Adaptive Communication: A Systematic Review

Abdullah Alqahtani[1], Nahier Aldhafferi[1], Atta-ur-Rahman[2], Kiran Sultan[3], and Mohammad Aftab Alam Khan[2]
[1] Dept. of CIS, College of CS & IT, Imam Abdulrahman Bin Faisal University, Dammam, P.O. Box 1982, Saudi Arabia
[2] Dept. of CS, College of CS & IT, Imam Abdulrahman Bin Faisal University, Dammam, P.O. Box 1982, Saudi Arabia
[3] Dept. of Computing and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia
Email: {aamqahtani, naldahfeeri, aaurrahman}@iau.edu.sa, kkhan2@kau.edu.sa, mkhan@iau.edu.sa

Abstract —Adaptive communication is one of the hottest areas of research for last two decades or so. This technique is recommended for many 3rd Generation (3G) and 4th Generation (4G) communication standards like WIFI (IEEE 802.11n/b/g) and WiMAX (IEEE 802.16/e) etc. These systems are mainly Orthogonal Frequency Division Multiplexing (OFDM) based communication systems. In OFDM systems there are several subcarriers that may exhibit different channel state information. In adaptive communication, the various transmission parameters like code rate, modulation scheme and power are adapted with respect to the channel state information at different subcarriers, so that the overall throughput of the system may be maximized while satisfying certain constraints like bit error rate and total transmit power, at the same time. In this paper, a comprehensive review of adaptive communication techniques along with their pros and cons and future directions is presented.

Index Terms—Adaptive communication, ACM, OFDM, 3G, 4G, 5G

I. Introduction

Adaptive communication has gained attention of most of the current and future communication systems. Many 3rd generation (3G) and 4th generation (4G) systems have employed it as the main feature of communication. These systems are mainly Orthogonal Frequency Division Multiplexing (OFDM) based systems. In OFDM systems, one large data stream is divided into several low data rate streams. Then these streams are modulated over different subcarriers that are orthogonal in nature. These subcarriers exhibit different channel conditions during transmission. So, a wide range of channel state information (CSI) is observable over the entire spectrum. In this way, using similar and/static communication parameters may end up with worst resource utilization. This is because some of the subcarriers may be okay with those parameters especially those where CSI is better but those with poor CSI may end up with huge Bit Error Rate (BER). Hence, this situation demands adaptive communication.

Adaptive communication is a technique in which different transmission parameters like code rate, modulation symbol, power and subcarriers etc. are chosen according to varying CSI of the sub-channels. It is done in such a way that the overall throughput of OFDM system is maximized while satisfying certain number of constraints most likely the desired BER and total transmit power available at transmitter etc., at the same time. So, it is a constrained optimization problem and the concept of adaptive communication ultimately leads to the optimum utilization of resources in a communication system environment. Different terminologies like link adaptation, adaptive resource allocation, dynamic resource allocation and optimum resource allocation are also referred in the literature to the same phenomenon.

From an extensive literature review it is observed that Adaptive coding and modulation is one of the hottest areas of research in wireless communication especially in Wireless Broadband Access (WBA) like IEEE802.11 (WIFI), IEEE802.16/e (WiMAX) etc. Adaptive modulation and adaptive coding is used to maximize throughput and minimize the BER for OFDM environment.

For sake of clarity literature review is categorized into following adaptive communication techniques observed in the literature.

- Adaptive Modulation
- Adaptive Coding
- Adaptive Coding and Modulation
- Adaptive Loading
- Adaptive Coding, Modulation and Loading

II. General Review

As described in the previous section, review will be presented the way adaptive communication evolve in the literature over past three decades or so.

