SIMULATION OF A DIGITAL COMMUNICATION SYSTEM

Alpaslan Güngör[1], *Feza Arıkan*[2], *Orhan Arıkan*[3]

[1]Türk Telekomünikasyon A.Ş., Aydınlıkevler, Ankara
+(90) 312 555 18 19, alparslan.gungor@turktelekom.com.tr
[2]Department of Electrical and Electronical Engineering, Hacettepe University, Beytepe, Ankara
+(90) 312 297 70 95, arikan@hacettepe.edu.tr
[2]Department of Electrical and Electronical Engineering, Bilkent University, Bilkent, Ankara
+(90) 312 290 12 57, oarikan@ee.bilkent.edu.tr

ABSTRACT

In this paper, basic components of a digital communication system are simulated by a computer program. The simulation program is modular and flexible to incorporate any future additions and updates. The simulation program allows the user to choose from various channel models, transmitter and receiver antenna systems, modulation and channel coding techniques. A communication system is defined by various parameters including the source, coding, modulation, antenna systems. In order to facilitate the input of these parameters and follow the flow of the simulation, the Graphical User Interface (GUI) is designed for convenience to the user. The input parameters can both be entered from the GUI or from prepared user files. The major contribution of this simulation system to the existing communication simulators is the addition of flexible antenna systems both at the transmitting and receiving ends. With this simulation program, the antenna arrays can be located anywhere on Earth, on any platform and array elements can be placed on the platform by any desired orientation. The simulation program results are compared with both theoretical computations and commercial simulator results and excellent agreement is observed in both cases.

1. INTRODUCTION

In this study, basic components of a digital communication system are simulated with channel models and noise by using flexible antenna systems both at the transmitting and receiving ends. As shown in Figure 1, a digital communication system is made up of both analog and digital parts. The digital part consists of digital source, source encoder-decoder, channel encoder-decoder and digital modulator-demodulator, and the analog part consists of analog source, transmitter and receiver antenna systems, channel models and noise models. The developed simulation program is capable of inputing both digital and analog sources. For analog inputs like speech signals, the source encoder-decoder uses Linear Predictive Coding (LPC). For the time being, there is no coding techniques for digital sources. In the channel encoder-decoder, Hamming, Bose-Chaudhuri-Hocquenghem (BCH) and Reed-Solomon (RS) error correction techniques are implemented. For the modulator/demodulator units, Binary Phase Shift Keying (BPSK), Coherent Frequency Shift Keying (CFSK) and Quadrature Phase Shift Keying (QPSK) are implemented. The simulation program allows the user to add other desired coding-decoding techniques and modulation-demodulation techniques easily.

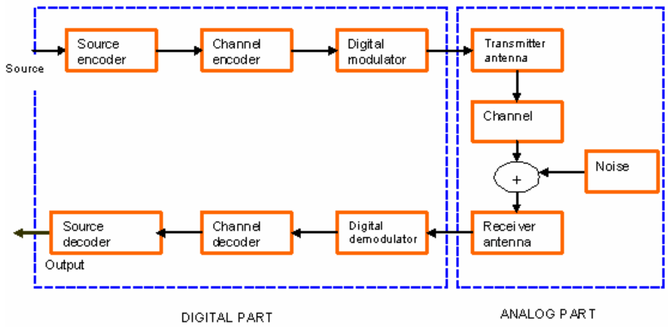

Figure 1: A Generic Digital Communication System

The antennas are transducers between free-space and transmitter and receiver systems. The antennas used in simulation program are narrowband antennas that are designed to communicate in VHF-UHF range. The readily incorporated antennas can be listed as electric dipole, magnetic dipole (loop), slot, rectangular aperture, circular aperture, microstrip and horn antennas. By using these antenna types, linear, planar or desired configuration of the arrays can be constructed with the desired number of elements. The simulation program allows the user to position the antenna arrays anywhere on Earth, on any platform. The antenna elements can be placed on the platform independent of each other with any desired orientation. Each antenna can be fed by a different amplitude and phase. In the simulation program, Additive White Gaussian Noise

