INTERNET INFRASTRUCTURE TECHNOLOGY CHART[1]

Important Information About Using and Relying on Information Contained in the Chart

This Internet Infrastructure Technology Chart is intended to help community decision makers and consumers better understand some of the common technologies used today to deliver high-speed internet service to homes and businesses, as well as a few that are expected become available in the next few years. The Chart lists both wired or "wireline" (connecting to the internet by wire or cable to a home and business) and "wireless" (connecting to the internet using a signal that is transmitted from a remote location). Of course, inside the home or business a device may connect wirelessly through a wireless modem and router

Generally Limited to "Fixed" Internet Service

Except for 5G the Technology Chart focuses on wireless internet access to a *fixed location* such as a home or business (fixed wireless internet) as opposed to access that is available on a mobile device such as a smartphone or a wireless internet "hot spot" (mobile wireless internet). While both technologies are extremely important, fixed wireless internet connects using an antenna fixed to a consumer's premises. For that reason, fixed wireless network connections are less affected by the number of individuals and mobile devices that are in range and attempting to access an internet service provider's transmitter. While individual circumstances may differ, this usually meant that fixed wireless internet service is more stable and reliable than mobile wireless internet, and therefore better suited for important home and business internet-based applications.

5G & Satellite

Fifth Generation or "5G" technologies relate to *mobile* wireless internet, and they are discussed in the Technology Chart primarily with the hope of fostering a better understanding of their respective capabilities and limitations, and also because some eventually may compliment fixed wireline internet networks. As described in the Technology Chart, 5G can involve up to three separate connection technologies, and each have dramatically different bandwidth and signal range characteristics. These are referred to as low, medium and high band 5G. While network build out has been underway for a couple of years, at this point is unclear when or whether all three "bands" will be generally available in most locations in the United States.

The Technology Chart also covers High Orbit Satellite Internet service currently available to consumers and Low Orbit Satellite Internet service. At this time Low Orbit Satellite Internet service is only offered in limited areas by Starlink. This technology has performed well in limited settings. It is added to the Technology Chart to provide a better understanding of its capabilities and the physical limitations that may impair widespread adoption of Low Orbit Satellite Internet.

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[1] This Technology Chart was prepared by the University of Missouri System Broadband Initiative Team with the assistance of Tim Templeton, a Computer Science degree candidate.

Bandwidth, Range & Throughput

The Technology Chart was prepared using source material noted in the references. Information is included in the Technology Chart regarding bandwidth of the various technologies. Bandwidth is the theoretical "speed" – the theoretical amount of data that can be transferred through an internet connection each second. The Technology Chart also shows the signal range (the effective range over which an internet signal can be transferred without amplification equipment).

Both the bandwidth and signal range values in the Technology Chart may differ significantly from those you will experience in your home or business. The overall performance of an internet connection (how well it works in a given situation) is typically referred to as "throughput" and there are many factors that effect it. You can test the connection speed you are using on the Missouri Broadband Resource Rail . Significant factors that are often overlooked by individuals and business are the quality of the equipment used *inside the home* and the *number of applications* in a home or business that are accessing the internet. Both can adversely affect throughput of a particular device or internet application, no matter the capabilities of the internet infrastructure being used.

The amount of Bandwidth a particular home or business *needs* can vary widely. Individuals often are surprised that they must account not only for traditional uses (laptop and desktop computers) but also for the many new appliances (televisions, radios, music streaming, doorbells, and thermostats, etc.) as well as each smart phone or tablet family members own. The FCC has published a Household Broadband Guide for consumers attempting to select the level of service they currently need. While it can be useful for assessing a household's current needs, it is less useful for communities that are attempting to determine the level of service that needed in the next few years to account for future growth in demand.

Fiber Optic Cable & the Last Mile Connection

All of the Wireline and Wireless technologies connect at some point to fiber optic cable ("fiber") to transmit data through the internet. All of the technologies described in the Technology Chart describe the means of transmitting data over the "last mile" of the connection – the last portion of its journey to the consumer's internet-connected device or appliance. Typically, this includes the portion of the physical network operated by the community's local internet service provider (an ISP).

