RECEIVING ULTRAWIDEBAND CHAOTIC SIGNALS IN INDOOR MULTIPATH ENVIRONMENT

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Abstract. **Possible methods for receiving ultra wideband chaotic signals are considered in case of multipath indoor propagation (line-of-sight channel model). The quality of receiving is estimated taking into account the total influence of the multitude of delayed beams as virtual noise. It is shown that the proposed approaches treated in the BER~10^{-3}.**

Index term: **multipath, ultra wideband, chaotic signal, chaotic radio pulse, optimal receiver, bit-error ratio.**

I. INTRODUCTION

The growing interest for using wideband and ultra wideband signals for communication can be explained by the following circumstances. First of all, such signals with wide spectrum can provide transmission of large volumes of information per time unit. Information channels, based on such signals, are assumed to have more effective distribution of channel resources between various users. It is important for design of modern multiple access communication systems. Another important reason is that we can decrease power spectrum density. It opens additional possibilities for reuse of spectrum band in the presence of other active communication systems. The official start to elaborate such communication standard was done by FCC in Spring 2002 [1].

At present there are some approaches to develop the communication systems, based on ultra wideband information carriers. Along with OFDM [2] and ultra-short pulse [3] technologies, the ultra wideband direct chaotic communication (UW DCC) technology was proposed [4-8]. It is based on the chaotic signals, generated directly in UH frequency region. Chaotic radio pulses – fragments of ultra wideband chaotic signal – are used as information carriers.

The indoor communication systems, using low power levels at short distances may be considered as promising application field of UW DCC. But such solutions result in multi-path problem due to numerous indoor reflections. Experimental investigations, carried out by a number of research labs allowed to form more or less four adequate multi-path channel models CM1-CM4 [9-12]. These models give estimates of the main channel characteristics for various situations (presence or absence of the direct beam, typical distance, etc) [13].

According to these models the multi-path channel may be statistically presented as a multitude of the beams with random values of amplitudes and random delay times. The distinctive feature of the CM1-CM4 is that the total sum of the beams is divided into the number of clusters. Each cluster contains group of close beams and is characterized by the average group time delay. The models correspond to various distances and typical propagation conditions: Line of Sight (LOS) for CM1 and Non -line of Sight (NLOS) for CM2-CM4. It is described in terms of mean values of delay times both for the clusters and the beams in each cluster.

The report is devoted to investigation of possible receiver of ultrawideband chaotic signals, propagating under indoor multi-path conditions. We describe the corresponding channel model, propose some possible receiver techniques and estimate the quality of the proposed algorithms from the point of view of bit-error ratio (BER).

The main part of this research is conducted under assumption that additive Gaussian noise (a.g.n.) is negligible. Obviously, the results obtained give the limits that are independent of any additive interference. Some remarks about rather simple involving a.g.n. in the analysis are made in the final part of the paper.

II. CHANNEL MODEL

The model CM1, corresponding to the LOS situation and the distances ~ 0-4m, is chosen as the base channel model [13]. This model gives an ensemble of channel impulse responses $h(t)$, which correspond to the typical indoor propagation. Using $h(t)$ it is possible to obtain the real responses for the ultra wideband chaotic signal.

The first task is to analyze what effect does the imposition of the delayed beams on the direct beam for such model. An amplitude-modulated ultrawideband chaotic signals were formed in the bandwidth Δf=1.58GHz.

The channel impulse response for the model CM1 is presented in Fig 1a. Typical fragment of the sequence of chaotic pulses, corresponding to the bit stream 110111, is shown in Fig. 1b. The value of duty cycle equals to 1/2.

Assume that the data rate R~110Mbps and the band-pass Δf~1,6 GHz. Than we have about M=15 independent samples of amplitude (A_j) at the output of the band-pass filter during information interval $\tau_{inf} \sim R^{-1}$~9 ns. When "1"

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is transmitted chaotic signal is generated on one half of that interval, that is duty cycle =1/2.

Each sample, propagating through the channel leaves a trace on the subsequent information intervals, which can be estimated using $h_i(t)$.

