IJCTA, 9(35), 2016, pp. 59-70

Influence of Packet Errors in Noisy Channel on Quality of Transmitted Image in JPEG 2000 Format Protected by JPWL

Sergey Vasilievich Skorokhod* Sergey Nickolaevich Drozdov* and Nail Shavkyatovich Khusainov*

Abstract : This article discusses image transfer in JPEG2000 format using JPWL antinoise coding (Wireless JPEG2000) via noisy channel with occurrence of packet errors. The main problem is recovery of received image with minimum deviations from input original. The aim of this work is to study experimentally the capability of JPWL protection to maintain quality of received and decoded image depending on the level of packet loss in data transmission channel. The experimental procedure consists of simulation of multiple transfer of JPWL protected image with the size of 1024 × 768 pixels and packet loss with the coded image data. Variable parameters of the study are: JPEG2000 coding procedure (reversible or irreversible conversion), Reed–Solomon codes used for JPWL protection, per cent of packet loss. Regular variant of JPWL protection is considered as well as combination of regular variant with algorithm of in-frame interleaving. The final experimental results are PSNR similarity extent of received and decoded image and input image, average per cent of completely recovered tiles with respect to tile number in code stream. The article describes the software complex developed for these studies, which includes JPEG2000 coder and decoder, JPWL coder and decoder, means of code stream dividing into RTP packets, simulating means of packet loss, assembling of frames from RTP packets. Operation flowcharts of JPEG2000 coder and decoder are described. It is mentioned that under conditions of packet errors JPEG2000 decoder should be able to process partially damaged or absent tiles. In-frame interleaving of code stream is described aimed at improvement of its stability with regard to packet errors. Three hypotheses are formulated. Hypothesis 1: in the case of packet loss the regular JPWL extension is unable to maintain quality of received and decoded image. Hypothesis 2: in the case of packet loss the regular JPWL extension in combination with algorithm of in-frame interleaving maintains the quality of received and decoded image. Hypothesis 3: in the case of packet loss and with application of algorithm of in-frame interleaving the PSNR value of received and decoded image depends statistically on the number of tiles completely recovered by JPWL decoder. As a consequence of experimental study the hypotheses 1 and 2 were completely confirmed, the hypothesis 3 was confirmed partially for the case of irreversible JPEG2000 conversion and requires for further study for the case of reversible conversion.

Keywords : JPEG2000, JPWL, packet errors, noiseless coding.

1. INTRODUCTION

This work analyzes the problem of JPEG2000 image transfer via noisy channel [1], wireless networks in particular. The transfer consists of transmission of network packets with image fragments. As a consequence of noise contamination a portion of packets can be distorted and discarded [2, 3]. A consequence of such packet errors is the absence of adjacent fragment of code stream in receiver, which either complicates image recovery in general, or makes it impossible. In order to protect JPEG2000 code stream during its

* Southern Federal University, ul. Bolshaya Sadovaya 105/42, Rostov-on-Don, 344006 Russia

transmission via wireless networks the ITUT.810 specification was developed [4], which describes a set of protection means known as JPWL, based on the Reed–Solomon codes.

This work continues previous studies [5], which experimentally analyzed capabilities of JPWL extension to correct packet errors. It was demonstrated that the regular JPWL extension cannot efficiently withstand packet errors. At the same time the combination of regular JPWL extension with the proposed method of in-frame interleaving enables efficient recovery of code stream.

The first aim of this work is experimental study of quality of recovered JPEG2000 image as a function of JPWL parameters and level of channel noises. The second aim is detection of statistic interrelation between the PSNR similarity extent of images and number of tiles completely recovered by JPWL decoder in combination with in-frame interleaving, which would permit assessment of distortion level of decoded image on the basis of statistics of JPWL decoding .

2. EXPERIMENTAL

Analyzed code stream structure

The experimental procedure is based on JPWL extension aimed at protection of JPEG2000 code stream [6]. Upon coding in this format image is divided into several square fragments (tiles), each of them is coded separately. The code stream structure is illustrated in Figure 1 [7].

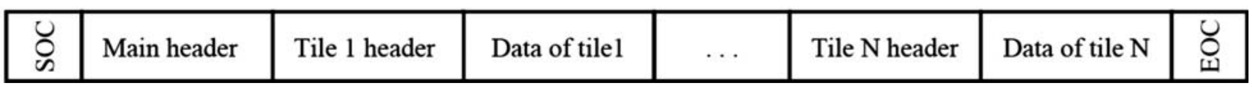

Figure 1: Structure of JPEG2000 code stream

SOC and EOC markers define start and end of specified frame. The main header contains data on total image: size, color set, number of tiles and others. The tile header includes data on image square fragment, including its reference to coordinate grid. Tile data are coded image fragment.

The main correction tool of JPWL errors are the Reed–Solomon codes [8] RS(n, k) (RS-codes). They are intended both for detection and for correction of (n-k)/2 distorted data in code word of n bytes, consisting of protected data fragment of k bytes and (n-k) bytes of parity codes. The RS(n, k) code makes it possible to correct up to (n-k)/2 distorted bytes in code word. The ITUT.810 specification provides for the use of RS-code family starting from the “weakest” RS(37,32) to the “strongest” RS(128,32) and RS(160,64).

