Rural broadband design and operational challenges

Capstone Project

Presented by

Aaron Pavez Bravo

University of Alberta

Master of Science in Internetworking

Edmonton, Canada

Supervisor

Juned Noonari

April 2021

Abstract

In this project, we will take a look at a Broadband network various topologies and delivery mechanisms from a practical perspective, details how different layer 1-3 components form a real-world broadband network, operational challenges for the broadband access network in remote areas, and technical comparative cases from the functional perspective and some estimated cost of some options.

The need for higher speeds and reliable connections has increased in the last few years. New technologies like IoT are connected to the same networks (IoT can be easily 1000 devices), AI, new security protocols, datacenter backups, cloud backups, 4k video, multiple people in the same household using zoom/Netflix, keep pushing for more and more speed which is met in the metropolitan centers but not in small towns or even some localities just outside the metro ring.

The Internet is a necessity and not a commodity anymore, so getting fiber everywhere must be one of the most critical tasks for the ISPs and government.

This project will focus on setting up a small ISP and the hardware/software needed to do it. I will also talk about the other things involved, like laying down the fiber, digging, permits, red tape, funding, and other related things to the ISP setting.

Project layout

This capstone project has six seven. Some of them will be shared (chapters one to four, meaning that each technology will have its introduction, research), while chapters five and six will be for the project.

Chapter I: Introduction

There will be one significant introduction of the project as a whole and new introductions on each technology chapter to introduce the components and how the technology works, the primary hardware used on each one, and the technology as a whole.
I will also talk about the old broadband technology and how it has changed and the future of broadband, discussing the new technology being brewed.

Chapter II: Technology Analysis

Research the technology and what's used on each one from the hardware perspective. The Methodology will be based on the description of the technology and why would you choose to install it, followed by a map of where you will find the fiber optic installation in the selected city (near Edmonton in this case), followed by a whole section with advantages/disadvantages and a how one would install that technology.

Chapter III: Prototype rural broadband solutions

In this chapter, you will see each technology analysis at work
I will show what hardware is needed for each technology to work (ex: switches, routers, OLT, ONT, the connectors, fiber to be used).
I will demonstrate with charts and network drawings the interconnections between the hardware.
The drawings will show how everything is connected, the hardware needed/used from the big ISP leased fiber, dark fiber, to the user home.
I will pick one major vendor (like Calix) and use one of the equipments they sell to create the fiber network and show how it works with diagrams.

Chapter IV: Implement network diagram simulation and monitoring

This chapter will demonstrate what I will show in chapter 3, created/implemented on cisco packet tracer, and discuss the other options available (gns3, EVE-NG).
I will also show what software we can use to monitor the network for errors and how to start a network troubleshooting/monitoring. Half of any installation is the troubleshooting and monitoring.

Chapter V: Discussion of Results

I will talk about my findings if there is something new to improve/make it easier to create/install these networks and provide hindsight on the whole project.

Chapter VI: Conclusions

This section will give a brief conclusion on the project, and everything learned, a brief explanation of what technology our efforts should be focused on.

Chapter VII: References

Table of contents

CHAPTER I Introduction

I 1.- Rural Broadband.

Rural broadband in Canada faces a national connectivity gap, slower internet access, and significantly less reliable than those in urban centers. Canada's Connectivity Strategy has set a speed goal of 50/10. In 2017 only 37% of rural households had access to 50/10 Mbps, compared with 97% of urban homes.

The problem here is almost similar in other parts of the world. Low internet bandwidth is shared between too many people with data caps and data throttle, which can be offset effortlessly in urban areas with more fiber connections. Still, for rural areas it is not quickly done, inexpensively.

Fiber is the king between speed/price in urban areas, while in rural towns, the cost to install and get a single cable between point A and B can be extremely high (10 to 12k per 1,6 km-1 mile, and that is only for the labor/workforce of digging trenches or setting the cable up on the poles)

This is the highest cost when installing fiber cable (which is not the cable itself or the equipment).

One of the new technologies that are coming strong is 5G. The most significant benefits of having a 5G service are the dramatic increase in bandwidth, low latency, and less tower congestion. It also promises download speeds of 20gbps. I will go through that technology and how a mix of fiber and 5G can get high-speed rural broadband.

I will also talk about older technology that can still be used to get internet to rural areas like WISP or copper, which are good options which we can use to get rural internet (I will discuss pros/cons and speeds)

One of the outcomes of this project is to give a detailed comparison of the technologies available and see if they reach the desired speed of 50/10 (or more to cover future necessities)

While most of the project will talk about technology, I also want to discuss how important it is to get internet everywhere, get the big ISP involvement and government funding, and why I care that rural broadband is one of the most critical steps to get people out of the big cities.

I 2.- The Old “Broadband” Technology.

In the beginning, we had modems. The first ones to appear could send data at the low speed of 100/300 bps (bits per second), while now we have speeds of 1000 Gbps(gigabits per second).
The evolution of broadband (which means using multiple channels, wider bandwidth, higher throughput over a single medium) has taken us to get the information faster and make decisions equally quicker. Also, the official FCC broadband definition is a minimum of 25 Mbps download and 3 Mbps upload (this definition can change and have changed since 2003).
There were many changes, protocols arose and died, some are still used now(TCP/IP), and some others reappeared with a different skin, but their internal shape was the same (that's why it is essential to study them (like the old ALOHAnet).
It's cardinal to specify that broadband has changed and shaped telecommunications, computer networks, and our lives. Without those changes, we would not have what we have today, a faster and reliable connection to the whole world.
With faster connections, we can send information to satellites, get pictures from the earth from those identical satellites, connect to the space station, and so much more. We can now stream movies from anyplace to anywhere and communicate with office branches faster than using mail.
The first consumer-grade equipment we saw was known as "modems" that beeped and hissed, they were slow, and you couldn't use the telephone while connected to the internet. In 1996 we got the 56k modem, and many of us lived and breathed with them.
However, those were not broadband. Those were the dial-up days since you could only use one service at a time.
Broadband came around in early 2000 when cable companies started to offer internet/tv/phone under the same line with new and faster speeds.
After that came Mobile Broadband. One of the first wireless internets we had was available in 1991 and was called 2G.
Moreover, we cannot forget about the king, the Optic Fiber. Discovered around 1920, it was first deployed in Turin in 1977.
Since then, Fiber has been improved, resulting in the fastest medium known to man so far.

I 3.- The future of Broadband.

What can we expect from the future broadband? Higher speeds and reliability. Now it is normal to see fiber connections (FTTH) of 1Gbps. Will we get 10Gbps in the future? Of course, we will. It is just a matter of time and a big task for the ISPs to improve, upgrade, reform, enhance and apply new techniques and technology to the fiber network already in place.
While most of the new fiber networks are PON, the only way we can achieve higher than 300 Mbps in the future is to change from PON to AON. PON shares the medium while AON connects one fiber to one customer.
Not everyone has access to 1Gbps, that is still a work in progress, but the technology keeps improving like the hollow fiber ,Twisted Light Spirals, 400GB transceivers, Fiber under the sea.
One of the big projects is to have more calves under the sea and have more countries connected to that backhaul. There is 5G too. Mobile broadband has come a long way, promising speeds up to 20Gbps, that will shadow fiber speeds. But the reality is different.

5G speed: 5G vs. 4G download speeds compared

	Average 5G download speed	4G
AT&T	65.2 Mbps	37.1 Mbps
Sprint	59.2 Mbps	32.5 Mbps
T-Mobile	69.5 Mbps	36.3 Mbps
Verizon	792.5 Mbps	53.3 Mbps

Taken from https://www.tomsguide.com/features/5g-vs-4g

There is still room for improvement; 5G is still relatively young and new.
From my perspective, where the future truly lies and where to put effort is in interconnecting everybody to FTTH with speeds higher than 1Gbps.
Single fiber mode to every home must be not only a dream but a fundamental need.
The pandemic we had at the beginning of 2019 tested the ISP and all the networks worldwide, and now more than ever-higher speeds at home is necessary. Working from home changed from being a luxury to a necessity.
The technologies will keep improving, and fiber will continue to be the king. Fixed wireless still has a long way to go (mainly because the spectrum is licensed and expensive). However, improvements (new antennas, protocols) keep the fixed wireless on the race and a valid (and sometimes) option for many rural towns in the world.

CHAPTER II Technology Analysis

II 1.- Introduction to Fiber

Fiber is by far the technology that connects the world. The core of the technology is light, and there is nothing faster than light in this universe.

By the end of this chapter, we will know about the best technology available in fiber optics hardware (the expensive fiber but with room for growth) and the best cheap hardware you can get while focusing on the essential, getting information from A to B as cheap/good way possible.

There has consistently been an argument about what is superior, copper, fiber, or wireless. However, all of those depend on the communication media and end-user market. Choosing one over the other only depends on what’s available and the user location, making the network designers' decision easier than before.

For longer hauls, there is SM(single mode). Nothing can beat it, and we can say that bandwidth in SM is unlimited. For shorter connections, multimode is used because the transceivers are less expensive in comparison to SM transceivers.

If we wanted to connect two buildings, fiber would be the obvious choice, we could use an SM cable between two switches/routers easily, but it becomes problematic when there is a road in between. Done with two antennas between buildings, in which case you will need a line of sight or radio optical wireless network to connect them. It is more cost-effective than running the fiber through the streets (getting the permits to do that would be far prohibitive) like the unlicensed or lightly licensed millimeter wave (mmWave) frequencies, such as the 60 GHz V-Band.

For shorter links, there is multimode fiber, which is less expensive because it uses cheaper LEDS or VCSEL sources in the transmitters, making the electronics way more affordable. Sometimes SM and MM are used simultaneously (hybrid cables) or with copper, ethernet. There are many choices that the network designer must know.

On the other hand, cabling premises with other technologies (copper, ethernet, coaxial) is still a good choice. Many buildings still have copper/coaxial cables running to the user desktops.

There is also fiber to the desktop(FTTD). While this looks like a fantastic idea, it is only possible on newer buildings or places where managing GBs of data is necessary (image rendering, video rendering, graphics designers, power users). 1Gb and 10Gb Ethernet network is cheaper than fiber and still a valid option.

However, that is not always true because fiber can negate rooms full of switches (used in ethernet/copper) and have a smaller server room and air conditioning footprint. Here the network designer's job is to understand the technology of cabling and the technology of communications and always be informed on the latest technology applications.

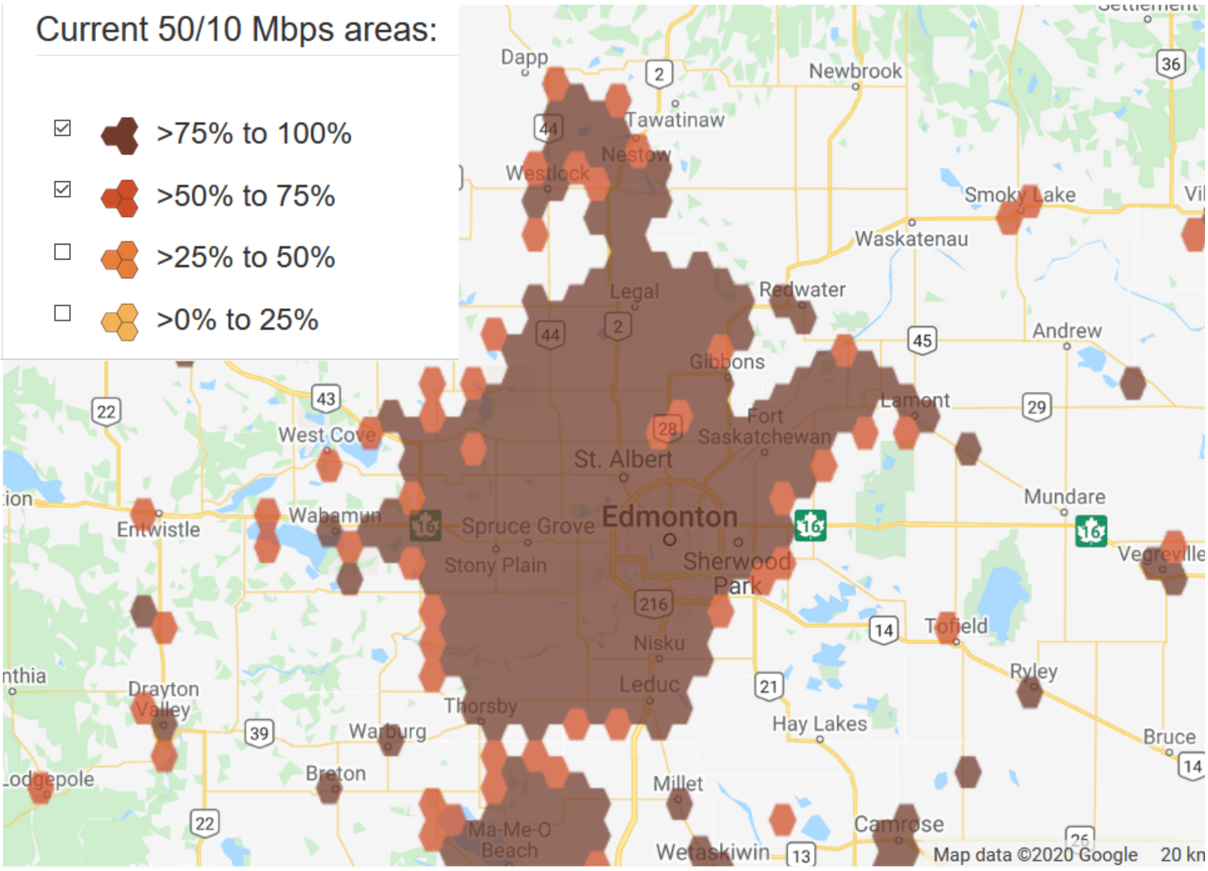
II 2.- Why choose Fiber Optic?

Why do I want to install fiber? That's the first question anyone trying to build an ISP must ask themselves. Being an ISP is not as lucrative as it looks and the only way to make money with it is to get as many people as possible under my service and make them as happy as I can.
There is one thing that we always need to remember, as a small ISP, you will be connecting the "last mile," which is the fiber to the user home or the nearest premise (ex: curb)
Why do we want FTTH? (Fiber to the home) because the last mile most probably is already there, BUT it's made out of coaxial cable, telephone lines, or wireless, which is not bad, but they will not give you the necessary speed to meet the 50/10 speed set up by the Canadian Radio-television and Telecommunications Commission.
Also, fiber has lower latency and higher download speeds (with a good plan and funding, we can even get 1gbps to rural homes).
One thing that it is usually done is to use telephone lines or coaxial cable already in place to help us to lower costs and create a mix of technologies that can provide us speeds of 6gbps using HFC(Hybrid fiber-coaxial), 10gbps with Ethernet, or even wireless using 5G or other radio technology. We can mix those technologies, but they all need good planning.
Setting up Ethernet as the last mile to the user is a good option, too, giving us 1 Gbps or exceeding the customer's necessities.
One thing I would like to mention is that the internet is not a commodity! It's a basic necessity.
Part of this project will always push that even in low population density areas, we must haul fiber, which will help boost the economy and bring younger people to outlying areas.

II 3.- Fiber optic map

Checking where to install is also part of the big plan because we need customers to make a profit, pay for network engineers, backups, fixing cables and hardware, and pay salaries.
One of the best free tools that we can use is the National Broadband Internet Service Availability Map.

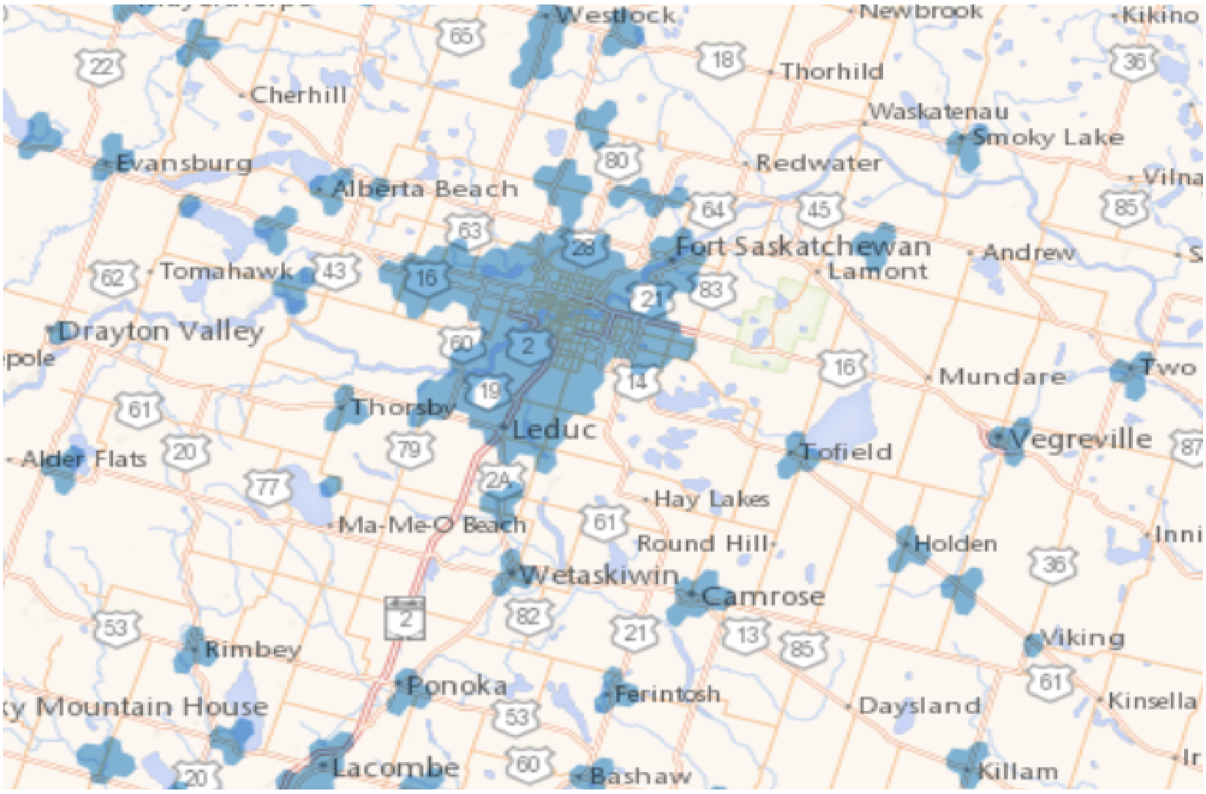
A quick look for 50/10 areas will show this:



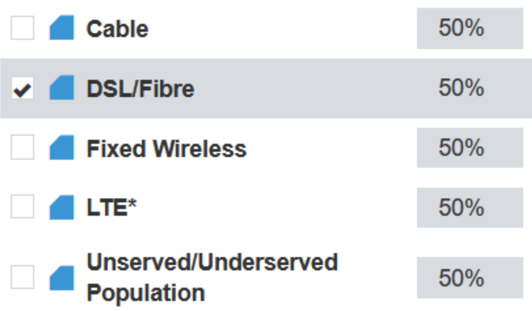
The color brown shows the areas with 50/10 coverage over 75%
The color red indicates the areas with 50/10 coverage from 50% to 70%

As we can see, some towns can be an excellent spot to set up an ISP and a quick search, for example, Andrew and Waskatenau: both locations have a low habitant count, less than 300 people (that is why the map does not show under brown/red) but it shows under yellow which are speeds of 5/1)
This is a good exercise where you can know in an instant where fiber is needed.
However, getting to those towns with low population density is a challenge. Hauling fiber to those places will not be easy, and you will not make much money, but it is imperative to do so. The government and Big ISPs should lend a helping hand to achieve this.

There is also Broadband Internet Coverage that can be used



In this map, we can select between the following options.



As we see, there is a straightforward overview of where fiber is present in Edmonton and nearby towns.

II 4.- Fiber in depth

There are many things needed for each technology to get to fruition. Fiber needs a lot of digging, planning. They can be set up in the big ISP poles already on the roads or even on the high voltage towers.
We can do the planning (using google earth) to check the fiber distance, the land I need to cross, whom I need to talk with to cross that land and how much I need to pay. Google earth can quickly help us to overcome the more expensive paid options out there.
However, the bulk of laying down fiber will be done on the field, walking the miles, and checking the terrain. That is one of the most critical parts of fiber planning.

II 4.1.- Fiber Advantages and disadvantages chart

PROS	CONS
Great Gbps speed/capacity	it becomes more expensive at a further distance(15-20k per km)
Immunity to interferences	The outdoor cable is expensive(armored cable is a must to avoid rodents breaking the internal fiber)
Fiber cannot be tapped.	In some countries, you need a special license to install fiber
Great km/speed (40km) varies per fiber cable mode	Special equipment needed to splice
Scalability (spare fibers)	More equipment needed(can be offset with good planning)
Shielded and reinforced cable (More expensive)	More fragile than Ethernet/Copper cables
Immediate costs (Specialist, skilled labor)	Long Term savings (the ability to put more fiber strands per KM can offset the immediate costs in the long run)
Dark fiber	Higher costs since they are owned by the big ISPs or energy power companies
A single core fiber can be divided into multiple channels with DWDM	Far more complicated Tx/Rx

II 4.2.- Fiber components speed chart

Fiber Type	Core Diameter	1 Gb Ethernet	10 Gb Ethernet	40 Gb Ethernet	100 Gb Ethernet
OM1 Multimode	62.5/125	275 Meters	33 Meters	Not Supported	Not Supported
OM2 Multimode	50/125	550 Meters	82 Meters	Not Supported	Not Supported
OM3 Multimode	50/125	550 Meters	300 Meters	100 Meters	100 Meters
OM4 Multimode	50/125	550 Meters	400 Meters	150 Meters	150 Meters
OM5 Multimode	50/125	550 Meters	400 Meters	150 Meters	150 Meters
Singlemode	9/125	Up to 2 Km using PSM4 transceiver			

Taken from https://www.cablexpress.com/blog/tips-for-determining-transceiver-and-fiber-cable-selection/

This chart shows the different OM cables and their supported speeds and distances. One thing to remember is that OM cables are used for short hauls. OM cables will not ever beat the single-mode speeds and capabilities.
Today the only OMx cables used are OM3 to OM5, OM 1 and OM 2 are discontinued.

II 4.3.- Multimode and single mode max distance

	Type	Core / Cladding (um)	Fast Ethernet 100Mb	Gigabit GbE	10Gigabit 10GbE	40Gigabit 40GbE	100Gigabit 100GbE	40G SWDM4	100G SWDM4
Multimode	OM1	62.5 / 125	2km	275m	33m	-	-	-	-
	OM2	50 / 125	2km	550m	82m	-	-	-	-
	OM3	50 / 125	2km	800m	300m	100m	100m	240m	75m
	OM4	50 / 125	2km	1100m	400m	150m	150m	350m	100m
	OM5	50 / 125	2km	1100m	400m	150m	150m	440m	150m
Singlemode	OS1/OS2	9 / 125	40km	100km	40km	40km	40km	-	-

Taken from https://www.universalnetworks.co.uk/faq/what-are-achievable-distances-of-singlemode-vs-multimode-fibre/

This chart shows the maximum distance each cable can achieve. As seen previously, the distance OM cables can attain are shorter than single-mode (but some proprietary cables/transceivers, according to some vendors, can increase them)
Mind you that some proprietary cables and transceivers might show different speeds/distances, so it is always important to check the white sheet of every cable you buy.

II 5.- Optical Network topologies

II 5.1.- AON vs. PON

In the quest to install fiber, there are two optical technologies we need to choose from, Active optical Network or Passive Optical Network.
Both of them offer high bandwidth and speed and advantages and disadvantages, but they accomplish different ends.

II 5.2.- AON

The Active Optical Network is PTP (Point-To-Point), meaning that each user has its dedicated fiber from the ISP (from the central office or the cabinet or nearer premises) directly to the user home (FTTH fiber to the home) and the bandwidth from that fiber is only for that user.
In an AON, electrical equipment is involved, such as routers, power supplies, switches, to manage signal distribution and route data to the right place.
With AON, you will also need housing for the equipment and cooling because the active equipment for managing signal transmission creates heat. This heat must be dissipated, which leads to the electricity costs increment.
AON is an expensive option, but it has its uses and different advantages and disadvantages than PON.

Also, in AON, each signal that leaves the Central Office is sent directly to the intended customer, and the switching cabinets can handle 1000 customers but is typically in the range of 400-500 (leaving enough space for monitoring, backhaul, and other ISP own services)
Usually, the network topology seen on the field is the Star topology which incorporates the customers' installations and a central office into an extensive switched ethernet network.
The switching cabinets can also perform layer 2/3 switching and routing. That way, the central office is the sole responsible for the layer three routings.

II 5.3.- PON

The Passive Optical Network's big difference with AON is that PON does not use any active electrically powered equipment. PON uses optic splitters to direct traffic on different wavelengths, and PONs are generally configured in tree or bus structures.
The splitters are capable of separating and collecting optical signals. That way, you only need electrical equipment at the source and the receiving end.
PON networks can serve up to 128 customers per fiber strand.
PON is also known as used as the Last Mile between the ISP and the customer.

In PON, each customer also receives signals intended for someone else, so encryption is needed and must be enforced. They can be combined at the cabinet for upstream signals, typically using Time Division Multiple Access (TDMA). The PON

also uses wavelength division multiplexing (WDM) to carry both upstream and downstream traffic, ex:
The 10 Gigabit PON wavelengths (1577 nm down / 1270 nm up) differ from GPON and EPON (1490 nm down /1310 nm up), allowing it to coexist on the same fiber with either of the Gigabit PONs.
PON also differs from AON in how the downstream data and upstream data flow.
Downstream is CM (Continuous Mode), meaning that the downstream path always has data on it.
Moreover, the upstream has to be done in BM (Burst More). Not doing so will cause ONUs to converge (with attenuation) and overlapping. To solve this, burst mode (BM) transmission is adopted for an upstream channel with time division (it will only transmit in its allocated time and slot)

PON System Specification Summary

	BPON	GPON	EPON
Standard	ITU-T G.983	ITU-T G.984	IEEE 802.3ah (1 Gb/s) IEEE 802.3av (10Gb/s)
Downstream Bitrate	155, 622 Mb/s, 1.2 Gb/s	155, 622 Mb/s, 1.2, 2.5 Gb/s	1.25 Gb/s, 10.3 Gb/s
Upstream Bitrate	155, 622 Mb/s	155, 622 Mb/s, 1.2, 2.5 Gb/s	1.25 Gb/s, 1.25 or 10.3 Gb/s
Downstream Wavelength	1490, 1550	1490	1490, 1550
Upstream Wavelength	1310	1310	1310
Protocol	ATM	Ethernet over ATM/IP or TDM	Ethernet
Video	RF at 1550 or IP at 1490	RF at 1550 or IP at 1490	IP Video
Max PON Splits	32	64	16
Transmitter Power*		OLT: ~0 to +6 dBm, ONT: ~ -4 to +2 dBm	
Power Budget*	~13dB (min) to 28dB (max) w/32 split	~13dB (min) to 28dB (max) w/32 split	
Coverage	<20 km	<60 km	<20 km

* There are several versions of each type that vary so these are typical ranges.

Taken from https://www.thefoa.org/tech/ref/appln/FTTH-PON.html

Upgrade PON System Specification Summary

	NG-PON2	XG-PON	XGS-PON
Standard	ITU-T G.989	ITU-T G.987	ITU-T G.9807
Downstream/Upstream Bitrate	10/2.5, 10/10, 2.5/2.5 Gb/s	10/2.5, 10/10 Gb/s	10/10 Gb/s
Downstream Wavelength	~1596-1603 nm	~1575-1580	Either same as GPON if no current GPON or XG-PON for overlay
Upstream Wavelength	~1524-1544	~1260-1280	Either same as GPON if no current GPON or XG-PON for overlay
Max PON Splits	64,128, 256	64,128, 256	64, 128, 256+
Power Budget*	14-29 dB (min - max) up to 20-35 dB (min - max) in 4 versions with up to 15 dB differential optical path loss	14-29 dB (min - max) up to 20-35 dB (min - max) in 4 versions with up to 20 dB differential optical path loss	13-28 dB (min - max) up to 20-35 dB (min - max) in 6 versions with up to 20 or 40 dB differential optical path loss in 2 versions
Coverage	20 and 40 km versions	60 km	60 km

Taken from https://www.thefoa.org/tech/ref/appln/FTTH-PON.html

Current PON Standards

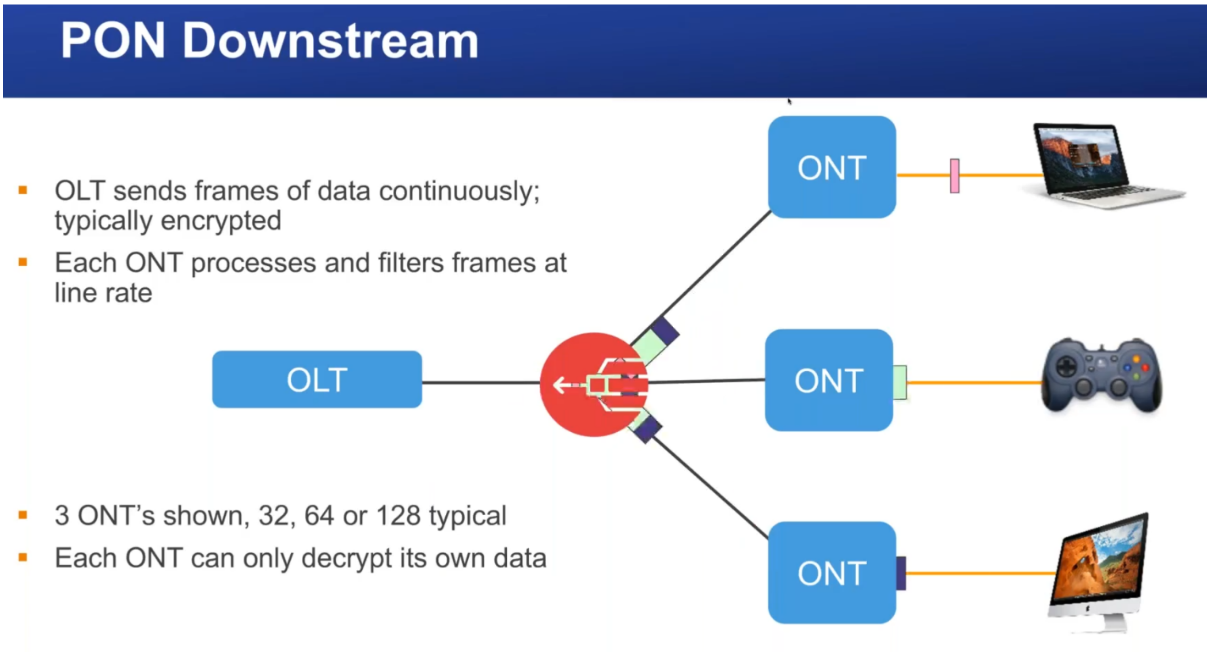
Standard	Nomenclature	Bandwidth Options	Wavelengths	Primary Focus
EPON	EPON	1.25G Down 1.25G Up	1490nm Down 1300nm Up	Residential services
GPON	GPON	2.5G Down 1.24G Up	1490nm Down 1300nm Up	Residential Services
10G EPON (IEEE 802.3av)	Next-gen EPON	10G Down 10G or 1G Up	1577nm Down 1270nm Up	10/10 MDU and Business
XG-PON (ITU G.987)	10G GPON	10G Down 2.5G Up	1577nm Down 1270nm Up	Residential
XGS-PON (ITU G.9807.1)	10G GPON	10G Down 10G Up	1577nm Down 1270nm Up	Residential/Business/MDU
NG-PON2 (ITU G.989)	NG-PON2	4 to 8 X 10G TDM Down 4 to 8 X 2.5G or 10G TDM Up 8 P2P Up and Down @100GHz	1596-1603nm 1532-1539nm 1610-1625nm	Residential/Business/MDU 5G Transport

Future Standards

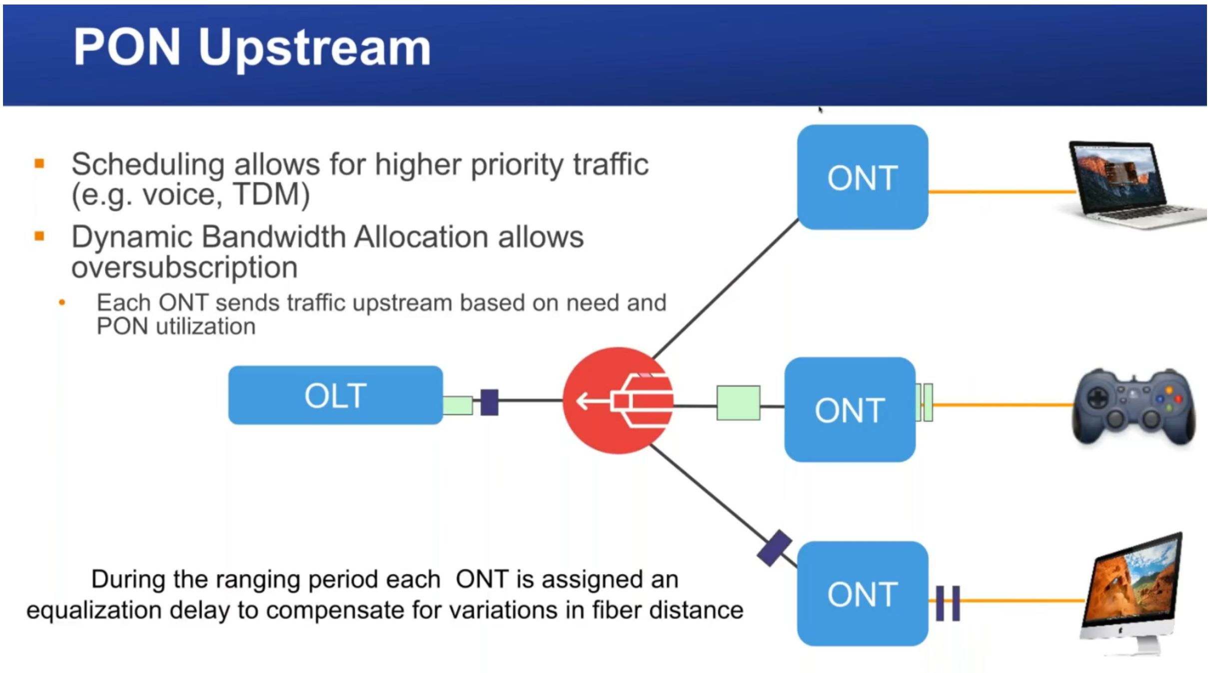
Standard	Nomenclature	Bandwidth	Wavelengths	Primary Focus
25G/50G-EPON (IEEE 802.3ca)	High Speed EPON	2 x 25G Down 2 x 10G Up 2 x 25G Up	High O-band Down Low O-Band Up	Business services/MDU 5G Transport
50G-PON (G.hsp.50G)	High Speed GPON	50G Down 10G/25G/50G Up	High O-band Down Low O-Band Up	Business Services/MDU 5G Transport
100G/200G-PON (G.hsp.TWDM)	High Speed GPON	2 to 4* x 50G Down 2 to 4* x 10G/25G/50G Up	High O-band Down* Low O-Band Up*	Business Services/MDU 5G Transport
IEEE 802.3cs (Super-PON)	Long Reach (50km) – Large Split (1024)	16 x 10G Down 16 x 2.5G/10G Up	L-Band Down C-Band Up (like NG-PON2)	Suited for Greenfield Residential/5G Transport
ITU G.9807.3 (Super-PON)	Long Reach (50km) – Large Split (1024)	16 x 10G Down 16 x 2.5G/10G Up	L-Band Down C-Band Up (like NG-PON2)	Suited for Greenfield Residential/5G Transport
WDM-PON*	Point to Point WDM	16* x 10G/25G PtP Down/Up Symmetrical	?	5G Fronthaul (eCPRI)

Taken from https://www.calix.com/solutions/technologies/10g-pon-solutions.html

This picture shows the current standard for the PONs networks.
20G, 50G, and 100G are still under development and progress is made every day.
The G.9807.3 is proprietary from Google.



Taken from https://www.calix.com/solutions/technologies/10g-pon-solutions.html



Taken from https://www.calix.com/solutions/technologies/10g-pon-solutions.html

This picture shows a summary of how the frames in a PON network works.

II 5.4.- AON/PON advantages and disadvantages chart

PROS	CONS
AON connects one strand to one user	PON is more efficient per user/strand
AON is less reliable, needs at least one switch aggregator for every 48 subscribers	PON needs less electrical equipment
AON links can be managed	PON passive splitters cannot be managed
AON has the whole strand bandwidth	PON shares the strand bandwidth
AON equipment gets expensive	PON less equipment need and passive splitting costs less
AON covers more distance(90 KM)	PON distance is way less (20 KM)
AON failing has less impact (only one user is impacted)	PON failing will impact 32 customers on the low end.
AON higher bandwidth allocation can use the total fiber bandwidth on one customer.	PON has to share the bandwidth; thus, it won't ever serve 1Gbps to 32 customers. To achieve that will need to serve fewer customers per strand.
AON is not prone to eavesdropping	PON shared medium makes it susceptible to hear the other customer.

II 5.5.- GPON VS EPON (XGPON AND GEPON)

These two are the most popular versions of PONs used for short-haul networks for Internet access, VoIP, digital TV, Radiofrequency over glass (RFoG), DOCSIS over fiber, and some more.
The primary differences between them are the protocols used for downstream/upstream and their speed.
GPON uses two different types of encapsulation. It uses GPON Encapsulation Mode, GEM, to provide a frame-oriented service. It also supports ATM encapsulation when working in an ATM network rather than Ethernet (which is not necessary on this project since SONET or SDH deprecates ATM)
EPON does not add any encapsulation but treats everything as Ethernet data which solves many programming issues since it is Ethernet!

II 5.5.1.- 10G EPON (10-Gbit/s Ethernet 802.3av):

The actual Bandwidth is 10.3125 Gbit/s, one is symmetric (10 Gbps uplink and downlink rates), and the other is asymmetric (10 Gbps downlink and 1 Gbps uplink).
1:128 split ratio, in comparison with EPON & GPON, the splitting capability is more robust and can handle extra users

II 5.5.2.-10G GPON (also called XGPON):

XG-PON uses Asymmetric for upstream and downstream (upstream 2.5Gbps, downstream 10Gbps).
1:128 split ratio can extend the maximum distance of XGPON to 40KM.
Let us consider that 10 Gbit/s EPON uses different optical wavelengths (downstream 1575nm-1580nm, upstream 1260nm-1280nm), so 10 Gbit/s EPON 1Gbit/s EPON can coexist on the same fiber. However, for them to work together, we use wavelength multiplexing. So a 10G EPON splitter can be connected to the ONU of EPON.

II 5.5.3.- Pros and Cons of EPON and GPON

There is a clear difference between EPON and GPON at layer 2, but there are other differences like Bandwidth, distance, efficiency, subscriber costs, and management.

II 5.5.3.1.- Bandwidth

The Bandwidth offered by the protocols are :
GPON allows II.e. 2.5gbits/s of Bandwidth (or 1.25gbit) downstream and 1.25 upstream to be shared by 64 customers or about 35 Mbits/sec per customer and upstream expandable from 155 Mbit/s to 2.5 Gbit/s.
GPON split ratios are 1:32, 1:64, and 1:128.
EPON allows 1gbits/sec symmetrical bandwidth split between 32 customers, or about 28 Mbits/sec per customer, of that 1gbit, is for customers and 250 for encoding.
EPON split ratio: 1:32
A design that allows 32x 1Gig services on a 2.5G GPON would result in an effective 12:8:1 oversubscription (32x 1G / 2.5G).
Network monitoring of the GPON utilization is a critical part of the ISP job, which can be done at the OLT port. With the proper monitoring software sending utilization notifications, we know how our network behaves and when it is necessary to increase capacity.
PON optical attenuation is (15 ~ 18dB loss). A larger split ratio will reduce the transmission distance.
When GPON split ratio is 1:16, the maximum distance supported is 20KM; When the optical split ratio is 1:32, the max length is 10KM.

II 5.5.4.- 10G EPON (10-Gbit/s Ethernet 802.3av)

10 Gbit/s EPON can operate symmetrically at 10 Gbit/s data rate in both directions and asymmetric, operating at 10 Gbit/s in the downstream (provider to a customer) direction and 1 Gbit/s in the upstream direction.

II 5.5.5.- 10G GPON (also called XGPON)

XG-PON is the 10GB version of GPON, which operates at 10 Gbit/s downstream and 2.5 Gbit/s upstream speed and uses multiplexing techniques to prevent data frames from interfering with one another.

Symmetric 10G-PON is also proposed as XG-PON2 with 10 Gbit/s upstream but would require more expensive burst-mode lasers and ONTs.

II 5.5.5.1.- Distance

On either protocol, the limitation comes from the optical DBs loss and budget.

In GPON, the maximum logical reach is 60 km, but The maximum physical distance between the ONU/ONT and the OLT, 20 KM, is the same for EPON.

The next generation of GPON, called 10G GPON or XG-PON, offers symmetric 10 Gb/second upload and download speeds.

GPON supports up to 128 ONUs. With EPON, there is no limit on the number of ONUs.

II 5.5.5.2.- CATV Support

Both protocols support (CATV) overlay. EPON uses the 1490 wavelength for downstream and 1310 for upstream, leaving the 1550nm for a CATV overlay.

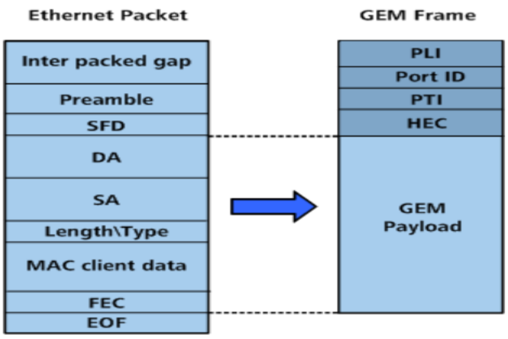
II 5.5.5.3.- Encryption

Since the DS data is broadcast to all ONUs attached to the PON, a malicious user can reprogram its ONU to listen to all the user’s DS.

"The encryption algorithm to be used is the advanced encryption standard (AES). It is a block cipher that operates on 16-byte (128-bit) blocks of data. It accepts 128, 192, and 256-bit keys.

The US channel has a unique feature that is highly directional, meaning that any ONU cannot see the US traffic from the other ONUs on the PON. This means that anything sent on the US channel can be seen by an attacker on the field. Nevertheless, to see anything on the US channel, someone must "Tap" the PON fiber. Many would consider this rationale because most of the fibers are in public spaces, and tapping on the fiber will probably harm and weaken the PON signals.

EPON, on the other hand, uses an AES, which multiple vendors support. Furthermore, EPON encryption is used on the downstream and upstream channels.



This image shows the difference between the EPON and GPON packet
Taken from https://www.router-switch.com/faq/what-is-gpon.html

PON cannot achieve symmetrical 1:1 Gbps speeds.
If you want to have a 10G network, you need to invest in XGS-PON, XG-PON (if you're going to invest in 40G, then you will need to check NG-PON2)

II 5.5.5.4.- GPON Limitations

- Passive, no control over the bandwidth allocation
- It cannot be symmetrical because passive splitters are used, thus slower speeds
- Difficult to update and scale since newer PONs need current equipment
- No Quality of Service (QoS) or Class of Service (CoS) therefore unable to prioritize data
- No SLA or MTTR. Servicing could take days instead of hours.
- Less secure since all the data is sent to all the subscribers
- Less reliable and grueling to troubleshoot
- It cannot support speeds over 1Gb.

