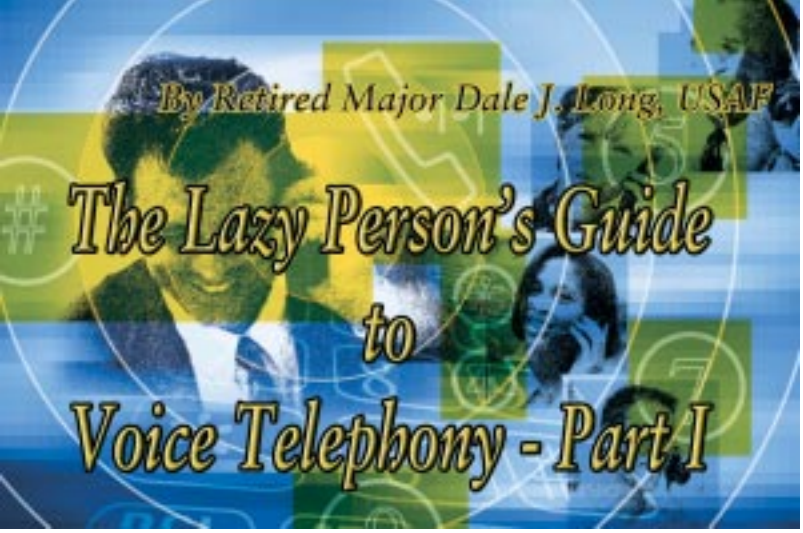

In today's world, most of us have three basic expectations: *Flip a switch and electricity will provide power; turn on a tap and you'll get water — and lift a telephone handset and you'll get a dial tone.*

Electricity, water and communications are the three main "flows" that keep modern society functioning. Over the next couple of issues, we will look at one of the main streams of communications flow: voice telephony. Originally developed in the 19th century, voice telephony became one of the killer applications of the 20th century. During the last 100 years, telephone lines have spanned the globe, linked most of the world, and served as the basis for later systems like the Internet. Its simplicity and effectiveness as a means of communication are the crowning achievements of modern technology.

Ease of use does not mean that it is simple technologically. Today, voice telephony involves a wide variety of technologies and protocols: circuit and packet switching, radiated and guided media, and analog and digital signaling, to name a few. But despite all the variations, vendors and equipment, you can pick up a phone anywhere in the world and call any other phone — if you know the number.

In recent years, telephony has been pushed out of the limelight by data and computer networking. Computer Help Desk technicians are greeted by office staff as saviors when they arrive to unstick a stuck PC. Telephone techs, on the other hand, get barely a nod as people walk past the closet where they are trying to figure out which of the 1,000 pairs of little blue and white wires on those old 66-blocks go to the phone on your desk.

So, this edition of the LPG is dedicated to all those people who make sure we can pick up a phone and talk to anyone, anywhere, in the world. We will start by looking at what it takes to connect the world with voice communications via circuit switching and guided (wired) media, the old traditional basis upon which telephony was founded. Once we have covered the basics, we will move on to wireless services and the latest trend in the voice world, voice over Internet Protocol (VoIP). But for now, and as usual when we examine any technology for the first time, let us wind up the Way Back Machine for a trip to the 19th century to see how it all started.

Telephony 101

Telephony is a system that converts the human voice to electrical impulses, transmits it and converts it to a tone that sounds like the original voice. The discovery that became the basis of the telephone came in 1831 when Englishman Michael Faraday proved that vibrations in a metal object could be converted to electrical impulses. It took another 30 years until German inventor Johann Philipp Reis built an apparatus that changed simple sounds to electricity and back again in 1861.

As with any new technology there were people willing to tell everyone else that voice telephony was impossible. In 1865, the Boston Post opined: *"Well-informed people know it is impossible to transmit the voice over wires. Even if it were, it would be of no practical value."* As with things like heavier-than-air flight, heart transplants and reliable overnight delivery, the pessimists were once again proved wrong.

