Dynamic Radio Resource Allocation and Optimization for OFDMA Cellular Networks

Nahla Mahmoud Satti, Syed Junaid Nawaz, Mohammad Patwary, and Mohamed Abdel-Maguid
Faculty of Computing, Engineering and Technology
Staffordshire University, ST18 0AD, United Kingdom.
nahlasatti@gmail.com, junaidnawaz@ieee.org, m.n.patwary@staffs.ac.uk, and m.m.abd-el-maguid@staffs.ac.uk

***Abstract*—This paper considered multiuser orthogonal frequency multiple access (OFDMA) scheme, which has been proposed as the transmission technique for 4th Generation (4G) cellular network. An optimum and dynamic radio resource (subcarrier and power) allocation scheme is proposed for OFDMA multiuser system. The proposed algorithm has considered a structured degree of flexibility among the services that can be provided from the network. The performance of the algorithm is evaluated through computer simulation, by applying it to multipath frequency selective fading channel with different number of users, SNR and channels conditions. The goal is to dynamically assign subcarrier and power while minimizing the total transmitted power under the constraint of guaranteed QoS to the users. The results shows that it outperform Static OFDM subcarrier and power allocation scheme achieves 3 dB SNR gain for a bit error rate of 10^{-2}. Notable amount of reduction in system capacity outage probability has been observed, while exploiting the proposed dynamic algorithm compared with the existing algorithm due to its more flexible nature in resource allocation.**

***Index Terms*—OFDM, CSI, Adaptive Systems, QoS.**

I. Introduction

Due to the increasing demand for high speed wireless services, OFDMA is required to use the bandwidth of the system more efficiently, while retaining a guaranteed quality of service (QoS). OFDMA is one of the multiple access transmission schemes for such high speed wireless systems due to its robustness in severe multipath fading channels. In OFDMA, the channel bandwidth is splitted into a number of narrowband subcarriers, which are orthogonal to each other. Each of these subcarriers undergo independent attenuation, thus provide frequency diversity. Within multiuser environment the degree of diversity is increasing as each subcarrier of a user have different attenuation, which lead toward having frequency diversity per user and multiuser diversity per subcarrier. The principle of transmitting data by dividing the data frame into several interleaved bit stream and modulate with narrowband subcarriers, was first introduced by author in [1] and known as multicarrier modulation (MCM). In [2], authors describe the performance of OFDM/FM modulation for digital communication over Rayleigh-fading mobile radio channels. The bit error rate (BER) is reduced due to the averaging effects of fading over the bits in the block. Recently, a number of algorithms have been developed to increase the information throughput and efficient use of bandwidth for high speed data services. With a given constraints of user demand and required QoS, it is one of the challenging tasks to find out an optimum radio resources allocation scheme in enhanced of information throughput [3], [4]. The algorithm proposed in [4] required to estimate the number of minimum subcarriers required to meet data rate demand from the user. However, it assumes that each user has flat fading channel and available bandwidth is enough to meet all user demand. The same algorithm search for the best subcarrier with rate-craving greedy algorithm (RCG) or amplitude craving greedy algorithm (ACG) [4], to provide maximum data rate to the users. However, in practice the bandwidth is limited and flat fading cannot always be guaranteed. Besides that, implementation of greedy algorithm is quiet computationally intensive. To maximize information throughput with the constraint of allocatable maximum power, the algorithm proposed in [5] searches the maximum number of allocatable bit per subcarrier in the form of adaptive modulation. But this algorithm become saturated within a deep fading channel. In [6], authors proposed an aggressive subchannel allocation (ASA) algorithm to maximize OFDMA system throughput, considering fairness of radio resource allocation among all users. In ASA, channel state information (CSI) is assumed to be known at the transmitter. Hence, the effectiveness of the algorithm depends on channel estimation algorithm employed at the receiver. In [3], an effective transmit power allocation and dynamic channel allocation schemes are proposed for partitioning based on OFDMA/FDD system. This allocation scheme improves sector throughput within cellular network, while considering QoS and fairness among users. In [7], authors have proposed the combination of fairness insured aggressive subchannel allocation (FASA), along with dynamic power allocation algorithm, to maximize fairness and throughput in OFDMA/TDD system. In [8], authors have proposed combined variable data transmission rate and power M.QAM (Quadrature amplitude modulation) to achieve a target QoS, where M is the number of points in each signal constellation. The authors in [9], have proposed a radio resource management procedure to improve the outage probability as a tradeoff off with information throughput. Authors proposed to allocate bandwidth, subchannel and power to users assuming each user received the same SNR (signal to noise ratio) to achieve fairness among users.

