning a Wireless Network

Training materials for wireless trainers

The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

This 45 minute talk gives a schematic procedure on how to plan a wireless network (or simply a wireless link), provides essentials of the pre-installation site survey and introduces Radio Mobile in more detail.
Version 1.1 revised by Rob, @2009-11-24
Version 1.4 revised by Ermanno and Carlo @2010-02-28 (name of the lecture changed)
Version 1.5 revised by Rob, @2010-03-01
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Goals

- To understand why there is a need for planning a wireless network (or link) and how it can be performed effectively
- To know what kind of information is valuable to collect when performing a site survey and how to do it
- To learn about some free tools that can simplify link planning and "what if" simulations

Why plan a wireless network?

- Let us start with a list of cases when planning is not really needed and can be skipped (or well simplified):
  - very simple deployments: for example an Access Point to serve a conference room
  - repeated installation of the same equipment in multiple sites, all similar to each other
  - experiments or tests, meant to "play" with new or old equipment you have already purchased
- In all the situations above, you can just *"go and install the equipment"*, without having to follow a (somewhat long and/or complex) planning procedure.

The case of very experienced people performing the installation is not listed here, because they also actually DO the planning in their minds, it's just not explicit.

In the first point, the definition of "very simple" is obviously strongly related to the skills and experience of the people that are going to perform the installations. YMMV ;-)

Hint for a discussion in the classroom: ask the students to imagine a few situations in which even the examples of this list will benefit from good planning, done in advance. Let them comment on other's proposals.
Some hints:
1) even a conference room may have needs like "number of clients" that will require the installation of more than an AP to be accomplished, so that issues like co-location/choice of the channels/positioning are relevant;
2) sites that look visually very similar at first glance, may end up being very different when analyzed from a "RF perspective", i.e. with different sources of interference. A site survey may be the only way to ensure that they are really all "similar", and this is part of the planning procedure;
3) to do a meaningful experiment or equipment test, you have to be sure that there are no "hidden variables" playing a role in your setup, and a good site survey may be very important. Planning for an experiment or temporary link may be even more critical than for a permanent installation, due to time constrains and other issues.

How to plan a wireless network

- A simple step-by-step procedure is presented here, as a guide to organize your own planning and design in the most effective way.
- Remember that in a complex field like wireless networking, there is never a unique and perfect step-by-step procedure that can guarantee success: you will have to adapt your planning scheme to fit the local situation with its advantages and constraints.
- Proper planning takes time. Remember to allocate a reasonable amount of time to do your planning in advance and to start doing it, right from the beginning of your project.

The teacher should emphasize the point that no procedure has to be followed blindly step-by-step, without a clear understanding of the reasons behind each step. What will be presented during this lecture comes from the experience of a team of experts, but is still far from complete and perfect. Many different approaches can lead you to a different and better result, if you know what you are doing. Sometimes even a random approach to a problem may have a better result than repeating the "expert's advices" without fully understanding them.

Define your goals

1) Define your goals and characterize the desired output of your project, with measurable figures like:

- average usage (number of clients connected)
- average / peak throughput (overall / per user)
- latency and other network issues that can influence the services running on the network
- reliability (percentage of downtime)
- maintenance costs

If you are working to design a network that will not be managed by yourself, all these parameters will be probably defined as part of the contract with your client. This is called a Service Level Agreement (SLA). Most of the time, their expected values will have a huge impact on the cost of deploying the network and this has to be discussed at an early stage of your commitment with the client.

Even if you are going to manage the network by yourself, it's advisable to state these parameters clearly in order to streamline the financial investments you are going to make, and to make the best choices for the purchase of all equipment.

