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# Reliability Improvement through Making the Most Use of Data Diverse Reception Capabilities

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**Abstract.** Analysis is made available of capabilities for improving data reliability by integrating the noiseless coding techniques (decoding) that, above all, is recommended by CCSDS, and the diversity reception techniques described in the Orange Book CCSDS 551.1-O-1 "Correlated Data Generation". The integration approach described in the aforesaid Orange Book is detailed. Demonstrative examples and simple calculations are cited to illustrate that data reliability is substantially improved. Herewith, the reasons are given for selecting the optimal integration method; otherwise, it could result in the degradation of reliability (the necessary condition for making the adequate choice – the technique conformity to the interference situation). It is proposed to make better use of the diversity reception techniques (obviously underappreciated by the CCSDS community).

**Keywords:** algorithm, analog implementation of digital signal, diversity channel, integration, noiseless coding techniques, diversity reception techniques, correlated data, radio link, symbol, interference situation conditions

When designing a radio link (radio channel), it is important to ensure the required reliability of the received data. The ways for ensuring the specified reliability (techniques, algorithms, etc. – further "technologies") are rather comprehensively and essentially described in the effective CCSDS documents relevant to the SLS area (in particular, see [1, 2, 3, etc.]; CCSDS – Consultative Committee for Space Data Systems; SLS – Space Link Services. However, the above documents do not describe the technologies for the diverse reception. The Orange Book CCSDS 551.1-O-1 "Correlated Data Generation" [4] (the ROSCOSMOS's contribution to CCSDS) makes an exception. The technology described in the Orange Book is based on the scientific results presented in the monography [5] and adapted to the CCSDS requirements. The technology addresses solely the diverse data reception and also contains approaches to integration of modulation techniques, noiseless coding, and diverse reception [4]. The presented results [4] could be provisionally divided into three groups:

1. The technologies and algorithms proposed for improving reliability of data received from data links (first of all, algorithms $A_4$ и $A_{42}$ adapted to the time-dependent interference conditions).
2. Approaches to integration of the proposed (aforementioned) technologies and algorithms and the algorithms and technologies for improving data reliability proposed by CCSDS.
3. The proposed models, criteria, and techniques for selection of rational strategies for improving data reliability.

It is justified [4] that the capabilities of the technologies for improving data reliability, being customary for the CCSDS Community, would be essentially expanded through applying the technologies relevant to the diverse reception of data. Nevertheless, the proposed technology [4] is rather isolated as compared to the traditional technologies recommended by CCSDS for improving reliability. The consequence (the consequence of the lack of proper integration) of such isolation is that the CCSDS Community is not using additional (and essential) capabilities for improving data reliability related to the diverse reception.

According to the publications, Russian scientists reached the peak in development of the diverse data reception theory in the 1960s –1970s of the 20th century (see [6, 7, 8, etc.]). A tendency to use the diverse reception to the full advantage, without emphasizing its priority, became very popular, i.e., the integrated approach to using different technologies for improving data reliability is apparent ("…the systems with repetition must not be opposed, as proposed by some authors, to the systems with the error control code" [8]).

Today, high priority is also given to the system (integrated) approach to the development of technologies for improving data reliability based on the above scientific results obtained by the Russian scientists, relative traditional CCSDS technologies [1, 2, 3, etc.], and the technology described in the Orange Book CCSDS 551.1-O-1 [4]. A need arose for using the diverse reception capabilities to the fullest extent, although they had previously seen little usage. Thereupon, it would be reasonable to devote more detailed consideration to integration of noiseless coding and diverse reception technologies (widely used by the CCSDS community).

The aim of this paper is to search for the possibilities for improving data reliability through integration of technologies based on the noiseless coding/decoding methods traditional for the CCSDS community and on the technology described in the Orange Book CCSDS 551.1-O-1 "Correlated Data Generation" related to the diverse reception and correlated data generation.

The substance of correlated data generation is explained in Fig. 1 [4].

Diverse channels are physical channels for transfer of a bit stream from a common data source [4]. A data frame is a finite data set having a certain structure (Transfer Frame [9], Transfer Frame with an attached synchro marker and Reed-Solomon code correcting bits [9], etc., i.e., specified data frames) [4]. The correlated data are the data acquired by the diverse reception [4].

Each transferred data frame corresponds to *n* of frames received from diverse channels.

