

1.0 Introduction

T1 stands for “transmission level 1”. T1 is a digital trunk, originally designed for voice transmission, built to replace analog voice transmission used on telephone trunks in the United States prior to the 1960s. Created by Bell Laboratory scientists and engineers, T1 introduced a leap forward in telephone network technology that significantly improved telephone call quality. To understand how and why T1 was created, it is necessary to understand fundamental concepts of a public switched telephone network, and limitations inherent in voice transmission within such a network.

2.0 Public Switched Telephone Network

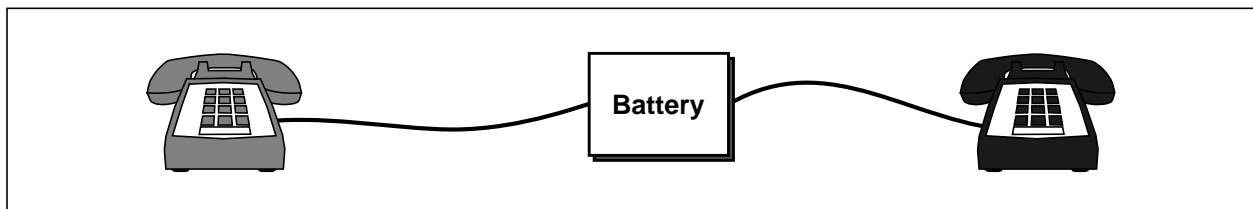


Figure 1: Simple Telephone Network

Figure 1 shows a simple telephone network consisting of two telephones, and a battery to supply power to the telephones. Unless this is a military field telephone, or other specialized intercom system, a two telephone network has limited usefulness.

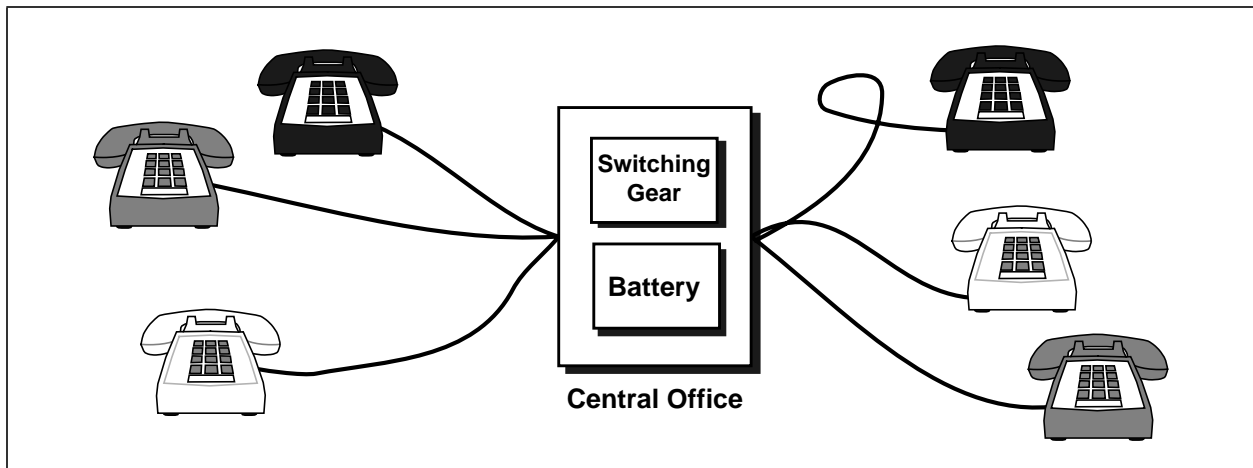


Figure 2: Local Telephone Network

Adding telephones builds a more-useful local network. Telephones are connected to a **Central Office (CO)**, which supplies the necessary switching gear, voice battery, wire cable facility terminations, etc. The telephone line (a single twisted-wire pair) connecting each telephone to the central office is often called the **local**, or **subscriber, loop**.

This local network is still not useful for calls out of the neighborhood.

