Cambium Networks

Ensuring Compliance with Network Objectives

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Abstract — Advice is provided to enable network operators to achieve the designed throughputs from their networks with expansion capability. Also advised are monitoring items to ensure a minimum of network outages.

Contents

1 Introduction

Fixed wireless systems have been deployed in more than 20 Million homes across the world connecting the unconnected with high speed reliable broadband. Precisely

because fixed wireless access networks are fixed, they can be installed professionally to achieve performance in line with intended design based on accurate and verifiable mathematical models. Professionals who have been used to deploying Microwave links realise that fixed wireless is capable of mathematical analysis and therefore good predictions of performance. The fixed wireless systems as described in this paper have shown themselves to be an economical and reliable method of connecting the unconnected throughput the world. However, wireless networks are often thought to be unreliable because of prior experiences with mobile networks, non-enterprise WiFi or other non fixed installations.

This document[1] provides advice to ISP decision makers and engineers about the techniques used to get good long-term performance. That performance depends upon good design, with plans for expansion, sourcing reliable technology and doing essential maintenance. This document points to Cambium processes which can be followed to achieve the network designer's aims.

Radio planning software with accurate models of antenna and radio system is recommended in the design phases of any radio system. Cambium recommends the use of LINKPlanner since it covers nearly all Cambium equipment, including significant detail on each of the equipment option settings. There are other tools which do radio planning, however Cambium has only reviewed and validated LINKPlanner as accurately modeling Cambium radio equipment.

The network components then need to be installed and records taken of the installation. To assist the Operator capture this vital information, Cambium has developed the mobile app cnArcher, these records can be automatically provided to cnMaestro to provide location data and baseline signal levels, so that installation engineers can be confident that the installation is achieving the designed link performance as indicated by Cambium LINKPlanner. Subsequently operations and support engineers can refer to these baselines to determine whether or not there is a significant deterioration in the line of sight or alignment of any given link.

Maintenance is a critical requirement even though the equipment itself has no maintainable components. It is necessary to ensure redundant parts are still working, the installation has not moved, or the line of sight obscured by foliage growing or buildings being built in the transmission path.

This paper outlines the methods which should be used to achieve a high-performing network and ensure a long term success in terms of performance and reliability.

[1] Latest version of this document is published here: https://www.cambiumnetworks.com/resource/ensuring-compliance-with-network-objectives/

2 Radio Planning Software

Wireless is often considered (by those unfamiliar) to be unreliable as a broadband delivery mechanism. Cambium LINKPlanner[2] has been providing the foundation for designing and verifying ultra-reliable networks for over 15 years. Cambium's long-term customers swear by LINKPlanner and have many links which have continued to work for 15 years to the required reliability and performance specifications including networks requiring 99.999% availability.

LINKPlanner is a fundamental starting point for any Cambium Networks design. It ensures that any particular Cambium equipment is modelled properly including the mathematics of MIMO non- or near-line-of-sight paths, a unique feature of LINK-Planner. It also mathematically models the potential rain fade and atmospheric ducting which may be relevant to Point-to-Point links in the backhaul. Cambium also includes hyper accurate software models of antenna lobe patterns allowing for accurate prediction of signal strength for any installation regardless of the subscriber link angle from the bore sight (centre line) of the sector.

LINKPlanner makes it possible to design a network that is reliable. The computer program computes the reliability[3] of wireless links for different throughputs. It also models the total sector throughput. Then some more simple computations involving contention can help with the capacity planning required for the whole sector and also the backhaul. Cambium also includes hyper accurate software models of antenna lobe patterns allowing for accurate prediction of signal strength for any installation regardless of the subscriber link angle from the bore sight (centre line) of the sector.

LINKPlanner makes it possible to design a network that is reliable. The computer program computes the reliability of wireless links for different throughputs. It also models the total sector throughput. Then some more simple computations involving contention can help with capacity planning required for the whole sector and the backhaul. Normally the contention computations required for the first stages of backhaul are particularly simple because the backhaul usually has greater capacity than the access layer. Many operators use (PMP / ePMP[4] sectors) to provide the last mile fixed wireless access layer.