In practice, the correlated data are generated by automatic retrieval and majorization.

With the automatic retrieval, data are automatically retrieved to a correlated data set from one diverse channel for which a gain factor is 1, with a gain factor of 0 for the rest. A notable feature of the automatic retrieval is that the data are retrieved to a correlated data set one block at a time. Its main limitation is that no capability is provided for mutual complementation of data contained in data sets retrieved from the diverse channels that relate to the same data set and differently distorted by interferences.

With majorization, the decision for retrieving data to a data set is made by voting, with a gain factor for each

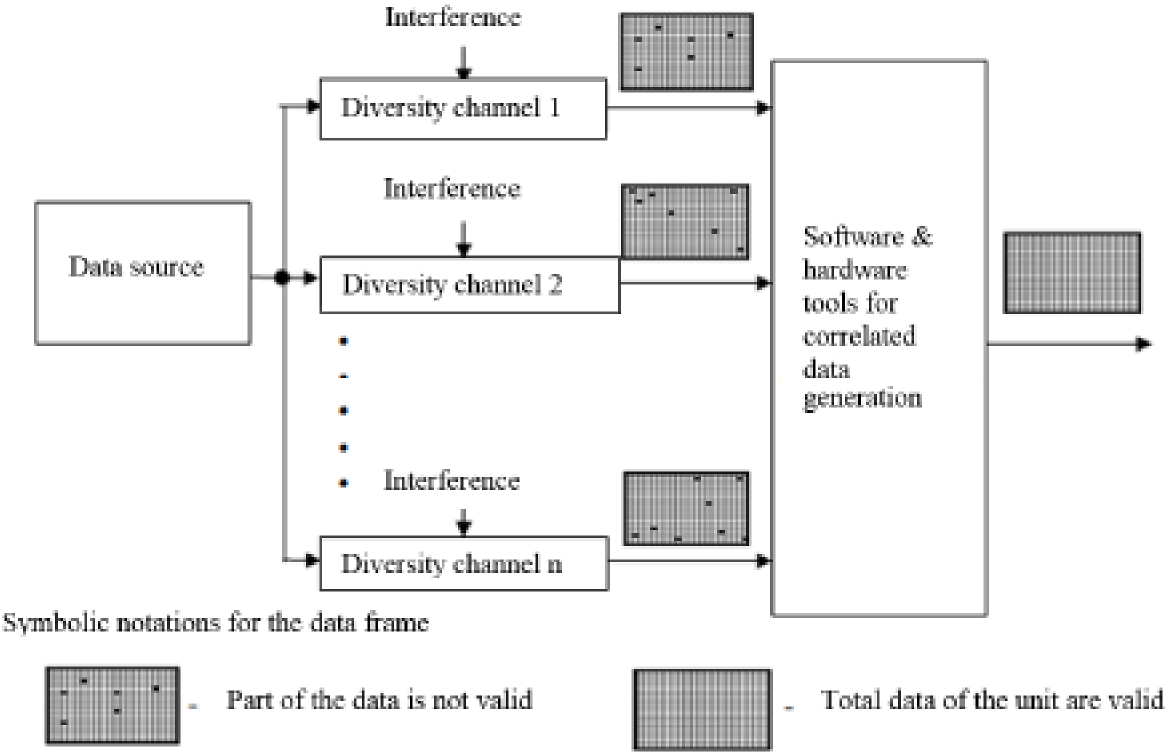

Fig. 1. Illustration of correlated data generation process

diverse channel being ${}^1/_n$ (where $n$ is the number of diverse channels). If, for example, {0,1} is the data alphabet, $n = 5$, the values of data from three diverse channels are equal to 0, and of the rest two equal to 1, the data with a 0 value is regarded to be transferred (is retrieved to the correlated data set). Its restriction is the low interference immunity when data in a large number of diverse channels are corrupted.

From the data frames acquired via the diverse channels the most reliable data retrieved from the analog implementation or a digital signal symbol are selected to the correlated data set (elementary data). Their size could be, in particular, 1 bit or bits (e.g., when using two- or four-position signal, respectively). The developed algorithms for correlated data generation, $A_4$ and $A_{42}$, ensure higher reliability than automatic retrieval and majorization [4, 5]. If each initial (received from a diverse channel) $m$-bit word ($m >> 1$) contains some invalid elementary data, there is a reason to expect that no invalid elementary data would be found in the generated word.