II 5.5.5.5.- Point to Point (P2P) Fibre

Much like AON, P2P uses one port connected to the ONT, allowing the use of that bandwidth only by that ONT(much like AON but without the active components)

P2P Benefits

- No sharing (no splitters)
- Supports speeds over 1Gb.
- AON can achieve Symmetrically Gbps speeds.
- Scalable and future proof.
- Easy to troubleshoot, one connection to one ONT.
- SLA and MTTR. Service is guaranteed to stay up and running, and repairs are made within hours to minimize downtime.
- QoS and CoS available.
- Ability to utilize Layer 2 and MPLS networks

P2P Limitations

- More expensive to implement.
- Not always available in rural locations.
- Potentially longer rollout times

II 5.6.- DWDM

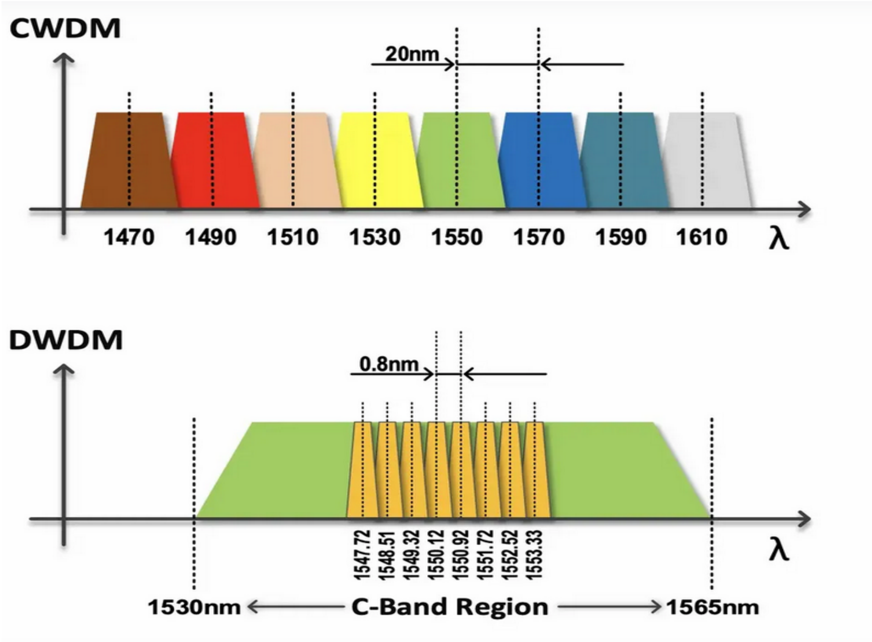
Acronym for Dense Wavelength Division Multiplexing, this optical technology is used to increase bandwidth over fiber.
This technology works by combining and transmitting multiple signals simultaneously, Using different wavelengths over the same fiber strand. It is like transforming the fiber strand into numerous virtual fibers.
This technique increases the carrying capacity exponentially. It is possible to multiplex 40 and up to 80 channels, making it possible to transmit data speeds at 400Gb/s.
One key advantage of DWDM is that its protocol and bit rate-independent. It can transmit IP, SONET/SDH, ATM, Ethernet over an optical channel.
One of the disadvantages is that it requires more complex equipment and expensive transmitters. Some components are Erbium-doped fiber amplifiers (EDFA), optical add and drop multiplexer(OADM), DWDM multiplexer, and DWDM demultiplexer.

There is also a technology called Coarse wavelength division multiplexing (CWDM), which in contrast to DWDM, uses less channel spacing; thus, the transceivers are cheaper and less complex, but the channels that can be used are set to 16 on a single fiber instead of 40 to 80.
This indeed looks like an excellent option to use on single fiber long hauls, but there is a price to pay for it, the equipment needed, and the EDFA is way higher than standard equipment for plain fiber.

II 5.7.- CWDM

Coarse Wavelength Division Multiplexing.
This system supports eight wavelengths (fewer than DWDM) per fiber and is designed to be used on short-range communications with broader wavelengths.
CWDM is based on 20-nm channel spacing from 1470 to 1610 nm. It usually is used on fiber hauls of 80km or less because optical amplifiers cannot be used with large spacing channels.
The wide spacing of channels allows us to use not such expensive optics (less than DWDM), and the distance/capacity is less than DWDM.
Usually, CWDM is used on lower-cost/capacity links (under 10G) and shorter distances.

II 5.8.- CWDM vs DWDM



This figure illustrates how the difference between how CWDM channels fit within the wavelength spectrum as compared to DWDM.

Taken from https://www.wwt.com/article/cwdm-or-dwdm-which-should-you-use-and-when

The most significant difference should use one or the other is that CWDM uses passive optical hardware components, and DWDM uses active components. Hence, CWDM is more suited for PON networks and DWDM for AON networks, where distance is essential. Also, CWDM is cost-effective and can be used for shorter than 80km hauls.

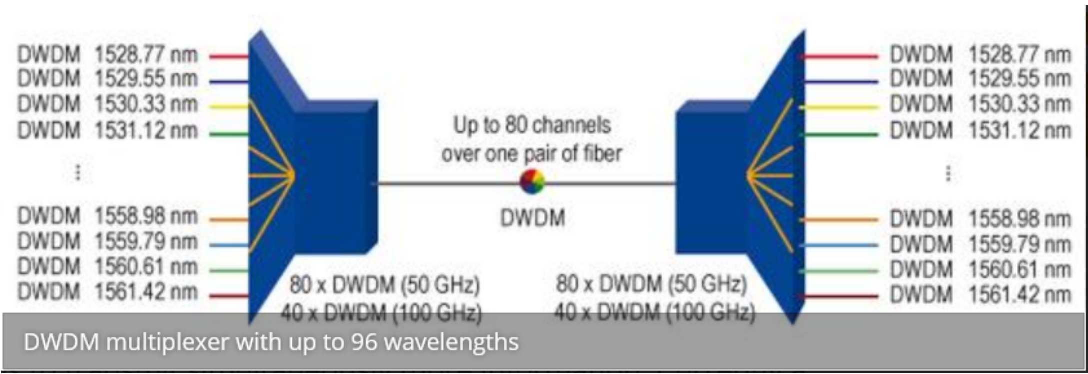
II 5.9.- SWDM

Shortwave Wavelength Division Multiplexing

This technology uses shorter wavelengths (850nm, 880nm, 910nm) on multimode fiber. It is a cost-effective option on MM since the VSCEL is cheaper and an excellent multiplex option on MM.

II 5.10.- DWDM (for SM cables)

Dense Wavelength Division Multiplexing

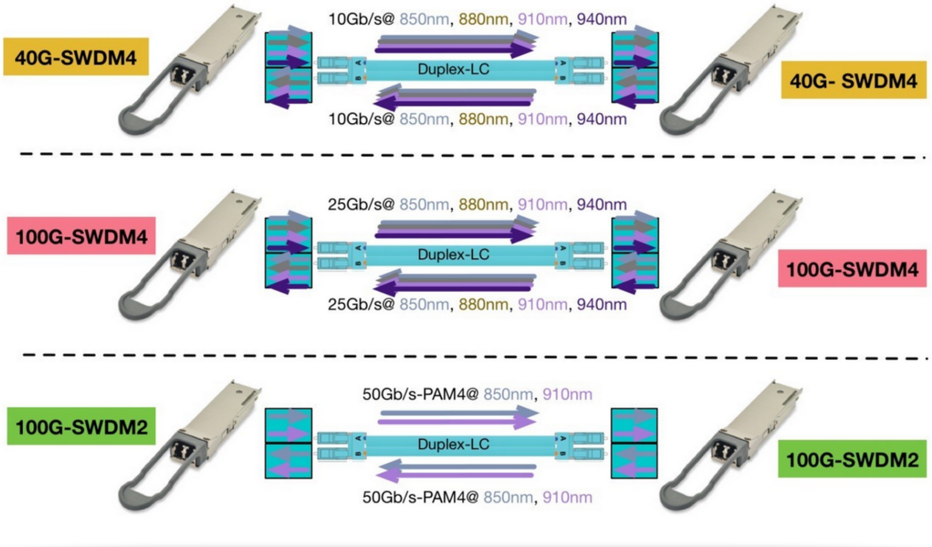


Taken from https://www.pandacomdirekt.com/technologies/detail/dwdm.html

Here is an example of how the DWDM works(much like CDWM but with more channels).
Multiplexing multiple signals with different wavelengths under the same single-mode fiber.

II 5.11.- SWDM (for OM cables)

Shortwave Wavelength Division Multiplexing



Taken from http://www.fowikll.com/b/swdm-shortwave-wavelength-division-multiplexing/

For shortwave, we have SWDM, just like DWDM but for OM cables.

II 5.12.- ONTs- OLTs/ONUs

OLT is the network hardware on the ISP side at the central office of the PON network.
Its function is to control the optical information in an ODN(Optical distribution network) in both directions. It transforms the signals used by fiber optic service (FiOS) to PON systems' framing and frequency. It also coordinates the multiplexing between the ONT conversion devices.

II 5.12.1.- Optical Network Unit(ONU)/Optical Line Terminal(ONT)

The ONT is the terminal point connected at the customer side ending in an optical cable and a modem/switch/router we all know (this will use an SFP or SFP+ at the end, depending on the speed signed on with the ISP.
Data received from the customer end is sent, aggregated, and optimized by the ONT to the upstream OLT. ONT is known too as an optical network unit (ONU).

II 5.12.2.- Dynamic bandwidth allocation algorithm (DBA) and oversubscription

Part of the GPON standard provides a Dynamic Bandwidth Allocation (DBA) tool that enables the ability to allocate the bandwidth per ONT and per ONT request by measuring the downstream/upstream.

A good DBA will quickly adjust the DS/US bandwidth according to the network's traffic. A low customer usage ONT can sit idle, allowing the usage of that same bandwidth by another customer on the same split, maximizing the PON bandwidth utilization.
Also, with a good DBA, the GPON network can be oversubscribed, increasing the network's ONTs. Let us see an example of 32 customers, where each receives 100Mbit/s; thus, the required capacity will be 3.2Gbit/s, 3x times the bandwidth for the GPON upstream. However, with a good DBA, these can be achieved and supported.
There are two types of DBAs, SR and NSR DBA, Status Reporting (SR) and Non-Status Reporting (NSR). SR-based algorithms are superior to NSR-based algorithms in all respects.

II 5.13.- GPON OMCI (ONU management and control interface)

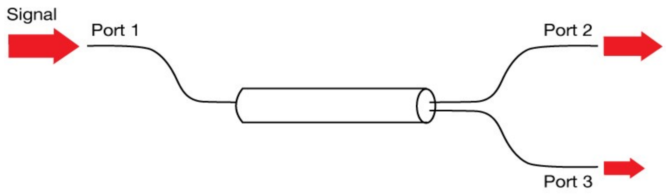
OMCI (ONU Management Control Interface) defines how the OLT uses the implementation and message format to configure, manage, monitor ONUs.
This message protocol is encapsulated on the GEM frame and has the highest transmission priority.

The OMCI also allows OLT to:

- Initiate and break connections across ONUs.
- Manage UNIs (User-Network Interface) at the ONUs.
- Request Configuration of ONUs.
- Request performance statistics.
- Monitor the alarms.
- Inform system failures.

II 6.- Splitting Fiber Technique, PLC and FTB splitters

One of the technologies used on fiber is that different wavelengths can coexist under the same core. Another technology used is that the same fiber core can be shared among many users, and for that, we need optical splitters. There are two splitters that we need to choose from, with their case use and advantages/disadvantages:



Signal splitting example
Taken from https://medium.com/@fiberstoreorenda/how-to-choose-between-plc-fbt-fiber-optic-splitters-ac4028498452

II 6.1.- What Is PLC Splitter?

PLC refers to a planar lightwave circuit. This splitter uses an optical chip to split the forthcoming input signal into various output signals or combine them onto one or two light beams.
This splitter has three layers, a substrate, a waveguide, and a lid. The most important one is the waveguide which lets the advance of specific percentages of light, equally splitting the incoming signal. Also, the PLC can use wavelengths from 1260 to 1650.
PLC splitters have high-quality performance, such as low insertion loss, low PDL, high return loss, and higher split (up to 1:64).

II 6.2.- What Is FTB Splitter?

FBT, or fused biconical taper, fuses several fibers jointly using heat on a specific location. After the fusing is done, they are protected by a glass tube and a steel tube.
The FTB splitters have lower costs, but they are bounded to use only specific wavelengths
(850, 1310, and 1550) The maximum insertion loss increases exponentially after 1:8 splits; this causes more errors and a higher failure rate. Thus FTB is entirely restricted in the number of splits in one coupling.
PLC splits costs are higher than FTB, so it depends on the application and budget, which one will be used. They both have their uses that need to be considered.
The network architect will need to consider each split's power budget on any of the techniques used.

Specification	FBT Splitter	PLC Splitter
Manufacturing	Two or more fibers are bound together and put on a fused-taper fiber device. The fibers are then drawn out according to the output branch and ratio with one fiber being singled out as the input.	Consist of one optical chip and several optical arrays depending on the output ratio. The optical arrays are coupled on both ends of the chip.
Wavelength	850 nm, 1310 nm, 1550 nm	1260 nm to 1650 nm
Input/Output	One or two inputs with an output maximum of 32 fibers.	One or two inputs with an output maximum of 64 fibers.
Input/Output cable	Bare optical fiber, 0.9 mm, 2.0 mm, 3.0 mm	Bare optical fiber, 0.9 mm, 2.0 mm, 3.0 mm
Temperature	-5°C to 75°C	-40°C to 85°C
Reliable splits	Up to 1:8 (can be larger with higher failure rate)	Up to 1:64
Cost	Lower cost	Higher cost

Taken from http://www.fiberopticshare.com/fbt-splitters-vs-plc-splitters-differences.html

II 7.- Splitting Level

In a PON network, there are two standard splitter configurations. One is the Centralized and the other is the Distributed(Cascade) approach:

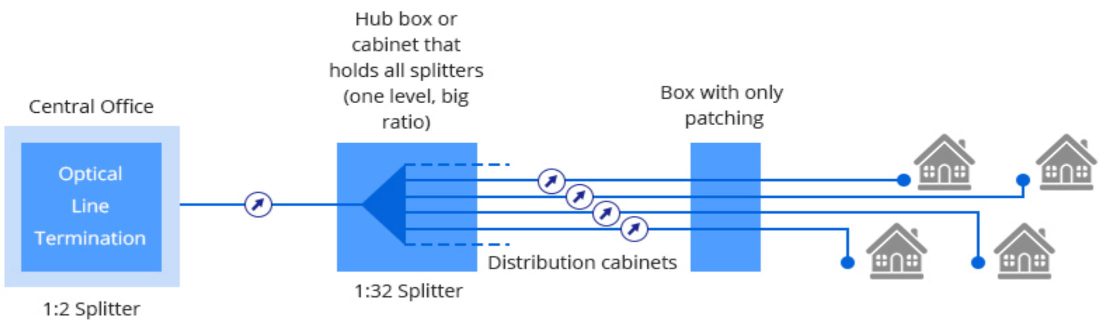
II 7.1.- Centralized split(One split level)

The centralized technique uses single-stage splitters located in a central hub in either a star or daisy-chain topology. The advantages it provides are the flexibility (the splitting 1:32 of a single strand to serve that many customers) and the equipment needed is way less.

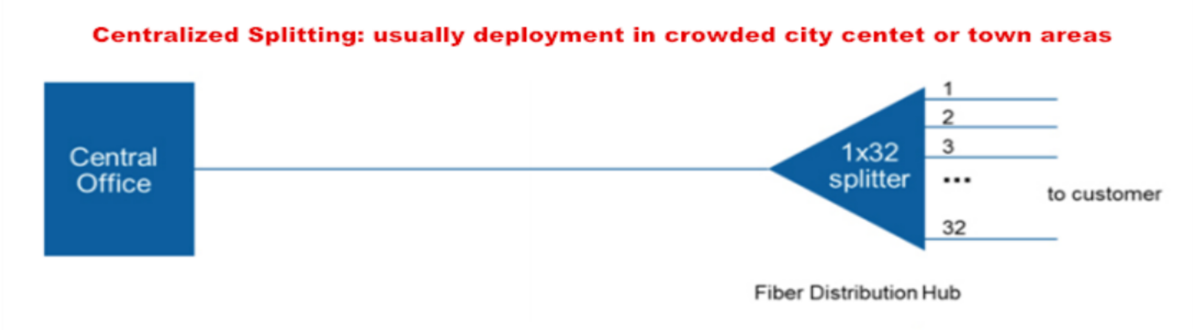
Centralized split architecture has been used broadly to reach subscribers in initial FTTH deployments. This approach regularly uses a 1:32 splitter located in a fiber distribution hub.

(FDH) . This splitter is directly connected via a single fiber to a GPON OLT in the central office. At the central office, 32 fibers are routed through distribution panels, splice ports, and/or access point connectors to 32 customers' homes, where they are connected to an ONT. Thus we have one OLT port that connects to 32 ONTs.

There is an option to use 1:64 with a 1:2 splitter in the central office and 1:32 to the users' homes.



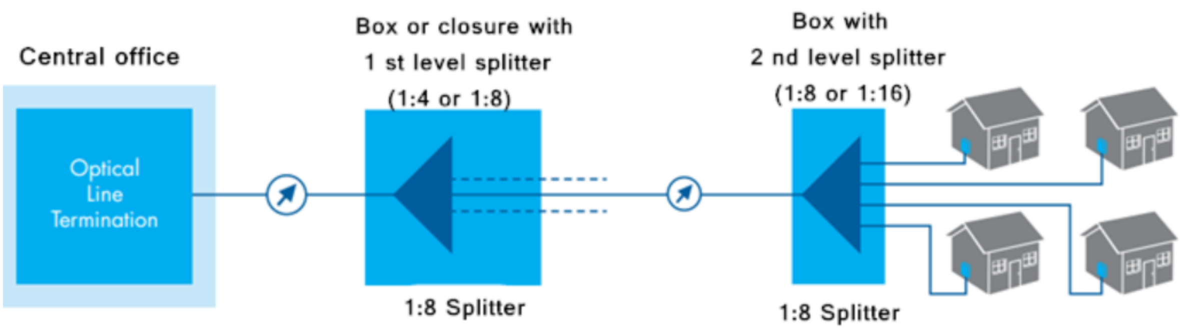
1:64 split ratio
Taken from https://community.fs.com/blog/centralized-splitting-vs-distributed-splitting-in-pon-based-ftth-networks.html



1:32 split ratio
Taken from https://community.fs.com/blog/how-to-design-your-ftth-network-splitting-level-and-ratio.html

II 7.2.- Distributed split (Two or more split levels)

Unlike the central splitting, the distributed split does not use a splitter at the central office. The OLT port is connected directly to an outside plant fiber or distribution.
That helps to move the bulk of the fiber distribution outside of the central office to enclosures closer to the customer's homes.
Instead of using a 1:32 splitter at the central office/distribution hub, a 1:4 or 1:8 splitter can be used. For example, eight fibers leave the FDH into the network instead of 32. Either approach still delivers 32 connections to the OLT, but how we achieve this changes.
This approach will use less fiber and fewer connectors, but it all depends on the customer layout and the method I need to use to get service to each customer.



Taken from https://optace.co.ke/blog/ftth-distribution-architectures-centralized-splitting-vs-distributed-splitting/

II 7.2.1.-Splitter loss chart

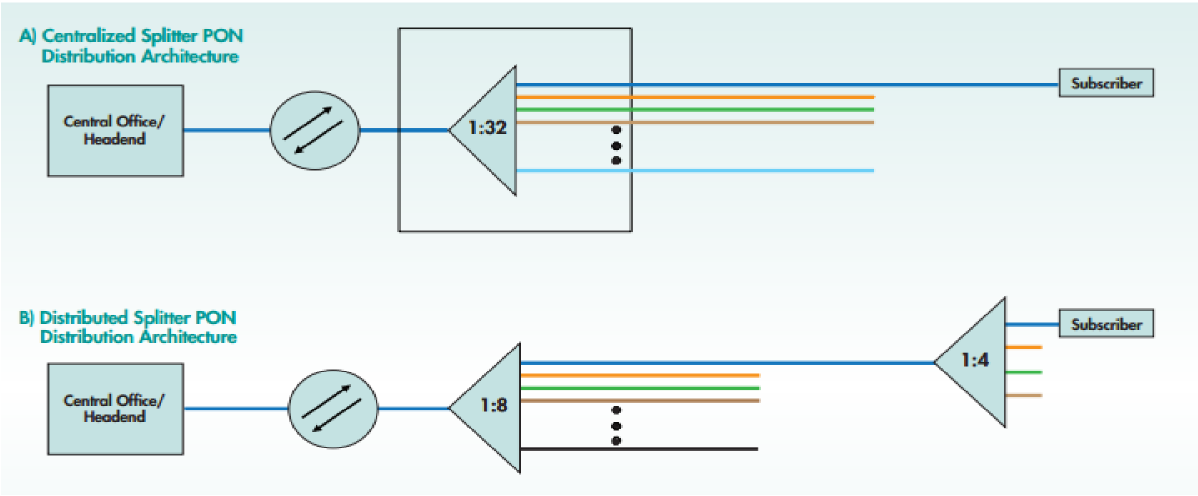
Number of Ports	Splitter Loss (dB) (excluding connections and excess splitter loss)
2	3
4	6
8	9
16	12
32	15
64	18

Taken from FTTH PON Guide Testing Passive Optical Networks 5th Edition EXFO

II 7.3.- Centralized Split Advantages and disadvantages

Centralized PROS	**Centralized CONS**
OLT utilization (pay as you grow)	More distribution fiber
Cost savings over a P2P architecture	splicing adds labor-intensive cost and complexity
Centralized cabinet for cable management, splicing, and terminating	Splicing requires detailed documentation, mapping which increments time and cost
Interconnection panels give the operator flexibility	Higher fiber count
Easier monitoring and maintenance	Possible more infrastructure needed
Distributed PROS	**Distributed CONS**
Flexibility in split ratios in the serving area	More actives and more splitters
Reduces splitter cabinets needed	Less flexible network
the amount of fiber required is much lower in the network's distribution portion	Less monitoring capabilities

II 7.4.- Different architecture view



Taken from http://www.tarluz.com/ftth/fttx-distribution-architectures-centralized-and-distributed-split-comparison/

As seen, the bulk of the fiber in the centralized splitter is in the central office, while the distributed is in the cabinet or outside the plant.

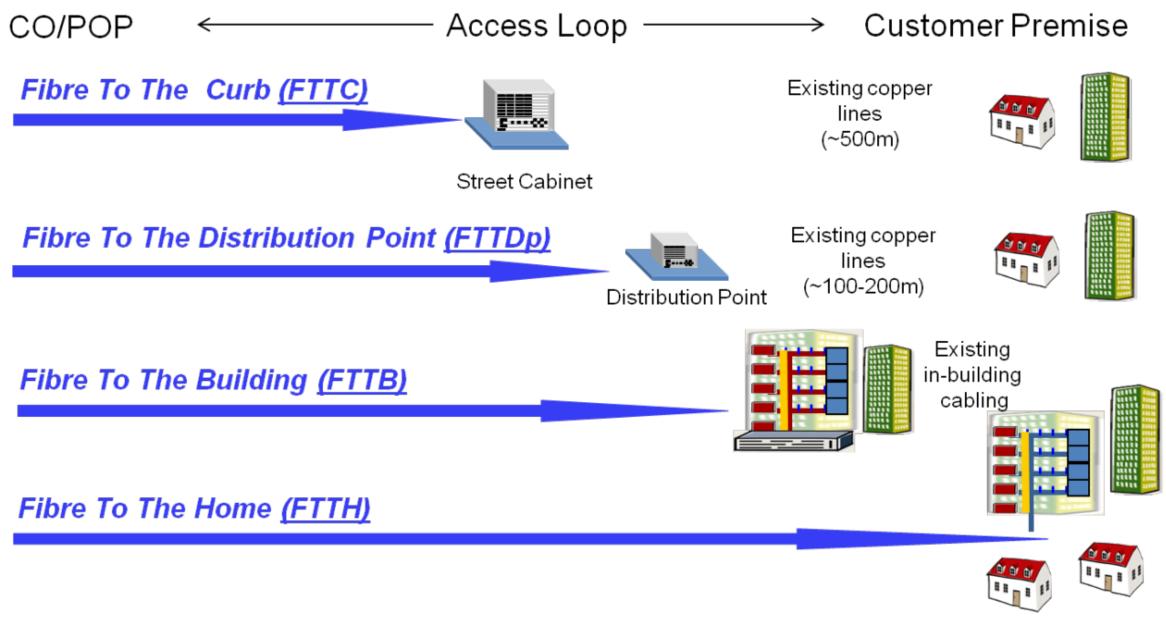


Figure 2: Different types of FTTx networks.

FTTH Handbook Edition 7 D&O Committee Revision date: 16/02/2016 Page 14

This picture shows the different acronyms and the different types of FTTx networks, and the components that make the difference.

II 8.- LC and SC Connectors

II 8.1.- SC Connector

Developed in the mid-eighties, this was one of the first connectors to hit the market when ceramic ferrules became the norm.
The SC connector has a push-pull coupling end face with a spring-loaded ceramic ferrule.
This connector dominated the fiber market a few years ago, where the older ST was the competition. However, after 30 years, it is still the second most popular connector, just losing with the LC connector small form.
The SC is ideally suited for datacoms and telecoms applications, including point to point and passive optical networking.

II 8.2.- LC connector

The LC connector became the SC's successor, but at the beginning, it was not so because of the high licensing fees from the inventor "Lucent corporation."
The LC connector has half of the SC's footprint and is very popular on crowded data centers or other high-density racks, panels, servers.
So the most significant difference between SC or LC is the size. The SC connector has a 2.5mm ferrule, and the LC features a 1.25mm ferrule which is precisely half of the SC size.
SC is a push-pull-connector, and LC is a latched connector, But nowadays, both SC or LC have both connectors.
Both connectors possess identical insertion loss and return loss. Generally, it depends on which part of the network the connector will be used, no matter if it is SC or LC or the other connectors available in the market.
TIA/EIA 568B.3 standard specifies a maximum insertion loss of 0.75 dB for both single-mode and multi-mode fiber links. Likewise, the minimal return loss is ≥26 dB for single-mode fiber and ≥20 dB for multi-mode fiber.

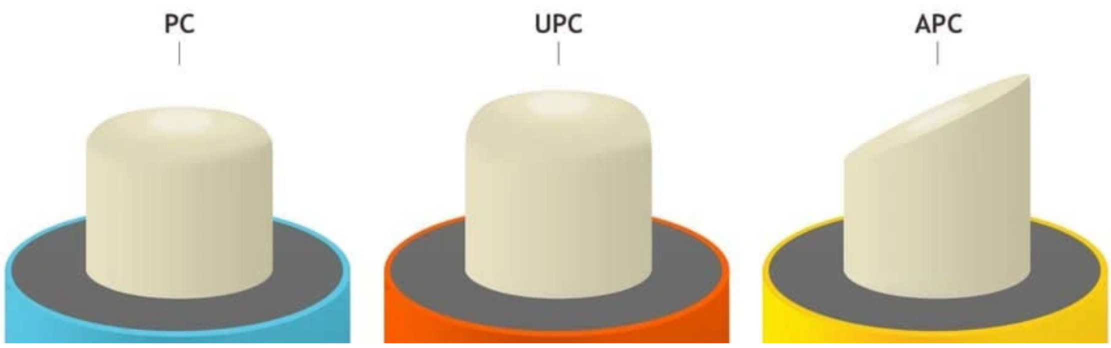
II 8.3.-SC Advantages and disadvantages chart

SC PROS	**SC CONS**
Non-optical disconnect design. Minimum back reflection when ultra-polished. The square shape enables connectors to be packed closely together. The push-pull design allows quick patching of cables into rack and wall mounts.	Smaller LC connectors are replacing these connectors in high-density applications.
SC connector is easily connected and pulling won’t cause the ferrule to disconnect.	Easy to fall out
Reliable and easy to fit.	An older cable used only for compatibility, outdated and replaced by LC.
LC PROS	**LC CONS**
The LC is the Small Form Factor (SFF) connector of choice for many single-mode applications. Half the size of the ST connector, the LC is ideal for high-density applications. Pull-resistant non-optical disconnect design	Some people with large fingers may have difficulty installing such a small connector.

II 9.- APC vs. UPC

Another thing to look at when installing fiber is the UPC (Ultra Physical Contact) or APC (Angled Physical Contact) specifications. One can look when buying the cable for the suffix “-UPC” or “-APC” added onto its name. For example, a fiber cable with SC connectors will be labeled SC-UPC or SC-APC.
UPC connectors are assembled using a unique polishing technique. This technique alters the glass inside the connector, allowing the laser signal to pass effortlessly, but this also makes the glass more brittle and simple to damage when the cable is plugged/unplugged too often.
APC, on the other hand, eliminates the wear and tear issue of the UPCs. The APC glass is angled at an 8° angle in addition to another polishing technique. The angle helps to stop the extra damage while it allows a tighter and more secure connection.
However, there is a catch. The connector requires to be connected on the right-side-up. At the same time, UPC can be connected any way you want.
APC ferrules propose return losses of -65dB. In contrast, a UPC ferrule usually is not more than -55dB.

- Physical Contact
- Ultra Physical Contact
- Angled Physical Contact



Taken from https://beyondtech.us/blogs/beyond-blog/guide-pc-upc-apc-connectors

Connector Polish	Nominal Reflectance (dB)	Nominal Reflectance (%)
FLAT	-20 dB	1%
PC	-40 dB	0.01%
UPC	-50 dB	0.001%
APC	-60 dB or higher	0.0001%

Taken from https://www.ppc-online.com/blog/picking-the-right-fiber-connector-pc-upc-or-apc

II 10.- MPO/MTP

MPO/MTP are names seen for a particular type of multi-fiber connector. This connector is larger than SC or LC but can support up to 24 fiber strands, ideal for data centers. This cable is used too for “breakout cables.” MPO/MTP is also used for fan-out or breakout cables

The cables use MPO/MTP on one end and several LC or SC connectors on the other. With 24 strands on one side, the opposite side can hold either 12 simplex or six duplex. Breakout cables are usually chosen to shorten installation time by reducing the number of cables that need to be used.

II 11.- SFPs and QSFPs

Today we have different optical transceivers available on the market. They come in various form factors offering speeds from 100Mbps to 100Gbps and are fully compliant to the MSA and IEEE 802.3.Some popular form factors are SFP, SFP+, XFP, GBIC, XENPAK, QSFP, and QSFP28.

ǁ 11.1.- SFP

The acronym stands for "small form-factor pluggable." These transceivers are small and hot-pluggable and half the size of the old GBIC transceivers (Gigabit Interface Converted), making them obsolete and hence is sometimes referred to as Mini-GBIC.
SPFs support SONET, Gigabit Ethernet, Fiber, and other standard interfaces.
One of SFPs' most significant concerns is they are not under a standard but a Multi-Source Agreement (MSA). Because of that, some vendors will lock you in with their connectors (Cisco and similar companies) with a firmware check, while other vendors have SFPs with blank EEPROMs, which can be reprogrammed to match any vendor.

Newer SFPs come with a DDM(Digital diagnostic monitoring) capacity, also known as Digital Optics Monitoring (DOM). This enables the customer or end-user to monitor the SFPs parameters like temp, laser bias current, voltage, optical output power, optical input power in real-time.

Another thing to consider about SFPs is the distance. There are two options: Short Reach (SR) SFP or Long Reach (LR) SFP.
Single-mode SFP transceivers can transmit anywhere from 2km to 80km. Standard Single-mode SFPs can communicate up to 10km, while Extended Single-mode SFPs, up to 80km.
For shorter distances and a cheaper option, multi-mode SFPs are a great solution. A Standard multi-mode SFP can transmit up to 500m, while an Extended multi-mode SFP, up to 2km.
There is also long-reach WDM SFP for multiplexing, simplex SFPs for single fiber, video-SFP for transmission of high-def video, and PON SFP transceivers for PON networks.

ǁ 11.2.- SFP+

SFP+ stands for Small Form-factor Pluggable Plus. These transceivers are the enhanced SFP version and can support data rates of 25 or 32 Gbps (more bandwidth coming soon).
The most notable difference between the SFP and SFP+ modules is the encoding method. These modules have more circuitry to be implemented on the host board instead of the module itself. SFP+ modules can be used in older appliances with XENPAK or X2 ports, using an active electronic adapter. There are two types of SFP+ modules; Linear SFP+ modules are most appropriate for 10GBase-LRM, otherwise, limiting modules are preferred. These contain a signal amplifier to re-shape the degraded (received) signal, whereas linear does not.

SFP+ also introduces direct attach for connecting two SFP+ ports without dedicated transceivers. Direct-attach cables (DAC) exist in passive (up to 7 m), active (up to 15 m), and active optical (AOC, up to 100 m) variants.

II 11.3.- SFP cable/Direct Attach Cable (DAC)

Direct-attach cables are Twinax cables with transceiver connections on both ends. These are used between network equipment in a server room. They are to be used on short distances. It is a trendy alternative to SFPs because these cables offer a complete solution (they have the receiver added to the cable), and the cable price is lower and requires less maintenance. It also provides less power consumption and its plug-and-play.
The data rates are similar to the SFPs transceivers, and they are available with SFPs, SFPs+ or QSFPs+.

II 11.4.- QSFP

The QSFP is an expansion of the original SFP. QSFP uses double fiber pairs. The Q stands for “quad.” The connector is still small and hot-pluggable, and they support ethernet and fiber, and the newer Infiniband is supported.
QSFP data rates get up to 1 Gbps per channel, allowing for 4X1 G cables and stackable networking designs that achieve better throughput.
The data rates supported are 4x1Gbps QSFP, 4x10Gbps QSFP+, 4x28Gbps QSFP28. It also supports Ethernet, Fiber Channel, InfiniBand, and SONET/SDH standards.

II 11.5.- QSFP+

QSFP+ is the upgraded transceiver from the normal QSFP. This connector has replaced almost completely the QSPFs, reaching 10gbps per line instead of the 1gbps of the normal QFSP, Achieving 40gbps (10x4 connectors) while keeping the small factor.
The newer QSFPs can support 50 (QSFP14), 100 (QSFP28), and 200 (QSFP56) Gbps connections.
Now one of the big questions is, how do you choose one over the other?.
Choosing the right connector is essential in network planning and for an efficient and budget-wise network.

II 11.6. GPON Class B+ vs. Class C+ vs. Class C++

There are three GPON SFP module types Class B+, Class C+, and Class C+++ GPON SFP module used for GPON OLT.
The distinction is the output optical power. Class C++ GPON SFP module output optical power is 7dBm, the Class C+ GPON SFP module output optical power is 5dBm. Of course, their optical receiver sensitivity is also different. The Class C++ optical receiver sensitivity is best.

Type	Class B+ GPON SFP module	Class C+ GPON SFP module	Class C++ GPON SFP module
wavelength	Tx: 1490nm	Tx: 1490nm	Tx: 1490nm
	Rx: 1310nm	Rx: 1310nm	Rx: 1310nm
rate	Tx: 2.488Gbit/s	Tx: 2.488Gbit/s	Tx: 2.488Gbit/s
	Rx: 1.244Gbit/s	Rx: 1.244Gbit/s	Rx: 1.244Gbit/s
Mini Output Power	1.5dBm	3dBm	6dBm
Mini Output Power	5dBm	7dBm	10dBm
Optical Receiver Sensitivity	-28dBm	-32dBm	-35dBm
Optical Connector	SC	SC	SC
Fiber type	Single mode	Single mode	Single mode
Receiver Overload	-8dBm	-8 dBm	-15dBm
Extinction Ratio	10dB	10dB	8.2dB

Taken from http://www.baudcom.com.cn/blog/difference-b-and-c-gpon-sfp-module

II 11.7.- Choosing the transceivers

There are some considerations when choosing the right transceivers:

II 11.7.1.- Network Traffic

When planning the network, the architect must choose the speed of it. In comparison, a high-end datacenter can select the biggest QSFP+ transceiver (200 Gbps) lower bandwidth networks can choose normal QSPF+ or QSFP14 (50 Gbps). Or mix and match them, but it will depend on what is connecting, a switch to another building? Then a QSFP28 might be a good option. If there is a need to have all the bandwidth possible to connect SANs? Then a QSFP56 might do the trick. However, this will also depend on the hardware bought. Not all of them support all the transceivers discussed. Also, the more bandwidth the QSFP is, the more expensive the router/switch will be.

Also, should consider room for growth and anticipate how much traffic will increase in the future. It might be alluring to save money and use the lower bandwidth transceivers, but if there will have significant changes in 1 year, two years, then there is no real saving. Designing the future network expansion is also a challenging topic, but it must be done beforehand, or there will be serious trouble in the future.

II 11.7.2.- Network Distance

SFPs and all of their variants work with SM and MM fiber cables, but each cable and network's physical length might determine which modes will be used.

When using SM fiber, the transceiver must match the kilometers you need for that cable, while if you use MM for shorter distances, there is room to choose lower bandwidth now and leave room for growth.

II 11.7.3.- Planning the switch room

Adding more channels, more transceivers, and more switches will increase the heat of the switch room. The architect will have to plan for cooling costs and heat management, and that will also determine where there will be more/less investing or make cuts on the data rates.

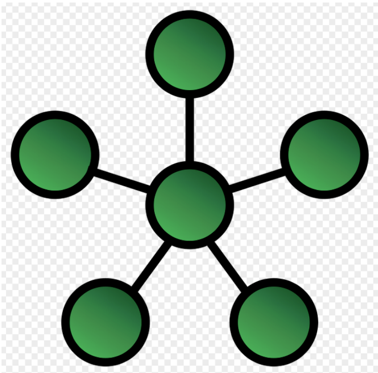
II 12.- Fiber Network architectures

We Will discuss the other topologies seen on the field and why we use Star/Ring/Tree.

II 12.1.- Star architecture

A star architecture hauls cables back to a central location using pre-terminated cabling, so it's very efficient from a splicing perspective. It uses about 35%-45% more cable than daisy-chained architectures, and there can be more part numbers due to different cable lengths. While cable can be seen as a relatively inexpensive part of an FTTH network's overall cost, the extra cable required in the star configuration carries additional labor costs for deployment.

Star architecture can use a multi-port service terminal (MST), a component of hardened connectivity lines – it offers the option of not splicing any of the dropped fibers at the distribution point. It's called a star because each terminal tail is taken back to a splice location. When used with a centralized split, each cable going between the MST and splice case will have one fiber per terminal port. When used with a distributed split, a single fiber between the terminal and splice case is used, and the terminal incorporates a 1x4 or 1x8 splitter. Distributed split architectures use the same amount of cable as centralized, but the fiber counts are a fraction, and consequently, the splicing costs are a fraction.

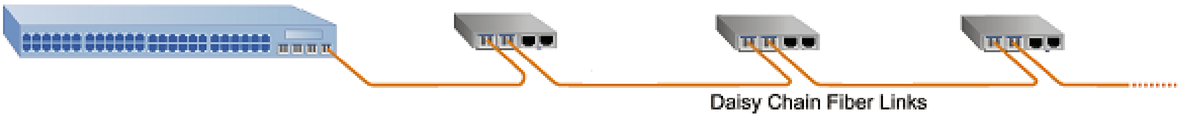


Network Star Architecture
Taken from https://en.wikipedia.org/wiki/Star_network#/media/File:StarNetwork.svg

II 12.2.- Daisy-chaining

Daisy-chaining can be a faster approach to deploy. It uses one cable and connects it through a cascade of fiber access terminals, leading to efficiency from a cable use and deployment labor standpoint. However, it may require special splicing skills because it may need more splicing than star architecture.
Splicing labor is a crucial cost factor in FTTH deployments. In a star topology, fiber splicing is done at the hub, where individual cables are laid from the hub to each terminal. In a daisy-chained topology, fiber cable runs through the streets. A hardened terminal is spliced onto the cable; this design forces compromises in

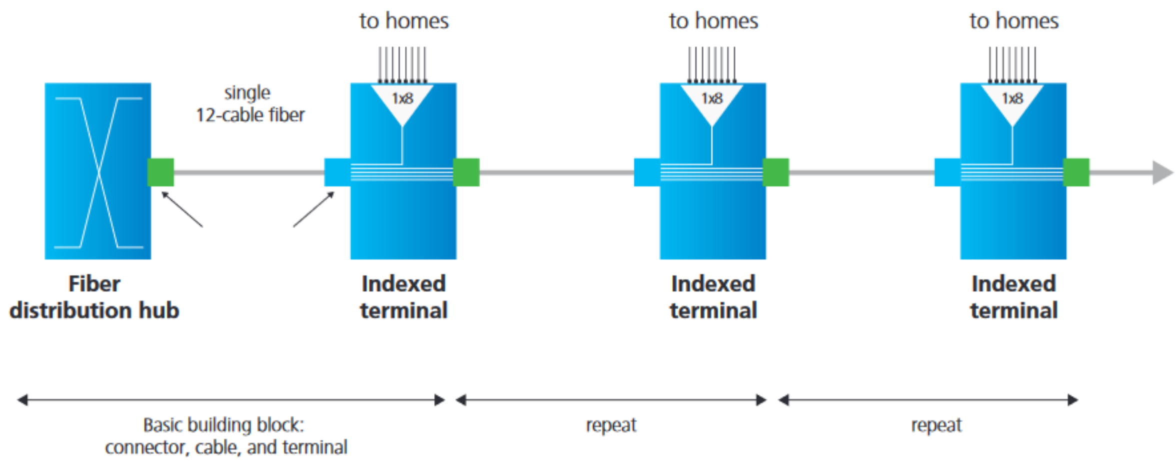
deployment time while increasing costs via the need for expensive, specialized splicing labor.
Splicing costs for a centralized split, whether star or daisy-chain architecture, are generally higher while distributed split stays low, as the splitter outputs are factory terminated.



Taken from https://www.arubanetworks.com/pdf/partners/Solution%20Guide%20Omnitron%20Final_2%20.pdf

II 12.3.- Fiber Indexing

This technique works like this, an X strand fiber cable (12 in this example) enters the first indexed terminal, In this terminal, one fiber is routed and split to the customers, and the remaining fibers are "indexed" or moved up as they exit the terminal to another terminal.
Meaning that while one fiber is out to the customer, the others are sent to another terminal where the next fiber drops and is connected to the next customer.
Fiber indexing has a great potential in reducing the work needed in the distribution network, significantly decreasing the deployment times. This, like any other network deployment, should be verified by the network specialist because it requires planning.
There are some advantages like reduced splicing labor, minimizing site surveys, and reduced inventory management costs.



Taken from https://www.commscope.com/Docs/Fiber_Indexing_A_Cost_Optimizing_Approach_WP-110968-EN.pdf

In Traditional cascade architectures, different terminals and fiber lengths are required. Cables are not standard throughout the network, which involves complex planning and custom cables. In contrast, fiber indexing reduces the cable configuration in the whole network; this enables faster and less costly customer connections and eliminates unnecessary splicing (which takes time), resulting in a faster customer network connection to the network and services with lower costs.