This paper proposes an algorithm for OFDMA system, which dynamically assigns subcarriers and adapt the trans-

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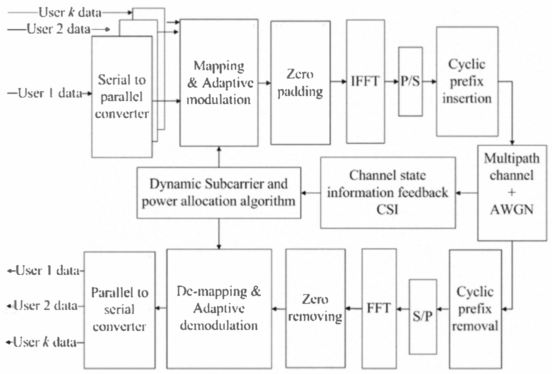

Fig. 1. Multiuser transmit-receive communication system model with OFDMA

mitted power based on CSI and traffic demand in multiuser environment. It also considers priority and cost among users and services within the system. This paper is organized as follows. In section II, the OFDMA system model is defined. Section III describes the proposed dynamic radio resource allocation algorithm. In Section IV, the performance of the proposed algorithm is evaluated through the simulation results. Finally section V presented with concluding remarks.

II. System Model

A multiuser communication system model with OFDMA, which has been considered for analysis in this paper is presented in Fig. 1. Information bits from each user is multiplexed and passes through the adaptive symbol mapper (modulator). Then the frequency domain complex symbols from the modulator is converted into time domain samples by taking IFFT. Then cyclic prefix is added to ensure orthogonality between subcarriers and eliminate intersymbol interference (ISI) and intercarrier interference (ICI).

Lets consider there are K number of users and each of them generating D number of bits at a time to transmits through multipath channel of different lengths L. Transmitted users data (signal) is passed through different frequency selective fading channels due to users location and mobility.

Lets assume that the received sample at the receiver at i-th time is r_i, which can be written as:

$$r_i = \sum_{k=1}^{K} y_k h_k + n_i \tag{1}$$

where y_k is the transmitted symbol from k-th user, h_k is channel fading coefficient and n_i is the gaussian noise sample with zero mean and unity variance at i-th time instant. i.e

$$y_k = x_{j,k} E_{j,k} \tag{2}$$

where $x_{j,k}$ is the j-th symbol and $E_{j,k}$ is the allocated energy on the j-th symbol from k-th user.

At the receiver the reverse task is performed as in the transmitter. First, the receiver remove the cyclic prefix and then perform FFT to convert the signal to frequency domain.

TABLE I
OFDM System Parameters [3]

System Parameters	Values
Carrier Frequency	2.3 GHz
Sampling Frequency	10 MHz
Effective Channel Bandwidth	8.75 MHz
FFT Size	1024
Cyclic Prefix	128
Used Sub-carriers	864
Data Subcarrier	768
pilot Subcarriers	96
Sub-carrier Spacing	9.765625 KHz
Channel Model	multi path Fading Channel Proakis Channels [10] Ped.A ,Veh.A [11]

Conventionally, an equal power and bit allocation schemes is considered within OFDMA [1]. An algorithm of combined adaptive modulation, subcarrier and power allocation scheme is proposed in the following section, considering the above mentioned system model. Table I shows OFDM symbol parameters, which has been considered within the proposed OFDMA system.