Data (signals) diversity is achieved through:

1. Frequency diversity (different carrier frequencies; e.g. UHF and VHF bands).
2. Polarization diversity (e.g., vertical and horizontal polarization signals).
3. Space diversity (to different spaced apart antennas).
4. Time diversity (using onboard data storage devices).

Consider now (by analogy with the energy gain from coding $g_c$) the energy gain $g_{dr}$ from diverse reception (DREG).

The energy gain from coding (CEG) $g_c$ is determined as a signal-to-noise ratio difference at the receiver input, with the uncoded $h^2_{0\,\mathrm{nc}}$, dB, transmission and with the coded $h^2_{0\,\mathrm{c}}$, dB, transmission, both ensuring identical error probability $P_{\mathrm{err}}$ per an information symbol [10, 11]:

$$g_c = h^2_{0\,\mathrm{nc}} - h^2_{0\,\mathrm{c}},\ \mathrm{dB} \qquad (1)$$

where $h_0^2 = \dfrac{E_b}{N_0}$ is the signal-to-noise ratio.

When calculating the energy gain from diverse reception, the signal-to-noise ratios are compared with respect to one diverse channel and all channels.

It is proved [8] that, assuming the optimal coherent addition and identity of all diverse channels (reception to diverse antennas), the signal-to-noise ratio increases $n$-fold:

$$h^2_{\Sigma\,\mathrm{n}} = nh^2_{0\,\mathrm{n}} \qquad (2)$$

where $h^2_{0\,\mathrm{n}}$ ($h^2_{\Sigma\,\mathrm{n}}$) is the signal-to-noise ratio in one diverse channel (as a result of diverse reception);

$n$ is the number of diverse channels.

The subindex "n" means that the signal-to-noise ratio was measured as factors of n. If it is given as dB, as in (1), the expression (2) takes the following form:

$$h^2_{\Sigma} = h^2_0 + 10\lg n\text{, dB.} \qquad (3)$$

Then, DREG (and (1), respectfully) will be calculated as:

$$g_{dr} = 10\lg n\text{, dB.} \qquad (4)$$

Table 1 contains results (4), illustrating DREG $g_{dr}$, depending on the number of the diverse channels $n$.

Table 1. The results illustrating capabilities of increasing DREG

| $n$ | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| $g_{dr}$, dB | 3.0 | 4.8 | 6.0 | 7.0 |

For comparison, note that [11] when the conventional code with a code rate $R_{code} = 1/2$ ($R_{\mathrm{code}} = k/n$, is used, where $k$ is the number of information symbols in the code word $n$) in length, CEG of the order of 5.1 dB at a bit error $10^{-5}$ is assured by implementing binary phase modulation and decoding by the Viterbi algorithm.

As follows from the minimum analysis results relating to DREG:

1. There are essential possibilities for improving power characteristics through using the diverse reception technologies.
2. The diverse reception and noiseless coding technologies are not alternative in principle (usually, there are no direct restrictions for their integration).

For reference [8], note that repetition $k$ of information bits for $d$ times is equal to implementing the systematic cycling error-correcting code with $n = dk$ and the Hemming distance $d$ (where $n$ is the code word length). In this case, errors are corrected by majorization (discrete addition as per [8] terms), that corresponds to the maximum likelihood criterion. Erros are detected if their number does not exceed $d - 1$, or corrected, if their repetition factor (with odd $d$) is $\frac{1}{2}(d-1)$ at most.

It is shown [8] that, when a redundant code word is repeated several times, with the minimum Hemming distance $d_1$, the resulting code with $d_{min} = d_1 d_2$ will be obtained, where $d_2$ is the number of repetitions. It is certain that $d_{min} = 15$ at $d_2 = 5$ and $d_1 = 3$. Such integration permits detecting 14 or correcting 7 errors, given that without channel diversity the detected/corrected errors ratio is 2 and 1.

Note that in the given example the invalid data are independent, with their probability being identical for each channel.

If data received from a significant part of diverse channels are corrupted (invalid), integration of diverse reception and noiseless coding (decoding) may result in degraded validity of the output data.

Let us explain this statement with examples of majorization and majority decoding integration.