The first practical telephones were invented by Elisha Gray and Alexander Graham Bell. Working independently, Gray and Bell both developed systems based on electromagnetic receivers with steel diaphragms. It was a tight race. Both men filed for patents at the New York patent office on February 14, 1876, but Bell got there first, beating Gray by a mere two hours. Even after the technical concept had been proven, there were still people who believed the telephone was of no practical value. In 1877, an unidentified New York financier allegedly told Bell that, *"The possibility of a private home telephone system throughout the country is out of the question. Almost the entire working population of the United States would be needed to switch [install] cable."*

And, in what ranks up there with the poorest business assessments ever made, there is this famous quote attributed to an 1877 Western Union memo: *"This 'telephone' has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us."* So, in response to Alexander Graham Bell's offer to sell Western Union the complete rights to the telephone for $100,000, Western Union President Carl Orton replied: *"What use would this company make of an electric toy?"* Once Bell Telephone negotiated rights of way for its cables and started building its network, Western Union's days as the premier communications company in the United States were numbered.

The House that Bell Built

The fundamental concept of operations for telephone systems has been a dedicated circuit connecting callers. The first phones were primitive devices, little more than a box with a hole where you both talked and listened. In Bell's demonstration model, the two units were directly connected by a single pair of wires. There was no need for a dial, as there was only one other device connected. But for the telephone to become practical commercially, you needed some way to connect callers that didn't involve setting up a different hard-wired phone for everyone you might want to call. What developed in response was the telephone exchange.

The exchange involved one or more operators working at a large switchboard. Callers would signal the operator by tapping on the diaphragm with a pencil. As this didn't turn out to be particularly healthy for the physical condition of the diaphragm, Thomas Watson (Bell's assistant) attached a small hammer to the side of the phone box that callers could use to send the signal. The hammer was soon replaced by a magneto powered with a hand crank. Turning the crank would activate a signal at the exchange and the operator would answer and manually connect the caller to the intended recipient. The establishment of a temporary dedicated circuit for each call (circuit switching) became the primary process of telephony for the first 100 years or so. In the days of operator-assisted calls, this meant you would call an operator who

connected your call to an operator working in the exchange that serviced your party. This sometimes involved going through several different exchanges, so the process of calling got more cumbersome and unreliable as more exchanges participated.

The first telephone exchange was installed in Hartford, Conn., in 1877, and the first exchange linking two major cities was established between New York and Boston in 1883. The first automatic telephone switch that did not require manual operation was patented by Almon Strowger of Kansas City in 1891, but because of the perceived complexity of automatic circuit switching (and in some cases, simple inertia) manual switchboards remained in common use in many places until the middle of the 20th century. In the last 50 years, telephone exchanges have become pretty much completely automated.

Automated switching, which was developed in 1923 by Frenchman Antoine Barnay, allows callers to signal the network by dialing numbers on their phones using pulses generated by a numbered rotary dial. Some of us are old enough to remember sticking our finger in a hole on a wheel, spinning it clockwise until we ran into the little finger stop, and then letting the wheel spin back into place. How far you turned the wheel determined how many clicks the phone made. The clicks we heard on the old mechanical pulse phones were actually momentary disruptions in the current over the telephone circuit. The switch would count each set of current breaks and store each number mechanically until an entire number had been dialed. This required a rigid addressing structure to operate effectively and was the reason for our current system of area codes, local prefixes and the need to dial "1" when calling outside your local dialing area. Many modern tone-based pushbutton phones still have a setting for pulse dialing to accommodate old central office equipment.

In the "plain old telephone system" (POTS), once a dedicated circuit connects the call, your voice is transmitted by a 4 kilohertz analog wave form via a process known as frequency division multiplexing. In a multi-channel analog carrier system, one channel might run at 0-4 kHz, the next at 4-8 kHz, the next at 8-12 kHz and so on, with some of the edge frequencies within each band reserved as guard bands between each channel to keep the signals from interfering with each other. Why use 4 kHz bands? It provides enough bandwidth to reproduce a recognizable human voice. Further, each channel supports a range of signal amplitude (strength) that relates to a volume level. The amplitude level is limited, so no matter how loud you scream over the network it won't exceed a certain volume on the other end of the line. Together, this combination of bandwidth and amplitude is not quite enough for perfect voice transmission, but it's good enough so you can make out the words and recognize familiar voices. This level of service is known as toll quality voice.