III. Proposed Algorithm

It is assumed to have a perfect channel estimation at the receiver exploiting the received pilot symbols, which has been transmitted prior to the transmission of information symbols. Estimated CSI, subcarrier allocation index as well as bit allocation schedule are proposed to be shared between the transmitter and receiver via common channel.

In this paper, an adaptive bit, subcarrier and power allocation scheme has been proposed within OFDMA multiuser system. For this purpose, multiuser CSI matrix is proposed to be constructed, exploiting the independent CSI received from each independent user.

Lets the time domain channel impulse response of K users are of the length $\{L_1, L_2, ...L_K\}$ respectively. The time domain CSI matrix $\mathbf{H}$ is constructed of size ($L_{\max} \times K$).

where $L_{\max}$= $\max\{L_1, L_2, ...L_K\}$. The impulse response of the k-th user is written as:

$$\mathbf{h}_K = [h_0, h_1, ...h_{L_K-1}]^T \tag{3}$$

If the length of the channel impulse response vector for any user is less than L_{max}, then additional zeros are appended within the vector, which are required to make the length of the impulse response vector equal to L_{max}. Hence the multiuser channel impulse response matrix $\mathbf{H}$ can be written as

$$\mathbf{H} = [\mathbf{h}_1, \mathbf{h}_2, \mathbf{h}_3, ...\mathbf{h}_K] \tag{4}$$

A. Proposed Subcarrier Allocation Scheme

In the proposed subcarrier allocation scheme, the number of FFT point is to be selected, depending on the number of candidate subcarriers within the given operating bandwidth.

The the frequency response of the multiuser channel matrix is constructed, which can be written as

$$\mathbf{H}_f = [\mathbf{f}_1, \mathbf{f}_2, ...\mathbf{f}_K] \quad (5)$$

where $\mathbf{f}_1 = [f_0, f_1, ...f_{N-1}]^T$ is the frequency response of the channel of user 1 for all subcarriers, N is the total number of subcarriers.

Depending on the amplitudes of the frequency response matrix $\mathbf{H}_f$, all the candidate subcarriers are classified into l different groups. Lets the subcarrier threshold in each group is defined by the threshold vector $\overrightarrow{\delta} = [\delta_0, \delta_1, \delta_2 ... \delta_{l-1}]$ where values are in ascending order, (i.e $\delta_0 = \delta_{\min}$ and $\delta_{l-1} = \delta_{\max}$).

Each group is determine by a threshold value of the subcarrier gain δ_{th}. Each of these groups is assigned with different modulation scheme and code rate. If the n-th subcarrier of k-th user with fading coefficient $f_k < \delta_{min}(l = 1)$ then it is proposed to be eliminated from the candidate subcarriers list, as it is consider to be in deep fade at that time instant only. The rest of the subcarrier are to be assigned with respective modulation schemes and code rates. The higher coefficient threshold of the group, is assigned with the higher modulation and code rate.

Based on the nature of channel fading, it is required to update bit and subcarrier allocation matrix while transmitting within a given time interval. For fast fading channel, more frequent update is required than that for slow fading channel.

B. Proposed Dynamic Power Allocation Scheme

Based on the user demand for a particular service (s_d) and the channel condition, it is considered to have a benchmark QoS within the network. Considering that benchmark, power allocation scheme for each subcarrier is proposed. To provide certain BER, the amount of power that is required to be allocated to a subcarrier is depends on the number of bits assigned within the modulation scheme and the instantaneous noise floor at the receiver.