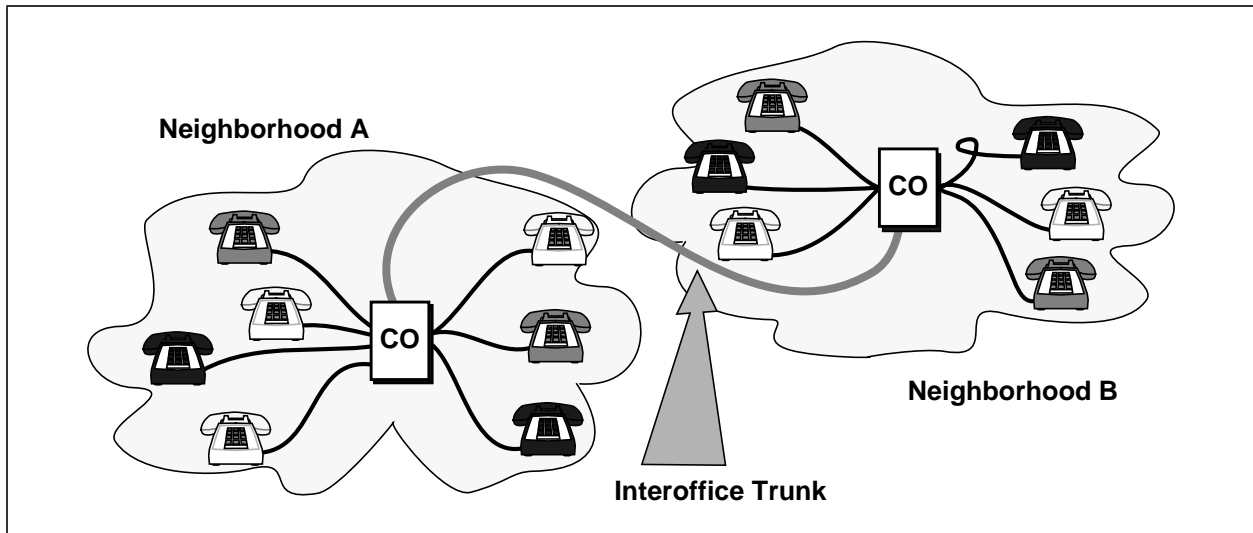


Figure 3: Interoffice Trunk Facility

The interoffice trunk facility allows telephone calls between central offices. Like the local loop, the first interoffice trunks carried only one conversation. The trunk is basically an ordinary telephone line, except it has a CO at both ends.

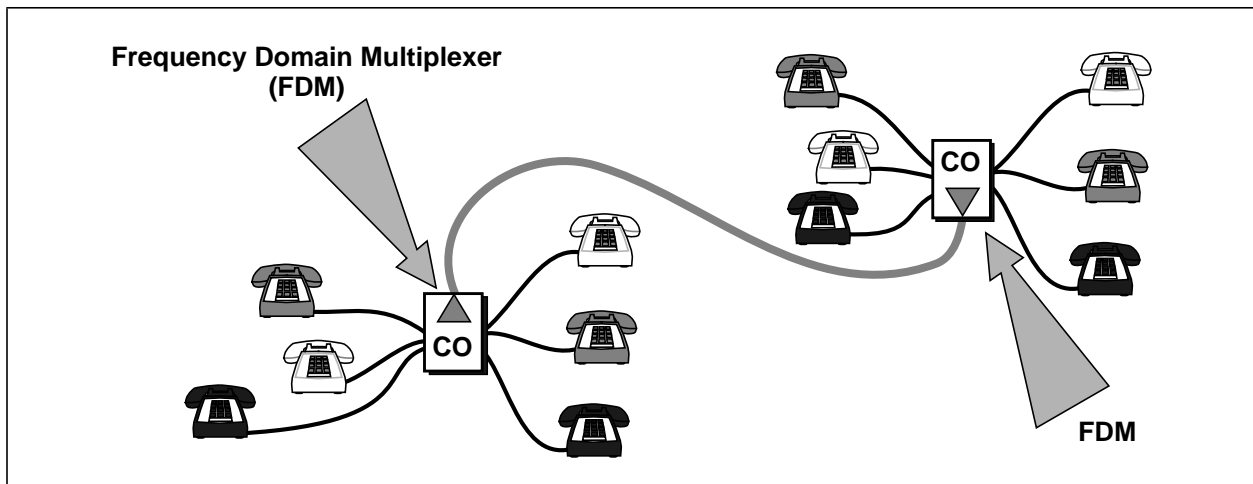


Figure 4: Frequency Domain Multiplexing

After the turn of the 20th century, the advent of vacuum tubes made **frequency domain multiplexing (FDM)** feasible. The wire pair that once carried a single voice could now carry 24 voice signals. In FDM, voice signals are “stacked”, or multiplexed, on a single wire pair. FDM divides a 96 kHz bandwidth into 24 uniform frequency bands. Each 4 kHz band within the 96 kHz overall bandwidth carries one voice signal. FDM offered a solution for the cable crowding that plagued urban areas in the late 1800s.