A. Adaptive Modulation

Initially the concept of adaptive communication was started with adaptive modulation in late eighties. In this way the modulation scheme was chosen according to the channel state information (CSI). For example, if channel conditions are good then a relatively high modulation scheme like 64QAM, 128 QAM or 256 QAM (Quadrature Amplitude Modulation) may be used and if channel conditions are poor then a low modulation scheme like binary phase shift keying (BPSK) may be used. So, when a range of such modulation schemes is available, then some criteria must be there to govern how

Manuscript received January 3, 2018; revised June 22, 2018.
*Corresponding author email: aaurrahman@iau.edu.sa
doi:10.12720/jcm.13.7.357-367

©2018 Journal of Communications

to choose the optimum modulation scheme for a given CSI.

Adaptive modulation based OFDM systems can be categorized into two classes. First uncoded adaptive modulation system and second one is coded adaptive modulation system.

1) Uncoded adaptive modulation systems

In these systems the performance of adaptive systems was investigated in an uncoded environment. That means, without existence of any practical forward error correction (FEC) scheme, several algorithms were proposed for adaptive communication by varying the modulation scheme with respect to the channel state information, especially in nineties. Since modulation was the only parameter to be optimized so traditional optimization techniques were used for this purpose like Lagrange multiplier etc.

Kalet (1989) [1] proposed adaptive modulation for Orthogonal Frequency Division Multiplexing (OFDM) system. In this way switching technique was utilized to choose the modulation scheme for the next transmission interval, given certain channel state information. Chow *et al*. (1995) [2] examined the same idea for Gaussian slowly varying dispersive fixed links.

Later, Cyzlwic (1996) [3] investigated same idea for wideband radio channels. In this scheme it was found that the required signal to noise ratio (SNR) for a target bit error rate (BER) of 10e-3 could be reduced from 15dB to 5dB by using adaptive modulation compared to fixed modulation in OFDM based radio channels.

Sastry *et al*. (2010) [4] proposed a fuzzy system based adaptive modulation scheme for OFDM system using non-data aided SNR estimation. The term non-data aided referred to as this scheme did not require any training data prior to estimation. In this paper, received QAM modulated signal was divided into its real and imaginary parts, then using fuzzy system deviation of each part was calculated that resulted in SNR estimation. Basically, the relationship between the deviation of the received symbol from its original position in the constellation and received SNR was found. That is, a received symbol, which is deviated from its original position in constellation, reveals a specific SNR at the subcarrier. A curve was found that depicts the relationship between deviation and signal to noise ratio. Now once given the deviation, one can get the SNR. Then based upon the existing modulation scheme and the estimated SNR, a fuzzy system was proposed that helped in finding the next possible modulation scheme. Significance of the scheme was shown through the bit error rate simulation results.

2) Coded adaptive modulation systems

In coded systems one thing that must be noticed is that code rate is not adaptive. Adaptive modulation is investigated for coded systems using a fixed code rate. Basically, the idea was to analyze adaptive modulation under a coded environment. These schemes are mostly referred to as adaptive coded modulation schemes. Several researchers take adaptive modulation as an optimization problem and propose efficient solution for encoded systems, like Fischer (1996) [5].

Link adaptation is also used for better results. It is based upon different approaches, like the one based upon imperfect channel estimation by Ye *et al*. (2002) [6]. So, in this paper rather than taking the assumption of Channel State Information (CSI) to be known at transmitter and receiver, more realistic approach is proposed. How the knowledge of CSI affects the performance, is investigated by comparing non-adaptive OFDM, adaptive OFDM with imperfect CSI and 100% known CSI.

In channel estimation slow and fast fading channels are also dealt and performance degradation is observed as well due to poor channel estimates. Most of the equations in this paper were referred to the work done by Chung *et al*. (2001) [7]. There it is shown that efficiency of adaptive modulation is nearly same for discrete and continuous rate adaptation, as well as, under the instantaneous average BER constraint. Also, they derived expressions for optimal power, rate and BER adaptation for different modulation schemes. This paper comprehensively covers the gain with and without adaptive modulation under various circumstances and various adaptive techniques.

SNR estimation is one of the key issues in adaptive OFDM since the decision for adaptation is based upon the instantaneous channel conditions. Received SNR estimation is another name given to channel estimation. This is because many adaptive algorithms follow consideration of received SNR for adapting the modulation scheme.

