RECEIVING ULTRAWIDEBAND CHAOTIC SIGNALS IN INDOOR MULTIPATH ENVIRONMENT

L.V. Kuzmin, V.A. Morozov, S.O. Starkov, B.A. Khadji

Institute of RadioEngineering and Electronics, Russian Academy of Sciences,
Mokhovaya St. 11, GSP-3, 103907, Moscow, Russia,

E-mail: chaos@mail.cplire.ru

Abstract. **Possible methods for receiving ultra wideband chaotic signals are considered in the 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, ultrawideband, 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).

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 11011, is shown in Fig. 1b. The value of duty cycle equals to 1/2. Assuming that sampling time is $\tau_s=1/(2\Delta f)$ we obtain the data rate ~ 110Mbps.So for transition of a bit we need the information interval ~ 9ns. The number of amplitude samples equals to 15. 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 the trace 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.

The total contribution $(A_\Sigma)_i$ of five preceding bits into the current sample A_i is presented in Fig. 2a. 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

$$[SNR]_i\,(\mathrm{dB})=10\mathrm{Lg}\,(A_i^2/A_\Sigma^2), \qquad (1)$$

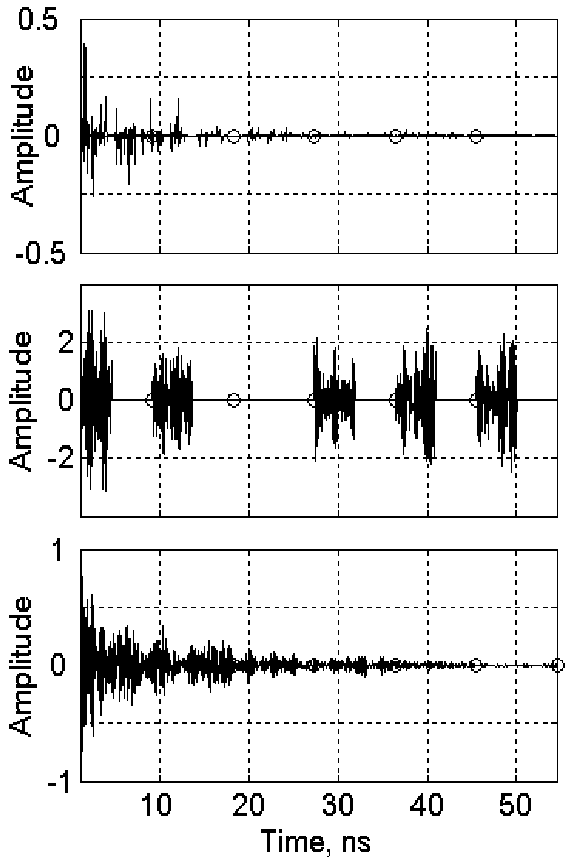


Fig. 1. An example of channel impulse response for channel CM1 - (a); a fragment of the sequence of chaotic radio pulses, corresponding to bit stream "11011" - (b); the result of propagation of the first chaotic radio pulse through the channel - (c).

where mean value $\overline{A}_i^2$ for the i-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 $(\overline{A}_\Sigma^{\,2})_i$ 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 $[SNR]_i$ is sufficiently large. It is also necessary to underline that both A_i and $(A_\Sigma)_i$ obey to Rayleigh distribution (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 on current information interval.

1. Optimal receiver is based on the comparison of relative densities of the probabilities for M sample amplitudes - $\{A_i\ ,\ i=1,\ M\}$ at the current information interval. The decision is made using the estimates $P(1)$ and $P(0)$ for two hypotheses: H_1 (for "1") and H_0 (for "0").

These estimates may be written (with some proportional coefficient) as

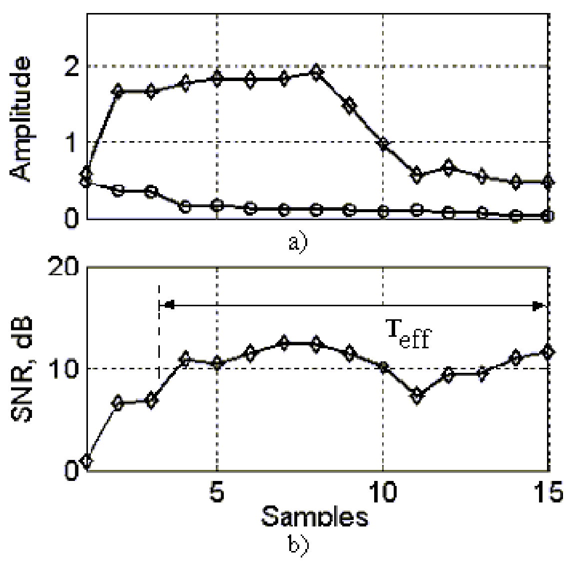


Fig. 2. The result of propagation of chaotic radio pulse through the indoor channel (the upper curve) and the total background of the previous five information intervals (circles)- (a); SNR performance - (b).

