Dialup Modem Impairment FAQ

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Dialup modem technology has come a long way from the days of 300 bit per second acoustic coupled modems. Modern dialup modems exploit digital nature of the public switched telephone network (PSTN). Most telephone circuits exhibit much better electrical characteristics then Phone Company is required to deliver. Modems exploit this to deliver higher data rates then would be possible if they assumed worst-case conditions. However, this results in user frustration when modem is unable to deliver advertised speed and Phone Company claims there is nothing wrong with the service. This paper examines common telephone line impairments and their effect on modem performance.

Modem speed is dependant on bandwidth and noise parameters of the telephone circuit. This has very little to do with the age of the installation or how it looks. The only way to accurately determine circuit quality is by testing.

Modem Standards

There have been many dialup modem standards developed over the years. This paper discusses the most popular: Bell 103/ITU-T V.21, Bell 212/ITU-T V.22, ITU-T V.32, ITU-T V.34, ITU-T V.90 and ITU-T V.92.

Bell 103 (circa 1962) is the granddaddy of modems. It uses frequency shift keying to deliver up to 300 bps in each direction. The ITU-T version is V.21.

Bell 212 (circa 1977) was the next step delivering 1200 bps in each direction. The ITU-T version is V.22. ITU created an improved version called V.22bis operating at 2400 bps.

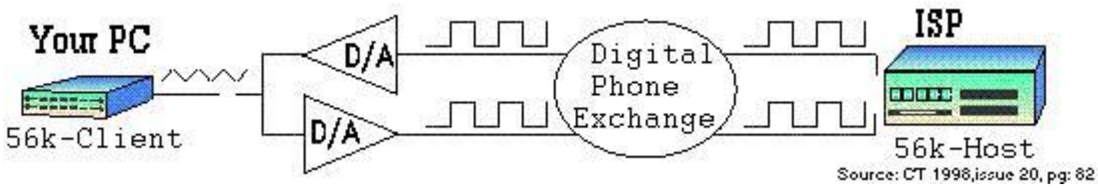
Bell 103 and 212 modems are still commonly used in situations where data rate is unimportant but fast connection setup is, such as alarm circuits.

ITU-T V.32 & V.32bis (circa 1991) increased speed to 9,600 bps and 14,400 bps respectively.

ITU-T V.34 (circa 1994) represents a dramatic departure from earlier standards made possible by advancements in semiconductor technology supporting a maximum speed of 33.6 kbps in each direction (initial version was limited to 28.8 kbps). V.34 automatically probes phone line to determine attenuation and noise characteristics allowing modem to adapt to varying line conditions. V.34 connect speed varies from a low of 2.4 kbps up to 33.6 kbps (or 28.8) in 2.4 kbps steps.

ITU-T V.90 & V.92 (circa 1998) is the pinnacle of dialup modem technology. It reflects the changing nature of the public switched telephone network. Today's public switched telephone network (PSTN) is almost entirely digital. The analog subscriber circuit is digitized near the customer and converted to a 64 kbps Pulse Code Modulation (PCM) bit stream. From there it is transported in digital rather then analog form. V.90 and V.92 exploit the digital nature of the modern phone network to deliver speed previously deemed unattainable. Downstream speed (toward subscriber) is up to 56 kbps upload maximum speed is 33.6 kbps. V.92 increased upload speed to 48 kbps and improved numerous other modem characteristics.

This magic requires that one and only one digital-to-analog conversion exist between ISP and user. The conversion typically takes place at the local central office serving the subscriber. The ISP modem is digitally terminated to Telco digital trunk and no additional conversions are allowed between the subscriber and ISP



The other requirement is a relatively short analog loop that has better bandwidth and noise characteristics then required for ordinary voice service. Copper phone circuit, called loop, has much greater bandwidth then required for voice service. This is what allows broadband DSL be carried over the same circuit used for voice. In the Unites States the FCC requires a minimum of 2700 Hz bandwidth from 300-3000 Hz for voice grade service. Almost all subscriber circuits are digitized at the local telephone switching office or remote terminal making the conversion process the main determinant of bandwidth. Common practice is to sample voice 8,000 times per second quantized to 8-bits, as specified in ITU-T Rec. G.711, called PCM. To prevent aliasing a bandpass filter limits maximum frequency to less then half the digital sample rate (4,000 Hz). Low frequencies are attenuated to minimize effects of 50/60 Hz power noise.

Modem speed is limited by the number of discrete steps that can be distinguished by the codec in the presence of noise. Conversion process is logarithmic to reduce number of bits needed for adequate voice reproduction. Two logarithmic curves were developed A-law (Europe) and u-law (US). Logarithmic conversion results in very little difference between smallest steps. This was done to minimize audible effects of noise during quiet passages. Unfortunately it reduces number of bits that can be unambiguously detected to 7 reducing best-case theoretical data rate to 56 kbps.

Another speed constraint is power. FCC limits transmit power to 12 dBm. There is a common misperception FCC directly limits maximum modem speed. That is not the case. FCC regulations are designed to optimize voice performance of the public switched telephone network. It is a side effect of these regulations that limit modem speed to about 53,333 bps

V.90 and V.92 modems take advantage of these characteristics to deliver much higher speed then if they assumed worst-case conditions. As an example 56,000 bps requires 3600 Hz bandwidth; in range 150-3750Hz. See http://www.hal-pc.org/~wdg/56k.html for detailed bandwidth discussion. This is why local Telco tends to be unhelpful dealing with dialup modem speed complaints when phone service is operating normally. Optimum modem performance requires characteristics significantly beyond those required for voice service.

