БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ . BULGARIAN ACADEMY OF SCIENCES

КИБЕРНЕТИКА И ИНФОРМАЦИОННИ ТЕХНОЛОГИИ · Том **4**, № 2
CYBERNETICS AND INFORMATION TECHNOLOGIES · Volume **4**, No 2

София . 2004 . Sofia

Detection with the Help of an OS CFAR Processor in CDMA Networks in the Presence of Multipath Interference*

Christo Kabakchiev, Vladimir Kyovtorov, Ivan Garvanov

Institute of Information Technologies, 1113 Sofia
E-mails: ckabakchiev@iit.bas.bg ckabakchiev@yahoo.com
vladimir_ak@yahoo.com igarvanov@iit.bas.bg igarvanov@yahoo.com

***Abstract**: In this paper we discuss the problem of secondary application of CDMA wireless communication networks for low flying target detection. It is reduced to a PN signal detection in multipath interference by using a passive correlation receiver with an OS CFAR processor. We perform noise level estimation in both windows, applying the order statistic (OS) approach. The Minimum of Average decision threshold is used as an OS estimation criterion of efficiency. The parameters of the correlation receiver with an OS CFAR are obtained by Monte Carlo simulation. The results may be applied for target detection in multistatic radars using the existing communication networks.*

***Keywords**: passive correlation receivers, OS CFAR processor, multipath interference.*

1. Introduction

The contemporary communication networks reveal interesting secondary applications. One of these applications is the flying target detection [1, 2]. Our aim is to use the existing CDMA wireless network for low flying target detection and tracking. For this purpose small passive radar receivers could be added to the base stations. It is well known that several small radars are more efficient than one, which covers the same

* The work reported is supported by IIT- 010059/2004, MPS Ltd. Grant “RDR” and Bulgarian NF “SR” Grant No TH-1305/2003. We wish to express our kind gratitude to Assoc. Prof. Vladimir Baronkin.

area [3]. Considering the characteristics of the pilot signal in CDMA networks, the high energy, continuous code sequence with big base, we choose it as a signal in our pseudo-radar network [4, 5]. We suppose the target goes through only one cell, and only the pilot signal is received by the base station. The multipath interference is a forward scattered pilot signal from different adjacent objects and background. According to Turin's investigations [9-11], the multipath propagation is typical for the spread spectrum communications. In these systems, the RAKE receiving approach is well known where the signals have the same information [4]. In our case this approach is inapplicable because we estimate the target range. The task is resolved as detection of PN signals (CDMA IS 95 pilot signal), in multipath interference [1, 2], applied in wireless communication systems.

We suppose that the target signal is a pulse train from forward scattered signals in the presence of multipath interference on the input of a coherent passive receiver (radar receiver). We assume that at the input of the correlation receiver the target echo from communication signal fluctuates according to Swerling II case model, and the multipath interference is with a Poisson distribution of probability in the flow and Rayleigh distribution of their amplitudes. The Turin's model for multipath propagation is used [9-11]. The signals phase distribution is not considered. We work with the pilot signal and a correlation receiver, according to CDMA IS-95 standard [4]. The signal has good auto-correlation and ambiguity functions, which is important for radar applications. The pilot signal is easily detectable, because it has no data modulation [4]. Moreover, this signal is emitted continually and does not appear casually, which makes it different from the paging or traffic channels. Such approach can be used with other complex signals, which are used in other communication systems (GPS, CDMA 2000, WCDMA [12-14]).

Detecting in the presence of multipath with a fixed threshold claims high interference to noise ratio (INR). Using CFAR could improve this ratio, as it is done with the detection in the pulse jamming presence. The multipath can cause an interference, which can be interpreted as a jamming process. The detection in the jamming environment with CFAR is described in [15-19]. The proposed by Himonas [18] and further developed by B e h a r et al. [15] API CFAR processor with censoring in both – test and reference window needs minimum ADT (average decision threshold) in the ambience of intensive jamming with Poisson distribution and Rayleigh amplitude distribution. Behar elaborates this problem in [15] with a more complex and more general statistical description model than the model used in [18].

Furthermore, we investigate the problem concerning the synthesizing of CFAR processor with a communication signal (IS-95 pilot signal) in multipath interference. Our hypothesis was to use Behar's proposed API CFAR detector for target signal detection in multipath presence. After a number of simulations of the censoring algorithms behavior of this detector, it was found that the censoring doesn't work properly. The reason is the lack of clearly defined difference between the white gaussian noise and the multipath effect performance, and the height dynamic of the average order statistic. For this reason we have to use an order statistic approach (OS) for

** The glossary used is found on page 120.

noise level estimation in both windows [20, 21]. The Minimum of Average decision threshold is the criterion of this estimations efficiency [20]. The best interference appraisal is made with the help of the Monte-Carlo simulation results. The CFAR efficiency is evaluated by the detection and the false alarm probability for different values of the interference-to-noise ratio (INR), and for different probability of appearance of multipath interference.

All results are obtained in MATLAB environment by Monte-Carlo simulation. The results achieved in this paper may be successfully applied for moving target detection by using existing communication networks.

2. Detection in CDMA networks in the presence of multipath interference – problem formulation

The contemporary CDMA communication networks are used for data transfer via air interface for mobile subscribers [4]. Generally, the networks consist of base stations (BS), each BS covers an area (cell). The cells have different sizes depending on the environment (pico cell <100 m, and micro cell <1 km). The air interface consists of a pilot signal, a synchronization signal, paging and traffic channels. The pilot signal is the same for the whole network and it is used for phase initialization of demodulation (supports the system coherence) [4]. The synchronization channel is demodulated by all mobiles and contains important system information conveyed by the "synch channel message", which is broadcast repeatedly. The paging channels are used to alert the mobile for incoming calls, to convey channel assignments and to transmit system overhead information. The Traffic channels carry the digital voice or data to the mobile user. In the covering area of the communication networks all moving and fixed objects reflect these signals.

Our aim is to use the existing CDMA wireless network for secondary application – radar detection of low flying targets. For this purpose, BS could be added with passive radar receivers. As a result, we could obtain a pseudo radar coherent network from small radars (Fig.1).

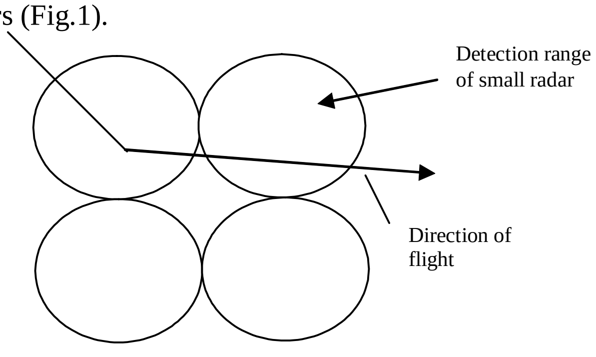

Fig. 1. Small radar net [3]

In this case the target could cross the pseudo-network from these small radars, during the flying over the wireless communication network. Our receivers could be obtained in the global synchronization time from GSP or CDMA network, be phased synchronized with the CDMA network, and managed through own or central control system. We suppose the target goes through only one cell and only the pilot signal is received from the base station.

