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Modernization of Algorithms for Generating Correlated Data When Integrating Diverse Reception Methods and Noiseless Decoding Methods

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Abstract. Some aspects of integration of diverse reception methods and noiseless coding (decoding) methods are considered for cases of soft decision demodulation (in particular, Viterbi decoding). Since the devel-oped algorithms for generating correlated data A4 and A42 that adapt to the time-varying conditions of the interference situation and ensure high data reliability, are oriented toward hard decision demodula-tion they need to be modernized to implement the above-mentioned integration. The essence of the modernization is described, and legitimacy of the modernization is justified. The modernization is connected with the formation of reliability estimates for the symbols (in particular, symbols in the form of the four-position signal implementation) received under the unfavorable conditions that are due to systematic errors caused by channel interference, as it has been deduced from experiments.

Keywords: algorithms for correlated data generation, analog implementation of four-position (two-position) signal, hard decision demodulation, noiseless coding (decoding) methods, diverse reception methods, soft decision demodulation, symbol.

It is shown [1, 2] that diverse reception methods and noiseless coding (decoding) methods are not alternative in principle. Moreover, when they are integrated, the possibilities for reliability improvement increase. In such a case, it is necessary to observe certain rules. In particular, in the case of sequential application, first, the correlated data is obtained, and then they are decoded [1, 2]. This approach makes it possible to use rationally the integration possibilities; it is relevant in the case of applying highly efficient algorithms A_4 and A_{42} for generating correlated data [1, 2], adapting to the time-varying conditions of the interference situation, and subsequent decoding oriented toward the hard decision demodulation.

However, if the decoding is oriented toward the soft decision demodulation (in particular, Viterbi decoding), then the algorithms A_4 and A_{42} [3] need to be modernized (in case they are applied). In this case, it is necessary that the format (structure) of a datum at the software-hardware output for correlated data generation or at the decoder input with traditional soft decoding be the same. The components of such a datum are sharply delimited. It consists of an elementary datum and its estimate, namely: its high bits refer to an information datum selected from a certain received symbol, or to an analog implementation of a digital signal (refer to the elementary datum in terms of [1, 2, 3]), and low bits refer to reliability estimate of this symbol (of this analog implementation of a digital signal or of this elementary datum).

The purpose of the work is recommendations on correlated data generation for subsequent decoding oriented toward the soft decision (for) demodulation.

An example of an output three-bit datum of an eight-level soft modem for the modernized algorithm A_{42} is considered [3] (see Fig. 7.8 and explanations to it [4]). Fig. 1 is similar to Fig. 7.8 of [4]). In Table 1, e_i are values of an elementary one-bit datum of i-th diverse channel (0 and 1); the leftmost column of estimates ei contains estimates of the most reliable elementary data «0» and «1», and rightmost column contains the least reliable ones. Values of these estimates are conditional (they may not be the same for the circuit implementation of the corresponding software and hardware). They are primarily chosen for clarity. Their substance is related to the Euclidean distance that is characteristic of the soft decoding scheme (and not to the Hamming distance, as in the case of the hard decoding scheme) [4].

Table 1. Values of the elementary one-bit data e_i and corresponding two-bit estimates

e_i	Estimates e_i			
0	00	01	10	11
1	11	10	01	00

Further generation of correlated data shall be performed by the algorithm A_4 (A_{42}), with using, as usual, only elementary data acquired from the diverse channels [1, 2]. If an elementary datum e_{cor} is selected for the correlated data block and elementary data of the same value and corresponding to the same transferred datum and the aforecited correlated datum e_{cor} are acquired from the i_1, …, i_h diverse channels, then the reliability estimate of a symbol from one of the i1, …, ih channels is added to this correlated datum, which value matches the most reliable symbol (elementary datum). This addition results in generation of a datum e_{cor_est}, the structure of which is identical to the structure of a soft modem output datum (Table 2). It means that the format of the words (data) e_{cor_est} and e_{i_est} are the same (where e_{i_est} is a datum containing the reliability estimate of the received symbol from the i-th diverse channel).

Table 2. An example illustrating how correlated data e_{cor_est} are generated by using the modified algorithm A_{42}

e_{cor}	Reliability estimates of symbols for diverse channels, i =					e_{cor_est}
	1	2	3	4	5	
1	-	01	00	-	11	111
0	-	-	-	-	01	001
0	10	10	01	11	-	001
…..	…..	…..	…..	…..	…..	…..