Notes on the different parameters:
- average usage: it refers to the average number of clients that can connect to your APs. To overcome limitations in the maximum possible number of clients (due usually to firmware constraints of your AP devices) you may increase the number of such APs or change model/brand. Keep in mind that the max number of clients that an AP device might support does not provide any indication of the number of clients that may really make an effective use of the connection (see next point about this).
- average/peak throughput: this is the value of perceived quality of the network (the "speed" of it). You want to maximize these values in order to satisfy your clients. This is not a value that comes from a single device of your system, but it's an overall result of the entire network structure and quality. It is often difficult to forecast these values in advance, and they are affected by many factors, for example: the number of **concurrent** connected users; the **type and destination of traffic** the clients are generating; the presence of **bottlenecks** in your net infrastructure; the presence of **interference**; excessive **broadcasts** due to poor design of the net; and many others. Possible techniques to improve the perceived speed are: subnetting and routing instead of bridging; the use of proxy/cacheing solutions; a better design of your network!
- latency and other network issues: latency, jitter, packet errors, asymmetric bandwidth allocation, routing errors. These are all relevant for real-time services like voice over IP (VoIP), audio and video chat, videoconferencing, and others. Besides addressing all misconfiguration issues, a possible way to mitigate the problem of high latency in wireless networks is the adoption of better hardware and full duplex equipment/protocols (avoiding Time-Division Duplexing, TDD). Non-WiFi devices and protocols will help a lot in providing guaranteed Quality of Service (QoS) in your network. For example, TDMA (Time-Division Multiple Access) is a technique that allocates a fixed amount of time (time-slots) to every client, in order to deliver a guaranteed amount of bandwidth and a fixed latency; it is an alternative to CSMA (Carrier-Sense Multiple Access) that is used by WiFi, which provides random access to the media and therefore cannot guarantee any minimum value of latency. Be aware that the so-called QoS for WiFi provided by 802.11e is very limited in what it can achieve and cannot compare to TDMA solutions.
- reliability: the goal of providing a high level of reliability to your network always implies higher costs. This may be justified in specific situations, when a failure in your network will have critical effects (like when it provides services to hospitals or life-caring services or similar). Possible techniques to increase the system reliability are: use of redundant equipment at all possible stages; use of controlled power supplies (Uninterruptible Power Supplies, UPS) and/or diesel generators and voltage regulators; adoption of dynamic routing to overcome failures in specific hops; connection to multiple ISPs.
- maintenance costs: there is no such thing as a wireless network with zero maintenance! By deploying and owning your network you will not incur in monthly fees, but you will need to allocate resources for the periodic maintenance tasks (for example: cleaning of antennas, checking connectors, enclosures and cables to ensure they are still weatherproof, checking the status of batteries) and for eventual

Understand constraints

2) Understand which are the constraints and limitations, like for example:

- local availability of equipment
- regulatory aspects (permits, fees, allowed frequencies and power, equipment homologation)
- limitations of the ISP
- access to sites and infrastructures
- availability of power (and its quality/reliability)
- human resources (for deployment/maintenance)
- financial constraints (budget)

Notes on the different aspects:
- local availability of equipment: may be often convenient to choose locally source-able equipment, even if it not the best performing one, for easiness of replacement, cost and guarantee. Consider the cost and obstacles to import telecom equipment. Consider import duties and limitations (for example, lead-acid batteries cannot be carried by airplane and the cost of their transportation may be prohibitive because of their weight). In case you are importing equipment from other countries, always consider if the guarantee provided by the manufacturer is still valid and at which conditions (i.e. is the cost of shipping for repair/replacement covered?), how long will the shipment take (including custom clearance) and possible compatibility issues (like for example the type of electrical plugs, frequency and voltage of power supplies, temperature range for device operation).
- regulatory aspects: WiFi uses the unlicensed spectrum as per recommendations given by the International Telecommunications Union (ITU), but the local regulations always prevail and can impose additional restrictions. Permits may be required before the deployment and operation of WiFi devices, license fees may also be applied. Many countries require that all telecommunication equipment be homologated in the country (even before being imported). There is a lecture dealing specifically with these aspects.
- limitations of the ISP: your provider of Internet connectivity may add constraints that affect your planning. For example, if you can only relay on a satellite connection, there will be an unavoidable long latency you cannot overcome, therefore it's not worth trying to minimize the latency of your wireless network. The total bandwidth assigned to your network by the ISP will be the ultimate bottleneck for your communications with the outside world, therefore planning for a higher throughput in your wireless network males sense only if you are forecasting a relevant amount of internal-only traffic (i.e. not going to the ISP). Additional technical limitations of your ISP may be the availability and quantity of public IP addresses and restrictions on the allowed traffic (imposed with firewalling and traffic-shaping).
- access to sites and infrastructures: Keep in mind that an unencumbered access to the locations of your equipment is of paramount importance during installation, maintenance and fault restoration. It's not just a matter of formal authorizations, but you should know who has the keys, he/she should know you, and all relevant contact telephone numbers have to be in your possession. For repeater sites in remote locations, access may be cumbersome during the rain season, ability to perform a remote monitoring and control there may solve you a lot of troubles and it's worth to invest in more robust equipment for these sites. Special limitations may be in place on telecom towers (i.e. only qualified telecom personnel may be allowed to climb the towers), but also on many building a ladder may be required to access to the roof.
- availability of power (and its quality/reliability): Power failures are by far the most common reason for interruption of services and permanent damage of equipment. The frequency and duration of expected outages must be considered when planning your network. Having a choice among different locations for your installation, you may want to prefer the ones with better guarantees of a reliable stable power source (like for example sites where other telecom operators are already present with diesel generators and UPS, if you can agree with them to share these resources).