From all other signals used in CDMA network, we chose the pilot signal as a signal used in our radar. It is the most powerful signal, with continued code sequence with big period of repetition and uninterrupted in time. The reflected signal from the target consists of many independent reflecting elements, and many plains in the microwave range have such distributions [22]. We suppose relatively fast target fluctuations, so that the target cross section is independent from pulse to pulse in one scanning beam. Such distribution is known as Swelnig II model with apriori known parameters. A specific interference in the CDMA communication networks is the multipath, caused by the spread spectrum character of the signals. We use the well-known Turin's model for multipath propagation in urban areas with apriori known parameters. It describes a flow with a Rayleigh distribution and Poisson probability of appearance of amplitude. Time delay is assumed up to the flow of approximately 20 μs or 3 km. These interferences together with the background interference covered all small cells (micro and pico). As a difference from the background interference, which conceals the target signal, the multipath propagation forms many not real targets and worsens detection and estimation.

The problem of radar detection in the CDMA cell is to reduce the detection with unknown coordinates and velocity of the pilot signal in presence of multipath interference with apriori known parameters of the signal and interference. We use the approach for detection and estimation of the moving targets in the surveillance radar together with some of the well-known methods for background suppressing (for example Moving Target Detection – MTD, Adaptive Moving Target Detection – AMTD or Space Time Adaptive processing – STAP) [6, 7, 8]. In this case the target detection with unknown coordinates and velocity is reduced to the multichannel range target detection in a fixed velocity (azimuth) channel [6, 7, 8]. The use of CFAR approach enables the keeping of false alarm rate in all the range distance. As a result, the target detection in one communication cell could be transformed as a target CFAR detection in the moving window on the range in all channels of velocity (in any channel azimuth). In our paper we do not investigate moving targets. Then the target detection is reduced to pilot signal CFAR detection in the moving window on the range (in any channel azimuth), in the presence of multipath interference. We use a base-band model of a coherent passive receiver (a correlator and CFAR detector, Fig.2).

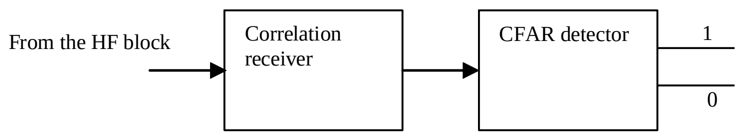

Fig. 2. Simple block diagram of receiver

3. Signal and environment model

In this paper we study the signal and environment models similar to the ones proposed in [9-11]:

(1) $$w(t) = a_0 s(t - t_d) + \sum_{k=1}^{\infty} a_k s(t - t_k) + n(t),$$

where: $a_0 s(t - t_d)$ is the reflected signal in every range element of the signal matrix (a cell); a has an amplitude fluctuating independently according to Rayleigh distribution law (Swerling II target model); $s(t)$ is the PN communication pilot signal; t_d is the time delay of the direct signal; $\sum_{k=1}^{\infty} a_k s(t - t_k)$ is Turin's multipath model, where a_k is the amplitude fluctuating according to Rayleigh distribution law, t_k is the delay time with Poisson probability of appearance; $n(t)$ is the additive white gaussian noise.

We do not consider the uniform random distribution of phases in the multipath model. The emitted signal is continuous, but the received signal can be considered as pulse signal after the use of a correlator with fixed length. The received signal is sampled in range by using M+1 resolution cells resulting in a matrix with M+1 rows on range and L columns on azimuth. Each column of the data matrix consists of the values of the signal obtained for L pulse intervals in one range resolution cell. This matrix is used for signal processing in the correlator. The output matrix is used by the CFAR processor. The first $M/2$ and the last $M/2$ rows of the data matrix are used as a reference window in order to estimate the "noise-plus-interference" level in the test resolution cell of the radar. In this case the samples of the reference cells result in a matrix X of the size $M \times L$. The test cell or the radar target image includes the elements of the $M/2+1$ row of the data matrix and is a vector Z of length L. In the presence of a desired signal from a target, the elements of the test resolution cell are independent random variables with distribution law (1). The elements of the reference window are independent random variables, which can be defined as (1), setting $a_0 s(t - t_d) = 0$.

3.1. Signal model

In our case, the reflected signal is a PN code communication pilot signal. The IS-95A standard is based on spread spectrum signals (SSS) with direct spreading (DS) [4]. It is established that these signals could possibly be used as radar signals, because they are synthesized with a low cross correlation function in order to minimize the influence between particular channels [4, 5]. We focus our attention to the Pilot signal, which is uninterrupted and consists of simple signals. It is used primarily as coherent phases reference for demodulation of the other channels. For this reason, IS-95 requires that the chip timing and carrier phase of each downlink channel be in very close agreement. The pilot signal includes constant logical 0, it is modulated at Walsh chip rate of 1.2288 Mcps by the 0-th row of the 64×64 Hadamart matrix, which is the Walsh sequence consisting of 64 zeros-thus, in effect, it is not modulated at all. The two distinct short PN codes I and Q are maximal length sequences generated by 15-stage shift registers and lengthened by the insertion of one chip per period in a specific location in the PN sequence Thus, these PN codes have periods equal to the normal sequence length of $2^{15}-1$ = 32 767 plus one chip, or 32 768 chips [4]. The PN-code spreading is followed by classic QPSK modulation of the radio frequency carrier. This signal is perfect for secondary surveillance as it is more powerful than the others. Because it is a synchro-signal, the standard demands acquisition in signal-to-noise ratio of –15 dB.

In this paper Swerling II model is used for describing the signal fluctuations in the pulse train coming directly from the target.

3.2. Multipath model

Three types of communication channel models exist – empirical, deterministic, and a combination of both. We use the suggested by Turin communication channel model [9-11]. It is described as pulse train with Rayleigh amplitude distribution, Poisson probability of appearance and uniform random distribution of phases.

Despite of the fact that the model has been developed in 1975, it is still valid and used [23]. We perform the Turin's model simulation as a pulse train with Poisson probability of appearance in one cell of the signal matrix, similarly to that in [15-17, 19, 21]. In accordance with Turin's model, we choose (9×8) width for the signal matrix and probability of appearance P_a=0.2 at the input of the CFAR.

4. A passive receiver for target detection in the presence of multipath interference

4.1. A correlation receiver

We use the baseband acquisition diagram for the pilot signal of CDMA-IS 95 A [4]. It consists of a correlator and a threshold detector with a fixed threshold (Fig.3). In our case we use an OS CFAR processor for target detection in the presence of multipath interference. The quadrature components at the baseband filter input are [4]:

(2.1)
$$r_I(t) = \left[r(t)\times\sqrt{2}\cos(\omega_0 t)\right]_{\text{lowpass}} = \sqrt{\frac{E_c}{T_c}}C'_I(t)+n_I(t)$$
$$=\sqrt{\frac{E_c}{T_c}}C_I(t)\cos(\phi_\omega)+\sqrt{\frac{E_c}{T_c}}C_Q(t)\sin(\phi_\omega)+n_I(t),$$

(2.2)
$$r_Q(t) = \left[r(t)\times\sqrt{2}\sin(\omega_0 t)\right]_{\text{lowpass}} = \sqrt{\frac{E_c}{T_c}}C'_Q(t)+n_Q(t)$$
$$=\sqrt{\frac{E_c}{T_c}}C_Q(t)\cos(\phi_\omega)-\sqrt{\frac{E_c}{T_c}}C_I(t)\sin(\phi_\omega)+n_Q(t),$$

where $C_I(t)$ and $C_Q(t)$ are PN sequences in the I and Q channels respectively, $n(t)$ is the additive Gaussian white noise (AWGN), $n_I(t)$ and $n_Q(t)$ are the corresponding noise in both channels (statistically independent white gaussian noise [4]).