Protection of code stream is provided by addition of special segments EPC and EPB by JPWL coder. The EPC segment provides possibility to protect against errors. It is embedded only in the main header and informs decoder that the code stream contains JPWL extension; in addition it contains description of applied protection method and their parameters, if required. The EPB segment is the block which provides protection against errors on the basis of RS-codes. It is embedded into main header and tile headers; it contains parameters of applied protection and redundant parity codes. Data protection using EPB block is illustrated in Figure 2.

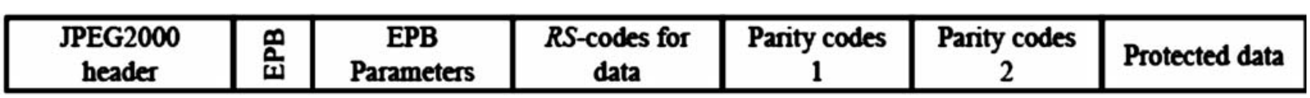

Figure 2: Data protection using EPB

JPEG2000 header, fields of EPB segment and type of RS-codes, applied for data protection, are corrected by means of a predefined RS-code stipulated in ITUT.810 [4] and parity codes 1. The type of predefined code is determined by position of EPB segment in JPEG2000 header and purpose of this header. After successful correction the type of RS-codes is known, which was used for data protection, then the data are corrected using parity codes 2.

The correction is not always successful. If higher amount of bytes are distorted in code word than can be corrected by RS-code, it cannot be recovered. In this case JPWL decoder marks unrecovered fragment of code stream using descriptor (segment) of residual error RED. This descriptor is used only in the headers of decoded code stream. It informs JPEG2000 decoder, whether the segments of code stream contain residual distortions or not.

Research procedure and program.

The research procedure consists of simulation of transfer of JPWL protected image with the size of 1024 × 768 pixels, preliminary coded by JPEG2000 coder using tiles with the size of 128 × 128 (48 tiles in total). The image is repeatedly (1000 times) loaded into our software system, where it is subsequently processed at the following stages:

- JPEG2000 coding;
- JPWL coding;
- Dividing into RTP packets corresponding to RFC 5371 specification [9, 10];
- Simulation of packet loss in terms of preset loss per cent;
- Assembling of code stream from the remaining packets;
- JPWL decoding and counting of decoding statistics;
- JPEG2000 decoding, comparison of decoded image with the input and calculation of PSNR and MSE deviations;
- Calculation of average value of decoding statistics, PSNR and MSE on the basis of processing of 1000 image copies.

Permanent parameters in the research are the input image, method of header protection, size of RTP packet, size and number of tiles. The main header and the tile headers are protected by RS-codes stipulated in T.810 specification. The size of RTP packet us 1024 bytes. It was found elsewhere [5] that the size and number of tiles actually do not influence on the code stream recovery by JPWL decoder. Hence, in this work the size and number of tiles are not varied.

Variable parameters in this research are JPEG2000 coding method (reversible or irreversible conversion), types of RS-codes, applied for data protection, per cent of packet loss in noisy channel, and JPWL coding method (without or with in-frame interleaving). The research program is summarized in Table 1.

Table 1

Research program

JPEG2000 coding method	*RS-codes for data protection*	*RTP packet loss per cent*	*JPWL coding method*
Reversible Irreversible	RS(37,32), RS(64,32), RS(96,32), RS(128,32)	1, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50	W/o interleaving With interleaving

Statistic results of decoding are the number of tiles, completely and partially recovered by JPWL decoder, deviations of PSNR and MSE.

It should be mentioned that the most important part of code stream is the main header. Therefore, it is additionally protected by redundant duplication of packets containing its fragments [11], and in this regard packet errors in this research are not applied to the packets of main header.

3. MATERIALS AND METHODS

Structure and operation of software complex

This research is aided with specialized software complex comprised of two modules: preprocessing and simulating. Operation flowchart of the complex is illustrated in Figure 3.

Since the features of JPWL coder and decoder were discussed in details elsewhere [5] here we mention only the features of JPEG2000 coder and decoder.