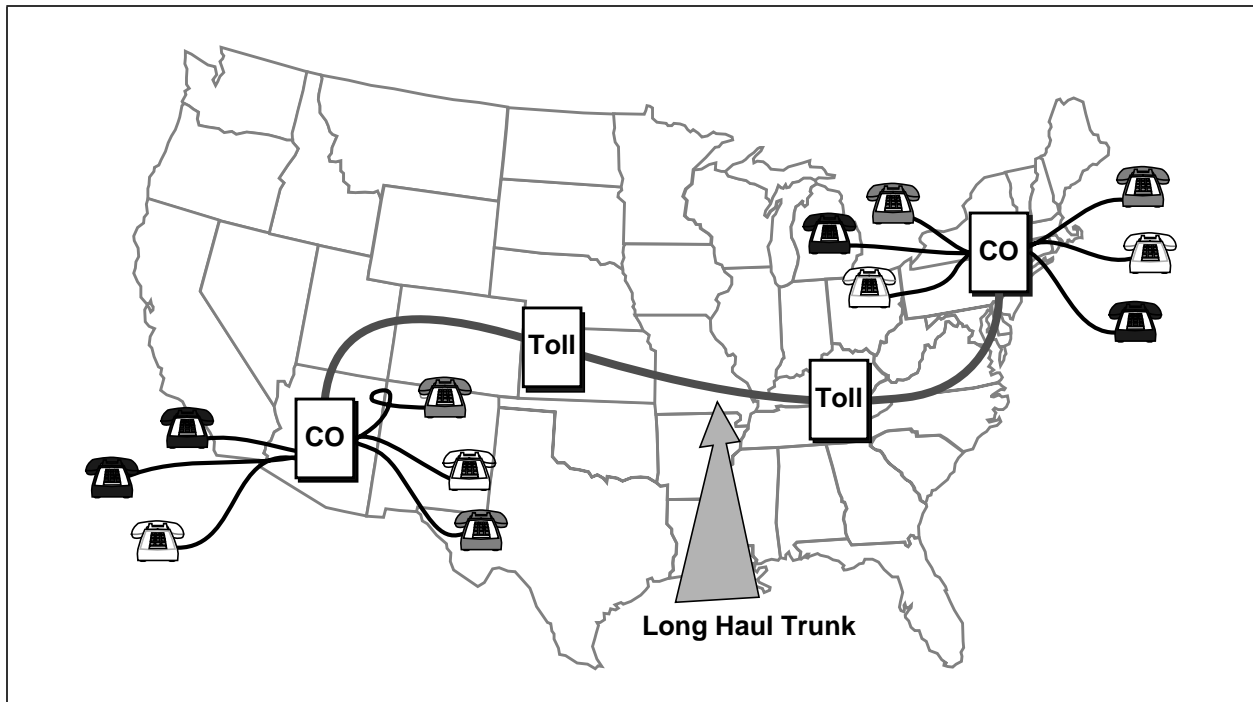


Figure 5: Long Distance Connections

While FDM offered an improvement in trunking efficiency by packing 24 telephone calls onto one trunk line, it did not resolve the problem of signal distortion in long-distance voice connections. An inherent problem with analog voice signal is that it becomes distorted and degraded when transmitted over distances. Conversations over **analog transmission facilities** become more difficult with distance.

T1 was developed to address these problems with analog voice transmission over interoffice trunk facilities.

3.0 Problems with Analog Voice Transmission

Telephone connections began with analog transmission. Figure 6 shows a voice “print” (left image), or the variation of a voice signal over time. This could be a graph of sound pressure against a surface or an electrical signal modulated by voice.

Zooming in on one word (center image) begins to reveal a repetitive structure in the voice signal.

Zooming in further (right image), it is apparent that the voice signal is **continuously variable** over time. Its amplitude changes minutely from one instant of time to the next. This is a characteristic of an **analog** signal. It is this characteristic that poses a problem with long-distance transmission.