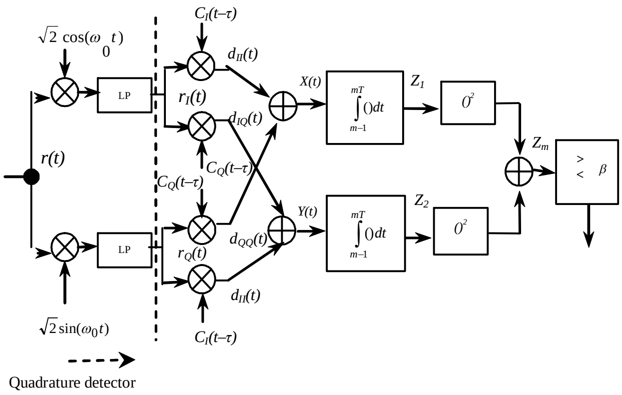

Fig. 3. Filter diagram

The probability density function Z_m (Fig.3) at the output of the correlator is given with [4]:

(3) $$p_{Z_m}(\alpha) = \begin{cases} \frac{1}{2\sigma^2} e^{-\frac{1}{2}(\lambda + \frac{\alpha}{\sigma^2})} I_0\left(\sqrt{\frac{\lambda\alpha}{\sigma^2}}\right), & \alpha \geq 0, \\ 0 \text{ othrewise,} \end{cases}$$

where $\sigma^2 = N_0'T$, λ is a noncentrality parameter, $\lambda = 4NR^2(\tau)\frac{E_c}{N_0'}$ and $N = T/T_c$, N is the number of pulses (chips) used in the integration, T is the observation interval, T_c is the duration of one chip, E_c is the chip energy.

4.2. OS CFAR processor

Our hypothesis was that we can use the proposed by B e h a r a t a l. [15] API CFAR detector for signal detection in the presence of multipath interference. After performing a number of simulations, we established that the censoring algorithm does not work effectively. Due to the lack of clearly defined difference between the white Gaussian noise and the multipath effect performance in the test and reference windows, it stops the using of the censoring algorithm in the ordered statistics. Additionally, the signal after the correlation receiver is very dynamic. Differently from pulse radars, for which it is considered that there is no signal in the reference window, in our case, due to the fact that the model works with continuous signals, the statistics in both, the test and reference windows, have similar structures, including white noise, signal, and multipath interference. The difference is that the statistics in the test window contains a pulse train reflected from the target. Therefore we use the OS approach for noise level estimation in both windows. The minimum of the average decision threshold is used as a criterion of effectiveness of these estimations [20]. The rank-ordered parameters, giving the best OS estimation, are chosen by using Monte Carlo simulation. The effective estimations are equivalent to those elements of the ordered statistics in both windows, where the minimum SNR occurs for P_d=0.5 and fixed P_{fa}. In order to optimize these estimations, we change dependently and independently the rank-ordered parameters (from (3/4)L to (1/8)L), as it is done in [20]. The results revealed that the minimum ADT is achieved for the rank-ordered parameter combination $k_1=(1/8)L$ и $k=(3/16)R$. For the other combinations, the ADT is higher approximately with 5-6 dB.

We use in our work a new modification of the two-dimensional OS CFAR processor, which is very effective in the presence of multipath interference.

4.3. Analysis of two-dimensional OS CFAR processor

The algorithm consists of the following two stages.

Stage 1. The elements of the reference window $\vec{x}=(x_1, x_2, ..., x_R)$, $R=ML$ and the test resolution cell $\vec{z}=(z_1, z_2, ..., z_L)$ are rank-ordered according to increasing magnitude:

(4) $$x_1^{(1)} \le x_2^{(1)} \le \ldots \le x_i^{(1)} \le \ldots \le x_N^{(1)} \text{ and } z_1^{(1)} \le z_2^{(1)} \le \ldots \le z_j^{(1)} \le \ldots \le z_L^{(1)}.$$

Stage 2. The main idea of an OS CFAR procedure is to select one main value $x_k^{(1)},\ k \in \{1, 2, ..., R\}$ and $z_{k_1}^{(1)},\ k_1 \in \{1, 2, ..., L\}$ from the sequence in (4) and to use it as estimates V and q_0 for the average noise power and the average signal power of the observed reference and test window:

(5) $$V = x_k^{(1)} \text{ and } q_0 = z_{k_1}^{(1)}.$$

The rank-ordered parameters k and k_1 of the OS CFAR procedure are chosen in such a way that the average decision threshold of the OS CFAR processor to be with a minimum value.

The target is then detected according to the following algorithm:

(6) $$\begin{cases} H_{1:} : \Phi(q_0) = 1, & q_0 \ge T_a V, \\ H_0 : \Phi(q_0) = 0, & q_0 < T_a V, \end{cases}$$

where H_1 is the hypothesis that the test resolution cells contain the echoes from the target and H_0 is the hypothesis that the test resolution cells contain white noise, signal, and multipath interference. The constant T_a is a scale factor, which is determined in order to maintain a given false alarm probability constant. The probability of target detection is determined as:

$$P_{\mathrm{d}} = P(q_0 > T_{\mathrm{a}} V \mid H_1) = \int_0^{\infty} P_V(V) dV \int_{T_{\mathrm{a}} V}^{\infty} P_q(q_0 / H_1) dq_0 , \tag{7}$$

where $P_V(V)$ is the probability density function (PDF) of the noise level estimate in the reference window and $P_q(q_0/H_1)$ is the conditional PDF of the test window, under hypothesis H_1.

The probability of false alarm is determined by substituting $s = 0$, that is:

$$P_{\mathrm{fa}} = P(q_0 > T_{\mathrm{a}} V \mid H_0) = \int_0^{\infty} P_V(V) dV \int_{T_{\mathrm{a}} V}^{\infty} P_q(q_0 / H_0) dq_0 , \tag{8}$$

where $P_q(q_0/H_0)$ is the conditional PDF of the test window, under hypothesis H_0. On the output on the corelator, we have not the analytical equation for the probability density function (PDF): of the noise level estimate in the reference and the test window, under hypothesis H_1 and H_0. Then we use Monte-Carlo simulation approach for estimation of probability performance of OS CFAR processor.

5. MATLAB Simulation model of the passive receiver in the presence of multipath and additive white gaussian noise (describing the MATLAB model)

In our investigation we use a Monte Carlo simulation approach. In this case, it is important to use a correct model, because all statistical results, which describe the behavior of our system, depend on the model correctness. Due to this reason, we use some adjustments to control the correctness of the separate parts of the model. In that way we can check the correctness of the complete model (we perform the superposition adjacent of the system). The model that we consider, consists of a simulation model of the input signals and interference, a correlator, CFAR and resolving system.

The block diagram of our model is shown in Fig. 4. The block diagram shows the blocks for formation of the pilot signal, the multipath signal, the forward scattered signal, white gaussian noise, the correlator and the CFAR detector. In the present work the PN pilot signal waveform is received from the MATLAB 6.5R13, Simulink CDMA reference blockset [24].