The total effect is illustrated in Fig 1c. Here we present its aftereffect (its "tale") of the first bit (Fig 1a) on the subsequent information intervals.

As can be seen in Fig 1c only some nearest preceding bits provide the essential influence on the signal at the current information interval. So further we should take into account only five preceding intervals ($5\tau_{inf}$).

The total contribution $(A_\Sigma)_j$ of five preceding bits into the current sample A_j is presented in Fig. 2a when "1" is in the previous bit position. It designated by circles. This figure also illustrates the effect of propagation through the channel for the chaotic radio pulse, corresponding to the information bit "1" (the upper curve). It results in some delay by ~3 amplitude samples. The amplitudes of the samples for the "own" information interval decrease essentially slower than the total "background" of the previous information intervals. So we can estimate the effective signal-to-noise ratio for i-th sample as

$$[SNR]_i(\text{dB})=10\lg\left(<A_{s,j}{}^2>/<A_{\Sigma,j}{}^2>\right),$$

where symbol "s" corresponds to the amplitude of chaotic signal.

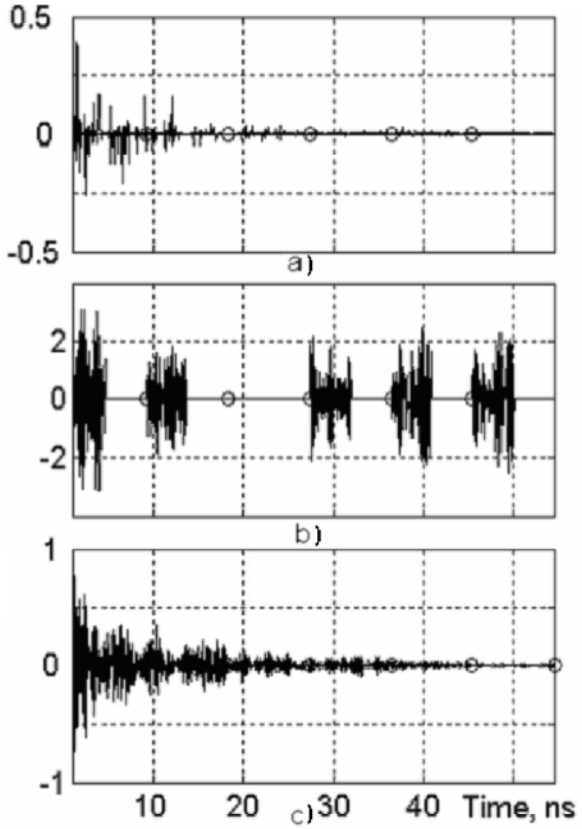


Fig. 1. An example of channel impulse response for channel CM1 - (a); a fragment of the sequence of chaotic radio pulses, corresponding to bit stream "110111" - (b); the result of propagation of the first chaotic radio pulse through the channel - (c).

where mean value $<A_{s,j}{}^2>$ for the j-th sample (when "1" is transmitted) may be considered as the signal; and the mean total value of the "tails" from five previous information intervals $<A_{\Sigma,j}{}^2>$ may be treated as the "noise" power. The behavior of such a value is shown in Fig. 2b. This allow us to point a time region T_{eff} on the information intervals. where the value of $[SNR]_j$ is sufficiently large. It is also necessary to underline that both $A_{s,j}$ and $A_{\Sigma,j}$ obey to Rayleigh probability density function (p.d.f.) (Fig. 3).

III. RECEIVING ALGORITHMS

Taking into account the channel model, described in the previous chapter, let us consider some algorithms for estimation of BER at current information interval.