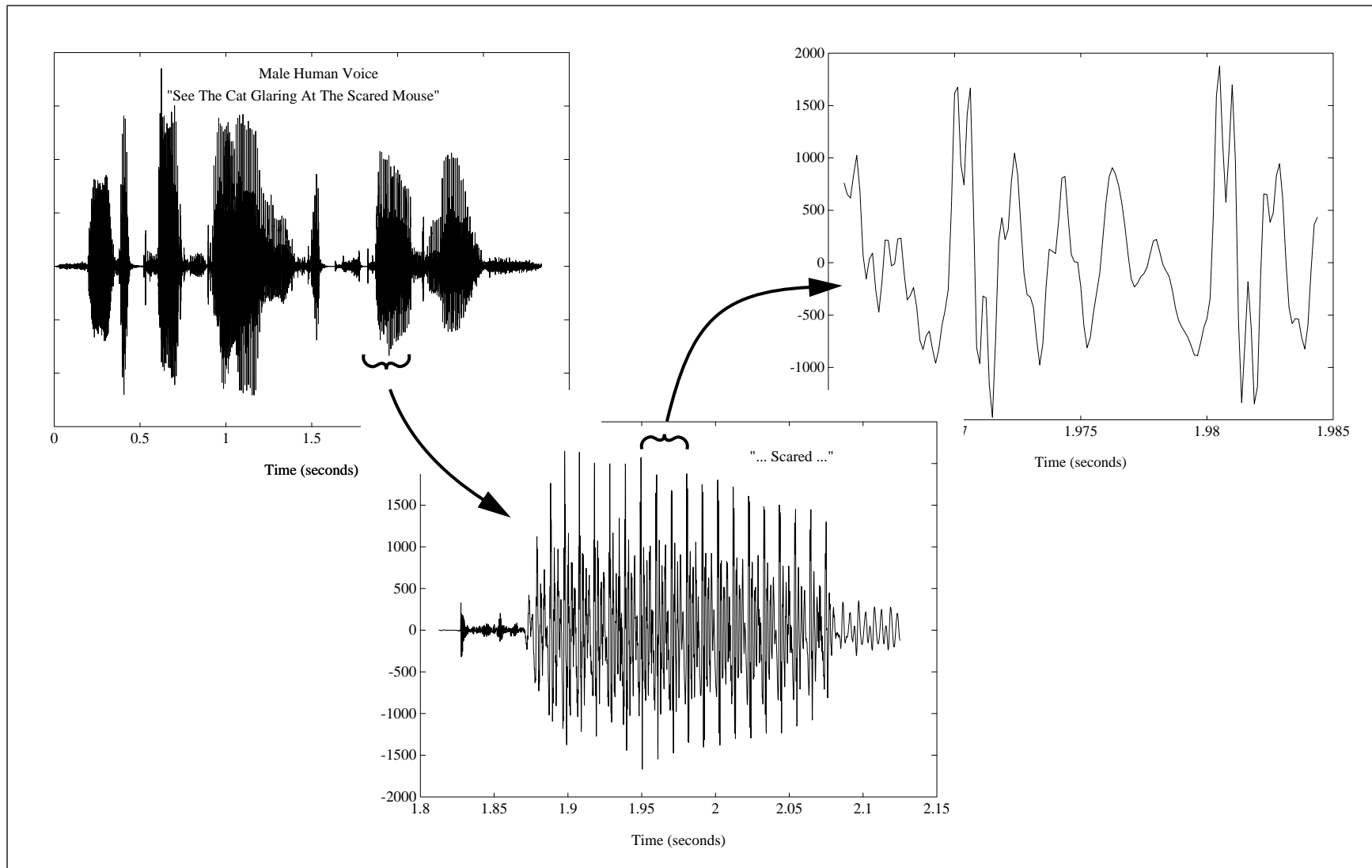


Figure 6: Human Voice - A Continuously-Variable Signal

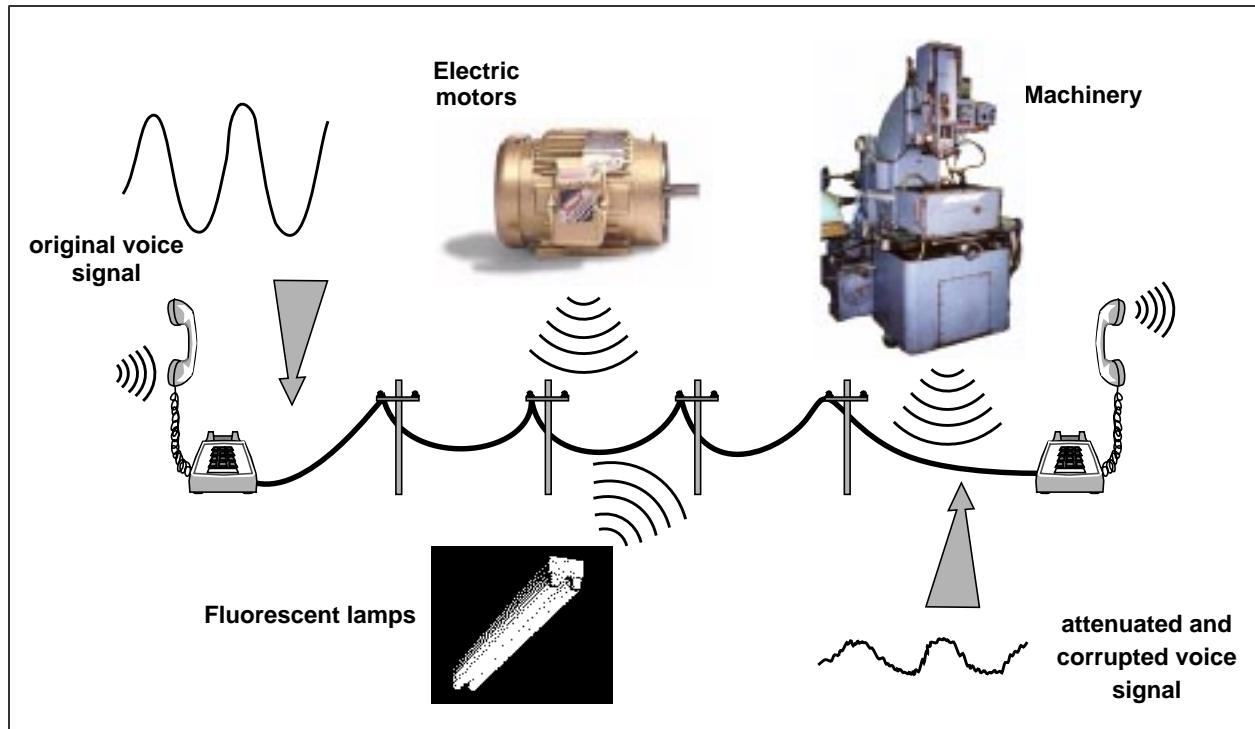


Figure 7: Voice Signal Degradation over a simple Telephone Connection

Figure 7 shows why a voice signal becomes degraded as it is transmitted over a telephone circuit. Voice transmission at left starts out from the telephone as a “clean” signal. At the far end of the transmission path, the signal is **attenuated** and corrupted with **noise**. The voice is weaker and no longer “clean” by time it reaches the telephone on the right.

Losses in the telephone line account for the weakening of voice signal. Noise sources near the telephone line route, such as electric motors, fluorescent lights, and industrial machinery, create electrical interferences that add noise to voice signal. The telephone wire acts as an antenna, picking up interference and corrupting the voice signal.

A **line amplifier** added to the telephone circuit in Figure 8 boosts the level of the weak voice signal. The signal at the receiving telephone is now at the proper level to be heard. Although the volume may be at a comfortable level, the voice signal is still corrupted by noise. The amplifier boosts not only the voice signal, but any noise that corrupts the voice signal as well. To make matters worse, the amplifier itself adds noise to the voice signal.