There are several other advantages of fiber indexing:

- Increased flexibility with no signal loss. Minimal signal strength impact(in cascade, there is an impact). The hardened connectors keep adequate link budgets from the beginning to the daisy-chain end.
- It has enhanced fiber utilization. By connecting the last terminal to any fiber distribution hub, the network can then feed each terminal's reverse port's reverse path. Then it can be connected to a subscriber's cable drop cable or be used to deliver other services at that terminal location.
- Efficient inventory management. Fewer part numbers and equipment are used throughout the installations.
- Reduced time used onsite to size each cable since most of the cables are not custom made.
- Fewer issues while deploying cables with factory pre-prepared cables and terminals.
- Less cable handling and less testing of the same cables and terminals.

II 12.4.- All-splice vs. hardened connectivity

In typical cascade splitting, there is loss when cutting and handling. Each cable and splicing takes a toll on everything used, so having a hardened approach (no cutting on the field, everything pre-made at a factory with all the advantages it brings)
With everything pre-built, there is less manual splicing (reducing cost and time) and improving reliability (everything comes already made and tested)
Indeed indexing seems the best option out of the three mentioned, less of everything, and pre-made cables and terminals show how good it can be. Let's take a look at the advantages of good planning with fiber indexing:

Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Length (ft)	150	220	300	400	480	600	80	200	320	430	225	350	450	595	715
Segment	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Length (ft)	495	645	770	890	1005	850	1025	1160	1275	260	490	840	1290	1620	1895

Total Cable 20,025 ft

Figure 1A: Typical fiber distribution network today for a hub serving up to 240 homes. Individual cables are laid from the hub to each terminal (blue circles) in a star topology. Each terminal services up to 8 homes

Segment	H-7	7-8	8-9	9-10	10-6	6-5	5-4	4-3	3-2	2-1	H-11	11-12	12-13	13-14	14-15
Length (ft)	80	120	120	110	255	120	80	100	80	70	225	125	100	145	120
Segment	15-20	20-19	19-18	18-17	17-16	H-25	25-26	26-27	27-28	28-29	29-30	30-24	24-23	23-22	22-21
Length (ft)	365	115	120	125	150	260	230	350	450	330	275	485	115	135	175

Total Cable 5,530 ft

Figure 1B: Fiber Indexing uses a linear daisy-chain topology, with terminals that perform multiple functions

Taken from https://www.commscope.com/Docs/Fiber_Indexing_A_Cost_Optimizing_Approach_WP-110968-EN.pdf

II 13.- Requirements for fiber installation

II 13.1.- First you need to check the place you want to install

Everything starts on where do I want to install, how many customers I can get and how far I'm from the nearest fiber connection from a big ISP.

- Find the ISP near you
- The other option available in Alberta is to find a fiber connection from the Alberta SuperNet (wolfpaw). The options are 1gbps to 10gbps.
- Remember that you will need two fibers for redundancy, if possible, from two different ISPs.

II 13.2.-Then survey the customers

It's necessary to go onsite and talk with all the possible customers, call a round table and let them know your plans and come with a speech that not only will benefit you but also will give something to the people and add benefits to the population, that way you can even get them all under contract.

II 13.3.- Check upstream connection with a big company

Check where the nearest fiber connection is, and then lay out the fiber plan and where digging is needed. There is also another option, getting "Transit" from the local Cable company to an IXP. If there is no direct connection to an IXP, there are other options that can be discussed. The majority of cable companies will sell something called "IP Transit" over their network. IP Transit means that the ISPs allow sending traffic over their fiber but do not provide an Internet connection. Essentially they provide a port from the local cable company's network in town somewhere and another port at a data center in a major urban center – and the traffic goes in one end and out the other.

This option's advantage is a much lower rate for transit to an IXP and then buy a cheap gateway at the other end. There might be a need to install appliances in a city that could be some kilometers away, but the cost savings are worth the hassle. Sometimes the company you obtain gateway from already interconnects with your cable company.

II 13.4.- Then check if there is dark fiber

Some ISPs might have already laid out fiber, but since the last mile is expensive and the towns nearby are not profitable enough for them, they might lease it.

II 13.5.- Check for Point-of-Presence (PoP) sites

The largest Alberta providers outside of the big ISPs (Telus, Shaw, Bell) are MCSNet, CCI Wireless, and Explornet.
There are no fiber maps or any information outside the Alberta SuperNet known where to check for dark fiber sites or any fiber for that matter.
Looking at their tower locations to get a sense of the PoP's, where the antennas are, fiber is close.

II 13.6.- Lease from a known big ISP the unused fiber

A big part of the fiber layout is finding an ISP, leasing the nearest fiber, and installing ours.

II 13.7.- If there is no Dark fiber or any fiber connection near find an IXP

An IXP (Internet exchange point) is a physical location that different ISP uses to route the traffic sharing switches and costs.
In short, they can grant access to their switches and "lend" you a port to connect your fiber.
The method used to pay for it is to pay for the "Transit" or "Peering."
Transit is a paid-for service and uses BGP to announce the network to the upstream provider.
Peering is used to share an IP address without an intermediary.
Between big ISPs, there can be an arrangement to share the location and share the network to have a free connection between them, but for smaller ISPs, there is a cost and will be charged to use this option, which is less than getting fiber by other means.

II 13.8.- Check for Single-Mode Fiber (SMF) with potential for Wavelength Division Multiplexing (WDM) providers (ex epcor)

The unlimited bandwidth of single-mode fiber makes it the undisputed king on speed. WDM brings even more speed. If able to get a hand, for example, epcor dark fiber, it will bring speeds of 400Gb and more in the future.

II 13.9.- Calculate DB loss (The Loss Budget)

Another essential part of the fiber installment is to Calculate the DB loss through all the install phases. Checking how many DBs are lost per KM, connector loss splices loss is a must. A handy guide for it can be found on the FOA site
And a lot more about DB loss and the math behind it on the same site too.
The FOA gives an excellent in-depth understanding of what needs to be done to lay down fiber, and there is a particular part called “to add the GIS” to any planning(geoinformation system)
Quote “ GIS (geographic information system) data on the location of the cable and every component - cables, utility holes/handholes, splice locations, and full descriptions, plus test data.

II 13.9.1.- The Loss Budget

One crucial task and one of the first needed to be performed when designing a fiber-optic network is to do the Loss Budget.

To appropriately identify the loss budget, the following key parameters are generally considered:

- Transmitter: launch power, temperature, and aging
- Fiber connections: splitter, connectors, and splices
- Cable: fiber loss and temperature effects
- Receiver: detector sensitivity
- Others: safety margin and repairs

If one of the variables above fails to be under the specifications, the network performance will drop, or the degradation can lead to a network failure.
Depending on the PON deployed, the loss budget will vary. For example, in the case of “Class B GPON,” the maximum loss budget for the upstream path at 1.25 Gbit/s can be 32 dB (delta between minimal sensitivity and maximum launch power). Note that the transmitter's launch power can vary. If we consider the same system with a launch power of –2 dBm, the loss budget will then become 26 dB (delta between minimal sensitivity and minimal launch power).

Type		BPON								GPON									
Standard		ITU-T G.983 series								ITU-T G.984.1									
Optical distribution network class (ODN)		B	A	B	A	B	B	A	B	A	B	A	B	A	B	A	B	A	B
		Downstream					Upstream			Downstream				Upstream					
Nominal bit rate		156	622,08		1244,16		156	622,08		1244,16		2488,32		155,52		622,08		1244,16	
$\langle P_{launch} \rangle$Min	dBm	–4	–7	–2	–4	+1	–4	–6	–1	–4	+1	0	+5	–6	–4	–6	–1	–3	–2
$\langle P_{launch} \rangle$Max	dBm	+2	–1	+4	+1	+6	+2	–1	+4	+1	+6	+4	+9	0	+2	–1	+4	+2	+3
Sensitivity Min	dBm	–30	–28	–28	–25	–25	–30	–27	–27	–25	–25	–21	–21	–27	–30	–27	–27	–24	–28

An example of the typical total loss budget calculation can be illustrated as follows:

- Splitter loss (1x4, 1x8, 1x16, 1x32) usually accounts for the majority of the system's loss: approximately 16 dB for 1x32 splitters.
- Insertion loss is typically around 0.7 to 1.0 dB per WDM coupler, generally used to combine the video signal (1550 nm) with data and voice signals (1310/1490 nm).
- Connector and splice losses are typically around 2.0 to 3.0 dB for the complete link, from the OLT to ONT.
- Fiber loss equals attenuation multiplied by distance. The maximum distance being limited by the loss budget at the worst-case attenuation wavelength (1310 nm with around 0.33 dB/km attenuation). The maximum length typically ranges from 4 to 20 km.

The loss budget calculation should be one of the first things verified before any deployment. It should be mandatory to ensure that the class of the system selected is compatible with the topology that will be deployed. If, for example, a system is designed with the elements listed above and if the launch power of the transmitter at 1310 nm is –4 dBm with a detector sensitivity of –28 dBm, the allowed loss budget of 24 dB will compromise the system's performance at 1310 nm (upstream). Therefore, the total loss measured during network deployment should not exceed the system design's total loss budget. It should have enough of a buffer to allow for any loss fluctuation that could occur during the system's lifecycle.

II 13.10.- Google Earth for Fiber Mapping

It is an excellent and inexpensive tool to calculate the path, length, km, and everything to lay down the fiber.

II 13.11.- Try to get funding to lay rural fiber if needed

Canada CRTC plans to get 50/10 are underway. There are still slots to apply and get part of the $700 million cake.

While it is not easy to get funding, this is an excellent place to start.
Another way to get funding is to talk to communities and build up the necessary money to dig and get the fiber. Not an easy thing to do too, but tight and caring communities can surprise many people. There are many histories on how fiber has changed the communities lives and all around them.
There are NGOs too that can help the communities with the necessary funding, like Swift Rural broadband or many like it. check the options available in your location.
There are options, but remember that it will not be easy.

II 13.12.- How to deal with Paperwork and Red Tape

Like any government in the world, there is a lot of paperwork and red tape involved in fiber installations(especially when it involves crossing a street or anything done outside a building and in a public space)
The expression "cutting of red tape" usually refers to a cutback of administrative obstacles. It is also used as a counterbalance to justify the reduction or removal of protective standards or regulations. Business representatives often claim red tape is a barrier to the business, particularly small businesses.

Big ISPs can get around this using lawyers, but small businesses cannot afford that luxury.
One way to avoid most of the paperwork/red tape is to use "contractors" who already have all the permits.
If you want to dig, get a contractor, lay down the fiber, get another one. While this might seem the expensive option, it is the one you should use to avoid any issues about the permits/paperwork.
This link should shed some light on the problems that too much red tape brings, from The Canadian Federation of Independent Business (CFIB), the country’s small business champion.
Nevertheless, here is the challenge, as a growing ISP, you might get into it and build something far more significant than ever imagined. Not everything is about technology.

II 13.13.- Look for companies to do the digging

Most of the budget will be spent here. Digging and planning where the fiber will be placed is going to be the most expensive part.
Digging calls for permits, buying the service from a known company, leasing vehicles if done by yourself, planning with the Alberta government where you can dig.
There is a possible new trenching method called "MicroTrenching" that could be used.
If done by yourself, there are some rules to follow before digging provided by
The Damage Prevention Process in Alberta

Call before you dig! The single location that will help you to know where you can/cannot dig.
Request a locate online — AlbertaOneCall.com or ClickBeforeYouDig.com

II 13.14.- Check leases to run fiber on poles

Another option to set down the fiber is to lease pole space. This is an expensive option, on par with digging, because poles are owned, mainly by the power companies or the big ISP, and even getting an estimate is expensive.

II 13.15.- Check how to dig your own trenches

There is a lot needed to dig your own trenches, like permits that will not be covered in this project.
In the next chapter (implementation), I will assume a professional service already does the work.

II 13.16.- Run two or more fiber for redundancy

An essential part of it all is to run redundancy and be redundant in all (power, backup hardware, generators)
Being redundant will help us to keep and maintain 99% uptime needed (in case one of the fiber is down for whatever reason, you will have another one ready to use in an instant)

II 13.17.- Run them under armored ducts

(rodents/woodpeckers can break the cable)

Armored fiber will be needed in places where rodents or any animal capable of biting the fiber exists.
Also, there are some rules to follow on which fiber we need to use inside a user home being fire retardant (this will come later if needed)
Armored and fire retardant fiber is expensive, but they are needed on external installs and building safety code compliance.

II 13.18.- Protocols to use

The protocol most used is BGP . so I will have to advertise my own AS to the dark/lease fiber ISP, and I can run my own OSPF in my LAN (OSPF is more straightforward to set up and maintain).
There are some BGP analyzers online that can help you on this. And you can also do a mix of BGP, MPLS to engineer the traffic.
This indeed looks like the best option but requires an in-depth understanding of this network protocol and it depends if the ISP wants to peer with you.
One of the best options for a growing small ISP is to use OSPF, which is Good, pretty, and cheap. It is easy to use and configure. It does the work wonderfully and

can be used from medium to big complex networks. The GPON part does not need anything else, GPON is its own protocol, and from each GPON port, I can serve multiple users. The VLAN port has all the routing information.

II 14.- Documentation

As important as choosing the right equipment, method of installation and components, there is a critical part called “Documentation” where it is needed to document everything on the network, from equipment, strands, ports, VLANs, anything used on the network must be documented. Failing to do so will increase troubleshooting times, timely replacing a bad component, SLAs, and even being able to fix a problem at all.

Once the components are selected, they will be added to the documentation for future reference as estimating costs for new purchases and installations.
After installation, each component is marked at the access point for easier identification.

Documenting the fiber optic plant is essential in any design and installation process. Both can save time and materials allowing that same planning a future and easy upgrading.
It also speeds up the cable pulling during installation and since the routing and terminations are already documented.
After this and every component has been installed, the documentation can be completed adding the final customer’s test data and acceptance.
Suppose the equipment is reassigned or moved(as often this is). In that case, the proper documentation will allow easier rerouting to the new endpoints and allows effortless troubleshooting since everything is at hand to trace links and find faulty links.
This is also true for contractors. Proper documentation is required as the final part of any installation and for acceptance.

1) First, the documentation starts at the cable plant. OSP (outside plant cables) require thorough documentation of the overall route and the exact location of the cables (ex: on which side of the street, on which poles, where the buried cables are, how deep if there are markers or tracing tape buried too. Premise cables or inside the plant need the same details documented in order to find the cable at any location.
2) The fiber optic backbone is composed of several strands, which are connected to several and different links that might not be in the same direction or place. Therefore it must be documented as to the path of every fiber, connection and test.

This is what the documentation should contain (this is an example, documentation varies from company to company)

- Paths: where the cable plant is located and the link paths in every cable.
- Cable: manufacturer, type, length, fiber type and size.
- Splice and termination points (at distance markers, patch panels).
- Connections types : (splice or connectors and types), fibers connected, test data.

II 14.1.-The Documentation Process

Documentation begins with a basic design of the network. A drawing on building blueprints may work for a small building, but a large campus, metropolitan or long-distance network will probably have a CAD layout. One best way to do it is to use the facilities drawing and draw on it all cables and connection points. Identify all the wires and racks, panels in closets, then transfer the data to a DB.

Fiber optic cables, especially backbone cables, can have several fibers that connect several different links, which may not go to the same place. Therefore, the fiber optic cable plant should be documented for cable location, each fiber's path, interconnections, and each test result. You must record the fiber and cable specifications: the manufacturer, type of cable, type of fiber, how many fibers, cable construction type, length, and installation method (buried, aerial, riser, plenum)

It is also helpful to document the panel type, HW being used, and end equipment is connected. If you are installing a fiber plant with many dark (unused) fibers, some will probably be left open or unterminated at the panels, which should be documented. Whenever designing a network, it's an excellent idea to keep spare fibers and interconnection points in panels for expansions, rerouting, or moving equipment.

Documentation is more than keeping records. It is vital to label components with color-coded permanent labels in reachable locations. Once a labeling scheme has been determined, each cable, accessible fiber, and termination point requires some labeling for identification. A simple scheme is preferred, if possible, explanations provided on patch panels or inside the cover of termination boxes.

II 14.2.- Protecting Records

Access to any knowledge must be restricted.

Cable plant documentation records are vital documents. Keep copies of the document, more than one, and backups too. Either on a computer or paper, in several locations for preservation. If one copy is given to the customer, the installer should keep one on their records for future work on the project. One complete set must be kept on paper with a "restore kit," alongside tools and directions on managing an outage or any damaged cable. Documentation must be updated to be helpful, so that task should be assigned to one onsite engineer with instructions on informing the parties involved in the project.

II 14.3.- Installation Design

Once we finished everything talked about above, we plan the installation. Coordinating is needed and the activities of people and companies. The best way to keep everything in line is to create a checklist based on the design drawn in the project's early stages.

II 14.4.- The Project Manager

It is essential to have the main point of contact for the project. The PM needs to be involved from the beginning, understand the project's aims, the technical aspects, the physical configuration, and be familiar with all the people. Likewise, all the parties working on the project need to know this person, directions on how to contact them (even 24/7), and who the backup is if one is required.

The backup person should be someone profoundly involved and with an excellent technical background but may not have complete decision authority. The backup can be the one in charge of the documentation and schedules.

II 14.5.- Design Checklist

Planning for a project is essential to the success of the project. The list below is comprehensive, but each project will have some of its own unique requirements that need to be added. Not all steps need to be done serially, as some can be done parallel to reduce the project's design time. The architect must interface with many other people and organizations in creating a project. Contacts of outside sources should be maintained with the documentation.

II 14.6.- Design process

- Link requirements
- Link route selected, inspected, special requirements like inspections and permits.
- Communications appliances and HW requirements.
- Cable plant components.
- Coordination with facilities, electrical and other personnel.
- Documentation completed and ready for installation.
- Write a test plan.
- Write restoration plans.

II 14.7.- Contractor package for the install

- Documentation, drawings, bills of materials, instructions.
- Permits available for inspection.
- Guidelines to inspect quality at every step.
- Daily review of progress.
- Safety rules posted on the job site(s).

II 14.8.- Requirements for completion of cable plant installation

- Final inspection.
- Review test data of the cable plant.
- Instructions to set/test communications system.
- Final update of documentation.
- Update and complete restoration plan, store components, and documentation.

II 14.9.- Developing A Project Checklist

The final checklist will have many items. Each one needs a full description, where and when it will be required and who is responsible for it. Components like cables and hardware should indicate vendors, delivery times, where, when, and sometimes how it needs to be delivered. Special installation equipment needs to be also scheduled, with notes of what is to be purchased or rented. On non-secure sites, there might be security guards who may need to arrange visits to the job site.

A work plan must be created that indicates what special skills will be needed. Outside plant installations (OSP) often have areas of expertise for different types of work. One can be pulling cables and the other splicing. Some might do one part of the job since all fiber installations need trained people on specialized equipment like fusion splicers or OTDRs and installation practices like climbing poles or plowing-in cables.

All personnel on the project must be instructed on the safety rules and a written copy of them. Supervisors and workers must have contact numbers for the project manager, backup, and other personnel they may need to contact. Since some projects require working outside regular work hours, like airports or government buildings, where the cabling is regularly done at night, having an onsite PM while the work is being done is vital.

During the installation, a well-informed person should be onsite to monitor the installation's progress, inspect quality, review the test data, create progress reports, and notify the PMs if something looks wrong. If the PM is not an expert on the field, having someone available who is technical is essential. That person must have the authority to stop work or require fixes if significant problems are found.

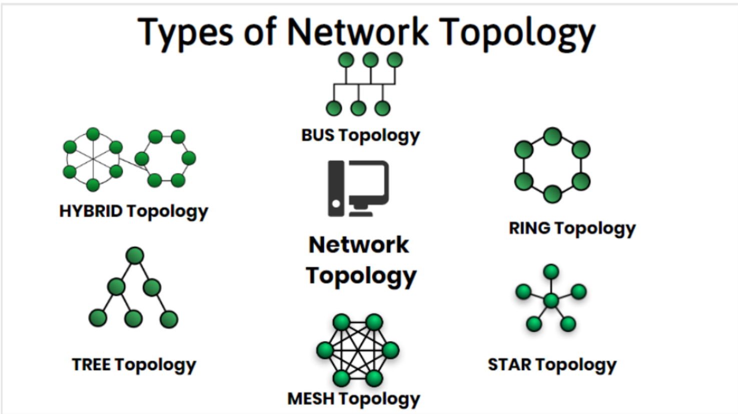
What I’ve described above speaks of a macro way to document the fiber. Now I will talk of the “network” that should be documented (best practices gotten from various sources).

II 14.10.- Design a network documentation policy

This policy should detail what network components must be documented, especially each server, switch and router. This also helps to communicate to the network administrators what is exactly expected to be documented and how.

II 14.11.- Create a network topology diagram

Usually, you will have one of these topologies:



With this map as a base, you need to include each network segment, the routers connected to each of them, servers, gateways, and any other major networking hardware piece.
This can be done quickly for smaller networks on one map, but the segments must be done separately from the main map for more extensive networks. Thus each segment will have its map.

This policy should detail what network components must be documented, especially each server, switch, and router. This also helps to communicate to the network administrators what is exactly expected to be documented and how.

II 14.12.- Document server names, roles, and IP addresses

The "must-have" information is the server's name, IP address, and role(DHCP, DNS) of the server on the network diagram.
Keep in mind that each server can have different NIC cards or even be used for multi-purposes. All of that should be documented.
All the other information from that server (like OS version, patches, and any additional information that's not needed immediately) should be documented as an appendix.

II 14.13.- Changelog for every server

Anything done on the server, being that a part replaced, patches, applications installed, modified settings should be logged and documented. Any future issues with the server can be better troubleshot with that information at hand.
It will also help in case a rebuild is needed.

II 14.14.- SW versions and licenses

Each application version running on the server must be kept on the documentation. One good praxis is to keep the SW license and receipt of that SW if an audit is needed.

II 14.15.- Hardware Component

Every component must be documented, and the information needed is:

- How and where is the device connected to the network.
- The device configuration
- Does a backup exist? The device itself and the configuration.
- Firmware running.

II 14.16.- Document your backup procedures

Backups of everything are a must. It is the best defense against catastrophes.
The backup section of the documentation should have the software being used, where the server is doing the backup, the information on how the SW is used, what version it is being used.
If there are Tape backups, document the rotation scheme, what is on each tape, and where are stored.

II 14.17.- Label everything

Besides the documentation, you need to physically label each cable, server, tray, gateways, routers, switches.
The easier to ID any component, the better. Remember that in a crowded DC, everything looks identical!.

II 14.18.- Evaluate your documentation

Once the documentation is ready (and even before that), you evaluate if the information is enough, if something is missing, or even sufficient for the customer's needs.
The documentation must be thought of as a critical part of DR(Disaster recovery).
Once it has been completed, do a peer review and ask the people involved in the network installation, backup, troubleshooting to check and add any comments.
The last part is to check if that document is good enough for even an L1 engineer, without understanding how the network is set up, to rebuild the network or any part

of it if a calamity strikes. If ELI5 (explain like I am 5), consider it a good job creating the documentation.

II 14.19.- Critical network documentation

II 14.19.1.- Layer 1 and 2 diagram

Layer 1 diagram shows the physical interconnections between network equipment. It includes link speeds, cabling type, type of connector—also individual port numbers and designations. Usually, When drawing faster, links are depicted with thicker lines, and different colors are used for fiber, copper, Ethernet, storage. This sketch and how the colors and lines are used must be shown on the diagram.
Layer 2 includes the VLAN numbers, link aggregation, and trunk connections. It will also have the spanning-tree information such as root bridge and link priorities which are not default.
Often layer one and layer two diagrams are drawn together.
Layer 3 includes IP segments and all the network devices interconnected. Also should have all layer three switches, routers, firewalls. IP portions should indicate any VLAN ID number and a brief description of the intended function. IP network and a mask are a must. And IPV6 IP if you are using them(at this age, you should)
Redundancy should be indicated too. If you are using VRRP or any other vendor redundancy, they must be on the diagram.

These must-have diagrams and the minimum information they should hold, but it all boils down on how you want to do it. They can have more information but remember to document everything that's important on your network.

II 14.19.2.- Circuit number table

Another critical documentation to have, if you own any WAN circuits or voice, should be documented. This list should have the circuit number and provider and any information on where the circuit goes.
If you have MPLS, this must be on the diagram and should include all the MPLS provisioning information. If this is an internet circuit, the information can vary depending on the provider.
Point-to-point should contain what's on the other side.
It's also good to have any phone number from the provider if any circuits go down to get a hold of support. Special support contract information should be here too.

II 14.19.3.- IP address allocation table

You can use a spreadsheet or database or any SW for this purpose, including all the internal and external IPV4 and IPV6.
Every subnet should be registered separately. Individual devices must be recorded.
If you are using DHCP, you must include the DHCP pool of addresses and the devices that get the address from DHCP.

Static address "MUST" be recorded!
It is also vital for any network to "reserve" addresses for the future and what particular purpose they will fill. Any address not used should be recorded too. To avoid conflicts and giving the same address twice.
NAT addresses must be recorded too, and what they do and used for. If you have multiple DMZ or devices mapped to a single external address using different ports, that must be recorded. Each NAT rule should be recorded.

II 14.19.4.- Rack layout diagram

The rack layout shows the server room and wiring closets and all the equipment and patch panels information. If you have equipment accessible from the front and the back of the cabinet, they must be recorded as such—diagrams from front and back.
The layout must include the numerical position on the rack.
This layout will be used to plan where the next equipment will be installed, tell the technician and IT staff where the equipment is, and when you need to power off one of the devices not to shut down the wrong one.

II 14.19.5.- WiFi diagram

WiFi should be documented too, every enterprise out there uses WiFi for many of the devices. You should document the components, floor layout, and the physical location of the APs with the RF radiation pattern. This is useful if you are using special antennas with different radiation patterns.
It will also include the SSIDs, the purpose of the WiFi, and the security mechanism.

II 14.19.6.- Cable plan

The cable plan shows the jack numbers to the ports' physical location on the user's desktop and will also have the wall plate number.

II 14.19.7.- Routing protocol diagram

Routing should have its diagram too. If you are using OSPF, BGP, or any routing protocol, they should have their diagram.
The diagram should have the AS systems, internal areas, redistribution points, and any particular feature as router tagging or filtering.

II 14.19.8.- Security diagram

In the layer three diagrams, you have firewalls. However, it is handy to have a security diagram with any other security features you have, like IDS/IPS devices, active or passive taps.
This section can also have firewall rules, log servers, and SIEM solutions.

II 14.19.9.- Cloud services diagram

If you have any cloud services like AWS, Azure, G-Cloud, they must be documented. This diagram should include any security zones, virtual servers, networks, firewalls, load balancers, WAF devices, or any other cloud services; they must be in here.
If you manage VPNs between the cloud and the internal network, it is imperative to document everything about it.

II 14.19.10.- Patching table

You can have many different cables running in a DC like fiber, copper, Twinax, InfiniBand. All those should be documented to prevent any failures or fix them quickly.
The minimum recommended information to have is:

- Where is the port connected to
- ID on those ports
- ID on the cables
- Patch cord used
- Type of cable in detail (copper, ethernet, fiber SM or MM)
- Connector types

II 14.19.11.- Asset tracking

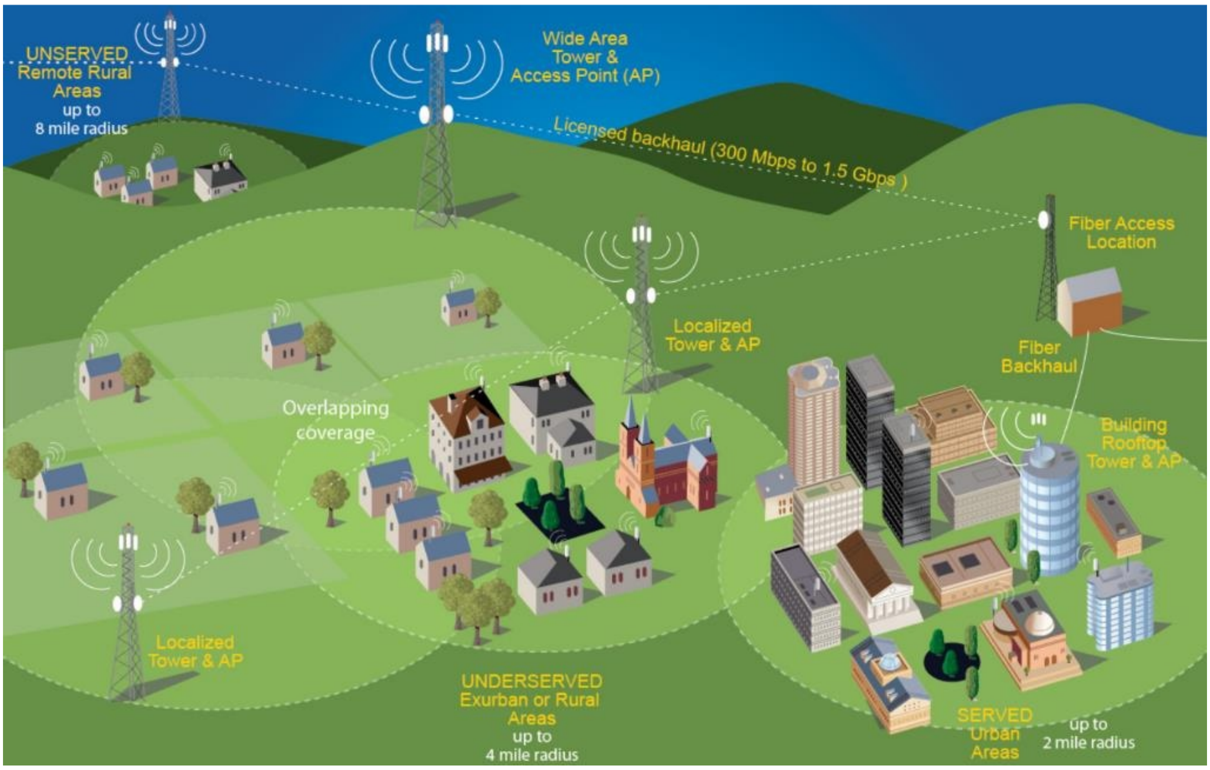
This table must have the manufacturer name, model, serial numbers, and license numbers to identify installed and owned equipment.
It also has the support contracts and the information needed to contact them.

II 14.19.12.- Password vault

Most of the passwords used should be documented, but not in plain text format, and you should use a vault or any other SW like it.
There are occasions you will use static passwords and credentials on your network devices, most of the time, you will use an authentication system, but sometimes you won't. Moreover, for those times when things break, password vaults must be documented thoroughly.

II 15.- Introduction to WISP

WISP technology “Fixed wireless internet service providers” (WISPs) deliver reliable, affordable broadband to customers in fixed locations such as residences, businesses, and schools.”



Taken from wispa.org

II 16.- What WISP is:

It is Wireless internet. Know as WiFi (or any other Wireless technology from) created to operate over 900MHz, 2.4Ghz, 4.9Ghz, 5Ghz, 24Ghz, and 60GHz bands in the unlicensed/licensed frequencies of the UHF band and other bands from 6Ghz to 80Ghz.

Radio waves that travel through the air from a source tower are received by another tower or sent to another to fill the gap(called backhaul/backbone). The last tower sends the signal to your antenna installed at your location and then provided to you via a network cable(Fiber most of the time) to your wireless router.

It uses line-of-sight point-to-point and point-to-multipoint microwave links between their towers and millimeter-wave links for transmitting and receiving signals to the customer.

WISP uses either WiFi, LTE, future 5G, or unlicensed spectrum band at 900 MHz, along with 2.4 and 5 GHz between the tower and subscriber and higher millimeter-wave frequencies for the tower-to-tower links (30GHz to 300GHz).

The customer has a transceiver(which translates the signal captured on the dish) and a directional antenna(or dish that captures the signal), which is mounted

outdoors with line of sight to the tower providing access to the internet. A cable(usually fiber, can be ethernet) then connects to a modem or router.
Download speeds are increasing, and today top out at about 30 Mb/s(some more now with 5Ghz or 60GHz spectrum)

One of the biggest problems with WISP right now is the "channel crowding," right now the 900 Mhz, 2.4ghz spectrum is heavily overfilled, too many clients leaving little bandwidth available and adding interferences from many sources (the 2.4GHz band has the most problems, this is not only used by WiFi but old cordless phones, garage doors, baby monitors and many other devices. This causes much congestion and may end up in dropped connections and slower speeds.

A typical WISP installation can consist of an initial fiber point of distribution connected to an antenna that will transmit a signal to another antenna (this is going to be a backhaul connection). The final antenna sends the signal to the customer antenna, which will connect via fiber cable to the customer router.

Alternatively, you might want to use 4g technology to transmit the 4g signals to as many towers as necessary till you get to the customer antenna or any other technology. The antennas work as relays to any signal you want to send from any technology.

The WISP speed depends on factors like Line of sight (there cannot be anything between the tower signal and the customer antenna/dish. If you are using a 5GHz signal, you cannot have branches, buildings in between. The signal degrades/attenuates more than a 900 MHz or 2.4 GHz signal. The attenuation values can even be different within the same material when comparing signal loss for 2.4GHz vs. 5GHz bands.
As frequency increases, path loss increases. With materials, it's the same. As frequency increases from 2.4GHz band to 5 GHz band, transmission loss will also increase.

That's why the planning part of the WISP installation must be done. Taking into consideration the LOS, it must be as free as possible from any obstructions.
You also have to consider the spectrum you will use. 900MHz and 2.4GHz must be avoided at all costs, which leaves the higher unlicensed bandwidth or pay for a licensed spectrum, increasing the costs substantially.

II 17.- Why choose WISP

Just like laying FTTH, WISP comes to fill the void left by the ISPs in rural towns or any place without access to reliable internet (ADSL mostly). If you cannot get there using fiber, WISP is an excellent option to do it.
The big difference here is that WISP can be the cheaper option and get to the farthest towns sooner than fiber. Building towers and setting up antennas is far easier than digging trenches or installing fiber on poles or high tension towers.
WISP will be used on the last mile and can be used alongside other technologies to get to the user's home.
WISP is the sole bridge in the internet divide. We all know that ADSL is subpar to fiber. The coaxial advantage is that it can handle TV packages, and that's it. With coaxial, you still need to dig trenches or set them on poles). We cannot ask for higher speeds because the big ISPs won't add more resources to the already exhausted technology. After all, that won't bring them more money.
Right now, there is a spectrum divide and a fight to free some of them as unlicensed since paying for a licensed spectrum is far too prohibitive.
WISP covers that, at this age, we don't need any more TV bundles or phone lines. High internet speeds can give us IP phones, Netflix or any other streaming sites, online music, or youtube. That's why it's imperative to put more resources on these technologies till we can get everyone with fiber.

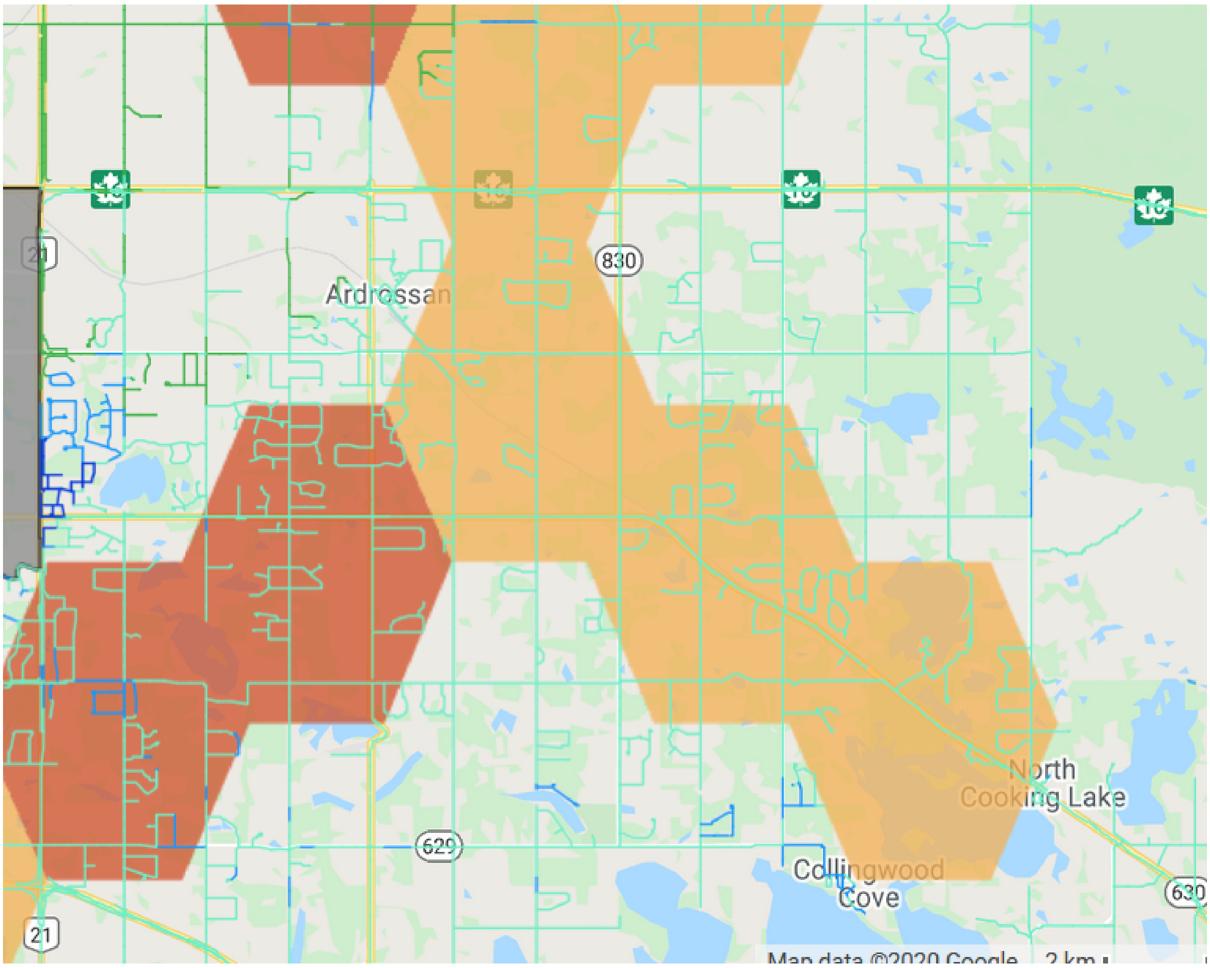
WISP brings better connectivity, bringing more jobs, economic growth for the business, and people to rural areas that do not have and won't have fiber installations any time soon.
Therefore WISP right now covers that big gap left by the big ISP's inability to invest more resources to increase bandwidth and speeds.

One thing to remember is that WISP is better suited for rural areas free of obstacles. This is not made to be used in high-density areas with buildings or too many trees. We can use an antenna to connect to facilities where fiber is prohibitive (if you want to cross a road), but it won't be a good option in crowded areas where there is no line of sight.

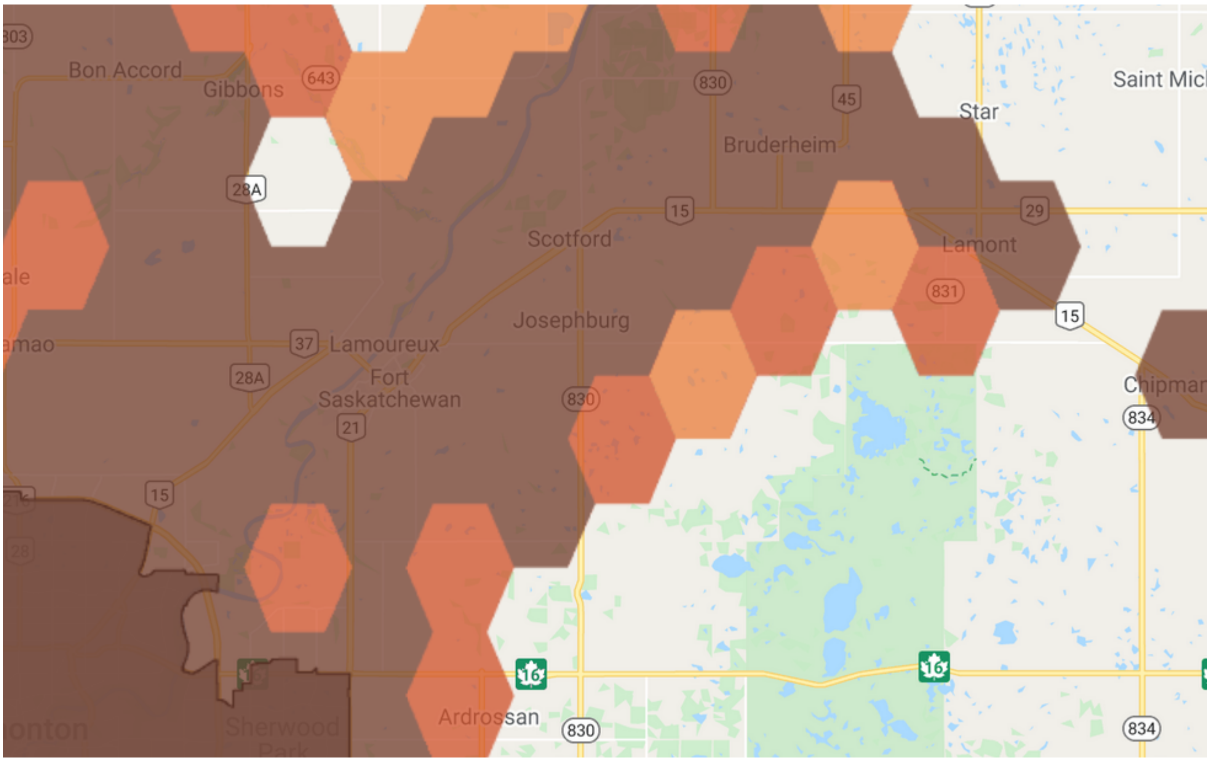
One of WISP’s good things is that you can set up a company with few people or do it alone. Of course, it could be a significant endeavor but working alone or with one other person, you will see returns and a higher cash flow that will help increase the workers, towers, reliability, coverage, bandwidth.

II 18.- WISP Map

As we saw with fiber, there is a map available to check the technologies at one's disposal in any part of Canada.