(AWGN) channel and Rayleigh fading channel are implemented. Due to a large number of various parameters to define the communication system, the user can enter the parameters from previously prepared files or from the screen by the help of a user friendly menu in Graphical User Interface (GUI). The simulation program neglects the coupling between the antennas and near-Earth effects. These missing corrections can be easily incorporated to the existing program in the future. In order to test the performance of the simulation program, the results are compared with both theoretical computations and commercial simulator outputs. It is observed that excellent agreement is observed and the simulator can be further developed to be used in both analytical and practical studies to test cases where experimentation is expensive and new analytical coding, modulation, diversity, array design techniques are to be implemented. In the first section, a brief review of antenna array theory is presented. The simulation results are provided in second section.

1. BRIEF REVIEW OF ANTENNA ARRAYS

A generic antenna array consists of M non-uniformly oriented elements is shown in Figure 2.

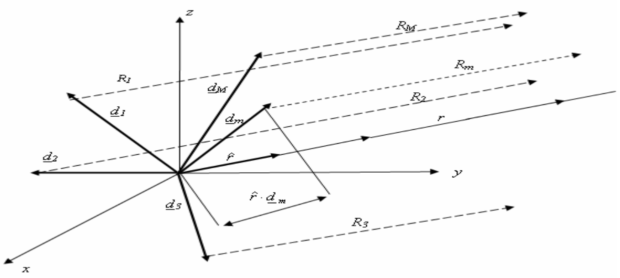

Figure 2: A generic M-element array.

The far-zone electric field radiated by a reference antenna located at the origin is given by

$$\underline{E}_0(\underline{r}) = jk_0 Z_0 \frac{e^{-jk_0 r}}{4\pi r} \underline{F}(\theta,\phi) \tag{1}$$

where $\underline{F}(\theta,\phi)$ electric field pattern of the antenna, [1]. For each antenna shown in Figure 2, the electric field radiation is given by

$$\underline{E}_m(\underline{r}) = jk_0 Z_0 \frac{e^{-jk_0 R_m}}{4\pi R_m} \underline{F}_m(\theta,\phi) \tag{2}$$

For far zone where $|\mathbf{r}| >> d_m$, where $m = 1,2, \ldots, M$, the rays from all of the antennas in the array are essentially parallel. Thus the distance from mth antenna to the far-field point of interest can be written as $R_m \approx r$ in the amplitude factor. However, this approximation can not be used in the exponential function and the distance R_m is given by

$$R_m = r - \hat{r} \cdot \underline{d}_m \tag{3}$$

As a consequence, the phase difference between mth antenna and the reference antenna is equal to $k_0 \hat{r} \cdot \underline{d}_m$. The total field of the array consists of M elements can be given by

$$\underline{E}(\underline{r}) = jk_0 Z_0 \frac{e^{-jk_0 r}}{4\pi r} \sum_{m=1}^{M} A_m \underline{F}_m(\theta,\phi) e^{jk_0 \hat{r}\cdot \underline{d}_m} e^{j\beta_m} \tag{4}$$

In (4), A_m and β_m represent amplitude and phase of the excitation in mth element. If all elements have same antenna pattern, $\underline{F}_m(\theta,\phi) = \underline{F}(\theta,\phi)$, (4) can be given by

$$\underline{E}(\underline{r}) = jk_0 Z_0 \frac{e^{-jk_0 r}}{4\pi r} \underline{F}(\theta,\phi) \sum_{m=1}^{M} A_m e^{jk_0 \hat{r}\cdot \underline{d}_m} e^{j\beta_m} \tag{5}$$

(5) can be written as the product of the electric field of a single element at a selected reference point (usually the origin) and the array factor AF given by

$$AF = \sum_{m=1}^{M} A_m e^{jk_0 \hat{r}\cdot \underline{d}_m} e^{j\beta_m} \tag{6}$$

The array factor is a function of the number of elements, their geometrical arrangement, their relative magnitudes, and their relative phases [3]. The radiated power from an antenna system is proportional to the square of the elecric field and hence

$$P(\theta,\phi) \propto |\underline{F}(\theta,\phi)|^2 |AF|^2 \tag{7}$$

This relation expresses the concept of pattern multiplication which states that the radiation pattern of an array is the product of the pattern function of the individual radiating element with the array pattern function. In an antenna array, the directivity is mainly contributed by the array factor.