Digital Evolution

As manual switchboards were phased out after World War II, we started moving from analog to digital telephony. Digital transmission offers a lot of advantages, including more efficient use of bandwidth, better error handling, enhanced management and control of calls. Virtually all telephone switches today are digital in some way. Most transmission facilities are digital, with the exception of the copper wire local loops serving some residences and small businesses.

Transmitting voice, an analog waveform, over a digital network requires conversion of the analog signal into a digital format and back to analog on the receiving end. Telephone systems do this through a process known as Pulse Code Modulation (PCM). Harry Nyquist, an engineer at AT&T in 1928, determined that to convert analog voice to a digital format, send it over a digital circuit to reproduce high-quality analog voice at the receiving end, then sample the amplitude of the analog sine wave at twice the highest frequency on the line.

This means that we should sample at twice the highest frequency on our 4kHz toll quality voice channel, a rate of 4,000 x 2, or 8,000 times a second. If we do one more bit (or in this case, byte) of math, 8,000 samples per second times 8 bits per byte equals 64,000 bits per second, or 64 Kbps, which is a voice-grade digital channel, the basic building block of our modern digital circuits. Sampling 8,000 times a second means that the sampling process must take place at intervals of 125 microseconds. Each sample is coded into an 8-bit digital value, the resulting 8-bit bytes are woven together (interleaved) by multiplexers, and sent across multichannel digital circuits (e.g., a T1 circuit with 24- 64 kHz channels). These bytes are directed and redirected by switches across whatever circuits connect the switches in the network and are ultimately decoded back into an analog form on the receiving end. The decoded signal is only an approximation of the original analog signal, but it is close enough to be recognizable and understandable to the human ear.

Precise timing is the critical piece of this puzzle. The phone network must be in a position to accept, switch, transport and deliver every byte of voice precisely every 125 milliseconds (ms). That means that delay (latency) must be minimal and any variation in delay (jitter) must be virtually nil. Unlike the packet-based data sent by computer networks, voice quality will not readily survive latency or jitter.

Phoning Home

Telephones are relatively simple in design, but allow access to one of the most complex networks in the world. They have five main components. Three of the five are easy to pick out because we use and see their functionality every day. The transmitter converts acoustic energy (the sound of your voice vibrating the diaphragm) into electrical energy. The receiver converts electrical energy into acoustical energy (the voice coming out of the phone). The signaling device (key pad, dialing wheel, etc.) is used to get the network's attention and identify the destination. The two less obvious technologies that make this all work are the transformer and the balance circuitry. The transformer electrically separates the receiver from the transmitter. The transformer allows you to talk and listen at the same time. Because of the transformer, telephones operate in full-duplex mode, which means that the circuit is two-way all the time.

The balance circuitry reduces sidetone, which is what you hear when you speak into the microphone and hear yourself through the speaker. This allows the person speaking to get some feedback about what they sound like without drowning out the person on the other end of the line. If you want some idea of what your sidetone would sound like without the balance circuitry, have someone else in your house pick up an extension while you are on the phone. On most home systems, they will sound much louder than the external caller due to proximity.

Modern phones use much more technically sophisticated signaling

and switching systems than the original models, but the basic principles are the same. When you pick up a handset it generates a loop current in the circuit. This current is powered by batteries in the telephone company's central office. That is why even though your power goes out, telephones that don't depend on your home's electrical system for power may still work. (I recommend you always keep at least one wired phone in your house. Cordless phones don't work during blackouts.)

When your phone generates the loop current, it is detected by a line scanner and the central office connects equipment to your line and sends you a dial tone. At the same time, a dual-tone multi-frequency receiver is activated and connected for your line to detect the tones generated by the keypad or interpret the clicks. Once you enter all the numbers, they are entered in the switch's memory. Another central office program reads the numbers, determines the best route for your call and sends a command to the switching matrix to establish a connection. That, in a nutshell, is how a telephone works.

