American Journal of Mobile Systems, Applications and Services
Vol. 1, No. 1, 2015, pp. 12-19
http://www.aiscience.org/journal/ajmsas

Adaptive Interference Reduction in the Mobile Communication Systems

Isiaka A. Alimi[1, *], Oluyomi Aboderin[2]

[1]Department of Electrical and Electronics Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure, Nigeria
[2]Department of Engineering and Space Systems, National Space Research and Development Agency, Abuja, Nigeria

Abstract

The multipath fading has been observed as one of the major issues in wireless systems particularly in the mobile communication systems. Its effect leads to significant impairment in the signal received by the mobile units. This necessitates the need to take multipath fading into consideration in designing an effective radio communication system by implementation of schemes which enable the effects to be minimized. Rake receiver has been observed as a viable solution to reduce multipath effect in wideband code division multiple access (WCDMA) systems. The implementation of Rake receiver gives better performance in terms of the bit error rate (BER) and the associated system throughput. However, Rake receiver consists of sub-component which increases the system computations and also brings about high power consumption. In this paper, we proposed a simplified system that is based on ordered successive interference cancellation (OSIC) which is a feasible scheme in a real-time mobile scenario to reduce multipath effect and multi-user interference. The simulation results obtained show significant performance improvement in symbol-error-rate (SER) over different signal-to-noise ratio (SNR) considered.

Keywords

Wideband Code Division Multiple Access (WCDMA), Third Generation (3G), Rake Receiver, Multiuser Detection (MUD), Ordered Successive Interference Cancellation (OSIC)

Received: May 20, 2015 / Accepted: June 4, 2015 / Published online: July 13, 2015

1. Introduction

One of the major trends in the next generation mobile communication systems is on network convergence in which there are seamless and efficient coexistence of wide varieties of communication services such as high speed data, video, multimedia traffic and voice signals within a single network [1]. The feasibility of network convergence has been observed in the Third Generation (3G) Cellular Systems in which wideband code division multiple access (WCDMA) is employed to support high data rate and low latency multimedia services over the wireless cellular networks [2] with the aim of preventing interference among users in dispersive channels. In the CDMA downlink, Walsh-Hadamard codes or orthogonal variable spreading factor (OVSF) codes are employed for the transmission. However, in a typical wireless environment, the orthogonality of the code is destroyed by multipath fading and subsequently results in intracell interference between users [3, 4]. This anomaly is caused by the multipath transmission which is created by the wireless channels that hinders signal propagation. The multipath transmission happens when a transmitted signal is received from different paths and with different time delays. The multiple paths have different propagation lengths which can cause amplitude and phase fluctuations. The concept is depicted in Figure 1.

* Corresponding author
E-mail address: compeasywalus2@yahoo.com (I. A. Alimi), jayyomi@yahoo.com (O. Aboderin)

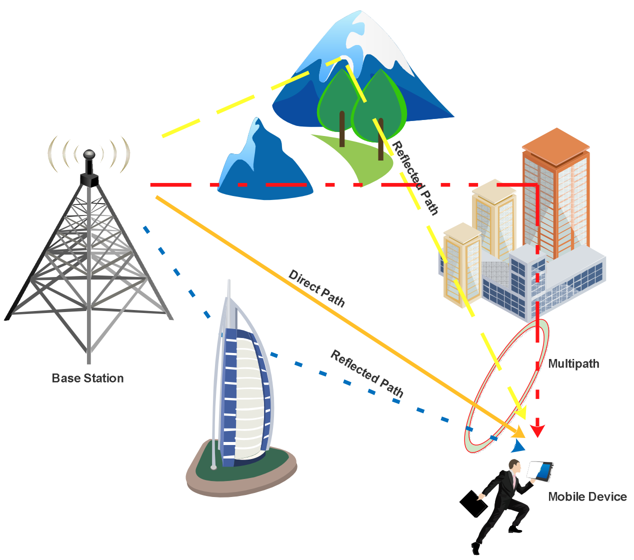

Figure 1. Multipath Propagation Concept.

