CHAPTER 11

Compression of Telemetry

SHEILA HORAN

OVERVIEW

Telemetry compression is not a well-defined problem. Each application of compression needs to address different data types. This wide variety has made a single compression technique impossible. Telemetry now encompasses every type of data. The only way to approach compression for this type of problem will involve hybrid techniques. Telemetry has seemed to resist compression, but its time has come.

11.1 WHAT IS TELEMETRY?

According to the National Telecommunications and Information Administration's Institute for Telecommunication Sciences, telemetry is "the use of telecommunication for automatically indicating or recording measurements at a distance from the measuring instrument"; it is "the transmission of nonvoice signals for the purpose of automatically indicating or recording measurements at a distance from the measuring instrument" [1]. Measurement at a distance then implies that the information is transported by some means from where the data are taken to the user. The form of transportation may be a coaxial cable or a fiber optic cable or the data may be transmitted through space. The distance may be very small or light-years away. However far the information travels, it will use some bandwidth to transmit the information. The content of this information can be almost anything. For the Federal Bureau of Investigations, which conducts covert operations, the information gathered could be sounds or voices. In some cases the information is the reflected signal of radar, sonar, or even X rays. Originally the term referred to the housekeeping functions of spacecraft or aircraft. Measurements of the craft's vital data (and human medical readings) were taken, organized, and then transmitted by packets or frames

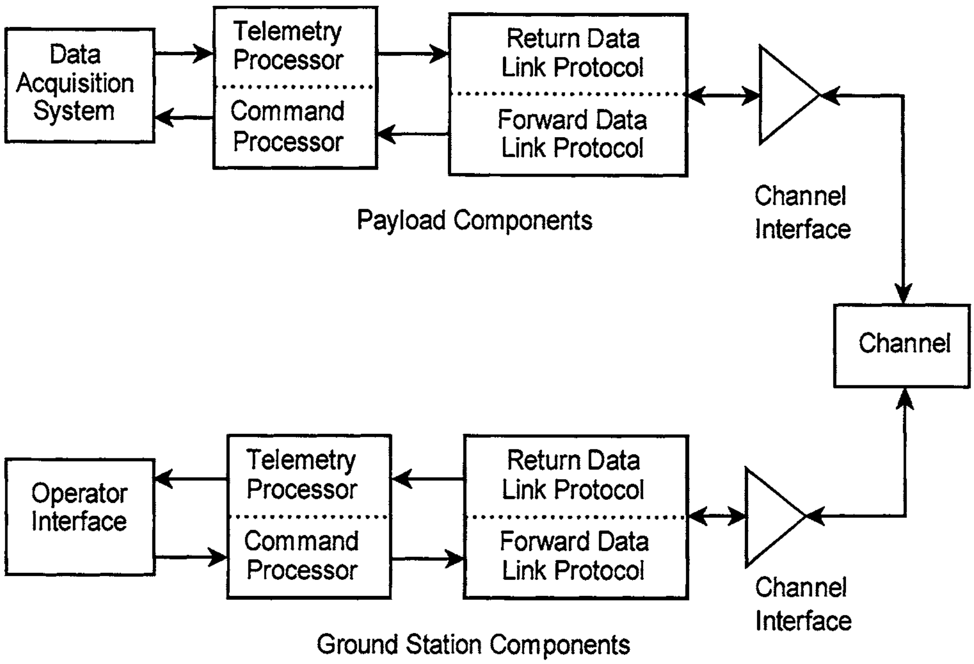

FIGURE 11.1
Satellite telemetry system [3].

on a special link received and then monitored. In the first method, time division multiplexing, the measurements are either buffered or integrated into the data to be transmitted. In the second method, frequency division multiplexing, the measurements are sent at particular frequencies. An example of a satellite telemetry system can be seen in Fig. 11.1.

Packet format is flexible in the type of data to be sent. The data are sent in a burst and have an address heading indicating where their destination is. This allows the use of different packet types each time the data are sent. Figure 11.2 shows the possible flow of the data into the packet format.