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[2] Cambium Link Planner ISP Radio Planning software: https://www.cambiumnetworks.com/products/software/linkplanner/

[3] Use of correct models are critical to the design of your Wireless Network.
It is possible that other Planning Software can give acceptable results, however this requires additional care and work on the part of the designer / engineer to ensure the correct equipment values are being entered into the models.

[4] Cambium ePMP Access Products: https://www.cambiumnetworks.com/products/epmp/

3 Installation of CPE components

A network will only be as good as its weakest component. It is therefore important that due care and attention to detail is applied when installing the Customer Premises Equipment (CPE). LINKPlanner can provide an installation report for the installer to use to obtain the margins required for each CPE type on a given installation. Cambium CPEs have built in alignment tools to make correct alignment of the CPE with the base station. cnArcher will help with obtaining the correct direction and also upload locations and updated customer details at the end of the visit. Records should be taken of the installation success in terms of signal levels, throughputs achieved, and any other determinant. For this reason, Cambium develped cnArcher[5] which helps obtaining the correct direction for the alignment of CPE and recording the critical network parameters at the time of install and also upload locations and updated customer details at the end of the visit.

cnMaestro[6] can then monitor the RF signal levels at the sector and CPE and can be used to ensure that the links continue to operate to the designed capacity; it also assists by alerting the wireless operator when items require maintenance.

Normally a variety of CPE are available which have different gains and beam widths. These are applied as necessary to achieve cost, range or interference resistance objectives with larger higher gain CPE providing increased range and better resistance to interference. This interference resistance is achieved because the main lobe of the CPE is more focussed in the direction of the base stations, thus simultaneously suppressing reception and emission of interference in all directions outside from the direction of the main antenna lobe.

4 Interference Sources and Mitigation Processes

Interference can affect any communications system. The ability to identify and mitigate interference in both the design and the operation stages of the network is essential for the provision of reliable and performant networks. Radio Frequency Communications are no exception. Cambium Point to MultiPoint networks all have the capability of synchronisation using GPS. This simplifies the design so that the

[5] Cambium cnArcher Installer Radio alignment and KPI recording mobile application for Installation engineers: https://www.cambiumnetworks.com/products/software/cnarcher/

[6] Cambium cnMaestro ISP Management Software: https://www.cambiumnetworks.com/products/software/cnmaestro-management/

number of interference sources is minimised. Examples of interference and their mitigations are:

- The interference between adjacent / co-located radio components or sectors – this type of interference between base stations is eliminated because all base stations are transmitting at the same time and also receiving at the same time synchronised by GPS;
- Four sector base stations can be designed to use only two frequencies since the back side of one sector antenna has a large attenuation (30dB) relative to the front side of the opposite sector – this allows for greater flexibility in channel selection and In higher capacity sites with extra sectors, this concept and approach can be extended either by using high performance antennas, or by adding another frequency as required;
- Where an operator has a base station with 2 sectors pointing in opposite directions, a CPE at short range from one sector can possibly interfere with a sector pointing in the opposite direction when trying to receive from a long-distance CPE. Cambium systems' use of uplink transmit power control ensures by trimming the transmit power, that any CPE at a short range from one sector does not interfere with the receiver on another sector;
- In a network that has a 4-frequency reuse plan Interference can occur from a CPE which can 'see' a more distant base station using the same frequency in the same general direction. The use of high gain CPE antennas with a tighter main lobe or strategic use of natural obstructions by repositioning the CPE behind a building can obscure the other long-distance base station. In the unlikely event the CPE location is flat and devoid of any buildings one can simply switch to using another channel, and
- Interference can occur from sources not owned by the operator. In this case the performance can be improved by the use of MUMIMO (Multi-User Multiple In Multiple Out) reducing the modulation requirement, or by using narrower receive beams (e.g. ePMP2000 Smart antennas), tightly focused antennas such as scalar horn antennas or parabolic dishes.

