Considerations about the Modeling of Software Defined Radio for Mobile Communications Networks

Lucian Morgos and Nistor Daniel Trip
Department of Electronics,
University of Oradea, Faculty of Electrical Engineering and Information Technology,
1, Universitatii St., 410087, Oradea, Romania, E-Mail: lmorgos@uoradea.ro, dtrip@uoradea.ro

Abstract* – This paper presents the contribution of the authors regarding the modeling of a software defined radio - SDR. The digital radios are base on ADC interfaces that convert the base band signal in a digital format and a DSP that accomplish the demodulation according to a suitable digital processing algorithm. To test the model the authors chosen a radio signal with a Weibull distribution quadrature amplitude modulation QAM that pass through a scattering medium till the RF front end of the SDR. The fading effect was also taken into consideration. The results of the demodulation using the proposed model of SDR were compared with a Rayleigh distribution. The simulation results made by the help of MATLAB program emphasize the effects of the quantization levels of the ADC circuit.

***Keywords:* software defined radio, envelope distribution, scattering, quadrature amplitude demodulation**

I. INTRODUCTION

In the classic method, the whole processing chain of received signals into a receiver is treated by means of analogical circuits. This classic approach encounters some disadvantages such as: immunity to the noise is reduced; the interference produced by strong signals with the frequency closed to the frequency of the received signals can not be canceled due to the poor characteristics of the filtering blocks, to mention only few of them. To overpass all these drawbacks, expensive professional equipments must be used. During the time, in order to improve the performances of the radio equipments, some functional stages of the receivers, such as: PLL, local oscillator, mechanical user interface, mechanical tuning and so on where changed with their digital counter parts circuits: digital PLL, frequency synthesizer, LCD driven by a digital circuit and digital tuning respectively. Tacking into consideration the technological development in the field of analog to digital converters ADC and digital signal processors DSP one can observe the existence of a new possibility to accomplish radio equipment. Based on this two key component parts, the main idea in a software defined radio is to digitize the received signal in a point as closed as possible to the RF input of the receiver [1]. It is obvious that the input RF front end of the receiver can not be removed and also the heterodyne stage that “brings” the received RF signal into the base band. Using a DSP, the software defined radio can treat in real time more than one band or one channel, as in the case of the mobile communication networks. The SDR [1] could also operate in multimode simultaneously. At least at a glance, SDR is flexible, implementing many performing tasks with a unique hardware configuration as it will be mentioned in a later section of the paper. Another valuable advantage of a SDR is the fact that on the same hardware could be updated the programs or changes them with other news with more facilities and performances. In this paper is presented a model for a mono band mono channel SDR and a test methodology to check the basic performances of this kind of receiver.

To test the SDR model was used a radio signal with a distributed Weibull quadrature amplitude modulation that pass through a scattering medium till the RF front end of the SDR. This signal pass a scattering medium with a Rayleigh fading. The base band of the received signal is then digitized by means of an ADC circuit and then QAM demodulated by a DSP.

The authors focus their investigation on the probability distribution and the power outage probability of the envelope of the demodulated signals, tacking into account the resolution of the ADC. The results of the demodulation using the proposed model were compared with a theoretical model based on Rayleigh distribution – [2], [3], [4]. All simulations were made by the help of MATLAB program.

II. MODELING CHANNEL WITH RAYLEIGH FADING

We suppose as radio waves propagate from a transmitting antenna, and travel through free space undergoing absorption, reflection, refraction, diffraction, and scattering. They are greatly affected by the ground terrain, the atmosphere, and the objects in their path, like buildings, bridges, hills, trees and so on. These multiple physical phenomena are responsible for most of the characteristic features of the received signal. In most of the mobile or cellular systems, the height of the mobile antenna may be smaller than the surrounding structures. Thus, the existence of a direct or line-of-sight path between the transmitter and the receiver is highly unlikely.

In such a case, propagation is mainly due to reflection and scattering from the buildings and by diffraction over and/or around them.

So, in practice, the transmitted signal arrives at the receiver via several paths with different time delays creating a multipath situation as in Fig.1.

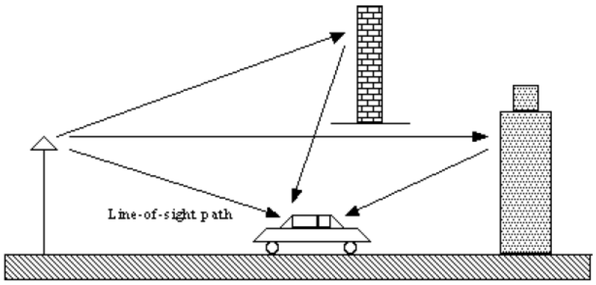

Fig.1. Mechanism of radio propagation in a mobile environment.