Physical Limitations Affecting Performance

Some performance parameters for technologies described below are based on the physical properties (physics) – and they operate to limit the performance their performance characteristics.

- Wireless internet infrastructure technologies all operate by transmitting an electromagnetic signal (such as a radio wave) through the air (and in some cases through outer space as well). Generally, the frequency of the wave (the number of *waves* that pass a fixed point in a second) determines both the amount of information the signal (it's bandwidth) and the distance over which the signal can travel (the signal range). This means that wireless technologies that use higher frequencies will have a higher "bandwidth" or "faster internet speed." However, the trade-off for greater bandwidth is that the signal cannot travel as far, and it will be more susceptible to interference such as

bad weather, foliage and even building walls. Several wireless technologies in the chart require a direct "line of site" between the ISP's transmitter and the customer's antenna to work properly.

- Wireline internet infrastructure also operate by transmitting electromagnetic signals. However, wireline technologies generally are not susceptible to physical obstructions or weather (except of course the risk that the wire connection will be cut in a storm or by someone accidently cutting the cable). However, wireline connection technologies also have different signal ranges over which they can effectively carry internet data. Once that signal range is exceeded, the connection first slows and then stops working entirely. However, unlike wireless connections, the material capable to achieving the highest bandwidth/speed (fiber optic cable) also has the longest signal range.

Further Improvements Likely in the Future

Internet infrastructure technologies for both wireline and wireless internet connections continue to improve. Researchers are constantly developing new ways of manipulating the electromagnetic signal and improving materials in ways that improve bandwidth, signal range and throughput. This makes it difficult to place firm limits on the bandwidth or range of a particular technology. For that reason, the Technology Chart, prepared 2021, may be outdated as new technologies are introduced and deployed.

Wireless Technologies

Wireless Technology	Description Signal Frequency noted is based on millions of cycles per second (MHz) or billions of cycles per second (GHz)	Practical Bandwidth Under Ideal Conditions -Millions of bits of data per second (Mbps) or Billions of bits of data per second (Gbps)	Signal Range (without signal amplification)	Advantages	Disadvantages	Reference
TV White Space (TVWS) Also known as "Airband"	Wireless internet data is transmitted over unused portions of the electromagnetic spectrum allocated to VHF and UHF television Signal transmits at 470 MHZ to 790 MHZ	Over 180 Mbps	Between 6 miles (No line of site to tower) to 31 miles with a clear line of site to the tower	Longer Range and better penetration than 5G High Band and Mid Band and CBRS technologies	Slower theoretical speeds compared to other wireless options	TV White Spaces FAQ and Engineering Best Practices TV White Space for Rural Broadband Service
5G "low band"	Wireless internet data is transmitted over the 600MHz, 800MHz and 900MHz radio frequency bands allocated for fifth-generation cellular systems. 5G networks re currently being "built out" by many telecommunication companies ("telecoms"), particularly in rural areas of the United States.	300 Mbps This is Peak bandwidth only at or very near ISPs tower – Normally speeds are much slower, but somewhat better than 4G or LTE connections	Comparable to TVWS Range Approximately 6 miles (No line of site to tower) to 31 miles without line of site Bandwidth is significantly reduced at greater distances	Primary use will be or mobile internet access (smart phone and hot spots). Primary advantage is range and higher speeds when comparted to 4G and LTE in use today. 5G enabled devices likely will be designed to work with mid and/or high band 5G (see below), allowing for much higher bandwidth ("higher speed") when device is in range of transmitter.	Service may not be reliable as fixed wireless or wireline internet because ISP (usually a telecom) cannot control the number of devices attempting to access the network Use of the spectrum is licensed by the FCC. To use, a provider would have to secure access from licensee or the FCC	Definitive Guide Low, Mid & Mand 5G 5G Spectrum - Low, Mid and High Bands Explained
CBRS (fixed wireless)	Transmits over 3.5 and 5 GHZ	Up to 100 Mbps	Up to 6 miles but requires a line of site installation	Much of spectrum is unlicensed Easy to install and low cost as fiber is close and suitable site for transmitter antenna	Signal interference can be a problem over unlicensed spectrum Tendency to "overbuild the system (too many	WISPs & CBRS Range