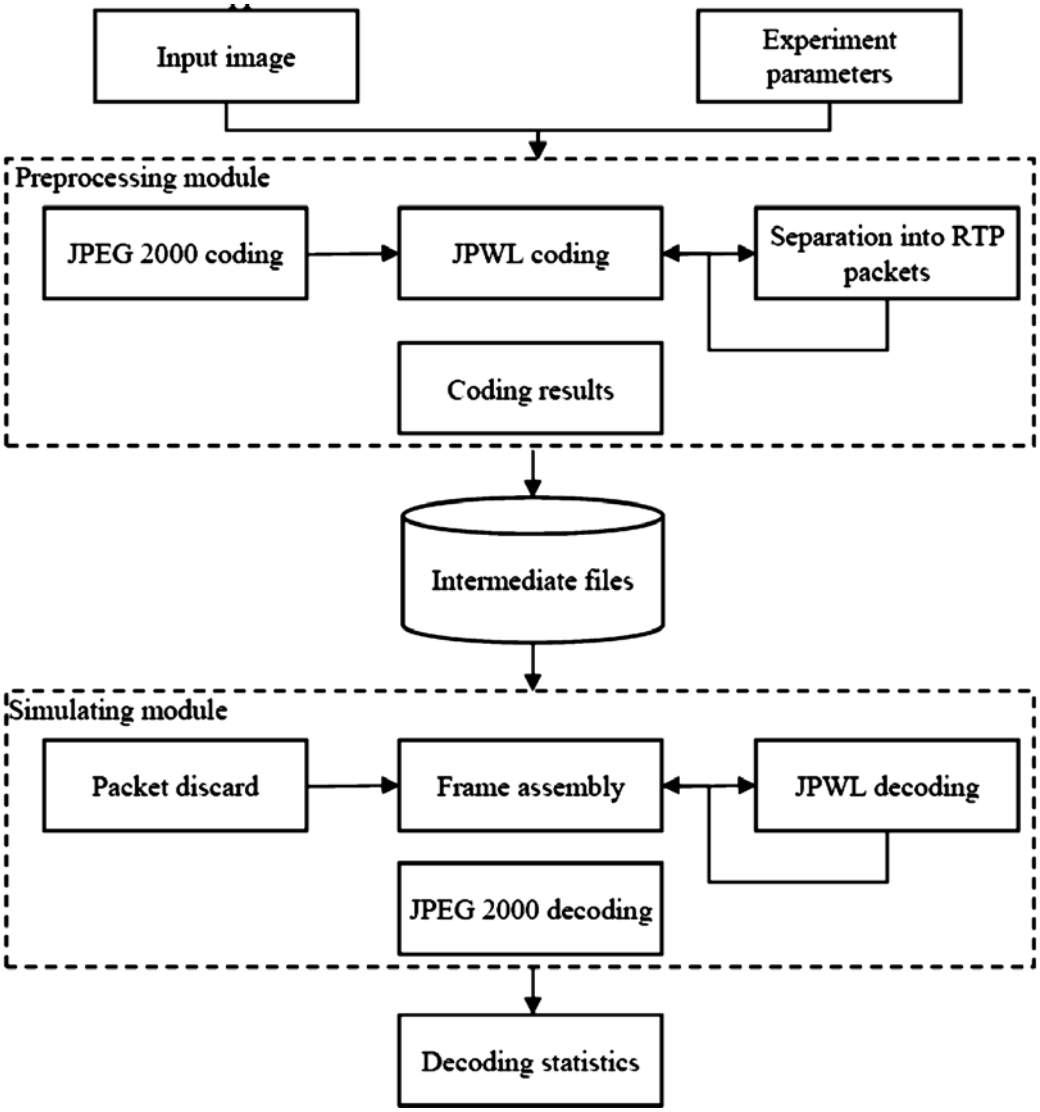

Figure 3: Researching software complex

JPEG2000 coder

The coder, developed for video broadcasting system, performs image coding in accordance with JPEG2000 standard [18]. Implementation of the standard corresponds to the requirements of Profile 0 and Class 0 (ITU-T T.800, 2003). An exclusion is possibility of image coding with the size up to 1024 × 768 pixels and number of color components from 1 to 3. These values exceeds the requirements of Profile 0 and Class 0.

Generalized operation flowchart of JPEG2000 coder is illustrated in Figure 4.

Tile data are coded in accordance with JPEG2000 standard, the procedure is comprised of the following stages [17]:

- Image dividing into color components;
- Image conversion from RGB color model to YCbCr (reversible or irreversible);
- Direct multi-level wavelet conversion (reversible or irreversible);
- Dividing into conversion levels and frequency bands;
- Dividing into coding blocks and arrangement of coder passing over block bit planes;
- Arithmetic coding of bit stream;
- Code stream dividing into packets;
- Delivering of code packets to output stream which is directed to input of JPWL coder.

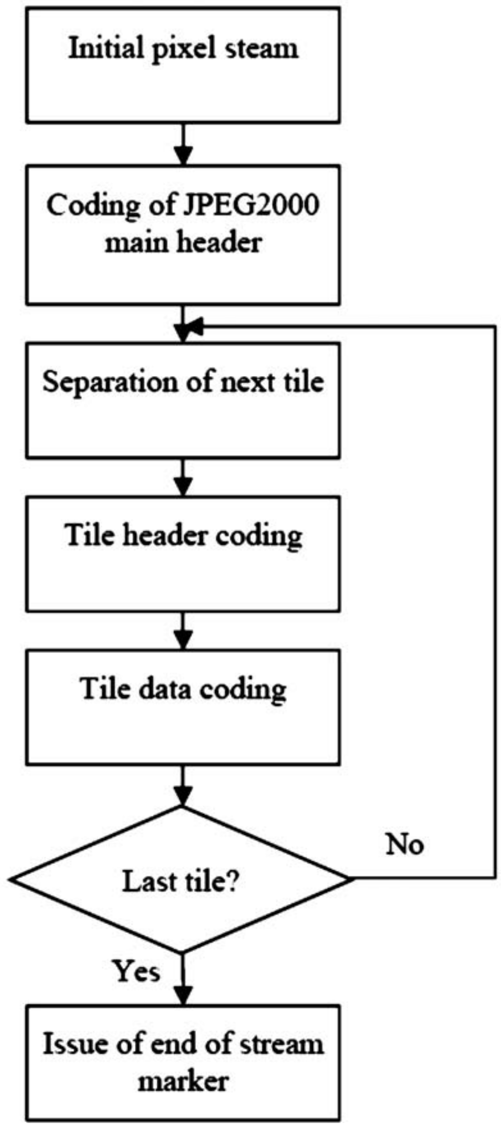

Figure 4: Operation of JPEG2000 coder

JPEG2000 decoder

The developed decoder meets the requirements of JPEG2000 standard at the level of Profile 0 and Class 0 with extensions described above for the coder (image size up to 1024 × 768 pixels, number of color components from 1 to 3). A peculiar feature of the decoder is its capability to process code streams incompletely recovered after JPWL decoding. This capability is based on incremental pattern of coding according to JPEG2000 standard. If tail part of code stream is discarded, then for the tile it is possible to decode the starting part of the stream, which enables recovery of initial tile image, though with poorer quality.