In his MS thesis, Kant *et al*. (2007) [8] investigates various link adaptation schemes for IEEE 802.11n. In this dissertation it is shown that a fast-adaptive coding and modulation scheme exploits instantaneous knowledge of channel state information to rapidly adapt the transmission parameters according to the change in channel statistics.

Different techniques are investigated in literature for SNR estimation, e.g., this task is mostly accomplished by sending training sequences called pilot signals. This decreases effective channel capacity. An adaptive technique is introduced, which is based on tracking the time variation of the channel to adapt the number and distribution of the pilot symbols aiming at maximizing the capacity by Omar *et al*. (2008) [9]. The performance results showed a significant improvement in BER is found but the system throughput is slightly compromised.

Fuzzy logic in cognitive radio is used for channel estimation in WiMAX systems by Shatila et al. (2009) [10]. Using results of this technique by the same authors, Cognitive Radio (CR) is used for decision making in which fuzzy logic is used for reasoning. The cognitive engine controls the type of modulation, code rate and number of subcarriers to maintain a good system throughput without wasting available bandwidth. Fuzzy C-Mean clustering algorithm is used for cognition also various types of channels have been investigated along

©2018 Journal of Communications

with various channel characteristics like fading type and Doppler effects.

Faezah *et al*. (2009) [11] proposed a switching SNR threshold based adaptive modulation scheme for OFDM system and investigated the performance of adaptive coded modulation based communication techniques. A new adaptation algorithm was introduced that was based upon the average value of instantaneous SNR in the sub-band as the switching parameter. Sub-band was given a name to group of subcarriers having same channel conditions. The scheme was then demonstrated for two cases namely, with transmission blocking and without transmission blocking. With transmission blocking, if a subcarrier experiences very poor channel state information then it may be closed or blocked, so practically those subcarriers do not contribute in overall system throughput. In this way, the available power was redistributed among rest of the subcarriers. In case of without transmission blocking, the sub-channels with poor CSI were not blocked. For comparison, M-ary phase shift keying (PSK) and ¬M-QAM were used with and without channel coding. In this regard various code rates were used, but scheme was only adaptive in modulation sense not in coding.

Shatila *et al*. (2010) [12] proposed an adaptive resource management scheme for vague channel environments using cognitive radios. In this work different transmission parameters like code rate, modulation symbol and number of subcarriers are adapted in a WiMAX environment. Fuzzy Logic has been used for reasoning by cognitive radios. In this proposal cognitive engine controls the type of modulation, code rate and number of subcarriers such that bandwidth should not be wasted.

In the above cited literature, forward error correcting (FEC) scheme were either not used or if used, then their role was not highlighted. The focus was investigation of role of adaptive modulation in enhancement of spectral efficiency of OFDM system. But in subsequent literature reviews coded modulation was focused in which role of adaptive modulation was investigated for coded systems but code rate remains fixed in these schemes.

Turbo coded adaptive modulation was investigated by Liew (1999) [13] and different adaptive schemes were analyzed by Keller et al. (2000) [14]. In these papers, the adaptive scheme was categorized like estimation, adaptation and synchronization. Estimation means finding CSI at receiver, adaptation means the criteria to adapt modulation symbol with respect to CSI and synchronization means receiver should know the new modulation scheme being used.

For single antenna OFDM systems, coded bit and power loading problem was addressed by Li *et al*. (2007) [15] using Low Density Parity Check (LDPC) codes originally motivated by Caire et al (1998) [16]. Many bit interleaved coded modulation (BICM) systems have been proposed like Song *et al*. (2006) [17] and Stierstorfer *et al*. (2007) [18].

The concept of adaptive modulation is not only used for wireless communication channels but also for power line channel. Power line communication systems are also OFDM based systems. Tsugi *et al*. (2008) [19] proposed an adaptive modulation technique for OFDM based impulsive power line channels.