1. *Optimal receiver (OR)*. The OR's decision about the current binary information symbol ε_i is made by comparing the conventional p.d.f. $P(0)$ and $P(1)$ of the sequence of amplitudes A_j on the band pass filter output during the last information interval for hypotheses H_0 (ε_i=0) and H_1 (ε_i=1); j=1,…M. We suppose that previous m information symbols are already known and the probability of their error (BER) is sufficiently low. For chaotic signals used in our research the conventional p.d.f. of amplitudes A_j are very close to the Raleigh distribution.

$$p(A_j)=\frac{A_j}{\sigma_j}\exp\left(\frac{-A_j^2}{2\sigma_j^2}\right), \qquad (1)$$

where σ_j^2 -is controlled by information symbol ε_i and the "tails" of the L previous information intervals. We suppose that $h(t)$ is known, so the sequence of σ_j^2 may be estimated for any possible sequences of L previously received information symbols. In our research we took L=5 as a reasonable length of $h(t)$: $h(t)$ becomes small enough at t~ 40-50ns.

The rest part of the OR algorithm looks oobvious: the probabilities $P_i(0)$ and $P_i(1)$ are computed for statistically independent amplitudes A_j (j=1,..M) for given $h(t)$ and $\{\varepsilon_i \dots \varepsilon_{i-L}\}$, assuming that ε_i=0 or ε_i=1:

$$P(1)=\prod_{j=1}^{M}P_j(1),$$
$$P(0)=\prod_{j=1}^{M}P_j(0), \qquad (2)$$

where $P_j(1)$ is the probability density of the amplitude A_j assuming, that we receive a symbol "1", and $P_j(0)$ is the probability density of the amplitude A_j assuming that we receive a symbol "0" with the total "tail" of the previous information intervals. M - is the number of samples within the information interval. Here M=15.

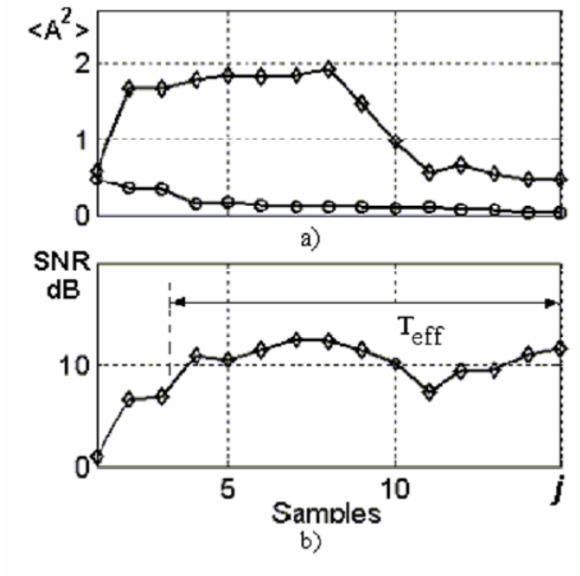


Fig. 2. The result of propagation of chaotic radio pulse through the indoor channel (the upper curve) and the total background of the previous five information intervals (circles)- (a); SNR performance - (b).

$P_j(1)$ and $P_j(0)$ are estimated using Rayleigh p.d.f. for the amplitudes A_j:

$$P_j(0) = \frac{A_j}{(\sigma_j(0))^2}\exp\left(-\frac{A_j^2}{2(\sigma_j(0))^2}\right) \text{ (for "0")} \quad (3)$$

and

$$P_j(1) = \frac{A_j}{(\sigma_j(1))^2}\exp\left(-\frac{A_j^2}{2(\sigma_j(1))^2}\right) \text{ (for "1").} \quad (4)$$

The parameter σ_j (0) in the first distribution corresponds to the total "noise" due to the previous L=5 information intervals. It can be calculated as we know the channel response and previous L received bits.

In order to determine parameter $\sigma_j(1)$ it is necessary to take into account p.d.f. of j-th amplitude sample in the case of transmitted "1":

$$\sigma_j^2(1) = \sigma_j^2(0) + 0.5\langle A_{s,j}(1)^2\rangle, \quad (5)$$

where $\langle A_{s,j}(1)^2\rangle$ gives the energy profile of chaotic pulse in the current information interval.

The decision about current bit is made from simple inequality $P(1)>P(0)$. If this inequality is true then "1" is received. Otherwise this is the case of "0". After that similar procedure is made on the subsequent information interval.