It has been observed that multipath fading degrades the quality of the received signal and also lead to sub-optimal performance in the wireless mobile communication systems. Despite the implementation of advanced technique such as multiuser detection (MUD) that can significantly improve the overall performance of a WCDMA system, the Rake receiver is still considered as the receiver structure of choice for 3G systems [5, 6]. Furthermore, it has been stated in [5] that Rake receiver is the fundamental building block of some receiver structures that employ serial or parallel multiuser interference cancellation. According to [7] Multi Access Interference (MAI), Inter Symbol Interference (ISI) and Spreading Factor (S. F) are the issues that limit the BER performance of a typical Rake receiver. It has been observed that the corresponding number of fingers of Rake receiver, the channel type, in addition to the spreading factor have substantial impact on the network capacity of the wireless communication system. Furthermore, the overall performance also requires precise estimation of bit error rate [8]. The bit error rate performance of a receiver is the Figure of merit that allows different designs to be compared in a fair manner. Mostly, a Rake receiver is made of matched filter and channel estimator which make the system to be computationally complex and power consuming [9]. Consequently, there is need for less complex and power efficient system. There are various solutions that have been proposed in the literature to address the issues of system complexity and power efficiency, one of such is a generalized Rake receiver for interference suppression and multipath mitigation that is proposed in [2] for a WCDMA system. The paper proposed a receiver that consist of different combining weights which are derived from a maximum likelihood detector and is viable for systems with orthogonal downlink spreading code. Furthermore, [4] proposed an area and power efficient rake receiver architecture for base and mobile-stations in which the direct sequence spread spectrum technique is employed. In the work, to reduce the circuit complexity, a common parallel de-spreader which provides precomputed sub-symbols to fingers are employed to enable each finger to operate at a lower clock speed to save the power. Also, in [5], the problem of channel tracking for Rake receivers in propagation environments characterized by closely spaced multipath components is considered. The paper provides estimation algorithms that can nullify or suppress the deteriorating effects of multipath propagation on both timing and phasor estimations. According to the results presented, implementation of the algorithms leads to performance improvements in terms of signal-to-noise ratio. Moreover, in [9], a cross-layer design scheme that combines the greedy list-based parallel interference cancellation (GL-PIC) detection technique and a low cost greedy multi-relay selection algorithm for the uplink of cooperative DS-CDMA systems is proposed. With reference to the results presented, the technique can offer considerable gains in terms of bit error rate compared to conventional schemes.

This paper focuses on taking advantage of the multipath to improve reception quality in fading conditions with the aid of Rake receiver so as to improve the system symbol-error-rate (SER). To achieve this goal, a simplified and effective Rake receiver which is based on ordered successive interference cancellation (OSIC) scheme is proposed. In the next section, a brief system overview of WCDMA system and Rake receiver are discussed. The mathematical description of the system model in terms of the transmitter, the channel and the receiver is presented in Section 3. Section 4 discusses both linear and nonlinear interference cancellation techniques but with emphasis on ordered successive interference cancellation (OSIC) scheme that is employed in this paper. Section 5 presents the simulation results and discussions based on models developed in MATLAB®. Then, conclusions are drawn in Section 6.

2. System Overview

A Rake receiver is a radio receiver which is mainly use in wideband code division multiple access systems (WCDMA). The concept of operation in a WCDMA system is that all the users transmit their signals in the same band concurrently and the transmitted bit by each user is spread by the orthogonal variable spreading factor (OVSF) and scrambling code of the transmitter. The length of the scrambling code is known as the spreading factor and it has been observed that larger spreading factors give a better resistance against interference. In addition, at the receiver, the received multipath signal is de-spread by multiplying it with the same spreading sequence employed at the transmitter. The code generator at the receiver gives the spreading sequence which is employed in de-spreading and correlation operations. The Rake receiver has multiple fingers each of which is assigned to a different multipath component and independently decodes a single multipath component. The contribution of each finger is then combined so as to exploit the transmission characteristic of each multipath transmission component [4].

The impulse responses of the multipath channel are obtained by a matched filter for signal de-spreading. The filter tracks and monitors multipath channel peaks with regard to the speeds of mobile station as well as the propagation environment. The number of Rake fingers is determined by the chip rate and the channel profile. Higher chip rate gives more resolvable paths, however, it lead to wider bandwidth. To exploit all energy from the channel, more Rake fingers are required. However, large number of fingers results in implementation problems and combination losses. The finger outputs can be combined with the implementation of equal-gain combining which is a method each output is weigh equally. Similarly, another method uses the data to evaluate weights, which maximize the Signal-to-Noise Ratio (SNR) of the combined output [4, 10, 11].