Another important tool in the RF engineer's interference mitigation armoury is the ability to monitor and subsequently identify interference. Cambium recommends that link KPIs such as latency and bandwidth utilisation be monitored. Link performance degradation can be quickly seen from increases in latency and reduced bandwidth utilisation. Degradation of the link performance can be a symptom of noise on the channel, a misaligned link or link obstruction. Engineers can utilise a spectrum analyser to identify if there is noise by giving the engineer the ability to measure and identify the spectrum use as seen from the installed antenna. All Cambium AP and CPE equipment includes a built in spectrum analyser function that allows the support engineer to analyse the spectrum the device is operating in

and determine if there is interference, (in-terms of type and probability) and allows the engineer to find and then select a channel that is not affected by the detected interference.

Cambium also have developed eDetect which allows support engineers to collect interference data over a period of time from remote subscribers without disconnecting the subscriber. This can be useful for identifying interference and allows the support engineer to identify channels to avoid due to interference.

Cambium equipment also indicate signal to noise ratio on both the sector and the CPE to give an engineer confidence that the RF environment is capable of sustaining high bandwidth and conversely when action is required to move the CPE or sector to a different channel.

5 Other Capacity Options

More modern Cambium systems being released now use MUMIMO to increase capacity For example, in the PMP 450[7] range there is PMP 450m which multiplies the capacity by a maximum of 7 by combining beam forming with multiple transceivers. Preseem, who monitor wireless networks, show this to be *the* most effective base station component in wireless access[8]. In the ePMP range the ePMP3000 range which also uses MUMIMO doubles the capacity of a sector.

These MUMIMO technologies not only increase capacity of sectors but also reduce the Signal to Interference ratios because it becomes less important to ensure the higher modulation modes for every CPE. Cambium will provide further upgrades to base station with newer improved base station models, while still maintaining compatibility with the CPE which operators are presently deploying.

6 Designing for success

When designing a wireless network, it is necessary to consider how the network will need to evolve when the number of subscribers requiring service increases and also when each subscriber requires greater throughput. How can the future requirements be accommodated without being too costly at the early stages? Using a supplier that continues to connect the older CPE equipment is vital in keeping the total cost

[7] Cambium PMP 450 Access Products: https://www.cambiumnetworks.com/products/pmp-450/

[8] Preseem Fixed Wireless Network Report: https://www.preseem.com/fixed-wireless-network-report/

of ownership low. Cambium allows the operator to upgrade sector capacity without replacing already deployed CPEs.

Installing subscribers is the most expensive part of any broadband network. Cambium systems are designed to be capable of increasing capacity without reinstalling subscribers. Over 8 years the same subscriber equipment has been able to be attached to base station components with increased capacity.

Examples of changes that have allowed the same subscriber devices to be used on the PMP 450 system:

- Moving from SISO to MIMO ensuring that the two capabilities were available simultaneously on the same base station doubling the capacity and improving reliability,
- More flexible RF bandwidth from 20 MHz to 7, 15, 20, 30 or 40 MHz,
- Modulation changes from 16 QAM through to 256 QAM doubling capacity,
- Higher processing speeds to enable full use of the radio capability,
- 14×14 MUMIMO to multiply the ultimate capacity by 7.

The newer ePMP product range has also evolved;

- ePMP1000 subscriber devices are still supported,
- ePMP2000 introduced uplink beam steering to reduce interference,
- ePMP3000 introduced 4×4 MUMIMO, doubling the capacity of the original sectors.

Synchronisation through the use of GPS minimises the interference in the network separating upstream from downstream. Synchronisation also enables the use of sectorisation to increase capacity. Typically a network will be designed innitially using 4 sector base stations, possibly without installing all sectors on each station. As the capacity requirement increases, so sub-sectorisation can improve the capacity of the site. In Italy one of our customers has a single site on a mountain covering 180 degrees. This site had 13 sectors at the last count, many including MUMIMO. The capacity of this site is much more than 20 times the original capacity and yet is delivering service to mostly the same subscriber equipment (CPE). This shows Cambium's commitment to co-operating with operators by maintaining backward compatibility and ensures that the network originally designed and implemented can evolve to meet new requirements as subscriber demand and hence operator requirements grow.