Generalized operation flowchart of JPEG2000 decoder is illustrated in Figure 5.

If JPEG2000 decoder detects RED marker in the header of next decoded tile, indicating at impossibility of complete recovery of code stream by JPWL extension, the decoder extracts the address of the first unrecovered stream area from the data following this marker. Tile data are decoded up to this address and the remaining part of tile code stream is discarded. In extreme case, when unrecovered area is located in the very start of tile code stream, the tile data cannot be decoded.

Tile data are decoded in accordance with JPEG2000 standard and consists of step-by-step execution of procedures inverse to coding stages.

An important aspect of decoder operation is its capability of decoding not of all expected tiles but only of those presented in code stream [12-15, 17]. Upon transmission of highly noisy image both a part of tile data and whole tiles can be lost. If a tile is absent, then decoder fills its pixels with neutral grey color.

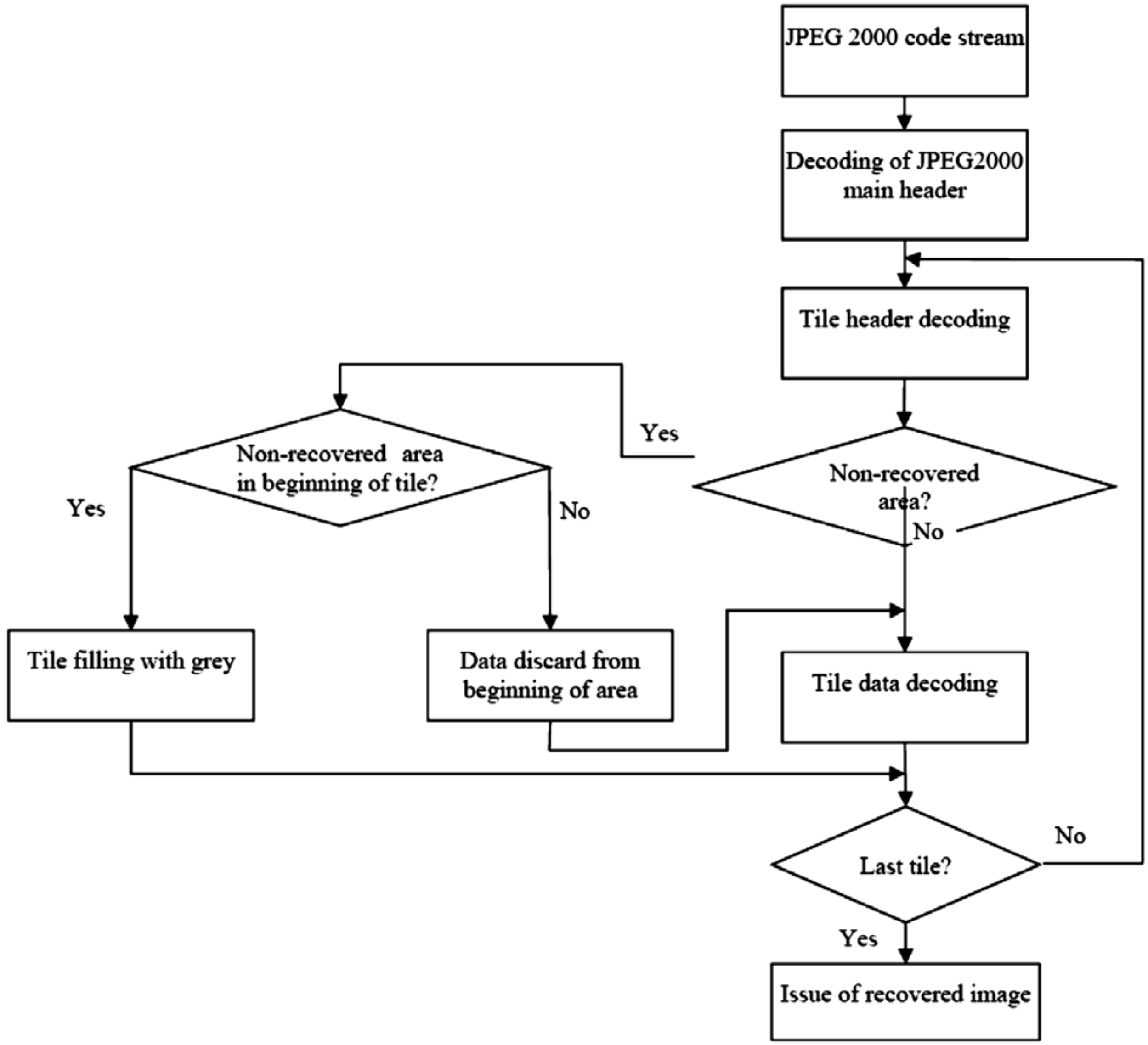

Figure 5: Operation of JPEG2000 decoder

Interleaving

Algorithm of in-frame interleaving implemented in JPWL coder and decoder [16] was discussed in details elsewhere [5]. Since this algorithm is the subject of this experimental study let us describe briefly its essence. The algorithm operates as follows: the main header is unchanged, and the remaining part of JPWL code stream is rearranged. The main header contains EPC segment, where total length of code stream is written. The difference between the total length and the length of main header defines the length of data to be rearranged. These data are considered as rectangular matrix filled row-wise. The data in this matrix are rearranged so it is filled column-wise.