3. System Model

The model for the wireless mobile communication systems transmit and receive signals in a realistic mobile scenario for the base station and mobile unit of WCDMA systems can be realized in stages. The signal is generated at the transmitter and passes through the channel in which it experiences multipath effect before getting to the receiver. The model for each of the WCDMA communication element is presented in this section.

3.1. Transmitter Model

The Spread Spectrum technique which is a transmission scheme in which a pseudo-noise code is employed as a modulation waveform to spread the signal energy over a bandwidth which is much greater than the signal information bandwidth is a viable coding technique. At the receiver, the signal is despread using a synchronized replica of the pseudo-noise code. Pseudo-noise (PN) sequences are binary sequences which are employed in code generation in Rake receiver scheme. PN sequences such as maximal length, Gold codes and Kasami sequences have noise-like randomness properties which make their implementation viable [12]. In this work, Gold codes are employed because of their better cross-correlation properties than maximum length linear feedback shift register (LFSR) sequences. Gold codes are generated by linear combination of preferred pairs of m-sequences with the same degree with different offset in Galois field [12]. This method is illustrated in Figure 2. The correlation function in the Gold codes takes on three possible values which are $\{-1, -t(n) \text{ or } t(n) - 2\}$. The term $t(n)$ depends exclusively on the length of the LFSR employed and it is given by

$$t(n) = \begin{cases} 2^{(n+1)/2} & n\ odd \\ 2^{(n+2)/2} & n\ even \end{cases} \quad (1)$$

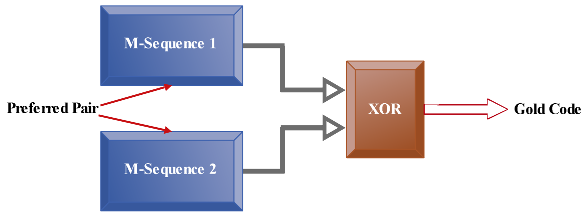

Figure 2. Generation of Gold codes from a pairs of M-sequences.

The CDMA transmitter then sends the complex valued data sequence x_n which are spread by the spreading factor N_c using the effective spreading sequence q_v. The complex valued spread sequence is transmitted using a pulse shaping filter $p(t)$. The Third-Generation Partnership Program (3 GPP) specification for the pulse shaping filter is the root-raised-cosine (RRC) function also known as the square-root-raised-cosine (SRRC) filter with a roll-off factor of 0.22. The resultant baseband transmit signal is given in [3] as;

$$s(t) = \sum_n x_n \sum_{v=0}^{N_c-1} q_v p\left(t - nT - vT_c\right) \quad (2)$$

where T and T_c are the symbol and chip duration respectively. According to [3] the spreading sequence q_v can be replaced by $q_n N_c + v$ in order to incorporate effective spreading sequences with a periodicity longer than one symbol.

3.2. Channel Model

In accordance with the wide-sense stationary uncorrelated scattering (WSSUS) model, the transmitted signals propagate through multipath channel that has L independent paths which are characterized by different time delay τ_l and the time-variant complex multipath fading coefficient c_l [3]. As a WSSUS channel is assumed, the fading coefficients of different paths are independent. Therefore, the impulse response of the multipath channel between the mobile unit and the base station is modeled by [8, 11] as;

$$h(\tau) = \sum_{l=0}^{L-1} c_l(t)\delta\left(\tau - \tau_l\right) \quad (3)$$

where δ is the impulse function. Depending on the specific propagation environment, c_l is a positive random variable with density function that can be represented by include

Rayleigh, Rician or more generally a Nakagami distribution [11].

3.3. Receiver Model

The received signal is the sum of signal transmitted which passes through the multipath fading channel and the additive white Gaussian noise (AWGN) $z(t)$ with power-spectrum-density of $N_0/2$. Hence, the received signal at time, t is expressed in [3, 8] as;

$$r(t) = \sum_{l=0}^{L-1} c_l(t) \sum_n x_n \sum_{v=0}^{N_c-1} q_n N_c + v\, p_T\left(t - nT - vT_c - \tau_l\right) + z(t) \quad (4)$$

For simplicity, but without loss of generality, a generalized MIMO scheme with N_t transmit antennas and N_r receive antennas is assumed. According to [13], [14] the received signal $r(t)$ can be modeled in matrix notation as;

$$\boldsymbol{r} = \boldsymbol{H}\boldsymbol{s} + \boldsymbol{z} \quad (5)$$

where s is the transmitted data symbol vector, r is the received signal vector, H is the channel matrix which contains the channel information of all users and z is the complex additive white, Gaussian noise (AWGN) vector. To detect the transmitted symbol vector s from vector r, interference cancellation techniques are required.