As with all broadband networks suppliers and operators, there is a mutual cooperation which ensures that the network originally designed can evolve to new requirements not envisaged in the original deployment.

6.1 Managing Risk Through Design Measures

Final speed and reliability of delivery of broadband is dependent upon the whole network. It is necessary to ensure that backhaul is correctly dimensioned and also to ensure that the backhaul does not have any single point of failure. Generally it is good practise to have backup routes to the network and internet in order to minimise the effect of single point of failures. All single point of failures for multiple customers should be minimised some examples of single point of failures and their risk management are outlined below

- Power to remote sites on top of a hill or a mountain can, in the event of a storm, be down for a number of hours, it is therefore advised that network operators have a power redundancy strategy, such as UPS, and Generator or large capacity DC Battery banks. Because of Cambiums PMP and ePMP radio equipment is DC powered, the operator has a wider choice of power redundancy solutions available to them. Whatever the method the operator should size the UPS / battery solution according to the site load, taking due care to add additional capacity for power redundancy as the site expands.
- Point to point links can be a single point of failure and this can be managed through the use of additional redundant point to point links. Each primary and backup point to point link should be monitored to ensure they are capable of carrying subscriber traffic.

Both the network designer and operator should take a risk management approach to redundancy when designing and operating the network. That is, arterial sites should have more redundancy than sites on the extremities of a network, based on the number of potential subscribers that would be affected by the outage on that site. The operator should be cognisant of the type of subscribers and the SLAs given to the subscribers so that the operator can deliver the expected SLA to each subscriber.

At the access layer Cambium equipment is MIMO so there is inherent redundancy of the RF components (power amplifiers, filters, cables and low noise amplifiers). This also contributes to the reliability of the service provided by Cambium equipment. That said, redundancy does not help if prompt detection of the failed channel through cnMaestro is not harnessed or acted upon.

7 OSI Layers

An operator of any type of network must consider the lower OSI layers. It is important that the operator conserves the finite RF bandwidth available so that it is used only for the required traffic for the subscriber. All networks need a certain

amount of Broadcast / Multicast traffic. That said if the Broadcast / Multicast traffic is not carefully managed it can consume excessive resources and negatively impact subscriber experience. To make the point in a different manner, there is not much point in investing in the best available RF Equipment that gives an operator more bandwidth per MHz of spectrum, only to waste it through inadequate management / implementation of Internetworking best practices. As networks scale network operators need to utilise design measures that limit broadcast domains and hence utilise routers, and other measures such as switch / bridge isolation measures where necessary that would limit / control unwanted broadcast / multicast / flood traffic that would otherwise waste the valuable finite bandwidth resources of the network. As subscribers' capacity demand evolves routers are required at each division of the network to ensure that only the required traffic passes while stopping unintended traffic. It is also important that the network is protected from virus and other unwanted traffic.

7.1 Network Access and Privacy Security measures

Protecting the operator's network from unauthorised access can be best achieved by solid standards-based network access control measures based on best current cryptographic standards. Subscribers should not be able to access the routers and base stations within the operator's network. Cambium CPEs and access points all authenticate clients and access points using AES (Advanced Encryption Standard) CCMP (as is used in WIFi Protected Access version 2 (WPA2)). AES encryption protects the network from unauthorised third-parties gaining access to network resources and simultaneously network customers' individual data in flight is protected from unwanted eavesdropping. The chipsets in Cambium equipment implement this encryption in hardware and do not negatively impact customer performance. All modern RF network operators should implement these security measures as standard practice.