Let L is the total length of code stream, M is the length of main header. Then, according to [19] the amount of columns and rows of the matrix is calculated as follows:

$$N_C = \left\lceil \sqrt{L-M} \right\rceil, \; N_R = \left\lceil \frac{L-M}{N_C} \right\rceil.$$

It should be noted that as a consequence of such rearrangement the length of code stream slightly increases on the coder side, since up to N_R-1 “excessive” elements can be added to the matrix. JPWL coder and decoder should consider this fact.

The difference of the proposed interleaving method and that described in [19] is that in this case all code stream is interleaved except for the main header. In [19] it is proposed to rearrange only parity codes written in EPB segments.

4. RESEARCHING

Hypotheses and criteria

Three hypotheses are verified in this work.

Hypothesis 1. Regular JPWL tools, corresponding to T.810 specification, cannot recover image under conditions of packet errors. The criterion, confirming this hypothesis, is the existence of descending hyperbolic function of PSNR similarity extent of input and recovered image on per cent of packet errors when sharp drop appears at first which finally fades out.

It has been demonstrated elsewhere [5] that regular JPWL tools cannot correct packet errors, which leads either to complete loss of tiles, either to partial loss of tile data. Partially damaged tiles can be decoded by JPEG2000 decoder, however, their quality will be significantly impaired which should lead to decrease in PSNR value.

Hypothesis 2. Regular JPWL tools applied in combination with interleaving algorithm promote efficient image recovery under conditions of packet errors. Recovery capability depends on the applied RS-codes and per cent of packet errors. The criterion, confirming this hypothesis, is nonlinear dependence of per cent of packet loss and PSNR value, at which the PSNR value is constant at maximum possible level up to certain loss values, and it starts to decrease after exceeding of certain threshold of packet loss depending on the applied RS-code.

Hypothesis 3. When in-frame interleaving algorithm is used, the PSNR value statistically depends on the amount of tiles completely decoded by JPWL decoder. The criterion, confirming this hypothesis, is the coefficient of correlation between PSNR and amount of completely recovered tiles, its value should be in excess of 0.95.

Color BMP image with the size of 1024 × 768 is used as test pattern.

Verification of hypothesis 1

Let us perform experiment 1 to verify hypothesis 1. The experiments was performed in two variants of JPEG2000 coding:

- Using reversible conversion, when compression rate is not high but it is possible to completely recover image by JPEG2000 decoder. PSNR for input and recovered image in this case equals to infinity, which is set to 100000 in the experiments.
- Using irreversible conversion, when high compression rate is achieved but JPEG2000 decoder recovers image with errors. PSNR for input and recovered image in this case equals to 33.26.

The applied RS-codes and simulated per cent of RTP packet loss are preset in the research program. The experimental results are summarized in Table 2. The size of JPWL code stream and PSNR average value are shown for each type of RS-codes.

The obtained result completely confirms hypothesis 1. In all columns we have descending hyperbolic dependence of PSNR on per cent of packet loss with sharp drop at start and fading out in the end. The plot of irreversible conversion and codes RS(37,32) is illustrated in Figure 6. Here only PSNR line of coder is shown which characterizes the error level added by JPEG2000 coder.

Table 2

Results of experiment 1

Packet loss, %	*RS(37,32) 1059178/117760 byte*		*RS(64,32) 1822653 /195961 byte*		*RS(96,32) 2727453 /288837 byte*		*RS(128,32) 3633073 /381573 byte*	
	Revers.	*Irrevers.*	*Revers.*	*Irrevers.*	*Revers.*	*Irrevers.*	*Revers.*	*Irrevers.*
1	28.6	28.4	26.7	26.5	27.7	27.4	25.6	28.2
3	20.8	22.6	20.7	21.0	21.5	22.3	19.5	22.5
5	18.3	20.3	17.5	18.7	18.3	19.3	16.7	19.6
10	14.5	15.6	14.7	15.3	16.3	16.1	14.8	16.2
15	12.9	13.9	13.4	13.6	13.6	13.9	12.3	14.1
20	11.7	12.5	11.8	12.1	12.5	12.7	11.1	12.8
25	10.7	11.4	10.8	11.0	11.4	11.4	10.3	11.4
30	10.0	10.8	10.2	10.3	10.8	10.8	9.5	10.9
35	9.4	9.8	9.4	9.7	10.0	10.1	9.1	10.2
40	9.0	9.5	8.7	9.0	9.3	9.4	8.5	9.5
45	8.4	8.8	8.5	8.7	8.8	8.8	7.8	9.0
50	8.0	8.5	8.1	8.2	8.6	8.4	7.6	8.5