Thus, the first row of Table 2 describes the case for which e_{cor} is 1, the best estimate of reliability is 11 (it refers to the fifth diverse channel), and the datum e_{cor_est} is 111.

The propriety of the established procedure for selection of reliability estimates for correlated elementary data is related to the entities of symbol reliability estimates (reliability estimates of elementary data) pertaining to a separate diverse channel (e.g., shown in Figure 1), as well as the peculiarities of the elementary data selection for a correlated data set when implementing the algorithm A_4 (A_{42}) [1, 2].

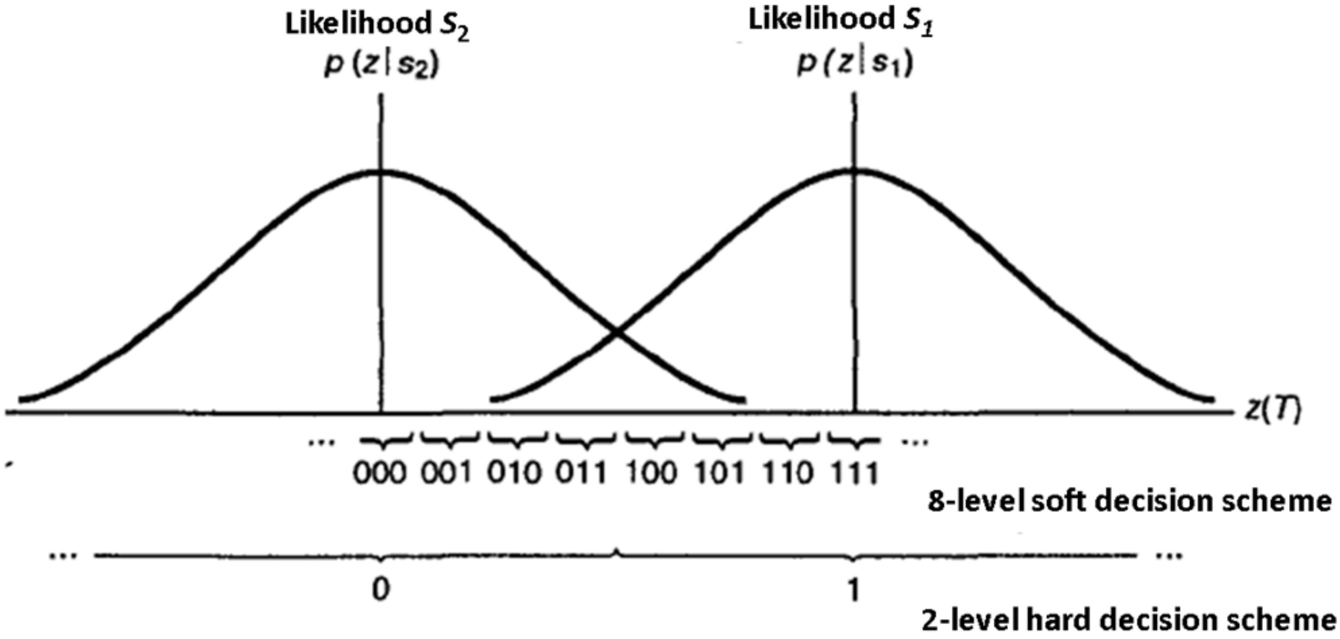

Fig. 1. Graphs explaining how the hard decision decoding scheme and the soft decision decoding scheme work

The closer the received signal value z is to any position of an ideal signal («0» or «1» are for the example in question, see Fig. 1), the less the probability of its erroneous identification is. The following statement is also true: the minimum deviations of the received signals z from their ideal values most often correspond to the most reliable elementary datum. On the other hand, the reliability provided by the algorithms A_4 and A_{42} is not worse than the reliability when using auto-selection (i.e. $P_{er\_i} \geq P_{er\_cor}$, $i = 1, 2, \ldots, n$, where P_{er_i} is the probability of identification error in the i-th diverse channel, P_{er_cor} is the probability of an erroneous elementary correlated datum) [1]. For example, if from n data blocks received from the diverse channels and corresponding to the same transmitted data block, the minimum amount of invalid elementary data (in comparison with the remaining blocks) is contained in the n-th block, but at the same time $P_{er\_n} > P_{er\_cor}$ and correlated data are obtained using the algorithms A_4 and A_{42}, then the reliability estimates of the elementary data of the n-th block should be worse than the estimates for the block of the received correlated data selected from the estimates corresponding to the elementary data of the i_1-th, …, i_h-th diverse channels. In other words, it is logical that reliability estimates of the correlated elementary data obtained using the algorithms A_4 and A_{42} are no worse than when using auto-selection.