7.2 Network Equipment Management Interface Security Measures

Cambium network equipment has sophisticated network management capabilities. Ensuring that only authorised administrators access the management interfaces of the network equipment in an operators' network is critical to a network's reliability. Operators should utilise encrypted and authenticated management protocols when accessing their equipment. All modern Cambium radio equipment comes with encrypted and authenticated management interfaces such as;

- HTTPS – HTTP over TLS Web configuration
- SSH – Secure Shell

HTTPS / TLS is an encrypted and authenticated web management interface and SSH Secure Shell is an encrypted and authenticated command line terminal /console management system for routers. HTTPS / TLS and SSH protect vital administration user names and passwords from being intercepted by third parties on the network by;

1. Encrypting communications between the administrator's device, and the network equipment under management.
2. Authenticating the network equipment's identity using digital signatures to thwart man-in-the-middle(MITM) attacks.

7.3 ISP Management Interface Security Measures

As with the management of individual network equipment configuration interfaces, the management interfaces of centralised administration systems such as cnMaestro should also be protected in the same manner as the management interfaces of the network devices themselves. cnMaestro management / telemetry traffic between the network equipment and the cnMaestro is protected also by HTTPS – HTTP over TLS. This ensures that onboarding, monitoring and management of equipment through cnMaestro is secured even across third-party networks.

7.4 Network Infrastructure Security

It is recommended that the operator deploy a suitable network architecture to limit what the subscriber (and Third-parties on the Internet) can see when traversing the operators network.

This can be achieved by an appropriate network overlay or tunneled setup. Cambium provides PPPoE clients on all CPEs and provides the cnMaestro C4000 appliances to allow an operator to Tunnel subscriber traffic across its internal network links. This allows the Operator to design a network so that while the end subscribers may be connected and accessible directly from the internet, the Operator's equipment can be isolated.

7.5 Redundancy

No network will be fault free. It is important that attention is given to the areas where traffic from large numbers of subscribers pass can fail over to different routes. Of course it is also important to test that the redundant routes work.

8 Maintenance

All broadband delivery systems that cover a wide area and require maintenance to ensure that performance does not decrease with time. All broadband systems must have monitoring to ensure that no link affecting metrics degrade over time.

8.1 Common Broadband Maintenance

Final speed and reliability of delivery of broadband is dependent upon the whole network. It is necessary to ensure that backhaul is correctly dimensioned both in the initial design and in the operation of the network. As time goes on it is inevitable that additional demand will be placed on the network over time as:

1. The number of subscribers increases, and
2. The demand of each individual subscriber increases

It is therefore crucial that ISPs implement monitoring systems should ensure that capacity of individual sectors and the backhaul to a site are never close to overload. A 20% margin of safety, minimises the possibility of packet drops due to instantaneous bursts of traffic exceeding the link capacity.

8.2 Monitoring

Monitoring any given link KPIs can assist an ISP maintain high quality of service for its customers in line with its intended network design and alert an ISP operator to upgrade network components if / when required.

All links should have the following KPIs monitored

- Latency – round trip time should be low and consistent
- Bandwidth utilization— should be less than 80% of link capacity and sudden unexpected drops in utilisation should be investigated
- Speed and Duplex of the interface should be per installed equipment maximum capability. Sudden drops in speed can indicate a fault in the cabling
- Link uptime
- Frame errors, discards etc.

Optical links should have in addition to the above, the following KPIs monitored:

- Transceiver Received signal strength on each side of the link— should be consistent per design
- Transceiver Transmit power on each side of the link

Radio links should have in addition to the above the following KPIs monitored:

- Radio Received signal strength on each side of the link— should be consistent per design
- Signal to noise Ratio SNR or noise floor – the signal to noise ratio should be as high as possible, while the noise floor should be as low as possible.

Any deviation of these KPIs would prompt the ISP operator to implement corrective maintenance.

8.3 Radio Maintenance

Foliage, vermin, mechanical damage and degradation due to water ingress are a threat to reliability common to all broadband distribution systems. Wireless broadband is no exception. Cambium developed cnMaestro to assist operators monitor their radio systems to help mitigate these threats. The signal strength and SNR of all links is measured and monitored so as to enable early detection of a degradation of the signal strength and / or SNR. The operator can intervene and where appropriate the faulty components can be replaced avoid unscheduled outages.