3.4. Interference Cancellation Techniques

The concept of most of linear interference cancellation techniques operation is that the desired layer is detected while other layers are considered as interference. The nulling of each layer can be performed with a ZF or an MMSE equalizer. Subsequently, when the transmitted symbol vector has been detected, a decision on the vector is made either by quantization or by calculating the log-likelihood ratios (LLR) of the transmitted bits. The linear detectors are optimal if the channel matrix is orthogonal. Conversely, this is not usually the case in practice. Method such as lattice reduction (LR) can be employed to transform the channel matrix into a more orthogonal one. Furthermore, in fading channels, linear detectors suffer significant performance degradation mainly when there is spatial correlation between the antenna elements [15, 16].

The linear interference cancellation techniques have the disadvantage that some of the diversity potential of the receiver antenna array is lost in the decoding process. Therefore, their performances are not up to that of maximum likelihood (ML) decoder. There are some nonlinear techniques such as ordered successive interference cancellation (OSIC), parallel interference cancellation (PIC) and sorted QR decomposition (SQRD) that have been shown to have significant performance improvements by taking the advantage of diversity potential of receive antennas. In the parallel interference cancellation (PIC), all the layers are detected simultaneously and then cancelled from each other followed by another stage of detection. PIC was proposed to reduce the latency from SIC but has a higher computational complexity. The SQRD algorithm performance is extremely close to that of OSIC but the SQRD algorithm always requires less computation effort to decode multiple antennas symbols compared to the OSIC decoder [16, 17].

4. Methodology

An example of SIC is V-BLAST which is based on detection algorithm with sorted cancellation ordering [13]. In the SIC, signal components are detected in a sequential bias. For instance, in each data stream, the successively detected j^{th} stage symbol $\hat{x}_j$ is subtracted from the received signal, while the remaining received signal with reduced interference is used for signal estimation for the ensuing streams. This process continues until all transmitted symbols have been detected. If the detected symbol is obtained by the MMSE nulling matrix, then the MMSE estimate corresponding to each layer's data stream is

$$\hat{x}_i = (H^H H + \langle\sigma^2\rangle I)^{-1} H^H [r_i] \quad (6)$$

where $(.)^H$ denotes the Hermitian transposition.

The SIC receiver can suffer from error propagation if an incorrect detected symbol is used in the cancellation process [10]. To improve on the performance of SIC, ordered SIC (OSIC) is introduced in which post-detection signal-to-interference-plus-noise-ratio (SINR) is used to decide the order of detection. In OSIC, the layer with the highest SINR is detected first and its interference is cancelled from other streams. This process is also prone to error propagation. Therefore, to constrain the error propagation, it is desirable to detect reliable signals in the early stages. For instance, suppose the received power at both antennas equivalent to the first transmitted symbol is

$$Px_j \sum_{i=1}^{2} \left\{ \left| h_{i,j} \right|^2 \right\} \quad j = 1 \quad (7)$$

where elements $h_{i,j}$ are channel coefficients from the jth transmit to ith receive antennas and that of the received power at both antennas equivalent to the second transmitted symbol is

$$Px_j \sum_{i=1}^{2} \left\{ \left| h_{i,j} \right|^2 \right\} \quad j = 2 \quad (8)$$

If $Px_2 > Px_1$, the receiver decides to eliminate effect of $\hat{x}_2$ from the received vector and $\hat{x}_1$ will be re-estimated. The cancellation is in descending order of signal strength because of the fact that it is easier to acquire and perform demodulation on the strongest user [10]. This enables high probability of making an accurate decision. Moreover, when the strongest user is removed, the multi-access interference (MAI) from it to other users will be eliminated. As the cancellation process continues, the weakest user will see a huge reduction in MAI and this will help in its detection.

After obtaining $\hat{x}_j$ by the MLD scheme, it is then weighted with its corresponding channel coefficient and subtracted from the received signal vector like

$$r_i = y_i - h_{i,j}\hat{x}_j\big]_{j=n} i = 1, 2, \cdots, n_r$$

$$and \ \ j = 1, 2, \cdots, n_t \tag{9}$$

So as to have a modified received signal vector, therefore, we have

$$r_i = h_{i,j}x_j + n_i\big]_{j \neq n} \ \ i = 1, 2, \cdots, n_r$$

$$and \ \ j = 1, 2, \cdots, n_t \tag{10}$$

The iteration will continue until all transmitted symbols have been detected.