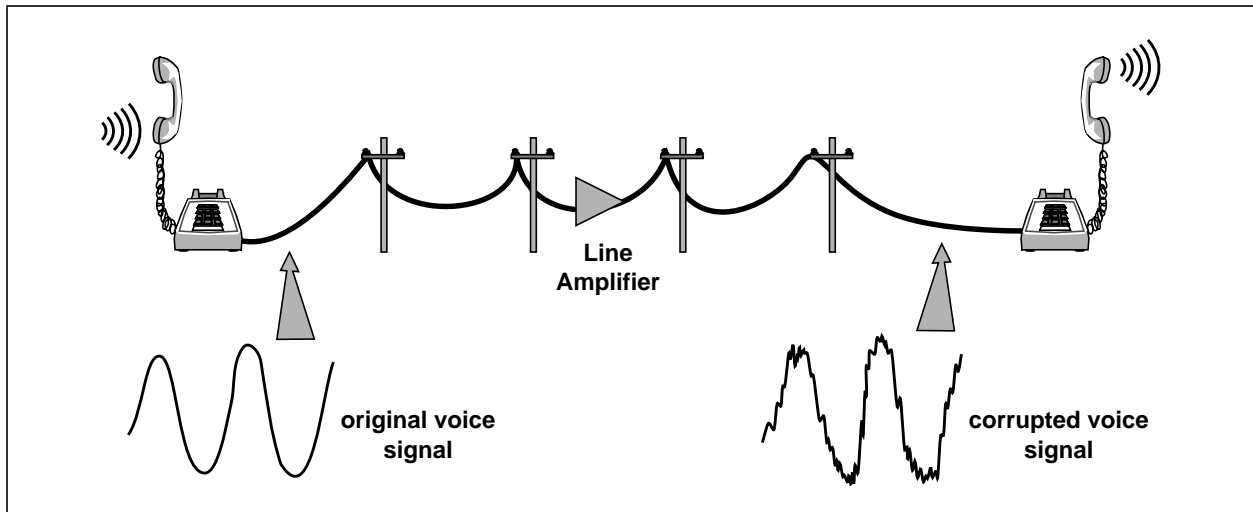


Figure 8: Amplifiers Boost Voice Signal

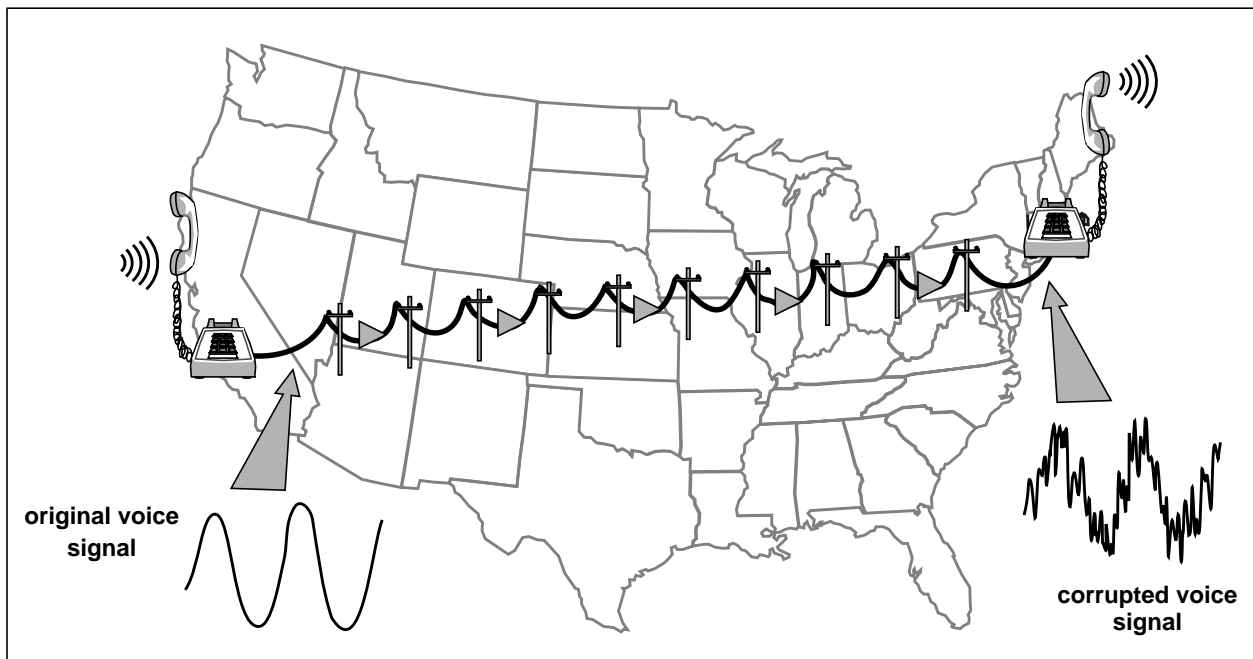


Figure 9: Long Distance call requires many Amplifiers

Long distance transmission may require many amplifiers. Each time a signal is amplified, it sounds less like the original signal. The voice becomes “muddier” and more difficult to understand. This property of irreversible corruption for an analog signal ultimately limits its effective transmission distance. T1 was developed to overcome this limitation.