The normalization of the received signal is essential.

It is shown [5] that the normalization of the received four-position telemetry signal (Figure 2) is based on bringing the telemetry values of each diverse channel to a unified measurement scale (to nominal levels).

Table. 3 implies that in the case of the above normalization, selection of two high bits of a binary eight-bit word corresponding to an analog implementation of a four-position signal (see Figure 2) is equivalent to the use of threshold separation (equivalent to data recognition). The values of the thresholds 1, 2, and 3 are 63.5, 127.5, and 191.5 binary units respectively. Such normalization and identification provide very high reliability, if the interference component of a received signal is additive, and its mathematical expectation is zero [5]. They also provide clear separation of chunks of data related to the reliability estimates of elementary data, and elementary data themselves, which is very important.

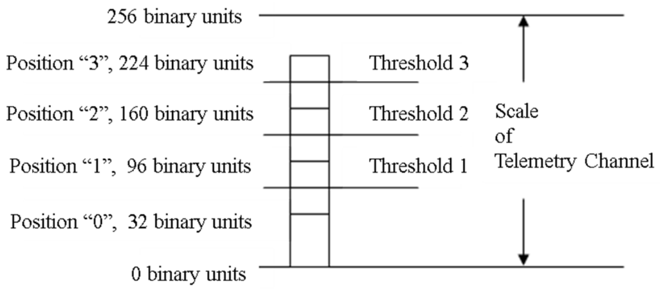

Fig. 2. A graph of a four-position signal with nominal values of position levels

Table 3. The results of binary-coded representation of the values of nominal position levels for a four-position signal

Position No.	Values of position levels, binary units	bit values							
		1	2	3	4	5	6	7	8
1	32	0	0	0	0	0	1	0	0
2	96	0	0	0	0	0	1	1	0
3	160	0	0	0	0	0	1	0	1
4	224	0	0	0	0	0	1	1	1

Information on reliability estimates is contained in the fragment b_e of the word e, from the first to the sixth bits, shown in Table. 3. They characterize deviation of a received four-position signal from its nominal level. These characteristics are the initial data for obtaining reliability estimates of elementary data in the format required for further decoding. In the context of the purpose of this work, the determination of this format is premature.

However, it is necessary pay attention to some features associated with it.

Thus, because of the asymmetry of the communication channel, interference with a negative sign and a positive sign at the positions «0» and «3», respectively, do not cause errors in the data recognition considered above (see Figure 2). In these cases, values of deviation of a received four-position signal from its nominal levels «0» and «3» (respectively from 32 and 224 binary units) are not important [6]. Because of the asymmetry (in particular, the above one) with a received degraded four-position signal, double bit errors are possible. For example, it is the case when position «2» (10) is transferred, and it is recognized as position «1» (01); and vice versa: «1» is transferred, and it is recognized as «2». To reduce the probability of such errors, Gray modulation codes are used [4]. For example, for the above four-position signal (see Figure 2) in such a case, it is expedient to determine the following correspondence between the position number and binary digits of an elementary datum: «0» - 00, «1» - 01, «2» - 11, «3» - 10. Therefore, the probability of a double bit error will significantly decrease (see the example above). We have a single bit error: the position «2» (11) is transmitted, and the position «1» (01) is recognized; and vice versa. It is shown [6] that elimination of asymmetry can be also achieved by shifting the levels of the first and third thresholds to the corresponding nominal levels of the extreme positions. However, the data reliability degrades, which is unacceptable.

