COMPRESSION OF TRANSMULTIPLEXED ACOUSTIC SIGNALS

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ABSTRACT

Transmultiplexers provide many signals over a single transmission line. An example of the 8-channel transmultiplexer is presented. The specific frequency properties of the transmultiplexed signal make it possible to apply the compression methods effectively. Wavelet packets were introduced to split the signal spectrum into its frequency components. The four-level wavelet packet decomposition was provided by means of the discrete Meyer wavelets. The diversity in the frequency of the spectrum values justify applying the entropy coding in lossless compression. The arithmetic and Huffman coding were tested as examples of compression method for transmultiplexed signal. The coding was conducted separately for different subbands. Finally, the advantages and disadvantages of lossless compression methods were compared to each other.

1. TRANSMULTIPLEXERS

In transmultiplexing systems [1,3] the input signals are combined for the transmission by a single channel and next recovered by a receiver. Figure 1 shows the classical structure of the $M = 8$ channel transmultiplexer. The input signals $s_i^{\text{in}} \in \Re^N$, where $i \in \{1,2,...,M\}$ is a signal number, were upsampled, then filtered and finally summed to obtain a composite signal $s \in \Re^{M(N-1)+1}$ which is transmitted over a single transmission channel. At the receiver end, the signal is relayed to the M-channels of the detransmultiplexation part, filtered and next downsampled [2] to recover the original signals.

The upsampling procedure increases M-times and the downsampling procedure decreases M-times the number of samples. Although the number of samples is varying, the time of signal duration does not change because the sampling density decreases M-times for upsampling and increases M-times for the downsampling procedure.

Transmultiplexing does not make distortions because digital filters (examples of their frequency characteristics are presented in Figure 2) satisfy the requirements of a perfect reconstruction.

2. COMPRESSION

In a compression algorithm the number of bits needed to represent the signal or its spectrum is minimized. Compression algorithms have made communication and the storage of data effective and efficient. Our fundamental concept of compression is to split up the frequency band of a signal and then use less bits to represent the most frequently occurring values, and more bits for the less occurring ones. If there is a severe skew in the frequency distribution some compression gain must be obtained.

Over the past several years, the wavelet methods have gained widespread acceptance in signal compression. Multirate processing is related to signal transformation using wavelets. Wavelet packets are a way to ana-

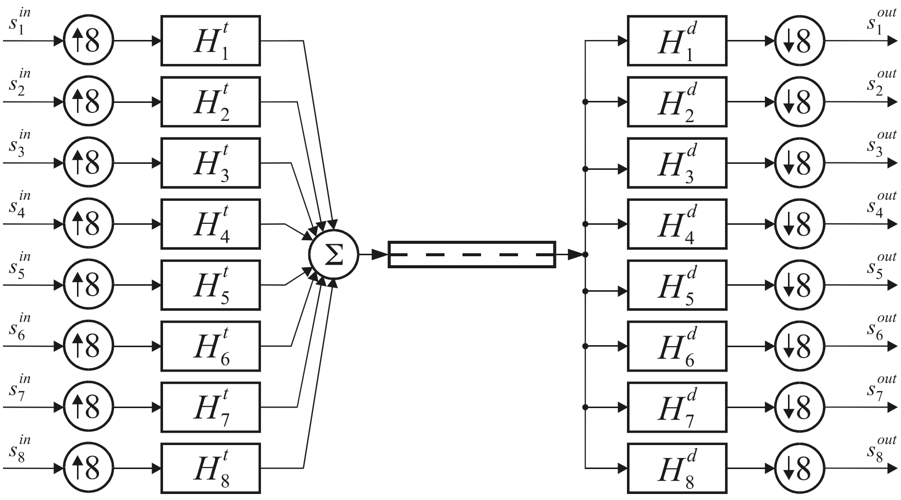

Figure 1. Scheme of 8-channel transmultiplexer

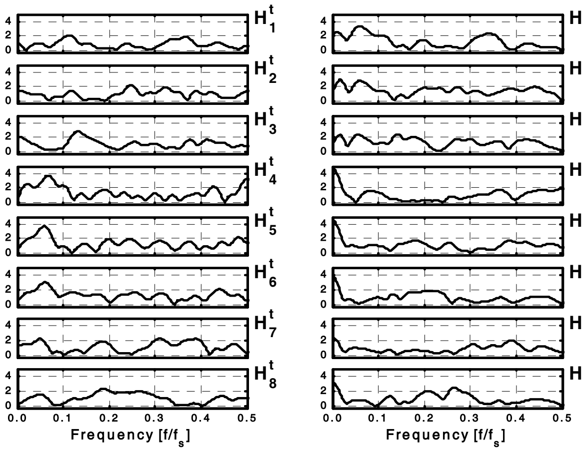

Figure 2. An example of the amplitude characteristics of filters: transmultiplexer (left side) and detransmultiplexer (right side)