Wireless Technology	Description Signal Frequency noted is based on millions of cycles per second (MHz) or billions of cycles per second (GHz)	Practical Bandwidth Under Ideal Conditions -Millions of bits of data per second (Mbps) or Billions of bits of data per second (Gbps)	Signal Range (without signal amplification)	Advantages	Disadvantages	Reference
					subscribers accessing the same tower Line of sight required. Weather and obstructions	
5G "mid band"	Wireless internet data is transmitted over the 1GHz to 6GHz radio frequency bands allocated for fifth-generation cellular systems.	600-900 Peak Speeds	Comparable to television broadcast signal (See TVWS above)	May be a good compromise between bandwidth and signal range	Same as 5G low band	5G Spectrum - Low, Mid & High Bands Explained Definitive Guide Low, Mid & Mand 5G
5G "mmWave" or 5G "high band"	Wireless internet data is transmitted over the 24GHz to 100GHz radio frequency bands allocated for fifth-generation cellular systems.	At least 1 Gbps (theoretically much higher)	Range limited to a few hundred feet	Extremely high bandwidth near the transmitter antenna Antenna units relatively small can be mounted on utility poles	Same as 5G low band Low signal range may limit deployment to urban areas	5G Spectrum - Low, Mid & High Bands Explained Definitive Guide Low, Mid & Mand 5G
High Earth **Orbit Satellite**	Satellite orbiting approximately 24,000 miles above the Earth at a stationary point relative to the Earther surface. Signal transmits at 14 – 15 GHz	Up to 25 Mbps	No limit so long as good weather and line of site between antenna and satellite	So long as line of site to antenna it should work anywhere in the United States	Weather and line of site issues Data Caps and historically higher cost than other technologies Long time between sender receiver makes interactive	Satellite Internet in the United States.

Wireless Technology	Description Signal Frequency noted is based on millions of cycles per second (MHz) or billions of cycles per second (GHz)	Practical Bandwidth Under Ideal Conditions -Millions of bits of data per second (Mbps) or Billions of bits of data per second (Gbps)	Signal Range (without signal amplification)	Advantages	Disadvantages	Reference
					video and similar "live applications" impractical	
Low Earth **Orbit Satellite**	Several Planned; Starlink operating on limited basis Starlink when fully deployed 12,000+ satellites orbiting a few hundred miles above the Earth (less than 2000 now) Signal Transmits at 40-74 GHz	Various: Median 40 -93 Mbps 2021	No limit so long as good weather and line of site between antenna and at least one satellite	Higher potential speed & much lower latency than Satellite Potentially available to user with antenna and equipment located anywhere on Earth	Line of Site to Satellite Necessary Weather may disrupt signal Network Capacity Unknown	Starlink Capacity Assessment by Fiber Broadband Association Starlink Compendium (updates periodically)