B. Adaptive Coding

Though adaptive communication for orthogonal frequency division multiplexing (OFDM) systems is not a new concept but application of a practical channel code is quite a recent approach. Adaptive coding is a concept used in adaptive communication in which forward effort correction (FEC) code rate is changed with respect to the channel conditions.

For example, if channel conditions are good, then a relatively high code like 2/3 or 3/4 or even no coding can be used and if channel conditions are poor then a relatively low code rate like 1/2 or 1/3 can be used, so that bit error rate (BER) can be controlled. In fact, the concept of adaptive communication is to play around that what bit rate can be achieve and what bit error rate should be maintained etc. In the following papers modulation scheme was kept constant, while code rate was varied with respect to channel conditions.

Al-Askary (2006) [20], in his doctoral thesis, proposed adaptive coding scheme for OFDM systems using concatenated multi-level codes. In this proposed technique same modulation scheme was used for all the OFDM subcarriers during a transmission interval, while different code rates were used on different subcarriers. System could adapt firstly the modulation scheme for all the subcarriers based on average received SNR. Once decided the modulation, different code rates for different subcarriers were chosen in such a way the overall system's target packet error rate (PER) must not go beyond 0.4.

So, the OFDM system with all the subcarriers with a common modulation scheme and different code rates by using Concatenated codes were investigated over AWGN channel. The decision for the unified modulation and various code rates per subcarriers were taken by modulation and coding thresholds, respectively, defined in terms of received signal to noise ratio. The main reason for using this strategy was structural compatibility of concatenated multilevel codes and generalized multilevel codes where multiple subcarriers' data was modulated jointly. He also investigated a detailed study of Generalized Multilevel codes, their construction, decoding, BER performance and decoding complexity.

C. Adaptive Coding and Modulation

In this way both code rate and modulation were varied to cope with channel hostilities. Though it seems obvious that now there are two variables to play around with the channel conditions but at the same time complexity of the optimization problem grows high. This is because now one must choose the right combination of code rate and

©2018 Journal of Communications

modulation scheme to combat with the channel's bad situations.

Stiglmayr *et al*. (2007) [21] proposed an adaptive coding and modulation scheme using bit interleaved coded modulation (BICM) and rate compatible punctured convolutional codes. Different combinations of codes and modulations were investigated. Similarly, Lei *et al.* (2007) [22] proposed an optimal approach based on prediction of the average bit error rate of all subcarriers and adaptive coding and modulation for Turbo coded OFDM systems was investigated.

Bockelmann *et al*. (2008) [23] proposed Mutual Information (MI) as a figure of merit to select the next modulation symbol on per subcarrier basis, since MI is taken as a measure of channel condition on a particular subcarrier. In this technique a single user Mulit-Input Multi-Output OFDM (MIMO-OFDM) was assumed where special multiplexing was used. It is quite interesting that mutual information is a measure of channel state information and this is used as adaptation criteria. Based upon Normalized Average Mutual Information (NAMI), modulation of individual subcarrier is chosen for minimization of BER and maximization of code rate. Mutual Information is calculated by channel decomposition and Jesen's inequality. All the simulations are carried for Convolutional Codes (CC) with maximum a posteriori probability (max-APP) decoder and Turbo codes (TC). It is observed that performance of turbo codes is better than convolutional codes in mutual information sense. Channel decomposition is used to calculate the mutual information. Also, it is shown that singular value decomposition (SVD) is sensitive to long changes in Eigen values but sorted QR decomposition (SQRD) is insensitive to the changes. So, results are generated by using SQRD. Entropy approximation is carried out using Jesen's inequality which helps in reduction in complexity compared to other methods of mutual information calculations. All the calculations are carried under additive white Gaussian noise (AWGN) channel.