Lets assume $q_{k,n}$ is the number of bits assigned in each modulated symbol within n-th subcarrier for the k-th user. $\gamma_{k,n}$ is the signal to noise ratio (SNR) of the respective subcarrier. Hence, for the given OFDMA multiuser system the BER benchmark can be written as [8]:

$$BER \leq \frac{1}{5}\exp\left(\frac{-1.5\gamma_{k,n}}{2^{q_{k,n}} - 1}\right) \quad (6)$$

$$q_{k,n} = \log_2\left(1 + \frac{\gamma_{k,n}}{\Gamma}\right) \quad (7)$$

$$\Gamma = \frac{-\ln(5BER)}{1.5} \quad (8)$$

where Γ is the optimized cutoff fade depth.

There should be minimum level of $\gamma_{k,n}$ that is required to guarantee the required BER benchmark at the receiver for the demanded service s_d. If the noise floor within the subcarrier is denoted as σ^2 and the fading coefficient of the n-th subcarrier of the k-th user is $f_{k,n}$, then it is proposed to allocate $p_{k,n}$ amount of power to that subcarrier, which meets the following condition :

$$\frac{p_{k,n} f_{k,n}^2}{\sigma^2} \geq \gamma_{k,n} \quad (9)$$

Optimization condition is to minimize total transmitted power can be written as :

$$\Delta = \max\left(\sum_{n=1}^{N}\sum_{k=1}^{K}(p_{max}, s_{d,k} - p_{k,n}.f_{k,n}^2)\right) \quad (10)$$

Hence

$$p_{opt} = \sum_{n=1}^{N}\sum_{k=1}^{K}(p_{k,n}) \quad (11)$$

where $p_{opt} \leq p_{max}$

Subsequently, the subcarrier with higher gain coefficient is assigned with lower power adjustment to achieve the target SNR. More power adjustment is required for the lower gain coefficient. It is proposed to adapt the power allocated to the subcarrier, as there is no control of the subcarrier gain coefficient $f_{k,n}$ and at the same time $q_{k,n}$ depend on $f_{k,n}$.

Hence the probability of the k-th user to be assigned with the n-th subcarrier to have access to $s_{d,k}$ services from the network can be described as :

$$P(p_{n,k} \leq p_{max,s_{d,k}} | f_{k,n}, \sigma^2) = 1 - Q\left(\frac{p_{max,s_{d,k}} - p_{n,k}}{\sigma}\right) \quad (12)$$

where p_{max} is the maximum allowable transmitted power, $s_{d,k}$ is the demand service for k-th user.

C. Priority Scheme

To utilize the resources among users fairly, a resource allocation priority factor is proposed. To demonstrate this, it is required to create a default prioritization of all services that can be provided from the system. Lets assume there are Q different service that can be provided by the system of interest. Hence, service with the highest priority is to have cost "Q" and service with the lowest priority is to have cost "1". To estimate the allocation priority factor (C_s) of the demand s-th service, the parameter are proposed to considered as listed below:

α = number of requests received for particular service.

β = revenue generate from particular service.

λ = flexibility factor to provide particular service from the system.

where the factor involve with each of these parameters are related as $X_\alpha > X_\beta > X_\lambda$. There are three different descending order lists of services base of α, β and λ respectively.

$$C_{s_d} = X_\alpha \times d(s_d, \alpha) + X_\beta \times d(s_d, \beta) + X_\lambda \times d(s_d, \lambda) \quad (13)$$

where $d(s_d, \alpha)$, $d(s_{d;} \beta)$, $d(s_{d;} \lambda)$ are the cost factor of s_d service for α, β and λ respectively.

$$C_{s_d} = f(\alpha_{ser}, \beta_{ser}, \lambda_{ser}) \tag{14}$$

Having the estimate of allocation factor for all the services, a service priority list is created at the descending order of the allocation priority factor. The service to the user with the highest allocation priority factor is served first among all users, which has demanded that service from the system. The allocation procedure continues following the allocation cost factor order.

The proposed dynamic resource allocation scheme is integration of all three segments of allocation algorithm. Considering different optimization parameters as described in III-A, III-B and III-C. The integration algorithm flow chart is shown in Fig.2. Where $p_{max/user}(s_d, M, C)$ is the maximum allowable transmitted power per user to provide service s_d with modulation level M and code rate C. M_l, C_l is the lower level of modulation and code rate respectively. M_{min}, C_{min} is the lowest possible modulation and code rate and $|C|$ is the maximum allocation priority factor.