Design and simulation

3) Feasibility check: **design** and **simulate** the architecture of your wireless network, considering aspects like:

- location of nodes and their access (maps...)
- equipment to be deployed in each node
- availability of antenna support structures
- RF power link budget and Line-of-Sight clearance for each hop (with the help of Radio Mobile)
- source of powering for each equipment
- selection of frequency of operation for each hop
- co-location and interference issues in each node

Notes on the different aspects:
- location of nodes and their access: this tasks can be accomplished using paper maps and "good old" techniques, but nowadays is much easier with the help of computers and Internet. A simple but effective tool to look for optimal location of nodes is **Google Earth**, available for free. It shows a view of any place on Earth from a bird-eye perspective that you can manipulate at your pleasure, making it very easy to make a virtual visit of the place. We will see it with more detail in the next slide.
- equipment to be deployed in each node: the two most important parameters to consider at this stage are the transmit power and the receiver sensitivity, which must match the constraints of the power budget for the link.
- details of the antenna support structures: when choosing sites, it's important to consider the availability of pre-existent mounting structures, like telecom towers or masts, tall buildings or elevated tanks/silos, etc.
- RF power link budget and Line-of-Sight clearance for each hop: a calculation of the signal attenuation due to the distance and propagation effects should be done for all hops. This can be performed "by hand", using the formulas described in the previous lecture on Link Budget, or with the assistance of a software tool like Radio Mobile. Such a tool is also of great help for the calculation of the coverage area for a base station. The best use of radio Mobile is to **simulate different alternatives and scenarios for your network**, i.e. changing TX power and sensitivity of radios, gain and height of antennas, and any other relevant parameters, until you find an optimal solution.
- source of powering for each equipment: the grid is always the most economical option for powering your equipment, but it's not everywhere available (and is often unreliable and subject to spikes and sags). Alternative sources of electrical power, like photovoltaic systems or wind generators, are more expensive and require batteries. The choice of location is therefore highly influenced by the availability of grid power.
- selection of frequency of operation for each hop: the very first choice that has to be done is between the two WiFi bands of 2.4 and 5 GHz. The first constraint here may be the regulatory environment of the country, which may allow for either one or both of these frequencies. The second constraint is the presence of interference: due to its popularity the 2.4 GHz band is most likely used by many other devices, while 5 GHz can be relatively free. Although the opposite may also be true; it's impossible to tell before you perform a site survey! The link budget will be affected by the choice of frequency, but the antenna gain (higher at 5GHz for the same antenna size) might compensate for the increased free space loss at 5 GHz.
- co-location and interference issues in each node: previous knowledge of the presence of other WiFi operators in the site and of their frequencies of operation can help you to plan accordingly, in order to avoid receiving or causing interference. Likewise, broadcast FM transmitters operating in a certain site will not preclude the deployment of your network but might cause interferences at the ethernet level. Broadcast AM transmitters operate at a much higher power and cause high currents to circulate across the structure of the tower and therefore must be avoided.

Google Earth

http://earth.google.com/

- Verify line-of-sight between locations
- Log precise GPS coordinates
- Terrain data is available nearly everywhere
- Building data is available in some cities

The photos (clockwise) are Malawi, San Francisco, and Seattle.

Free download at *http://earth.google.com/*

Note that Google Earth requires constant (substantial) Internet access to work properly.

When dealing with maps and GPS coordinates make sure that the same reference, called a *datum*, is used in both cases, otherwise substantial errors might crop up.
GPS normally uses WG84 datum while maps can use a great variety of datum.
Identify a salient and accessible feature of the map and get its coordinates with the GPS. Compare with the map reading and establish an appropriate correction factor if necessary.

Link simulation with Radio Mobile

There are many programs that can be used to simulate radio links and base station coverage, some costing thousand of dollars.

By using a link simulator, you can save considerable time. If a link is proven to be impossible in simulation, there is no need to perform a site survey at all.

Radio Mobile is a free program developed for radio amateurs by Roger Coudè that is based on the well known Longley-Rice Irregular Terrain Model and predicts radio propagation from 20 MHz to 20 GHz making use of several sets of freely available Digital Elevation Maps.

This program has been used for a number of years by radiohams and WiFi engineers with good results, provided that sound judgment is employed, since like every model has limitations and in particular the free digital maps do not include buildings and other structures. More details will be given at a later stage of this lecture.

Site survey

4) Site survey: **inspection** of every relevant site, evaluating its positive and negative aspects like:

- accessibility to the site and inside the structure
- electrical power provisioning, grounding
- survey of the e.m. spectrum and its usage (to select the best operating channels to use)
- Line-of-Sight clearance towards other nodes
- pre-existing structures for antenna mounting
- arrange for practical considerations before the actual installation (required personnel, keys, ladders, etc)
- document everything with notes and pictures, take precise measurements where possible, take GPS coordinates and elevation data