We use the model of base-band gaussian noise generator from [4]. It is based on Rician decomposition (9)-(10), which is easy for modeling. For this reason it is widely used in the computer simulations (Fig. 5) [4]. As it is said in theory [4], the two channel statistical independence is achieved by two independent uniformly random generators:

$$\begin{aligned} x(t) &= x_{\mathrm{c}}(t)\cos(\omega_0 t) - x_{\mathrm{s}}(t)\sin(\omega_0 t), \\ x_{\mathrm{c}}(t) &= R(t)\cos(\phi(t)), \\ x_{\mathrm{s}}(t) &= R(t)\sin(\phi(t)); \end{aligned} \tag{9}$$

$$\begin{aligned} R(t) &= \sqrt{x_{\mathrm{c}}^2(t) + x_{\mathrm{s}}^2(t)}, \\ \phi(t) &= \mathrm{arctg}\left[\frac{x_{\mathrm{s}}(t)}{x_{\mathrm{c}}(t)}\right]. \end{aligned} \tag{10}$$

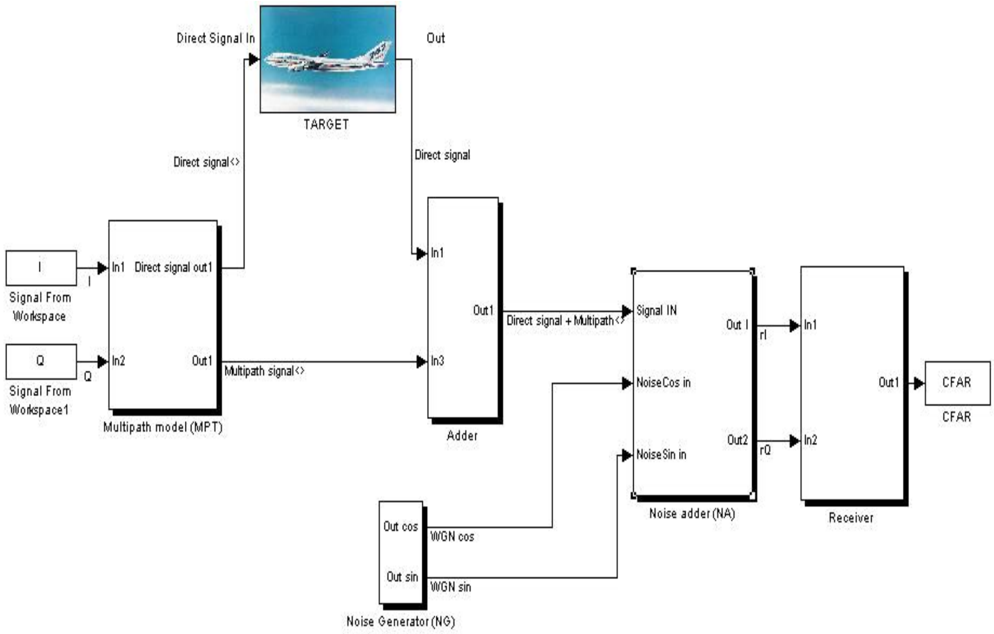

Fig. 4. Simulation model of the passive receiver in the presence of multipath

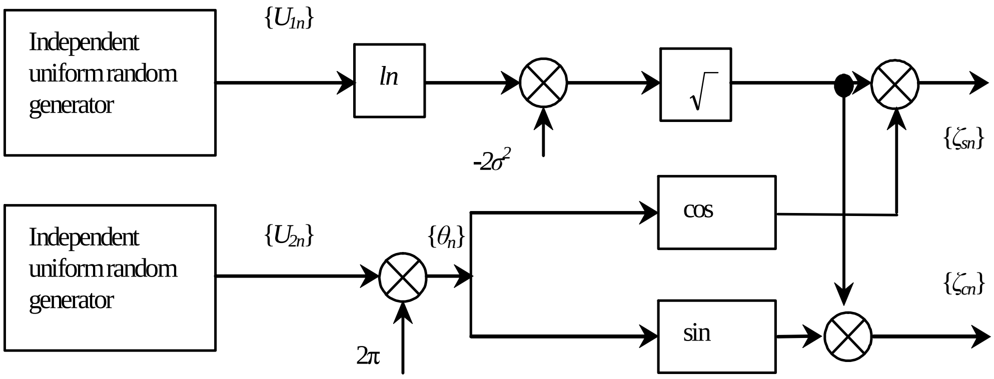

Fig. 5. Diagram of the generation of two independent Gaussian random variables from two independent uniform random variables

The MATLAB simulation model of the multipath with a direct signal issue is shown in Fig.6. The model consists of: probability of Poisson appearance controller (1), two synchronized tape delay lines (2), and a direct channel to the target.

The computer model of the correlator is made according to the theory described in [4] and 3.2. The model of OS CFAR is according to 3.3.

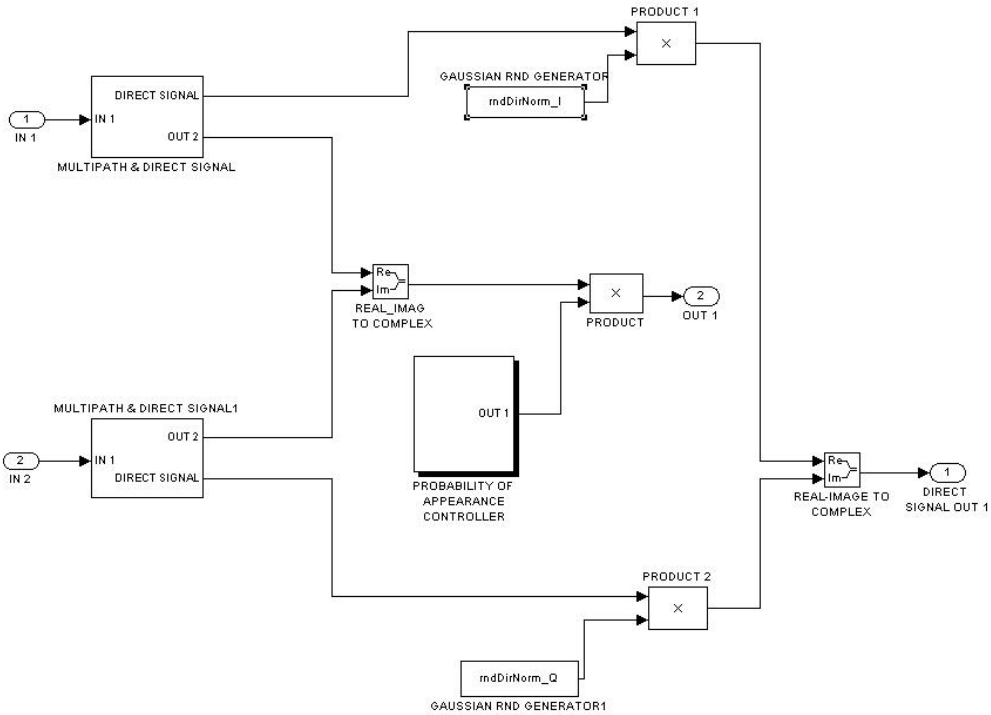

Fig. 6. The MATLAB simulation model of the multipath propagation (block diagram)

6. Simulation results

6.1. Model verification

We use the mathematical model of the correlator in [4], implemented in SUMILINK of MATLAB environment. We have obtained: simulation results of P_d depending on P_{fa}, and SNR of the pilot signal in white gaussian noise presence, and a numerical analysis in MATLAB, and P_d versus P_{fa} and SNR of the pilot signal is performed [4]. To make a verification of our simulation model we have compared both results. The chosen P_{fa} is not appropriate for radiolocation applications, because of its low order. We have chosen these quantities in order to be compared with the theoretical results in the theory of communication applications.