D. Robustness Analysis and Comparison

The amount of power allocated to the k-th user within the proposed algorithm is given as :

$$p_{k,new} = \frac{\gamma_{n,k} . \sigma^2}{f_{k,n}^2} \tag{15}$$

Hence the allocated power to the k-th user can defined by the following expression :

$$p_{k,new} = f(f_k, \gamma_{n,k}) \tag{16}$$

The power allocation scheme proposed in [9] defined that the instantaneous assignment of power is :

$$p_k = \frac{p_{max} . f_k}{\sum_{k=1}^{K} f_k} \tag{17}$$

i.e

$$p_k = f(p_{max}, f_k) \tag{18}$$

However, the authors in [9] proposed to keep p_{max} to a fixed value, while assigning resources to the users. Subsequently, it become obvious that the gradient of the allocated power with the proposed algorithm to achieve the target SNR threshold γ_{th} is greater than the gradient of the existing algorithm such as [9].

i.e

$$\frac{d}{d\gamma_{th}}(p_k(new)) > \frac{d}{d\gamma_{th}}(p_k(exist)) \tag{19}$$

These gradients represent the degree of robustness comparison of the proposed algorithm with the existing one, which is directly involved with the outage probability of a user within the system. As dynamic selection of modulation and coding scheme is also considered in the proposed algorithm based on the channel gain coefficient to achieve the target signal to noise ratio threshold γ_{th}, for the demand service s_d.

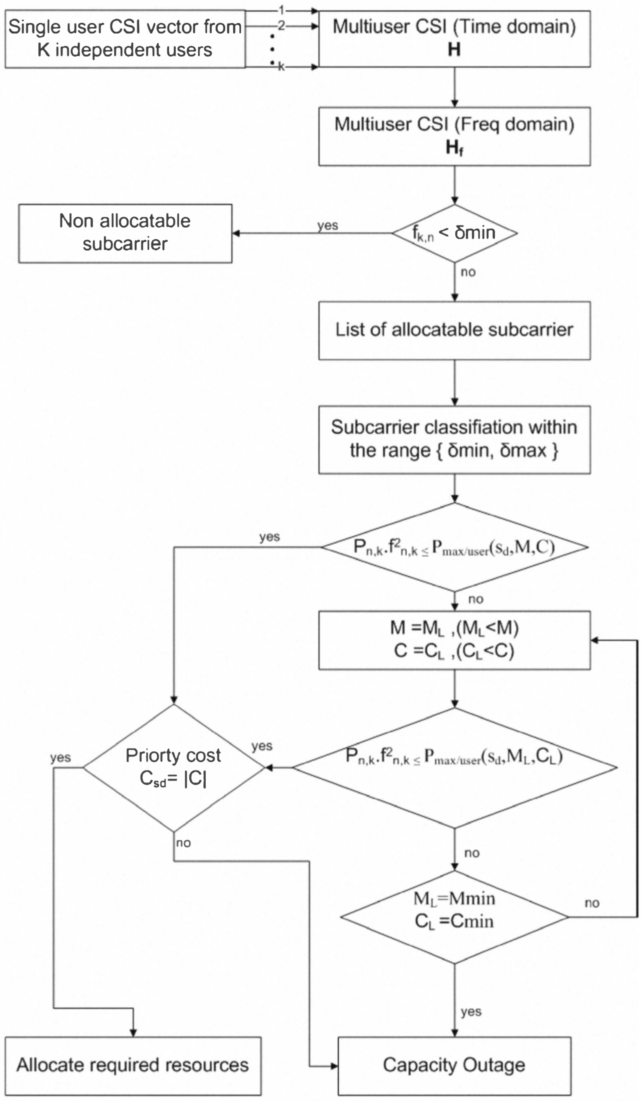

Fig. 2. Proposed algorithm flow chart

The outage probability of the k-th user exploiting the proposed subcarrier and power allocation scheme is defined as:

$$Pr(o) = f(\gamma_{th}, M, C) \tag{20}$$

Where M is the number of bits assigned within the modulated symbol and C is the inverse of coding rate for demand service. On the other hand.

