Multipath Effect in Multilateration Surveillance System

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ABSTRACT

This paper is dedicated to the investigation of the errors, caused by multipath effect of signal propagation. Multipath effect was modelled and analyzed on the basis of polarization characteristics of received signal.

Keywords: multilateration system, multipath, polarization, linear depolarization ratio.

1. INTRODUCTION

Multilateration surveillance systems are widely deployed in airports all over the world. This system provides high accuracy of target localization even at difficult terrain scenario and inclement weather. Multilateration system is used both for airport surface and en-route surveillance (Wide area multilateration). System's principle of operation is based on the time difference of arrival technique (TDoA) [1]. The main problem which arises during the process of system implementation is optimal location of its components in order to provide high accuracy of target localization in the defined surveillance volume. This task was solved with the Genetic optimization algorithm on the basis of the Cramer-Rao Lower Bound inequality [2]. However this approach gives representation of the total error, which includes all kinds of errors that influence the system accuracy. And it is very difficult to analyze influence of particular type of error on the resultant accuracy.

Multipath effect takes place when transmitted signal travels more than one path before arrival to receiving antenna. Reflection, diffraction and scattering are related with multipath propagation. Nature of the propagation depends on the transmitted signal characteristics, transmitter-receiver distance and propagation environment. Aim of this research is to investigate influence of multipath signal propagation on the resultant accuracy of target localization and to take into account this effect on the stage of system implementation.

2. SIMULATION RESULTS

Reflected signals render variations in signal power density, polarization and time of arrival. Therefore recognition of multipath signal could be performed by means of each parameter. For example, time of arrival of the reflected signal to the receiver will be greater than of direct one. Elimination of this effect can be achieved by implementation of propagated time threshold between actual and expected time of arrival [3].

Power density and polarization of reflected signal depends on the electrical properties of reflection surface (conductivity and relative permittivity), frequency of transmitted signal and propagation medium. ICAO established thresholds for minimum and maximum levels of received signal strength (18.5-27 dB/W). As to the polarization, it should be predominantly vertical [4].

Resultant field intensity for reflected signal is:

$$E_{tot}^{refl} = E_h^{refl} + E_v^{refl}, \tag{1}$$

where E_h^{refl} and E_v^{refl} are field intensities in horizontal and vertical planes correspondently:

$$E_h^{refl} = \Gamma_h \cdot E_h^{inc}, \tag{2}$$

$$E_v^{refl} = \Gamma_v \cdot E_v^{inc}, \tag{3}$$

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where Γ_h and Γ_v are reflection coefficients for horizontal and vertical polarization [5]:

$$\Gamma_h = \frac{\sin\theta - \sqrt{\varepsilon - \cos^2\theta}}{\sin\theta + \sqrt{\varepsilon - \cos^2\theta}}, \tag{4}$$

$$\Gamma_v = \frac{\varepsilon\sin\theta - \sqrt{\varepsilon - \cos^2\theta}}{\varepsilon\sin\theta + \sqrt{\varepsilon - \cos^2\theta}}, \tag{5}$$

where $\varepsilon = \varepsilon_r - j\dfrac{\sigma}{\omega\varepsilon_0}$ is the complex dielectric constant,

σ is the conductivity of the reflection surface,

ε_r is the relative permittivity of reflection surface,

θ is grazing angle of the signal.

E_h^{inc} and E_v^{inc} are field intensities of the incident signal.

In this work we analyze the field intensity of the reflected signal and its polarization. Initial field intensity for transmitted signal was taken of $E = 300$ Volts/m. Polarization of the transmitted signal is vertical, frequency of transmitted signal is $f = 1090$ MHz. Calculation results of signal intensities for different reflection surfaces (concrete, medium dry ground and sea water) are shown in Fig. 1-3 where red and blue color correspond to horizontal and vertical component correspondingly.