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

where $P_j(1)$ is the probability density of the amplitude A_j assuming, that we receive a symbol "1".

$$P(0)=\prod_{j=1}^{M} P_j(0), \qquad (3)$$

where $P_j(0)$ is the probability density of the amplitude A_j assuming that we receive a symbol "0" or the total "tail" of the previous information intervals. M - is the duration of interval for the estimation.

$P_j(1)$ and $P_j(0)$ are estimated using Rayleigh distribution 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 five information intervals. It can be calculated in advance as we know the channel response and previous five received bits (there are 32 possible combinations).

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

$$\sigma_j^2(1) = \sigma_j^2(0) + 0.5\langle A_j(1)\rangle^2. \quad (5)$$

The decision about current bit is made from simple inequality P(1)>P(0). If this non equality is true then "1" is received. Otherwise this is the case of "0". Calculation of values P(1) and P(0) must be done on the time interval T_{eff} in order to exclude the contribution of the first three samples $A_1\, A_2\, A_3$ with relatively low *SNR* level and to use all the length of the information interval. After that similar procedure is made on the subsequent information interval.

Estimation of such receiving gave typical values of BER up to ~ 10^{-3}.

2. A more simple algorithm does not use normalizing procedure for the sample amplitudes on values $\sigma_j^2(1)$ and $\sigma_j^2(0)$. It is based on the integral characteristics of the received signal, a statistics $L = \sum_{j=1}^{M} A_j^2$. We should analyze the distribution function of L 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 and missed symbol detection.

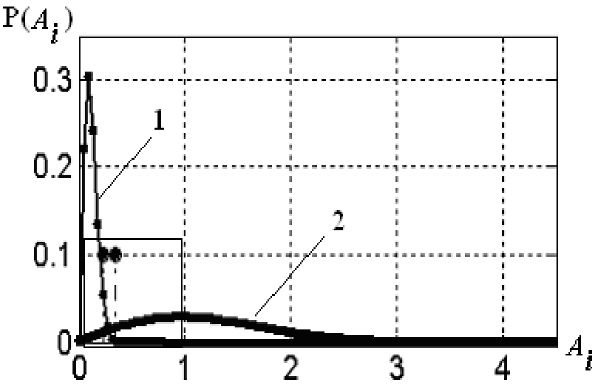
3. Another possibility is a preliminary choice of the false alarm probability for all sample amplitudes at the common low level ~10^{-3}. After that the probability of missed detection is estimated using the criterion "*K* from *M*". According to this criterion the decision about input "1" is made if the level of amplitude exceeds the threshold for even *K* (or more) samples of the information interval. For low levels of false alarm probabilities on each sample P_i (“0” →”1”) and for K=1 the total probabilities of false alarm P(“0” →”1”) and missed symbol detection P(“1” →”0”) will be approximately equal:

$$P(\text{“0”} \to \text{”1”}) \approx \sum_{i=1}^{M} P_i(\text{"0"} \to \text{"1"}) \quad (6)$$

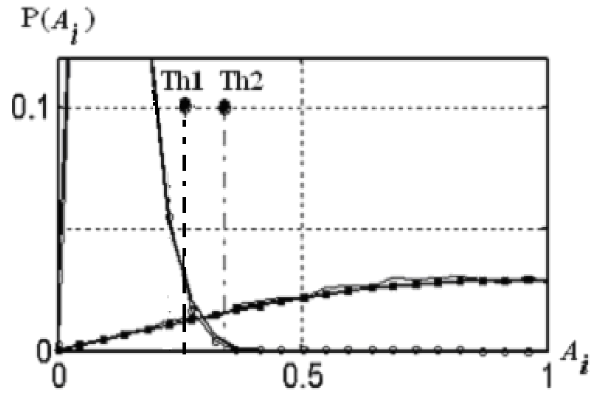
and

$$P(\text{“1”} \to \text{”0”}) \approx \prod_{i=1}^{M} P_i(\text{"1"} \to \text{"0"}) \quad (7)$$

This is the case when total error probabilities were ~ $2\text{x}10^{-3}$. Typical distribution curves for average sample amplitude are presented in Fig 3. The distribution curve 1 in Fig 3a corresponds to the input "0" and the curve 2 - to the input "1". The thresholds Th1 and Th2 correspond to the second and third algorithm respectively. Zoomed fragment of Fig 3a is shown below in Fig. 3b.



a)



b)

Fig. 3. Typical distribution curves $P(A_i)$ for average sample amplitude A_i: 1- corresponds to the input “0”; 2- corresponds to the input “1” (a). Zoomed fragment - (b). Th1 and Th2 - the threshold levels for the second and third receiving algorithms.

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).

The analysis of BER distributions vs ensemble of channels (number of impulse channel characteristics, generating in assumption of model CM1) will be done later.

At whole our investigation confirms that indoor multi-path propagation can seriously complicate the receiving of the chaotic signals. Even for more or less well propagating channel, line of sight model, the level of BER will be ~ $10^{-3} \div 5\times10^{-4}$.

The situation may be improved by a decrease of duty cycle. 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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