For this purpose (see example from § 5.3 [10]), a systematic code (7, 3) is considered, with the following generating $G$ and check $H$ matrices ($G\times T^{\mathrm{T}} = 0$, where index "T" means transposition):

$$G = \begin{vmatrix} 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 \end{vmatrix},$$

$$H = \begin{vmatrix} 1 & 0 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 1 \end{vmatrix}.$$

Coding is performed by the following rule:

$$\mathbf{b} = \mathbf{a}\times\mathbf{G}$$

where $\mathbf{a} = |a_1, a_2, \ldots, a_k|$ is the code word raw matrix at the coder input;

$\mathbf{b} = |b_1, b_2, \ldots, b_n|$ is the code word raw matrix at the coder output;

$\mathbf{G}$ is the code ($n$, $k$) generation matrix.

So, $\mathbf{a} = |a_1, a_2, a_3|$, $\mathbf{b} = |b_1, b_2, b_3, b_4, b_5, b_6, b_7|$, and the following equations considered in performing the relevant coding are correct:

$$b_1 = a_1,\ b_2 = a_2,\ b_3 = a_3,$$

$$b_4 = a_1 \oplus a_3,\ b_5 = a_1 \oplus a_2 \oplus a_3,$$

$$b_6 = a_1 \oplus a_2,\ b_7 = a_2 \oplus a_3.$$

Check ratios are:

$$b_1 \oplus b_3 \oplus b_4 = 0,$$

$$b_1 \oplus b_2 \oplus b_3 \oplus b_5 = 0,$$

$b_1 \oplus b_2 \oplus b_6 = 0,$

$b_2 \oplus b_3 \oplus b_7 = 0.$

Using the check ratios, the following estimates were made (for brevity sake, below are the estimates only for $b_1$):

$b_1 = b_1,\ b_1 = b_3 \oplus b_4,$

$b_1 = b_5 \oplus b_7,\ b_1 = b_2 \oplus b_6.$

The solution on each received information signal is made by "majority of votes", or majorization. Assume that the following estimates are obtained (see § 5.3 [10]):

$b_1 = b_1 = 1,\ b_1 = b_3 \oplus b_4 = 1,$

$b_1 = b_5 \oplus b_7 = 1,\ b_1 = b_2 \oplus b_6 = 0.$

As far as the number of estimates "1" exceeds the number of estimates "0", the solution $b_1 = 1$ is accepted.

With the aforesaid integration, different methods may be used to derive estimates $b_1$, $b_2$, and $b_3$ (the "voting" techniques to derive estimates ($b_1$, $b_2$, and $b_3$) and the number of "votings" will drastically increase. For example, the formula expression for deriving estimates, $b_1 = b_3 \oplus b_4$, by one method is transformed as: $b_{1i} = b_{3i} \oplus b_{4i}$; for other methods: $b_{1i} = b_{3j} \oplus b_{4k}$; $i, j, k = 1, 2, \ldots, n$; $i \neq j$, $i \neq k$, $j \neq k$; where $i$, $j$, $k$ are the identification numbers (conventions) of diverse channels to which the corresponding $b_1$, $b_3$, and $b_4$ are related; $n$ is the number of diverse channels.

As follows from the above example, irrespective of methods used to derive $b_1$, $b_2$, and $b_3$ (and similar ones), if the probabilities of receiving invalid data from diverse channels are relatively low and about the same, with independent errors, the presented integration is advisable and data reliability will be substantially improved. If data received from all diverse channels, except of one, are fully corrupted (invalid), and data from one channel are valid, it is clear that the information will be totally lost.

Apparently, there is a risk of enhancing the error propagation effect in major decoders [11] as a result of unsuccessful integration of diverse reception and noiseless coding/decoding technologies. The given example implies that the unsuccessful integration may be caused by inconformity to real conditions of the interference situation for which the selected technology ensuring the required validity is intended. However, this comment is also true relative to other technologies ensuring the required interference resistance.

Note that in the CCSDS recommendations (particularly, see [1, 2, 3, etc.]), to assess the interference resistance, consideration is usually given to communication channels where interference is manifested as Additive White Gaussian Noises (AWGN). This approach has the advantages of certainty (unambiguity) of the derived estimates, availability of the required methodological support and software.