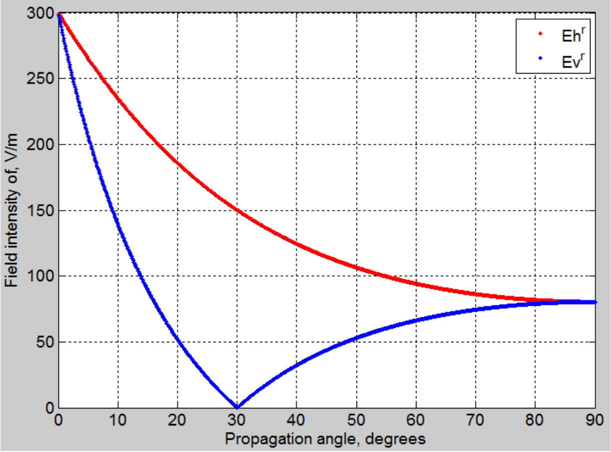

Figure 1 – Dependence of signal intensity components on propagation angle for concrete

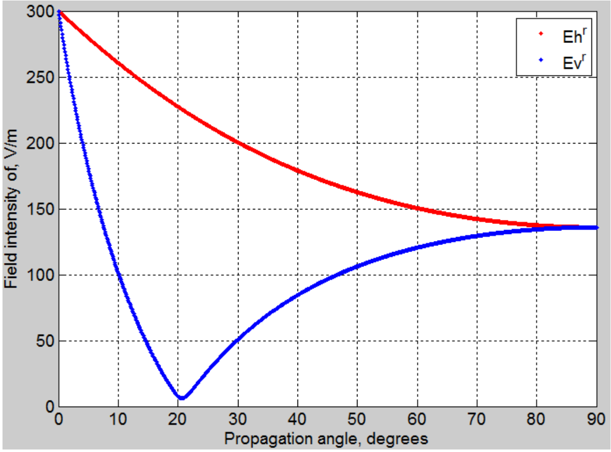

Figure 2 – Dependence of signal intensity components on propagation angle for medium dry ground

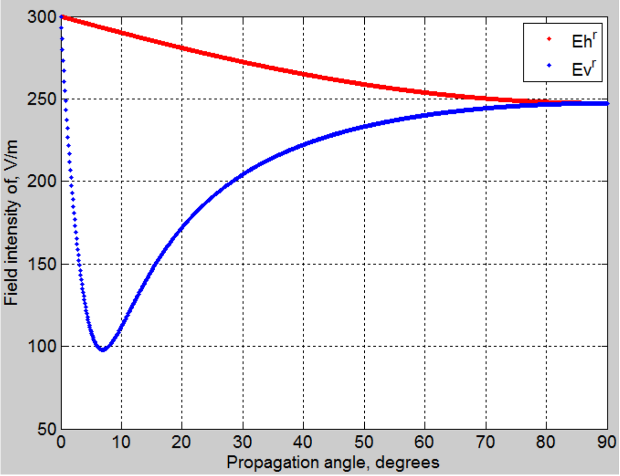

Figure 3 – Dependence of signal intensity components on propagation angle for sea water

As it is seen from Fig.1, Fig.2, and Fig.3, the values of field intensities for horizontal and vertical components are different. These values depend on the propagation angle and properties of the reflection surface. However, a horizontal component is always present in the reflected signal. When antenna receives both vertical and horizontal components, the presence and value of the horizontal component of field intensity might be used as an indication that received signal is reflected.

Let us analyze the reflected signals with the help of linear depolarization ratio (LDR) that is typically used in polarimetric meteorological radar:

$$LDR = 10\log\frac{P_{hv}}{P_{vv}} , \tag{6}$$

where P_{vv} is the received signal power of vertical polarization component (co-polarized), P_{hv} is the received signal power of the cross-polarization component. Corresponding graphs of LDR calculation for corresponding reflection surfaces are shown on Fig. 4-6.