Fig. 7 shows the results obtained from the simulation analysis of P_d versus P_{fa} in the E_c/N_0 = 15 dB for different lengths of the signal used (a part of the pilot signal) N = 32, 64, 96 chips. The simulation results are obtained with Monte-Carlo simulation (10 000 runs). N denotes the number of chips used in the reference sequence. From the obvious coincidence between the two results we can draw the conclusion that the model of the correlator is correct. The more the reference chips increase, the more the probability of detection rises (Fig.7). In Figs. 7 and 8 the correlator probability characteristics are shown. These results are obtained with the help of numerical and simulation analysis for a signal with different length.

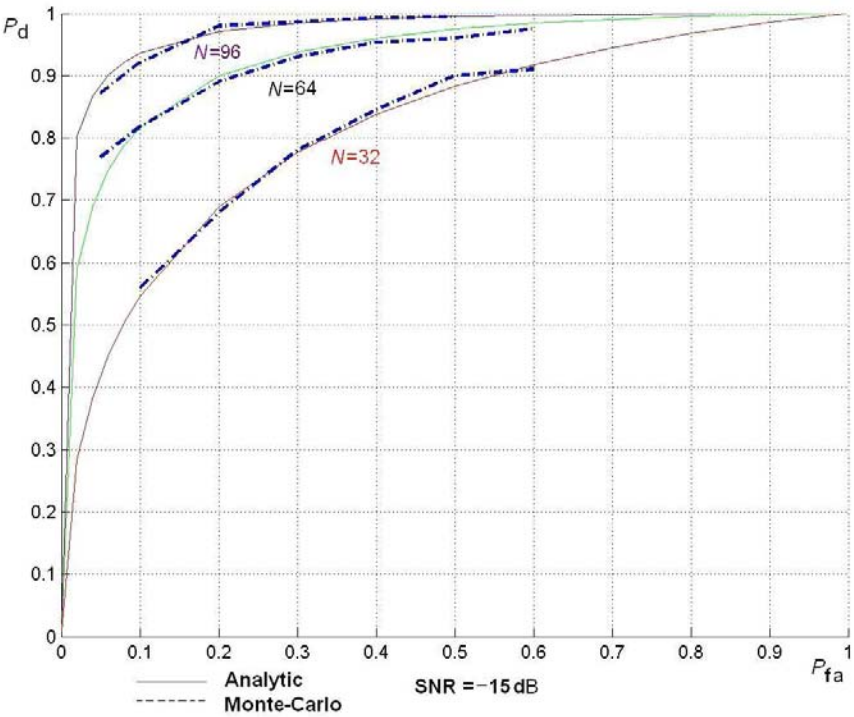

Fig. 7. Upper bound on acquisition detection probability versus false alarm probability for the case of E_c/N_0= –15 dB [7]

In Fig.7 P_d versus *SNR* is shown with constant probability of false alarm P_{fa}=0.1. We can see from the figure that in the *SNR*= –15 dB the probability of detection is P_d=0.5÷0.9 according to the length of the signal used N = 32, 64, 96. The distinctions in the Average Decision Trheshold (*ADT*) for different lengths of the filter are 3–5 dB. The probability of false alarm $P_{fa}I$ versus the detection threshold, with E_c/N_0 = –15 dB with different lengths of the used signal is shown in Fig. 8. We can see that to maintain the same probability of false alarm P_{fa}=0.1, for different lengths of the reference signal in the correlator the threshold changes drastically from 30 to 110. From the slope of the curve it follows that the longer the length of the used signal is, the higher threshold is needed for constant P_{fa}. These results are confirmed in the next chapter too. As total conclusion concerning Fig.8 and Fig.9, it is obvious that there is very good coincidence between the numerical and the simulation result, which confirms again the regularity of the results obtained.

A simulation analysis of the multipath generator is performed. At the Fig. 11 are presented a graphical results of the probability of appearance P_a in one detection cell for a different period of observation T_e=10Δ, 15Δ, 20Δ, 25Δ, 30Δ versus the number of arrived rays (Δ – is the signal's range resolution). This number is up to 30 according to the Turin's experiment. Graphical results of the theoretical Poisson distribution (dashed line), and simulation results from the block generating the multipath (solid lines) are shown. We estimate the fitting between the two results (theoretical and simulated) using the criterion for Cramer-Von Mises.

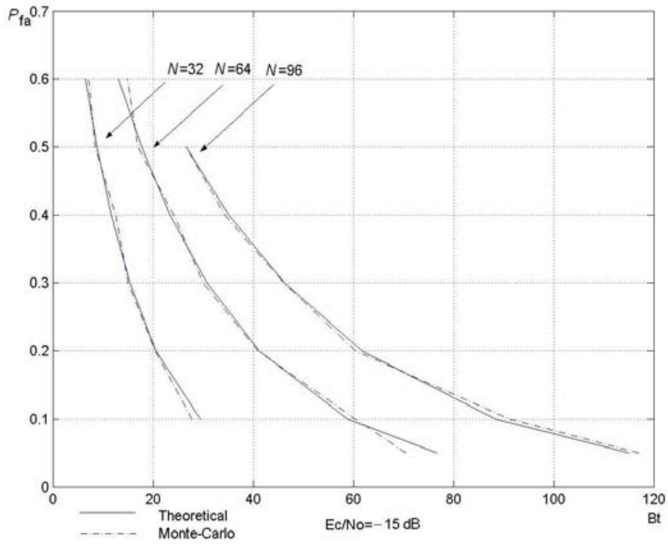

Fig. 8. Probability of false alarm versus scale factor

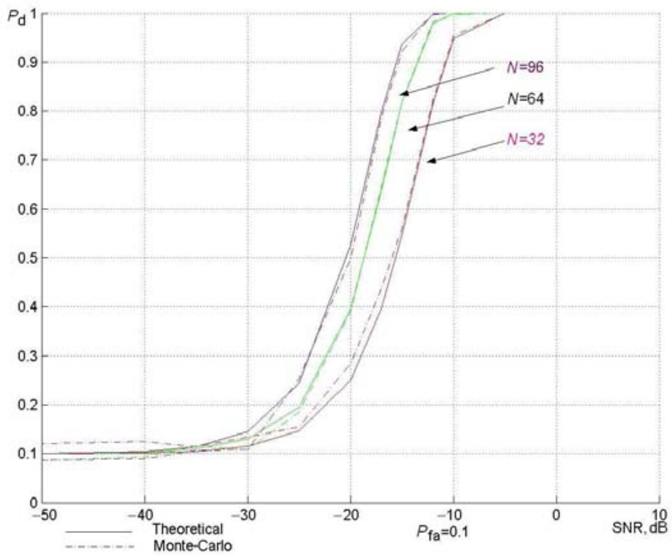

Fig. 9. Detection probability of the correlation receiver

(11) $$\omega^2 = \int_{-\infty}^{\infty} \left[P(x) - P^*(x)\right]^2 dP(x),$$

where ω^2 is the error coming from the theoretical $P(x)$ and experimental drawn $P^*(x)$.