Telemetry frames have more of a definite fixed structure and tend to be used when lots of data will be sent with multiple measurements over time. In each frame, the measurements are usually in the same place in the frame.

In general the payload would be the sensor(s), or the device that accumulates data, and the ground station is where the data would be processed. The channel refers to the transmission medium between where the data are acquired and where the data are delivered. There are two main formats for telemetry data. The data are either put into packets (used especially for Internet users) or put into telemetry frames. Examples of the packet telemetry are shown in Figs. 11.2 and 11.3, and examples of frame telemetry are shown in Figs. 11.4 and 11.5.

The internal ordering of packet or frame telemetry can change for different uses, but the outer structure of each is the same no matter what the application.

Today, telemetry includes images and voice data as well as the housekeeping type of data.

Some of the telemetry used by the Air Force interleaves the pilot's voice data with the aircraft monitoring data. Each military exercise that is performed has its own telemetry order. Hence every telemetry data packet or frame is unique. This adds to the complications of compression. Each test could require a different compression technique.

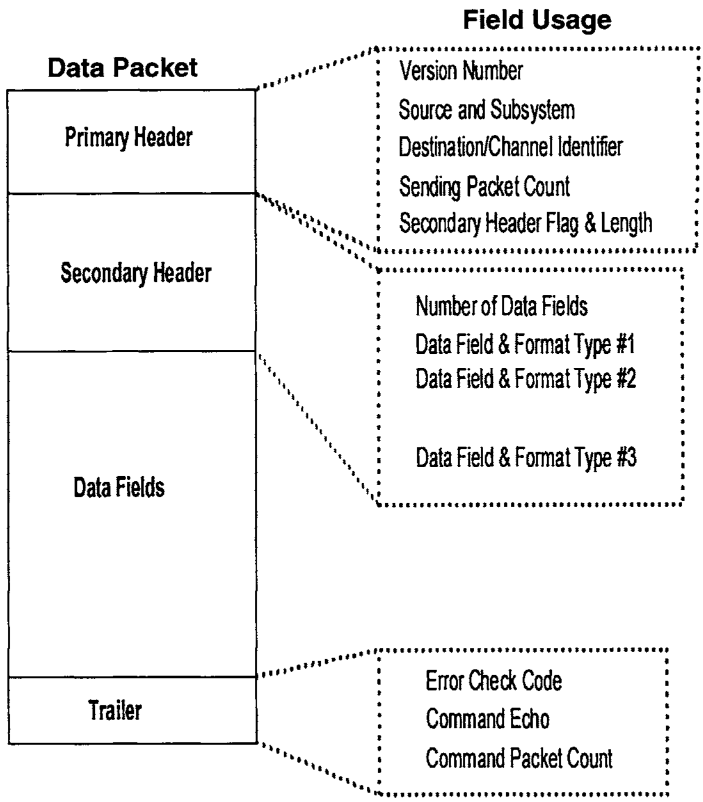

FIGURE 11.2
Packet structure for telemetry data [3].