5. Simulation Results and Discussions

The WCDMA system is simulated for different wireless environmental conditions using MATLAB® software. The simulated QPSK symbols of the users are spread with the spreading code sequences and transmitted through the modeled multipath fading channel in which the impulse response follows Rayleigh distribution. Furthermore, at the receiver, white Gaussian noise is added to the multipath signals which further degrade the signal. The algorithm is then applied to extract the transmitted signal of the first user from the received noisy signal. It is observed that the signal at the output of the receiver is relatively better than that at the input of the receiver. The result is depicted in Figure 3.

Moreover, the system SERs are investigated by varying the number of users and taken the corresponding value of SER. The iterations are executed several times to study the effect of dispersive nature of the channel as well as the number of users on the system. The result is presented in Table 1. The dispersive nature of the channel can be inferred from the table as the value of SER varies from one value to another for different iteration. Also, the mean SER is evaluated and the plot of the mean SER and number of users is shown in Figure 5. It is observed that as the number of the users increase, the SER also increases.

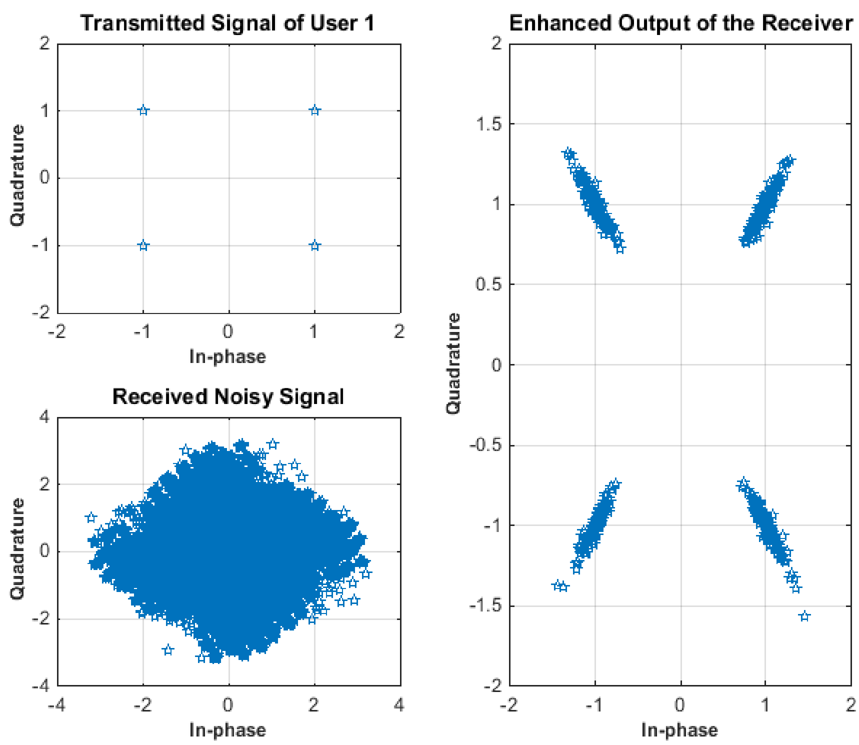

Figure 3. Constellation diagrams for user 1.Furthermore, the level of deterioration of the received signal by user 1 with increase in the number of users in a cell is considered. In this set up, the signal transmitted by user 1 is observed and the numbers of users in the cell are gradually increased. It was observed that as the number of user k increases, the level of multi-user interference increases. Also, the scatter plots obtained for user 1 after the implementation is illustrated in Figure 4.