Bockelmann *et al*. (2009) [24] proposed Rate Enhancement of BICM-OFDM with Adaptive Coded Modulation via a Bisection approach. In this technique different code rates and modulation schemes are initially plotted, and then a rate power curve is found. Bisection method decides suitable modulation code pair for a certain channel state information. First, performance of all code rates (1/4, 1/3, 1/2, 2/3) for (4, 8, 16) amplitude shift keying (ASK) is achieved in terms of frame error rate (FER) and SNR. By fixing FER to .01% a rate power curve (based upon rate-power pairs) was achieved. From those rate power pairs, set of those pairs is selected that forms a convex set. Based upon convex set, there formulated a look up table. Then coded bisection algorithm is used to choose rate power pair for a certain subcarrier based upon the slope parameters. Basically, this approach utilizes the concept of finding maxima of a curve by first derivative.

Li *et al*. (2007) [25] proposed a Mutual-Information-Based Adaptive Bit-Loading Algorithms for Low Density Parity Check (LDPC) Coded OFDM. In this scheme mutual information is used to estimate the received signal to noise ratio (SNR) that will further be used for adapting the certain parameters.

Convolutional coded link adaptation technique for IEEE 802.11n (2004) is proposed by Peng *et al*. (2007) [26]. This technique dynamically selects the best Modulation and Coding Scheme (MCS) based upon channel conditions and PHY (physical) layer performance requested by the application concerned. Also, it is shown that coded performance at the decoder's output can be modeled as a function of decoder's input (uncoded) BER and the code rate. For MIMO-OFDM systems with different modulation schemes for different spatial streams at each subcarrier, they proposed a simple and accurate method for computing BER for each spatial stream from different subcarriers. Also, different approaches for searching and selecting MCS are discussed, like when to choose spatial multiplexing and when to choose diversity gain. In spatial multiplexing different antennas may be carrying a different signal. In this way the signal is multiplexed on the transmit antennas. This is the case when channel is good and in this way the achievable data rate is quite high and sometimes it is considered as order of the transmit antennas. Another situation is when channel is hostile. Now instead of getting more data rates, data integrity becomes the focus. So, in this technique same signal is sent over various antennas. Sending same signal over various antennas is referred to as spatial diversity. Though data rates are not high, but due to diversity factor data integrity is improved.

MIMO based OFDM is also investigated for throughput maximization of OFDMA system Zerrouk *et al* [27]. A detailed study of MIMO with WiMAX IEEE 802.16 and IEEE 802.16e (2006) is presented for diverse scenario and their benefits are shown. At low SNR space time block code (STBC) is preferred while for higher SNRs adaptive MIMO is switched to spatial multiplexing (SM). It is shown that using SM the throughput can be doubled. All the results were carried out in Adaptive Modulation and Coding scenario. Also, it is explained that the proposed system supports Adaptive MIMO Switching (AMS).

A proposal for mobile WiMAX is given by Tarhini *et al*. (2007) [28] where adaptive modulation and coding (AMC) is one of its features. In this case it selects the best modulation and code pair based upon three criteria namely, received SNR, user's distance from base station (BS) and type of user that is streaming (privileged) or elastic (ordinary). An expression of SNR versus radius (distance) is achieved for all modulation schemes. Then a look up table is built based upon the values obtained from the curve that depicted the expression. Finally based upon received SNR and distance, code and modulation can be chosen.

Das *et al*. (2007) [29] addressed the link adaptation problem due to static lookup table based adaptive techniques. In this paper, it was focused that performance of the static lookup table deteriorates with the passage of time as different impairments like temperature etc in the wireless devices make them less reliable for adaptation process. Effects of performance degradation in wireless devices due to temperature, has been investigated by Leyssenne *et al*. (2006) [30].

Using machine learning techniques in adaptive communication is a quite recent perspective. Yun *et al*. (2009) [31] proposed a multi-class support vector machine for adapting parameters in MIMO-OFDM systems. This work was further extended by Daniel et al. (2010) [32]. In his work he proposed a link adaptation technique for convolutionally coded MIMO-OFDM wireless systems using a supervised machine learning algorithm and SNR ordering. It was shown that machine learning algorithm through the classification is a fast-adaptive approach in which algorithm can learn from the observation of past transmission history.

