

A loss-resistant method of seismic data transmission over wireless data networks

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ABSTRACT

A recent continuous seismic monitoring effort employed a wireless network for data transfer. Problems with maintaining network connectivity were observed and traced to data packet loss. The network protocol used in the project, TCP, was found to be ill-suited for the application. The TCP protocol reacts poorly to instances of packet loss as a result of random radio interference. A method for handshake-free data transmission is proposed. This technique uses a combination of data re-sequencing and interpolation-based reconstruction as a means of overcoming occasional packet loss. The method is illustrated with examples showing the effectiveness of this technique in transferring band-limited seismic data.

INTRODUCTION

Acquiring seismic data without wires has great appeal. Either for permanent seismic monitoring applications or temporary exploration surveys, removing a dependency on cables greatly eases the task of data acquisition. Remote monitoring installations require wireless data connectivity since running cables over large distances is costly and environmentally disruptive. In developed environments, wireless networks reduce costly roadway crossings or line-pole installations.

Data loss

Data loss is common over wireless communication channels. Data loss is typically attributable to radio interference - either human-made or natural. The interference usually results in low-level data errors. Error detection and correction methods, typically implemented in radio equipment, mitigate the problem, but in the event of sustained interference, the wireless channel has no option but to drop data from the transmission channel. Though most wireless systems employ some means of concealing this data loss using forward error correction or automatic retransmission, data loss is statistically inevitable.

At a high level, data loss can be overcome by using a handshaking protocol. Data bytes are formed into packets of 50 to 2000 bytes (typically). After each packet is transferred from source to receiver, an acknowledgement is sent from receiver to source. Should a packet be lost, no acknowledgement is received, and the source retransmits the packet.

One common handshaking protocol is called *TCP protocol*. Many common internet applications base their communications on this protocol. E-mail, web access, remote terminal access and many other networking applications employ TCP protocol as the basis of their communications. This protocol requires a bi-directional communications channel so that the sender (a web server, for example) knows if a packet of data arrives successfully at the receiver (a web browser). TCP protocol and other handshaking

protocols have been employed successfully for seismic data transmission. A recent project familiar to the author, employed an IEEE 802.11b wireless network with TCP protocol to transmit a continuous seismic data stream from a remote acquisition system to a data collection and processing system. The TCP/IP protocol was poorly suited for handling the (inevitable) wireless packet loss. Even though the data channel had adequate bandwidth to transmit the data, the presence of packet loss caused a severe degradation in the sustained transfer rates. When the transfer rate dropped below the acquisition rate, continual transfer of data was unsustainable and the connection had to be restarted.

The TCP protocol was designed to cope with network congestion as the primary cause of packet loss. In the event of network congestion, end-to-end transmission delays typically increase, and TCP adjusts to cope accordingly. Unfortunately, packet-loss over wireless networks triggers TCP's congestion avoidance mechanism. Even though the link is not congested, TCP drops its transmission window size which severely reduces the data transmission rate. The end-to-end network performance can drop so severely that large-scale data loss occurs. Only a restart of the network connection can restore communications to their full data rate.

Adaptive quality

When considering the task of monitoring continuous seismic data, we must consider what is *really* most important. Generally speaking, with seismic monitoring systems we are willing to sacrifice data quality in order to prevent any gaps in coverage. Data protocols which provide end-to-end data protection are particularly helpful for transferring data which must be immutable (bank account details, for example). Wireless data links provide no guarantee of transmission integrity. It is certain that, over time, a link using TCP protocol (or any other end-to-end protocol) will eventually break down unless it has a significant bandwidth surplus. Improved "wireless aware" protocols may be helpful in mitigating the negative effects of packet loss, but they ultimately have two flaws: (1) a portion of the network bandwidth must be allocated for handshaking, and (2) in the event of high (intermittent) packet loss, the protocol will always introduce lapses in coverage.

Let us consider an approach to seismic data transfer which assumes that short-term packet loss will occur and assumes that degraded seismic data is better than no seismic data. A final assumption is that the seismic data is band-limited, and consists of data with a power spectrum well below the Nyquist frequency.

An adaptive-quality data transfer protocol

The new protocol keeps the mechanics of packet transmission as simple as possible. Packets are transmitted using *User Datagram Protocol* (UDP) which sends packets of data without any handshake. UDP offers no mechanism to detect or repair lost packets in the end-to-end transfer. Most modern network operating systems offer UDP as an alternate transmission method to TCP. Unlike TCP, UDP allows purely unidirectional data transfer. This has the added benefit of maximizing available data bandwidth.