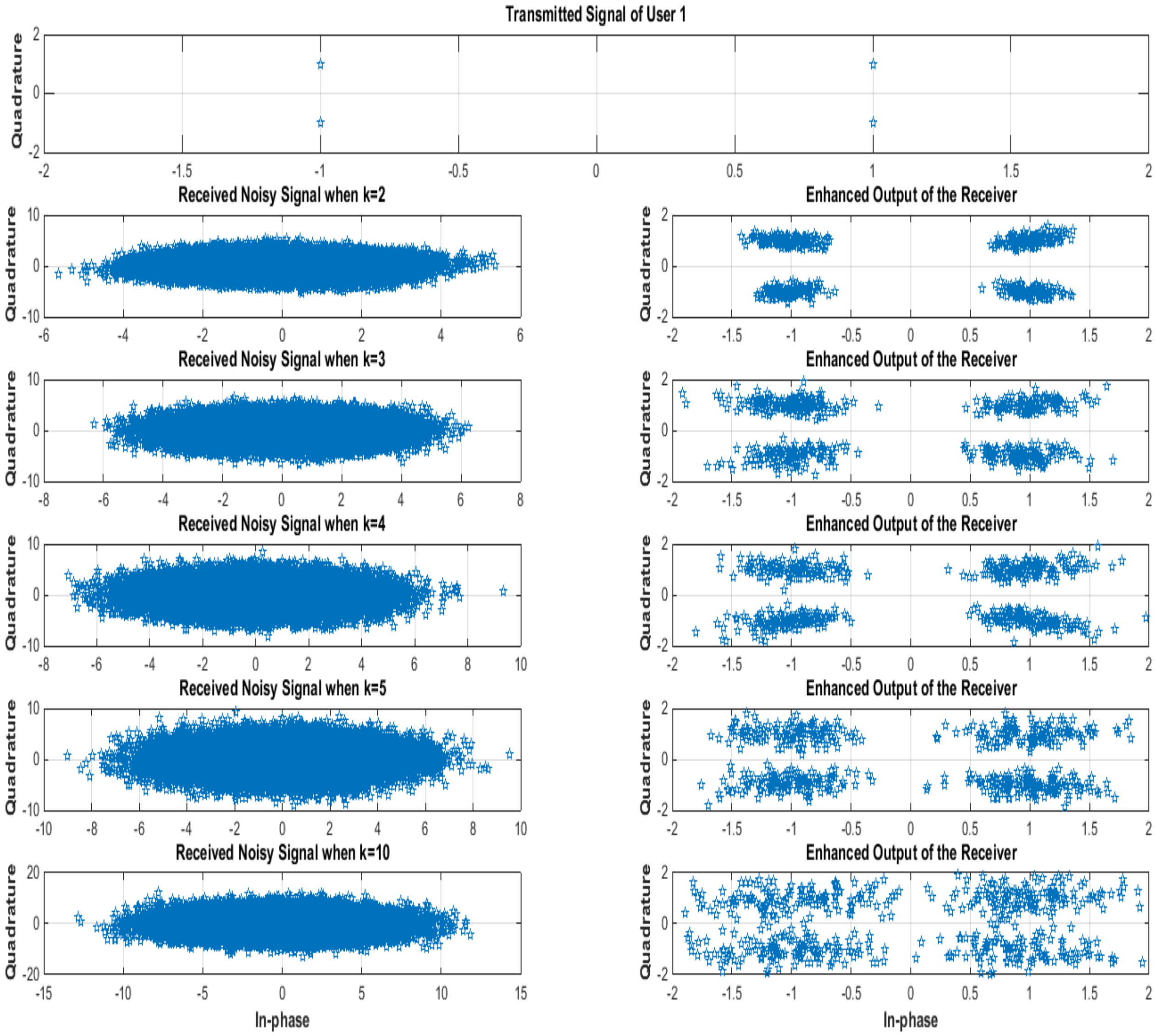

Figure 4. Constellation diagrams with increase in the number of users.

Table 1. Comparisons of SER with different number of user.

k	SER											Mean/Avg. SER
	1	2	3	4	5	6	7	8	9	10	11	
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0.0020	0.0020	0	0	0	0	0.000364
6	0	0	0	0	0.0020	0.0020	0	0	0	0	0	0.000364
7	0	0	0	0.0020	0.0020	0.0020	0.0020	0	0.0020	0	0.0039	0.001264
8	0.0039	0.0059	0.0039	0.0020	0.0039	0.0020	0.0020	0.0020	0	0	0.0039	0.002682
9	0.0118	0.0039	0.0079	0.0079	0.0059	0.0039	0.0059	0.0059	0.0098	0	0.0059	0.006255
10	0.0098	0.0098	0.0118	0.0079	0.0157	0.0098	0.0079	0.0118	0.0079	0.0157	0.0216	0.011791
11	0.0255	0.0216	0.0196	0.0275	0.0138	0.0079	0.0157	0.0020	0.0138	0.0039	0.0157	0.015182
12	0.0236	0.0236	0.0216	0.0295	0.0157	0.0216	0.0098	0.0236	0.0236	0.0177	0.0254	0.021427
13	0.0098	0.0334	0.0255	0.0177	0.0413	0.0157	0.0177	0.0177	0.0216	0.0393	0.0255	0.024109
14	0.0236	0.0295	0.0432	0.0236	0.0196	0.0236	0.0177	0.0177	0.0432	0.0530	0.0236	0.028936
15	0.0393	0.0472	0.0511	0.0491	0.0491	0.0491	0.0236	0.0354	0.0393	0.0373	0.0432	0.042155