lyze a signal using base functions which are well localized both in time and in frequency. The frequency methods enables us to exploit the knowledge connected with the frequency properties of human hearing. Moreover the local character of wavelets does not introduce the block effects and makes it possible to conduct compression in real time systems. This type of processing is the main advantage in compression. Multirate processing involves digital filters that may be used to process a signal in real time.

Some frequencies of the audio transmultiplexed signal appeared frequently in the spectrum while the other frequencies are almost not detectable. Without compression the original signals and their spectra use 16 bits accuracy. Both, the Huffman and arithmetic algorithms are based on statistical coding. The probability of a spectrum value has a direct bearing on the length of its representation. The more probable the occurrence of a value is, the shorter will be its bit-size representation. Sequences of spectrum values are represented by individual codes, according to their probability of occurrence. Decompression takes the compressed bit stream as input and produces decompressed output which exactly matches the input.

The periodicity, presented in Figure 4, of the spectrum of the transmultiplexed signal, result from the periodicity involved by upsampling the signals which have

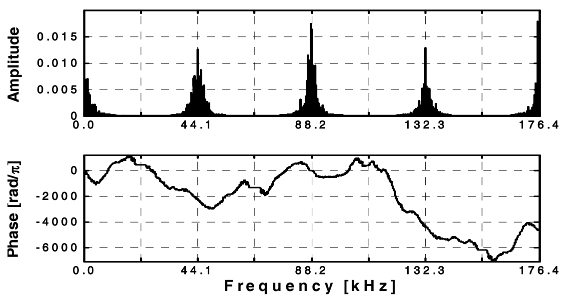

Figure 3. The amplitude and phase spectra of the transmitted signal

Fourier spectra presented in Figure 3. The sampling density in the frequency domain for both cases, presented in Figure 3 and Figure 4, are the same but the number of samples are different. The spectrum of upsampled signal consists of the original spectrum and moreover its shifted frequency components are added.

3. MULTILEVEL DECOMPOSITION

The wavelet packet transform gives a tool that can be used to analyze time varying signals. The wavelet packet algorithm generates [2] a set of subband spectra that are derived from a single transmutiplexed signal. By using a filter bank the subband spectra are produced by cascading the filtering and downsampling operations. As shown in Figure 5, the wavelet packet transform can be viewed as a tree. The coefficients of wavelet series

$$s(t) = \sum_n c_{m+1,n} \varphi_{m+1,n}(t) \tag{1}$$

for the original signal $s(t)$ are the root of the tree, where $\{\varphi_{m+1,n}\}$ are the orthogonal scale functions of the $(m+1)$ resolution level. The next level of the tree is the result of a one step of the wavelet discrete transform

$$c_{m,n} = \sum h_{k-2n} c_{m+1,k} \tag{2}$$

$$d_{m,n} = \sum g_{k-2n} c_{m+1,k} \tag{3}$$

where h_m and g_m are the constant coefficients which depend on the assumed scale function $\varphi(t)$. Subsequent levels in the tree are constructed by recursively applying the wavelet transform step (2) to the low (A - approximation) and (3) to the high (D - detail) pass filter results of the previous wavelet transform step. Multirate processing (see the left part of Figure 5) involves the application of filtering and downsampling. The main subject lies in the design of lowpass and highpass filters which produce useful transformations and allow the recovery of almost the entire original signal. To recover the signal from the wavelet spectrum, the inverse discrete wavelet filter bank (the right part of Figure 5) is used.