Outage probability of existing algorithm [9] can be expressed as :

$$Pr(o) = f(\gamma_{th}) \tag{21}$$

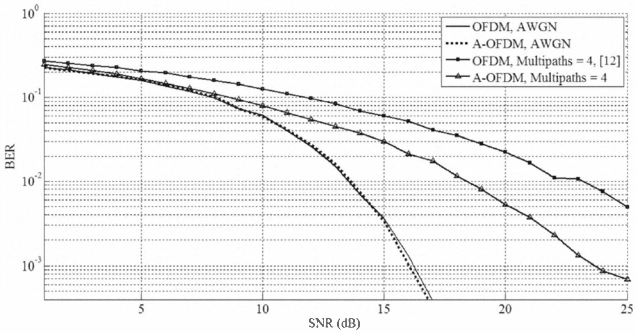

Fig. 3. BER vs SNR (threshold1 = -2.6dB ,threshold2 = -1.2dB, 3 users)

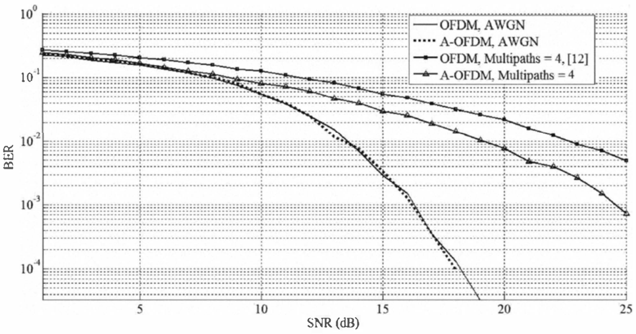

Fig. 4. BER vs SNR (threshold1 = -5.2dB ,threshold2 = -1.5dB, 3 users)

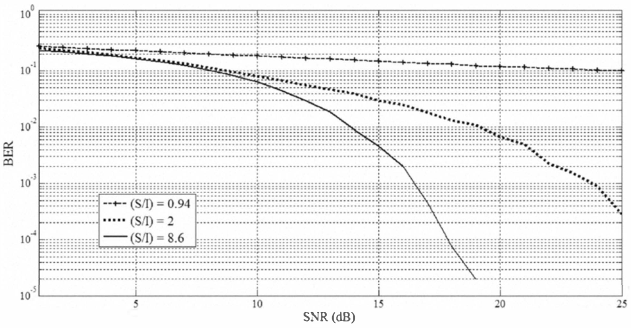

Fig. 5. BER vs SNR for 3 different channel condition (signal to interference ratio(k)) multipath channels for 6 users using the proposed algorithm

It is evident from equation (20) and (21) that the proposed algorithm reduce capacity outage probability compared to existing resource allocation algorithm due to its variable dependency on the modulation and coding scheme.

IV. Simulation Results

To evaluate the performance of proposed algorithm; the system with three users is considered. The channel impulse response lengths are L_1, L_2 and L_3 respectively and three different modulation schemes (i.e BPSK, QPSK, 8-QAM) have been considered. The subcarrier frequency response threshold vector is considered as $[\delta_0\ \delta_1]$.