Fig.10 shows the curve fitting error versus the time of observation T_e. As we know [24] a coincidence over 5% is a bad fit, we can conclude that the model has the right probability of appearance on the case of T_e =10Δ or P_a=0.2 and a fixed number of coming rays 30 (Figs. 10 and 11). T_e is the duration of observation window, or the length of a row from the signal matrix in our case. Therefore, in our investigations we use the probability of appearance P_a=0.2 with an observation time T_e=10Δ. In that way, with the curve fitting method we limit our model. This restriction doesn't mean that in the investigations other probability of appearances in one cell, or times of observations (see Turin's model) are allowed [9-11].

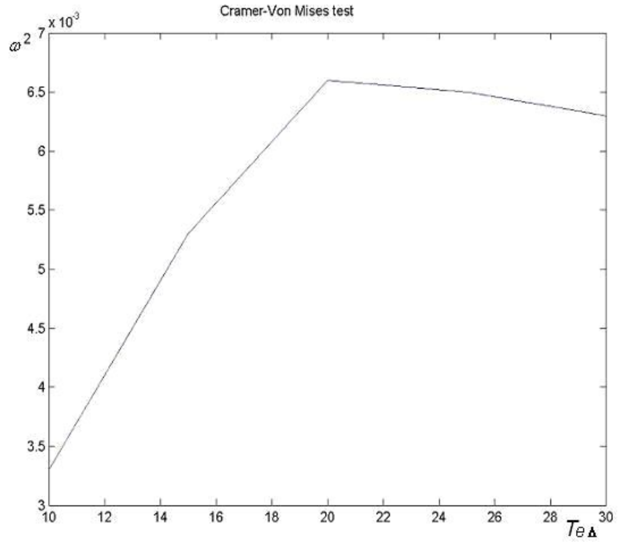

Fig. 10. Comparison of the goodness between the theoretical curve and the experimental curve according the Cramer-Von Mises test

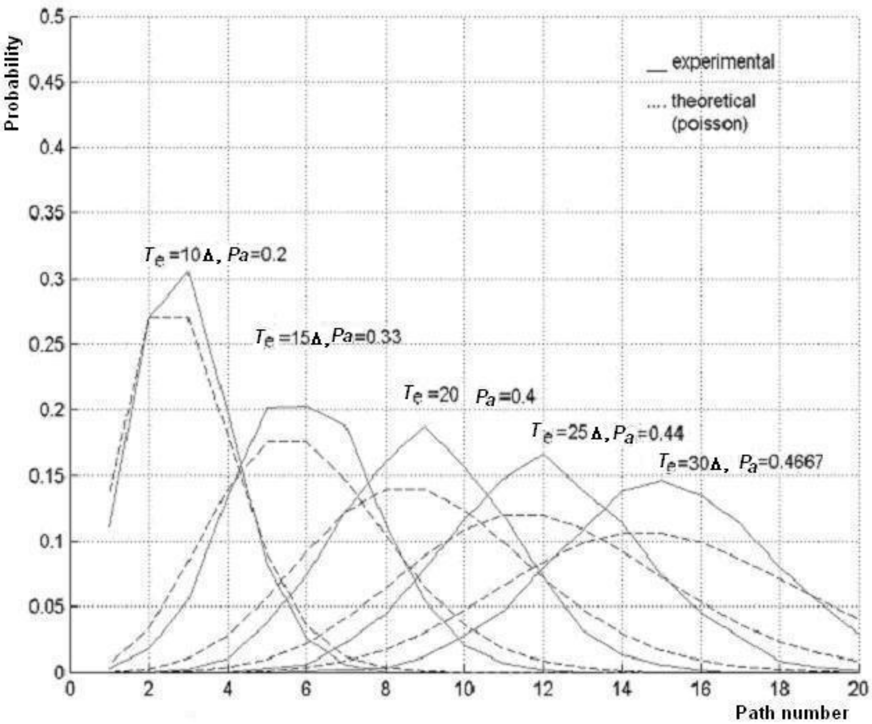

Fig. 11. Rays' time of appearance

6.2. Simulation results

The statistical characteristics of the output of a passive receiver in the presence of multipath interference are achieved by Monte-Carlo simulation, for example performing 250 runs for calculation of the detection probability and 10^4 runs for calculation of the false alarm probability for $P_{fa} = 1.10^{-3}$. In our work we consider that the average signal energy coming from the multipath propagation (the interference to noise ratio) is constant for all simulation runs and its value is INR=10 dB. The passive receiver is modeled as a sequence of a correlator for a PN sequence and an OS CFAR processor. The length of the reference correlation sequence is fixed to N=96. Fig.12 shows the signal received at the output of the correlator, as a result of mixing of the target reflected signal and the multipath interference. The investigation is performed for a fixed matrix size of the reference window 8×8. In order to achieve a reference window with this size, the matrix size at the input of the correlator should be (N+8)×8. This matrix contains target reflected signal, multipath interference and white Gaussian noise. Therefore, they overlap in this part of the matrix, and their average energies are summed in the correlator. The following characteristics are obtained by Monte-Carlo simulation: statistical average ordered statistics (OS) for the reference and the test windows; average decision threshold; detection and false alarm probability. Fig. 13 shows the statistical average OS of the mixture of white gaussian noise and compressed signal (at the output of the correlator) in the reference window.

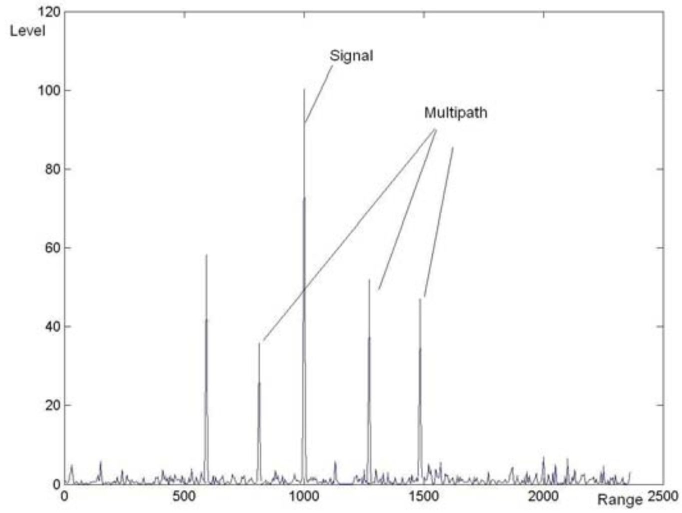

Fig. 12. The effect of mulptipath propagation on the correlation receiver’s output

This picture clarifies the influence of the signal level over the estimation. The OS has a highly expressed exponential character with great dynamics. It is obvious that the average level of the OS changes much when the SNR is increased over 10 dB. Fig.14 shows a mixture of the white gaussian noise, the signal and the multipath interference at the output of the correlator. This component has a different SNR=10, 20 dB and a probability of appearance of the multipath components P_a = 0.1 and 0.2. The reference window is of the size 8×8. The typical difference between the two domains is observed when multipath propagation is present in the reference window and there is no target signal in the averaged OS. If the mixture contains the target

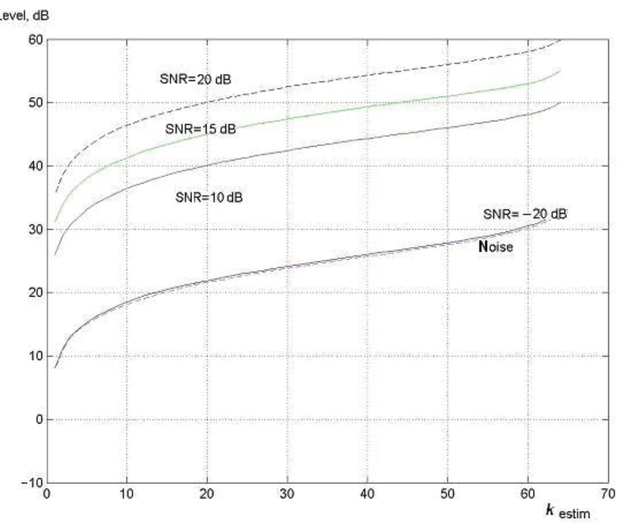

Fig. 13. Average order statistic in the presence of signal and noise for the reference window

reflected signal, the multipath interference and the white Gaussian noise, then the statistical average OS acquires the typical exponential mode, and the increasing of the SNR ratio leads to the disappearance of the existing difference between the two domains. It is due to the increased average energy resulting from the overlapping of the signals in the correlator. The absence of clearly defined border between the output noise level and the multipath interference, and the high signal dynamics, makes the proposed by H i m o n a s [18] censoring algorithm ineffective in this situation.