At the receiver, these multipath waves with randomly distributed amplitudes and phases combine to give a resultant signal that fluctuates in time and space. Therefore, a receiver at one location may have a signal that is much different from the signal at another location, only a short distance away, because of the change in the phase relationship among the incoming radio waves. This causes significant fluctuations in the signal amplitude.

The mobile antenna, instead of receiving the signal over one line-of-sight path, receives a number of reflected and scattered waves, as shown in Fig.1. Because of the varying path lengths, the phases are random, and consequently, the instantaneous received power becomes a random variable. In the case of a demodulated carrier, the transmitted signal at frequency ω_c reaches the receiver via a number of paths, the i^{th} path having an amplitude a_i, and a phase φ_i. If we assume that there is no direct path or line-of sight LOS component, the received signal s(t) can be expressed as

$$s(t) = \sum_{i=1}^{N} a_i \cos(\omega_c t + \phi_i) \quad (1)$$

where N is the number of paths. The phase φ_i depends on the varying path lengths, changing by 2π when the path length changes by a wavelength. Therefore, the phases are uniformly distributed over $[0, 2\pi]$. When there is relative motion between the transmitter and the receiver, eqn. (1) must be modified to include the effects of motion induced frequency and phase shifts.

Let the i^{th} reflected wave with amplitude a_i and phase φ_i arrive at the receiver from an angle ψ_i relative to the direction of motion of the antenna. The Doppler shift of this wave is given by

$$\omega_{di} = \frac{\omega_c v}{c} \cos\psi_i \quad (2)$$

where v is the velocity of the mobile, c is the speed of light ($3x10^8$ m / s), and the ψ_i's are uniformly distributed over $[0, 2\pi]$. The received signal s(t) can now be written as

$$s(t) = \sum_{i=1}^{N} a_i \cos(\omega_c t + \omega_{di} t + \phi_i) \quad (3)$$

Expressing the signal in phase and in quadrature form, eqn. (3) can be written as

$$s(t) = I(t)\cos\omega_c t - Q(t)\sin\omega_c t \quad (4)$$

where the in phase and in quadrature components are respectively given as

$$I(t) = \sum_{i=1}^{N} a_i \cos(\omega_{di} t + \phi_i) \quad (5)$$

$$Q(t) = \sum_{i=1}^{N} a_i \sin(\omega_{di} t + \phi_i) \quad (6)$$

The envelope R is given by

$$R = \sqrt{[I(t)]^2 + [Q(t)]^2} \quad (7)$$

When N is large, the in phase and quadrature components will be Gaussian [7]. The probability density function of the received signal envelope, f(r), can be shown to be Rayleigh given by

$$f(r) = \frac{r}{\sigma^2} \exp\left\{-\frac{r^2}{2\sigma^2}\right\}, \quad r \geq 0. \quad (8)$$

The multipath faded signal was simulated using MATLAB to understand the relationship between the number of paths N and statistics of the received signal. For a given time instant, the received signal in the case of a stationary receiver was generated using equation (1). Generating the signal using equation (3) allowed the inclusion of Doppler effect induced by motion. The path amplitudes a_i were taken to be Weibull distributed and were generated using the function weibrnd from the Statistics Toolbox. The 2- parameter Weibull distribution allowed the flexibility of making it easy to see the effects of varying scattering amplitudes. The phase φ_i were taken to be uniform in $[0, 2\pi]$ and were generated using the function *unifrnd* from the Statistics Toolbox. The signal was then demodulated to get the in phase and in quadrature components, using the command *demod* from the Signal Processing Toolbox. Subsequently, the envelope was calculated using equation (7).

III. SOFTWARE DEFINED RADIO MODEL

The proposed model of the SDR is based on the next circuit diagram – figure 2.

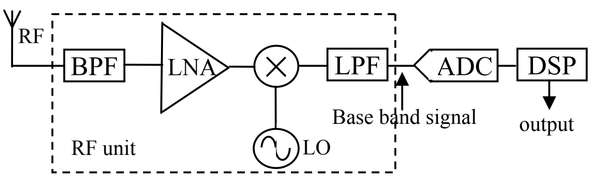

Fig.2 Basic structure of software defined radio

In Fig.2, the RF signal that comes from the antenna is passed through a band-pass filter then amplified in a low noise RF amplifier LNA. Mixing the signal from the output of the LNA with a harmonic signal produced locally produce a signal that after a low-pass filtering becomes the modulated base band signal that contains the useful information. The modulated signal in the base band, in the frequency domain, it spread on a channel that could be one of a mobile network system. This signal is digitized by the

help of a wide band ADC. The digitized signal is then processed by the help of the DSP. The DSP main functions are demodulation, filtering and interfacing with other equipments based on specific standards. The interface with other equipments is also a function of a program that runs on the DSP. Since a program can be updated, modified, enhanced and so on, on can observe that the SDR are very flexible and reconfigurable, fact that emphasizes the new facilities offered by these radios.
In the case in which the carrier of the RF received signal supported a quadrature amplitude modulation at the emission, the demodulation process based on the DSP are presented in the next circuit diagram – Fig.3.