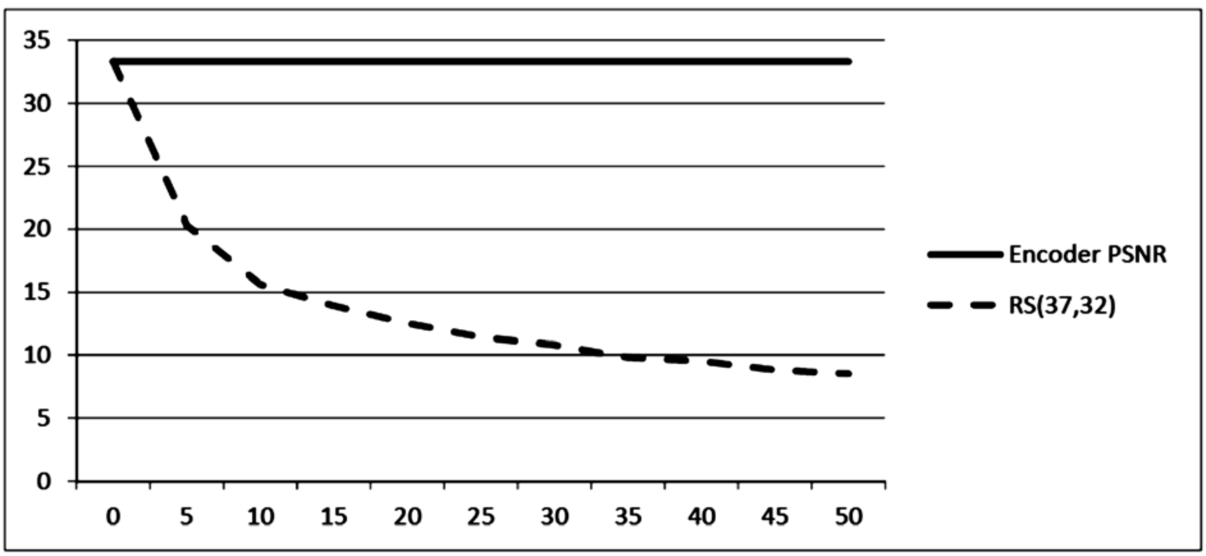

Figure 6: The graph of the experiment 1

Verification of hypothesis 2

Let us perform experiment 2 to verify hypothesis 2. Its initial data correspond to experiment 1, but regular protection is combined with interleaving algorithm. Experimental results are summarized in Table 3.

Analysis of Table 3 confirms hypothesis 2. Indeed, for each type of RS-codes it is possible to highlight threshold value of packet loss. At loss level lower than the threshold the image is recovered with high quality, and with low quality at values higher than the threshold. According to Table 3 the loss threshold for RS(37,32) equals to 1%, RS(64,32) – 10%, RS(96,32) – 20%, RS(128,32) – 25%

Since the code RS(128,32) is the most intensive code, applied in JPWL system, it is possible to conclude that JPWL in combination with the proposed algorithm of in-frame interleaving can efficiently correct up to 25% of packet loss.

Table 3
Results of experiment 2

Packet loss, %	*RS(37,32) 1059178/117760 byte*		*RS(64,32) 1822653 /195961 byte*		*RS(96,32) 2727453 /288837 byte*		*RS(128,32) 3633073 /381573 byte*	
	Revers.	*Irrevers.*	*Revers.*	*Irrevers.*	*Revers.*	*Irrevers.*	*Revers.*	*Irrevers.*
1	100000	29.1	100000	33.3	100000	33.3	100000	33.3
3	17.0	15.2	100000	33.2	100000	33.3	100000	33.3
5	14.0	13.5	100000	32.9	100000	33.3	100000	33.3
10	12.4	12.5	43358	28.0	100000	33.0	100000	33.2
15	12.3	12.1	23.9	20.1	93335	32.3	100000	32.5
20	12.2	11.6	16.6	13.8	10031	23.7	80004	27.3
25	11.9	10.0	12.2	11.3	21.1	14.4	3353	17.5
30	10.0	8.0	9.4	8.9	10.5	10.2	11.51	10.3
35	7.1	6.8	6.9	7.1	6.8	7.0	7.0	7.1
40	5.6	6.0	5.6	5.9	5.7	5.9	5.7	5.9
45	5.5	5.6	5.5	5.6	5.5	5.6	5.5	5.6
50	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5

Figure 7 illustrates PSNR as a function of packet loss for various *RS*-codes. The plots are based on the results of decoding with irreversible conversion. The obtained dependences completely correspond to the criterion confirming hypothesis 2.