The protocol we propose employs data re-sequencing and predictive re-assembly as a means of combating packet loss. Rather than send all data samples from the seismic monitoring station to the receiver sequentially, they are transmitted out of sequence in a

pseudorandom order. The receiving system re-sequences the data using an inverse scrambling operator. It is thereby able to recover the original waveform sequence. Any packet loss gets spread out over time. Since the seismic data is typically band-limited, interpolation of the missing samples repairs the waveform with a minimum of distortion. An added benefit of the protocol is that it is very simple to implement in a low-speed acquisition-control computer. Remote acquisition systems are frequently battery powered, and any loss-mitigation technique must require very little CPU overhead. We shall provide a series of examples to illustrate the method.

Figure 1 shows a sine-wave of 1000 samples length, which suffers 2 instances of packet loss. For this example, we assume data packets are 100 samples long. A 1000 sample pseudorandom shuffling operator is applied to the samples. If the same packet loss occurs to the shuffled data, the effects of the packet loss are distributed over the waveform for a period of time equal to the shuffling operator's length (Figure 1d). Figure 1e shows how the waveform may be reconstructed by filling the data gaps through interpolation.

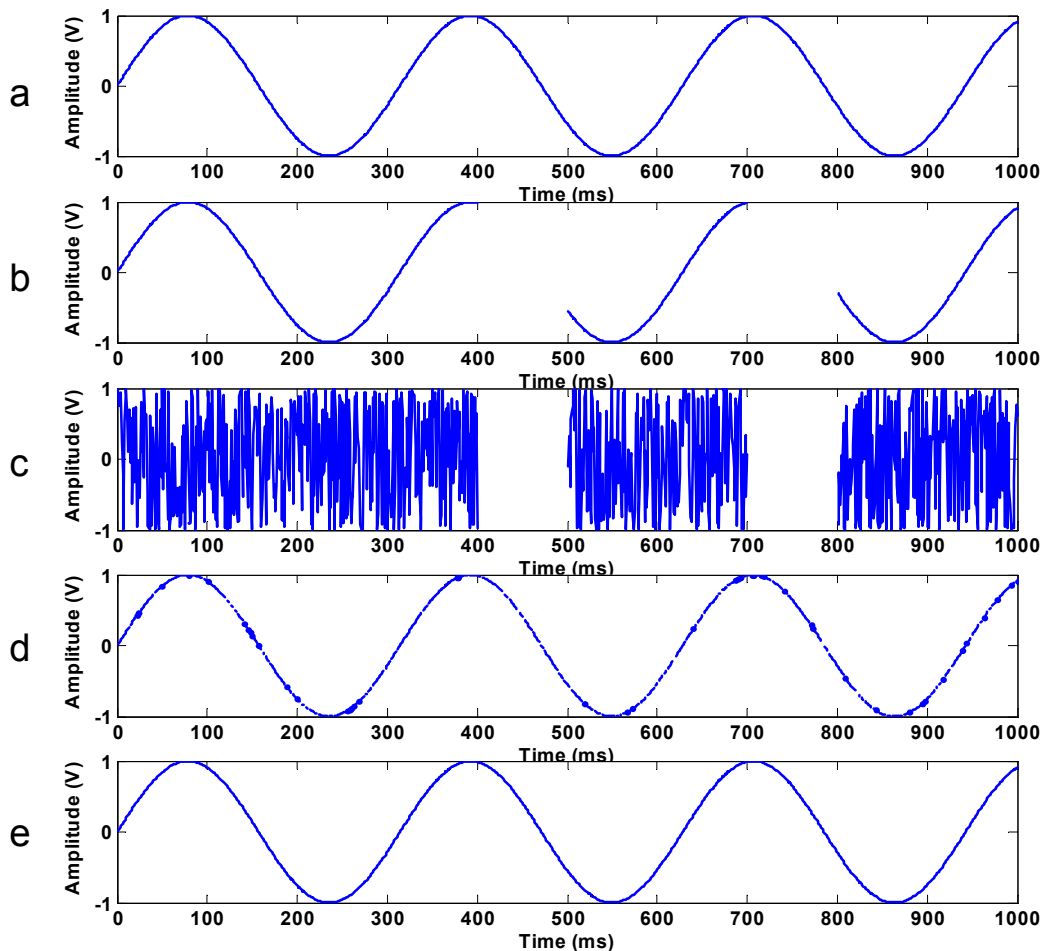


FIG. 1. An example of the seismic data reconstruction after lossy transmission. Original data (a) are severely damage by two instances of packet loss (b). (c) shows pseudorandom shuffling of the data after the same packet loss. (d) shows the the packet loss effect after the data are un-shuffled. (e) shows the data after interpolation-based reconstruction.