In the developed simulation program, the user can design any type of array from the GUI menus both at transmitting and receiving ends. Also, for convenience to the user, two special arrays, namely Broadside array and Ordinary End-Fire array, can be chosen from the GUI menu. Broadside array pattern has its maximum radiation at an angle which is perpendicular to the antenna platform. It is obtained when all the transmitting antennas are in phase. Ordinary End-Fire array has its maximum radiation in the direction af the antenna platform. It is obtained when there is a phase difference depends on the wave number and the distance from the reference antenna as $\beta=-k_0 d$ or $\beta=k_0 d$.

Equation (5) is based on the assumption that the all antennas in the array have same orientation. But in this study, it is posibble that each antenna has different orientation. Hence, the far-zone electric field of the array is based on (4).

2. THE DEVELOPED SIMULATION PROGRAM

The detailed description of the simulation program is provided in [3]. The simulated system can input both digital and analog sources. For analog inputs, two examples of speech signals are readily loaded. The source encoder-decoder uses Linear Predictive Coding (LPC). For the digital sources, the program enables the user to enter any desired bit sequence or the input can be chosen from the menu. Currently, there is no coding techniques for digital sources. In the channel encoder-decoder, Hamming, Bose-Chaudhuri-Hocquenghem (BCH) and Reed-Solomon (RS) error correction techniques; and for the modulator/demodulator units, Binary Phase Shift Keying (BPSK), Coherent Frequency Shift Keying (CFSK) and Quadrature Phase Shift Keying (QPSK) are implemented. The user can choose from electric dipole, magnetic dipole (loop), slot, rectangular aperture, circular aperture, microstrip and horn antennas in designing both transmitter and receiver arrays. By using these antenna types, linear, planar or desired configuration of the arrays can be constructed with the desired number of elements. AWGN channel and Rayleigh fading channel are also implemented. In order to facilitate the input antenna positions and computation of incoming electric field, various coordinate systems are defined in [3]. The total field of the array consists of M elements in Earth coordinate system can be given by

$$\underline{E}_e(\underline{r}_e,t)=\left\{jk_0Z_0\frac{e^{-jk_0r_e}}{4\pi r_e}\sum_{m=1}^{M}A_m\underline{F}_{em}(\theta_{vsm},\phi_{vsm})e^{j(k_0\hat{r}_e\bullet\underline{d}_{evm}+\beta_m)}\right\}S_l(t)e^{jw_ct} \quad (8)$$

In (8), r_e is the magnitude of the distance vector, $\underline{r}_e$, directed from the origin of the source antenna system to origin of the receiver antenna system with respect to Earth coordinate system, $\hat{r}_e$ is the unit vector in the radiation direction, $\underline{d}_{evm}$ is the distance vector from the origin of the transmitter array to mth antenna with respect to Earth coordinate system, $\underline{F}_{em}(\theta_{vsm}, \phi_{vsm})$ is electric field pattern vector of the mth transmitter antenna with respect to Earth coordinate system, A_m and β_m reperesent amplitude and phase excitation of the mth element, $S_l(t)$ is the baseband representation of the modulated signal, w_c is the carrier frequency. The receiver array consists of N elements. The incident electric field to the nth antenna (n = 1,2, . . .,N) with respect to Earth coordinate system can be given as

$$\underline{E}_{asne}=\underline{E}_e(\underline{r}_e,t)e^{-jk_0\underline{d}_{ane}\bullet\hat{r}_e} \quad (9)$$