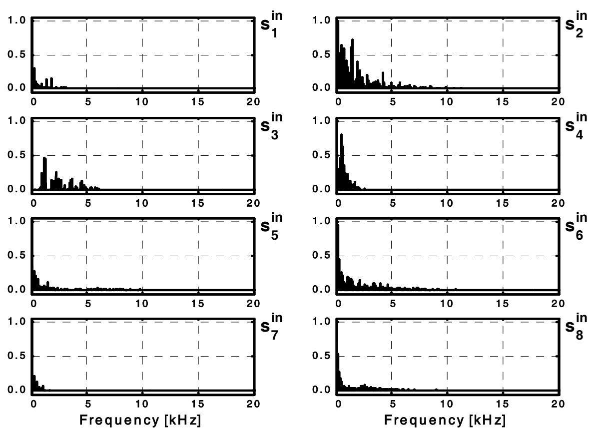

Figure 4. Spectra of the input signals

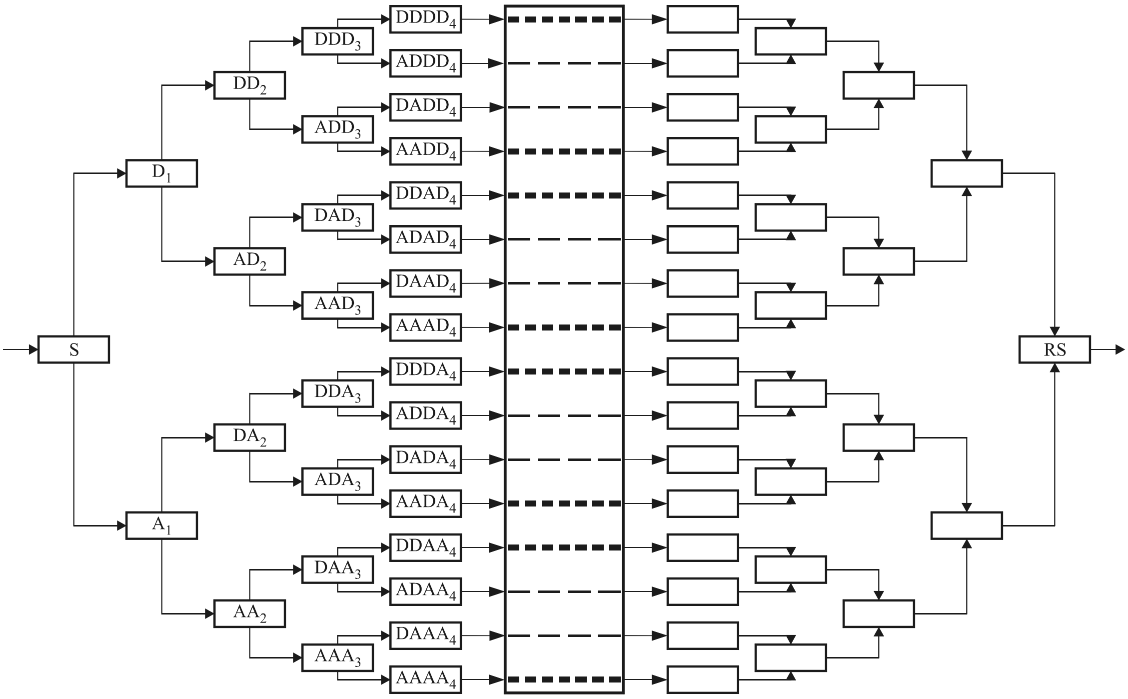

Figure 5. Decomposition of transmultiplexed signal, compression and signal synthesis

4. EXAMPLE

To verify the frequency properties of transmitted signals and the efficiency of compression method, some examples (speech, acoustic and artificial signals) were analyzed. One of them is presented below. The following was assumed:

- transmultiplexer consists of 8-channels,
- all filters are of 40-th order,
- discrete Meyer wavelet was applied,
- all acoustic signals consist of N = 131 072 samples (3 seconds approximately).

The construction of wavelet packet tree is shown in Figure 5. Wavelet packets are well localized both in the time and frequency domain. Figure 5 is an example of the four-level packets generated by using the discrete Meyer wavelet packet filters.

The absolute values of the coefficients of the wavelet packet decomposition are presented in Figure 6. The frequency is plotted on the vertical axis and time on the horizontal axis. The stages of a decomposition of the transmulitiplexed signal with equal bands are presented. Each successive stage decomposes its input vectors twice (see Figure 5). Each output vector has half of the number of samples of the input vector. Thus, the frequency domain of the signal spectrum is partitioned twice and the transform with N stages has 2^N spectra.