Notes on the different aspects:
- accessibility to the site and inside the structure: consider the accessibility by car during all seasons and weather conditions, and the permission required to enter the site. Consider the accessibility limitations and the permission required to enter the building/tower (is it open during weekends? Who has the keys?)
- electrical power provisioning, grounding: The things you have to look for are: availability and quality of grid power (ask the locals), authorization to use diesel generators already on site (check if they have spare power available), availability of a good grounding system (and lightning protection system).
- survey of the e.m. spectrum and its usage: the ideal procedure is to leave a spectrum analyzer running on site (attached to an omni antenna) to record the level of noise and interferences, at least for 24 hours of a working day, but ideally for a week.
- LoS clearance towards other nodes: a visual inspection can be done, better if with binoculars or a small telescope, to identify and locate possible obstacles in the direction of interest.
- look for existing structures for antenna mounting: towers, masts, strong structures on the roof of buildings, water-tanks and silos are all good structures that will save you the cost of building your own tower/mast. The size and shape of the pipes should be compatible with the antenna mounting brackets you plan to use.
- arrange for practical considerations before the actual installation: since you are visiting a remote site that may be difficult to reach, try to agree already at this time with the local people all details of your next visit (that may happen during the installation phase), possibly planning with them any needed assistance/access/etc.
- document everything with notes and pictures, and take precise measurements where possible: it's of paramount importance to write down all relevant details of the structure, including dimensions and diameters of masts, that you may need when purchasing/preparing the stuff that's going to be installed there. Use a GPS receiver to record precise coordinates of the antenna location, including the elevation (if you have a barometric altimeter, it can give you a more precise value of the elevation, provided it has been calibrated with a known reference nearby). Take many pictures in all directions and of all structures around, with dimensional references. Take photos of the local people working/living on the site, take notes of their names. All this information will eventually become very valuable.

A paper notebook is often more useful than a laptop for taking notes in the field, because of the sunlight that can make the screen unreadable. A printed map of the area is crucial when working on long distance links to help find landmarks.

A compass will allow you to find the magnetic bearing to the other end of a long distance link. Remember that magnetic north and true geographic north do not always coincide (the angular difference between them in a certain location is called declination).

A GPS can simplify the process of finding the remote bearing, and allows you to log the precise latitude and longitude of a site. If you have a barometric altimeter, this can give you a more precise value of the elevation (referred to a place of known elevation, or after proper calibration with the value of atmospheric pressure).

Using binoculars or a small telescope, you can pick out landmarks or the location of the other end of a link. This will help later when aligning antennas, and will assist in finding possible obstacles in the path.

Taking photos of the interior and exterior areas will simplify installation and maintenance later.

Often overlooked tips

- For very long distance links, it can be difficult to spot the remote end. In the daytime, mirrors can be used to reflect light and make the other end easier to spot. At night, spot lights or strobe lights can help.
- A tethered balloon can also help locate the remote end of a link, as well as to estimate the necessary tower elevation needed to overcome any obstacles.
- Mobile phone coverage is not universal. Bring a pair of radios when working in remote places (especially for antenna alignment).
- Umbrellas can help shield glare on laptop screens on a sunny day.
- Safety first: wear gloves, helmet and harness when climbing towers.
- Don’t forget about the weather: wear a hat, sunglasses, and sun screen when appropriate.