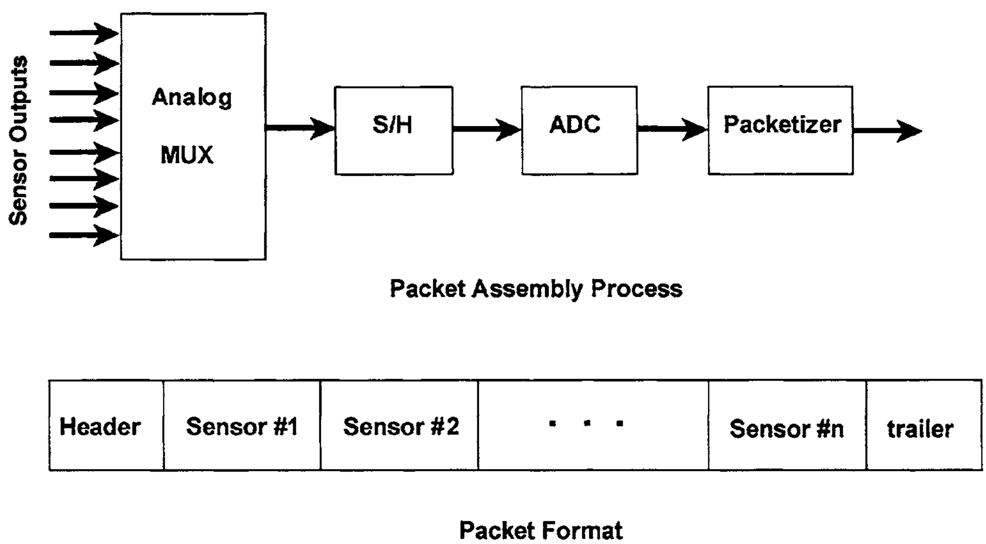

FIGURE 11.3
Packet telemetry format [3].

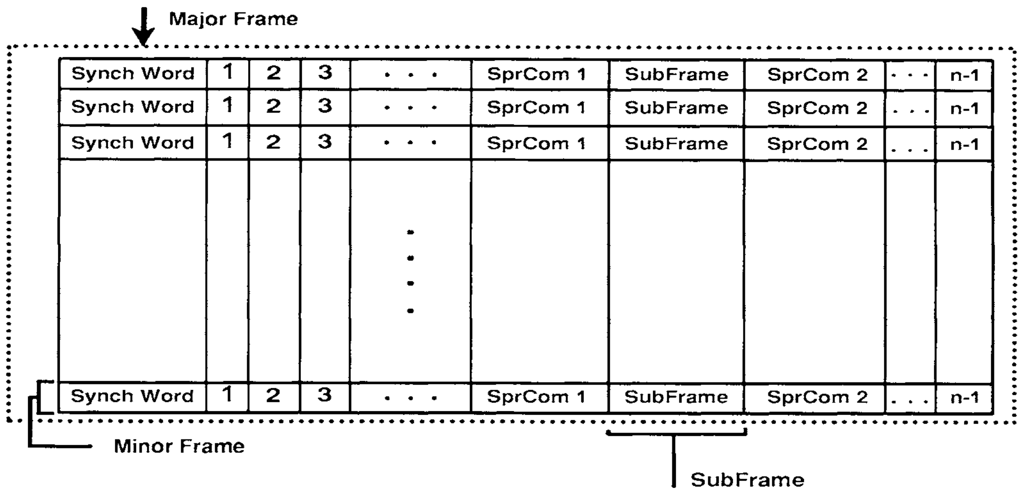

FIGURE 11.4
Major frame structure for telemetry data [3].

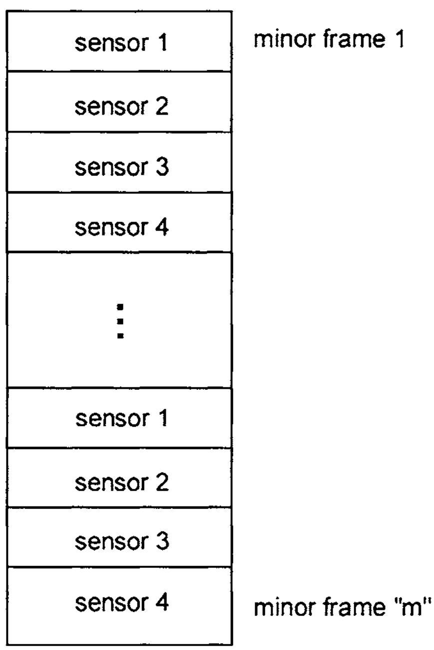

FIGURE 11.5
Minor frame structure for telemetry frames [3].

11.2 ISSUES INVOLVED IN COMPRESSION OF TELEMETRY

11.2.1 Why Use Compression on Telemetry

Bandwidth is a precious commodity. Bandwidth is the amount of frequency space that a signal takes to transmit its information. There are several different definitions of bandwidth. Two common definitions are the 3-dB bandwidth and the null-to-null bandwidth. For a given power spectrum of a signal, the 3-dB bandwidth is where the signal power is down 3 dB from the maximum.