Transmultiplexed signals do not use the whole range of frequencies. In 99,9 % the information is transmitted in subbands which constitute a half of the whole band. It is easy to distinguish important and unimportant bands. In both, but especially in unimportant ones there occur specific values much more probable than others (see Figure 8). That enables us to use the entropy codes to

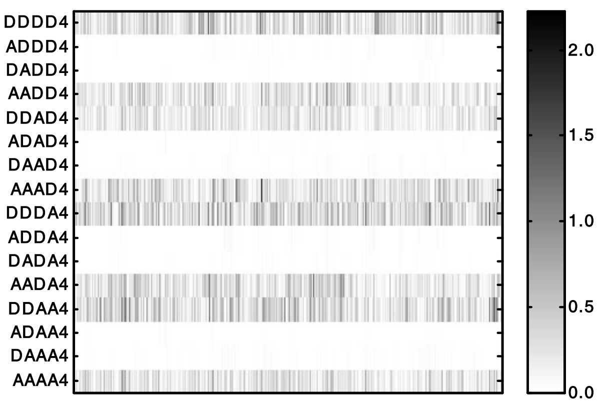

Figure 6. The absolute values of the time-frequency spectrum

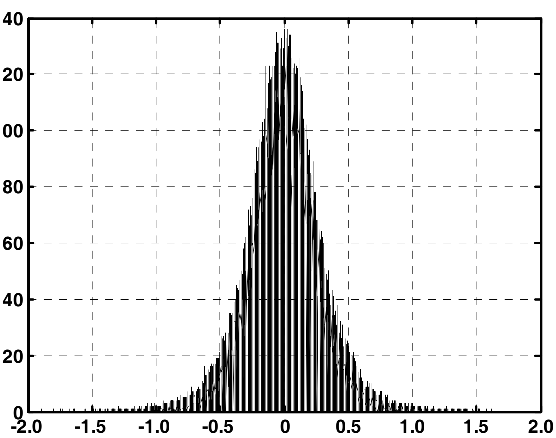

Figure 7. Histogram of the multiplexed signal

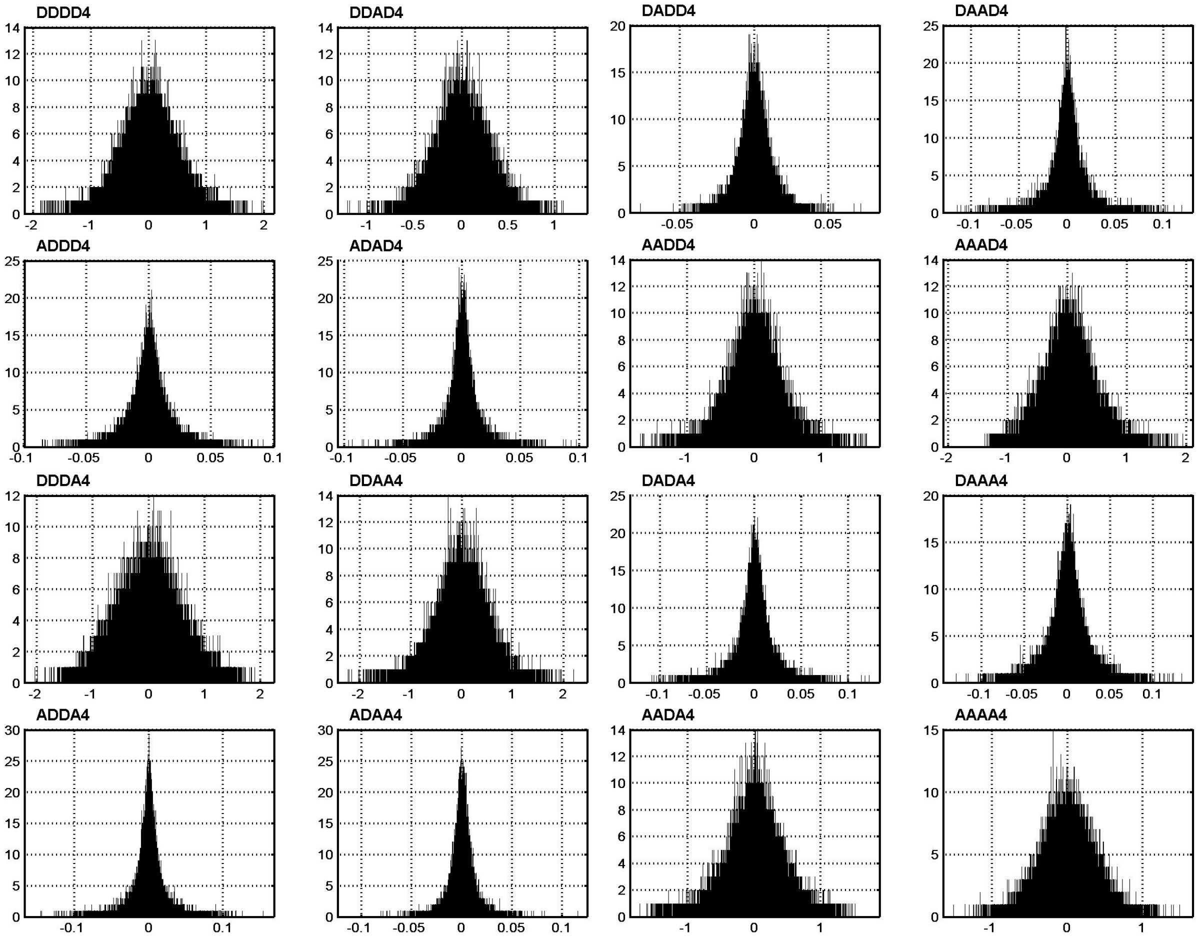

Figure 8. Histograms of wavelet spectra in end-nodes. Upper and lower plots present the important bands with 16-bit quantization and the central plots presents the unimportant bands with 8-bit quantization

compress the signals. Important subbands need 16-bit quantization while unimportant subbands need 8-bit quantization, only. The quatization levels are described by the natural numbers.

The spectrum of transmultiplexed signal consists of 1 048 616 words and 16-bit quantization gives 16 777 856 bits. The arithmetic coding decreases this bit stream to 10 205 521 bits. Its distribution between the different bands is presented in Table 1. Hence, the degree of the lossless compression is equal to 1.644.

Table 1. The length of codes obtained after arithmetic compression

quantizer 8 bit		quantizer 16 bit	
Node	Code length	Node	Code length
ADDD4	458 964	DDDD4	903 651
DADD4	382 918	AADD4	929 333
ADAD4	354 108	DDAD4	910 879
DAAD4	354 941	AAAD4	940 147
ADDA4	349 842	DDDA4	918 259
DADA4	321 267	AADA4	885 788
ADAA4	315 675	DDAA4	908 733
ADAA4	344 626	AAAA4	926 390

Huffman coding and commercial ZIP software (version from Windows Commander 4.11 with parameter “maximal compression”) has been used to compress signals in three different cases.