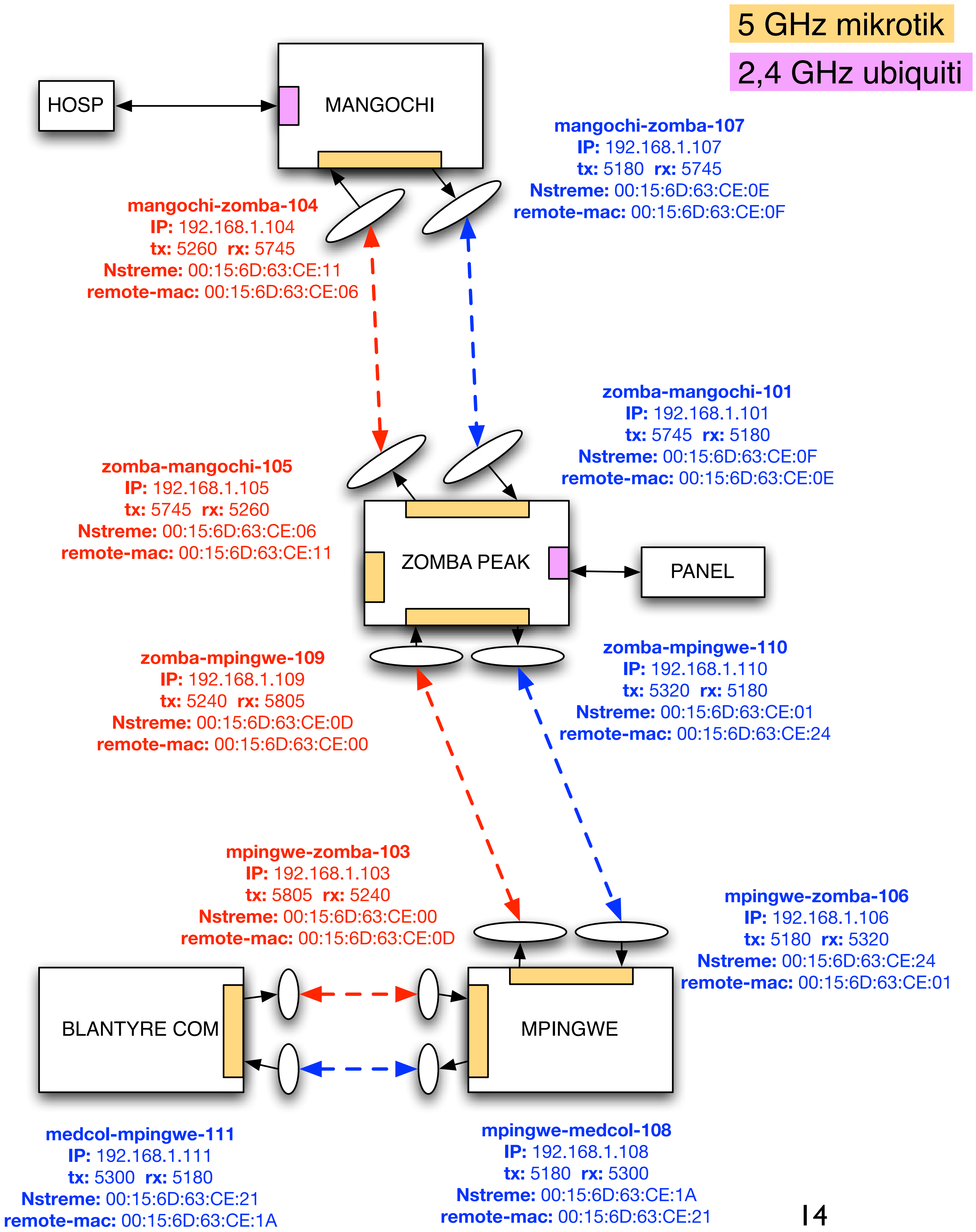
A few tips from the experts.

Final design

5) Final design of your wireless network, using the relevant information acquired during the site survey:

- final choice of equipment for every node
- recalculation of power budget for every hop
- detailed plans for antenna mounting and the running of all RF/ethernet/power/grounding cables
- frequency plan
- network topology and architecture, IP addressing scheme

Notes on the different aspects:
- final choice of equipment for every node: the two most important parameters to consider are the transmit power and the receiver sensitivity, which must match the constraints of the power budget for the link. The purchase cost is just a fraction of the overall cost of the project, so it's often worthwhile to consider purchasing a better and more expensive equipment if this helps to reduce other costs (maintenance, running costs, etc.).
- recalculation of power budget for every hop: done for the last time, after having decided the final location of nodes, equipment characteristics and antenna gains. The expected value of received signal at every site will be used during the installation phase to determine when the correct alignment of antennas is achieved.
- detailed plans for antenna mounting and running cables: this information will be used during installation but may be also required by the owner of the premises, and may be very useful for future maintenance works by others and also yourself.
- frequency plan: write a list with the selected frequency/channel for all APs and client stations at every site, as well as the SSID and other relevant information.
- network topology and architecture, IP addressing scheme: make a plan of all relevant IP parameters of your network, specify the type (straight/crossover) and length of UTP ethernet cables (if they must run outdoor, choose FTP cables or consider using a grounded conduit to protect them from the weather and interference). Where possible, plan for physical and logical redundancy of critical IP paths to avoid single points of failure that can bring down the whole network. Remember to include switches/hubs and other network devices where needed. Make sure you do not have any ethernet loops. Consider possible future expansion of your network and plan accordingly.



Here is an example of a network plan, with IP and MAC addresses, host names, locations, interconnections, operating bands, and frequency choices.

Walk through the network map and comment on the information provided, as well as what may have been left out.

Pre-deployment

6) Final steps before deployment (not the night before ;-):

- draft a timing scheme for all purchases, transportation and deployment of equipment
- plan in advance the allocation of human resources: who is going where and when, to do what (and inform them in advance!)
- configure and test all equipment before leaving the lab (run a full simulation of the network whenever is possible)
- prepare a checklist of all equipment/tools/supplies you will need at each site
- label all devices with relevant information like passwords, IP addresses, port names, etc...

These steps are self-explanatory. Regarding the last one, you can note that sensitive information like passwords and IP addresses can be removed after the installation, leaving only the minimum information needed to identify the device when doing maintenance.