$\underline{E}_{asne}$ is the noiseless incident electric field to the nth antenna with respect to Earth coordinate system. After the conversion of the electric field from the Earth coordinate system to the nth antenna coordinate system, the open circuit voltage induced on the nth receiver antenna can be given as

$$V_{ocn}=\underline{h}_{effasn}\cdot\underline{E}_{asn} \quad (10)$$

where $\underline{h}_{effasn}$ is the effective kength of the nth antenna with respect to nth antenna coordinate system, [1]. V_{ocn} is a $[1,L]$ matrix. L is the number of the samples in V_{ocn}. In Figure 1, the noise is added to the electric field propagated in free space. In the simulation program, the noise is added at the input of the demodulator and it is assumed to incorporate the channel noise, antenna noise, cosmic noise and the receiver noise. The open circuit voltage with added noise is given by

$$V_{ocng}=V_{ocn}+v_n \quad (11)$$

Thus, the signal to noise ratio (SNR) is defined as the ratio of the signal and noise powers at the demodulator input. The power of the open circuit voltage induced on the antenna is given as

$$\mathrm{S}=\frac{\left[V_{ocn}.V_{ocn}^T\right]}{L} \quad (12)$$

The noise variance σ^2 from the user defined SNR value is given as

$$\sigma^2=\frac{\mathrm{S}}{10^{(SNR)/10}} \quad (13)$$

After obtaining the V_{ocng}, the signals are sent to the demodulator, channel decoder, and source decoder. The signals can be futher be processed for a variety of applications such as tracking, direction finding, space-time coding, spatial and polarization diversity. In order to compare the simulator performance with theoretical computations and commercial simulator results, a bit sequence is generated. Bit error rate (BER) is a standard performance measure and in the following figures BER for BPSK, QPSK and CFSK for AWGN channel and Rayleigh fading channel are presented. The simulation is performed with one half wave dipole in VHF band, both at transmitting and receiving ends. The distance between the transmitter and receiver is 371 m. In case of AWGN channel, bit error rates for BPSK, QPSK and CFSK are shown in Figure 3, Figure 4 and Figure 5, respectively. The results for each modulation technique are compared for theoretical computations in [4] and denoted by * in figures. As shown Figure 3, Figure 4 and Figure5, the simulation produces BER results for 100 iterations is not sufficient to match the theoretical results. For 1000 iterations, the simulation results and theoretical computations are in accordance. As a consequence, for this scenario, in order to duplicate the theoretical finding, the simulation program needs at least 1000 iterations. In Figure 6, BER for BPSK, QPSK and CFSK modulations are provided for 1000 iterations for AWGN channel