Firstly, we compressed the multiplexed signal (quantized and recorded by using 16-bit words; its histogram is presented in Figure 7) which previously consisted of 2 097 231 bytes. The ZIP compression has decreased it to 1 240 179 bytes. Hence, the degree of compression is equal to 1.6792. The Huffman coding has been used for the same signal. Because of the 16-bit quantization 30896 integer numbers have been used as symbols. We have obtained entrophy 14.0859 and degree of compression 1.1331.

Another solution is compressing all bands separately (see Figure 8). The multiplexed signal has also been quantized and recorded by using 16-bit words. The coefficients of 4 level wavelet decomposition have been calculated with using Mayer wavelet and quantized (16-bit). Such signals have been compressed by ZIP and Huffman coding. Results of Huffman coding are presented in Table 2. The average degree of compression is 1.1566.

Table 2. Huffman coding of decomposed signal

Node	Number of symbols	Entropy	Degree of compression
AAAA4	23458	14.2231	1.1227
AAAD4	22897	14.1638	1.1274
AADA4	23252	14.1854	1.1257
AADD4	23012	14.1681	1.1270
ADAA4	12249	13.0237	1.2260
ADAD4	14490	13.2784	1.2024
ADDA4	13744	13.1282	1.2162
ADDD4	17712	13.6512	1.1696
DAAA4	17570	13.6437	1.1703
DAAD4	15434	13.3903	1.1924
DADA4	15692	13.4263	1.1892
DADD4	15874	13.5248	1.1805
DDAA4	22872	14.1792	1.1261
DDAD4	23228	14.2021	1.1243
DDDA4	26720	14.4366	1.1062
DDDD4	24067	14.2610	1.1197

Table 3. ZIP compression of decomposed signal

Node	Degree of compression	Node	Degree of compression
AAAA4	1.8086	DAAA4	2.0862
AAAD4	1.8423	DAAD4	2.1625
AADA4	1.8552	DADA4	2.1551
AADD4	1.8656	DADD4	2.2336
ADAA4	2.2471	DDAA4	1.8187
ADAD4	2.2156	DDAD4	1.8912
ADDA4	2.1654	DDDA4	1.8251
ADDD4	2.1716	DDDD4	1.8660

The effect of ZIP compression of the same signals is presented in Table 3. The average degree of compression is 2.0131.