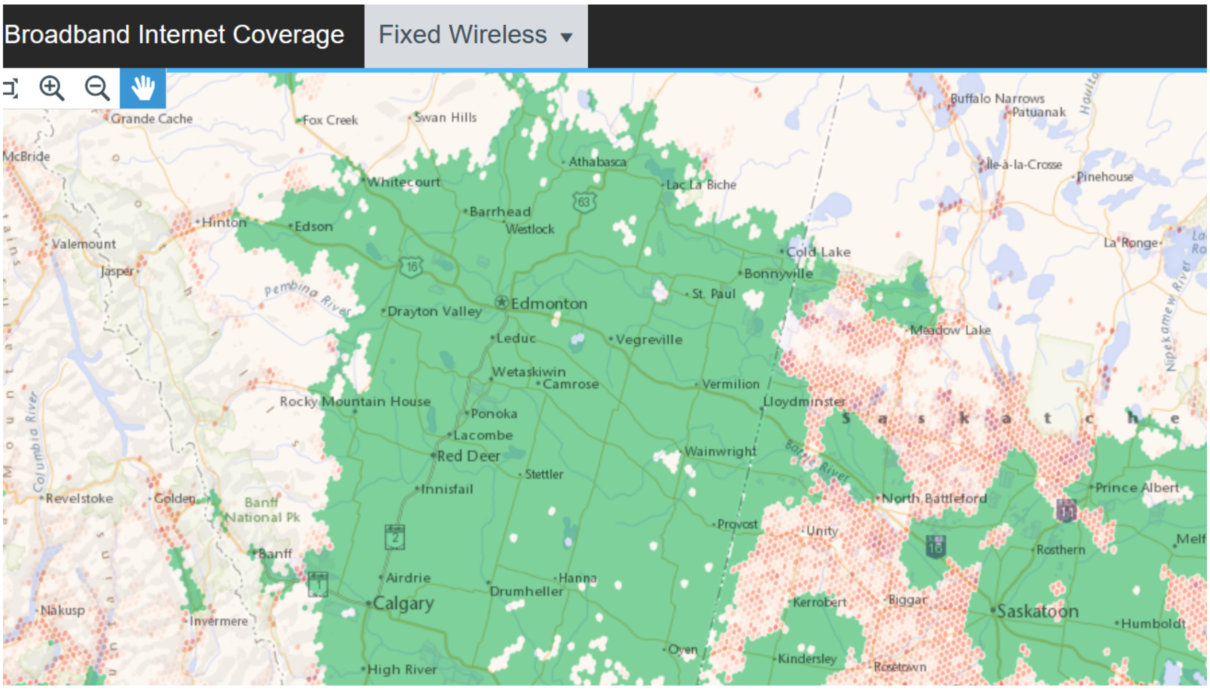


From the page, we get that light orange color is >25% to 50% coverage for 50/10 speeds, and dark orange is >50% to 75% coverage.
This map shows the wireless coverage, which translates to where we can get funding and where to set up my own WISP.



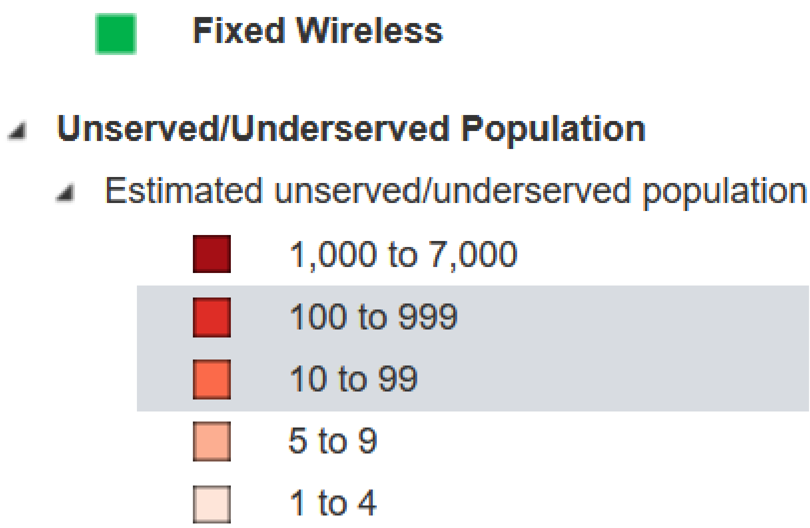
On this map, I can see that the coverage is >75% to 100% for 50/10 outside of the Edmonton area (where the black box is on the lower-left corner)
The map clearly shows where there are options to increase one business.

Coverage map (check fixed-wireless option)



This map shows wireless technology coverage (you can also check for Cable, fiber) in Green, and the red dots are the underserved areas with population.

This is an excellent tool that can be used alongside the previous map to fully cover what's necessary to create a new business plan.



II 19.- WISP in depth

There are three major licensed frequency bands available for WISPs to provide coverage to customers, and a fourth is gaining acceptance for large trunk links. Spectrum bands are described in terms of their frequency range; the ranges stay the same in most regions, while details such as channel availability vary widely between jurisdictions.
The most used bands are 900Mhz, 2.4Ghz, and 5.8Ghz. There are proposals to free the 6Ghz spectrum as unlicensed still in the works.

II 19.1.- 900 Mhz

Old cordless phones, SCADA systems usually use the 900Mhz, and WISP, which provides the "last mile" too tricky and away from fiber internet customers. 900Mhz was one of the first unlicensed spectrum made available to WISPs. Unfortunately, it's highly congested, and sometimes this is the only option available to many customers in rural areas since nothing else is accessible. The 900Mhz does an outstanding job of penetrating foliage, walls, small/low obstacles. But the 900Mhz is relatively tiny, so it's typically left for high-bandwidth links or servicing multiple customers from a single site.

II 19.2.- 2.4Ghz

WiFi is the most known technology that uses the 2.4Ghz spectrum. Like 900Mhz band, it offers a good foliage penetration potential and can go through most walls and obstacles. But just like the 900Mhz band, it's highly congested, noisy because it's used all around us. Imagine a high building with 200 apartments. All of them will have WiFi. And which band do you think they use? 2.4Ghz.

Just like the 900Mhz band, 2.4Ghz are used by many other types of equipment like baby monitors, cordless phones. Bluetooth uses this band too (the only difference is that Bluetooth hops in the signal so it won't be much of an impact, and it uses the 2.45Ghz band)

A word of caution! With the bands mentioned above:
None of the ones mentioned is an excellent idea to use at this time and age, 900Mhz is too crowded, and it's slow. With 2.4Ghz is the same, they are not to be used by any WISP. There are better unlicensed options out there and equipment for them(5.8Ghz, 24Ghz, 60Ghz).

II 19.3.- 5.8Ghz

The 5.8Ghz band is famous among WISPs. It offers very high speeds and bandwidth but very low penetration. With 5Ghz, the foliage of a tree can disable a signal and won't reach the customer. Coated windows, walls will cause problems, so good planning and high
towers are necessary, which is not bad because that same aspect becomes a noise-free and largely uncongested spectrum.
Some companies are offering equipment that can achieve 1.7 Gbps to the customer, which matches fiber speeds where a single radio can serve up to 100 users using channel bandwidth between 20 and 80 Mhz in the 5.8Ghz band. This is achieved thanks to 5.8Ghz new techniques like MIMO, MU-MIMO, dynamic spectrum management, mmWave radios.II 19.4.- 24Ghz
The 24Ghz band is used for high-speed PTP links over relatively short distances (8 km and less. 24ghz is susceptible to rain fade and weather). This band provides a very high bandwidth (1.5gbps) with very little noise. Just like 5Ghz, this signal does not penetrate obstacles nor foliage.
Most WISPs use the 24Ghz or greater for backhaul links between antennas.

Band	Advantages	Disadvantages
900 Mhz	Good penetration of obstacles.	Often noisy, small band available.
2.4 Ghz	OK penetration of obstacles.	Often very noisy, medium band available.
5.8 Ghz	Often quite clean, large band available.	Poor penetration of obstacles.
24 Ghz	Generally very clean.	No penetration of obstacles.

One good thing about WISP is that you can use multiple towers called "Relay towers," and you can hop between them. A good plan will be to install towers 25km

or less apart from each other if you have a good line of sight with nothing blocking the signal, you can set up a good backbone.
And just like fiber, you need a plan for redundancy because setting up towers along the main road, and one of them is down, you will lose a connection right away. Planning, redundancy, and disaster recovery plan are a must.

There is a lot of planning. First, you need to plan how to make money. Then how many customers per antenna, the download speeds you will offer.
You need to know the numbers! Prepare for the worst and create a plan for everything.
If you are going to compete against Cable/DSL in towns/cities, that's probably not a wise idea.
Cable/DSL already has everything to offer better internet plans alongside TV and phone, so selling only internet at the same price won't get you anywhere.
Check the competition! , if you think you can do better and offer way better download speeds, you will surely win many customers.
Which takes us to avoid growing too fast. Most companies try to sell service more quickly than they can build towers or add new Access Points, which will be detrimental for the service. Remember that with too many people on the same channel, the spectrum will consume the bandwidth very, very fast.

II 19.5.- WISP advantages/ disadvantages chart

PROS	CONS
Almost on par with fiber, but the RF component makes it less reliable	Crowded spectrums
Fantastic on good weather areas	Licensed Bands
It can be installed faster and easier than any other technology	Obstacles can decrease a signal really fast
With good planning, the speed can be on par with fiber	Signal decreases with bad weather
Way more reliable than Satellite	Antennas need to be high to achieve a good LOS, meaning that technicians have to climb, adding some danger to the mix.
Cheaper than sending a satellite	Need more QoS and to carefully assign bandwidth
Very easy to install and connect a customer	One point of access for each customer(one antenna they connect to)

II 19.6.- WISP components speed chart

WISP download/upload speeds, like any other technology, are at the 1G at most. Some expensive antennas can achieve more, but they are really, really expensive and the case use changes depending on the distance.
For the price of those antennas(30k some of them), it will be better to plan a Fiber installation.
The higher the spectrum, the lower the distance! This is the real problem and the use of unlicensed spectrum, which in some countries is not possible.
So instead, I will talk here about OVERSUBSCRIPTION, which must be done in any WISP.

II 19.6.1.- Oversubscription

Let's say you have a layer two network with access SW and a central core SW. The access SW has 24 user ports and one uplink port. The uplink is connected to the core switch.
Each access switch has 24 - 1Gb user ports and a 10 GB uplink port. So if all the users transmitted to the server simultaneously, they would require 24Gb of bandwidth (24 x 1Gb), but the uplink is only 10Gb, limiting the maximum bandwidth to all the user ports.
We say then the uplink port is "oversubscribed" because the maximum bandwidth (24Gb) is significantly higher than the bandwidth available (10Gb).
Oversubscription is demonstrated as a ratio of required bandwidth to available bandwidth.
To sum up, it should be 24Gb / 10Gb or 2:4:1.
This oversubscription idea is based on the fact that, statistically, not all ports require the max bandwidth at the same time.
This is not a configuration. This is something you need to consider where the uplink is limited. The network topology should account for that in technologies like WISP, where the bandwidth is scarce.

Oversubscription should be closely monitored. The only way to know when you hit the maximum throughput you have and can offer is by monitoring.
That way, you will know when and where you need to grow, where to set up new antennas, where the congestion is, and what time of the day you need more bandwidth.

II 20.- Wisp HW components

This section will discuss the different components that make a WISP network and what to keep in mind when choosing them.
There are different technologies on each component. Having them all will result in more expensive equipment, so it's important to know what you need and what's required to create a WISP network.

II 20.1.- Antennas

The antenna is the main actor on a WISP network. More than a router or switch because the antenna's quality will determine how good the service will be.
There are many options to choose from. The antennas we will see will be from Ubiquiti, mimosa, and cambium.

What spectrum to use
The antennas for backhaul will either be 24Ghz or 60Ghz. 24G has the advantage it doesn't suffer from interference as much as 60Ghz and has a longer distance.

Align antennas:

- Google Earth to measure distances and heights.
- A GPS.
- And whatever software your antenna uses to calibrate.

Ensure the antennas are aligned to the center of the signal path and angle and on the same level plane.
The network designer must calculate the Free loss path, EIRP, Fresnel zone, and link budget to use and use them well. They are quickly done, and some manufacturers are offering free tools to design and do some of the calculations.

II 20.1.1.- Free Path Loss

The formula used to calculate FSPL in dB at a given distance is:

FSPL (dB) = $10\log10[(4\pi df/c)]^2$
d = distance (m)
f = frequency (Hz)
c = speed of light (m)

or

FSPL(dB)=20log(d)+20log(f)+32.44

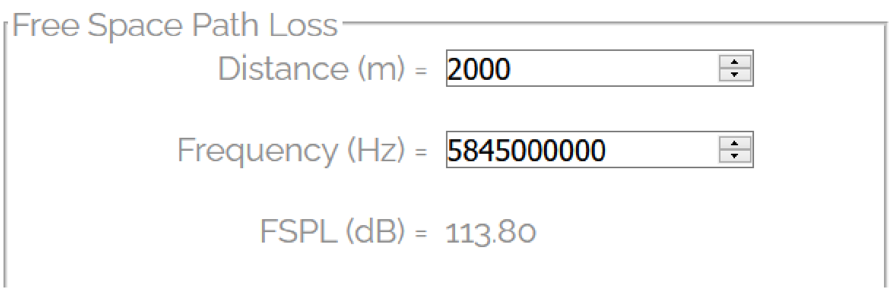
or adding the antenna gain
F=20log(d)+20log(f)+32.44−Gtx−Grx

Frequencies are chosen depending on the available unused WiFi spectrum at the antenna sites.

Example:

Link 1
d = 1700m
f = 5,845,000,000Hz
c = 299792458m
FSPL (dB) = $10\log10[(4\pi(1700m)(5,845,000,000Hz))/(299792458m)]^2$
FSPL (dB) = 111.9737 dB ≈ 112 dB

Link 2
d = 2000m
f = 5,785,000,000Hz
c = 299792458m
FSPL (dB) = $10\log10[(4\pi(1640m)(5,785,000,000Hz))/(299792458m)]^2$
FSPL (dB) = 113.80 dB

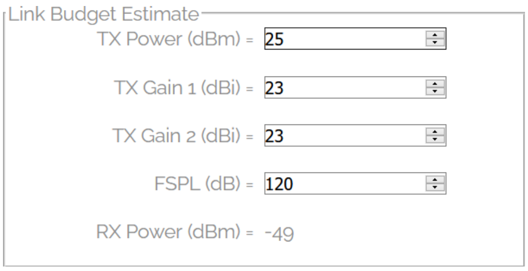


II 20.1.2.- Link Budget

There are some variables that we need to calculate on each antenna installation. These are path loss, transmit power, and antenna gain.
This is the formula that can help us calculate the RX signal strength for outdoor links>
RX signal strength = TX power + antenna gains - path loss
Let us see an example using two Ubiquiti 5Ghz TDMA with AirMax(this is a proprietary protocol)

Link 1:
2 x Ubiquiti PowerBeam PBE-5AC-500
TX power = 25dBm
TX antenna gain = 23dBi
Path loss = 120dB ->this comes from the Free loss calculation

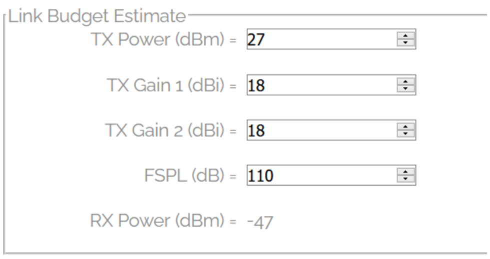
RX signal strength = 25dBm + (23 dBi + 23dBi) - 120dB
RX signal strength = -49dBm



Link 2:
2 x Ubiquiti NanoBeam NBE-5AC-19
TX power = 27dBm
TX antenna gain = 18dBi
Path loss = 110dB

RX signal strength = 27dBm + (18 dBi + 18dBi) - 110dB
RX signal strength = -48dBm

For achieving maximum performance, we recommend keeping the signal strength between -40dBm and -60dBm.



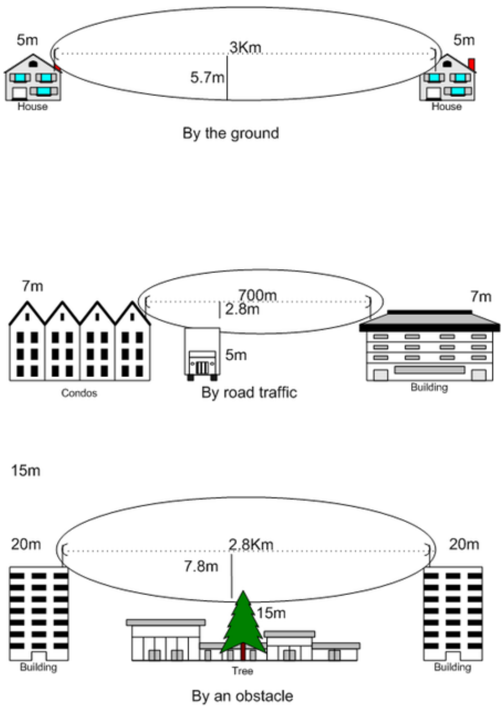
Now we have two calculations that will help us understand where we can install our antennas.

The 3rd one is the Fresnel Zone Calculations.

In short, the Fresnel zone will tell us how high shall the antenna be to avoid the obstacles in the first zone.

II 20.1.3.- Fresnel Zone

“Radiofrequency line of sight is defined by Fresnel Zones, which are ellipse-shaped areas betwixt two antennas. The calculation shows the radius of the Fresnel Zone at its widest point. The distance between the two antennas and the frequency of operation is required to compute the radius of the Fresnel Zone.”

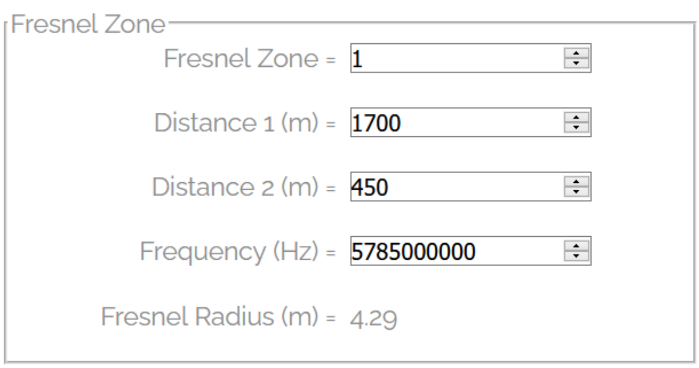


Taken from https://en.wikipedia.org/wiki/Fresnel_zone

For example, if we wanted to set two antennas on top of a lake, we will need to calculate the Fresnel zone to avoid it since it's a reflective surface.

Using the example of Link 1 d = 1700m and height of 450m.
Calculations we have that the first zone is at 4.29 meters. You should set the antenna at that height or higher.
"The primary Fresnel zone is required to be at least 60% clear of any obstruction to ensure the highest performance of the wireless link."

Radius of N (m) = $\sqrt{[(N)(\lambda)(d1)(d2)/(d1+d2)}$
N = Fresnel zone (e.g., 1 = first 2 = second)
λ = Wavelength (m)
d1 = Distance from radio 1
d2 = Distance from radio 2



II 20.1.4.- EIRP Calculation

With the calculations done and regulations being checked for your area, it's time to see if the calculations meet the legal disposition in place. First, we calculate the Effective Isotropic Radiated Power (EIRP). The formula is provided below:

EIRP = TX Transmitter Pw + TX antenna gain - Attenuation
(Loss, e.g., cables, connectors)

Note: Many Ubiquiti hardware has the transmitter integrated into the antenna and so there are no cables. Attenuation can be set to 0 or 1dB of loss.

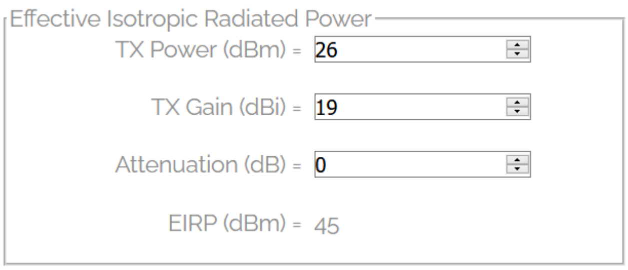
Link 1:
PowerBeam PBE-5AC-500
TX power = 22dBm
TX antenna gain = 27dBi

EIRP = 22dBm + 27dBi - 0dB
EIRP = 49 dBm -> This is OK for PtP Links

Link 2:
NanoBeam NBE-5AC-19
TX power = 26dBm
TX antenna gain = 19dBi

EIRP = 26dBm + 19dBi - 0dB
EIRP = 45 dBm -> This must be lowered when using PtmP links(1w = 36dBm)

Summing-up
Both links are well within the legal requirements for PtP links of 53dBm total EIRP. But link two will possibly have multiple clients connected to the same antenna and become a PtMP link. In that case, the TX power will need to be reduced to meet the legal total EIRP of 36dBm for PtMP links. To calculate the maximum TX power allowed, use the following calculation:



II 20.2.- Wider Beam

When using PtmP links, you should choose between a broader or narrower beam. Usually, you would select a narrow beam to serve fewer people but with the ability to focus only on them.
And you will use a wider one if you have houses with too much spread and don't want to use two narrow beam antennas.

II 20.3.- DownTilt

There are some antennas with the capability to move up and down and tilt the RF beam to avoid flooding the radar space (when there are radars bases near the town, you want to serve with WISP).

II 20.4.- DFS (Dynamic Frequency Selection)

DFS (Dynamic Frequency Selection) is a method that allows wireless LANs to coexist with radar systems. As the name says, it changes the channel automatically to avoid issues with the radars.
In Canada, any Wi-Fi devices operating on channels 52-64, 100-116, and 132-140 have to employ a DFS radar detection mechanism.

Analyze the sector where you will install the antenna
Environmental challenges like the wind can hurt any antenna by moving them, so you need to choose a good spot to install them and a sturdy base.

II 20.5.- Use MIMO or MU-MIMO antennas

If you can buy them, use them.
To put it simply, MU-MIMO gives an AP the ability to communicate with multiple receiving antennas simultaneously "in the downlink," in the same channel, with the same channel size.

II 20.6.- Full Duplex for backhaul

To achieve this, we need A dual antenna! One used for sending and the other for receiving.
Some antennas have different sized dishes, some smaller antenna on the bottom transmits, and the larger antenna on the top receives.

II 20.7.- Avoid Omni antennas

Always use directional antennas which focus energy on one particular direction. This will help you to send the signal only where you want to.

II 20.8.- Now let's check an antenna in detail:

https://www.cambiumnetworks.com/products/epmp/epmp-3000/

ePMP™ 3000 Access Point with MU-MIMO (Datasheet https://cdn.cambiumnetworks.com/wp-content/uploads/2020/11/Cambium_Networks_data_sheet_ePMP_3000_Series.pdf)

KEY SPECIFICATIONS:
* MU-MIMO support with peak throughput of 1.2 Gbps
* 256QAM-5/6, 80 MHz support
* Supports a wide frequency range: 4910-5970 MHz
* 802.3at compliant 100/1000BaseT interface
* Frequency re-use with GPS sync, interference mitigation with beam-steering antenna and dynamic filtering

II 20.9.- GPS Sync

GPS Sync stops problems that occur with several access points (APs) that are too close together. When it is enabled, all synchronized APs will transmit simultaneously and receive concurrently. The result is a substantial reduction in co-location interference.

II 20.10.- beam steering antenna

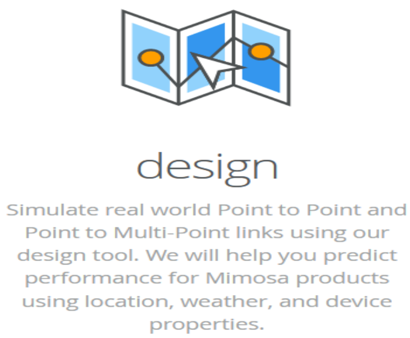
Antenna beamforming allows an antenna system consisting of many individual antennas to have the beam's direction rotate by changing the phase and amplitude of the signals applied to the respective antenna elements in the array.

II 20.11.- Dynamic Interference Filtering

The receiver radio needs adequate filtering. The receiver's ability to 'listen' to the desired signal while blocking out other in-band channel sources is known as radio selectivity.

II 20.12.- Test your PtP-PtmP link

One of the most significant advantages today is that many vendors allow you to create and simulate your own links with accurate live maps and calculate right away all the calculations we already made, friendly and accessible.



Mimosa
https://cloud.mimosa.co/app/welcome.html#/login

Ubiquiti
https://link.ull.com/#

These simulators work as intended and will give you the high-level view you need before installing anything. Still, it’s imperative and necessary "after" doing the simulation to go onsite and check the surrounding area and where you will install your tower.
After that, you will also need to test the links onsite. If there is a big pool of water (like a lake or anything similar), remember that the Fresnel zone will have a massive impact on your signal.

After everything has been done on paper, you "MUST" test onsite your towers and equipment. Everything else (like routing) can be done in simulators(like packet tracer, EVE-NG, GNS3). Still, the actual testing and measurements of the signal must be done on-site.

II 21.- Network topologies to be used

Here will go the most used network topologies on wisp installations and their differences and use cases.

II 21.1.- Centralized WISP Network

One of the most common network topologies used with WISPs is to have one central location or Network Operations Center (NOC) or Point of Presence (POP) for access control, provisioning, activation, and billing business functions.

Like a typical LAN, there is a DC(backhaul) that will distribute the incoming fiber connection from a Big ISP and use DHCP. You can use any IPv4 block you want for your LAN, but one should try to get an IPv4 block to use.

Then on the DC, you will set a giant antenna that will communicate with another, then another, till you get to the customer with your signal. Usually, you will use the

5.8Ghz spectrum to connect an antenna to the customer and a higher unlicensed(24Ghz or 60Ghz) to connect antennas (backhaul)
At the customer's home, you will have another antenna that will get the incoming signal and transmit it through Ethernet or Fiber(even coaxial) to the Client Premise Equipment (CPE).

The connection is point-to-point from customer to ISP's antennas and multipoint-to-point from ISP antenna to customers.

II 21.2.- Mesh WISP network

It is not a good idea for WISPs because, in a mesh configuration, all the antennas communicate with each other, causing the bandwidth to drop and increase any channel's noise and create a CSMA RF hell. Also, using mesh will set your bandwidth to half-duplex right away.
Every link, or "hop," between routers will decrease the bandwidth by half in a mesh network.

II 21.3.- Backup site

There is also an option to run another set of antennas a few KMs away to be used as a backup if there is a problem with the "Main" network.

II 21.4.- Point to Point

A PtP link is a long direct connection between antennas without any impediments or obstacles between them. From a suitable link, you need free LOS between antennas. The PtP is used as the network's backbone connecting the NOC, where the fiber and internet are shared.

II 21.5.- Point to Multipoint

They are used typically to connect the customers to a primary antenna and then to the NOC. An antenna can serve multiple customers.

II 21.6.- Equipment restrictions for each spectrum

There are restrictions on how much power the equipment can use not to cause any interference. Check the local requirements.

II 22.- Bridged or Routing

When choosing a network to deploy WISP, what matters most is how big it will be or how much you will grow in the future—deciding between those two will impact the network to deploy. At first, many WISPs go for a network easy to manage without any routing, choosing only switches and VLANs. But in the end, that will leave no room for growth, and having to change topologies is way more complex and time-consuming than doing it initially.

II 22.1.- Bridged

One of the most common networks used because it only needs L2 equipment, and there is minimal networking knowledge required to make them run.
Just connect a bunch of L2 switches, and you are done.
But there are many limitations and performance issues because they don't scale very well beyond a certain point.
The problems you will face using a bridged network are broadcast storms, ARP storms, subnetting(there is none), no security. It's best to avoid this network if you plan to use something more than a .254 address. (that means that having .253 addresses the performance drops heavily)

II 22.2.- Routing

Routing eliminates the broadcast storms to an extent. Shrinking the broadcast traffic to a smaller collision domain. It utilizes more efficiently, and like the name says, it "Routes," it allows only the packets from and to.
A router can work with QoS, NAT, VLANs, improved security. With routers, you can now control the traffic, which means you can do traffic shaping and Rate limit.
The QoS can also help you prioritize some traffic(Like VoIP and Video) over all the other traffic. Increases scalability, simplifies the troubleshooting, and you can set up failover and redundancy.

II 22.3.- NAT and Double NAT

NAT is something we must live with. Double NAT is a problem that will arise because IPv4 addresses are expensive and scarce.
Probably the IP address you get from your ISP won't be private(most of the time, it will be), so if you know you are under NAT, avoid setting another one.
Double NAT means that you are already behind a NAT(your ISP), then you set a router on your LAN to do NAT again. Double NAT must be avoided! , there won't be any problem with surfing the web, email, and essential things, but problems will arise with Game consoles, cameras, NAS, or any other thing that needs a valid IP and port.

II 22.4.- Plan IP (plan your network IP)

A great deal of work must be done at planning the IP addresses to use on the new network. The link below is an app that can help with the planning, which is like any network planning.
You can use any IP block you want(10.x.x.x, 192.x.x.x, these are the normal ones you see on any enterprise). But one thing to remember, VLANs and a different subnetting for each router and antenna.

II 22.5.- Channels Available

There are three channels available in the 60GHz band in Canada. These channels are 2.16GHz wide:

- 1st channel: from 57.24 GHz to 59.40 GHz.
- 2nd channel: from 59.40 GHz to 61.56 GHz.
- 3rd channel: from 61.56 GHz to 63.72 GHz.

These **60Ghz** links are excellent for short distances up to 1.5km but will be difficult getting any signal at anything more than that. The 1.5Km limit is due to the absorption of the **60GHz** signal by oxygen in the atmosphere.

5.8 GHz spectrum band

UNII3	149	5.745 MHz	Indoor & Outside	1 W	4 W
	153	5.765 MHz	Indoor & Outside	1 W	4 W
	157	5.785 MHz	Indoor & Outside	1 W	4 W
	161	5.805 MHz	Indoor & Outside	1 W	4 W
	165	5.825 MHz	Indoor & Outside	1 W	4 W

II 23.- WISP Network architectures

As we have seen so far, the network architecture won't change from a technology to another. The same architecture that we use on fiber can be used on WISP, be it either star, ring, bus, or any other can be used on any network out there.
To use one or the other will only depend on the terrain, the customer's location, and which one we want to use.
Mainly one can follow the following list when choosing a network topology (physical):

- Budget
- Hardware equipment available
- Implementation Simplicity
- Size of the network
- Reliability and backup
- Future Proof

For more information about the topologies, please check here :
[II 12.- Fiber Network architectures]

II 24- Routing architecture

For the routing architecture to use in a WISP, we first need to know the options available.
For a WISP, we have

- Bridged network
- Static Routing
- OSPF
- BGP
- OSPF/BGP/MPLS (taking advantage of each protocol strength for a large WISP network)

For more in-depth information on each routing protocol, please check here:
III 4.4 Wisp high-level network diagram

II 25.- Documentation

For detailed network documentation, please refer to Fiber documentation.

II 14.- Documentation 58

II 25.1 WISP documentation

Here I will talk only about the documentation WISP should hold. Besides the documentation we talked about in the previous chapter, WISPs must consider the following information that needs to be saved for future troubleshooting.

- Routing configured at the towers.
- Tower configuration
- Backups
- Customers served by a particular tower
- Height of each tower
- Security plan and how each tower is guarded and the Written InformationSecurity Plan

II 25.2 Written Information Security

A WISP should have a document stating how the customer's confidential data is protected, how it is being watched. Who is ensuring it is protected. This WISP technical document should have the administrative and technical safeguards that your organization has in place. Anyone or any inside the company with access to client or employee information must ensure that all that information is secure.

Examples of some administrative safeguards:

- Clarity on how confidential data and is protected
- Where data is located (shared drive, cloud, hard copy format)
- Monitoring access to confidential data and ensuring only the necessary people can access the data
- Roles and responsibilities of how the WISP will respond against a cyber-attack or incident and internal/external procedures to communicate those issues to the customers.

Technical safeguards include:

- Evaluation of technical safeguards (pen testing, encryption, SW patches, tracking documents).
- Implementation of additional technical safeguards is encouraged.

Running a business like this, the complications come on the law side.
If you have doubts, don't hesitate to contact the necessary lawyer that can help you create all the administrative documentation needed.

II 26.- Introduction to LEO

LEO or low earth orbit, That's how we call the earth orbit of 2000 km of altitude or less and where most of the human-made objects in outer space are.
The LEO orbit is between 1000km and as low as 160 km, compared to GEO 35,786 kilometers. To understand how low the LEO orbit is, airplanes do not fly over 14 km.

This orbit is being used because the gravitational pull is slightly less than the earth's gravity. This orbit is easily reachable, more than the other orbits (less rocket fuel needed and latency between an earth antenna to a satellite is very low, and the bandwidth is higher, the energy required to send a signal is lower, compared to MEO or GEO). LEO is far more accessible for servicing crew.

The energy needed to put a satellite into LEO orbit is low compared to other orbits, and a satellite in LEO needs less powerful amplifiers. LEO is used by various communication applications by companies like Iridium(Phone system), Starlink(SpaceX), and Telesat, to name some of them.

With all of this, LEO looks as attractive as it can be since it's an excellent alternative to GEO, which has dominated the commercial and government communication satellite system since 1960. One of the main reasons LEO is gaining more popularity against GEO or even fiber is that the short propagation delay is lower. This is because the speed of electromagnetic wave propagation via LEO satellites is 50% greater than that of light in fiber optic cable. This fact eliminates the long propagation delay property that has become synonymous with GEO communications satellite systems.
Usually, the LEO satellite configuration used is a "Constellation of multiple satellites," which travels at the same speed and communicates with each other. We will see that the constellation looks like a net most of the time. This lets them cover larger areas.

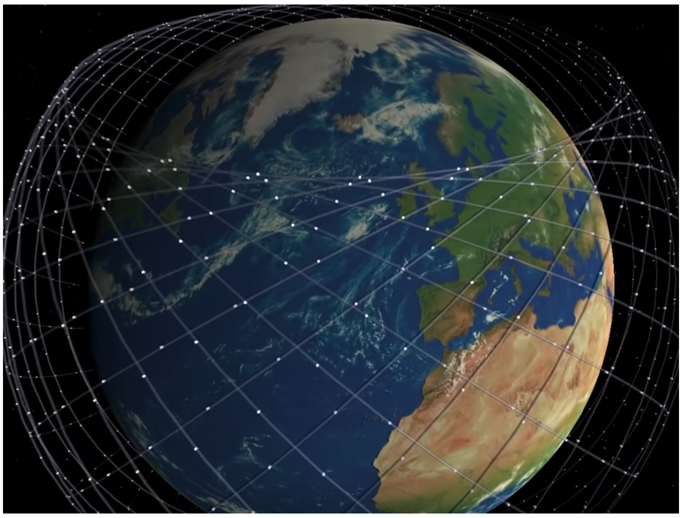


Illustration of the Starlink grid Taken from https://www.youtube.com/watch?v=AdKNCBrkZQ4&feature=emb_title

II 27.- Why choose LEO

Like any other option out there, it all boils down to fill the void left by the fiber unavailability and the use of Laser communications instead of Radio Frequencies. Very much like WISP, LEO satellites are meant to service the rural towns outside the fiber's grasp.

And that's not all. Many practical applications can be delivered by satellite constellation like space-based internet(which is the sole and greater purpose about satellites in LEO orbit), space cybersecurity(Laser instead of RF), AI autonomous vehicles, space-based cloud storage.

Why laser instead of RF? It's all about speed, security, and reliability. We know that at higher RF spectrum, at higher bandwidth, lower reliability, which is severely inhibited by atmospheric attenuation.

Lasers can easily circumvent the atmospheric problem because the available hardware is more mature than RF, and we can reuse the propagation techniques that are already known and quantified.

Also, the security of lasers they are more challenging to detect simply due to physics.

The RF beam transmitted from a LEO satellite is going to be several kilometers wide (around 100 km), while the laser width from the same altitude can be just a mere 300 meters.

And the speed, there are some projects like the User Modem and Amplifier (ILLUMA) project, which says they can achieve 10 to 100 times the throughput of an RF channel (ILLUMA program will be 1.2 Gbps).

Right now, the ISS, through the TDRS(Tracking and Data Relay Satellite), can get speeds of 300 Mbps.

There is also the latency of LEO, which is 30-50 ms round trip compared to GEO: 600-800 ms round trip.

And something to notice, the refractive index (n) in fiber is 47% slower than space (latency won't ever be an issue). Latency is introduced by the electronics and equipment used to send the signal—n=1.47 in typical fiber, n=1.0 in air or vacuum.

Another main reason to use LEO satellites is cheaper access to space in less expensive space-originated data, the smaller satellites (CubeSats/smallsats) operating in a constellation,

use of components off the shelf, new launch business (rideshare)

There is one thing everybody needs to remember. The LEO satellite constellation is not made for urban areas. Congestion on a sole satellite is an issue, just like sharing the same cell tower. Although we talk about using a constellation of satellites, the congestion will be just the same. The antennas on earth are fixed and pointing to the same location where the next satellite will travel.

II 28.- LEO satellite map

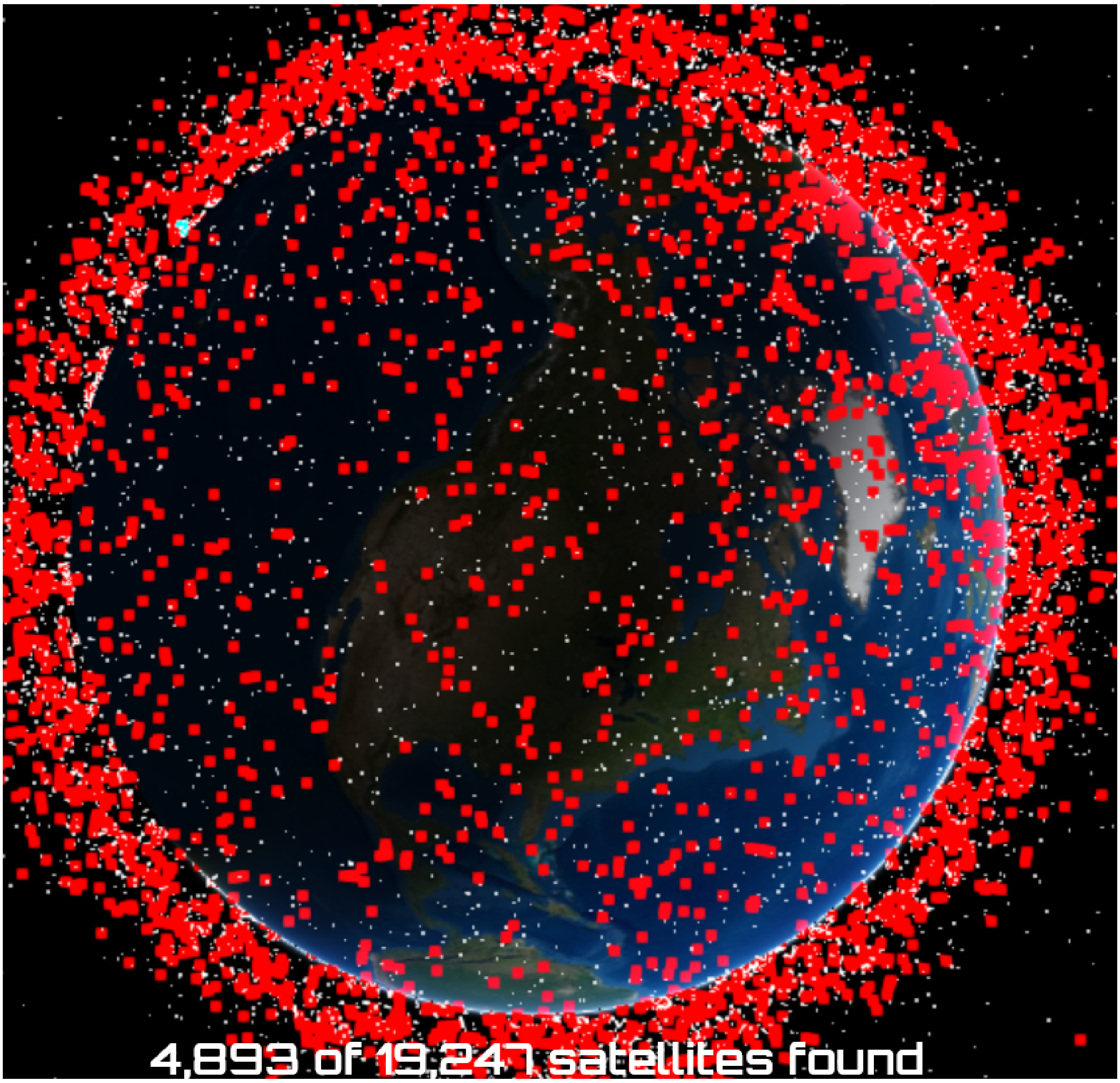
The first link will show the satellites already in orbit, and the RF Band(s) used the position and the satellite service they provide.

You can check the list of Authorized and Approved Canadian Satellites on the ic.gs.ca site.

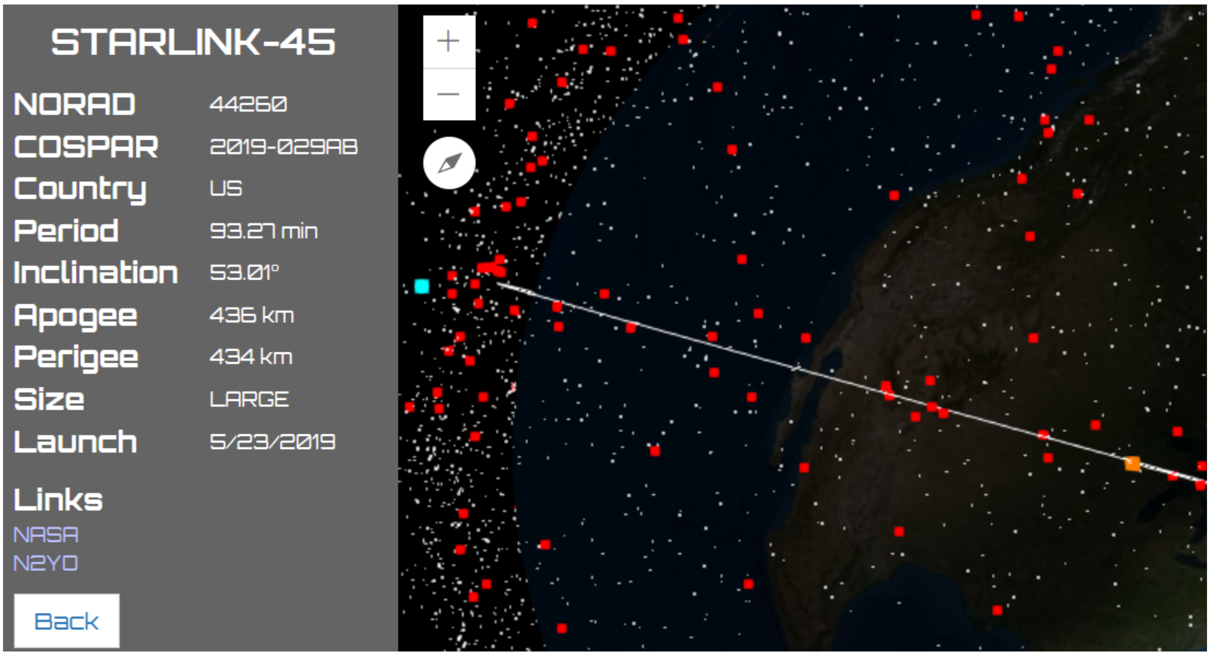
Spectrum management Canada "Provides access to the radiofrequency spectrum by issuing authorities for its use, minimizing interference, securing Canada's access to it through international negotiations, and by ensuring its safe and efficient use."

If you want to get creative, check: https://maps.esrII.com/rc/sat2/index.html

This will give you a complete view of all the satellites in orbit. You can use the filters and get something like this (by selecting the LEO filter and US satellites). There are filters for Starlink too.



Here is with the Starlink filter on:



Starlink "Train" https://findstarlink.com/#247;3

And if you are wondering if you can send your own satellite to space?
You can send your satellite into space with the help of NASA's Cubesat Launch Initiative.
There is also the CubeSat initiative which is very interesting and worth the read

With the following information, you can get a picture of what and where you can get satellite coverage or which RF bands are available to send your satellites.