Daniels *et al*. (2012) [33] proposed an online (real-time) support vector machine (SVM) algorithm for adaptive modulation and coding (AMC) for selective channels originally motivated by Xu et al (2006) [34]. The system model used was IEEE 802.11n for simulations and it was shown that the proposed scheme exhibits better performance as well as low complexity compare to conventional lookup-table based adaptive modulation and coding algorithms. The reduction in complexity was mainly achieved by linear kernel function that drastically reduced the memory requirements of the online algorithm. Moreover, the proposed scheme, in selective channels, could optimize AMC to the unique and potentially dynamic hardware characteristics of each wireless device. The proposed scheme was compared with SVM with radial basis function (RBF) and k-nearest neighbor (kNN) algorithm. In this paper it was also shown that with linear kernel 14% of training data becomes support vectors and with RBF kernels 100% of training data becomes support vectors.

D. Adaptive Coding, Modulation and Loading

Loading problem in multicarrier system is a name given to power distribution among different OFDM subcarriers. The power allocation may be equal or different for each subcarrier. Adaptive power is also considered for optimizing the overall throughput of the OFDM system.

A low complexity algorithm for proportional resource allocation in Orthogonal Frequency Division Multiple Access (OFDMA) system was proposed by Wong et al. (2004) [35]. In this work a linear method and root finding algorithm were used to allocate power and data rates to users. Jianwei *et al*. (2006) [36] proposed a gradient based solution for single user downlink scheduling and resource allocation for downlink OFDM wireless systems and a 96.6% utility was achieved.

Trifonov *et al*. (2007) [37] proposed an Adaptive data transmission in downlink Multi Input Multi Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system with pre-equalization. The schemes were investigated using Water-filling algorithm and adaptive LQ decomposing. Water-filling is very famous loading algorithm for multicarrier systems in which more power is given to the subcarrier with high channel to interference noise ratio (CINR) and vice versa, to maximize the total data rate.

A Genetic Algorithm (GA) based adaptive resource allocation scheme was proposed by Reddy *et al*. [38], to increase the user data rate. In this paper water-filling principle was used as a fitness function for Genetic Algorithm to find the fitness of a chromosome. Moreover, it was shown that chromosome length helps to achieve optimum power requirement. A novel efficient resource allocation algorithm for multiuser OFDM system using a joint allocation method and root finding algorithm to achieve good performance even with low signal to noise ratio (SNR) was proposed by Gunaseelan *et al*. (2008) [39].

Rahman *et al*. (2008) [40] worked on several techniques for adaptive bit and adaptive power allocation for multi-antenna assisted broadband OFDM systems. After investigation of various techniques, it was found that to combat the channel hostilities in multipath systems adaptive power and bit allocation plays a key role.

Another interesting paper with adaptive resource allocation based on modified genetic algorithm (GA) and particle swarm optimization (PSO) for multiuser OFDM system was proposed by Ahmed *et al*. (2008) [41]. Genetic algorithm has been modified by using a fractional generation gap. With this change, modified GA converges faster than the native one and it was also found that PSO performs better than GA.

An approach akin to the previous one, ant colony optimization (ACO), another famous nature inspired evolutionary technique for subcarrier allocation in OFDMA based wireless system was proposed by Chatzifotis et al. (2009) [42]. Proposed technique was found capable of finding one optimal solution in a short period of time.

Adaptive subcarrier and power allocation with fairness for multi-user space-time block-coded (STBC) OFDM system was investigated in contrast to Greedy algorithm, as well as, Water-filling principle by Xu et al. (2009) [43]. An optimization problem for power constraints and use Genetic algorithm (GA) to maximize the sum capacity of OFDM system with the total power constraint was investigated by Liu *et al*. (2009) [44].

Moreover, it was shown that Genetic algorithm is better than the conventional methods. A scheme for resource allocation in downlink MIMO-OFDMA with proportional fairness where dominant Eigen channels obtained from MIMO state matrix are used to formulate the scheme with low complexity by Fuwa *et al*. (2009) [45]. Proposed scheme provides much better capacity gain than static allocation method.