Finally we use 16-bit quantization for nodes DDDD4, AADD4, DDAD4, AAAD4, DDDA4, AADA4, DDAA4 and AAAA4 which are important bands and 8-bit quantization for others whose coefficients mostly equal 0. For such signals we applied ZIP compression and Huffman coding. The result of Huffman coding is presented in Table 4. The average degree of compression is 1.6025.

The results for case with using 16-bit and 8-bit quantization and using ZIP compression are shown in Table 5. The average degree of compression is 1.8462 for nodes with 16-bit quantization, and 6.7928 for 8-bit ones. That results in total average 4.3195.

5. CONCLUSION

Transmultiplexation changes the parallel transmission into a serial transmission. In other words it converts M vectors $s_i^{in} \in \Re^N$ in to a single vector $s \in \Re^{M \cdot N}$ which has M-times more elements. The main advantage lies in the great variety of realizations which are available by the proper designing of digital filters H^t and H^d. Through a comparison of the input and output signals, no distortions except the delay, were noticeable as a result of transmultiplexation.

Table 4. Huffman coding of decomposed signal with 16-bit and 8-bit quantization for different bands.

	Node	Number of symbols	Entrophy	Degree of compression
16 - bit	AAAA4	23458	14.2231	1.1227
	AAAD4	22897	14.1638	1.1274
	AADA4	23252	14.1854	1.1257
	AADD4	23012	14.1681	1.1270
	DDAA4	22872	14.1792	1.1261
	DDAD4	23228	14.2021	1.1243
	DDDA4	26720	14.4366	1.1062
	DDDD4	24067	14.2610	1.1197
8 - bit	ADAA4	148	5.2529	1.5136
	ADAD4	187	5.5606	1.4288
	ADDA4	194	5.4155	1.4689
	ADDD4	216	6.0008	1.3287
	DAAA4	200	5.9845	1.3319
	DAAD4	210	5.7050	1.3936
	DADA4	198	5.7361	1.3863
	DADD4	163	5.8119	1.3717

Table 5. ZIP compression of decomposed signal with 16-bit and 8-bit quantization for different bands.

8-bit quantization		16-bit quantization	
Node	Degree of compression	Node	Degree of compression
ADAA4	8.3298	AAAA4	1.8082
ADAD4	8.0713	AAAD4	1.8419
ADDA4	6.0578	AADA4	1.8548
ADDD4	6.2813	AADD4	1.8651
DAAA4	4.8961	DDAA4	1.8183
DAAD4	6.1406	DDAD4	1.8907
DADA4	5.9044	DDDA4	1.8247
DADD4	8.6612	DDDD4	1.8656

The power of the wavelet packet analysis is that it allows signal frequency variation through time to be examined. The wavelet packets method offers a riche range of possibilities for signal compression. The spectrum of transmultiplexed signal has special properties. The lack of high frequencies in the input signals leads to small values of the transmitted signal spectrum for some frequencies. The location of these frequencies depends on the number of channels and can be easily determine. This makes it possible to apply some effective compression methods to reduce the sion methods to reduce the number of bits of the transmitted signal. Another relevant property is that arithmetic and Huffman coding are lossless compression schemes.

Table 6 depicts the difference in efficiency of compression between commercial solutions, Huffman and arithmetic coding. Standard methods in general use (such as ZIP) code single digits of numeral data. We have used arithmetic coding for compression of integer numbers. As shown in Figure 7 and 8, certain values of digital data are more common than others. These methods require a smaller amount of bits for the more common numbers (peaks of histograms presented in Figure 7 and 8), which apparently results in substantial compression. General methods are designed universally to such extent that they are also efficient in compression of transmultiplexed signals.

Table 6. Efficiency of various methods of compression

Compression method	Degree of compression
arithmetic coding	1.644
ZIP for multiplexed signal	1.6792
Huffman coding of multiplexed signal	1.1331
Huffman coding of decomposed signal (16-bit)	1.1566
ZIP compression of decomposed signal (16-bit)	2.0131
Huffman coding of decomposed signal (16-bit and 8-bit)	1.6025
ZIP compression of decomposed signal (16-bit and 8-bit)	4.3195

6. ACKNOWLEDGEMENT

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