Deployment

7) Deployment:

- install all equipment, antennas and cabling
- fine-tune the antenna alignment with a signal generator and signal strength meter (if available)
- test the power supplies and ethernet cables
- check if the radios are working
- check if the links are established
- fine-tune the antenna alignment using the readings of the receivers (if not done before at point 2)
- do performance tests on each individual link and on the complete network
- weatherproof all outdoor connectors and enclosures, tighten all antenna mounting brackets

There will be other lectures devoted to outdoor installation, powering and long-distance links, in which many details will be explained.
Do not forget to properly ground all devices and structures.
Remove sensitive information written on labels attached to the equipment.
Label both ends of each cable (ethernet, power and RF).

Post-deployment

8) Post-deployment tasks (to be done on-site during the installation or immediately after the installation):

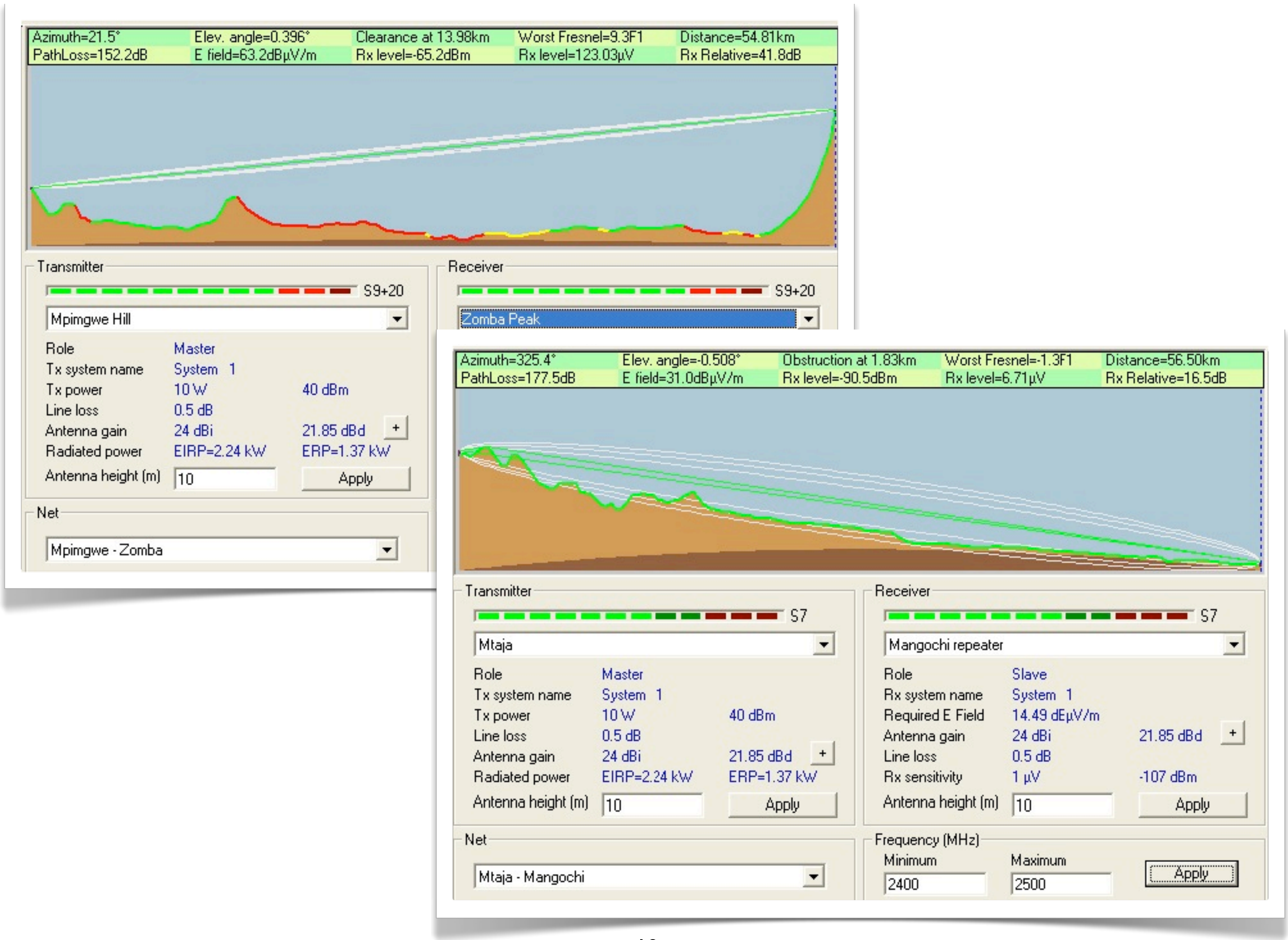
    - document the actual configuration of all devices
    - revise the schemes of the running of RF, ethernet, power and grounding cables (with diagrams), documenting any difference from the original planning
    - record the RF signal strength at every receiver, for future comparison and reference
    - devise a maintenance schedule for visiting each site

Link simulations with Radio Mobile

Radio Mobile runs in Windows but it can be used in Linux or MAC by means of emulators.