©2018 Journal of Communications

A PSO based Adaptive multicarrier cooperative communication technique which utilizes the subcarrier in deep fade using a relay node to improve the bandwidth efficiency was proposed by Chakravarthy *et al*. (2010) [46]. In this scheme centralized and distributed versions of PSO were investigated. Similarly, a low complexity subcarrier and power allocation technique based upon GA to maximize the sum of user data rates in MIMO-OFDMA system was proposed by Sharma *et al*. (2010) [47].

Al-Janabi *et al*. (2010) [48] proposed a bit and power allocation strategy for Adaptive Modulation and Coding (AMC) based MIMO-OFDMA Wi-MAX system. The scheme maximizes the average system throughput by allocating the available resources optimally among the utilized bands depending on the corresponding channel conditioning and total transmission power constraints. The power allocation algorithm distributes the transmission power among the bands of all transmit antennas according to the power constraints and the channel state information (CSI) and the bit allocation algorithm selects the suitable modulation coding scheme (MCS) options for different bands based on the assigned power and the channel conditions. Another GA based efficient real-time subcarrier and bit allocation for multiuser OFDM transmission technique was proposed in which overall transmit power was minimized under user constraint by Chriaa *et al*. (2011) [49].

A subcarrier-chunk based technique in which resource allocation problem for the downlink of distributed Multi-Input Single-Output Orthogonal Frequency Division Multiple Access (MISO-OFDMA) wireless systems with fairness guarantee was proposed by Papoutsis *et al*. (2011) [50]. The scheme dramatically reduces the complexity and fairness among users' data rates is very satisfactory despite the loss with respect to the unconstrained case where the only target is the maximization of the sum data rate. Along with many adaptive parameters like code rate, modulation symbol and power, subcarrier bandwidth is another parameter being used. Das *et al*. (2008) [51] investigated the role of adaptive subcarrier bandwidth allocation in an OFDM environment. In this technique the bandwidth allocation was subject to the user requirement in a multi-user system. The overall system throughput was maximized by optimum allocation of bandwidth according to users' needs.

In [52], [53], authors investigated the concept of adaptive communication in OFDMA Cognitive Radio Network (CRN) based cross-layer adaptive resource allocation for video streaming with and without perfect CSI information respectively. Similarly, in [54], authors investigated the concept of adaptive communication for Wireless Sensor Networks (WSN) for rate enhancement and better BER performance. In [55], users investigated a power allocation and channel selection scheme for smart metering system. In [56], a fuzzy logic based scheme for only adaptive modulation was investigated for an arbitrary OFDM based system. In [57], authors presented a review of adaptive communication techniques for OFDM systems.

In [58], authors presented an adaptive communication technique using PSO and fuzzy system. It was tried to adapt the code rate, modulation and power in a typical OFDM system. Similarly, in [59], authors investigated the role of firefly pack nature inspired heuristic algorithm for sake of efficient adaptive resource allocation in communication system. Moreover, in [60], authors proposed a modified multi-dimensional Genetic Algorithm for adaptive communication in the OFDM environment.

III. Adaptive Communication using Fuzzy Systems

In this section we focused on the design of the proposed Fuzzy Rule Base System (FRBS) for the solution of the constrained optimization problem of adaptive coding and modulation. The choice of fuzzy system for the solution of this problem is adequate in a sense that such systems are considered for the situations that are vague, unclear and missing certain information. In our problem it is quite suitable because the formulated problem is highly nonlinear and unpredictable because channel state information (CSI) at individual OFDM subcarriers is changed quite rapidly in radio environment. So, the adaptive system should be smart enough to choose the optimum modulation code combination even with such rapid changes in channel state.