The null-to-null bandwidth is the amount of frequency that is between the first two nulls of the signal (the first low points from the maximum). Given that the bit rate $= R =$ (number of data bits sent)/s, the bandwidths for binary-phase shift keying (a common type of modulation used to transmit data) are [2] as follows: 3-dB bandwidth, $0.88R$; and null-to-null bandwidth, $1.0R$.

If the number of data bits was reduced by half, then one would need only half the bandwidth to transmit the data or one could then send twice as much in the same amount of bandwidth.

With the increase in use of wireless technology, it has become imperative that bandwidth be used efficiently. To this end, data need to be reduced or modulation techniques need to be used to minimize the required bandwidth. Data compression (coding) is one technique to reduce the bandwidth needed to transmit data.

The goals of data coding are as follows:

- Reduce the amount of data;
- Find codes that take into account redundancy, structure, and patterns;
- Break up data into random groups.

Since telemetry data measure quantities that are unknown (as in engine temperature, pressures, speeds, etc.), the need for lossless data reception is important. One of the greatest fears of anyone conducting experiments or receiving data from anywhere is that the data might become corrupted or be lost. When data are compressed, there is less redundancy in the data. This makes it harder to retrieve data once they have been corrupted. When something unexpected happens, e.g., a test goes wrong, these measurements are extremely important to help the engineers understand what happened. So, along with the lossless data compression, channel coding may be needed to ensure no loss of data. What can be done is to channel code the compressed data to protect them against errors. But when channel coding is added, the amount of data is increased. If an appropriate channel/source-coding scheme is selected, then the compressed data with the channel coding combined will still be less data than there would have been originally.

To achieve bandwidth reduction or data reduction (for storage requirements), the compression technique needs to losslessly compress the data taking into account data structure, patterns, and redundancy.

11.2.2 Structure of the Data

The data structure of the frame or packet can be used to advantage. After the initial frame of data is sent, subsequent frames could be sent as a difference in the frames. If the location of the measurements in the frame remains the same from frame to frame, then the values will generally stay within a given range. This means that the differences between the frames would be small, giving smaller numerical values to send. Smaller sized numbers just by themselves can lead to compression. The resulting frame structure would remain the same, but the frame itself would be smaller in size.

11.2.3 Size Requirements

With the advances that have been made in technology, the processor needed to perform the compression could be the size of a single chip. The interfaces to connect the chip to the original process could all be placed on just one card added to the data collection device. The weight would amount to only ounces. The hard part is not in building the device to do the compression, but in deciding what compression to use.

11.3 EXISTING TELEMETRY COMPRESSION

There are many different types of data compression algorithms in place. The first level of data compression comes in deciding how often to take the samples. How often to take the measurements depends on the rapidity with which the data change. The quicker the change (the higher the frequency of change), the faster the data need to be sampled. The slower the change, the slower the data can be sampled. The problem here often is that the scientists and engineers may not know in advance how quickly the signal will change. To account for this, most data are oversampled. If the signal can be monitored, and the sampling changed as needed, this could optimize the number of samples taken. The Nyquist Theorem states that a band-limited signal (with band limit B) can be correctly recovered if the signal is sampled at most every t_S seconds, where $t_S = 1/(2B)$. If in addition there is noise present in the signal (with a signal-to-noise ratio of 10), then a more realistic sampling time would be $t_S = 1/(5B)$ [3].

Much of the current telemetry is images. When images are the information being transmitted, then the compression techniques for images are the appropriate ones to use. When voice data are being transmitted, then accepted techniques for voice compression are used. The challenge comes when many different types of data are interspersed in the data to be sent. In this case, either a frame to frame (or packet to packet) differencing can be done or the format of the data can be reorganized to take advantage of the structure of the data. Table 11.1 lists some of the current applications of compression for telemetry data. It is clear that there are a wide variety of compression techniques. Each type of data is different and so requires a different type of compression scheme.