It provides all sort of details for point to point links, including expected signal level at any point along the path, including diffraction losses due to obstacles.

Automatically builds a profile between two points in the digital map showing Fresnel Zone and Earth Curvature Clearance, as well as required antenna heights and it is a wonderful tool for exploring "what if?" scenarios.

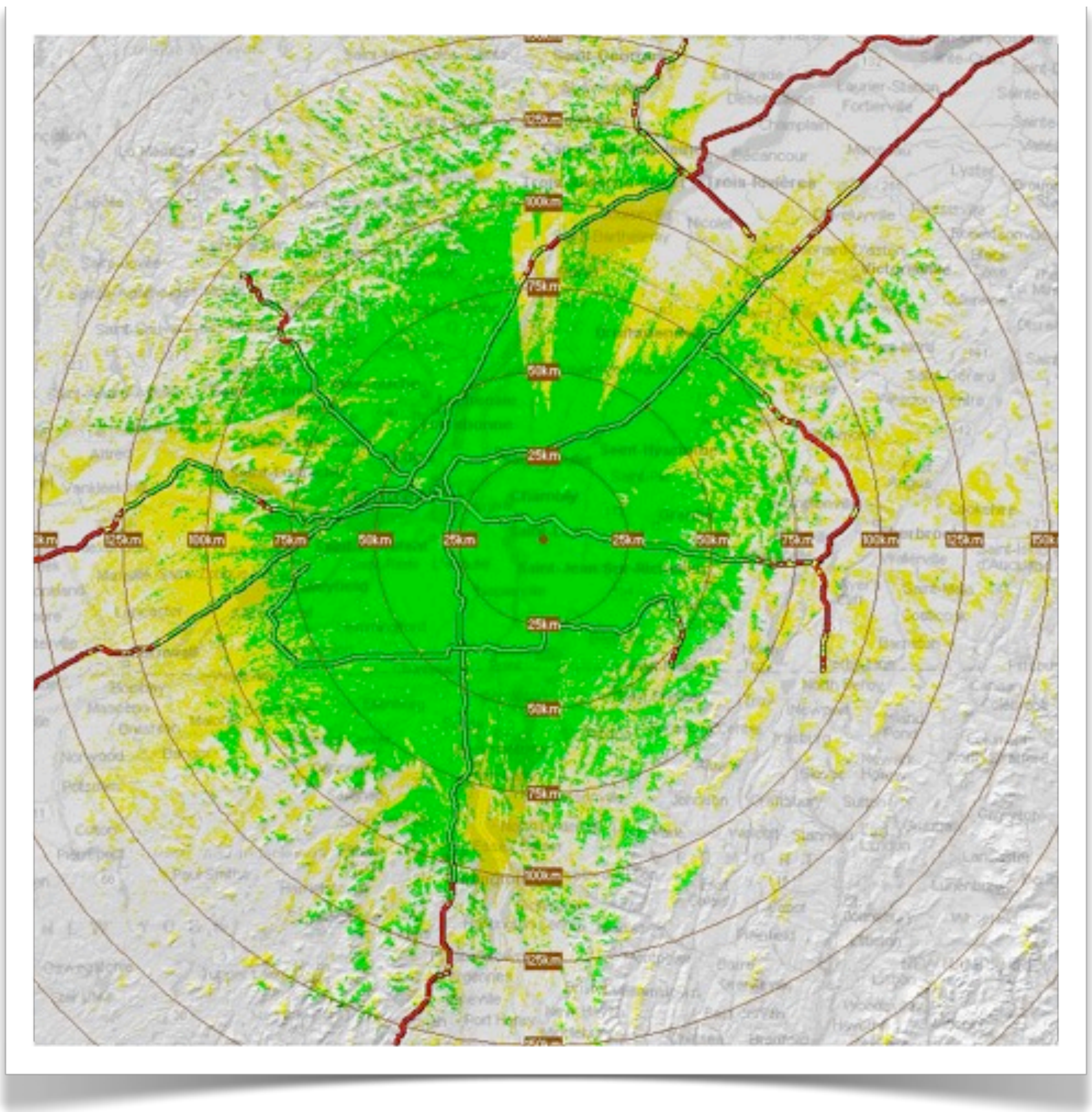


Radio Mobile showing line-of-sight terrain profiles for good and poor links. Note the curvature of the earth in the 56 km example on the right.

Fresnel Zones are shown as white curved (ellipses) lines. The worst first Fresnel zone is reported.

For point to multipoint links, it will provide Base Station coverage areas (as shown), suggest convenient sites for base station placement, and allows changing the antenna pattern while assessing how it will affect coverage.