One external threat to radio link reliability is, signal reduction due to growth of foliage in the path, or the summer / winter effect of trees. This can be managed through training the Install engineers to identify and highlight such risks to both the operator and the subscriber. This foliage risk can easily be monitored, and a maintenance program initiated when values are outside specification.

Links may be classified as line of sight, through trees or around buildings. While line of sight links are the most reliable, LINKPlanner predicts the fading characteristics of each type assigning a reliability to each throughput. Each of these have their own characteristics of instantaneous signal reduction or seasonal signal reduction. They can then be monitored against such classification to enable preventative maintenance to occur on links which are outside the expected characteristics. Since the systems are mostly above ground vermin is not normally a problem except in open cabinets.

cnMaestro can also be used to monitor the spare capacity in the network, particularly the PMP capacity. It also monitors the capacity being used in the backhaul network of point to point links.

9 Conclusions

This document shows through the use of a combination LINKPlanner, LINKPlanner installation report, frequency selection, judicious choice of antennae installation

quality control, monitoring and operation of Cambium equipment, an ISP can use spectrum optimally to reliably achieve the performance of the equipment as stated in their respective datasheets.

Cambium supports it's customers not only through the design and manufacture of best in class RF equipment. Cambium also equips operators with accurate design tools to select the correct antenna and radio equipment for a given task. Operators who use tools like cnArcher and Cambium equipment can be confident of achieving optimal performance of their networks from day one of installation. Combining the radio planning and installation management software with the monitoring and management solutions such as cnMaestro, reliable performance can be maintained throughout the service life of the network equipment.

In Italy wireless technologies have been shown to consistently outperform wireline technologies on a national basis[9]. By following the best practices outlined in this document an ISP can consistently provide high-speed reliable broadband and repeat the successes enjoyed by many ISPs worldwide who have chosen Cambium as their equipment provider.

[9] Netflix Speed Index: https://ispspeedindex.netflix.com/country/italy/

10 References

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Cambium Link Planner ISP Radio Planning software: https://www.cambiumnetworks.com/products/software/linkplanner/
Smokeping Latency graphing software: https://oss.oetiker.ch/smokeping/
MRTG SNMP graphing software: https://oss.oetiker.ch/mrtg/

11 Glossary

AES	Advanced Encryption Standard
CCMP	Counter Mode Cipher Block Chaining Message Authentication Code Protocol
CPE	Customer Premises Equipment
cnArcher	A Smart Phone Application which assist installs
cnMaestro	A network management application which assists monitoring and debugging faults, radio or network
eDetect	A system within ePMP to help identify interference
ePMP	A Point to Multi-point system based upon 802.11 which is optimised for long range broadband access
ePMP1000	A version of the ePMP Access Points
ePMP2000	A version of the ePMP Access Points with uplink narrow beams for interference reduction
ePMP3000	A version of the ePMP Access Points with 4x4 MUMIMO
GPS	Global Positioning System, which provides accurate time synchronisation
HTTP	Hypertext Transfer Protocol
ISP	Internet Service Provider
KPI	Key Performance Indicator
LINKPlanner	A computer application which enables accurate prediction of performance for Cambium equipment
MIMO	Multiple In Multiple Out, a radio transmission technology which doubles the normal spectral efficiency (SISO) and improves reliability
MUMIMO	Multi-User MIMO, a radio technology which multiplies the throughput by 3-10 times relative to MIMO
OSI	Open Standards Interconnection model
PMP450	A Cambium Proprietary Point to Multi-point System
PMP450m	A Cambium Proprietary Point to Multi-point System with 14x14 MUMIMO
PPPoE	Point to Point Protocol over Ethernet
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
SISO	Single In Single Out, a basic radio transmission technology using a single polarisation
SNR	Signal to Noise Ratio
SSH	Secure Shell
TLS	Transport Layer Security
WPA2	WIFi Protected Access version 2