In the case considered (see Table 3), the datum b_e contains information on the reliability estimate of an elementary datum presented by two high bits – the seventh and eighth ones. However, it is possible to have the datum e_{cor_est} in the format of a one-bit elementary datum instead of a two-bit elementary datum, which is necessary for further decoding. This means that it becomes necessary to generate two words from each source word containing a two-bit elementary datum, in each of which an estimate of its reliability (a b_e-type datum) is attached to a bit of the elementary datum. It is assumed that the essence of such generation will be determined in the future.

The bit capacity of the b_e-type datum is set depending on the required accuracy of reliability estimates. To get rough estimate, you just need to drop its lower-order digits.

Some practical aspects concerning the justification of the required accuracy of the reliability estimates of the b_e-type are considered, related to the normalization of the received four-position telemetry signal (see Figure 2).

Experiments proved [5] that the quality of the normalization performed by hardware at ground receiving and recording stations (RRS) of the BRS-4 (BRS-4M, BRS-4MK) type is unacceptably low. There is a wide spread of telemetry values obtained by different RRSs involved in receiving telemetry information (TMI) from one source, compared with each other and compared with nominal levels (see, for example, the onboard calibration mean values of the position median of four-position signals $U_{med\_i\_mean}$, where i is a position number, available from experiments and represented in binary units in Table 4). Therefore, now at the Cosmodrome computing center (CC) the normalization is repeated when the TMI is processed by an analog implementation of an analog signal.

Table 4. Experimental data characterizing the quality of normalization performed at RRS

RRS	$U_{med\_1\_mean}$	$U_{med\_2\_ mean}$	$U_{med\_3\_ mean}$	$U_{med\_4\_ mean}$
MK-12a	31	98	166	235
MK-16б	30	92	155	220
Nominal levels	32	96	160	224

The results of the studies [5] performed at the Cosmodrome CC showed that the best possible normalization capabilities are provided when using the four-position sinusoidal signal of the onboard calibration of BITS of BRS-4 type «Scut-40», a feature of which is a priori known phase (Fig. 3). To bring the signals to nominal levels (see Fig. 2), the following transformations are necessary:

$$u_{norm} = au + b, \qquad (1)$$

where u_{norm} (u) is the value of normalized (not normalized) telemetry;

a, b – coefficients.

Coefficients a and b (1) are obtained by solving a system of two equations:

$$\begin{cases} U_{norm\_max} = aU_{med\_4} + b, \\ U_{norm\_min} = aU_{med\_1} + b. \end{cases} \qquad (2)$$

From (2) it follows that

$$a = \frac{U_{norm\_max} - U_{norm\_min}}{U_{med\_4} - U_{med\_1}} = \frac{224 - 32}{U_{med\_4} - U_{med\_1}} = \frac{192}{U_{med\_4} - U_{med\_1}}, \qquad (3)$$

$$b = U_{norm\_max} - aU_{med\_4} = 224 - aU_{med\_4}.$$

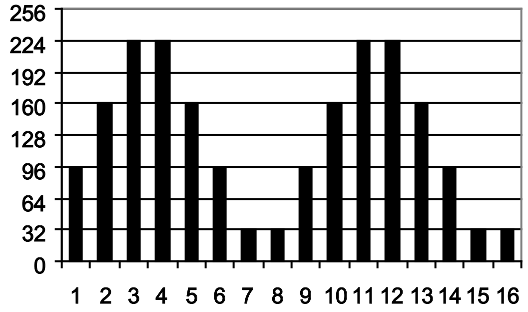

Fig. 3. A graph of a four-position sine wave signal of onboard calibration

The position medians of the onboard calibration signal (not the average values of position levels) make it possible to avoid shifting estimates of the values of the first and fourth positions when the received signal exceeds the edges of the telemetry channel scale (see Fig. 2).

Requirements Δu_{acc} for acceptable interference are established [5]:

$$|U_{nom\_i} - U_{med\_i}| < \Delta u_{acc},\ i = 1, 2, 3, 4, \qquad (4)$$

где Unom_i is the nominal value of the i-th position level of a four-position signal.

During the normalization process, the values of the coefficients a and b are calculated and continuously updated for each data block within time intervals of relatively stable reception of TMI (when condition (4) is satisfied). If condition (4) is not satisfied (i.e. there is relatively strong interference within the diverse channels), then the previously calculated and stored values of the coefficients a and b are used.