However, in practice, errors are often grouped into clusters of errors. The results of applying the same technologies in interference situations with AWGN and in conditions with strongly dependent errors (with errors grouped into clusters) are quite different. In particular, the scientific-methodological instrument [12] is proposed to describe such interference situation conditions. In the 1960s – 1970s of the 20th century (see [6, 7, 8, etc.]), domestic scientists placed more emphasis in their papers to description of different interference conditions and results of applying different technologies for improving interference resistance under such conditions. Specifically, when considering the analog implementations of diverse reception, much attention is devoted to computing optimum gain factors of analog implementations of analog and (more often) digital signals from each diverse channel (each branch as per [8]), with different interference situation conditions.

A tendency to a more comprehensive consideration of interference situation features is also observed when analyzing the CCSDS technologies. It is believed [11] that the preliminary use of a soft modem (considering to a certain extent characters of interferences in a communication channel) gives the a gain of 2 dB compared to a hard modem, with the following decoding of conventional codes by the Viterbi algorithm.

The proposed technology [4] is remarkable in that for correlated data generation the only data from diverse channels are used (the reliability estimates of the received symbols similar to the generated by a soft modem are not used). Herewith, it is justified [4, 5] that, when integrating the diverse data reception and noiseless coding/decoding technologies, it is necessary to receive correlated data at the first instance and then to perform the decoding in order to ensure the maximum reliability.

It is evident that the proposed current technology [4] is suited for handling data generated with the aid of a hard modem; with a soft modem, the reliability assessments of the received symbols will be ignored; thereby, the follow-on decoding intended for the soft solution at demodulation will be flawed (in particular, the Viterbi decoding being traditional for the CCSDS community).

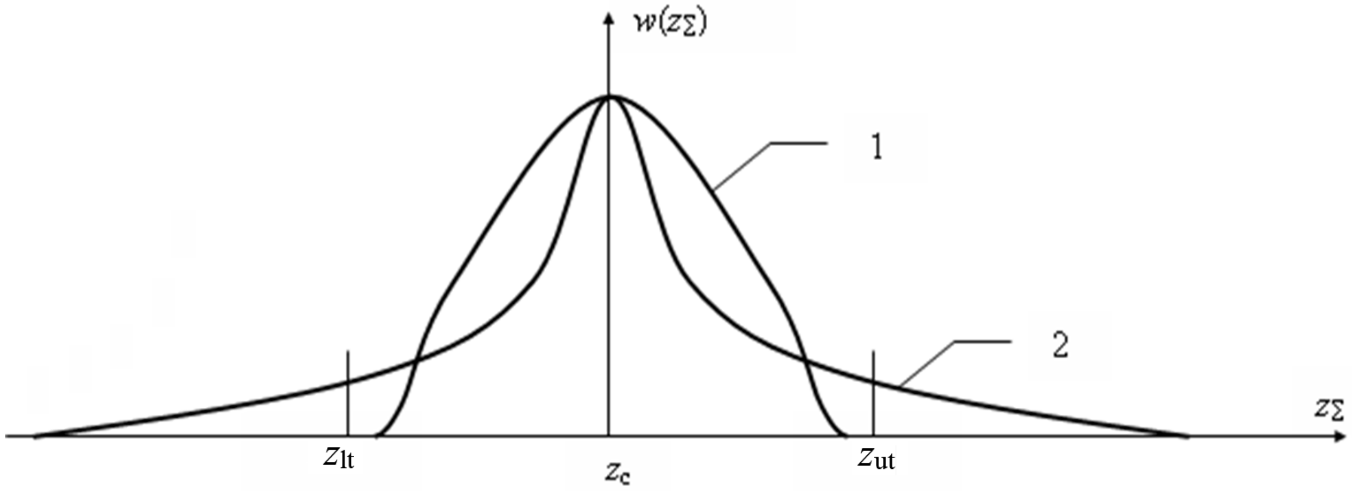

Fig. 2. Plots of interference probability density distribution in the sum signal

Below is a short overview concerning a more comprehensive consideration of interference situation when implementing the diverse reception methods (a more detailed description of these capabilities is given in [5]). This is concerned with ensuring the required completeness of information on how the interference effects the signals acquired from diverse channels.