Moreover, the values of SNR and the number of users are varied to study the relationship between the SER and the BER. The result of the study is depicted in Figure 6. It is observed that at high SNR the SER is low but it increases when SNR decreases. Also, the result confirms that as the number of users' increases the SER also increases.

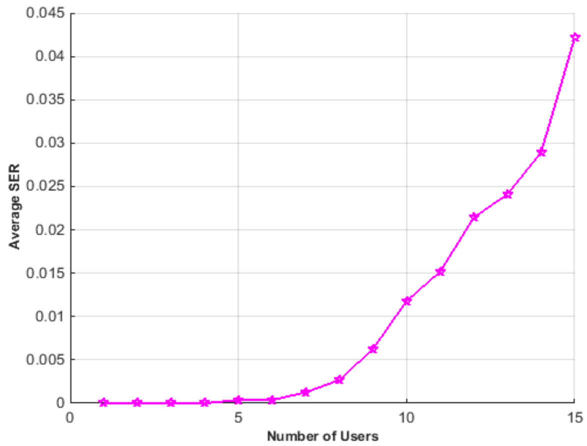

Figure 5. Mean SER and number of users.

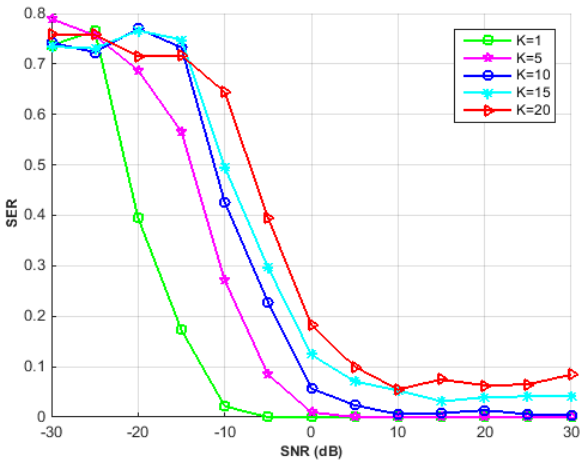

Figure 6. Relationship between the SER and the BER.

6. Conclusion

The multipath fading is one of the known practical problems in wireless mobile communication systems and its effect lead to significant impairment in the received signal by the mobile units (MU). The simulation results show that, Rake receiver can be used to reduce multipath fading in WCDMA based mobile communication systems. The increase in the quality of the received signal and performance improvement is directly proportional to the number of Rake receiver's fingers. In this paper, we proposed a simplified and effective system based on ordered successive interference cancellation (OSIC) algorithm that is applicable in a realistic mobile scenario for base and mobile units of WCDMA systems. Also, the simulation results show that the proposed OSIC based scheme comparatively gives a significant performance improvement by reducing the SER of the system.

References

[1] R. Manish and S. S. Amanpreet, "Performance evaluation of Rake and pre-Rake receiver for a wireless DSCDMA system," *International Journal of Engineering and Technology*, vol. 2 no. 7, pp. 1333-1335, July, 2012.

[2] G. E. Bottomley, T. Ottosson, and Y. E. Wang, "A generalized Rake receiver for interference suppression," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 8, pp. 1536-1545, August 2000.

[3] T. Ojanperä and R. Prasad, *Wideband CDMA for Third Generation Mobile Communications,* Norwood MA, USA: Artect House Inc, 1998, pp. 439.

[4] H. Lee and D. S. Ha, "An area and power efficient Rake receiver architecture for DSSS systems," in *Proc. 2003 IEEE International SOC Conference,* Portland, Oregon, pp. 103-106.

[5] G. Fock, J. Baltersee, P. Schulz-Rittich, and H. Meyr, "Channel tracking for Rake receivers in closely spaced multipath environments," *IEEE Journal on Selected Areas in Communications*, vol. 19, no. 12, pp. 2420- 2431, Dec. 2001.