It is seen (see Fig. 2) that in the normalized form

$$U_{norm\_med\_1} = U_{nom\_min} = 32, \qquad (5)$$

$$U_{norm\_med\_4} = U_{nom\_max} = 224,$$

where $U_{norm\_med\_1}$ ($U_{norm\_med\_4}$) is the normalized value of the first (fourth) position median of the onboard calibration four-position signal.

For example, note that for the TMI RRS MK-12a and MK-16b (see Table 4), the specified formula (1) will be given by:

$$u_{norm\_MK\text{-}12} = 0{,}9412 \cdot u + 2{,}824,$$

$$u_{norm\_MK\text{-}16} = 1{,}0105 \cdot u + 1{,}690.$$

The maximum position deviation from the nominal values is $\Delta u_{max\_MK\text{-}12} = 224 - 235 = -11$(binary units), which is approximately 5.7% of the nominal scale of the reference signal; $\Delta u_{max\_MK\text{-}16} = 160 - 155 = 5$(binary units) which is approximately 2.6% of the nominal scale of the reference signal (see (4)). In fact, these are characteristics of a systematic error; their values are relatively small, but they can significantly degrade reliability (see Table 5 below and explanations to it).

The process of normalization is very important in terms of code conversion «LS-UK», which consists in selecting two semantic bits from an analog implementation of a four-position signal, represented in the structure of LS and S4 in the form of an eight-bit binary word [5].

At the Cosmodrome CC, tests of threshold setting methods when selecting a two-digit elementary datum from an analog implementation of a four-position signal were conducted [5].

In particular, the following methods of setting thresholds have been tested.

1. Automatic setting of thresholds in Threshold Separation Units (TSU) of Digital Input Equipment (DIE) (normal operation mode of TSU of DIE, usually used in computer centers) with the training of TSU devices based on an onboard calibration four-position signal (see Fig. 3). (The name of the equipment «DIE» is assigned by its developer – IT NPO (IT Research and Production Association)).

2. Selection of the two high bits from eight-bit words corresponding to an analog implementation of a four-position signal (a method implemented with some applied computer programs providing transformations of the TMI structure of S4-type or LS-type into the structure of the UK-type).

3. Automatic setting, within the data block length, of threshold levels equal to half the sum of the medians of adjacent positions of an on-board calibration four-position signal. For example, to determine the value of the first threshold with the test on-board calibration four-position signal, the medians for the first and second positions are calculated, summed and divided by 2. The method is proposed for operation with the onboard radio telemetry system "SKUT-40" TMI containing a priori known onboard calibration four-position signal (see Fig. 3).

The first method was chosen as the basic one. During the tests a real TMI was used. Table 5 presents the results obtained with the scores E [1, 2] (E = -1 means that the test method provides *significantly* less reliability than the basic method, E = 0 means that the test method provides appoximately the same reliability, and E = 1 implies *significantly* more reliability).

Table 5. The test results of threshold setting methods when applying code conversion «S4-UK»

Method No.	Quantity of data block (%), E =		
	-1	0	1
2	2	32	66
3	0	8	92

The third method provides the highest reliability, and its advantage is overwhelming (see Table 5). From the essences of the second and third methods it follows that with high-quality normalization of the received four-position signals and subsequent selection of the two high bits from the eight-bit words of the TMI with structure of S4-type or LS-type (as it is done with the second method), an effect similar to the third method is obtained. That means that they provide the relatively high reliability, as in the case of the third method. Herein, normalization is equivalent to eliminating systematic errors caused by interference (their mathematical expectation is more than zero), and the results of the experiment show that even with relatively small systematic errors that cause the position deviations of the received four-position signal from their nominal values, the reliability significantly [1, 2] deteriorates.

Thus, there are good possibilities for improving reliability by combining methods of diverse reception and noiseless coding (decoding) in cases where the decoding is oriented toward a soft decision demodulation. At the same time, modernization of the developed algorithms for generating correlated data A4 and A42, which is necessary to create conditions for the aforementioned decoding, does not require much effort. However, the successful modernization requires measures to normalize the received signals (to bring the levels of received m-position signals to their nominal values). The reliability provided by the algorithms A4 and A42, as well as the accuracy of reliability estimates of the received symbols (reliability estimates of analog implementation of the received m-position signals) required for a soft decision decoding depend on the quality of the above normalization.

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