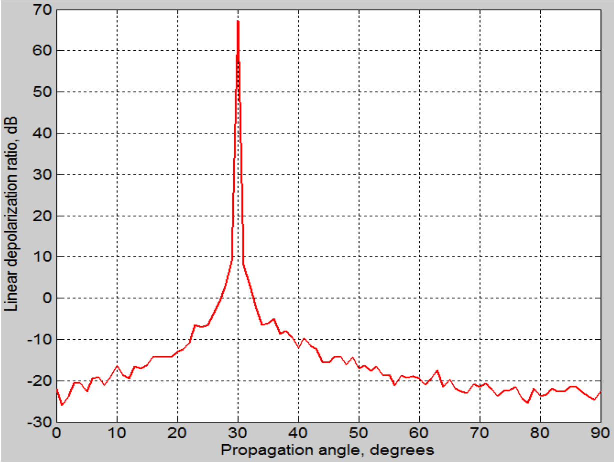

Figure 4 – Dependence of LDR on propagation angle for concrete

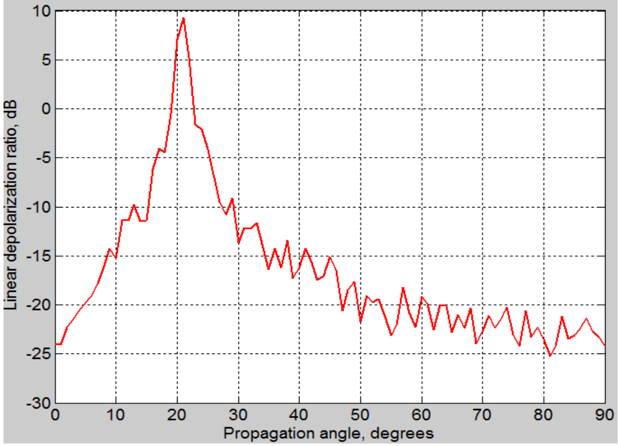

Figure 4 – Dependence of LDR on propagation angle for medium dry ground

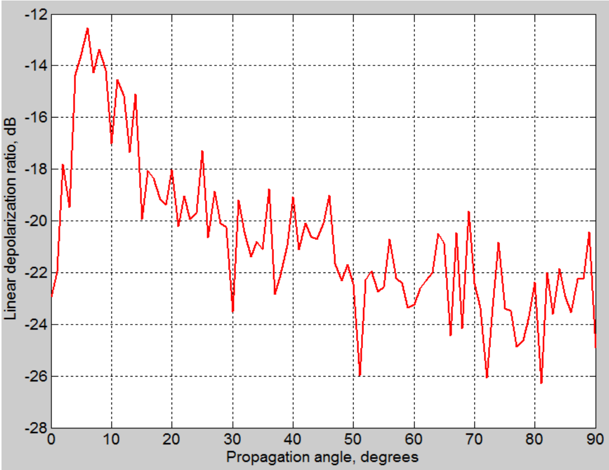

Figure 6 – Dependence of LDR on propagation angle for concrete

As it is seen from Fig. 4-6, LDR parameter represents characteristics of the reflection surface and it depends on the propagation angle. At Brewster's angles LDR is positive, therefore co-polar component is equal to zero (in our case it is vertical component). Therefore when signal is reflected at the angle, which is equal to the Brewster's one, high value of LDR could be used as an indicator of reflected signal.

In case harmonic oscillations a tilt angle of the polarization ellipse is [6]:

$$\varphi = arctg\frac{E_{vv}}{E_{hv}}, \tag{7}$$

where E_{vv} is an amplitude of the vertical component of the field intensity of received signal;

E_{hv} is an amplitude of the horizontal component of the field intensity of received signal.

Using relation between field intensity and power density:

$$LDR = 10\log\frac{P_{hv}}{P_{vv}} = 10\log\left(\frac{E_{hv}}{E_{vv}}\right)^2 = 10\log\left(\frac{1}{tg\varphi_r}\right)^2, \tag{8}$$

where φ_r is the tilt angle of the polarization ellipse of received signal.

In the case of LOS (Line of Sight) signal with vertical polarization, tilt angle of polarization ellipse in the received signal is $\varphi_r = 90^0$. This angle changes when reflecting from different objects. Degree of change depends on the geometrical and electromagnetic properties of reflecting object. We assumed that after reflection, polarization angle of the transmitted signal was changed on some value $x = 0^0 \div 45^0$. Fig. 7 shows dependence of LDR on the changed value of polarization angle. Of course, these calculations have been done for ideal case. They just demonstrate the principle, that is, LDR is one of possible polarimetric parameters, which are sensitive to change of polarization that can happen due to reflection of the signal from complex and non-symmetrical objects.

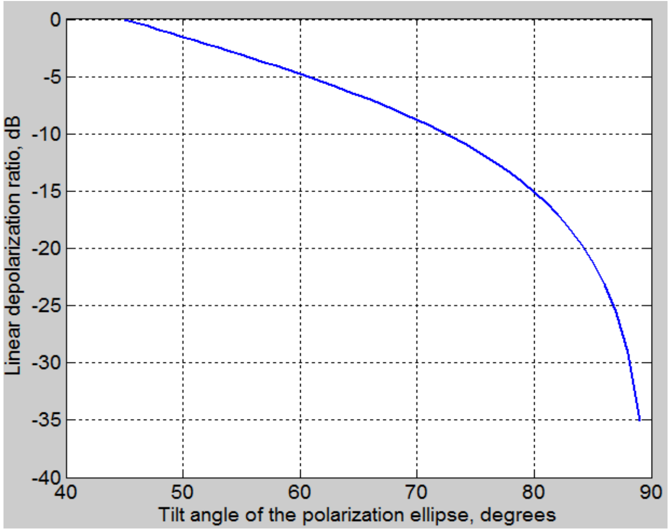

Figure 7 – Dependence of the linear depolarization ratio on the angle of polarization