There is also one thing nobody mentions and very few people talk about, and it's the space debris. The vast amount of smaller satellites with a shorter life than GEO satellites is already a considerable problem. I will talk about how SpaceX and other companies will tackle this problem and how much debris is expected to be created on an already junk, cluttered planet.

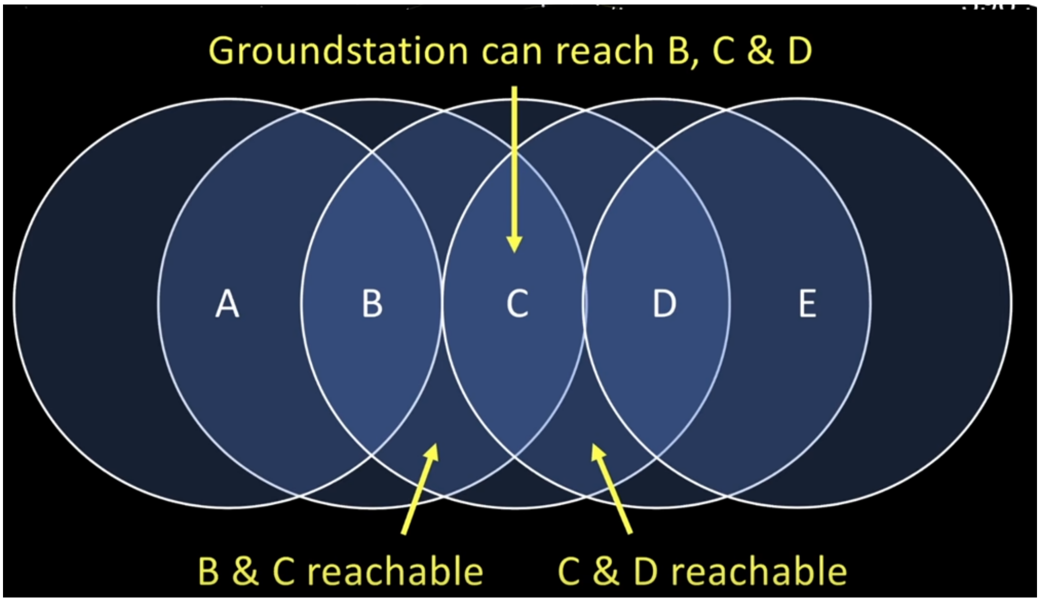
II 29.- LEO in depth

Having your constellation sounds like a good idea, but the price might be prohibitive. It will be far more cost-wise to fund a fiber installation.
But if you want to create your own, I will describe the essentials parts of the satellites and what RF band they can use alongside the capabilities and restrictions.
I will also talk about space optical communication using laser beams.
For all intents and purposes, the primary examples I will use on this part of the project will come from SpaceX since it's the more mature, extravagant, and fully operational on a beta stage.

II 29.1.- What's Starlink?

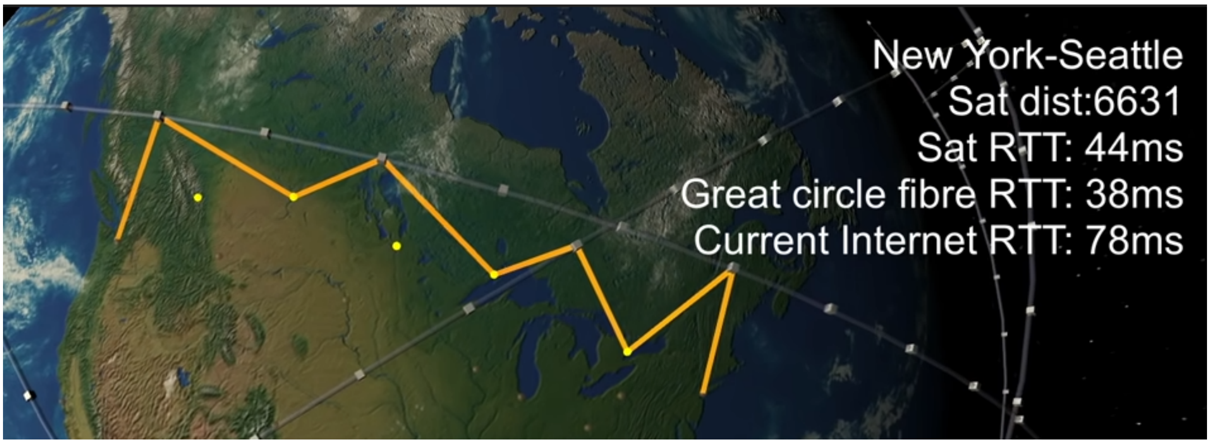
Starlink is a constellation of small satellites (Around 180Kg) that will orbit the earth on the LEO orbit and ground stations that pick up the RF signals.
At the moment, Starlink shares the RF spectrum with OneSat and Telesat satellites.
The equipment used on Starlink is E Band phased array antennas. Opticalinter-satellite links(although the first satellites sent are not equipped with those, the newer ones launched in 2020 can communicate between them using those links).
One of the advantages of the Phased array antennas is one of the most advanced phased array antennas globally, including the military.
How does it work, then? The Antenna on the customer site will communicate with the passing satellite, and that satellite will relay the packets to a ground station and then to another satellite and back. But Starlink will initially bounce signals off ground/ocean relays. They also can use the customer's antennas to relay the packets too.
These packets will bounce from customer antenna to satellite to ground station to satellite and back. The user links will be on the Ku-band, the gateway links on the Ka-band, Optical crosslinks(or inter-satellite links) between satellites(since 2020), and Digital payload with beam steering and shaping capabilities.

The first Starlink satellites did not have the option to use crosslink because of the price. Still, the commitment to get internet everywhere (and business, of course) will put the inter-satellite links on all the new satellites launched in 2021.
One of the latest news in January 2021 is that the new satellites launched on the polar orbit do have inter-satellite links.



Taken from https://youtu.be/m05abdGSOxY By Professor M Handley http://www0.cs.ucl.ac.uk/staff/M.Handley/

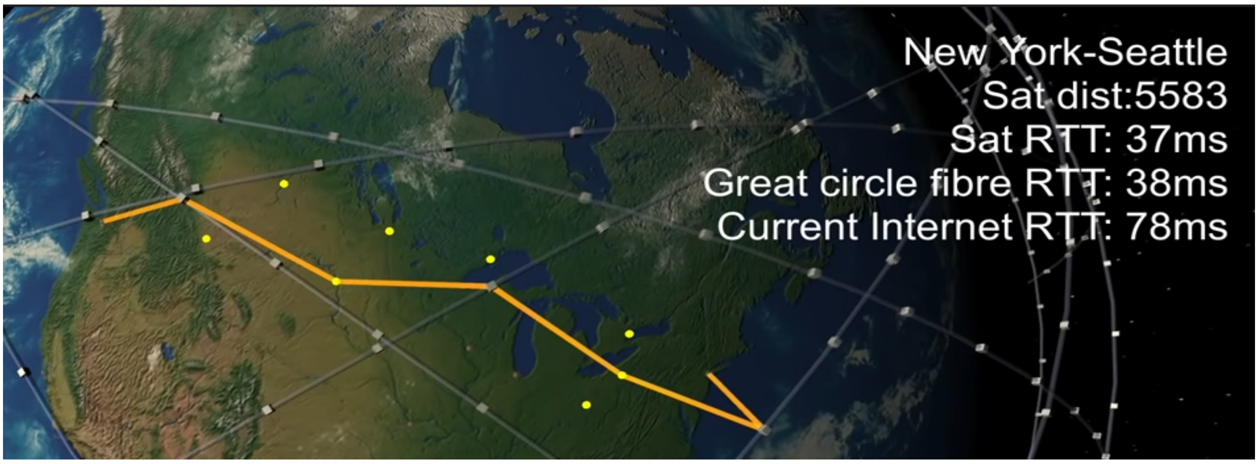
Ground stations are an essential part of Starlink (till the new inter-satellite links are up and running) because they are the ones that will relay the information from one satellite to the other and to the customer.



This is a Latency Simulation of satellite routing using the ground stations.

Taken from https://youtu.be/m05abdGSOxY By Professor M Handley http://www0.cs.ucl.ac.uk/staff/M.Handley/

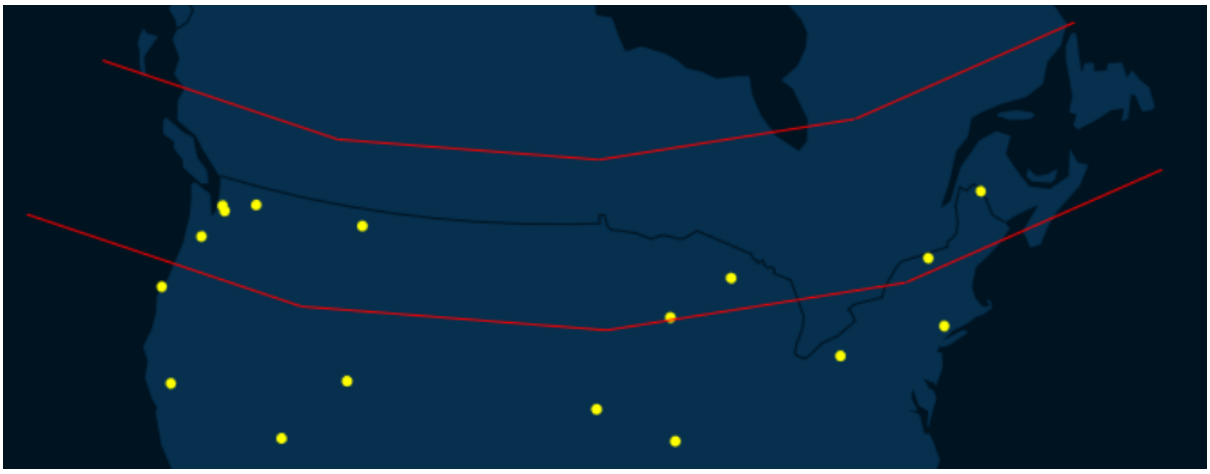
With more Satellites the communication path changes and so does the latency



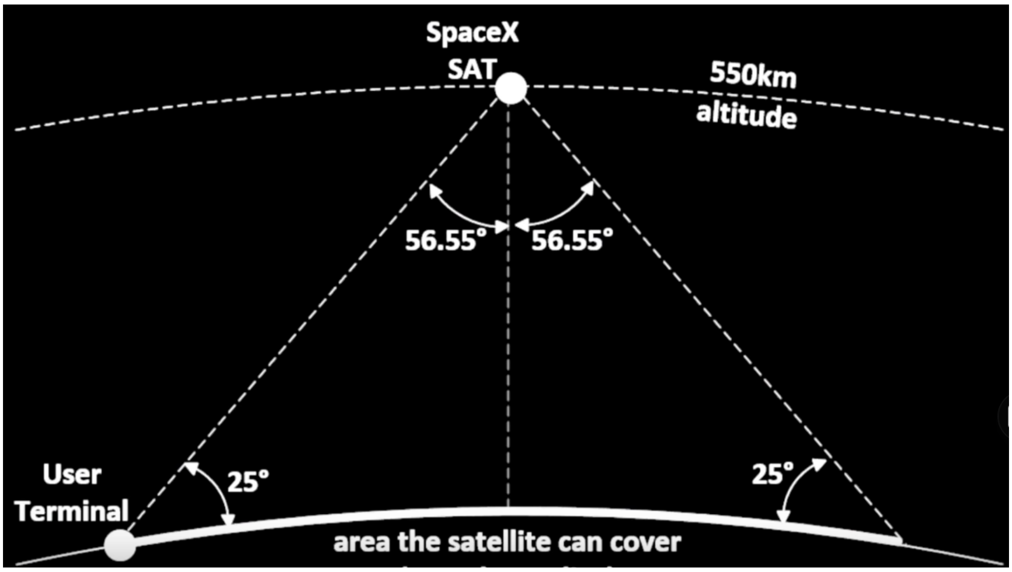
Taken from https://youtu.be/m05abdGSOxY By Professor M Handley http://www0.cs.ucl.ac.uk/staff/M.Handley/

Coverage (In degrees)
Starlink will have a satellite coverage north 70 degrees latitude and south at 55 degrees latitude.

Current Starlink Coverage



Taken from https://satellitemap.space/indexA.html



Taken from https://youtu.be/m05abdGSOxY The area that a single satellite can cover is 940.7 km.

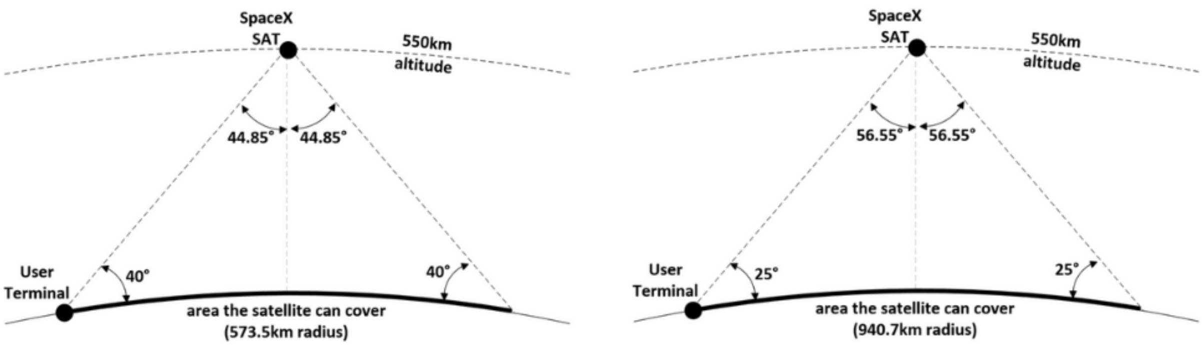


Figure A.3.1-1: Steerable Service Range of Ku-band Beams (550 km) At Full Deployment and Initial Launch

II 29.2.- Antenna

“Phased array usually means an electronically scanned array, a computer-controlled array of antennas which creates a beam of radio waves that can be steered electronically to point in different directions without moving the antennas.”
They are used in Starlink because of the ability to “Steer” or move the antenna and capture the RF signal from the moving satellite.

II 29.3.- Optical Inter-satellite link

The ISL (InterSatellite link) will be used as "Backhaul" for a higher throughput between satellites(1.8 Gbps) by bypassing the ground stations.
Using ISL will offer high operational security and immunity to interference sources while benefiting from a non-regulated optical frequency spectrum(No interference or jamming)

II 29.4.- Light pollution

One of the main issues that come with Starlink is that they will fill the already crowded night sky with brighter objects, making the astronomers work harder because those objects will appear on the images they capture daily.

II 29.5.- Debris

The other problem that arises is the debris because there is a great chance the satellites might collide. SpaceX says that each satellite is capable of tracking on-orbit debris and autonomously avoiding collisions. And that 95 percent of the satellites' components will quickly disintegrate in the earth's atmosphere during de-orbit at the ends of their lifetimes.

II 29.6.- SpaceX constellation Spectrum

SpaceX uses the Ku+Ka band (Ku-band utilizes approximately 12-18GHz, and Ka-band services use the 26.5-40GHz segment).

II 29.7.- Routing Protocol

There is little known about the protocol Starlink will use, only a tweet from SpaceX:
is said to be completely IP-less, won't utilize "standard IPv6 connections". In fact, he states it "will be simpler than IPv6 and have tiny packet overhead." It's also "definitely" going to be a peer-to-peer connection.

II 30.- Satellite advantages and disadvantages chart

II 30.1.- Satellite advantages

- LEO satellites in LEO orbit have better signal strength. The power needed for transmission is about 1w.
- Less delay (10 ms) in comparison to other orbits due to how close it is to the earth. Lower latency means they can be used on real-time-critical applications(interactive online apps, online gaming, or electronic trading).
- No need for bulky equipment thanks to the higher C/N signal ratio.
- LEO satellite can achieve superior frequency reuse thanks to a smaller footprint (The actual radio coverage).
- Greater global coverage thanks to its high elevation.
- Smaller satellites are cost-effective since they use less power and reduced hardware.

II 30.2.- Satellite disadvantages

- LEO's orbit is lower, so more satellites are needed to cover a particular region, and because of that, substantial bandwidth is lost while the satellites travel above the ocean.
- Considering the LEO satellites move constantly and hand over the service to the next satellite in the constellation, the next satellite on the "Train" is needed to cover any given region. That leads to the need for more satellites in orbit compared to GEO.
- Atmospheric effects are abundant, and they will cause gradual orbital disorientation; thus, regular maintenance is required to keep them on track.
- The LEO satellites are only visible for a short amount of time hence less time for testing or troubleshooting (this can be offset by using laser interlinks between them).
- Ground stations have increased complexities caused by the need to handle frequent handoffs between satellites.
- LEO has a shorter life span (5 to 8 years) while GEO has (7 to 15 years).
- Space debris has increased caused by the frequency of object launches, which causes collisions at orbital velocities, which are extremely dangerous and even deadly. Those collisions cause more debris in the process, creating a domino effect called Kessler Syndrome.

II 31.- Satellite Speed charts

Source: Reddit Starlink Forum

This is the “Better than nothing” beta stage showing that speeds are far greater than those from any cable company or ISP where Starlink has coverage.

Parameter	*Telesat*	*OneWeb*	*SpaceX*	
Avg. Data-rate	35.65	8.80	20.12	Gbps
Max. Data-rate	38.68	9.97	21.36	Gbps
# Active gateway antennas	2	1	1	-
Limiting factor	GW uplink	User downlink	GW uplink	-

Taken from http://www.mit.edu/~portillo/files/Comparison-LEO-IAC-2018-slides.pdf

A quick view of the speeds that each satellite technology can achieve.

Type of Link and Transmission Direction	Frequency Ranges
Downlink Channels Satellite to User Terminal or Satellite to Gateway	37.5 – 42.5 GHz
Uplink Channels User Terminal to Satellite or Gateway to Satellite	47.2 – 50.2 GHz 50.4 – 52.4 GHz
TT&C Downlink Beacon	37.5 – 37.75 GHz
TT&C Uplink	47.2 – 47.45 GHz

Table A.2-3: Frequency Bands Used by the SpaceX System

Taken from https://licensing.fcc.gov/myibfs/download.do?attachment_key=1252848

These are the frequency range authorized for the LEO region made by the FCC.

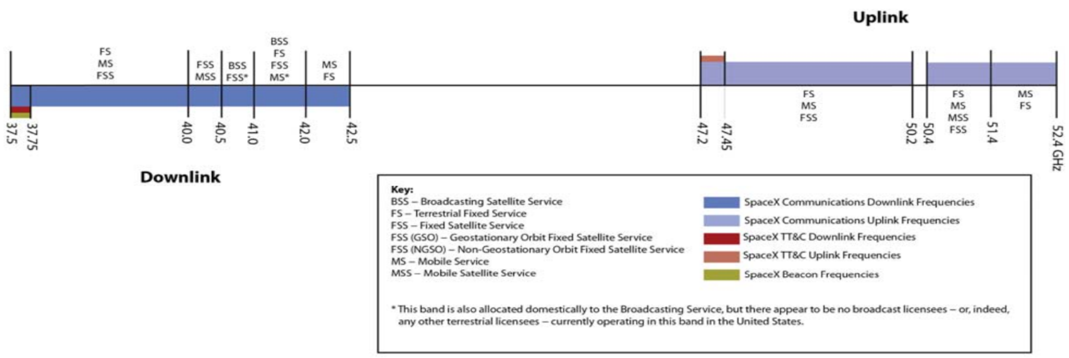


Figure A.2-4: V-Band Spectrum Used by the SpaceX System

Taken from https://licensing.fcc.gov/myibfs/download.do?attachment_key=1252848

As we have discussed earlier, the higher the frequency the higher the bandwidth.

II 32.- Network topologies to be used

Since there is little to nothing about the protocol used, I won't get into details on what can be used. Too much speculation.

II 33.- Satellite Network architecture

Not much information about what type of topology is used but there are some discussions about it, but all of them are just speculations.

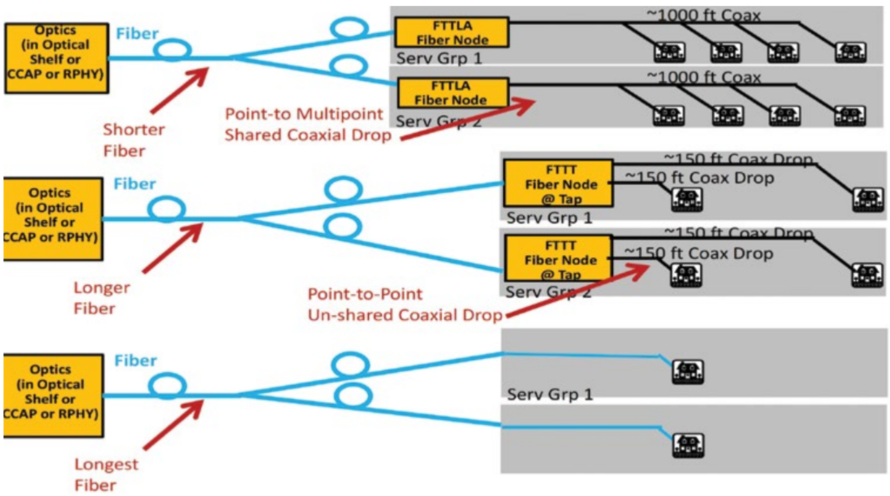
II 34.- Introduction to DOCSIS (3.0 ,3.1 and 4.0)

DOCSIS(Data-Over-Cable Service Interface Specifications) is used with coaxial cable, every time you check your TV with cable channels, that's coaxial, nowadays has been set aside by fiber. However, many rural towns still use coaxial, and one of the advantages over any other technology(even over the king, fiber) is that it's everywhere. Coaxial has been used extensively by cable television operators to serve as the last mile to customers' homes with an internet connection and cable channels and with VoIP.
This advantage is one of the greatest strengths of Coaxial because DOCSIS 3.1 at the time allows speeds of 10Gbps downstream and 1Gbps downstream. The newer DOCSIS 4.0 will enable 10Gbps downstream and 6 Gbps upstream, beating fiber for a long shot(not in speed but already there on the ground and poles). The protocol keeps improving over the years.

But, there is a big but, those speeds can only be achieved by using HFC networks (Hybrid-Coax). And with that, we saw a shift of using pure coax and added fiber to the coax plants.

Why Hybrid? Because cable operators had to install fiber to achieve greater speeds, the nearer to the user's home, the better. But that leaves with the question, how much fiber do I install before everything is fiber? HFC deploys are faster with more fiber, and coaxial cable is taken out of the picture and used in shorter hauls.

And there is also node0+ deep fiber and RFoG used for the same reason, to remove the slowest part of the coax network and give it new life. RFoG eliminates the need for HFC nodes, RF amplifiers, taps, and passives in the network, increasing the speeds and eliminating coax, and using it only on the short-haul.
There are two alternatives here, to completely remove coax in the future and keep pushing fiber(fiber for longer connections and using coax only on the premises like user homes) or keep a second network of pure fiber and run them at the same time, as a sort of transition, then remove the coax from existence, or keep a good mix of Fiber and Coax and keep pushing the technology just like telcos did with ADSL. According to DOCSIS creators, there is still room for improvement with the current HFC networks, using them as-is, introducing higher RF bands to the cable, putting fiber where needed, and using the existing coax.



Using DOCSIS to Meet the Larger BW Demand of the 2020 Decade and Beyond-Tom Cloonan, Ayham Al-Banna, Frank O'Keefe

This picture shows exactly how far a HFC has to go to get to users' homes. In contrast,we push for shorter fiber and then long hauls coax or longer fiber(FTTC) and shorter coax.

That's how the Business has been running , as usual, pushing the existing tech to its limits till there is no more room for growth (like ADSL).

II 35.- Why choose DOCSIS?

Let us see a comparison between DOCSIS versions.

Feature	DOCSIS 3.0	DOCSIS 3.1
Maximum upstream speed	200 Mbps	1 Gbps
Maximum downstream speed	1 Gbps	10 Gbps
Throughput	256-QAM (42.88 Mbps per 6 MHz channel)	4096-QAM (1.89 Gbps per 192 MHz channel)

DOCSIS 4.0 specification, DOCSIS 4.0 supports a downstream throughput with 4096-QAM

3.0	2006	1 Gbit/s	200 Mbit/s	Significantly increased downstream/upstream data rates, introduced support for IPv6, introduced channel bonding
3.1	2013	10 Gbit/s	1–2 Gbit/s	Significantly increased downstream/upstream data rates, restructured channel specifications
4.0	2017		6 Gbit/s	Significantly increased upstream data rates

Taken from https://en.wikipedia.org/wiki/DOCSIS

In this picture, we clearly see that the downstream for 3.0 is 1Gbps and upstream of 200 Mbps, while 3.1 and 4.0 downstream are up to 10Gbps with a big difference on the upstream where 4.0 makes a huge leap.

The Evolution of DOCSIS

	DOCSIS 1.0	DOCSIS 1.1	DOCSIS 2.0	DOCSIS 3.0	DOCSIS 3.1	FULL DUPLEX DOCSIS 3.1
Highlights	Initial cable broadband technology	Added voice over IP service	Higher upstream speed	Greatly enhances capacity	Up to 50% more data capacity and no plant upgrades required	Symmetrical streaming and increased upload speeds
Downstream Capacity	40 Mbps	40 Mbps	40 Mbps	1 Gbps	10 Gbps	10 Gbps
Upstream Capacity	10 Mbps	10 Mbps	30 Mbps	100 Mbps	1-2 Gbps	10 Gbps
Specification Release	1997	2001	2002	2006	2013	2017
Field Installations	1998	2002	2003	2008	2016	TBD

Taken from https://www.qorvo.com/design-hub/blog/enabling-10gbps-cable-networks-with-full-duplex-docsis-3-1

Nowadays, DOCSIS is looking to extend the RF range from 1.8GHz to 3Ghz(this is still on investigation), and all this is achieved by using HFC(hybrid fiber-coax), and DOCSIS 3.1 is looking at speeds of ~10Gbps Downstream capacity and ~2Gbps Upstream capacity on a 1.2GHz plant with a 204MHz high-split.

Cost of deployment is where Coax has a considerable advantage over fiber. As I mentioned before, installing new fiber is truly expensive (which involves permits, trenching, digging on users' lawns). The most considerable expense would be to change the customer's modem, backplates(the coax connection we can see on any room) to use higher frequencies, and a new drop for houses that don't have any coax installed).

There is also a reliability challenge. Due to mechanical and environmental degradation and coax plants' failures, Coax loses to fiber, far more reliable.

Between DOCSIS 3.0 to 3.1, there are many changes, the introduction of OFDM, more downstream and upstream channels, new error correction methods, more spectrum available. And with the new DOCSIS 4.0, there's a lot to choose from. Do we stay on 3.1? Many vendors are still struggling with the equipment, but there is always room for growth which is the most essential part of technology.

To summarize, the DS/US speeds changes from 3.0 to 3.1:

	Legacy Platforms*	Next-Gen Platforms*
Unique DOCSIS QAM	32	96+ to Full Spectrum
DS MB Throughput	1.2 GB	5 to 7 GB
US MB Throughput 5-42	100 MB	160 MB
US MB Throughput 5-200	330 (85 MHz cap)	1.2 GB
Service groups per chassis	~36 at 32 QAM Per	Up to 64 to 256 w/DAA

Taken from https://blogs.cisco.com/sp/the-benefits-of-docsis-3-1

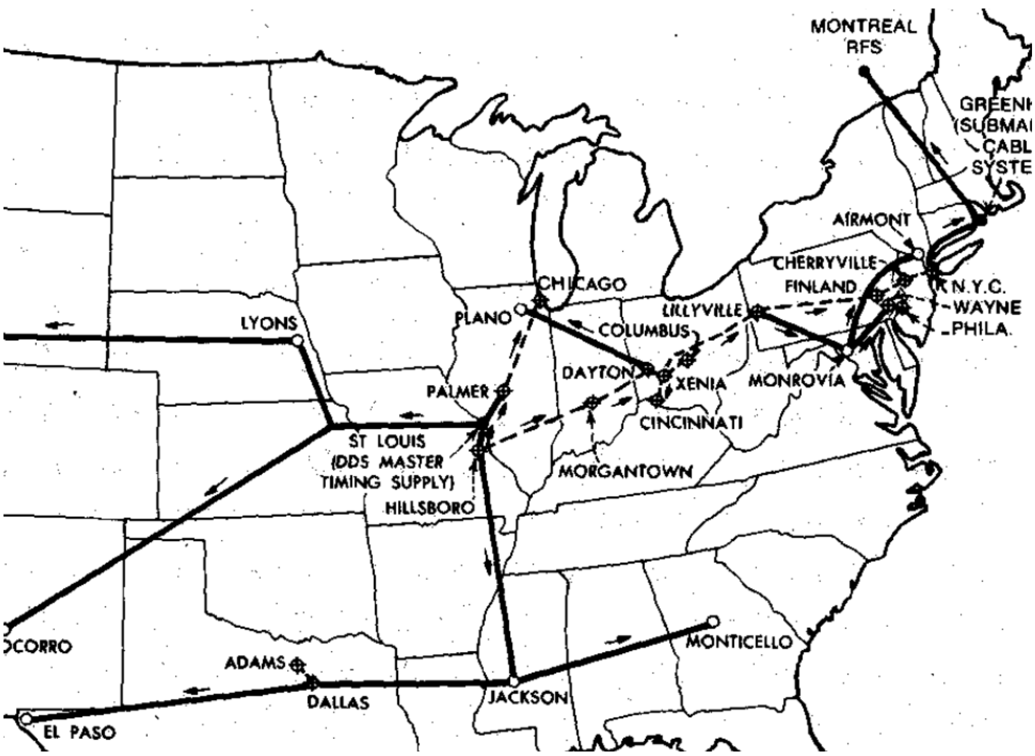
DOCSIS 3.0 256 QAM channel = 40 MB of throughput.
DOCSIS 3.1 OFDM allows QAM 1k, 2k, 4k and beyond.
A 1k QAM provides approximately 50 MB of throughput or a 25% increase in the same amount of spectrum.

II 36.- DOCSIS map

Here it is a bit more challenging to find where they have HFC facilities, trade secrets, but an excellent tool to use will be an internet finder near you.
On any of them you will see the plans offered, I've chosen Camrose as an example, and none of them seems to comply with the 50/10 CRTC plans(you will see plans with 120 Mbps speeds, but those are achieved using LTE/4G, and they all have data caps). Some of them, like Vmedia, offer FTTN(fiber to the node/neighbor), so it means they are using HFC, fiber to the nearest point, then coax to the customer.
Why could you ask? Well, coax max length is short, very short compared to fiber. To run a long haul of coax, you need amplifiers. One of the longest coax hauls known where installed by ATT and Bell called L-Carrier
On this example the amplifiers were used to re-modulate the signal and looping them more than twenty times.
By the end of the 70s, "the advancement of glass fiber and laser technology made copper coaxial cable obsolete for all long haul carrier service."

In short, you will likely find good internet speeds over coaxial in big cities rather than small towns because there aren't many long hauls of coaxial, and doing them (just like fiber) is not cost/effective for a small population. In this time and age, it is far more reliable to dig for fiber rather than coax. Although the price for installing fiber is higher, coaxial doesn't make sense for the long haul.

Here we can see some of the L-carrier in US.



Taken from http://www.coldwarcomms.org/l5/bsrf1.gif

II 37.- DOCSIS in depth

One of the first questions on the How is what do I want to support? Is this a new coaxial plant? An already established coax 3.0 looking forward to expanding and offering new download speeds and reliability?

Those questions will be crucial on what kind of HFC plan you will have. If you are full coax, then maybe it's time to do the transition to an HFC. Maybe build a newer fiber plant (deep fiber or node0) or run both and remove the coaxial in the future?
It all depends on my budget and what I want to offer.
But for all of them, first, we need to discuss the newer DOCSIS capabilities and how we can achieve a good HFC plant and keep increasing the DS and US speeds. And for that, we have the following technologies available under the newer DOCSIS 3.1.

There is a lot to learn with this technology because there is RF involved(Radio Frequency). Installing coax involves cables, amplifiers, backplates, faceplates, modems, and HFC networks. Newer DOCSIS means higher frequencies that could create more problems with actives/passives and mainly coax attenuation. The only way to avoid the coax issue would be to limit the amount of coax with fiber deep designs such as node + 0 amplifiers and RFoG, Remote PHY, and Full-duplex(Both new under DOCSIS 3.1)
Also, there is an issue with backward compatibility. Today, the modems we usually use cannot be used for newer DOCSIS protocols, so they must be replaced too, and newer modems can cost from $100 to $300 easily(for 3.1). There are no 4.0 modems at the moment.
New technology is also introduced with 3.1, the use of OFDM(Orthogonal frequency division multiplexing and OFDMA(Orthogonal frequency division multiple access).

II 37.1.- CABLES

There are many cables we can choose from, the main difference between them is Impedance, Core size, Dielectric Type, and Max Attenuation in DB, and each type of cable was created for a different environment/equipment (other types of cable for CCTV, amplifiers, antennas, amateur radio)
There are different types of cables we can choose from. The one we will use depends on what equipment we have. Since this is for internet connection, we will use the RG6 cable, which is the most used for this kind of install.

II 37.2.- OFDM and OFDMA

II 37.2.1.- OFDM

Multiplexing is when multiple digital signals are shared under the same medium, in this case, the DS(downstream) HFC plant.
The multiplexed signal is shared across all the cable modems in the DSM, which means all the bandwidth is shared between the subscribers. This is the most important thing to keep in mind. When we talk about 1Gbps or 10Gbps, the DS is shared with all of them.
Multiplexing = Shared bandwidth.

II 37.2.2.- OFDMA

This tech is used in the US(upstream) and means "Multiple Access," just like CDMA!, but faster. This means that the US is shared, and each modem is given a time slot or frequency range (subcarrier frequency) to access and transmit

Both of them are advantageous over the single carrier QAM used in previous versions of DOCSIS. SC-QAM works so far, but OFDM and OFDMA does it better.

II 37.3.- MODEMS

Most of the cable operators will give away or lease the modem the customer will use. This modem works like a router and a switch as a router because it routes the incoming traffic from the ISP (on the WAN port) and switching(and some more expensive modems routes to the customer ports too) between the other available ports(they usually come with 4 + the WAN port)
Usually, the modem they give you is the cheapest/cost they have. Those modems won't route that well or switch, for that matter. It is up to the customer to put the modem in BRIDGE mode, so the modem they give you will only pass the traffic to another router of your choosing. That way, you will increase your LAN speeds, and the routing will be done faster than using the ISP modem.
To squeeze all the speed you will have from your shining new DOCSIS 3.1 (1Gbps and this can be done with fiber too!), savvy customers will use pfsense + pihole and another combo to protect the traffic you get into your own home and speed things up.

Also to keep in mind are the DS and US channels. If you buy a new modem, you will see some numbers on the box and manual, ranging from 8x4 to 32x8. Those are the DS and US channels your modem has. The higher, the better.

II 37.4.- DOCSIS Protocols supported

On the new modem box, you will see which DOCSIS it supports. It will either be 3.0 or 3.1. Pick 3.1!

II 37.5.- ISP compatibility

And most big ISPs will support any modems you install, but the smaller ones won't. Most of them have a compatibility list that you need to check.

II 37.6.- Remote PHY

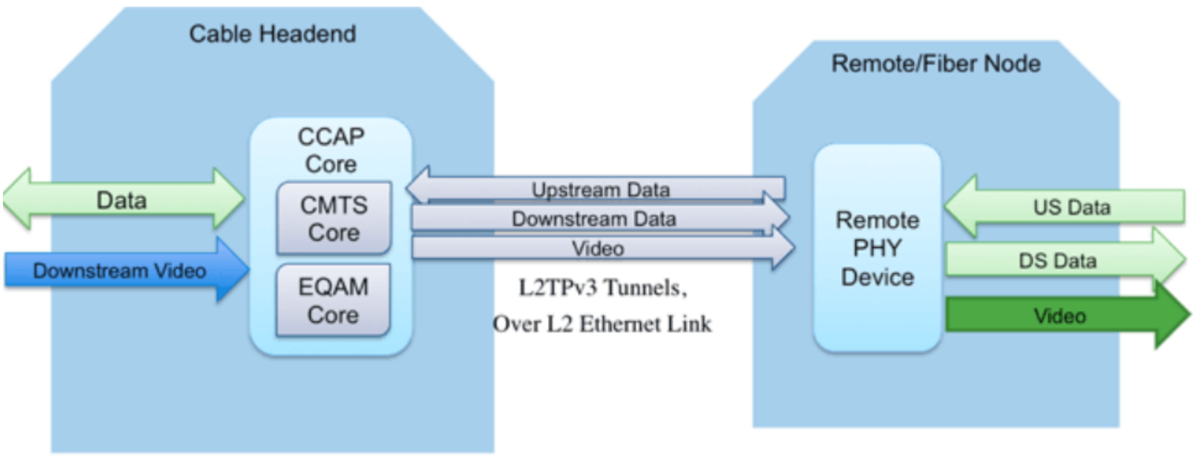
This new technology introduced on DOCSIS 3.1 pushes the RF layer to the fringe of the access network.
Cable operators still rely on CMTS Cable Modem Termination System (CMTS), where all the devices and traffic handling are done and concentrated on the headend. With the new traffic growth CO(Cable operators) have to feed even more bandwidth. Because of that, they have to change from a centralized architecture to a distributed one, which means that all the equipment that's under the same roof can be installed near the customer's home.
This is done by placing the RF processing as far on the network as possible and delivering digital format as long as possible.
Remote PHY places the processing MAC on one side and the PHY(signal generation) on the other side.
To make it simple, it means replacing the analog part of the cable plants for as much fiber you can and sending the RF converters at the edge, near the customer network.

There are some advantages to this:

- Boost the network capacity.
- More performance since the RF signals will only travel a short way to the customer.
- Substantially more reliable since most of the "Cable" will be replaced by fiber.
- Smaller Power consumption, moving the equipment not needed at the headend to the edge of the network.
- Reduced complexity on the headend, for the same reason, less equipment required.
- Future proof of the cable plants and being able to compete with fiber.
- R-PHY allows "Virtualization."

II 37.7.- R-PHY virtualization (Virtual CMTS)

The vCTMS is a virtualized software of the hardware-based CMTS. It runs on COTS(Common off the shelf) servers, and it performs all the CMTS functions, including common control, manage/forward IP traffic. Supports all the DOCSIS-related applications like DSG(DOCSIS set-top Gateway, out of band data for information such as program guides, channel lineups, and updated code images), PacketCable(used for VoIP), IPv4, and IPv6.
And like any other virtualized software, it can be scaled based on necessity by running new VMs, containers. It also can be deployed in Distribute or centralized, or Hybrid.



Taken from https://www.cablelabs.com/remote-phy-reality

II 37.8.- Full Duplex

DOCSIS 3.1 introduced full-duplex to battle fiber and achieve 10G, not an easy thing to do since there is a lot of work to overcome the full-duplex problems using RF signals.

There are challenges like:

- More fiber deep networks, remote PHY
- Echo cancellation**:** Since most of the bandwidth is used by the DS, there is a lot of echo, and the US is faint in the background. It requires sophisticated digital signal processing (DSP), adding more power consumption.
- Higher composite output power: the amplifier power needed for full-duplex exceeds what's on the market today.
- Modulation Error Ratio(MER) trying to get a lot of RF power with very little DC power and very few errors (low MER).
- DPD and Cable Tilt Compensation: add shaping and newer power amplifier efficiency.

II 37.9.- Flexible MAC Architecture

FMA breaks up the whole DOCSIS into parts, the CCAP management, the control, and data planes.
This disassembly of the headend architecture supports a mix of access network components with standardized multi-vendor interoperability.
MAC and PHY functions could be distributed between the various physical chassis and virtual implementations.
In short, FMA will let us break everything into smaller components, and the equipment generally seen on the headend can be installed anywhere on the network, which is usually near the customer.

II 38.- DOCSIS Advantages and disadvantages chart

II 38.1.- DOCSIS Advantages

- The ability to keep using the coaxial "last mile." There is no need to use or install fiber to the customer's home, thus keeping costs low since no digging is required.
- OFDM and OFDMA
- Fiber deep
- Remote PHY
- More channels available(3.0 had a max of 32 channels for DS) and more channels for US(8channels for US), so 32/8 channels available.
- Changing from centralized to Distributed architecture (DAA)
- wider frequency spectrum
- low-density parity-check (LDPC)

II 38.2.- DOCSIS Disadvantages

- Replacing many of the network's critical components, including neighborhood nodes, amplifiers, and power taps, allow for more customers' bandwidth.
- The paradigm change from coaxial plants to fiber.
- Latency and jitter with old cables, depending on the encoding used, there will be some—a trade-off for handling higher noise rates and attenuation.
- The bandwidth is still shared with other customers on the same premises(causing packet loss)

II 39.- DOCSIS speed charts

DOCSIS Version	Max Downstream Throughput	Max Upstream Throughput
1.x	42.88 (38) Mbit/s	10.24 (9) Mbit/s
2.0	42.88 (38) Mbit/s	30.72 (27) Mbit/s
3.0	n x 42.88 (38) Mbit/s 8 x 38 = 304 Mbit/s	n x 30.72 (27) Mbit/s 4 x 27 = 108 Mbit/sec

Taken from https://volpefirm.com/docsis3-tutorial-introduction/

<table>
<tr><th></th><th colspan="2">DOCSIS 3.0</th><th colspan="6">DOCSIS 3.1</th></tr>
<tr><th></th><th>Initial</th><th>Future</th><th colspan="3">Initial</th><th colspan="3">Future</th></tr>
<tr><td>DS Range (MHz)</td><td>54* - 1002</td><td>108 - 1002</td><td colspan="3">258 - 1218</td><td colspan="3">504 - 1794</td></tr>
<tr><td>DS QAM Order</td><td>256</td><td>256</td><td colspan="3">256-4096</td><td colspan="3">256-16,384</td></tr>
<tr><td># DS Channels</td><td>8 SC-QAM</td><td>24 SC-QAM</td><td colspan="3">5 x 192 MHz</td><td colspan="3">6 x 192 MHz</td></tr>
<tr><td>DS Capacity</td><td>300 Mbps</td><td>1 Gbps</td><td colspan="3">8 Gbps</td><td colspan="3">10 Gbps</td></tr>
<tr><td></td><td></td><td></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>US Range (MHz)</td><td>5 - 42</td><td>5 - 85</td><td colspan="2">5 - 85</td><td colspan="2">5 - 204</td><td colspan="2">5 – 400**</td></tr>
<tr><td>US QAM Order</td><td>64</td><td>64</td><td colspan="6">256-4096</td></tr>
<tr><td># US Channels</td><td>4 SC-QAM</td><td>12 SC-QAM</td><td colspan="4">2 x 96 MHz</td><td colspan="2">4 x 96 MHz</td></tr>
<tr><td>US Capacity</td><td>100 Mbps</td><td>300 Mbps</td><td colspan="2">400 Mbps</td><td colspan="2">1 Gbps</td><td colspan="2">2.5 Gbps</td></tr>
</table>

Taken from https://nerdtechy.com/best-cable-modem

Channel Config	Down Stream Channels					Upstream Channels		
	Total	DOCSIS Standard		EuroDOCSIS		Total	Data +	Data
Down/Up	Chann	Data+System	Data Only	Data+System	Data Only	Chann	Overhead	Only
1/1 *	1	42.88 Mbps	38 Mbps	55.62 Bbps	50 Mbps	1	30.72Mbps	27 Mbps
4/4	4	171.52 Mbps	152 Mbps	222.48 Mbps	200 Mbps	4	122.88 Mbps	108 Mbps
8/4	8	343.04 Mbps	304 Mbps	444.96 Mbps	400 Mbps	4	122.88 Mbps	108 Mbps
16/4	16	686.08 Mbps	608 Mbps	889.92 Mbps	800 Mbps	4	122.88 Mbps	108 Mbps
24/4	24	1029.12 Mbps	912 Mbps	1334.88 Mbps	1200 Mbps	8	245.76 Mbps	216 Mbps
32/4	32	1372.16 Mbps	1216 Mbps	1779.84 Mbps	1600 Mbps	8	245.76 Mbps	216 Mbps
* Single channel rates for reference and calculations. DocSis 3.x minimum is a 4/4 configuration.								