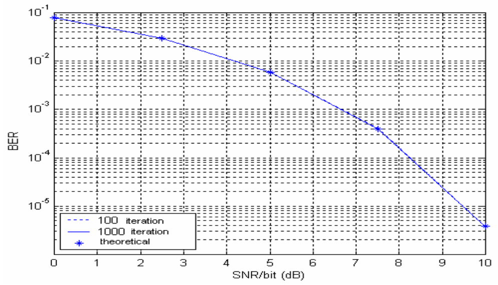

Figure 3: BER results for BPSK in AWGN channel

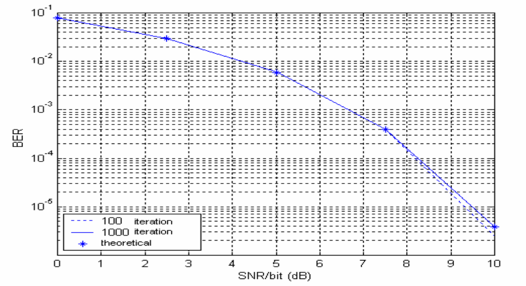

Figure 4: BER results for QPSK in AWGN channel

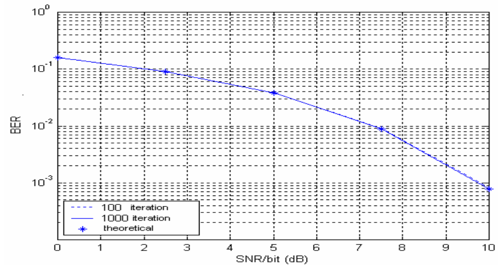

Figure 5: BER results for CFSK in AWGN channel

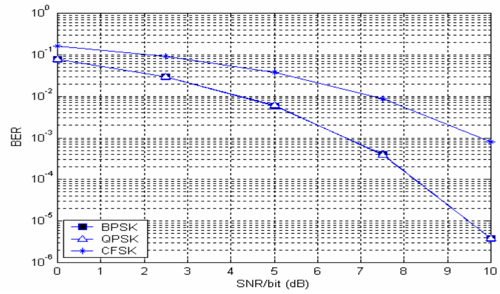

Figure 6: BER results for AWGN channel

In case of Rayleigh fading channel, open circuit voltage induced on the *n*th receiver antenna can be given as

$$V_{ocng}(t) = \alpha_n e^{-j\beta_n} V_{ocn}(t) + v_n(t) \quad (14)$$

where $\alpha_n e^{-j\beta_n}$ is attenuation factor and phase shift for *n*th path, $v_n(t)$ is white Gaussian noise. The amplitude α has Rayleigh distribution, β_n has uniform distribution. From the assumption that the channel is slowly fading, the phase shift can be recovered from the receiving signal. For Rayleigh fading channel, bit error rates for BPSK, QPSK and CFSK are given in Figure 7. The results for each modulation technique are compared for theoretical results in [4]. For 1000 iterations the simulated BER results agree with those of the theoretical computations. The simulation results are also compared with a commercial simulator in [3]. There is very good agreement in the received power obtained from [5] and the power obtained from the simulation program.

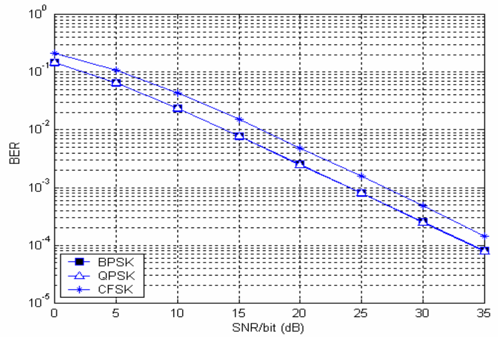

Figure 7: BER results for Rayleigh fading channel

3. CONCLUSION

In this study, basic components of a digital communication system are simulated complete with channel and noise models. The developed simulation program allows the user to design antenna arrays both at the transmitting and receiving ends. The simulation program is modular and flexible to incorporate any future additions and updates. In order to facilitate the input of the long list of necessary parameters for simulation and follow the flow of the simulation, a GUI based menu is designed for convenience to the user. The input parameters can both be entered from the GUI or from previously prepared user input files.

The performance of the simulation program is tested by obtaining the bit error rates for AWGN channel and Rayleigh fading channels, for BPSK, QPSK and CFSK modulation techniques. When the results are compared with theoretical computations, a very good agreement is observed for 1000 iterations. Also, the received power obtained from a commercial simulator agrees very well with the simulator results.

4. REFERENCES

[1] Collin, R.E., *Antennas and Radiowave Propagation*, McGraw-Hill, New York, 1985.

[2]Balanis, C.A., *Antenna Theory, Analysis and Design*, John Wiley & Sons, Inc., New York,1997.

[3]Güngör, A., Simulation of Digital Communication System, *MS Thesis (In Turkish)*, *Hacettepe University*, Beytepe, Ankara, 2005.

[4]Haykin, S., *Communications Systems,* John Wiley & Sons Inc., New York.

[5] ADS 2002 (Advanced Design System), http://eesof.tm.agilent.com.