Vertically polarized signal, which passes on the LOS trajectory, always has some horizontal component. This component is small, in comparison to the vertical one, and can be caused by the influence of different factors (noise, precipitation, etc.). We established this horizontal component is normally distributed random value ξ. Similar value was also added to the x, which in this case indicates some uncertainties in changes of tilt angle. Probability density functions of LDR are shown on Fig. 8 and Fig. 9 at different standard deviations of ξ.

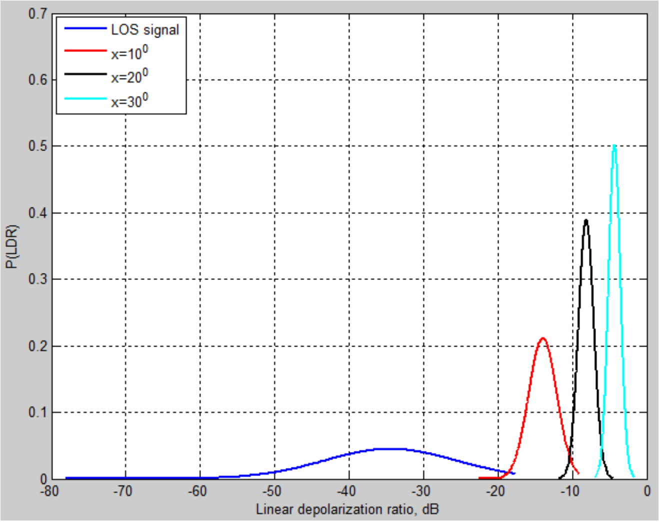

Figure 8 – Probability density functions of LDR (at $\sigma = 2$ for LOS and multipath signals)

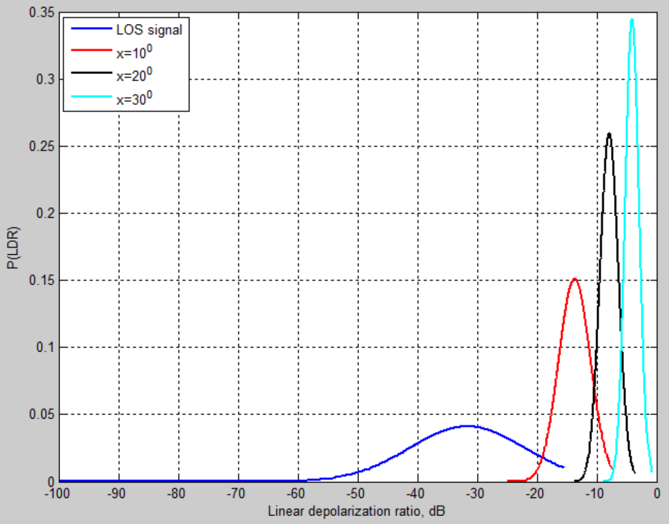

Figure 9 – Probability density functions of LDR (at $\sigma = 3$ for LOS and multipath signals)

As it is seen form Fig.8 and Fig.9 PDF of LOS signal intersects with PDF of multipath signal. Therefore some level of ambiguity is present. This level depends on the change in polarization angle of the multipath signal (the less is the change the higher is ambiguity) and on the standard deviation of random value ξ.

3. CONCLUSIONS

Obtained results show the change of signal polarization characteristics after reflection from complex objects. The higher reflectivity of the objects the harder to recognize LOS signal from multipath one. Nevertheless, the idea to use polarimetric properties of the signal to smooth away the problems of multipath propagation looks promising.

Further work will be focused on improvement of the model making calculations more realistic. Then such modeling should be checked by the real experimental data. The threshold of polarimetric informative parameters (like LDR) for LOS signal must be established.

These results can be used in the development of multipath scenario for specified surveillance area in order to predict influence of multipath signal propagation on the resultant accuracy of target localization and in the choice of the receiving antenna.

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