Taken from http://dtech.tkanthony.com/2016/05/maximum-cable-internet-speed-service.html

II 40.- DOCSIS Network topologies

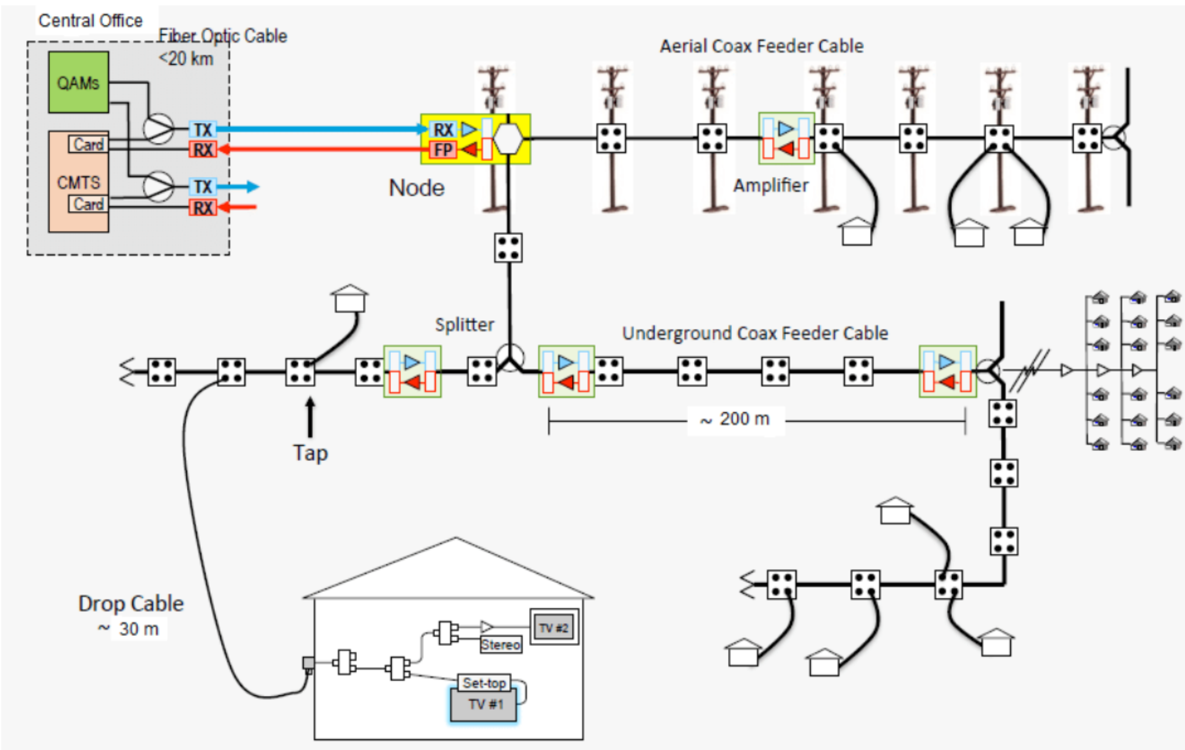
In the beginning, there was coaxial—the whole plant from the cable companies was made out of coaxial. Fiber was used to replace the coax on the Coax plant side to future proof those coax plants and make room for increased bandwidth. Soon Fiber was taking the place of coax and leaving them only at the customer side.

The reason for this is longevity. No one thought that outside plants, some several decades old, could support the spectrum of 3GHz or beyond. With the new changes to DOCSIS and the new spectrum used on the old cables, the aging infrastructure can be used, saving money and serving the same Gigabit speeds as Fiber or 5G.

We already know the network topologies that exist out there (Star, ring, bus), and all of them are used in one way or the other, but in an HFC topology, everything can be mixed to get the data running.

There is also the challenge to match the physical topology to the logical topology because, for many reasons, a physical ring cannot be used (obstacles, terrain). We use a different logical topology from physical topology or inverse.

II 40.1.- HFC topology

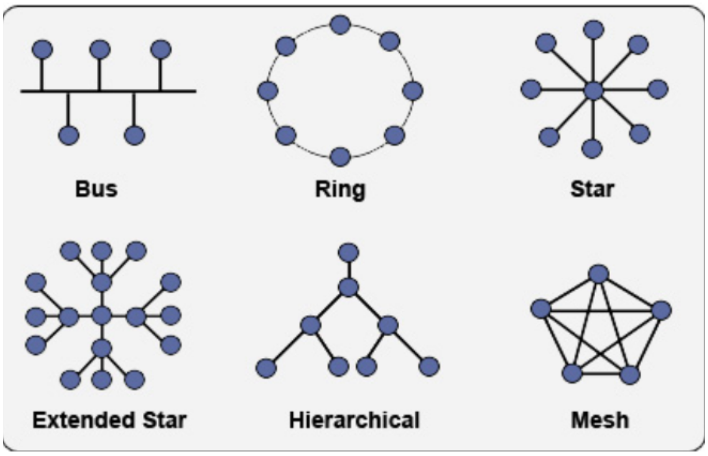


IPKO's HFC Network Topology

Taken from https://www.researchgate.net/figure/IPKOs-HFC-Network-Topology_fig2_308918787

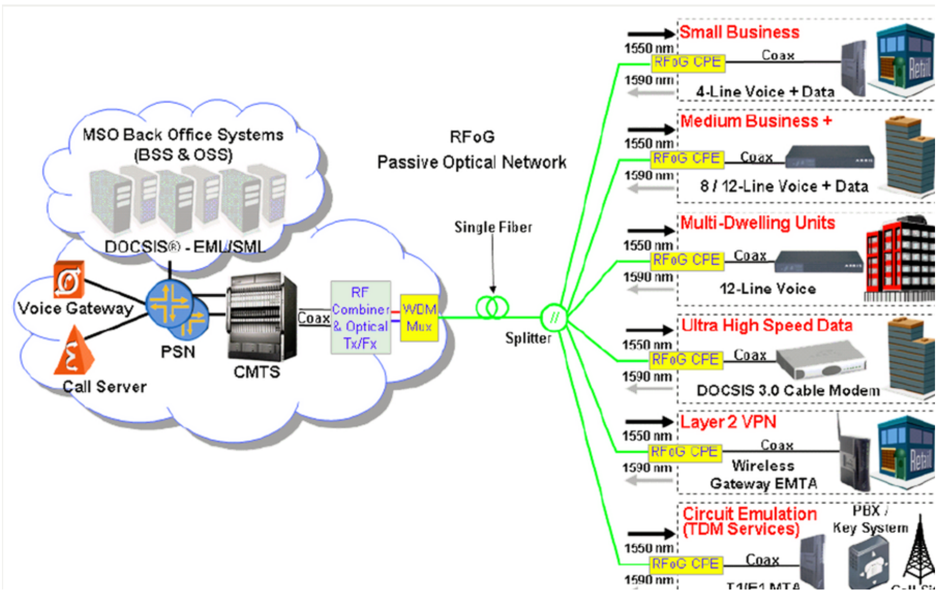
In the HFC topology, the star is the preferred configuration for outside-plant installations. The star topology offers a central hub from which the network administrator can manage the physical network.

If you choose to use a Star topology and the distance exceeds the transmission power, then we can use a Hierarchical star, where we set another central hub at the edge, and that becomes the central hub of a new start topology.



Taken from https://www.itprc.com/a-guide-to-network-topology/

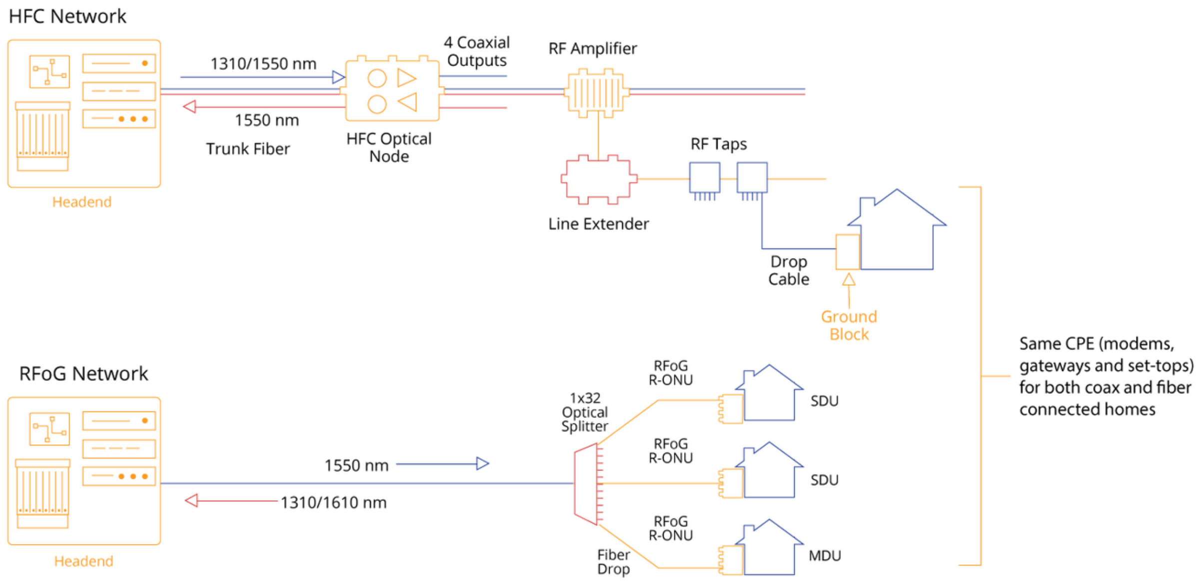
There is a performance hit on how deep are the fiber nodes in the plants. With longer cascades, you get more attenuation, noise, and worse filter roll-offs, weakening the band edges' signal. On the other hand, shorter cascades result in better performance.



Taken from https://telsoc.org/journal/ajtde-v2-n2/a40

Here we see how mixing fiber , RFoG and coax can increase the longevity of Coaxial plants.

Another technology used is the RFoG, where things simplify at the fiber level. You use splitters on the radio frequency, moving the fiber deeper into customer territory.



Taken from https://www.commscope.com/solutions/fixed-access-networks/fttx-with-obi-free-rfog/

II 40.2.- RFoG (radio frequency over glass)

RFoG (radio frequency over glass) is a fiber-deep network design in which the coaxial portion of an HFC (hybrid fiber-coaxial) network is replaced by a PON (passive optical network) architecture. Fiber to the home/premises (FTTH, FTTP) makes economic sense for new build, multi-dwelling units (MDU), businesses, and high-use consumers.

One of the most significant advantages of RFoG is that it eliminates the need for HFC nodes, RF amplifiers, taps, and passives in the network (everything that's installed to push more bandwidth with copper mixed with fiber), and you can use the existing cable head-end and customer equipment (modems, set-tops)

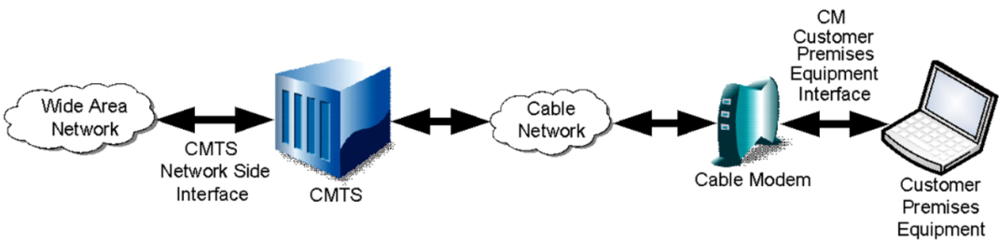
Another set of advantages:

- Support for DOCSIS 3.1 services
- The low-cost choice for rural deployments
- Similar performance to HFC
- Eliminates the RF noise innate to coaxial cables
- Lowers energy costs
- Lower maintenance costs by eliminating the HFC nodes and RF amplifiers
- Immune to environmental factors such as temperature, corrosion, humidity which causes cable degradation.

Disadvantages of RFoG

- RoF is an analog transmission, so all the inherent problems with RF signal impairments are present.
- It requires expensive special tools for maintenance and repair. Moreover, the initial cost of installation is also higher.
- It is more difficult to splice than wires at start/end joints. Moreover, it requires expensive connectors and interfacing tools.

Simplistic view of DOCSIS Network



Taken from https://www2.cs.duke.edu/courses/spring18/compsci356/slides/cable-hfc-intro.pdf

II 41.- Documentation

For detailed network documentation, please refer to Fiber documentation.

II 14.- Documentation 58

In this section I will talk only about the DOCSIS documentation.

Much like Fiber, DOCSIS can easily follow the same path. The topology is similar and you use cables, so anything that can be done in fiber documentation can be done here.

The big difference will be the remote PHY sites. Since all the backbone will be already fiber(HFC), there is not much to add to the documentation.

CHAPTER III.- Prototype rural broadband solutions

This section will see how to create a high-level network diagram and a detailed network diagram to help us implement the network technologies discussed.

The first steps to start creating a diagram of the deployment is to have the following parts of
the plan:

III 1.- Strategic network planning

This phase has two main outputs. Firstly, the general business case decision determines to what extent FTTH should be rolled out. Secondly, strategic decisions relating to, for example, the type of architecture that will be implemented and the choice of cable and duct technologies.

III 2.- High-level network planning

This is the phase where structural decisions for a particular geographical planning area are made. These include the placement of network functions(distribution points, branch points, etc.) and connectivity decisions (which location serves a particular area) and a preliminary bill of materials, including the installation length of cables and ducts and quantities for the various types of hardware. The aim is to generate the lowest-cost network plan within the boundaries of the previous planning phase's strategic decisions.

III 3.- Detailed network planning

This is the final planning step and the point at which the "to build" plan is generated. This includes the network documentation that is handed over to engineering departments or 3rd party construction companies. Further results of this planning phase include detailed connection information such as a splicing plan, the
labeling scheme and micro-duct connections.

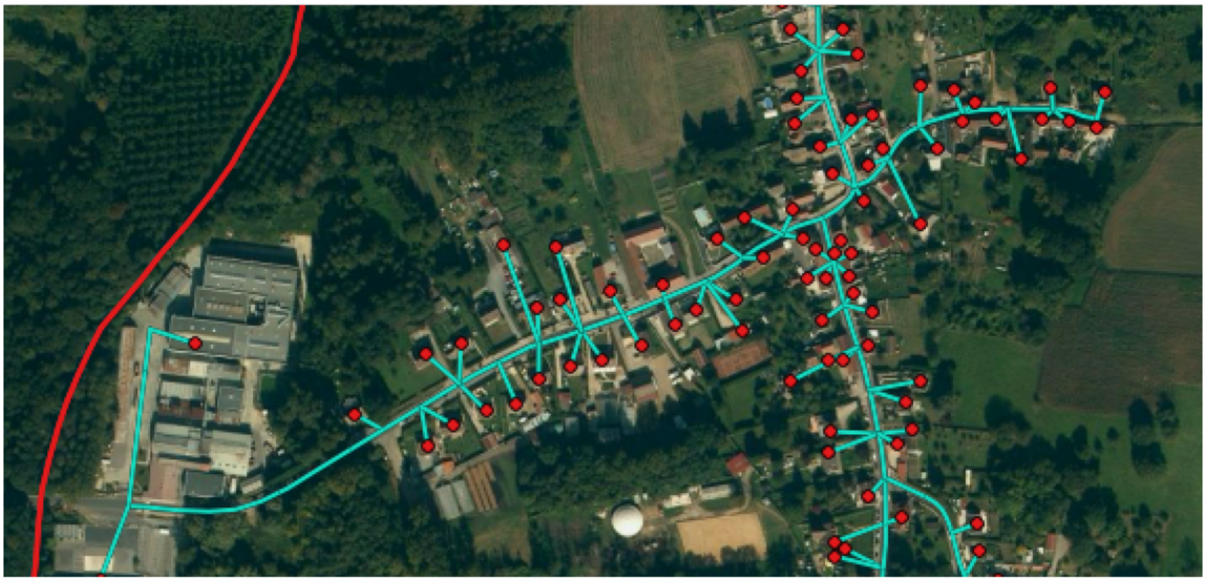
With each output, with the map from google maps or qgis, with the visits to the site already made, with the poles counted, the streets surveyed, we can start creating the high-level network plan.

III 4.- Fiber

First, we will start with the fiber deployment and start doing it by getting a simple satellite photo from google maps or using the QGIS internal plugin "Open maps" or the open maps openstreetmap.org or we can use the open.canada.ca Maps
Plenty of options to get the map where we want to start our diagram.

III 4.1.- How to create a Fiber deployment diagram

As we talked about before, first, we need to pick the place on the map. Thanks to the FTTH handbook, we see this:



FTTH Handbook Edition 7 D&O Committee Revision date: 16/02/2016 Page 35

This map was taken using Google Maps.

But there is a better alternative called Qgis," A Free and Open Source Geographic Information System."
Once installed, we can use the open street map plugin already installed.
Using the tool requires some learning, but you can draw lines, create layers, and many other things. This tool is fantastic for planning the network.

This is easily one of the most complete tools that can be used for this job. mastering QGIS or one of its variants makes the difference between a good plan and the best one.

Map view

Now that we have a map (this is near the place I live), we can draw our lines, get distances and plan our network just like the previous FTTH image. Using QGIS, you can draw on it and design/plan the network.

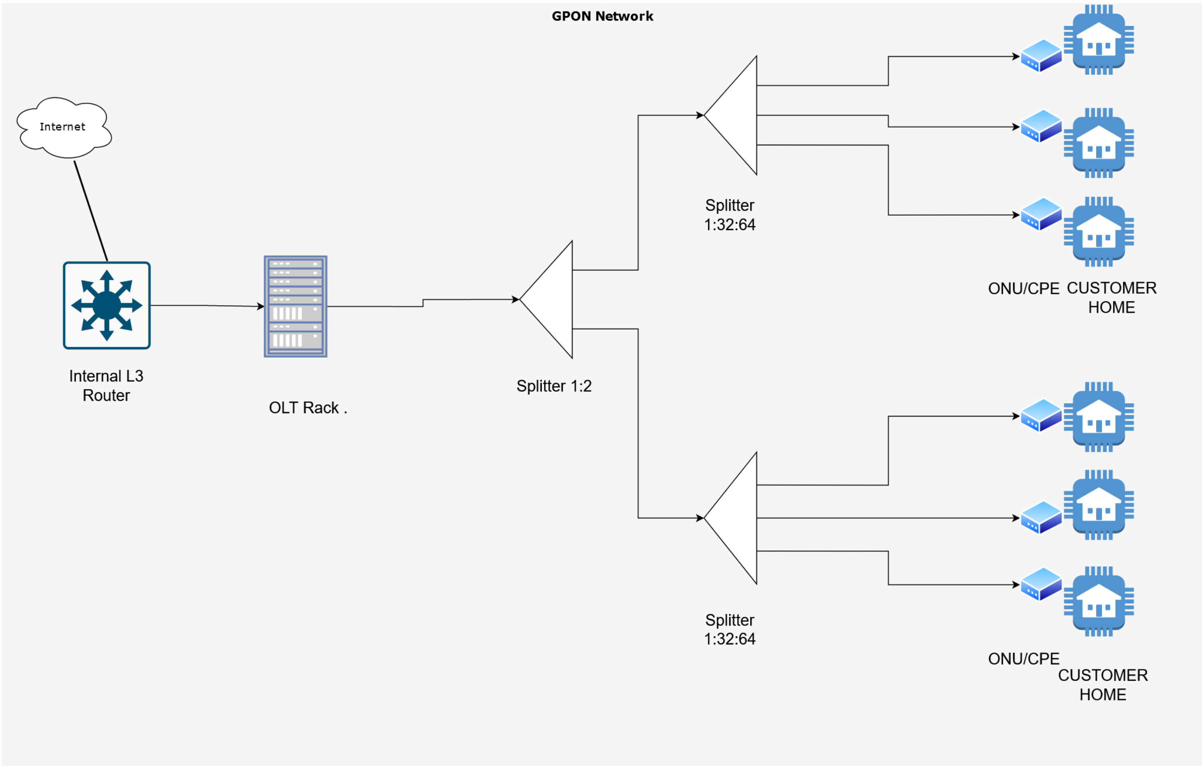
With the map at hand, we need to:

- Define area and planning
- Design rules and materials
- Pick an architecture (P2P, PON, or hybrid)
- Select the type of cabling to be used
- Choose building connection strategy (number of fibers per building, etc.)

III 4.2.- Fiber high level network diagram

These diagrams were created using DrawIO https://app.diagrams.net/

III 4.2.1.- Fiber GPON L3 Only Network

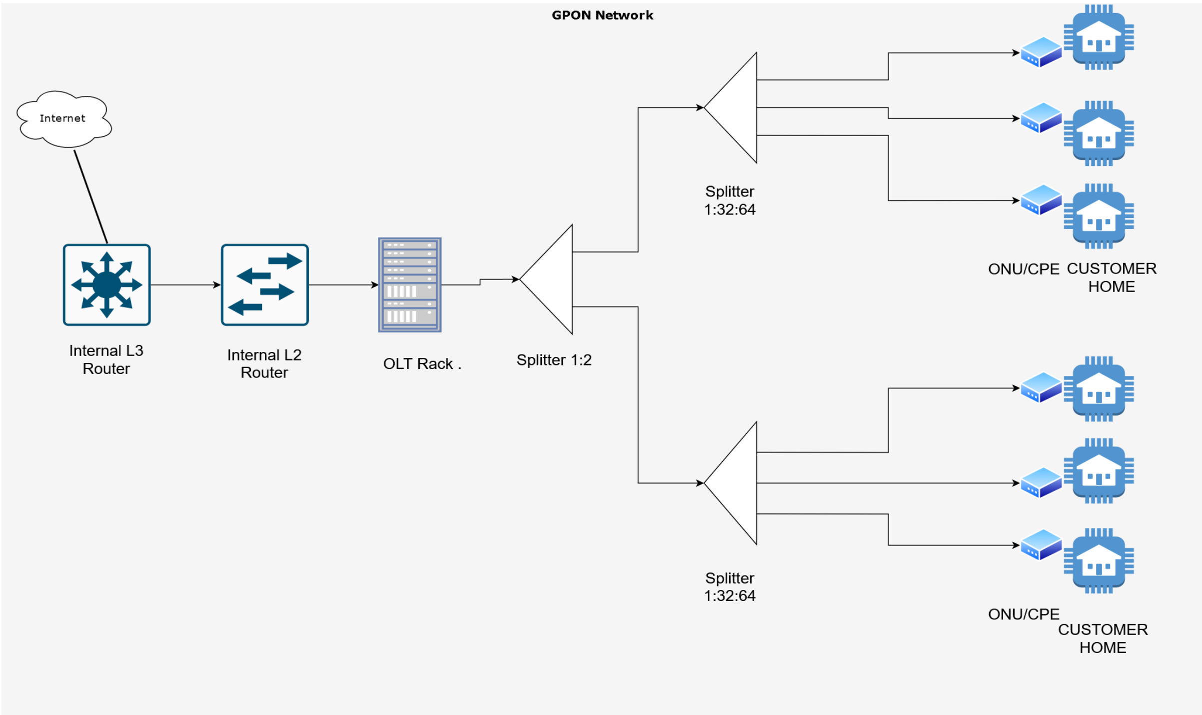


GPON L3 only

The diagram shows:

- As we see here, the primary connection called "Internet" is the ISP dark/leased fiber.
- The first router, called "Internal Router," is the one that translates and sends all the data from my internal GPON network to the exterior. This is an L2/L3 router that handles VLANs and routing at the same time. A bit more expensive but saves complexity.
- After that comes the OLT rack with several OLT in-line cards, each card has multiple fiber ports.
- Then we connect to a splitter from 1:4 to 1:16 or 1:32, depending on what we connect and the speeds we are going to serve.
- Then comes the final splitter near the customer's home, where the last strand will be split into 1:32 or 1:64. Remember that the split ratio will depend on how many customers to serve and the distance between them.
- Then from the last split, we connect to the CPE at the customer.

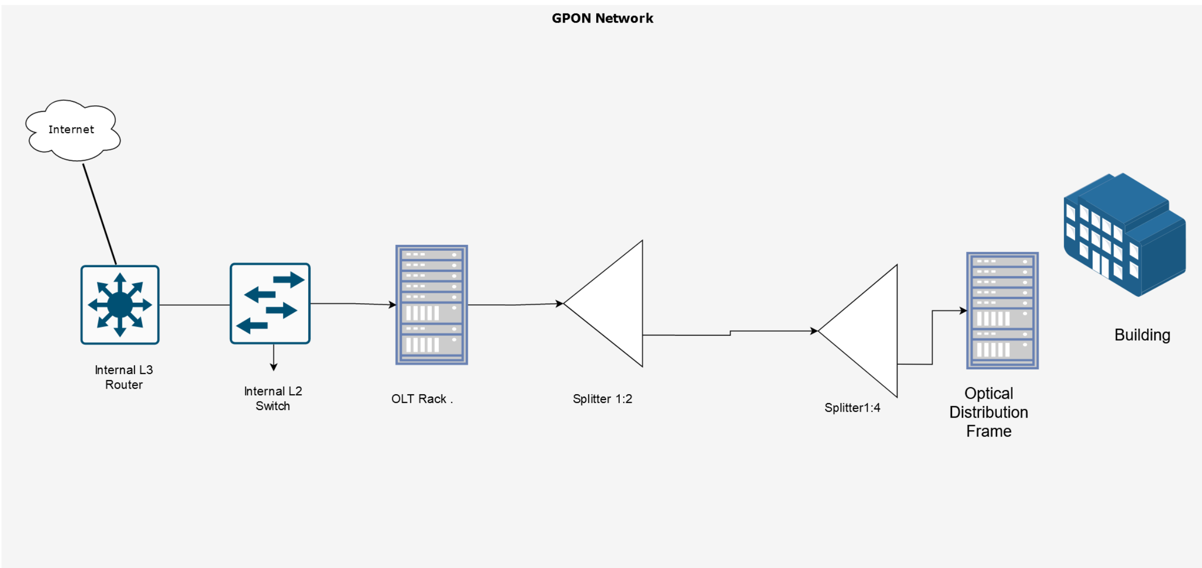
III 4.2.2.- Fiber L2 and L3 network



GPON L2 L3

On this diagram, the change made is to use an L2 switch to handle the VLANs and packet switching and the router to route IP packets. The L3 routers with no L2 capabilities are less expensive. This way, we can create an Access Layer with the L2 switch for future growth.

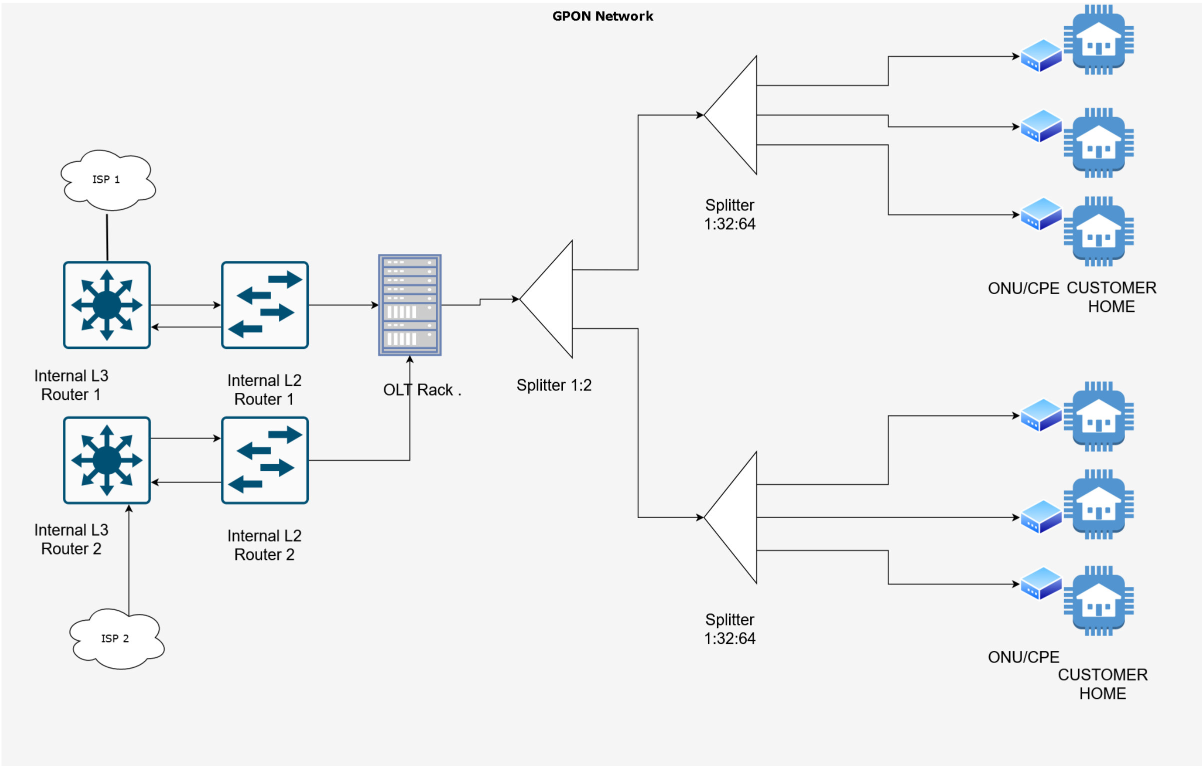
III 4.2.3.- Fiber L2 and L3 to ODF network



GPON L2 L3 to ODF

Another difference here is that when serving a building, the final destination might not be a CPE. It's usually a distribution rack where one fiber from the ISP is connected to the distribution. From there, it goes floor by floor to another distribution rack.

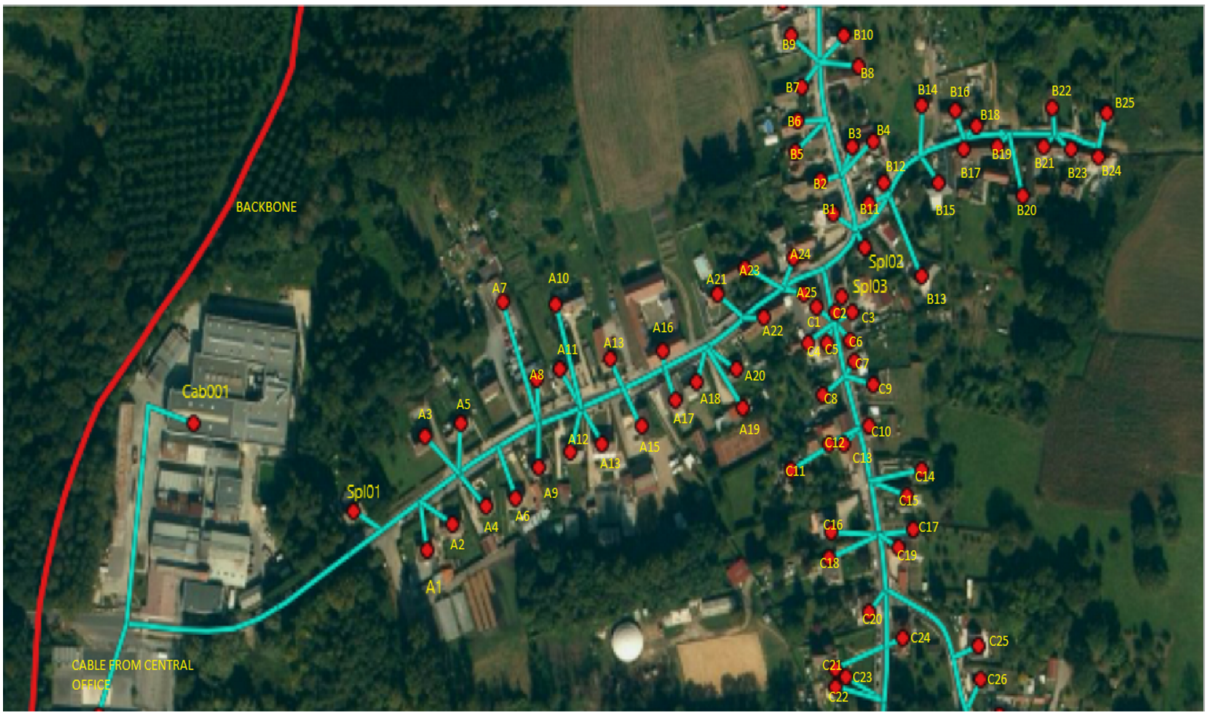
III 4.2.4.- Fiber L2 and L3 with backup link network



This diagram shows how we can have a fiber backup if one of the ISP fails or any issues with the routers/switches.
This is usually the way to do it. You need a backup, either equipment or another ISP fiber, to your site.
Also, you can change the topology to mesh, having a spare(one takes the load as soon as one of the equipment fails), There are many ways to do it, and the network engineer or designer must pick the best one that fits the design.
You can also use only one router and one switch at the beginning. If you don't have too many customers or a more powerful router (one that has more or manages more throughput), but you still need a second fiber from another different ISP.

The OLT rack has the necessary inline cards with GPON ports (or XGPON2, 10GPON, depending on the technology installed) to serve as many customers as you want.

III 4.2.5.- High level network diagram



Now, as an example, we will use the first picture again, and without much details, we can draw our high-level network plan:

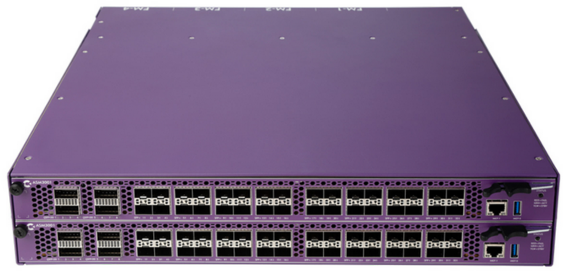
- Cab001 is the cabinet where the splices and equipment is (major equipment).
- Letters A, B, and C are the customers we will serve.
- Seeing this map, we would need three cabinets and three strands to serve this many customers.
- Customers in the A zone are 25. Those are going to be served from Spl01.
- Customers in the B zone are 25. Those will be served from Spl02.
- Customers in the C zone are 26. Those will be served from Spl03.

This exercise provides the high-level network needed for the first stage. This must be done in detail in the Detailed Network Planning.

We can add further details on the High level like the backbone SM cable running to serve other areas, where the Office cables are coming from, and any additional information that will increase our chances to build a perfect High detailed network plan.

III 4.2.6.- Example of Hardware for fiber network deployment

Let us use the Calix E9-2 as an example



Integrated OLT

- Distributed subscriber management
- Simplified subscriber/services provisioning
- Integrated very high density GPON, XGS-PON, NG-PON2 OLT

Aggregation Router with Distributed OLTs

- Centralized Subscriber Management
- Simplified subscriber/services provisioning
- Transform existing Layer 2 access network
- Aggregate OLTs such as E7-2, E7-20, C7, B6 and others

System Aggregation and Control Cards	Uplink Ports/Aggregation Ports	Interconnect Interfaces
CLX3001	2 QSFP-28 (40G/100G), 8 SFP+ (1G, 10G), 2 SFP (1G)	4 Interconnect Interfaces 400G -> 4*100G
ASM3001	32 x 1G / 10G SFP+ ports, 4 x 40G/100G/200G QSFP-DD ports	N/A

Line Card	Subscriber Ports	Uplink Ports
NG1601	16 NG-PON2/XGS-PON ports	4 QSFP-28 (40G / 100G)
GP1612	16 SFP GPON Ports (2.5G/1.25G)	2 QSFP-28 Ports (40G/100G)

Key Features

“System Innovation
Scalable to support 16 very high-density PON line cards when using the CLX3001 Control card
Aggregate existing Layer 2 access networks utilizing the ASM3001 Aggregation Services Manager
Flexible backplane enables system growth without replacement.

Fiber Innovation
GPON, XGS-PON, NG-PON2 scaling from 16 to 256 Ports in a single managed system
Full non-blocking, redundant uplink options

AXOS Module Supported
RPm, ARm, SMm on either the CLX3001 or ASM3001
Consolidate the functions of subscriber management, aggregation, edge routing w/ MPLS and OLT based on the modules chosen. “

Taken from https://www.calix.com/platforms/axos/axos-systems/e9-intelligent-edge-system.html

III 4.2.6.1.- Hardware in detail

To begin, the chosen HW supports GPON, XGS-PON, NGPON2. This provides the ability to build a future-proof 10GB PON with backward compatibility with GPON. A good choice if you want to create a PON network with higher bandwidth than GPON, which should always be, think about the future and how to keep growing.

Different uplink/aggregation ports (Link aggregation allows you to combine multiple ports/links into a single logical link between two networked devices) with different speeds.

16 ports on each inline card (16 inline cards supported) for 256 maximum ports(and each can serve from 23/64 customers depending on the distance)

One of the advantages of this equipment is that it reduces the necessary network equipment, consolidates system management(it's on the same equipment)

Carrier Class solution for remote system aggregation with Integrated Subscriber Management and Routing

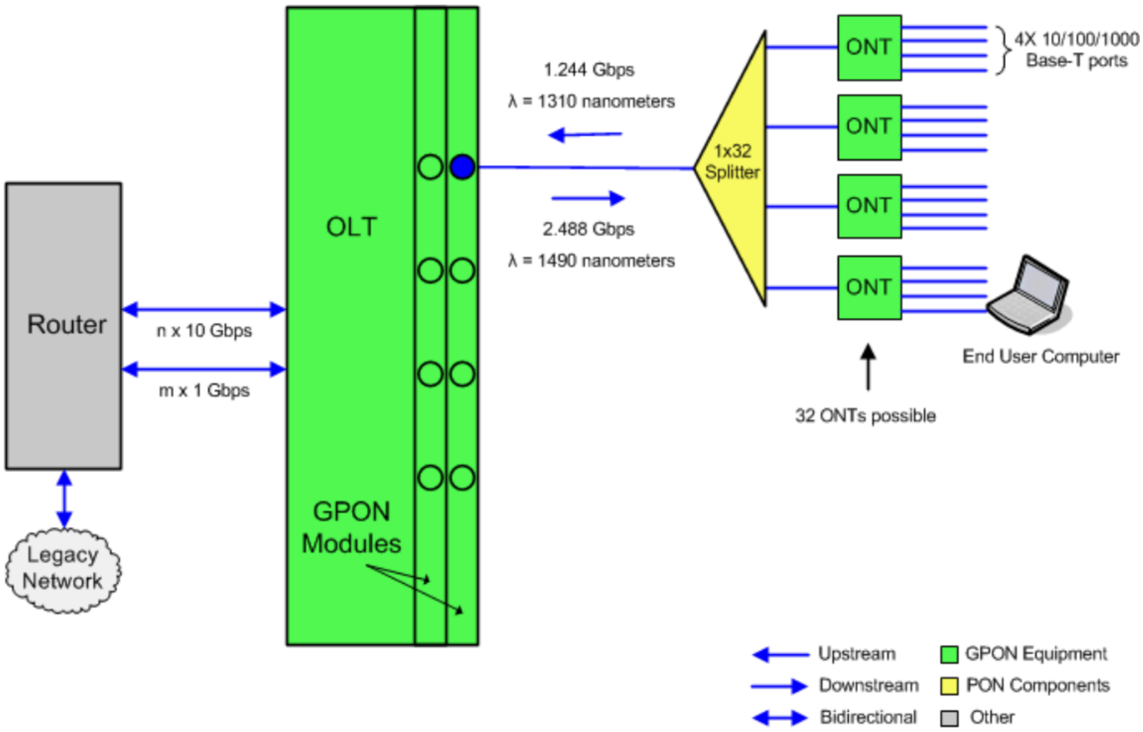
- L2 switching, L3 Routing, support for business, residential and Mobile services, Subscriber Management, VPN
- Ring (G.8032v2) and Point-to-Point (Unprotected/LAG) topologies supported
- High availability via LAG, ECMP or BFD
- HQoS

Everything on the same rack decreases the equipment needed and decreases complexity.

Let's take a closer look at the ASM3001:

- This ASM3001 has 32 SFP+ ports and 4 uplinks.
- They can be installed on the E9-2 chassis and be managed (all the installed ASM3001) from the same chassis.
- With a fully populated E9-2 chassis, we can have up to 256 PON ports (256 ports x 32 customers per port gives 8192 customers per chassis.

III 4.2.1.2.- A more in depth look to GPON

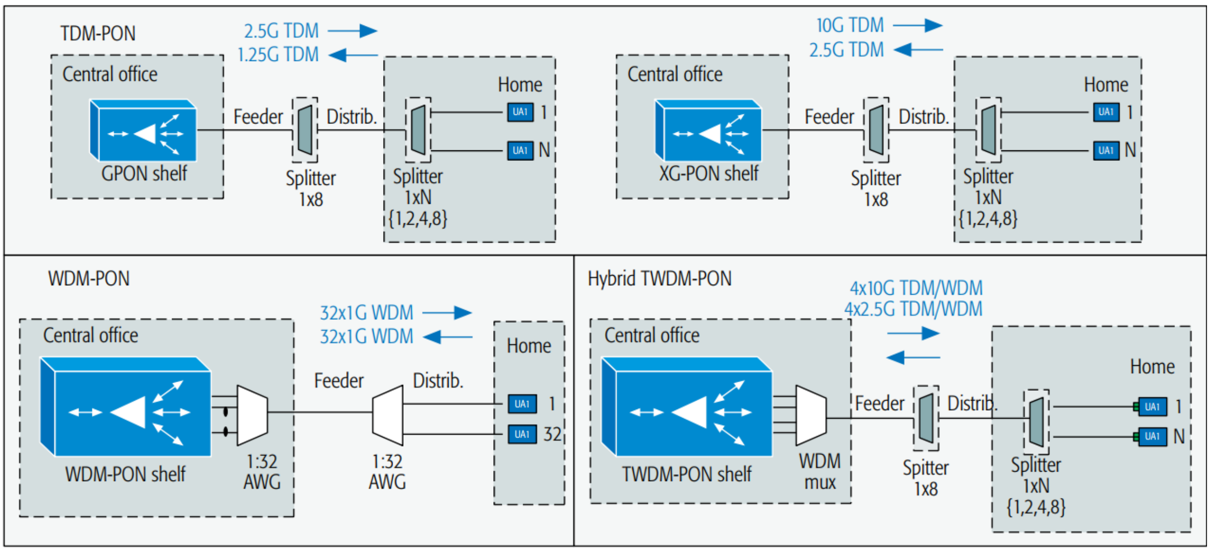


Taken from Deploying GPON Tutorial Sandia Labs Joseph P. Brenkosh - Jimmie V. Wolf

Here we can see the same as depicted above, but with the spectrum used to Upload/Download(in DWDM, you will see many more)

The CPE at the end can either use Ethernet to connect to the customer modem/router, or it could be fiber too(Ethernet can be used for 1GB but fiber it's always the best option).