V.90 and V.92 modems probe phone line to determine optimum connect speed. Download speed ranges from a high of 56,000 bps to a low of 28,000 bps in 1,333 bps steps. V.90 upload speed is same as V.34, 2,400-33,600 bps. V.92 upload speed is from 24 kbps to 48 kbps in 1.333 kbps steps. If modem cannot connect in digital mode it automatically falls back to V.34. Modem constantly evaluates line characteristics to compensate for changing conditions.

Telephone Line Requirements vs Modem Speed

300 bps (Bell 103 & ITU-T V.21 protocol)

If this works, it means your line is at least as good as the top two strands of barbed wire on a farmer's fence. A 300bps FSK modem will literally work over miles of barbed wire. If 300 baud doesn't work, maybe the string between the tin cans is too dry? :-)

1200 bps (Bell 212A & ITU-T V.22 protocol)

212A is, much more sensitive than 103, but is not bothered by phase shifts that higher speed modems cannot tolerate. If 1200 works and 2400 and up won't, it is likely that a digital carrier system is experiencing "uncontrolled clock slips," which generate phase jumps that 212A protocol can just barely handle, while higher speed protocols cannot.

Uncontrolled clock slips can be detected by making a connection at 2400 bps with all error correction turned off, and then looking for garble on received data that repeats the exact same character sequences frequently.

A typical (and real) example looks like this:
Local> {{{r{{{{m{xD{{rw3{{r{{{m{t({{xD{{{{v{{{t(t^O5rw3{{v:{{
Xyplex -701- Command syntax error

Note the repeated '{{{' sequences. There are others too, such as '{r', 'rw', 'xD' in that example. Some instances might be just a single character repeated every few seconds or minutes. The key is that it repeats the same sequence.

2400 to 12,000 bps (ITU-T V.32, V.32bis and V.34 protocols)

Connections limited to this range indicates severe channel impairment. Usually noise and bandwidth restrictions cause connect speeds this low. Long cable runs of over 5 or 6 miles can also cause it, as can very old analog carrier systems.

14.4 kbps (ITU-T V.32bis and V.34 protocols)

This is the minimum speed a V.34 modem should be able to connect at **if** telephone line is just able to meet specs. If this speed cannot be obtained either the modem is defective or line is out of specification.

16.8 kbps (ITU-T V.34 protocol)

This is the minimum speed most V.34 modems will actually be able to connect at on a minimally specified line. That means if modem can get this speed, the line **must** be within specification.

This is also the upper limit for connections through various types of digital carrier systems that use ADPCM or 32k bits per channel instead of standard 64 kbps PCM encoding. Due to lower sampling rate and fewer bits per sample more quantization noise is generated by the analog-to-digital conversions in these systems, thus reducing the Signal to Noise Ratio (SNR) limiting speed.

19.2 kbps to 26.4 kbps (ITU-T V.34 protocol)

Speed in this range generally indicates a bandwidth limited channel. Some older carrier systems and some digital systems that packetize and compress data are limited to 19.2 or 21.6 kbps. Long cable runs are also reason for connection speed of 26.4 kbps or below.

26.4 kbps, perhaps with occasional 24 and 28.8 (ITU v.34 protocol)

Usually indicates Subscriber Line Carrier (SLC) that has a "universal" interface to the Telco switch. Such an interface adds an extra DA/AD conversion, which prevents V.90/92 mode, and also adds at least 3 dB of quantization noise and a small amount of bandwidth restriction, all of which combine to usually disallow 28.8 kbps connection. Note that for modems, which measure Signal-to-Noise Ratios, 37 dB is the **best** that can be obtained on a connection through any form of 64 kbps channel PCM digital carrier. The specification for a voice grade telephone line is only 24 dB.

28.8 kbps to 33.6 kbps (ITU-T V.34 protocol)

Indicates a line is so close to perfect that it would be difficult for Telco to measure any change that would improve speed. This means SNR is better than about 32 dB, channel bandwidth is about 3,400 Hz, and circuit must not be very long. 33.6 kbps simply means the line is about as good as it can get.

28.0 kbps to 53.3 kbps (ITU-T V.92 & V.90 protocols)

Means there are no sharp bends in your cable, no goblins camped in any splice boxes, and you've been blessed by a supernatural entity. These connections amount to pure FM (Freaking Magic, if you will). If you breathe funny tomorrow your speed may drop significantly! Brand new, perfect line cards may or may not work. Cables that look good might work, or might not. Speed depends on parameters outside those required for voice grade telephone service. If you cannot get a V.90/92 connection the Telco is not obligated to change anything to fix it.

The minimum requirement to get a V.90/92 connection is a virtually noise free local loop (modems which measure SNR for V.90/92 connections will show values from 45 dB for lower speeds all the way up to 55-60 dB with higher speed connections), plus a digital connection to the ISP which has exactly one Digital-to-Analog conversion (codec in the line card for your line at the Telco switch) between the ISP and you.

Some digital trunks use a technique called robbed bit signaling. RBS is used only in a minority of US trunks nowadays. RBS uses the least significant bit of every 6th frame for inband signaling. Where it is found, each robbed bit will reduce data rate by 1,333 bps. Each trunk is free to use any frame so worst case situation is that all six possible positions are used degrading speed by 8,000 bps.

V.90/92 modems preferentially connect in digital mode if they cannot they automatically fallback to V.34. High-end connection speed of V.34 and low end of V.90/92 overlap. To determine if modem is in V.90/92 mode external modems typically include a mode indicator. For modems without this feature connect speed can be used to determine mode. If modem reports 28,000, 29,333, 30,667, 32,000, 33,333, 34,667 or higher it is in V.90/92 mode. If report is 33,600, 31,200, 28,800 or lower it is in V.34 mode.

54.6 kbps to 56.0 kbps (ITU-T V.92 & V.90 protocols)

These speeds are seen in Europe where higher transmit power is allowed.

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