There are technologies ignoring information on the law of interference propagation during the diverse reception. Among these technologies are least-squares method, least-modules method, etc. (the residual vector minimum norm serves as a criterion for these technologies), which offer advantages related to the simplicity of implementation, but are not always efficient due to incomplete information on the nature of the interference effect. The sum signal may be presented as:

$$z_\Sigma(t)=\sum_{i=1}^{n}\beta_i z_i(t) \tag{5}$$

where $b_i$ is the i-th diverse channel signal gain factor,

$$z_i(t) = w_i y(t) + x_i(t) \tag{6}$$

where $y(t)$ is the transmitted signal;

$w_i$ is the gain factor depending on signal propagation in the $i$-th diverse channel;

$x_i(t)$ is the interference in the $i$-th diverse channel.

Gain factors b are determined from the formula:

$$\beta_{xi}=\frac{w_i}{D_{xi}} \tag{7}$$

where $D_{xi}$ is the interference dispersion in the $i$-th diverse channel.

However, a biased approach to interference assessment is found in a number of papers (see critical comments on the Brennan's et al. works [6; 8]). These comments can be justified by a simple example. Assume that two groups of factors b (7) are estimated for receiving sum digital signals $z_S(t)$ (5), which application results in two options for the sum signal implementation distribution: $w_1(z_S)$ and $w_2(z_S)$ (Fig. 2). Suppose also that interference dispersions at the first diverse reception system output are larger than at the second system output: $D_{xS1} > D_{xS2}$. From the viewpoint of the analyzed technology, the second option is preferable. However, just the selection of the second option inherits errors when selecting the data from the sum signal; the errors are resulting from the sum signal lower and upper threshold overrun $z_{lt}$ and $z_{ut}$ (see Fig. 2).

As follows from the given example, the simplified approach to assigning parameters for the interference situation description will not ensure the good quality sum signal $z_S(t)$. Nevertheless, if it is known a priori that independent interferences with the distribution density obeying the normal law are present in the diverse channels, with factors calculated from formula (7), the sum signal $z_S(t)$ (5) corruptions will be minimal.

It is shown [5] that the problem of defining the rational content of parameters for describing the interference situation is rather strongly manifested when the interference found in the diverse channels related. In the absence of such a relation, the number of parameters can be decreased without the loss of the interference assessment quality. At the same time, introduction of a large number of parameters would not only complicate calculations, but could result in the inverse effect: the estimate quality degradation at transient behavior of the interference impact. Rather often, to consider the interference dependence, some interference effects have to be ignored because of the inability to take into account all the effects, the ignored effects are regarded as being of no consequence by the developers of the diverse reception system (that is more or less justified).

It can be seen [5] that, after the data having been selected from analog implementations of digital signals, information on the interference situation will not be completely lost, and, as the volume of the learning sample increases, so does the possibility of the information recovery. There is potential for developing rather efficient algorithms for correlated data generation (not cumulative analog implementations of signals) [5]. In particular, among those algorithms are $A_4$ and $A_{42}$ [4, 5]. Herewith, taking advantage of the information on the interference situation to the fullest extent is an urgent issue.

For further improvement of data reliability through making better use of the information on interference situations, consideration have been given to the possibility of receiving correlated data (via algorithms of the $A_4$ and $A_{42}$ type), with further decoding aimed at the relaxed solution at demodulation (specifically, Viterbi decoding).

In order to achieve the required conditions for such integration, it is necessary to modify the algorithms $A_4$ and $A_{42}$ (if those are to be used). The modification concerns the given soft modem content fed to the decoder when using the traditional soft decoding and to the software-hardware tools for correlated data generation (see Fig. 1), if the proposed integration has to be done. These data could be interpreted in the following way: its high-order bits are related to an information datum selected from the definite received symbol or the analog implementation of the digital signal (related to an elementary data – in terms [4]), and low bits are related to the symbol reliability assessment (to this analog implementation of the digital signal or this elementary data). If, for example, it is a one-bit elementary datum, and the output datum of the 8-level soft modem is three-bit (see Fig. 7.8 and explanations [13]), then, in pursuance of the proposed logic, two bits are allotted to estimate the reliability of the elementary datum (see Table 2).