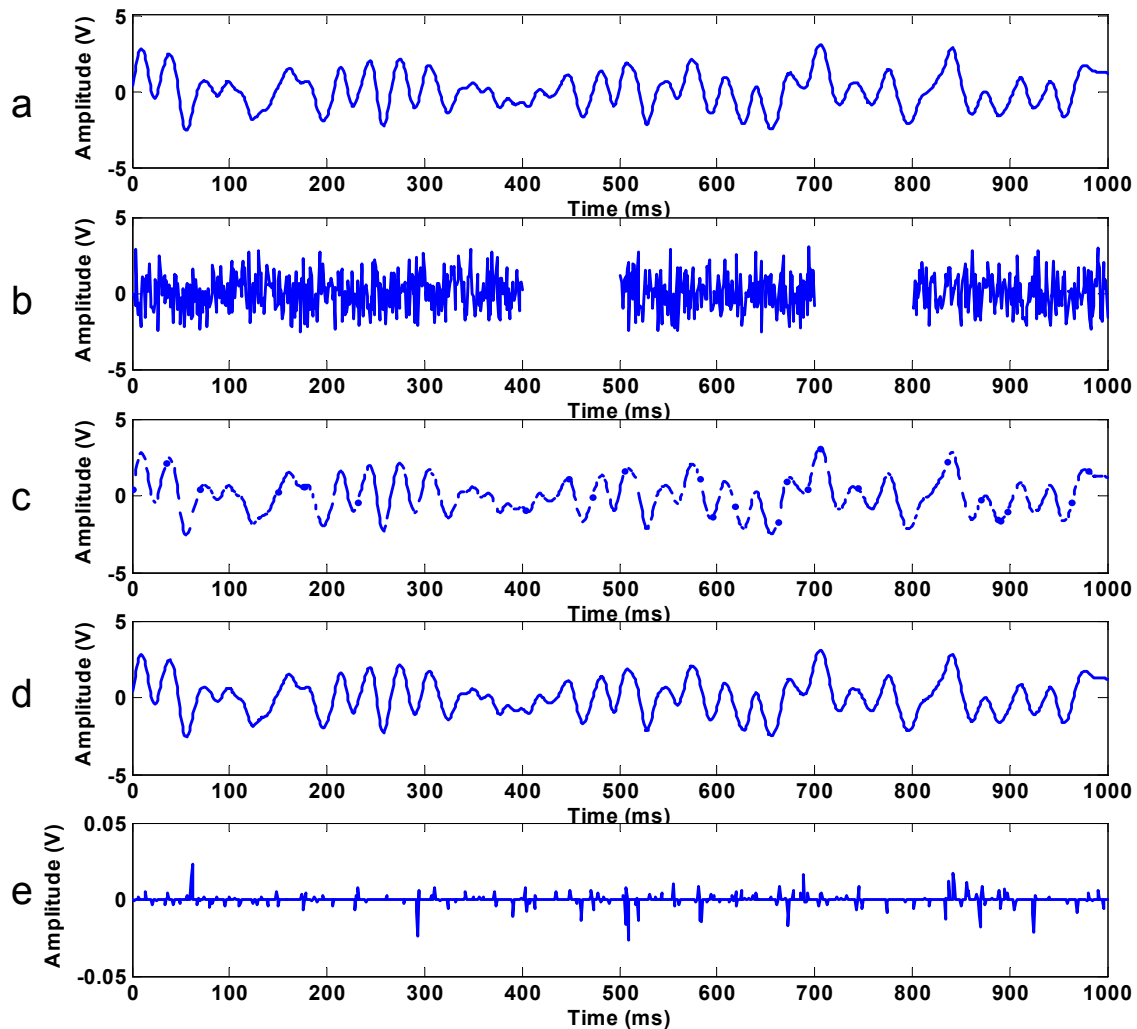


FIG. 2. Actual seismic data from a continuous monitoring data is subjected to packet loss: (a) original data, (b) shuffled data after packet loss, (c) unshuffled data showing the effects of packet loss, (d) data reconstructed via interpolation, (e) difference between the original and reconstructed signal.

Figure 2 illustrates the same transmission method using seismic data recorded at a passive seismic monitoring site. The data were acquired with a 28 Hz geophone at a sample rate of 1000 Hz. In the example, data are scrambled with a 1000 sample pseudorandom scrambling operator, transmitted (with packet loss), unscrambled, and reconstructed via interpolation. Figure 2e shows the difference signal between the input and reconstructed signals. In this case, the level of packet loss was 20%. If we consider the difference signal as noise, we compute a signal-to-noise ratio (SNR) of 50 dB for this example.