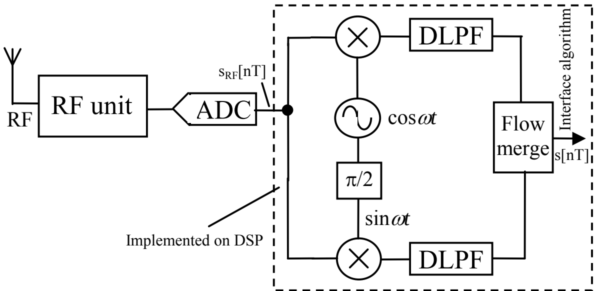

Fig.3 Circuit diagram for a QAM demodulation based on a DSP

The circuit diagram presented above can be written the next relation (9):

$$s[n] = [\sin \omega t \cdot h(t - nT_S) + \ldots \\ \ldots + \cos \omega t \cdot h(t - nT_S)] \cdot s_{RF}[n] \quad (9)$$

where T_S is the sampling period imposed by the ADC and DLPF are digital low-pass filters.

IV. SIMULATION RESULTS

To test the SDR model was used a radio with the carrier frequency 900MHz. The amplitude of the transmitted signal has a Weibull distribution and the modulation method is QAM. In Fig.4 are presented the signal at the RF front end of the receiver and its components: RF signal with Rayleigh fading and, in the last three time diagrams, in phase, in quadrature and envelope components of the demodulated signal.

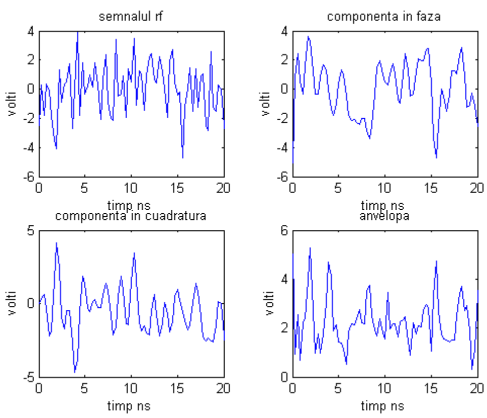

Fig.4 Received signals at the RF front end of the SDR

This signal passes through a scattering medium till the RF front end of the SDR. The medium produce 10 propagation paths. Using the probability distribution of the envelope in comparison with the theoretical Rayleigh distribution is shown in the next figure – Fig.5.

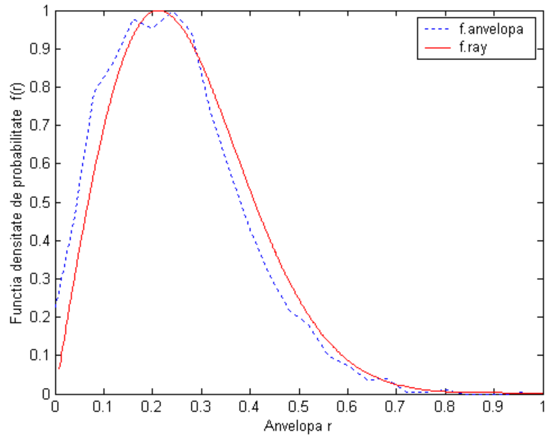

Fig.5 Comparison between the computed probability distribution of the envelope and theoretical Rayleigh probability distribution

In the next figure – Fig.6, is presented a comparison between the theoretical and computed outage power of the demodulated signal.

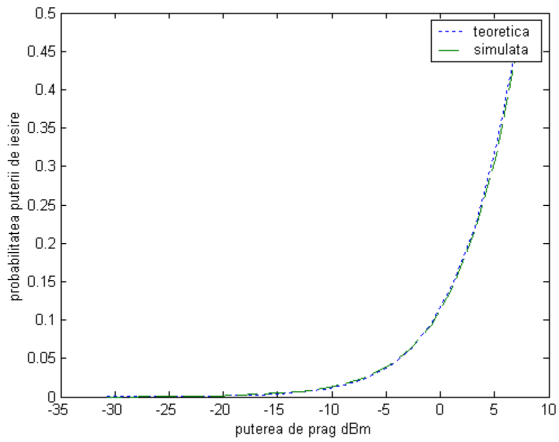

Fig.6 Comparison between the theoretical and computed power outage probability of the envelope

The next figures shown the probability distribution and the outage power of the envelope using the proposed model of the SDR. The base band width of the signal at the input of the ADC circuit is 200 kHz according the channel specifications. Tacking into account this condition, the sampling frequency of the ADC circuit was 1 MHz. The simulations were made for two different resolution of the ADC. First simulations were accomplished by 8 bit resolution and the last simulations were made using 12 bit resolution. In all next figures, the simulation results with the two resolutions were compared with the theoretical Rayleigh probability distribution and power outage probability of the envelope to check the characteristics and performances of the SDR using the proposed model.