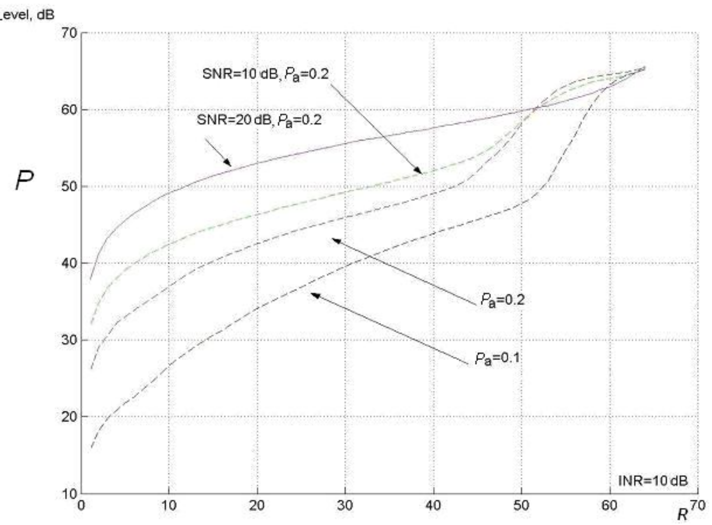

Fig. 14. Average order statistic in the presence of signa, noise, and multipath interference for the reference window

Fig.15 presents the changes of the average decision threshold (ADT) in the OS CFAR processor versus the changes of the rang-ordered parameters. The results are obtained for P_{fa} = 0.1, INR = 10 dB, P_a=0.2. The ADT of an optimal detector of a PN signal in the presence of white gaussian noise with fixed threshold and the ADT of the additional multipath interference are presented with solid lines. Both lines are obtained for fixed thresholds. It can be observed that for an appropriate combination of the two rang-ordered parameters, in the test and reference windows, the average decision threshold becomes smaller than the fixed threshold. The minimum ADT is obtained for the combination of the rank-ordered parameters k_1=(1/8)L and k=(3/16)R. In this case the improvement is about 10 dB.

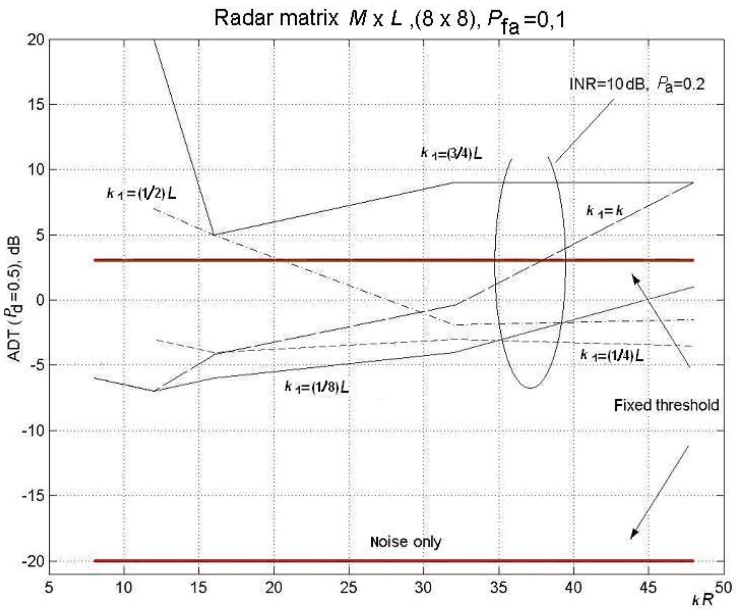

Fig. 15. Comparison between OS CFAR processor and fixed threshold detector in the presence of multipath interference and an optimal detector

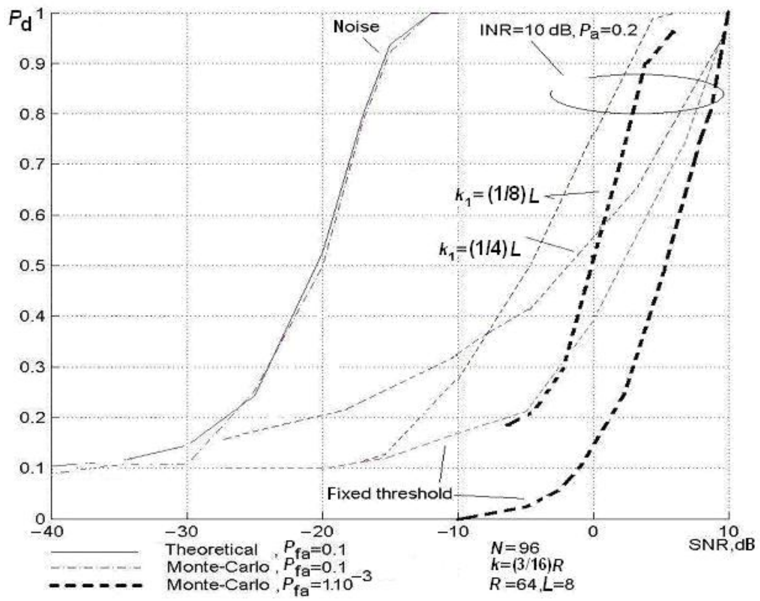

Fig. 16. Detection probability of OS CFAR in the presence of multipath interference with different probability of false alarm and rank-order parameters

The OS CFAR probability of detection versus the SNR is presented on Fig.16. This figure is similar to Fig.12. The results are received for the input parameters P_{fa}=0.1 и 0.001; P_a=0.2; INR=10 dB; k_1 = (1/8)L and (1/4)L; k = (3/16)R and (1/4)R. The detection probability is achieved by Monte-Carlo simulation and the numerical solution of equation (3) in the presence of white noise. A detector with fixed threshold demands a higher SNR for a determined value of the P_d in the presence of multipath interference. The 10 dB improvement, achieved for the OS CFAR processor with parameters k_1 = (1/8)L and k = (3/16)R in comparison with the detector with fixed threshold, is invariant to the change of the P_d.