The modeling of such receiving algorithm gave typical values of BER up to ~ $5*10^{-4}$.

2. A more simple threshold algorithm does not use normalizing procedure for the sample amplitudes with values $\sigma_j^2(1)$ and $\sigma_j^2(0)$. It is based on the integral energy of the received signal, a statistic $E = \sum_{j=1}^{M} A_j^2$. We should analyze the distribution function of E for two hypotheses (H_1 and H_0) and chose the value of threshold. The threshold level may be chosen by means of equalizing the probabilities of "false alarm" ("0"→"1") and "missed symbol" ("1"→"0"). This algorithm with simple summation of A_j^2 demonstrates BER significantly higher than OR case (~ 10^{-2}). Such deterioration was expected taking into account that the interference level from the previous "1" is rather high in the first part of information interval (samples 1,2,3) and signals amplitudes are significantly decreased in the second part of the information intervals (samples 10-15), where SNR holds rather high.

3. Another possibility is a preliminary choice of the false alarm probability for all sample amplitudes at the common low level ~10^{-3}. After that the probability of missed symbol is estimated using the criterion "at least one" from M samples in the interval T_{eff} exceeds the threshold. The threshold is set to have the total probabilities of false alarm P("0" →"1") and missed symbol P("1" →"0") approximately equal:

$$P(\text{"0"} \to \text{"1"}) \approx \sum_{j=1}^{M} P_j(\text{"0"} \to \text{"1"}) \quad (6)$$

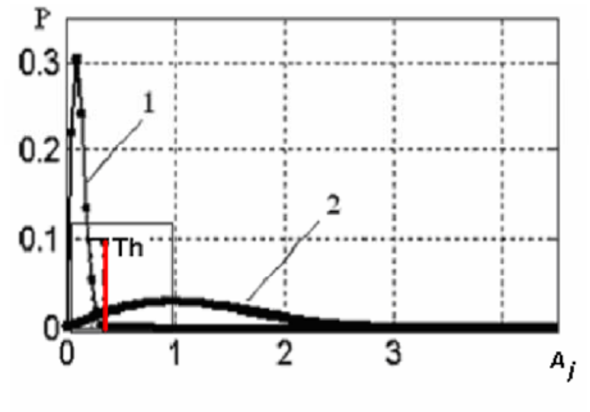
and

$$P(\text{"1"} \to \text{"0"}) \approx \prod_{j=1}^{M} P_j(\text{"1"} \to \text{"0"}) \cdot \quad (7)$$

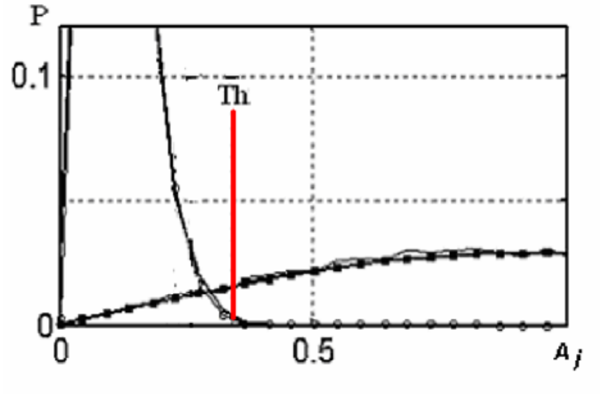
In this is the case we had total error probabilities ~ $2\text{x}10^{-3}$. Typical distribution curves for sample amplitude are presented in Fig 3. The distribution curve 1 in Fig 3a corresponds to the input "0" with "1" in previous information bit and the curve 2 - to the input "1" with "0" in previous information bit. Zoomed fragment of Fig 3a is shown below in Fig. 3b. It should be noted that thus algorithm is obviously the simplest one in the family of well known radar algorithms of signal detection by "k from n" rule. When k>1 the number of combinations leading to wrong decisions grows very quickly, the threshold optimization becomes rather complex, though ot doesn't give significant effect in BER.