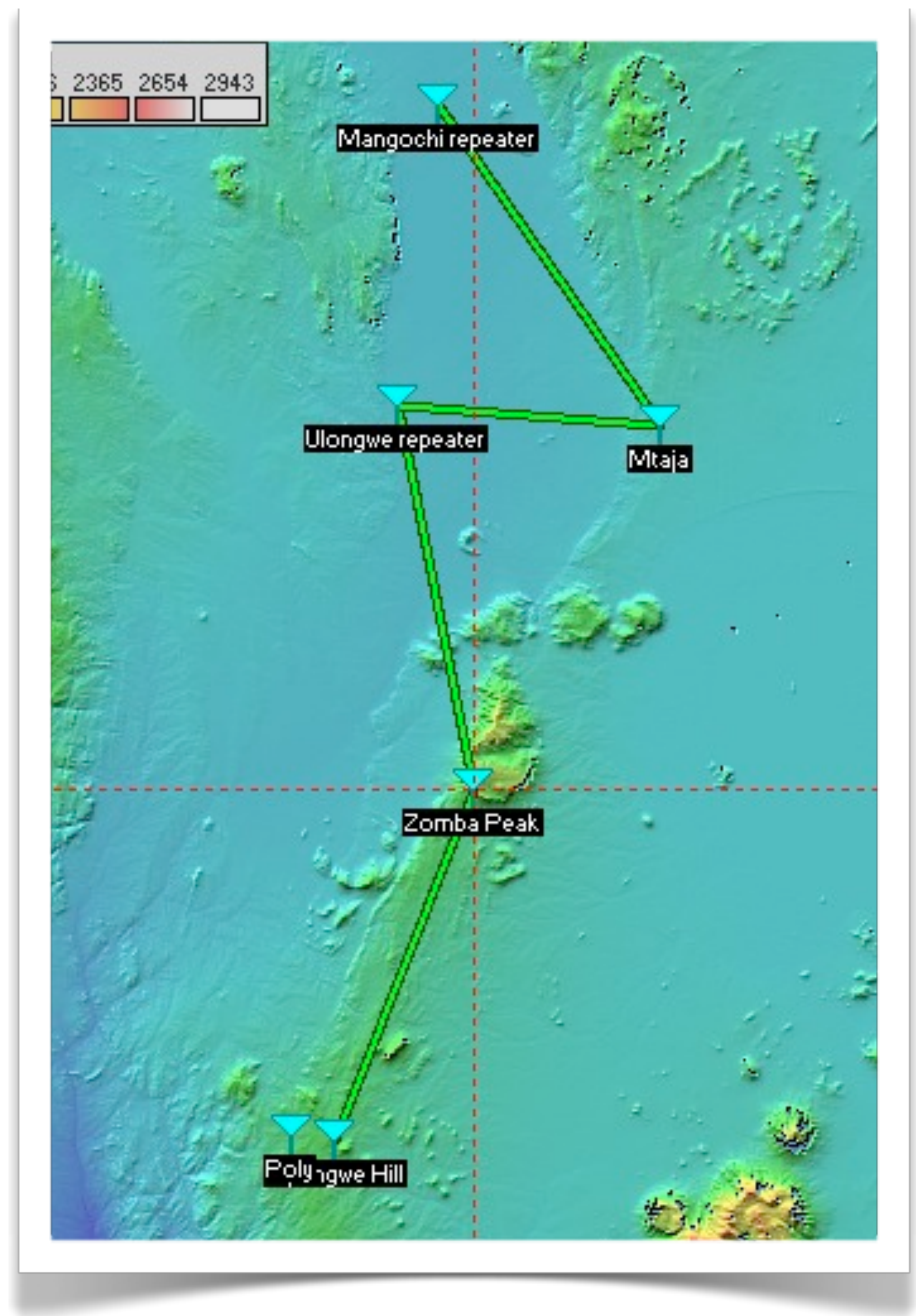
It works with true bearing but it will also provide the magnetic declination of the site so you can relate the compass reading with the map data.



Keep in mind that the difference between true bearing and magnetic bearing is called the magnetic declination and it changes from place to place and also changes in time.

The magnetic declination at any point and time can be obtained from:

*www.ngdc.noaa.gov/seg/geomag/jsp/**Declination**.jsp*



Radio Mobile showing network link diagrams.

Download Radio Mobile

Download Radio Mobile here:

http://www.cplus.org/rmw/english1.html

Instructions are provided there on how to get the digital elevations maps of the area of interest.

Digital elevation maps come in 1 degree longitude X degree latitude tiles so you might need to download a few tiles for your application.

Once you have downloaded the maps, you no longer need Internet access (unlike using Google Earth).

Conclusions

- Effort spent in planning will save ten times the effort in installation and maintenance.
- Configure and test all equipment "in the lab" before deploying it in the field.
- Keep good documentation of all configuration settings for all devices to assist in troubleshooting and expanding the network later.
- Don't forget to account for maintenance in your planning (both financial and logistical)!
- Tools such as Radio Mobile can automate many parts of the network planning process.

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as free download in many languages at:

http://wndw.net/