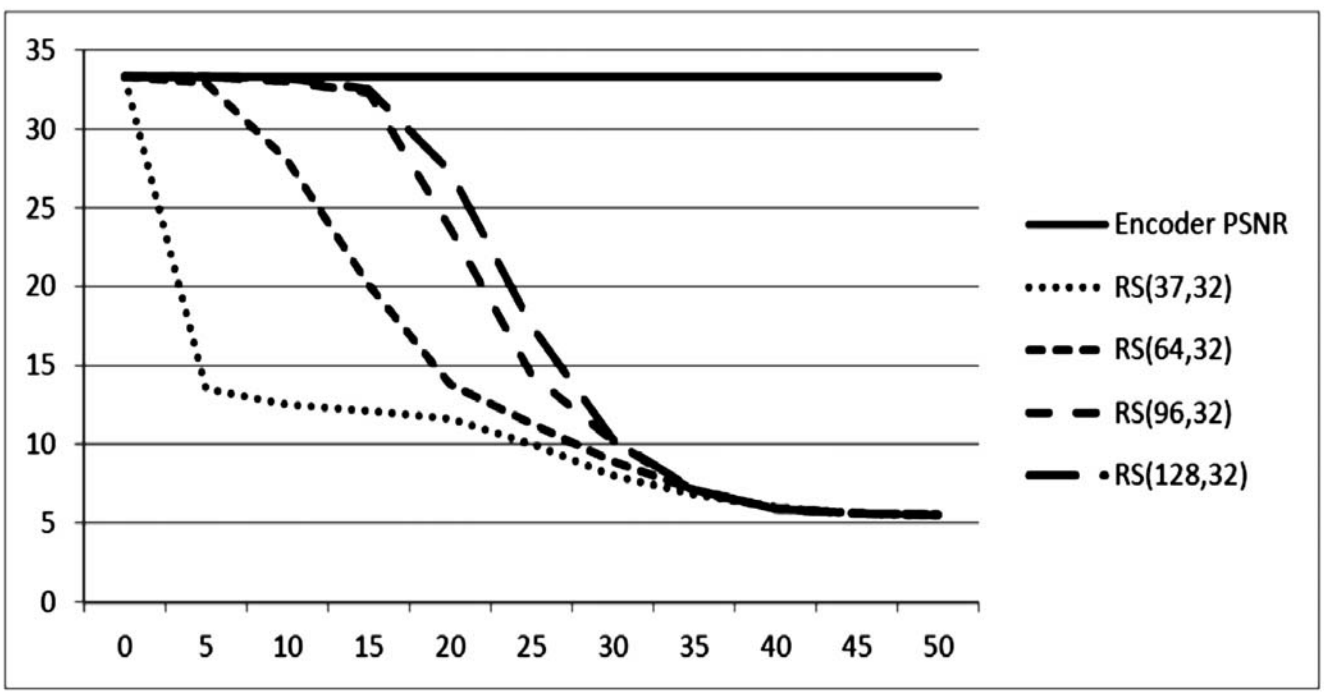

Figure 7: The graph of the experiment 2

Verification of hypothesis 3

In order to verify hypothesis 3 let us analyze statistical data of experiment 2 on average amount of tiles completely recovered by JPWL decoder, summarized in Table 4, and calculate the coefficient of correlation between the corresponding columns of Tables 3 and 4. The obtained correlation coefficient is shown in the last row of Table 4. Since the correlation coefficient strongly depends on numerical representation of infinity for reversible conversion, the correlation coefficient will be calculated only for irreversible conversion. In addition, the correlation coefficient will be calculated only for non-zero columns of Table 4.

Table 4

Amount of completely recovered tiles in experiment 2

Packet loss, %	*RS(37,32) 1059178/117760 byte*		*RS(64,32) 1822653 /195961 byte*		*RS(96,32) 2727453 /288837 byte*		*RS(128,32) 3633073 /381573 byte*	
	Revers.	*Irrevers.*	*Revers.*	*Irrevers.*	*Revers.*	*Irrevers.*	*Revers.*	*Irrevers.*
1	37.1	32.0	100	100	100	100	100	100
3	0	5	100	99.7	100	100	100	100
5	0	0.2	100	99.3	100	100	100	100
10	0	0	96.3	78.7	100	99.9	100	100
15	0	0	24.9	33.9	99.9	97.9	100	99.8
20	0	0	0.1	3.5	84.6	69.2	99.6	97.1
25	0	0	0	0.4	4.5	22.2	84.8	75.8
30	0	0	0	0	0	4.2	7.1	25.5
35	0	0	0	0	0	0.3	0	2.1
40	0	0	0	0	0	0	0	0.1
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
Correlation coefficient	–	0.999	–	0.997	–	0.997	–	0.965

The obtained results correspond to criterion of hypothesis 3 and partially confirm this hypothesis for the case of irreversible conversion but should be additionally investigated for the case of reversible conversion. This result assumes possibility of assessment of PSNR value and of quality of recovered image exclusively on the basis of data on amount of tiles completely recovered by JPWL decoder for preset RS-code.

5. FINAL REMARKS

This research was performed using software complex written in C, Microsoft Visual Studio 2008. The obtained results can be used for selection of optimum parameters of JPEG2000 and JPWL depending on the properties of data transfer channel.

Further studies will be devoted to development of algorithm of autonomous quality assessment of recovered image on the basis of statistics of JPWL decoding an automatic adaptation of JPWL parameters to noise level in data transfer channel.

This research was performed due to development of JPEG2000 decoder capable to decode partially recovered code stream, where some tiles can be absent and headers of existing tiles can contain segments of residual error RED, whereas the available decoders, such as Jas Per, Open Jpeg [20, 21]x cannot decode such code stream.

6. CONCLUSIONS

The following conclusion can be made on the basis of the performed experiments.

- Regular JPWL tools, corresponding to T.810 specification, are insufficient to protect JPEG2000 image upon its transfer via noisy channel.
- Combination of regular JPWL tools with algorithm of in-frame interleaving is a reliable method of protection of JPEG2000 image upon its transfer via noisy channel provided that the level of noise contamination is not higher than 25% of packet loss.
- When irreversible JPEG2000 conversion with high compression ratio is used, the quality of decoded image can be assessed by amount of tiles completely recovered by JPWL decoder, which makes it possible to formulate the problem of development of adaptive autonomous adaptation of JPWL parameters to the level of noise contamination of data transfer channel.