7. Conclusion

The task for secondary application in the CDMA wireless communication networks is presented in this paper – detection of low flying target in the presence of multipath interference. The task is considered only for one cell or one pseudo-coherent radar receiver. We use the approach for detection and estimation of the moving targets in surveillance radar together with the use of some of the well-known methods for background suppressing. In this case the target detection with unknown coordinates and velocity is reduced to multi channel range target detection at fixed velocity (azimuth) channel. The use of CFAR approach enables the keeping of false alarm rate in the whole range distance. The PN sequence, used in the CDMA communication networks, is chosen as a signal model. Swerling II target signal fluctuation is used as a pulse train model. The multipath propagation considered is a flow with a Poisson probability of appearance and Rayleigh amplitude distribution. As a result when the target does not move, the target detection in one communication cell could be transformed to a target OS CFAR detection in the moving window in the range (in any channel azimuth) with apriori known parameters for signal and interference. The criterion for efficiency of OS estimations ensures minimum of the average decision threshold [20]. The use of the censoring algorithm [15] in both windows is not efficient because of lack of clearly defined difference between the white Gaussian noise and the multipath interference in the test and reference windows, as well as the high dynamics of the average OS. For these reasons, we use the OS interference evaluation. The rank-ordered parameters, for which the best evaluation of the interference is achieved in the test and reference windows, are calculated by Monte-Carlo simulation. The minimum ADT is obtained for a combination of rank-ordered parameters k_1=(1/8)L and k = (3/16)R (for a reference window of size $L \times R$). 10 dB improvement for the OS CFAR processor is achieved for P_d=0.1, compared to the detector with fixed threshold, and 5 dB for P_d=1.10^{-3}. The results can be applied for target detection in multistatic radars using the existing communication networks.

References

1. C h e r n i a k o v, M., M. K u b i k. Secondary applications of wireless technology (SAWT). – In: European Conference on Wireless Technology, Paris, 2000.
2. C h e r n i a k o v, M., D. N e z l i n, K. K u b i k. Air target detection via bistatic radar based on LEOS communication signals. – IEE Proc. – Radar Sonar navigation, Vol 149, February 2002, No 1.
3. B a k e r, C. J., A. L. H u m e. Netted Radar Sensing. – IEEE AESS Systems Magazine, February 2003.
4. L e e, J., L. M i l l e r. CDMA Systems Engineering Handbook. Artech House, 1998.
5. K y o v t o r o v, V. A. Analysis of the possibilities for of secondary applications of CDMA cellular systems. – ICEST, 2003.
6. B a r t o n, D. Modern Radar System Analysis. Artech House, 1988.
7. H a y k i n, S. Adaptive Radar Detection and Estimation. John Wiley, 1992.
8. N i t z b e r g, R. Adaptive Signal Processing for Radar. Artech House, 1992.
9. T u r i n, G. L. e t a l. A statistical model of urban multipath propagation. – IEEE Trans. Vehicul.Technol., Feb.1972.
10. T u r i n, G. L. e t a l. Simulation of urban vehicule-monitoring systems. – IEEE Trans. Vehicul. Technol., Feb.1972.
11. S u z u k i, H. A. Statistical Model for Urban Radio Propagation. – IEEE Transactions on Communications, Vol. Com-25, July 1977, No7.
12. L a z a r o v, A., C. M i n c h e v. ISAR Technique with complementary phase code modulated signals. – In: PLANS 2004 Conference, Monterey, CA, April 26-29, 2004.
13. L a z a r o v, A., C. M i n c h e v. Three dimensional image reconstruction procedure over Barcer's code modulated ISAR signals. – In: Proc. of IEEE Radar Conference 2003, Huntsville, Alabama, USA, 5-8 May 2003.
14. L a z a r o v, A. Recurrent Kalman procedure for ISAR image reconstruction from Barcer's phase code modulated trajectory signals. – Cybernetics and Information Technologies, Vol 2, 2002, No 2, 100-112.
15. B e h a r, V., C. K a b a k c h i e v, L. D o u k o v s k a. An adaptive CFAR PI processor for radar target detection in pulse jamming. – VLSI, **SP-26**, 2000, 383-396.
16. G a r v a n o v , I., C. K a b a k c h i e v. Sensitivity of API CFAR detectors towards change of input parameters of pulse jamming. – In: Proc. of the International Radar Symposium – IRS 2004, Warszawa, Poland, 2004, 233-238.
17. G a r v a n o v, I., C. K a b a k c h i e v. Sensitivity of CFAR processors toward the change of input distribution of pulse jamming. – In: Proc. of IEEE, International Conference on Radar "Radar 2003", Adelaide, Australia, 2003, 121-126.
18. H i m o n a s, S. CFAR Integration processors in randomly arriving impulse interference. – IEEE Trans., Vol. AES-30, **3**, July, 1994, No 3, 809-816.
19. G a r v a n o v, I., V. B e h a r, C. K a b a k c h i e v. CFAR processors in pulse jamming. – In: Conference "Numerical Methods and Applications 2002 ", NMA 2002. Preprint: "Lectures Notes and Computer Science ", **LNCS 2542**, 2003, 291-298.
20. R o h l i n g, H. Radar CFAR thresholding in clutter and multiple target situation. – IEEE Trans., Vol. AES-19, July, 1983, No 4, 608-621.
21. A k i m o v, P., F. E v s t r a t o v, S. Z a h a r o v. Radio signal detection. Moscow, Radio and Communication, 1989, 195-203 (in Russian).
22. S k o l n i k, M. I. Radiolocation Manual. Vol. 1. Moscow, Sovetskoe RacChannel. – IEEE Transactions on Communications, Vol. 39, Oct.1991, No 10.
24. www.mathworks.com
25. R o h l i n g, H. 25 years research in range CFAR techniques. – In: Proc. IRS-2003, Germany, 2003, 363-368.
26. G a r v a n o v, I. Methods and algorithms for supporting constant frequency of false alarm under conditions of chaos-pulse disturbances. Ph. D. Thesis, Sofia, IIT–BAS, 2003 (in Bulgarian).

Glossary

ADT	Average decision Threshold	PDF	Probability Density Function
API	Adaptive Post-detection Integration	P_d	Detection Probability
AWGN	Additive Gaussian Noise	P_{fa}	Probability of False Alarm
CDMA	Code Division Multiply Access	QPSK	Quadra Phase Shift Key
CFAR	Constant False Alarm Rate	SNR	Signal to Noise Ratio
INR	Interference to Noise Ratio	MI	Multipath Interference
OS	Order Statistic		

OS CFAR детектиране на сигнали в CDMA мрежи в присъствието на многолъчево разпространение

Христо Кабакчиев, Владимир Кьовоторов, Иван Гарванов

Институт по информационни технологии, 1113 София
E-mails: ckabakchiev@iit.bas.bg ckabakchiev@yahoo.com
vladimir_ak@yahoo.com
igarvanov@iit.bas.bg igarvanov@yahoo.com

(Р е з ю м е)

В статията се разглежда задачата за вторично приложение на CDMA комуникационни мрежи – откриване на ниско летящи обекти. Тази задача е редуцирана до детектиране на псевдослучаен (PN) сигнал с използването на пасивен корелационен приемник с OS CFAR детектор в смущения, породени от многолъчевост. Като се използва подхода на подредените статистики (OS), се оценява шумовото ниво в двата прозореца на CFAR процесора (тестов и обучаващ). Като критерий за ефективност на оценката се използва минимумът на средния праг на откриване (Average Decision Threshold). Параметрите на корелационния приемник с OS CFAR детектор са получени с Монте-Карло симулация. Резултатите могат да бъдат приложени за откриване на цели в многопозиционни радари или мрежи от радари, използващи съществуващи комуникационни мрежи.