IV. CONCLUSION

So if we know the channel impulse response of the channel (for example by measuring in preliminary experiments) it is possible to analyze the input stream of chaotic radio pulses and to make a decision about input information bits. Though of described estimates were obtained in the absence of channel Gaussian noise, it is necessary to point that the channel noise can be taken into account by appropriate adding the term σ^2_{noise} to the $\sigma^2_j(0)$ in the distribution (3)-(4).



a)



b)

Fig. 3. Typical distribution curves *P*(*A*) for average sample amplitude: 1- corresponds to the input "0"; 2- corresponds to the input "1" (a). Zoomed fragment - (b). Th - the threshold level for the third receiving algorithms. Thing lines demonstrate the theoretical Raleigh p.d.f. for "signal" channel interference. Circles and squares correspond to the computer modeling.

At whole our investigation confirms that indoor multipath propagation can seriously complicate the receiving of the chaotic signals. At information rates >10^2 Mbps even for more or less well propagating channel, line of sight model, the level of BER will be ~ $10^{-3}\div5\times10^{-4}$.

The situation may be improved by a decrease of duty cycle when the protective intervals between chaotic pulses are increased. But this leads to lower data rate. Some further improvement of BER level can be achieved using additional error correcting coding.

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REFERENCES

[1] FCC News Release, February 14, 2002.

[2] A. Batra, J. Balakkrishnan, A. Dabak etc. Time frequency Interleaved OFDM. // *TI Physical Layer Proposals for IEEE P802.15.Working Group for Wireless Personal Networks (WPANs)*, May 2003.

[3] M.Z.Win, R Scholtz, M.A. Barnes. Ultra-Wide bandwidth signal propagation for indoor communication // In *Proc. of IEEE Int. Conf. On Comm.*, 1997, Montreal, Canada., pp.55-60.

[4] Dmitriev A.S., Kyarginsky B. Ye., Maksimov N.A., Panas A.I., Starkov S.O. The perspectives of Direct Chaotic Communication in Radio and Microwave frequency bandwidth. // *Radiotehnika*, 2000, № 3, P.9-20. (In Russian).

[5] A.S. Dmitriev, B.Ye. Kyrginsky, A.I. Panas, D.Yu. Puzikov, S.O. Starkov. The experiments on ultra wideband direct chaotic information transmitting in ultra high radio frequency.// *Radiotehnoka i Elektronika*, 2002, Vol. 47, N10, P. 1219-1228.(In Russian).

[6] Dmitriev A.S., Hasler M., Panas A.I., Zakharchenko K.V., Basic principles of direct chaotic communications. // *Nonlinear Phenomena in Complex Systems*, 2003, vol. 6, № 1, pp. 488-501.

[7] Dmitriev A.S., Kuzmin L.V., Panas A.I., Puzikov D. Yu., Starkov S.O., Direct Chaotic Communication, *Zarubegnaya radioelektronika. Uspehi sovremennoi radioelektroniki.* 2003, № 9, P. 26-42. (In Russian).

[8] Dmitriev A.S., Kyarginsky B.Ye., Panas A.I., and Starkov S.O. Experiments on ultra wideband direct chaotic information transmission in microwave band // *Int. J. Bifurcation & Chaos*, 2003, vol. 13, № 6, pp. 1495-1507.

[9] J.M. Cramer, R.A. Scholtz and M.Z. Win. On the analysis of UWB communication channel.//*Proceeding of MILCOM 1999*, 1999, vol. 2, pp. 1191-1195.

[10] S. Ghassemzadeh, R, Jana, C, Rice, etc. A Statistical Path Loss Model for In-Home UWB Channels // *IEEE UWBST*, May 2002.

[11] M.Z. Win and R. A. Scholtz. On the Robust of Ultra-Wide Bandwidth Signals in Dense Multipath Envirements // *IEEE Comm. Lett*, 1998, vol. 2., № 2, pp. 10-12.

[12] J. R. Foerster and Q. Li. UWB Channel Modeling Contribution from Intel // *IEEE P802.15-02/279-SG3a.*

[13] Channel Modeling Sub-committee Report Final. November 2002. *IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs).*