7. ACKNOWLEDGMENTS

This work was performed in the scope of Federal Project No. 3442 "Information-algorithmic provision of digital control, autonomous high precision navigation and synthetic vision for advanced aircrafts: development of theoretical foundations of designing, algorithms, efficient and reliable software implementation, application of high-efficient computation infrastructure for experimental simulation").

We are grateful to our colleagues P. P. Kravchenko, A. N. Zhiglatyi, and V. N. Lutai for their invaluable help in these studies.

8. REFERENCES

1. Taubman, D.S. (2002). JPEG2000: Image Compression Fundamentals, Standards and Practice/ D.S. Taubman, M.W. Marcellin. Boston : Kluwer Academic Publishers, p. 773.
2. S. V. Skorokhod and A. P. Stepanova, (2014). Aspects of synchronization of transmitter and receiver in video broadcasting, in: Proceedings, All-Russian Research and Practical Conference "Management of intellectual property and innovative activity of business entities, commercialization of technologies – 2014". Taganrog, pp. 122-125.
3. C. B. Skorokhod and A. P. Stepanova, (2015). "Some aspects of network interaction between transmitter and receiver during video broadcasting," Izv. YuFU, Tekh. Nauki, 4 (165): 171–181.
4. ITU-T Recommendation T.810. (2007). Information Technology JPEG2000 Image Coding System: Wireless. Geneva: ITU, p. 60.
5. Skorokhod S. V. (2015). The experimental studies of the jpwl tools ability to correct burst errors in a noisy channel when transmitting video in a jpeg 2000 format. Journal of Theoretical and Applied Information TechNology, 10th November, 81(1): 34-42.
6. S. V. Skorokhod and A. S. Artyukhova, (2014). Implementation of JPWL system for wideband video broadcasting, in: Proceedings, All-Russian Research and Practical Conference "Management of intellectual property and innovative activity of business entities, commercialization of technologies – 2014". Taganrog, pp. 131-134.
7. ITU-T Recommendation T.800. (2003). Information Technology JPEG2000 Image Coding System: Core Coding System. Geneva: ITU-T Series T: Terminal for Telematic Services, p. 212.
8. Morelos–Zaragoza R. H., (2002). The Art of Error Correcting Coding. John Wiley & Sons, Chichester.
9. Network Working Group RFC 5371. (2006). RTP Payload Format for JPEG2000 Video Streams. The Internet Security (IETF), p. 31.
10. Network Working Group RFC 3550. (2003). RTP: A Transport Protocol for Real-Time Applications. Schulzrinne: Blue Coat Systems Inc., p. 89.
11. Drozdov S. N. (2014). Implementation of JPEG2000 coding algorithms for video data transfer in real time. International Conference «Engineering & Telecommunication En&T 2014». November 26-28, 2014. Book of Abstracts. Moscow– Dolgoprudny : MIPT, p. 69.
12. Khusainov N. Sh., Drozdov S. N. and Skorokhod S. V. , et al. (2014). Features of designing and software implementation of video broadcasting on the basis of JPEG2000 standards, in: Proceedings, International Conference "Engineering & telecommunications - En&T 2014". Moscow, pp. 137-139.

13. Drozdov S. N., Zhiglatyi A. A. and Kravchenko P. P., et al., (2014). "An experience of implementation of video broadcasting in JPEG2000 format and challenges of JPEG2000 standard for video broadcasting and transfer of multispectral data from UAV," Izv. YuFU, Tekh. Nauki, 7 (156): 161–170.

14. Drozdov S. N., Zhiglatyi A. A. and Kravchenko P. P., et al., (N. D.). On experience of practical implementation of JPEG2000 standards in development of software for real time video streaming in constrained network resources, in: Proceedings, 9th All-Russia Research and Practical conference "Advanced Systems and Management Problems" and 4th Youth School-Seminar "Management and Data Processing in Engineering Systems". Taganrog, pp. 459-472.

15. Zhiglatyi A. A. and Kravchenko P. P., (2004). "Control of compression coefficient of image sequence in JPEG2000 coding for transmittance via telecommunication line with limited capacity," in International Conference «Engineering & Telecommunication En&T 2014».November 26-28, 2014. Book of Abstracts. Moscow– Dolgoprudny: MIPT, pp. 72-75

16. Skorokhod S. V. , Kravchenko P. P. and Khusainov N. Sh. (2014). "Analysis of protection means of video streaming in JPEG2000 format against errors in telecommunication line for on-board systems of video broadcasting," Izv. YuFU, Tekh. Nauki, 8 (157): 219–226.

17. Drozdov S. N., Zhiglatyi A. H. and Kravchenko P. P., et al., (2014). JPEG2000 Standard: Basic algorithms, examples of implementation and opportunities of application. Rostov-on-Don: Publishing House of YuFU.

18. Acharya T. (2005). JPEG2000 standard for image compression: concepts, algorithms and VLSI architecturcs. Hoboken : John Wiley & Sons, Inc., p. 274.

19. ITU-T Recommendation T.810. (2012). Information Technology JPEG2000 image coding system: Wireless. Amendment 1: IP based wireless networks. Geneva: ITU-T Series T: Terminal for Telematic Services, p. 6

20. Adams M. and Kossentini F. (N. D.). JasPer: A Software-Based JPEJ-2000 Codec Implementation. Retrieved September 1, 2015, fromhttp://www.ece.uvic.ca/~frodo/publications/icip2000.pdf

21. An open-source JPEG2000 codec written in C. Retrieved September 1, 2015, from http://www.openjpeg.org/