Table 11.1 Summary of Compression Techniques Used for Telemetry

Device	Compression Used	Reference
SPOT 4 image optical & radar remote sensing satellite	DPCM for imaging	[4]
ECG data compression	First-order prediction	[5]
EUMETSAT meteorological satellite	Lossless wavelet transform JPEG	[6]
COBE	Vector quantization, modified Huffman, runlength code, Chebyshev, Rice	[7]
Cassini	Walsh transform (images), Rice	[7]
Galileo	Dictionary substitution	[7]
Mars Pathfinder	JPEG	[7]
HST	H COMPRESS	[7]
STS	Block adaptive quantization	[7]
VIS	Hybrid mean residual, vector quantization, runlength, Huffman	[8]
NGST	Cosmic ray removal effects, Rice	[9]
Voyager	Rice	[10]
Space applications	Wavelets for high lossy compression, Rice for lossless compression	[11]
ESA Huygens Titan probe	DCT	[12]
ECG	Transform coding	[13]
Seismic data	First-order predictor, DPCM, wavelets	[13]
Missile/rocket	Zero-order predictor	[13]

Abbreviations: COBE, Cosmic Background Explorer; DPCM, Differential Pulse Code Modulation; ECG, Electrocardiogram; NGST, Next Generation Space Telescope; VIS, Visible Imaging System.

11.4 FUTURE OF TELEMETRY COMPRESSION

As the frequency spectrum becomes more congested, there will be an increased use of data compression. Telemetry data will take advantage of adaptive and hybrid types of data compression. Algorithms similar to the Rice algorithm, in which several types of data compression can be implemented, are the best techniques to use on data in general. More adaptive-type methods will be developed. Since each telemetry application is so specific, no one method of compression will be favored. Each telemetry application will need to utilize the best techniques that address its particular mix of data. Data compression will become a necessity.

11.5 REFERENCES

1. Telecom Glossary, 2000. Available at http://glossary.its.bldrdoc.gov/projects/telecomglossary2000.
2. Couch, L., 1993. *Digital and Analog Communication Systems*, p. 115, Table 2-4. Macmillan Co., New York.
3. Horan, S., 1993. *Introduction to PCM Telemetering Systems*. CRC Press, Boca Raton, FL.
4. SPOT Satellite Technical Data. Available at www.spot.com/home/system/introsat/seltec/seltec.htm.
5. Banville, I., and Armstrong, S., 1999. Quantification of real-time ECG data compression algorithms, In *Proceedings of the 1st Joint BMES/EMBS Conference, October 1999, Atlanta, GA*, p. 264. IEEE Publication, New York.
6. MSG Ground Segment LRIT/HRIT Mission Specific Implementation, EUMETSAT document MSG/SPE/057, September 21, 1999.
7. Freedman, I., and P. M. Farrelle, 1996. Systems Aspects of COBE Science Data, July 1996. Available at http://iraf.noao.edu/iraf/web/ADASS/adass_proc/adass_95/freedmani/freedmani.html.
8. Frank, L., J. Sigwarth, J. Craven, J. Cravens, J. Dolan, M. Dvorsky, P. Hardebeck, J. Harvey, and D. Muller, 1993. Visible Imaging System (VIS), December 1993. Available at www-pi.physics.uio.edu/vis/vis_description/node10.html and www-pi.physics.uiowa.edu/.
9. Nieto-Santisteban, M., D. Fixson, J. Offenberg, R. Hanisch, and H. S. Stockman, 1998. Data Compression for NGST. Available at http://monet.astro.uinc.edu/adass98/Proceedings/nieto-santistebanma.
10. Gray, R., 1997. Fundamentals of Data Compression, International Conference on Information, Communications, and Signal Processing, Singapore, September 1997. IEEE Publication, New York.
11. Consultative Committee for Space Data Systems (CCSDS), 1997. Lossless Data Compression, May 1997.
12. Ruffer, P., F. Rabe, and F. Gliem, 1992. A DCT image data processor for use on the Huygens Titan probe. In *Proceedings of the IGARSS*, pp. 678–680. IEEE Publication, New York.
13. Lynch, T., 1985. Data Compression Techniques and Applications. Reinhold, New York.