III 4.2.1.3.- Taxonomy of fiber PON access protocols



Taken from Provisioning 1 Gb/s Symmetrical Services with Next-Generation Passive Optical Network Technologies Rafael Sánchez, José Alberto Hernández, Julio Montalvo García, and David Larrabeiti

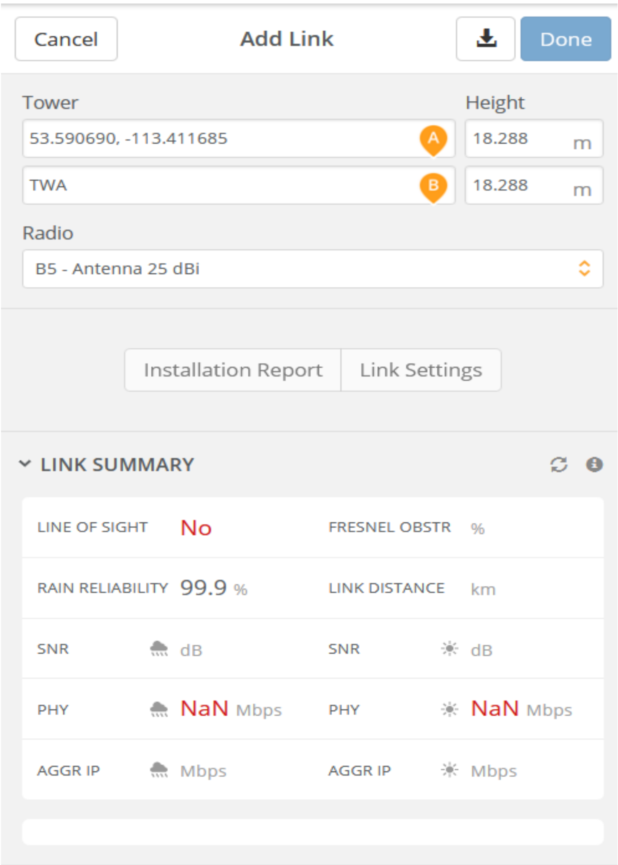
This diagram shows the differences between a normal PON and an NGPON/XGPON, which uses WDM. The most significant advantage of WDM is that it can use the same fiber strands with different wavelengths increasing the bandwidth up to 10GB.
This is the future of GPON. A newer ISP must work towards delivering NGPON and 10GB or should be in the ISP's future plans. Having the ability to increase the bandwidth by replacing some components is a game-changer.

III 4.3.- How to create a WISP deployment Diagram

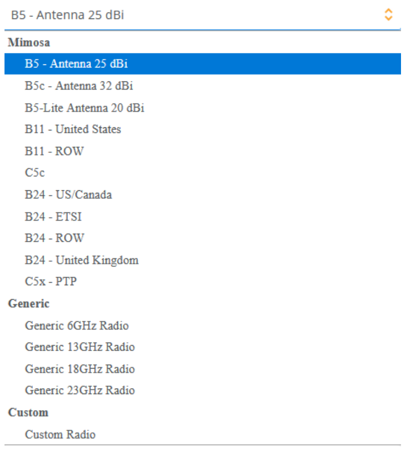
Like in the fiber deployment, WISP has its tools besides the maps to create a high-level diagram.
One of the tools discussed is the one available per vendor(like MikroTik, Ubiquiti, mimosa) that will let you install poles, antennas and check the distance and related information you need to check if the link/s are optimal or not.

Let's take Mimosa as an example:
https://cloud.mimosa.co/app/welcome.html#/login

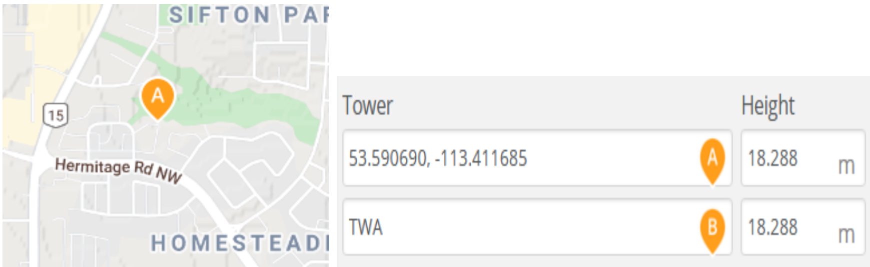
This is how "add a link" looks like. You have options like tower height,



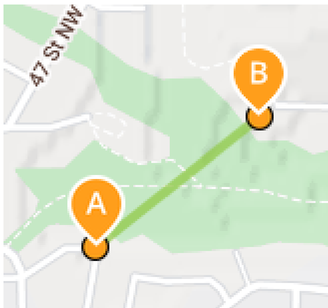
You can choose the antennas dBi



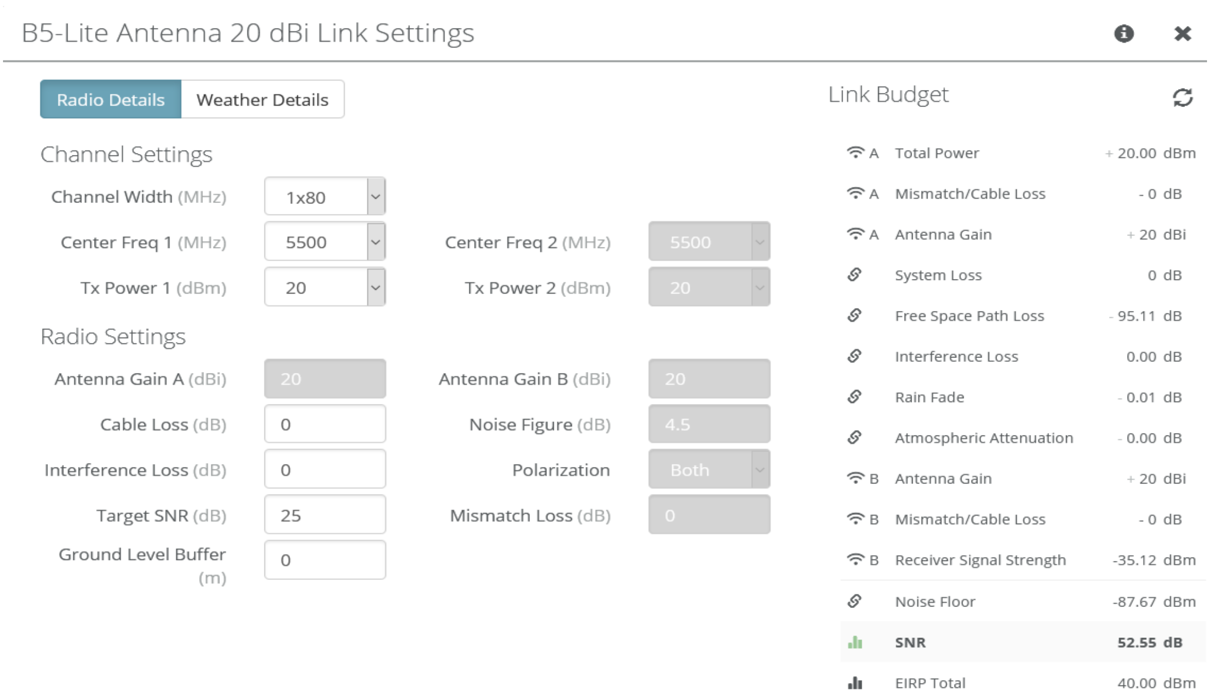
You can use either the map or coordinates to set a tower wherever you like



Now with two towers and a PtP link



With some simple settings, we can get this summary.



With a few clicks, you can get all the information needed to check if the link is viable or not. You also have more options, and you can put your custom numbers depending on the antennas and equipment you have.

With this tool at hand, deploying a WISP network becomes more effortless and matching what you will get from the onsite tests becomes simple and more straightforward.

III 4.4.- Wisp high level network diagram

Much like a fiber network, WISP works almost the same. The difference is the equipment, where I will only need routers and two ISPs for redundancy.

One of the differences here is that you will work with IP addresses, and here since most of the network is on our side and under our control, we need to plan not only the IPV4, but it must be dual-stack, with IPV6. IPV4 addresses are scarce and difficult to get, and IPV6 it's the future.

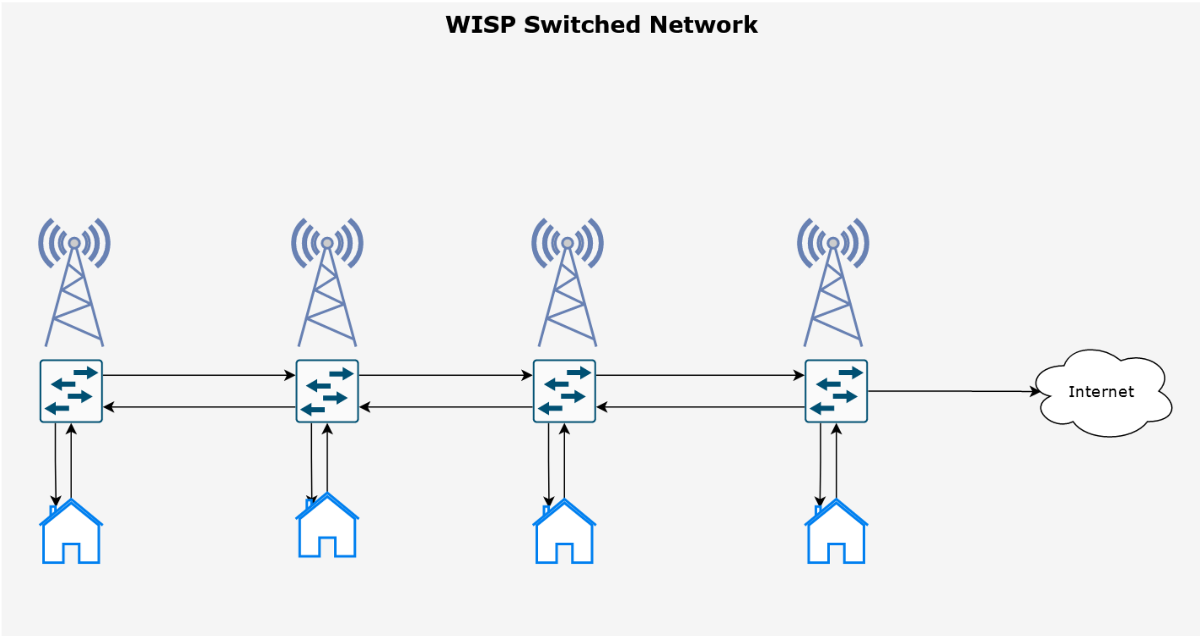
III 4.4.1.- Bridged Network

For small WISPs, this network looks simple and requires minimal network knowledge. They should be enough for a few customers. They do the work, but they won't scale after a certain point, and they can cause RF issues with the number of broadcasts sent across all towers.

For-profit, This network is not an option! This is only to show how a bridged network on WISP looks. This network has too many flaws, and one of the big ones is that it cannot be scaled, and changing it in the future for another routing it's almost impossible.

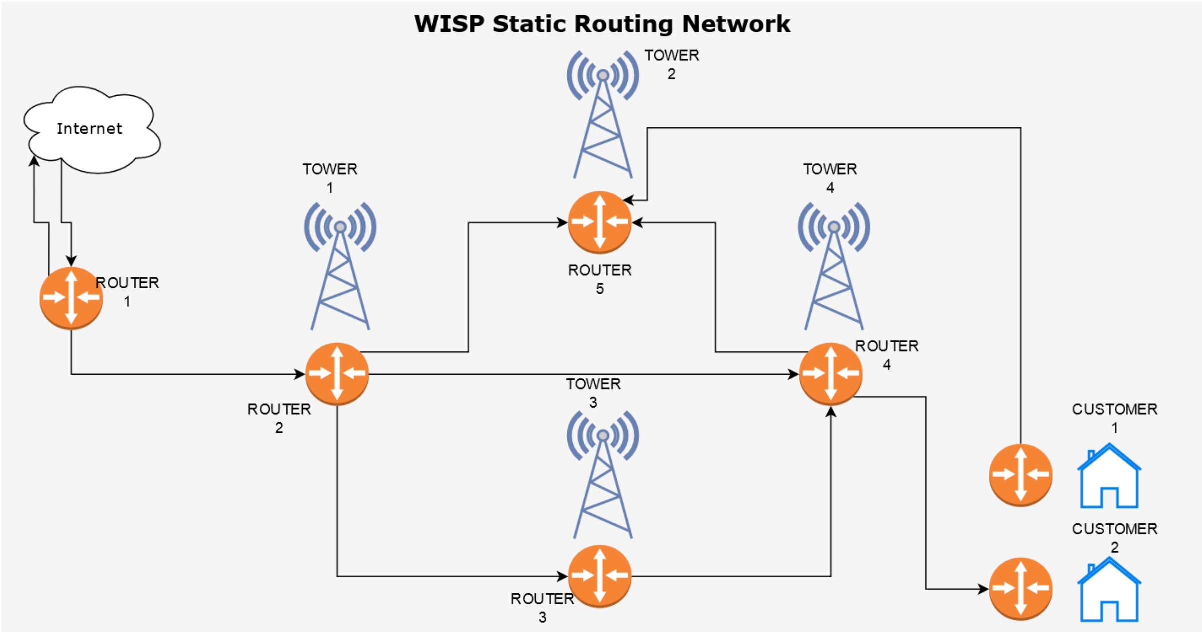
Indeed if you wish to use a network like this, it has its niche like:

- Simplicity
- Won't have more than 100 customers.
- Someone can manage it without a networking/technical background.



III 4.4.2 Static Routing

Here you will use a router on each tower, moving away from switches and broadcast issues, but having static routes increases the time needed to manage such a network.
This kind of routing is suitable for testing out the antennas. We can see if there are any RF issues and see if there will be any impact using another routing protocol (like OSPF). Lossy and/or high-latency RF networks can cause problems with dynamic protocols.



In this diagram, everything is static :

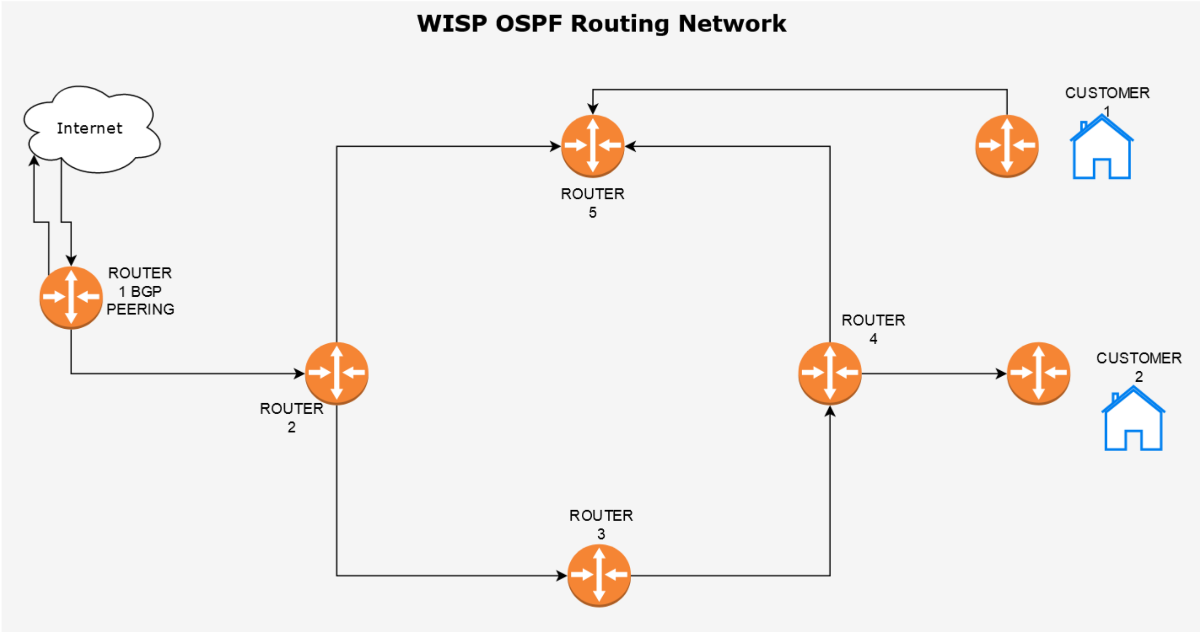
- Router 1 to Router 2 will have static routing IPV4 AND IPV6
- Router 2 to 3, 4, and 5 will have another set of static IPs and routes
- And from Router 5, a static IP and route to customer 1(served by Tower 2) and another set of IP and routes from router 4 to customer 2.

So you will see that this type of routing is very complicated to manage, every route must be configured, and every IP is static.
It's completely manageable with a few routers (let us say 5), but it becomes a nightmare after that.

For Small ISP with no growth planned in the future, it is safe to do a network like this, but if you plan to serve more customers, it's better to change to another and more robust routing protocol.

III 4.4.3 Dynamic routing with OSPF

OSPF is called a link-state protocol, which means it worries about the link speed, topology, and state of every router in an area. Due to the way OSPF works, this can cause a "ripple" effect or "flapping" Because of this behavior, it's better to put non-core routers at towers in different areas.
OSPF is exceptionally good at mapping out paths, speeds, and reachability for subnets, but its limitation on "policy," which BGP is better suited for.



Here router one will advertise with BGP routes for public prefixes.

- BGP and let the ISP do the advertisement
- Router 1 will have the default route 0.0.0.0
- All the other routers will have loopbacks
- Routes for loopbacks and paths and customer traffic are in OSPF.
- These routers belong to Area 0
- Customers get their IPV4 and IPV6 with DHCP.

III 4.4.4 Dynamic routing using iBGP/OSPFv2 & v3/MPLS

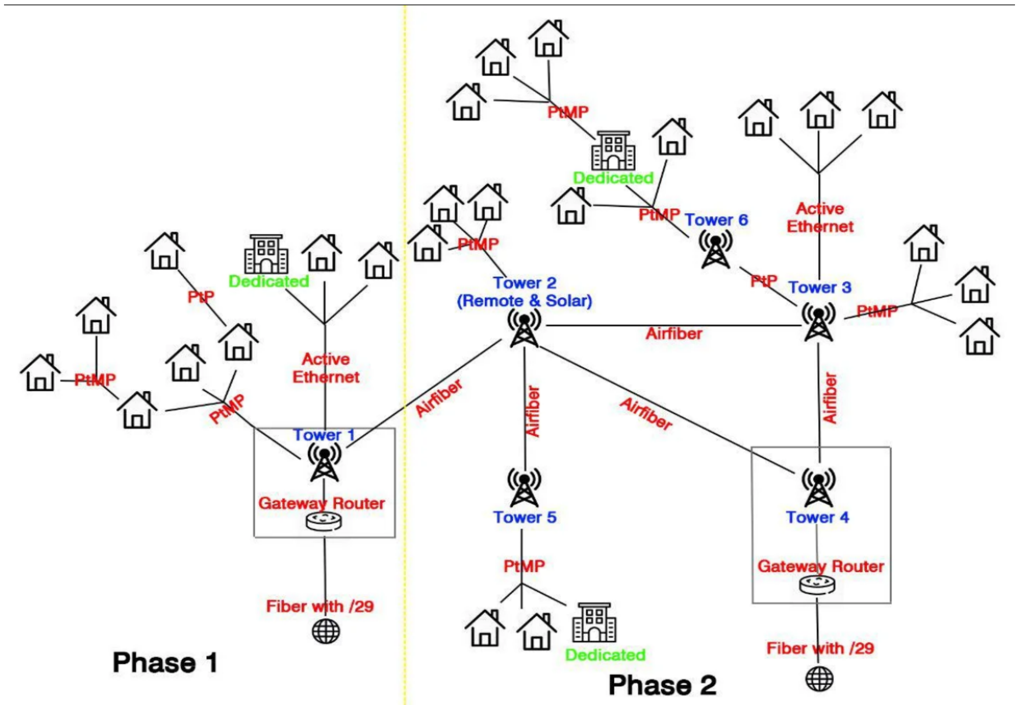
Policy is what describes BGP best. It isn't concerned about link speed, physical topology, or link-state like OSPF. It is focused on policy and the best path algorithm.

MPLS is a forwarding protocol that assigns labels to routes and allows "Service Abstraction" (a lecture about MPLS

iBGP "Internal BPG" uses recursive routing (next hop is not directly connected and requires route lookup) and does not change its next hop. So we use OSPF to advertise the next hop (normally a loopback), so it's always reachable.

The use of MPLS in a WISP network it's a handy tool because it allows the network to be sliced into virtual segments at layer 2 (L2VPN) or layer 3 (L3VPN) to deliver customer services.

The difference and how each element is configured can't be seen on the high-level diagram, only in the detailed one with IPs and areas. We will see one in the next chapter, but as an example, we can see here a complex WISP network that can benefit from OSPF/BGP.



Taken from https://preview.redd.it/ragk7tvbyta31.jpg?width=1151&format=pjpg&auto=webp&s=0e4f4c3629f3da0c1f2bdfd5af09024812fe11bb

III 4.4.5 Example of Hardware for WISP network deployment

As an example, we will check a Mimosa Antenna called A5x https://mimosa.co/product/a5x

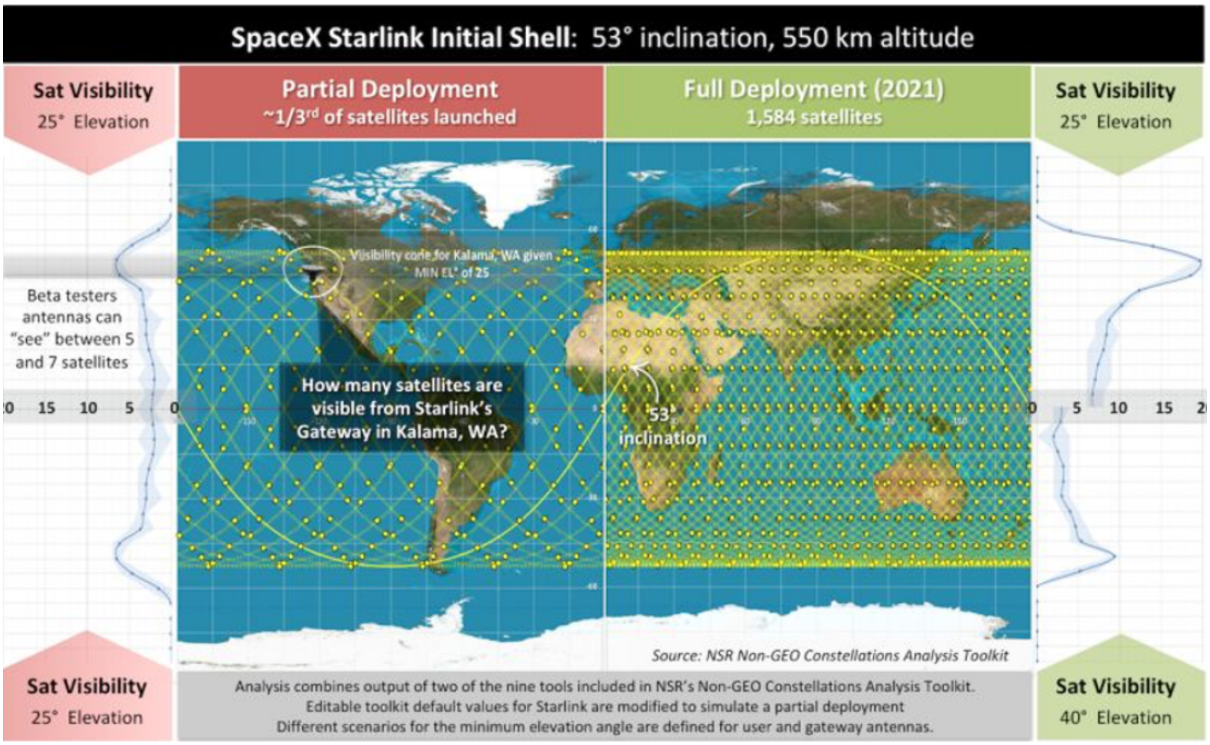
On the Datasheet, we will see the following information:
https://mimosa.co/uploads/CGFeedMaker/datasheets/Mimosa-by-Airspan-A5x-Datasheet_DS-0021-09.pdf?mtime=20200731133841

Performance
• Max Throughput: Up to 700 Mbps (IP)
• Client Capacity:64 clients (WiFi Interop);
44 clients (SRS/GPS sync)
• Wireless Protocols: WiFi Interop,Spectrum Reuse Synchronization (SRS/GPS sync)
Radio
• MIMO & Modulation: 2x2:2 MIMO OFDM up to MCS9 (256-QAM 5/6)
• Bandwidth: 20/40/80 MHz channels;Tunable in 5 MHz increments for GPS Sync;
Tunable to standard WiFi channels for WiFi Interop
• Frequency Range:5150-5850 MHz FCC/ETSI/CA (PN: 100-00107)4900-6400 MHz ROW(PN: 100-00107-1)Restricted by country of operation
• Max Output Power: 27 dBm
• Sensitivity (MCS 0):

-87 dBm @ 80 MHz
-90 dBm @ 40 MHz
-93 dBm @ 20 MHz
Power
• Max Power Consumption: 9-12.9 W
• System Power Method: Passive PoE (24-56 VDC)
• System Lightning & ESD Protection: 6 kV
• PoE PowerSupply: Passive POE compliant, 24-56 VDC (PoE injector not included)
Taken from A5x Datasheet https://mimosa.co/uploads/CGFeedMaker/datasheets/Mimosa-by-Airspan-A5x-Datasheet_DS-0021-09.pdf

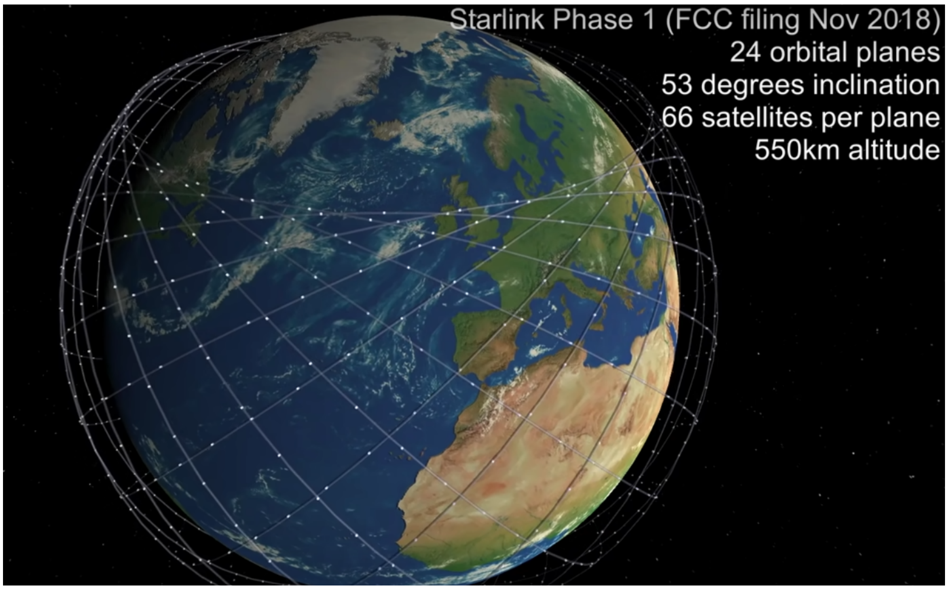
Interop: the capability of all the devices to interact freely and without hindrance between them IEEE 802.11h-2003
With GPS sync, you can reuse frequencies for back to back sectors
Some of these capabilities are the standard now and should always be checked for.
POE will power the equipment through an ethernet cable.

III 4.5 LEO High level network diagram



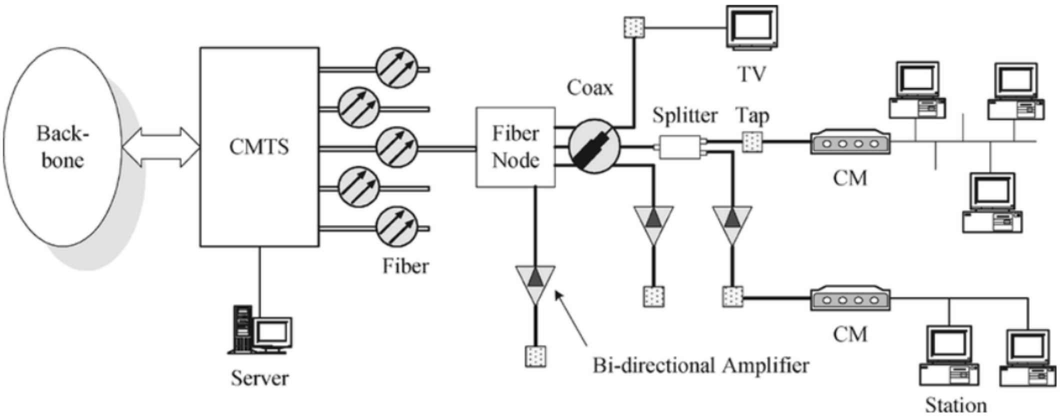
Taken from https://www.satellite-evolution.com/post/2020/09/23/nsr-bottom-line-spacex-raying-starlink-developments

What we know so far about the high-level network diagram for Starlink is the little information they have shared so far and the simulations we can see on the link below. But as described in section III 34.1.- What's Starlink? You will see how the network might work and how the satellites can send information from satellite to satellite and to ground stations.



Taken from https://www.youtube.com/watch?v=m05abdGSOxY&feature=youtu.be 1:37 min

III 4.6 DOCSIS High level network diagram



Architecture of HFC network.

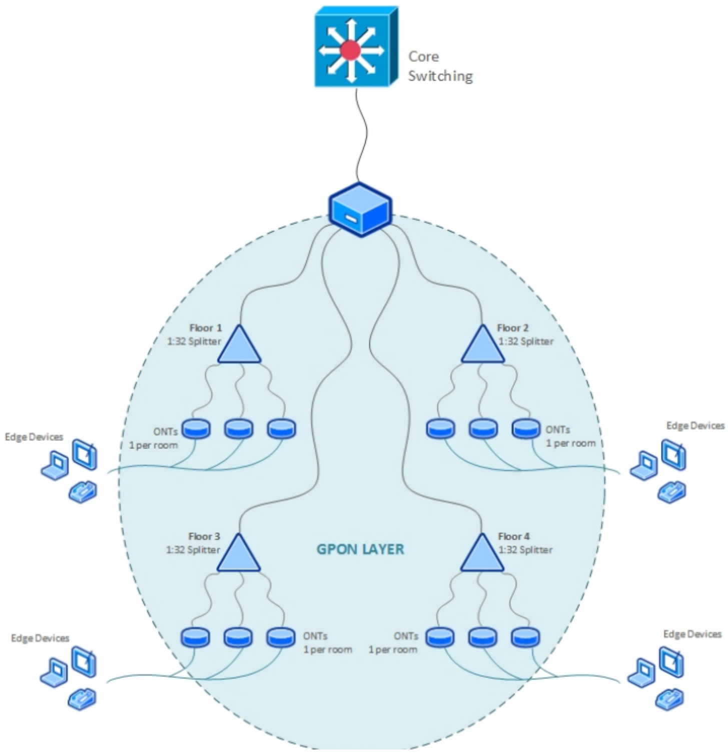
Taken from https://www.researchgate.net/figure/Architecture-of-HFC-network_fig1_3041197

As seen so far, coax buildings have disappeared to make room for fiber. That's the only option the cable companies have so far to be competitive against full fiber networks.
In the picture above, we can see the cable modem termination system (CMTS), which is connected using fiber, fiber to the backbone, fiber to the nodes, and so on. Most of the newer HFC installations will only have Coax from the last node to the customer.
In this document, I won't talk about creating an HFC network because it is out of the scope, and at this age, only cable companies that are already working for years can benefit from such networks. Future networks should be and must be full fiber and pushing to FTTH.

CHAPTER IV: IMPLEMENT NETWORK DIAGRAM SIMULATION AND MONITORING

In this chapter, we will see how to implement a network diagram (as a detailed network diagram we discussed in the previous chapter) with cisco packet tracer (and will discuss about the options available like GNS3, EVE-NG)

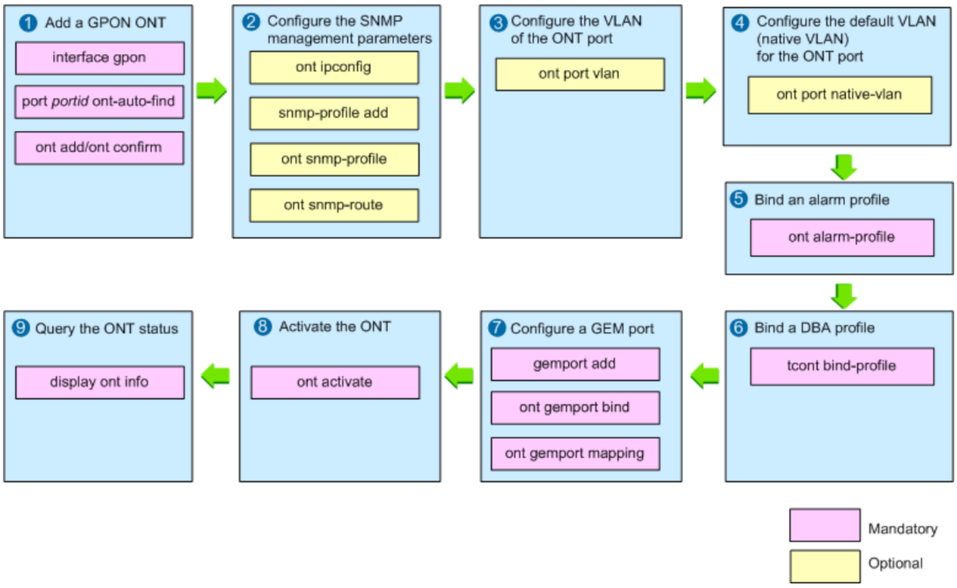
IV 1.- Detailed network Fiber routing diagram



Taken from https://packetpushers.net/campus-lan-design-a-different-approach/

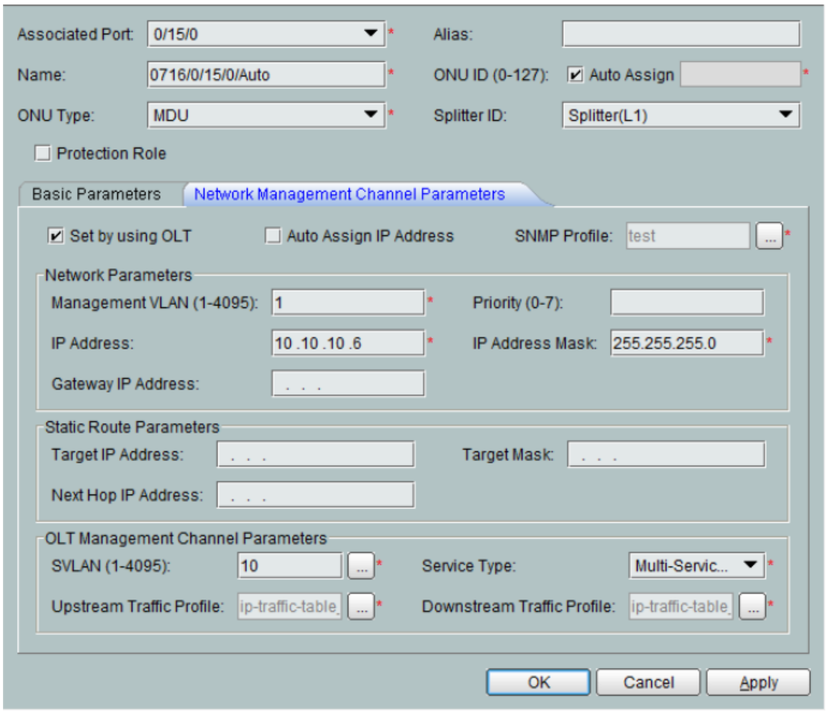
As you see here, the detailed fiber diagram will list the configuration of the splitter, the edge devices, the OLTs, and the connection to the outside(on this diagram is on the Core Switching).
The only thing missing here is the IP address which can be just like the ones we will see on the WISP section.
Generally, for a Fiber deployment, the IPs will come from the OLTs. All the configuration is made in there. If you have DHCP configured, it is up to the client how to get the IP addresses.
The way to configure the IPs is one per port. The OLTs will do the work to assign the final IP address to the CPE(or ONT)

IV 1.1.- Configuring a GPON OLT



https://www.thunder-link.com/docs/post/How-to-Configuring-a-GPON-ONT.html

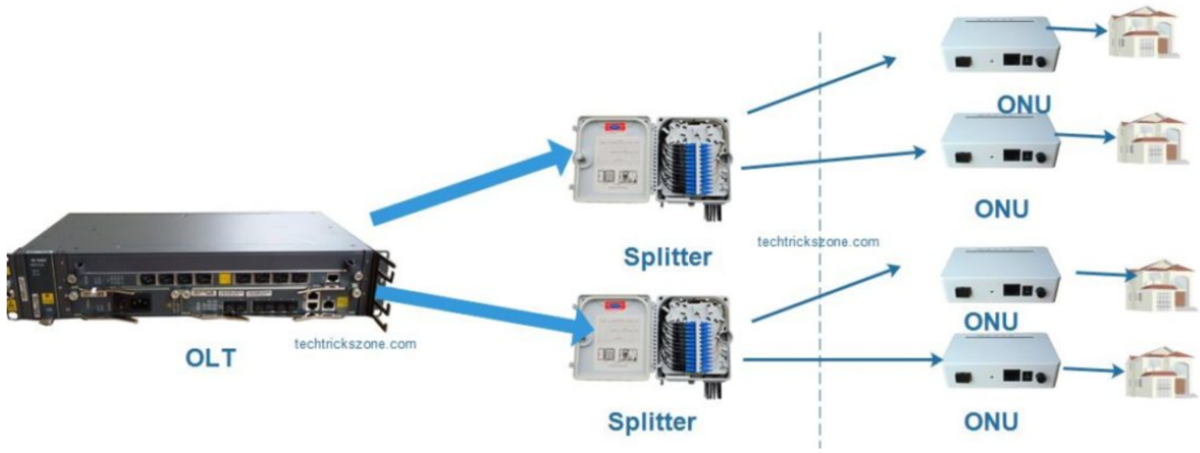
This diagram shows how normally a GPON port is configured from the interface itself to enable SNMP(for monitoring) .
This diagram can vary depending on the OLT you are configuring. Not all of them have the same options or the same names, but as default, most of the options listed here should be on the OLTs.



https://www.thunder-link.com/docs/post/How-to-configure-the-GPON-access-service-Profile-Mode.html

This picture shows the GUI view on the OLT port you are configuring. Here the IP is manually set instead of using DHCP.

IV 1.2.- A physical view of the HW wiring



Huawei MA5608T – Mini OLT (Optical Line Terminal)

https://techtrickszone.com/olt-gpon-onu-optical-fiber-network/

This is the standard view of how and OLT is connected to the splitters and the ONUSs(CPE or ONT)
As we discussed previously, we see that one port will connect to one splitter and that splitter will connect several ONU.

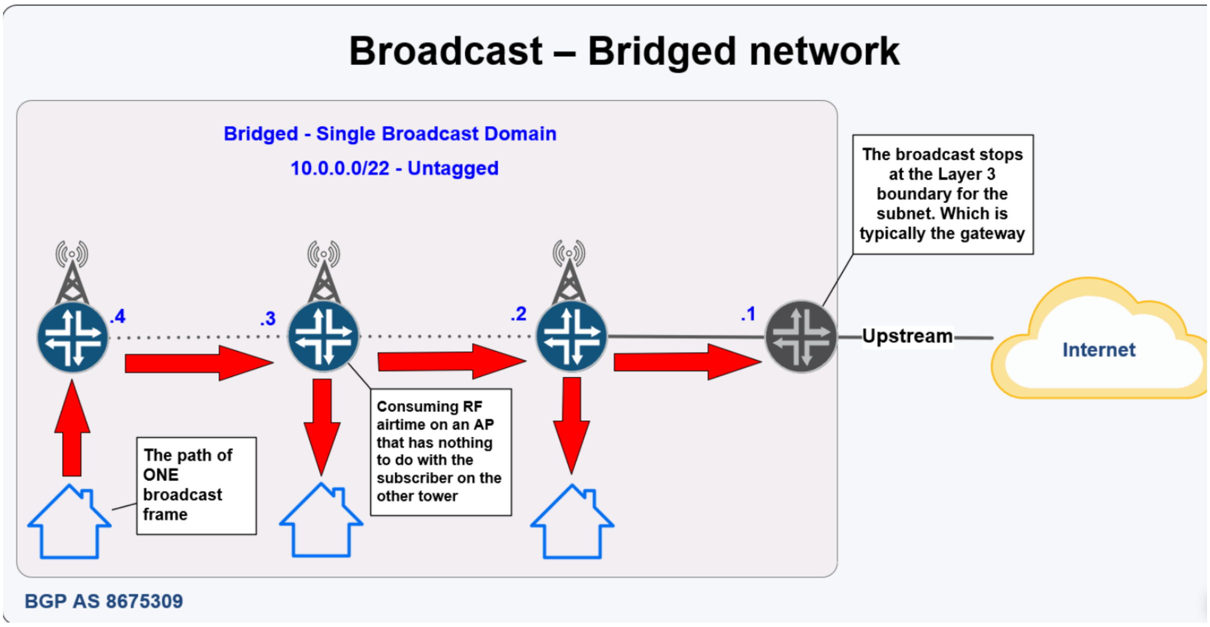
IV 2.- Detailed network WISP routing diagram

On the detailed network diagram, the most important thing to keep in mind is the subnetting.
An easy way to know how many IPs addresses you have under each octet is like this:

Subnet mask	Mask length	Mask octet	Subnet length	Number of addresses
255.255.255.254	31	4	1	2
255.255.255.252	30	4	2	4
255.255.255.248	29	4	3	8
255.255.255.240	28	4	4	16
255.255.255.224	27	4	5	32
255.255.255.192	26	4	6	64
255.255.255.128	25	4	7	128
255.255.255.0	24	3	8	256
255.255.254.0	23	3	9	512
255.255.252.0	22	3	10	1024
255.255.248.0	21	3	11	2048
255.255.240.0	20	3	12	4096
255.255.224.0	19	3	13	8192
255.255.192.0	18	3	14	16384
255.255.128.0	17	3	15	32768
255.255.0.0	16	2	16	65536
255.254.0.0	15	2	17	131072
255.252.0.0	14	2	18	262144
255.248.0.0	13	2	19	524288
255.240.0.0	12	2	20	1048576
255.224.0.0	11	2	21	2097152
255.192.0.0	10	2	22	4194304
255.128.0.0	9	2	23	8388608
255.0.0.0	8	1	24	16777216

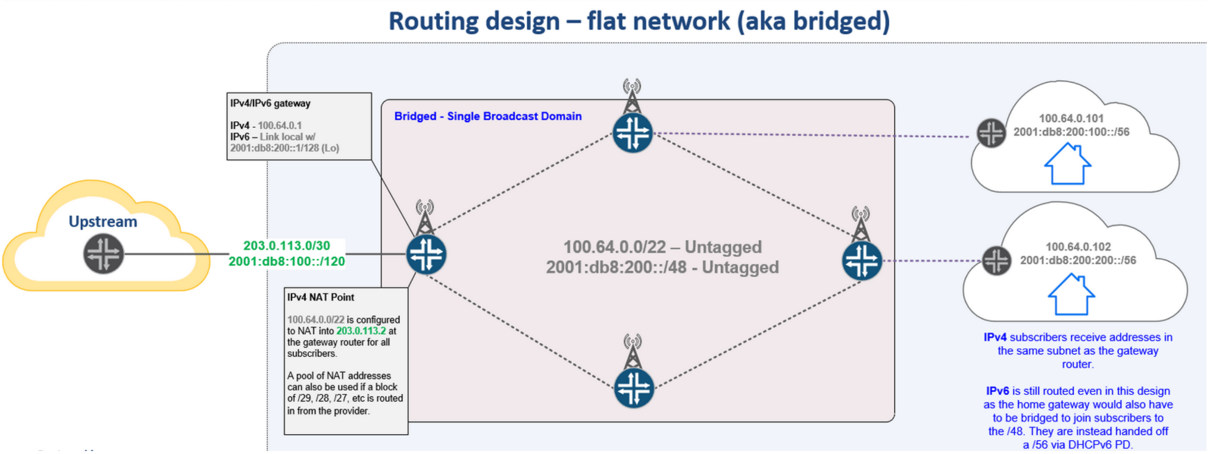
For example, with a mask length of 16 we have the IP address 10.10.x.x that's 65536 hosts for that address.
Usually, you would use 10.x.x.x , first X for Area, then the second X for Departments, and so on, depending on how your enterprise is established and how the Network Designer wants to use them.