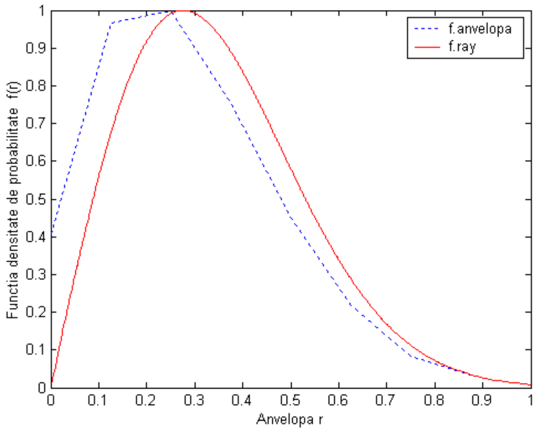

Fig.7 Probability distribution of the envelope using SDR model and 8 bit resolution for the ADC circuit

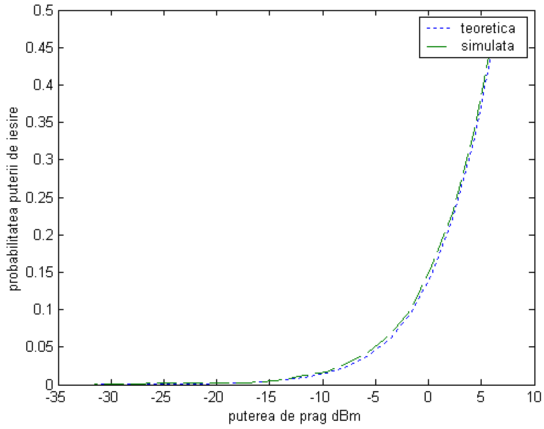

Fig.8 Power outage probability of the envelope using SDR model and 8 bit resolution for the ADC circuit

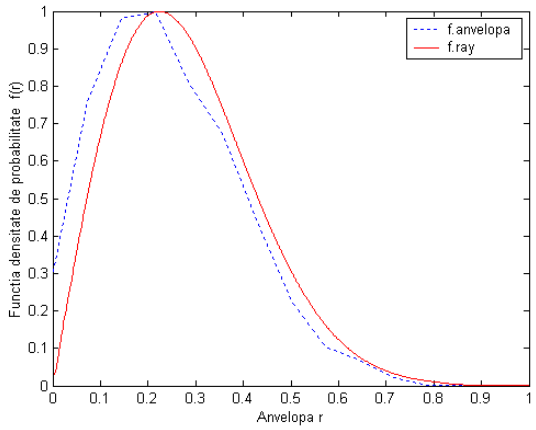

Fig.9 Probability distribution of the envelope using SDR model and 12 bit resolution for the ADC circuit

As one can see, the SDR model, presented in this paper, offers valuable results which are in good agreement with the theoretical model.

The resolution of the ADC influences the results in the following manner: the higher the resolution the more precisely results are obtained. Increasing the sampling frequency of the ADC circuit up to 1.2 MHz, did not bring more accurate results.

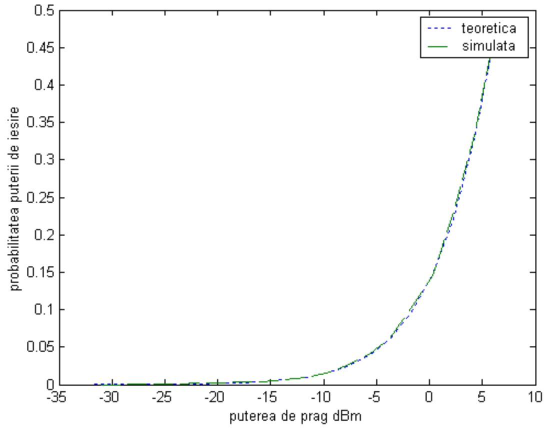

Fig.10 Power outage probability of the enevelope using SDR model and 12 bit resolution for the ADC circuit

V. CONCLUSIONS

In this work, the authors presented a model for a software defined radio together with a test method that is useful to evaluate the performances of the equipment in the presence of scattering propagation medium. The simulation result shown the influence of the resolution in the digitizing circuit and the number of the propagation path when the transmitter moves with a preselected speed. Based on the simulation results, the authors of the paper suggest the implementation of the proposed model by the help of the ADS7950 ADC and TMS320C5510 DSP, made by TI Inc.

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