Telephone Services

There are two basic ways to acquire phone service: buy it line by line from a vendor or buy a switch and set it up yourself. The first is what most of us do. The wiring in our house is connected to a local exchange carrier's central office via a twisted pair. Small organizations that need more than one line (small businesses, families with multiple teenagers, etc.) can buy lines individually or in bulk. Larger organizations may buy or lease a phone switch that is dedicated to their organization. Military bases often have telephone exchanges that rival small cities. But the military is not unique in owning and operating phone systems. Most large organizations that occupy any significant amount of facility space buy and run their own switches. There are a few reasons for this.

First, while individual lines may be relatively inexpensive, buying 1,000 lines when only 20 percent of your 1,000 people may be on the phone simultaneously will cost more than leasing trunk lines and sharing them through a private branch exchange (PBX). Second, when you control the switch, you control the services: voice mail, 911 service, caller ID, toll monitoring, auto-attendant features, calling restrictions, etc. You can tailor the services to your organization's business operations, which includes building full-featured call centers.

Third, in many cases it is simply less expensive to set up your own service. For example, any operation that relies on telephone contact with the public to conduct most of their business uses call centers. Having a telecommunications vendor build a call center can cost $1 million and the recurring charges for even basic call center services start at $30,000 per month. And you still have to pay for your phone service and provide staff to work the phones.

Buying a digital PBX supporting 50 plus employees, that has enough capacity to handle 300 plus calls per hour (at 5 minutes per call), and includes an auto-attendant programmed in seven languages can cost about $165,000. That price includes the cabling, switch, phones, initial programming and training. You will incur some cost for staff to support the system, but it is unlikely that it will exceed (or approach) what you would pay for commercial call center services. It is convenient to have someone else handle the technical details, but you pay a lot for that convenience.

Other advantages of deploying your own systems include having consistent prefixes and number ranges for your organization's components, managing your phone switches as part of your enterprise architecture, and ability to impose your own security constraints. Even systems for offices as small as six to eight people can be more cost effective over their life cycle. As with anything, look past the capital investment costs and calculate the cost difference over several years. (I use six years because it is just under the average age of the 133 PBXs in my current area of operations. Your mileage may vary.)

Call Me

Not only did the telephone spark a revolution in conducting business, it also contributed to sweeping social and cultural changes. The first telephone exchanges were run by male operators. Allegedly due to the arrogance and impatience of the male operators, telephone exchanges initially got lousy ratings for customer service. Because the work was indoors, had regular hours and didn't require a high degree of physical strength, Bell started hiring women as operators. They proved much more capable at customer service than male operators. Being a telephone operator was one of the first full-time jobs for women in the workplace. In combination with the filing cabinet and typewriter, the telephone was instrumental in the large-scale integration of women into the nation's business environment.

Not everyone was thrilled with the proliferation of telephones. Allowing more people to converse more often and at greater distances may be great for a capitalistic democracy, but if your power depends on absolute control of what information your population receives and exchanges, you might be a little wary. Joseph Stalin, one of the more famous experts in the field of totalitarian control, had this opinion of the telephone: *"It will unmake our work. No greater instrument of counterrevolution and conspiracy can be imagined."* Many countries tightly controlled or monitored access to telephone systems throughout most of the 20th century. Some still do.

Final Words

In considering any two-way connecting technology, the telephone, e-mail or radio, they are swords that cut both ways. You can reach out around the world, but you can also be intruded upon through constant access and accessibility.

Perhaps this is why Mark Twain said in 1890: *"It is my heart-warm and world-embracing Christmas hope and aspiration that all of us — the high, the low, the rich, the poor, the admired, the despised, the loved, the hated, the civilized, the savage — may eventually be gathered together in a heaven of everlasting rest and peace and bliss — except the inventor of the telephone."*

Twain lived at the end of an age where correspondence between great thinkers documented some of the greatest decisions of history. The telephone is an ephemeral medium. How much has been lost because it was spoken over the phone instead of documented in writing? To a writer like Twain, this loss would be a tragedy. As with any technology, its value lies in the use we make of it, and we are better off with it than without it.

Until then, Happy Networking!

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