IV 2.1.- Broadcast Bridged network



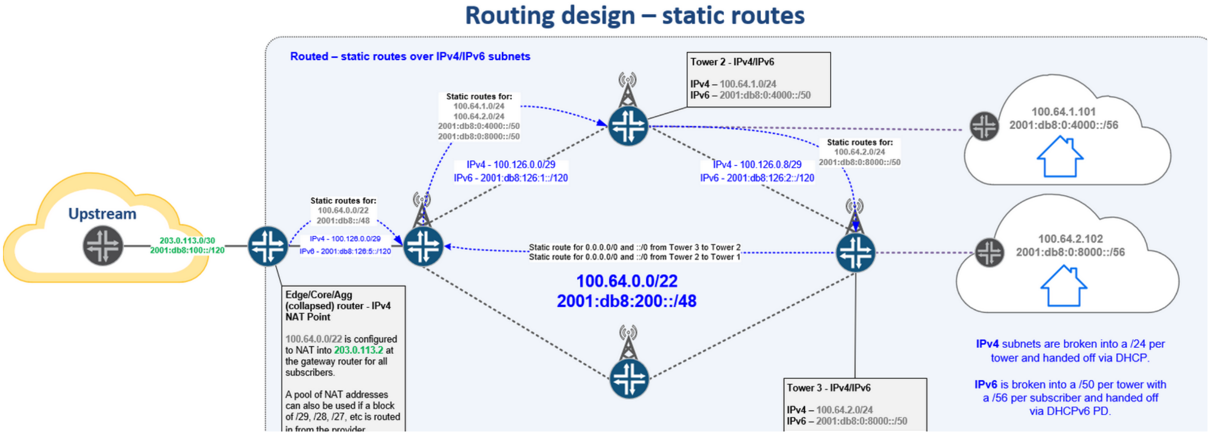
As discussed before, the broadcast of the bridged network diagram will look like this. Since all of them are under the same IP subnet, each switch on the antennas will have the same IP address. The only thing that changes is the last digit on the address, nothing more.

IV 2.2.- Bridged flat network



Here the IPs addresses of the switched will be the same, all under the same subnet. One thing to notice here is the use of NAT. Since you will only get one IP address from your ISP, it's necessary (on some networks) to use it since getting your hands on your own pool of IPV4 can be daunting and expensive. You can NAT with only one IPV4 address, but if your IP gets flagged for any issues, you might have problems with specific applications.

IV 2.3.- Static routing

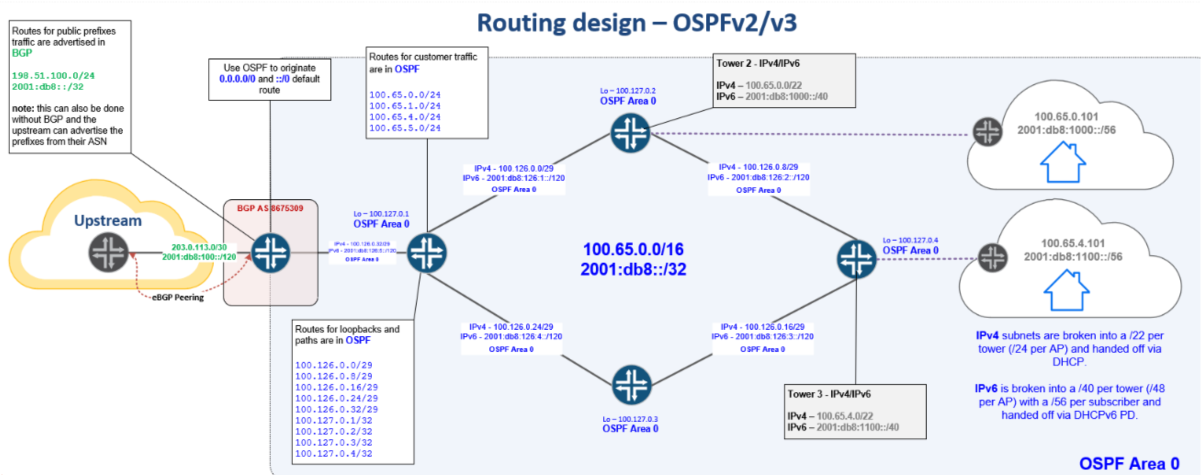


In this diagram, you see the static routes for each tower and to each tower. Static routes must be done to and from any single router. Also, they use the same subnet(here, you don't have the broadcast issue since you are using routers).
But one of the disadvantages of this design is the difficulty of growing more than a few routers. Maintaining static routes is cumbersome and difficult.
Keeping track of the static routes is not an easy task, and it becomes impossible after five routers.

The disadvantages of static routing include:

- They are not easy to implement in an extensive network.
- Managing the static configurations can become time-consuming
- If a link fails, a static route cannot reroute traffic.

IV 2.4 .-OSPF



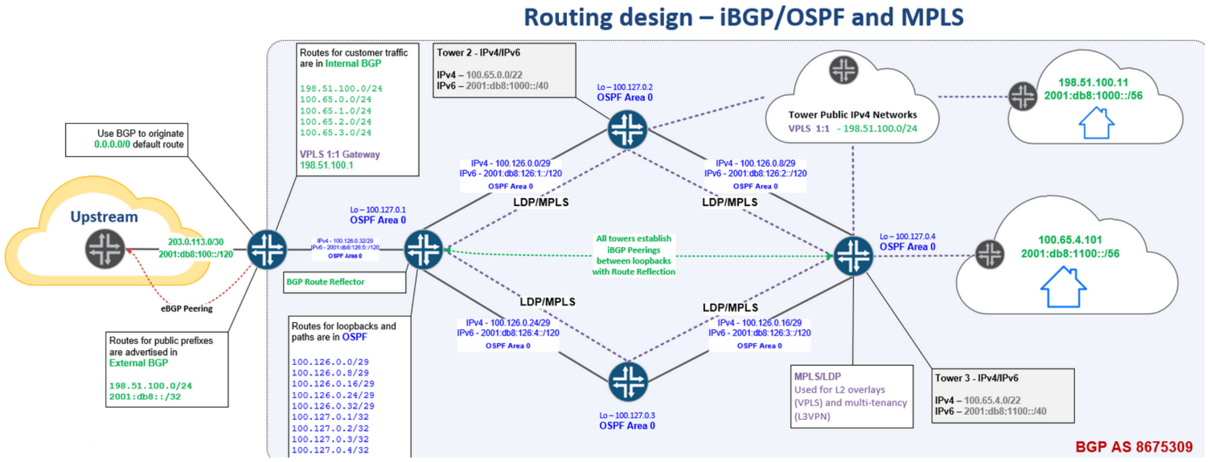
Here we can see the first dynamic routing and its usefulness. No more static routes, and all the routes are discovered automatically, and in case of any route failing, there will be another one to take its place.

OSPF advantages

- Load balancing
- Route summarization
- Unlimited hop counts
- Trigger updates for fast convergence
- A loop-free topology using SPF algorithm
- Classless protocol

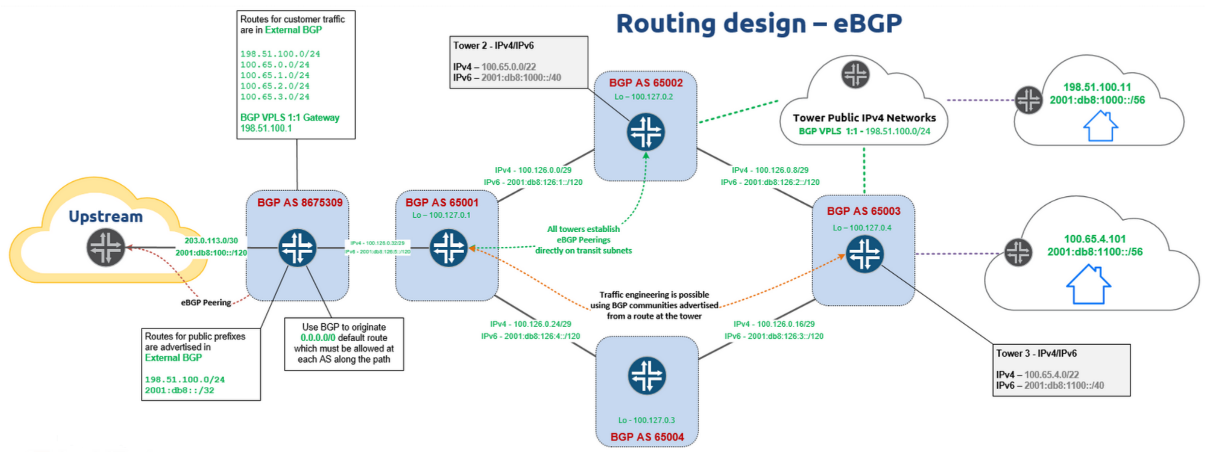
This is one of the easiest protocols to use, but it's best used alongside iBGP and uses those two strengths.

IV 2.5.- iBGP/OSPF/MPLS



Here the iBGP is used for policies when you peer with an outside eBGP from your ISP to learn internet routes.

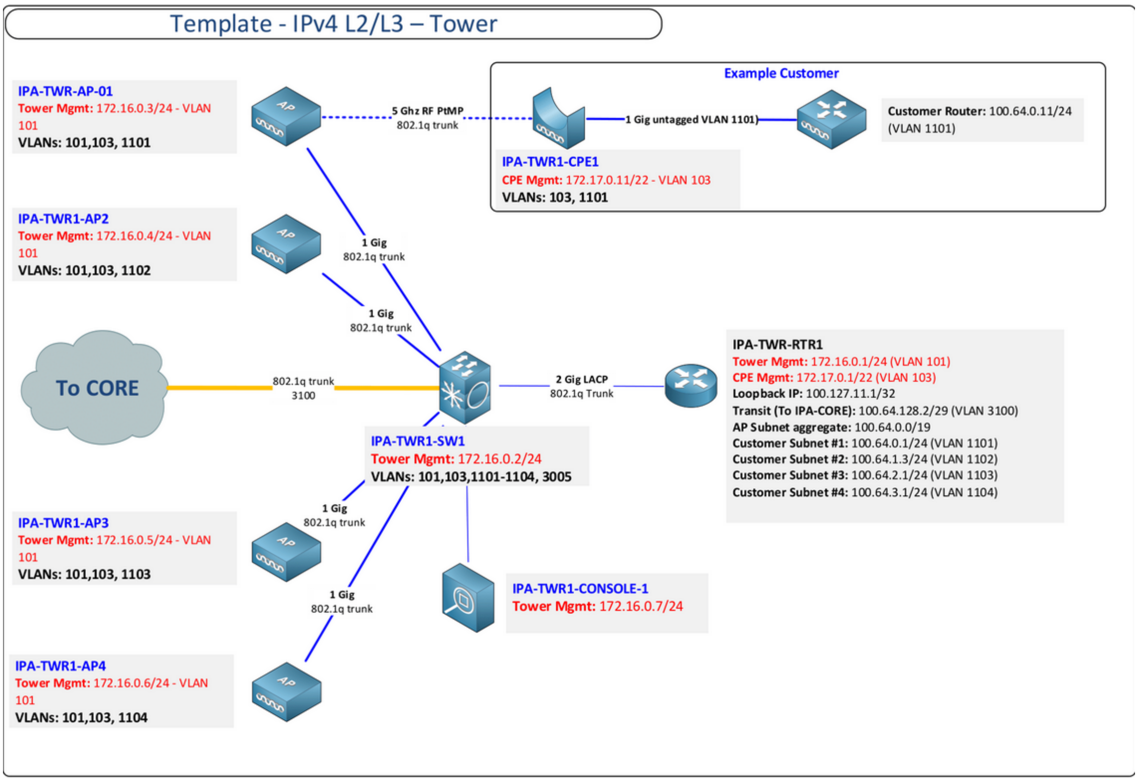
IV 2.6.- eBGP



Here in this design, we can see the use of eBGP to peer with the ISP AS. This is typically used to get the internet routes.

An advantage is to have multiple paths. These paths are always calculated automatically to provide you the shortest path to any other ASN, and your BGP router is constantly calculating the best path to the outside world.

IV 2.7.- L2/L3 with VLAN



In this picture, we see a diagram with switches, routers, and VLANs. This should be the base of every network diagram, and on top of this, we put the OSPF/iBGP/MPLS.

Every protocol does a different thing, and you can manage the traffic as you wish.

All the pictures were taken from the link below, all credit to the owner of that site.
https://stubarea51.net

IV 3.- About GNS3 / EVE-NG

Using Cisco packet tracer is the easiest option to create your network diagram. Still, other tools can take you a bit further, not only creating diagrams but testing the network with a real-world scenario using the same OS images that Cisco, Juniper, Arista, Alcatel, and a long list of vendors.

Some of the listed equipment is emulated, and some others run on VMs, which are the same OSs that run on those switches/routers.

If you can run a VM of it in Qemu, Virtualbox, or VMware, you can run it in GNS3.

EVE NG and VIRL does the same, emulate hardware and run OSs on VMs

Here is a list of the pros and cons of each software

GNS3 vs VIRL vs EVE-NG –

PARAMETER	GNS3	VIRL	EVE-NG
Origin	An open-source, free server/client interface meant for virtualization and network emulation. It is a Python based platform and supports Cisco router platforms.	A Cisco invented proprietary virtual network emulator that is highly regarded by individuals and educational institutions. Preferable choice for enterprise network.	First clientless multi-vendor virtual network simulator that has been developed for individuals and for smaller businesses. Both free community edition and paid professional editions are available.
Access to Software Images	Only accessible via the service contract or a program conducted by a college.	Can access them with annual subscription.	Only accessible via the service contract or a program conducted by a college.
Resource Optimization and Support	Both resource utilization and interface support are better than VIRL.	Limited base resource optimum utilization of server appliance and shortage of support to the serial interfaces.	Both resource utilization and interface support are better than VIRL.
As a Specialized Network Emulator	Requires to first download and then install an independent application to control network devices on the server.	Also requires to first download and then install an independent application to control network devices on the server.	Functions as a clientless network emulator performing virtually.
Terminal Application Requirement	Requires separate terminal application to function and modify network topology.	Requires separate terminal application to function and modify network topology.	Only needs lightweight terminal application like Putty, to build and modify a network topology. Can be used on both desktop and mobile devices.

Taken from https://ipwithease.com/gns3-vs-eve-ng-vs-virl/

IV 4.- Network monitoring

Monitoring the network and its components is crucial for any environment, be it small or an enterprise. Monitoring should be done in all the network equipment available.
To do this, we can follow the following points, and the software we can use is diverse and can be used interchangeably and mix them as you want since not one single software does everything you might need.

IV 4.1.- Device compatibility

A typical network nowadays will have a myriad of components from different vendors, and those vendors will have their tools already created to monitor those components. And most of them will allow you to do so from the "Cloud."
Having many vendors might be a tradeoff, but you make it up with coverage because not one network equipment can do it all.

IV 4.2.- Graphical visualization

Modern SW tools will have their graphical tool (which is easier to look at and get information from than a CLI/text-based log).
Visual tools enable quick ID of performance and topology. Simple charts and graphs look ok, but there are better.

IV 4.3.- Comprehend the data.

Many tools will only extract raw data, and that's how a network administrator will look at it (Wireshark, text logs).
It is critical to move past the view of packets into the realm of how network behavior affects applications. But, packet tracing is a skill on its own. Many network-related issues that cannot be traced to anything can be solved by checking the packets through the server->network->application. Sometimes, it's the only option that can give you any hindsight of a cunning and tricky problem.
From a high view of how an application behaves when using the network, there is also a lot to get from low-level issues like network congestion or device failures. All of those can help and train network admin troubleshooting skills. And understanding both can be a time saver.

IV 4.4.- Integration

No tool should work alone. Integrating and exporting the data from one tool to another to do the analysis is essential. That way, you will have a complete set of network monitoring services.

IV 4.5.- Troubleshooting

Troubleshooting a network issue, it's genuinely detective work. It's important to distinguish the forest from the trees. It's crucial to swoop leaves, but it's also a significant skill to elevate and see the network in its whole context and think outside the box. A good set of tools level the ground.
In large companies and enterprises, one good way to think about monitoring is layers.

IV 4.6.- Data collection

SNMP polls, traps, Syslog, Netflow feeds, vendor management systems.

IV 4.7.- Document important ports, locations

You will need a database or similar SW(Confluence comes to mind) to mark down the essential ports, service hours for a particular router, system location, equipment location.

IV 4.8.- Deduplication

Configure the SWs to only alert root cause and duplicated events once. You don't need to alert and fill the monitor with alerts from the same source.

IV 4.9.- Visualization and Classification:

Decide who sees what. In the case of an event, if it's red, yellow, green, send an SMS/page/email. Set different colors, alerts for different vendors.

IV 4.10.- Event History

It's essential to have the history and the date of certain events to check if the same issue already happened and be able to look for the documentation on how it was fixed.

IV 4.11.- Changelog

Keep the network changes and new information documented and easily accessible.
Also, an essential part of any network is to know when to make changes, how, and when. A VLAN change without further checking can cause havoc in the network, a bad switch config or bad copy/pasted router config can cause trouble.

- That's why it's crucial to create the related documentation on how to make those changes and a tool for those changes (like GitHub).
- syslog, unless you have a separate Syslog server.
- rancid, unless you already take care of configuration backups elsewhere.
- TFTP server with firmware images (no need for SFTP).
- Netflow collector with a web frontend (nfsen, or the flow view cacti plugin).

- cacti or equivalent service to track/graph bandwidth usage on every trunk, WAN, Internet Access circuits, IP SLAs.
- Reporting scripts (I like to have scripts running on the Syslog server to send a Syslog activity report every morning).

IV 4.12.- Wiki for network documentation

Inventories, diagrams, howtos, design guides, incident report/RCA templates, change roadmap templates. As you can see, monitoring a network is an entirely new beast that should be handled as a completely separate service. Having a dedicated engineer doing this will make things easier for any company/enterprise.

IV 4.12.- Network tools to backup configuration, keep track of changes

There are many tools for this, but the consensus of the best ones to use are

- oxidized scripts
- unimus
- librenms
- RANCID

IV 5.- About the monitoring software

There is software used to monitor a network, from routers, ports, traffic. Every SW might do the same as the other, and many can be used simultaneously, but they do it differently. Every one of them has advantages and disadvantages, but they are all powerful tools that must be installed and used on any network :

- Grafanna: observability dashboards
- Prometheus: open-source monitoring solution
- Nagios: The Industry Standard In IT Infrastructure Monitoring
- Icinga: the power to watch any host and any applicationOpenNMS: Enterprise-Class Open Source Network Management
- Zabbix: Solutions for any IT infrastructure, services, applications, resources
- Observium: low-maintenance auto-discovering network monitoring platform
- Cacti: network graphing solution designed to harness the power of data storage and graphing functionality.
- Shinken: Monitoring Solution. It's a Python Nagios® Core total and large environment management.
- Paessler PRTG Monitor (Not free, or Open Source, but very good) Monitor. Visualize. Relax.
- Stay ahead of IT infrastructure issues
- Spiceworks Network Monitor: Real-time up/down status and alerts for your critical web applications and services.

CHAPTER V: DISCUSSION OF RESULTS

As we have seen across this document, each technology has its advantages and disadvantages according to the environment they are used.
Not all of them were created equally, and they must be used according to what network I want to develop or have, for example:

V 1.- Fiber

Fiber is the king, no doubt about that. There is nothing faster than light and fiber since it uses light pulses to carry information. It's the fastest method nowadays. although crossing continents add latency to the network) but that latency is still lower than the one you have with coax or RF.

V 1.1.- About the fiber AON or PON

As seen with AON or PON, using one over the other is just a matter of what speeds I want to achieve with my network. If I want to have speeds higher than 1Gbps for customers, AON. PON won't ever reach those speeds (since the medium is shared)

V 1.2.- About the fiber SM or MM cables

SM mode wins against MM in long hauls (although SM is used in shorter hauls), but that depends on the application, server, or whatever you want to connect. MM is still the choice for data centers and connecting several fiber strands.

V 1.3.- About the fiber the connectors:

LC is used in High-density connections, SFP and SFP+ and XFP transceivers.
SC is used on GPON, EPON, GBIC, MADI.

V 1.4.- About the fiber UPC or APC

You will choose one over the other depending on the type of network you have and the type of services you are running. For some high-precision optical fiber signaling, APC should be the first to consider due to the low dB loss.

V 1.5.- About the fiber CWDM/DWDM/SWDM

CWDM is more suited for PON networks and DWDM for AON networks. SWDM is used on short connections and is best used on DCs.

V 1.6.- About the fiber GPON/EPON/XGPON/GEPON)

Choosing GPON/EPON over their 10GB options is now not the most optimal path to follow.

If you wish to invest in a fiber installation, make it future-proof so that you can give your customers greater speeds.

V 1.7.- About the fiber splitters and splitting level:

The main difference is that PLC is more expensive than FLC but can be used on higher split ratios, and FLC will have issues above 1:8. And FLC is constricted to only some wavelengths.

V 1.8.- About the fiber transceivers

Using one over the other is just a matter of planning. It's entirely acceptable to use only SFP and not SFP+ or QSFP instead of QSFP+. It All Depends on the network speed I want to achieve. keep in mind that newer transceivers are expensive

V 1.9.- About the fiber Network architecture

As architecture to use, you can mix and match them as you want. There is no need to use only one, but usually, you will see the Star topology it's the most popular. But there are still factories using bus or tree, and that's because their applications are made for those types of networks and use their strengths.
Fiber indexing is shown as the best path to save fiber and costs, and it is something to learn how to do and focus on it.
Hardened or all spliced will depend if the PON will change in the future, or you want to use hardened to make it as resilient as you can and avoid splicing onsite and wasting time that could be used somewhere else.
But those two will depend on the type of network, the time schedule if it will grow, and many other variants. But for me, using already made cables and avoid splicing onsite and having them pre factory-made where they are tested, and you know you will get the best cable you need, it's impressive.

V 1.10.- About the fiber Routing:

Routing fiber is only needed after the packets leave GPON equipment. On that side, you usually see a mix of OSPF and BGP, IS-IS and BGP, MPLS on top, or VRF. It doesn't matter. Wherever you use it should be robust, with backups, and resilient.

V 2.- WISP

V 2.1.- About the WISP spectrum

My result here is that you need to avoid 900Mhz, 2.4Ghz. The first option for a WISP is to use 5Ghz for customer connections and 24-60Ghz(if available unlicensed) for the backbone.
The highest unlicensed spectrum should be used for backbone, the highest you find, and can be used without repercussions. And the link will be PtP.
To connect the final customer, you will use 5Ghz and PtM with MIMO and all the other technologies that allow the best signal output possible.

V 2.2.- About the WISP routing

OSPF+BGP+VRF is the best option on a routed network without L2 switches. OSPF as an internal network protocol, BGP for policies, and VRF instead of VLANs.
Or, if you want to be as future proof as you can, use MPLS. MPLS will just add features to your network and will speed things up.
And AVOID Layer 2 switches! For WISP, you need a fully routed network to avoid broadcast issues that can eat your bandwidth. Here bandwidth is golden.

V 2.3.- About the WISP network topology

This will depend on the tower layout. Fully meshed must be avoided(bandwidth decreases by 50%). A star topology will depend on if I have many towers going out of my central office(where the fiber is). Cascade is one to keep in mind since you will connect a tower after the other. But you can create the topology as you want. Just keep it simple.

V 3.- LEO

There is not much to add here due to the low information we have for the routing, links, subnet, or other network details.
With LEO, this is the best option for far away customers and people who don't have reliable internet access. ADSL is awful, and Starlink will easily mop them out of the map.

V 4.- DOCSIS

For DOCSIS, I can honestly say that it is a waste of money to create a new DOCSIS plant and use RF, HFC, or anything instead of full fiber.
If you are going to invest money, do it on fiber. Fiber is the future. We just need to look at how to lower the digging and trenching costs.

CHAPTER VI: CONCLUSION

We have seen how the most used network technology works. Fiber by far is who takes the crown. Speed and reliability is its best characteristic and won't be beaten easily.
Fiber will continue to grow. New materials, new ways to move the light inside the core, new cores will increase the speeds we see today.

There is something we need to keep in mind about Fiber:

Digging and trenching: Technologies on this part haven't seen much improvement. The only improvement so far I've seen is micro-trenching. One could think that digging is easy, or trenching - what problems could we have? but they are an essential part of fiber installation. And most of the budget can easily be used here. Digging must have its revolution. We need to discuss new ways to do things or how to lower the costs. In ancient times, when trains were just showing their capability, we used only manpower to dig and set the train lines by hand? Why is that stopping us and cannot be done today?

I haven't found a clear answer to this question, but I will continue researching why the prices for those two things haven't gone down.

Bureaucracy: Like any technology, Fiber isn't short of this. Planning and installing new Fiber is a hassle and will continue to be one.
Like in digging, I haven't found a clear answer as to why to continue having problems. One thing that comes to mind is that the big ISP are pushing any competition back, lobbying, so they are the only ones with the business. But we all know that many millions of dollars are spent, and they just pocket the money and don't do the work they should do.
Much of the problems we have today with Fiber are created by them and the inability of the world government (this isn't only a problem here in Canada, I've seen first hand this problem is like this everywhere)
Much like the spectrum sale for satellites or WISP, only the big boys are left with the spoils.

But we have some exciting histories of people working with a donkey to lay Fiber, and that is something we should cherish and copy.

More fiber connections through the sea. This is what makes the difference. If Google can install fiber to Chile, then that must be the future. If it weren't for Cloud services, this wouldn't have happened.

For WISP, I can say that you can have some outstanding networks and speeds if done well. Many rural towns will benefit from this kind of technology, which is way faster to deploy than Fiber, and can get speeds close to Fiber.

The main problem with it is the spectrum. Licensed spectrum is far too expensive, leaving only unlicensed in some countries (luckily, Canada has 60Ghz -channel 2- unlicensed). We just need a good fiber connection to start deploying the backbone and using 5.8Ghz to PtM.

Qos and monitoring, WISP can really benefit from using newer and more robust protocols and start Qos on the applications running under those networks.

WISP should start behaving like ISPs, prioritizing applications, optimizing the network, backup the network in case of problems.

Plan for the environment! Many WISPs forget that sand, snow, rain can wreak havoc on the towers and dishes.

Battery backup for towers and equipment. This is a must for any WISP. Towers should keep and have power at all times.

Use Drones to survey new areas. And don't forget to check sector maps and do the actual walking through the place to check new installation areas.

And monitoring, monitoring, monitoring. Create alerts, set more alerts and keep an eye when you need to increase your backbone speed, where you need more towers, new towers if there are issues with the routers.

About Satellite today, Starlink is the best of the best out there. Their offerings and promises are being delivered, and rural towns of USA are already seeing their speeds bumped above 200Mbps (with some hiccups here and there since the Starlink constellation isn't fully running yet).
While there are other competitors, it's clear Starlink is carrying the baton. We will see how it develops and grows in the near future.

And DOCSIS? It is suitable only for people who already own RF coax plants. Just them and their customers can see any relevance in investing money in this technology.
Setting new HFC plants is just a waste of money. Go Fiber!.

CHAPTER VII: REFERENCES

Data and Computer communications - Tenth Edition William Stallings

1) High-Speed Access for All: Canada's Connectivity Strategy - Get connected https://www.ic.gc.ca/eic/site/139.nsf/eng/h_00002.html

2) Broadband Fund: Closing the Digital Divide in Canada | CRTC https://crtc.gc.ca/eng/internet/internet.htm

3) Communications Monitoring Report 2019 - Retail Fixed Internet Sector and Broadband Availability | CRTC https://crtc.gc.ca/eng/publications/reports/policymonitoring/2019/cmr9.htm

4) National Broadband Internet Service Availability Map https://www.ic.gc.ca/app/sitt/bbmap/hm.html?lang=eng

5) GSMA | Operator Requirements for 5G Core Connectivity Options - Future Networks https://www.gsma.com/futurenetworks/wiki/operator-requirements-for-5g-core-connectivity-options/

6) How Data Gaps (re)Make Rural Broadband Gaps by Helen Hambly, Reza Rajabiun :: SSRN https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3427482

7) Types of Broadband Connections | Federal Communications Commission https://www.fcc.gov/general/types-broadband-connections

8) Rural Broadband deployment https://www-deslibris-ca.login.ezproxy.library.ualberta.ca/ID/10101832

9) Accelerating broadband enablement in Rural Alberta https://www-deslibris-ca.login.ezproxy.library.ualberta.ca/ID/225822

10) Broadband connectivity in rural Canada: Overcoming the digital divide https://www-deslibris-ca.login.ezproxy.library.ualberta.ca/ID/10096313

11) Internet connectivity in a northern setting: A Churchill case study https://www-deslibris-ca.login.ezproxy.library.ualberta.ca/ID/224901

Fiber references

12) Duane Webber Cisco Systems, Inc REDUCING CAPEX AND OPEX THROUGH CONVERGED OPTICAL INFRASTRUCTURES

13) Government of Alberta – Economic Development and Trade, 2016 Understanding Community Broadband: The Alberta Broadband Toolkit was made.

14) Joseph P. Brenkosh, Jimmie V. Wolf,2011 Sandia Labs - Deploying GPON Tutorial

15) Rafael Sánchez, José Alberto Hernández, Julio Montalvo García, and David Larrabeiti February 2016 IEEE Communication Magazine - Provisioning 1 Gb/s Symmetrical Services with Next-Generation Passive Optical Network Technologies.

16) FTTH Handbook Edition 7 D&O Committee Revision date: 16/02/2016.

17) GPON G.984.3 Standard ITU 2014 ITU-T G.984.3 TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU (01/2014) SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-G.984.3-201401-I!!PDF-E&type=items

18) The Importance of Dynamic Bandwidth Allocation in GPON Networks White Paper by Onn Haran, Fellow and Amir Sheffer, Product Line Manager Issue No. 1: January 2008 PMC-Sierra, Inc https://pmcs.com/cgi-bin/document.pl?docnum=2072146

19) Fiber Link Power Budget: How to Make It Right? http://www.fiber-optic-transceiver-module.com/fiber-link-power-budget-calculation.html

20) What is an Internet exchange point? | How do IXPs work? https://www.cloudflare.com/learning/cdn/glossary/internet-exchange-point-ixp/

21) Fiber Optic Solutions EPCOR https://www.epcor.com/products-services/infrastructure/epcor-technologies/communication-systems/Pages/default.aspx

22) Beamforming & Beamsteering Antennas
https://www.electronics-notes.com/articles/antennas-propagation/smart-adaptive-antennas/beamforming-beamsteering-antenna-basics.php

23) Free Path Loss
https://www.georgetimmermans.com/long-range-wifi-link.html
https://www.everythingrf.com/rf-calculators/fresnel-zone-calculator

24) FOA Fiber Optics Association
https://fiberu.org/#fibercomm

25) GPON Multihoming
https://www.noction.com/knowledge-base/multihoming

26) UFiber GPON - Designing a GPON Network
https://help.ui.com/hc/en-us/articles/115011654907--UFiber-GPON-Designing-a-GPON-Network#6

27) How to Design Your FTTH Network Splitting Level and Ratio?
https://community.fs.com/blog/how-to-design-your-ftth-network-splitting-level-and-ratio.html

28) E7 EXA R3.x GPON Applications Guide December 2020
https://www.calix.com/content/calix/en/site-prod/library-html/systems-products/e-series/sysop/e7-ud/r3x/gpon/index.htm?toc36798131.htm?68728.htm

29) PON Link Budget Calculator https://info.support.huawei.com/AccessInfoTool/PON_Budget_Tool/index?language=en&domain=0

30) Fiber To The Home The Ultimate Guide https://get.ospinsight.com/fiber-to-the-home-the-ultimate-guide

31) Eli Laufer, Co-founder Lepton Systems Can Your Layer 1 Switch Do This? Value-added features that provide more of a good thing - http://www.leptonsys.com/blog/can-your-layer-1-switch-do-this-value-added-features-that-provide-more-of-a

32) Fiber Access Topologies: Star, Ring (or Bus), and Tree https://www.ad-net.com.tw/fiber-access-topologies-star-ring-or-bus-and-tree/

33) Mark D. Vaughn, Member, IEEE, David Kozischek, David Meis, Aleksandra Boskovic, and Richard E. Wagner NOVEMBER 2004 - Value of

Reach-and-Split Ratio Increase in FTTH Access Networks http://cfp.mit.edu/groups/BBWG_DOCS/Vaughn_Reach-FTTH.pdf

34) CommScope Definitions: What Is Fiber Network Convergence? https://www.commscope.com/blog/2016/commscope-definitions-what-is-fiber-network-convergence/

35) SFP PAGES SFPs: B+ and C+ – What's the Difference? https://www.multicominc.com/training/technical-resources/sfps-b-and-c-whats-the-difference/

36) Basic Knowledge About GPON SFP Transceivers https://community.fs.com/blog/basic-knowledge-about-gpon-sfp-transceivers.html

37) Hacker News https://news.ycombinator.com/news

38) Network Documentation Best Practices: What to Create & Why https://www.auvik.com/franklyit/blog/network-documentation-best-practices/

39) Network documentation checklist: 10 steps for channel partners https://searchitchannel.techtarget.com/feature/Channel-Checklist-10-steps-for-network-documentation

40) Mahmoud Al-Quzwini March 2014 - Design and implementation of a Fiber to the Home FTTH access network based on GPON https://www.researchgate.net/figure/mplementation-steps-of-the-GPON-FTTH-access-network_fig9_263025546 https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.686.363&rep=rep1&type=pdf

41) FOA Fiber Optic Measurement Units: "dB" and "dBm" https://www.thefoa.org/tech/ref/testing/test/dB.html

42) GIS reference https://www.qgis.org/en/site/

Microtrenching/trenching and digging

43) Authors: Hediyeh Vaseli, Leila Hashemian, Alireza Bayat abayat@ualberta.ca, Leon Gay, Ian Williams, and Jordan Melzer Publication: FACETS • 17 August 2017 - https://doi.org/10.1139/facets-2016-0043

https://www.researchgate.net/publication/319240647_Evaluation_of_fiber_optic_installation_methods_a_case_study_on_micro-trenching_in_Alberta_Canada

44) Author / Creator Hasanuzzaman, Md. September 2016 https://era.library.ualberta.ca/items/69ea5a7f-0d13-43c4-a642-e9a77022b97a

45) APPLICATION PROCEDURES FOR PLACEMENT OF UNDERGROUND TELECOMMUNICATION CABLES IN THE VICINITY OF TRANSPORTATION FACILITIES UNDER THE JURISDICTION OF ALBERTA TRANSPORTATION, June 2012

46) Taylor Warwick Consulting Limited September 15,2017- Northern Alberta Broadband Preparedness Project Peace Region Economic Development Alliance

47) Document Reference Number: ENET-TD003C-EN-P - Deploying a Fiber Optic Physical Infrastructure within a Converged Plantwide Ethernet Architecture Application Guide January 2018 Jens Myrup Pedersen, Gustav Helgi Haraldsson, and M. Tahir Riaz - Using Google Earth for Visualization in FTTH Network Planning

48) The Fiber Optic Association, Inc. December 2018 FOA Technical Bulletin Guide To Fiber Optic Network Design

49) The Calgary Regional Partnership by Craig Dobson – Taylor Warwick Consulting Limited September 28, 2016 Regional Broadband Investigation Needs,Opportunities, and Approaches At the Local Level and for the Calgary Region Municipal & Regional Opportunities & Options.

50) Organisation for Economic Co-operation and Development, May 10 2004 - Working Party on Telecommunication and Information Services Policies

51) Looking Ahead: AXOS Platform and E-Series Systems https://www.calix.com/content/dam/calix/marketing-documents/public/connexions_2019/Looking_Ahead-AXOS_Platform_E-Series_Systems.pdf

52) Which PON is right for you? EPON, GPON, XGS-PON, 10G EPON, NG-PON2...? https://www.calix.com/solutions/technologies/10g-pon-solutions.html

53) THE DEVELOPMENT OF BROADBAND ACCESS IN RURAL AND REMOTE AREAS

54) FTTH PON Guide Testing Passive Optical Networks 5th Edition

55) Occupational Health and Safety Code 2009 Part 32 Explanation Guide

WISP and Wireless references

56) Become Your Own Private ISP Today https://www.whoishostingthis.com/blog/2015/03/09/start-your-own-isp/

57) WISP Association https://wispa.org/

58) Broadband Wireless Exchange Magazine https://web.archive.org/web/20140324154446/http://www.bbwexchange.com/howto/

59) Start Your Own ISP https://startyourownisp.com/

60) KEVIN MYERS, NETWORK ARCHITECT / MANAGING PARTNER MTCINE #1409 MIKROTIK CERTIFIED TRAINER ISP Architecture – MPLS Overview, Design and Implementation for WISPs.

61) Michael Calabrese & Amir Nasr July 2020 - The 5.9 GHz Band Removing the Roadblock to Gigabit Wi-Fi Bernd Holznagel / Arnold Picot / Sebastian Deckers Nico Grove / Marc Schramm - Strategies for Rural Broadband

62) CanWISP March 29 2017 - Consultation on the technical and policy framework for radio local area networks devices operating in the 5150-5250 MHz frequency bands

63) Nordcity March 28th 2018 - Key Findings & The Case for Additional Spectrum for WISPs

64) OpenWISP Features https://openwisp.org/whatis.html

65) Starting a WISP: guide to selecting a routing architecture https://stubarea51.net/2020/03/03/starting-a-wisp-guide-to-selecting-a-routing-architecture/
https://stubarea51.net/2019/09/15/wisp-design-migrating-from-bridged-to-routed/
https://startyourownisp.com/posts/network-topology/

66) OSPF Neighbor Problems Explained https://www.cisco.com/c/en/us/support/docs/ip/open-shortest-path-first-ospf/13699-29.html

67) IP Routing: BGP Configuration Guide https://www.cisco.com/c/en/us/td/docs/ios-xml/ios/iproute_bgp/configuration/xe-16/irg-xe-16-book/bgp-policy-accounting-output-interface-accounting.html

68) MPLS Case use https://web.eecs.umich.edu/~sugih/courses/eecs489/lectures/20-MPLS+VPN.df

69) WISP knowledge center https://swiftfox.net/index.php/blog_posts/starting-a-wisp/

70) WISPs See Speed Bandwidth Boosts as High as 75% Using 5.9 GHz Spectrum https://www.telecompetitor.com/wisps-see-speed-bandwidth-boosts-as-high-as-75-using-5-9-ghz-spectrum/

71) Spectrum Bands: Different Frequencies http://wisptools.net/book/bookc2s2.php

72) Canada Spectrum outlook 2018-2022 https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11403.html

73) Canadian Table of Frequency Allocations https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf01678.html

74) Wireless histories https://muniwireless.com/2013/06/09/ill-give-you-two-5s-for-10-ghz/

75) Articles http://wisptools.net/articles.php

LEO references

76) Mark Handley Professor of Networked Systems. http://www0.cs.ucl.ac.uk/staff/M.Handley/

77) Evolving Cybersecurity in the NewSpace Era http://interactive.satellitetoday.com/via/april-2018/evolving-cybersecurity-in-the-newspace-era/_fragment.html

78) Starlink Satellite Constellation of SpaceX https://directory.eoportal.org/web/eoportal/satellite-missions/s/starlink

79) SpaceX Starlink Satellite Internet Update & Reality Check for RVers & Boaters https://www.youtube.com/watch?v=Yp_fKk4DJC0

80) Satellite Evolution Group Sep 23, 2020 - NSR bottom line: SpaceX-RAYing Starlink developments https://www.satellite-evolution.com/post/2020/09/23/nsr-bottom-line-spacex-raying-starlink-developments

81) SpaceX adds laser crosslinks to polar Starlink satellites https://spacenews.com/spacex-adds-laser-crosslinks-to-polar-starlink-satellites/ https://www.sundayvision.co.ug/spacex-is-adding-laser-cross-links-to-the-starlink-polar-satellites/

DOCSIS References

82) Hybrid fiber-coaxial https://en.wikipedia.org/wiki/Hybrid_fiber-coaxial

83) The role of coaxial cable in broadband networks

84) https://www.cablinginstall.com/home/article/16468612/the-role-of-coaxial-cable-in-broadband-networks

85) The challenges of deploying fiber alongside coax https://www.ppc-online.com/blog/the-challenges-of-deploying-fiber-alongside-coax

86) DOCSIS 3.1 vs. FTTH: Is That the Real Question? https://www.intraway.com/blog/DOCSIS-FTTH-Is-That-the-Real-Question

87) Get Ready 'Cause Here It Comes: DOCSIS 4.0 https://www.broadbandtechreport.com/docsis/article/14184376/get-ready-cause-here-it-comes-docsis-40

88) A Technical Guide to DOCSIS 3.1 and Beyond – Part 2: Technical Advantages https://www.incognito.com/blog/a-technical-guide-to-docsis-3-1-and-beyond-part-2-technical-advantages/

89) OFDM, Completely New in DOCSIS 3.1 https://volpefirm.com/ofdm/

90) Enabling 10 Gbps Cable Networks with Full Duplex DOCSIS 3.1 https://www.qorvo.com/design-hub/blog/enabling-10gbps-cable-networks-with-full-duplex-docsis-3-1

91) Remote-PHY and Full Duplex DOCSIS https://broadbandlibrary.com/remote-phy/

92) Demystifying OOB and R-PHY https://broadbandlibrary.com/out-of-band/

93) CableLabs DOCSIS® 3.1 Technology https://www.cablelabs.com/technologies/docsis-3-1

94) DOCSIS https://en.wikipedia.org/wiki/DOCSIS