Wireline Technologies

Wireline Technology	Description	Bandwidth Ideal Conditions (Mbps download)	Signal Range (without signal amplification)	Advantages	Disadvantages	Reference
General Discussion: Fiber optic Cable (Fiber)	One or more extremely thin strand of glass (or in some cases plastic) encased in a protective covering. Data is transmitted using electromagnetic light waves. An ISP may choose to terminate fiber deployment and use other technologies to deliver service to customer	Depending on type and application fiber has virtually unlimited bandwidth	Within ISP Network -- 25 miles or more depending on the type of Fiber used.	Highest bandwidth for all wireline technologies. Best Future Proof Options: Possible to upgrade to higher bandwidth without re-cabling.	Initial expense of deploy often is higher and greater cost to repair breaks	Single v. Multimode Fiber differences Single v. Multimode Fiber Applications Fiber Optic Cable Single vs. Multimode Fiber Optic Networks WDM Explained Fiber Optic Networks PON Explained
Fiber to the home (or premises) FTTH or FTTP	Fiber optic cable is deployed to the outside of the customer's home or premises. The type of fiber used can limit bandwidth and range of signal. Single Mode Fiber has virtually unlimited bandwidth (limited only be equipment used to transmit data) and a long range and virtually unlimited	Virtually unlimited for single mode fiber 1 to 40 Gbps for multimodal fiber	Single mode fiber – at least 25 miles or more. Multimode fiber: 100 to 1300 feet depending on grade of multimodal fiber	See General Discussion of Fiber Optic Cable	See General Discussion of Fiber Optic Cable	See General Discussion of Fiber Optic Cable
Hybrid-Fiber-Cable	ISP combines a fiber optic distribution to an endpoint (a "node" that then feeds signals to users via coaxial cable (similar to a cable TV system)..	1000 or higher, but range over coaxial cable is very limited at higher bandwidths	Range is limited to the distance covered by coaxial cable. 100 to several hundred feet. The distance varies depending on quality of coaxial cable and the required bandwidth	Less installation expense than FTTH or FTTP installations. Some existing cable systems can be retrofitted to HFC.	Signal degrades and bandwidth diminishes over coaxial portion of the network. ISPs often connect	https://readytogocables.com/what-is-the-range-of-a-coaxial-cable/ https://www.lightwaveonline.com/fttx/pon-systems/article/16673819/cabl

Wireline Technology	Description	Bandwidth Ideal Conditions (Mbps download)	Signal Range (without signal amplification)	Advantages	Disadvantages	Reference
					multiple locations using a single coaxial cable fiber access point. This can dramatically reduce throughput do to internet traffic from neighbors	elabs-full-duplex-docsis-31-specification-enables-hfc-symmetrical-10gbps-broadband
Hybrid-Fiber -Twisted Pair	Twisted Pair or Ethernet. The most common example is the ethernet cable used in home and business computer connections. Twisted pair is specially manufactured copper cable the is commonly used to bridge the last few feet between an outside or interior local area network and the end user.	10 Gbps or 1 Gbps depending on material	100-300 feet	Traditionally -- Lower cost and easy to work with.	Very limited range – usually for interior use only	Copper vs. Fiber Optic Cable

Wireline Technology	Description	Bandwidth Ideal Conditions (Mbps download)	Signal Range (without signal amplification)	Advantages	Disadvantages	Reference
Hybrid Fiber – VDSL **VDSL / FTTC Very High-Speed Digital Subscriber Line** **VDSL/VDSL2 /VDSL2+**	A type of upgraded Digital Subscriber Line (DSL) service. uses copper pair(s) (traditional telephone line) to connect to end user Fiber optic cable is installed to a location very close to the customer “Fiber To The Curb” (FTTC). VDSL2 & 2+ have higher bandwidth	55/3 Mbps (55 Mbps download 3 Mbps upload) 200/100 Mbps For VDSL2 and VDSL2+	1000 feet	May be possible to retrofit existing DSL system to provide interim solution in lieu of FTTH	Telecoms are abandoning traditional copper telephone lines and equipment Need to deploy fiber very close to end user to achieve sufficient bandwidth	https://vividcomm.com/2020/10/05/dsl-is-dead-whats-next/
Traditional ADSL & ADSL2+	Asynchronous Digital Subscriber Line – Uses copper pairs Second Generation Asynchronous Digital Subscriber Line (ITU G.992.5 Annex M)	ADSL 8/1.3 Mbps 24/3.3	N/A	Bandwidth inadequate for most household use	Telecoms are abandoning traditional copper telephone lines and equipment	https://vividcomm.com/2020/10/05/dsl-is-dead-whats-next/