If the frequency response of the channel f_n is less than δ_0, then that subcarrier is eliminated from allocation list. If

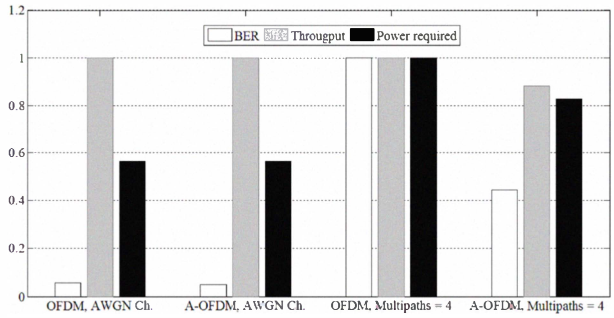

Fig. 6. BER, Throughput, Power required performance analysis with and without proposed algorithm for case2

$\delta_0 < f_n < \delta_1$ QPSK modulation scheme is considered during OFDM symbol mapping. Finally, the frequency responses with ($f_n > \delta_1$) are considered with 8-QAM modulation scheme.

Fig. 3 shows the performance comparison of the proposed algorithm with threshold δ_0 = -2.6 dB and δ_1 = -1.2 dB. For AWGN channel with static subcarrier allocation scheme, there is no impact of the proposed adaptive (dynamic) subcarrier allocation as expected due to the nature of AWGN channel. However, for frequency selective fading channel, receiver performance with the proposed subcarrier allocation scheme outperform the conventional static subcarrier allocation scheme with equal bit allocation scheme (EBA) [12] within OFDMA system. For a bit error rate (BER) of 10^{-2}, there is 3 dB SNR gain obtained with the proposed algorithm over static subcarrier allocation scheme. Fig. 4 shows the performance comparison of the proposed algorithm with threshold δ_0 = -5.2 dB and δ_1 = -1.5 dB. For a BER of 10^{-2} SNR gain has not change significantly, which has demonstrated the degree of robustness of the algorithm. The performance of the proposed algorithm considering a 6-user cluster within a system and with 3 different channel conditions is shown in Fig. 5. Signal to interference ratio (S/I) of these channels are -0.3, 3, 9 dB respectively. It is observed that the BER is decreases when (S/I) increased. It become evident in Fig. 5 that increasing the power within the channel with low SNR does not improve BER, as it increases the interference among the users. When (S/I) is high, it can achieve the desired BER at smaller SNR, which save more power. Fig. 6 demonstrates the performance comparison of the receiver with reference to BER, information throughput and required power with OFDMA transmission scheme, and multipath channel along with static and proposed dynamic subcarrier allocation schemes. The threshold vector [-2.6 , -1.2] dBs is considered with SNR of 15 dB. All the bar charts are normalized to 1.

BER in AWGN channel is low as compared to its counterparts, as no fading in the channel and signal to noise ratio can be improved by increasing the power. However, there is no effect of dynamic allocation within AWGN channel. For multipath fading channel with the proposed algorithm, BER is improved by 60% compared to EBA static OFDM system, due to the uses of the best subcarrier to send information symbol with highest modulation level. This improvement is achieved as trade off with the 12% of information throughput compared to its EBA-OFDM counterpart. Dynamic power allocation also does not save any power within AWGN channel compared with static power allocation scheme. However, exploiting the proposed adaptive power allocation scheme save 18% of the power compared to static power allocation scheme as in [12].

Considering the results shown in Fig.6 and exploiting equation (12) it is found that the outage probability is 1% for AWGN channel, 50% for existing static resource allocation and 13% for the proposed dynamic algorithm (A-OFDM), is estimated. Hence, there is a significant improvement observed within the system in terms of outage probability.

V. Conclusion

The algorithm proposed in this paper allocates the radio resources optimally within multiuser OFDMA system. Power and subcarriers have considered as the radio resources where frequency diversity is required. As the number of users increases, the frequency diversity also increases along with the optimum uses of the power. Due to the flexibility nature of resource allocation, significant reduction in outage probability is measured. A notable amount of reduction in BER is observed with lower transmit power, while exploiting the proposed dynamic resource allocation scheme. The degree of accuracy of the dynamic channel estimation and update is one of the key challenges that is required to focus on, to make the proposed algorithm more robust and efficient.

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