Table 2. Values of elementary one-bit data $e_i$ and relative two-bit estimates

| $e_i$ | Estimates $e_i$ | | | |
|---|---|---|---|---|
| 0 | 00 | 01 | 10 | 11 |
| 1 | 11 | 10 | 01 | 00 |

Table 2: $e_i$ is the value of elementary one-bit data from the $i$-th diverse channel (0 and 1); in the extreme left column estimates $e_i$ are the values of the most reliable elementary data “0” and “1”, and in the extreme right column are of the least reliable ones. Values of these estimates are provisional (this does not mean that the values shall be the same at the circuit implementation of the relative software-hardware tools). First of all, these estimates have been selected for descriptive reasons. Their essential is associated with the Euclidean distance typical for the soft decoding circuit (not the Xamming distance as in the case when the hard decoding circuit is used) [13].

The follow-on correlated data generation shall be performed by the algorithm $A_4$ ($A_{42}$), using, as usual, only elementary data acquired from the diverse channels [4, 5]. If an elementary datum $e_{cor}$ is selected to the correlated data frame, with elementary data of the same value and corresponding to the same transferred data and the aforesaid correlated datum $e_{cor}$ are acquired from the $i_1$, …, $i_h$ diverse channels, reliability estimates of a symbol from one of the channels $i_1$, …, $i_h$ are 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 that of a soft modem output datum (Table 3).

Table 3. 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 |
| ….. | ….. | ….. | ….. | ….. | ….. | ….. |

The logic of this approach to the selection of the most appropriate reliability estimate related to data $e_{cor}$ follows from the essentials of the algorithms $A_4$ and $A_{42}$.

The advantage of this approach is that the algorithm $A_4$ ($A_{42}$) gives the ability to improve the reliability of the correlated data against the data acquired from each separate diverse channel, and, consequently, each of the correlated elementary data shall have a higher reliability estimate, as compared to the relative estimates concerning separate diverse channels (of the aforesaid channel types $i_1, \ldots, i_h$). It would be true to assert that, in most cases, the probability of identifying an unreliable correlated elementary datum (of the $e_{cor}$ type) is lower against an elementary datum acquired from a diverse channel.

Note that for the previously mentioned integration it is necessary to generate a certain structure of the recorded data from the diverse channels. The data shall contain information on reliability estimates of symbols (elementary data). Herewith, the volume of the data received from a separate diverse channel with reliability estimates of symbols will be far beyond that of the traditionally generated data volume. For example, if a one-bit elementary datum and a three-bit datum are received from the output of an eight-level soft modem (see above), the data volume will increase about three-fold (specifically, a 3 Mbit/s instead of a 1Mbit/s data stream).

The increased data volume (data rate from a separate diverse channel) shall be considered, first of all, in the case of data/signal diversion in space when the selection of a strategy for delivering (acquiring) data to a common correlated data generation station has to be justified (recall that, to ensure the highest reliability, decoding shall be performed upon receiving correlated data) [4, 5]).

As follows from the obtained results, the proposed technology is adequate for integrating diverse reception and noiseless coding/decoding techniques. The proposed technology substantiates the previously considered approach [4, 5] to integration, with a refinement appropriate for the current conditions. Further development of this technology is associated with specifying the data structures, algorithms for correlated data generation and coding/decoding, as well as circuitries. First, this is true of the modified algorithms $A_4$ and $A_{42}$, conventional coding and decoding by the Viterbi algorithm.

Priority is also given to the development of the technology [4] by integrating the diverse reception and coding/decoding techniques, which involve the use of correlated data of the $e_{cor\_est}$ type (see Table 3) received through the modified algorithms $A_4$ and $A_{42}$, with the following identification of unreliable symbols (elementary data) at decoding.

The simplest example of using information on the reliability of received symbols is the Wagner method [8]. The backbone of this method is that, with errors in the received recovered bit sequence ("received elementary data sequence", in terms of [4, 5]), the value of the least reliable symbol is changed to an opposite and, if the symbol was in fact erroneous, the number of errors would be decreased. The analog to the Wagner method is the Borodin method (the Borodin method is applicable to codes with any base, while the Wagner method is designed only for binary codes) [8].

The examples with the Wagner and Borodin methods are given for specifying a trend of possible (and long-term) activities on the aforesaid integration, without detailing their substances and their integration.

Therefore, there are substantial resources for improving data reliability, which involve integration of the noiseless coding/decoding techniques recommended by CCSDS and diverse reception techniques (so clearly underestimated by the CCSDS community). In addition, a technology of current interest (in the context of the aforementioned integration) based on diverse reception is described in the Orange Book CCSDS 551.1-O-1 "Correlated Data Generation".

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