[6] Y. Sung and Y. Lim, L. Tong and A. Veen, "Signal processing advances for 3G WCDMA: from Rake receivers to blind techniques," *IEEE Communications Magazine*, vol.47, no.1, pp.48-54, January 2009.

[7] P. Kumar, B. K. Kanaujia and M. Gangadharappa, "BER performance analysis of Rake receiver in Rayleigh fading channel for UMTS environment," *International Journal of Engineering Science and Technology*, vol. 2, no.6, pp. 1690-1698, June 2010.

[8] K. Ohno, M. Itami and T. Ikegami, "Iterative Rake reception scheme using multi-carrier pulse for pulse based UWB system," in *Proc. 2013 IEEE International Conference on Ultra-Wideband,* Sydney, NSW, 2013, pp. 249-254.

[9] Gu, Jiaqi, R. C. de Lamare, "Joint parallel interference cancellation and relay selection algorithms based on greedy techniques for cooperative DS-CDMA systems," in *Proc. 2014 IEEE International Conference on Acoustics, Speech and Signal Processing,* Florence, Italy, 2014, pp. 2754 - 2758.

[10] T. S. Rappaport, *Wireless Communications Principles and Practice,* Prentice Hall, New Jersey, 1996, pp. 336-338.

[11] K. M. Krishna, A. Mitra and C. Ardil, "A simplified single correlator Rake receiver for CDMA communications," *International Journal of Electrical, Robotics, Electronics and Communications Engineering*, vol. 4, no. 2, pp. 13-16. 2010.

[12] A. Richardson, WCDMA Design Handbook, Cambridge University Press, 2005

[13] I. A. Alimi, J. J. Popoola, K. F. Akingbade, M. O. Kolawole, "Performance analysis of bit-error-rate and channel capacity of MIMO communication systems over multipath fading channels," *International Journal of Informatics and Communication Technology*, vol. 2, no. 2, pp. 57-63, July 2013.

[14] J. Zhan, B. Nazer, U. Erez and M. Gastpar, “Integer-forcing linear receivers,” *in Proc. 2010 IEEE International Symposium on Information Theory Proceedings*, Austin, TX, 2010, pp. 1022 - 1026.

[15] W. Qu, K. Niu, Z. He, and J. Lin, “A low complexity approach of chip-level MMSE equalization,” in *Proc. 2013 IEEE 5th International Symposium onMicrowave, Antenna, Propagation and EMC Technologies for Wireless Communications,* Chengdu, 2013, pp. 500 - 504.

[16] J. Ming and L. Hanzo, “Multiuser MIMO-OFDM for next-generation wireless systems,” *Proceedings of the IEEE*, vol. 95, no. 7, pp. 1430-1469, July 2007.

[17] V. Namboodiri, H. Liu and P. Spasojevic´, “Successive interference cancelation and MAP decoding for mobile MIMO OFDM systems and their convergence behavior,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, pp. 1-12, October 2012.

Biography

Alimi Isiaka Ajewale earns B.Tech. (Hons) and M.Eng. in Electrical and Electronics Engineering (Communication) from Ladoke Akintola University of Technology, Ogbomoso, Nigeria in 2001, and the Federal University of Technology, Akure, Nigeria in 2010 respectively. He is a Lecturer in the Department of Electrical and Electronics Engineering, Federal University of Technology, Akure, Nigeria. He has published 3 refereed international journals. He has extensive experience in radio transmission, as well as in Computer Networking. His areas of research are in Computer Networking and Security, Advanced Digital Signal Processing and Wireless communications. He is a COREN registered engineer.

Oluyomi Aboderin, a COREN registered engineer, received B.Tech. (Hons) in Electronic and Electrical Engineering and M.Sc. in Personal Mobile and Satellite Communication (PMSC) degrees from Ladoke Akintola University of Technology, Ogbomoso, Nigeria in 2001, and University of Bradford, Bradford, United Kingdom in 2010 respectively. He is a Research Engineer with National Space Research and Development Agency (NASRDA) Abuja, Nigeria. He is currently enrolled at the Faculty of Engineering University of Porto Porto, Portugal for his Doctoral degree program in Telecommunication. His research interest is in Satellite Channel Estimation and Modeling, Antenna design and Frequency Management for Next Generation Network (NGN).