The size of the scrambling operator, relative to the packet length, has an effect on the fidelity of the reconstruction. Figure 3 shows the SNR as we vary the number of sequentially-missing data points. We see that the SNR remains above 60 dB for data loss of 10% or less. Packet loss in a well-designed wireless network is usually much less than 1%. Given a network with 1% data loss, most packets will be received intact, but 1 time

out of 100 there will be a data error. Given a packet size of 100 samples, and a scrambling-operator length of 1000 samples, a single lost packet will result in 1000 samples of slightly degraded fidelity (an SNR of about 59 dB). In most cases this SNR is quite acceptable and a slight degradation in fidelity is preferable to an interruption in continuous monitoring.

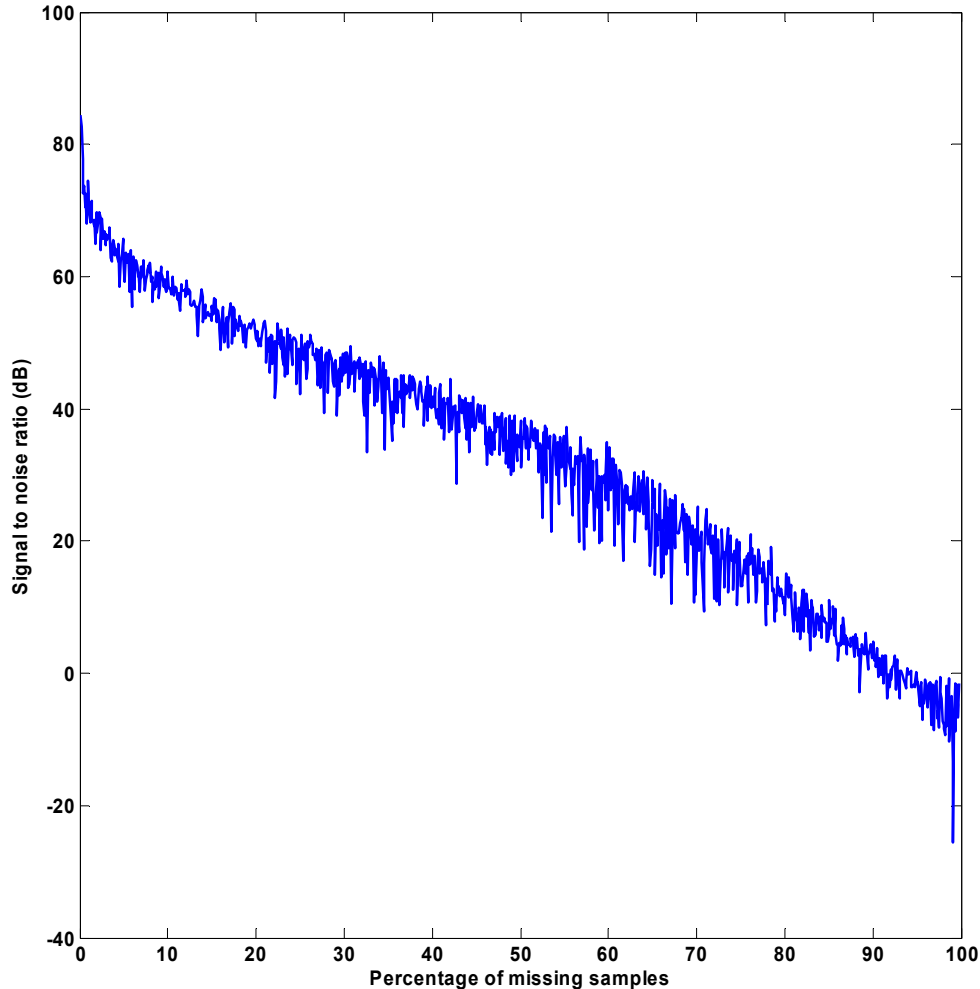


FIG. 3. A field-recorded waveform was subjected to variable amounts of data loss. The size of the missing packet was varied between 1 and 99% of the scrambling operator size. The signal-to-noise ratio of the recovered signal (in dB) is shown.

CONCLUSIONS

The deficiencies of transmitting data using TCP protocol have been discussed. Wireless networks with relatively small rates of packet loss prove problematic for the TCP protocol. A new method of data transmission using packet scrambling has been proposed. We show that this method may be used effectively for installations which transmit band-limited data streams. The technique is robust: High levels of packet loss will not cause a loss of continuous monitoring coverage.

REFERENCES

- Balakrishnan, H., Padmanabhan V.N., Seshan, S., and Katz, R.H., 1997, A comparison of mechanisms for improving TCP performance over wireless links: *IEEE/ACM Transactions on Networking*, **5**, 756-769
- Pankratov, K.K., FILLMISS – a Matlab program for interpolating values in a matrix., http://www.mathtools.net/MATLAB/Mathematics/Fitting_and_Interpolation/