A. System Model

The system model considered is an Orthogonal Frequency Division Multiplexing (OFDM) equivalent baseband model with N number of subcarriers. It is assumed that complete channel state information (CSI) is known at both transmitter and receiver sides. The frequency domain representation of system is given by;

$$r_n = h_n . \sqrt{p_n} . x_n + z_n ; \; n = 1, 2, ..., N \quad (1)$$

where r_n , h_n , $\sqrt{p_n}$, x_n and z_n denote received signal, channel coefficient, transmit power, transmit symbol and the additive while Gaussian noise (AWGN) at the subcarrier $n = 1, 2, ..., N$, respectively. The overall transmit power of the system is since power is $P_T = \sum_{n=1}^{N} p_n = Np$ considered same (flat) for all the subcarriers, and the noise distribution is complex Gaussian with zero mean and unit variance.

It is assumed that signal transmitted on the nth subcarrier is propagated over an independent non-dispersive single-path Rayleigh Fading channel and where each subcarrier faces a different amount of fading independent of each other. Hence, the channel coefficient of the nth subcarrier can be expressed as:

$$h_n = \alpha_n e^{j\theta_n} ; n = 1, 2, ..., N \quad (2)$$

©2018 Journal of Communications

where α_n is Rayleigh distributed random variable of nth subcarrier, and the phase θ_n is uniformly distributed over $[0, 2\pi]$. And j represents the complex number notation 'iota'. Fig. 1 shows the schematic diagram of the proposed system. According to this diagram, upon receiving the signal, channel coefficients and quality of service demands for all subcarriers is fed into the proposed fuzzy rule base system block, which in turn would decide the new modulation and coding scheme. The information about the new parameters in sent to the receiver via a feedback channel. Upon receiving the parameters transmitter starts using them and so on.

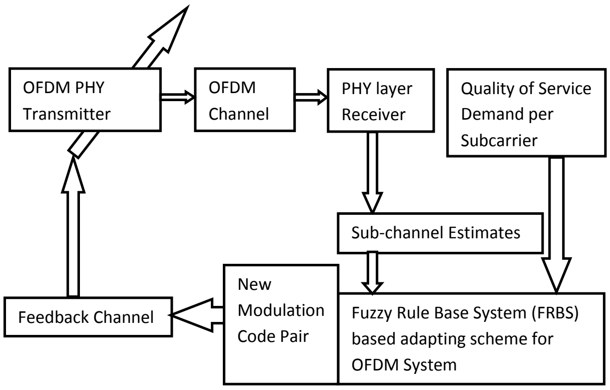


Fig. 1. Schematic of FRBS adaptive system

B. Problem Statement

In a typical OFDM environment the available channel bandwidth is divided into several orthogonal subcarriers. As each subcarrier may experience a different channel behavior, using a fixed modulation and coding scheme for all the subcarrier and for all the time may not be a good idea. In literature several adaptive communication techniques have been investigated, they do adapt the parameters like code rate and/or modulation scheme after each transmission interval; but once the parameters are chosen same combination of parameters is applied on all subcarriers.

Moreover, the decision for the next transmission parameters used is mostly done by average received signal to noise ratio (SNR) thresholds. In this way the chosen parameters may be very good for some subcarriers but for the rest it may not be a good choice. Consequently, the throughput of the system cannot be optimized. Another limiting factor in this regard is that SNR thresholds quite wide like same modulation code combination is inferred for 10dB SNR spectrum.

To overcome these limitations in [61] a Fuzzy Rule Base System was proposed for the solution of the constrained optimization problem that can be stated as,

"Maximize the overall data rate of OFDM system by varying the code rate and modulation scheme such that the bit error rate and total transmit power should remain under certain thresholds."

Mathematically, this problem can be written as;

$$\begin{aligned} &\max \quad R_{Total} = \frac{1}{N}\sum_{n=1}^{N} r_n \\ &\text{s.t,} \\ &BER_n \le BER_{QoS_n} \\ &\textit{and} \\ &\sum_{n=1}^{N} p_n < P_T \end{aligned} \tag{3}$$

where $r_n = (\log_2(M))_n R_n$ is bit rate of the nth subcarrier, which is product of code rate R_n and bits per modulation symbol used $(\log_2(M))_n$ at nth subcarrier also known as modulation code product, P_T is the available transmit power and BER_{QoS_n} is the target BER that depends upon a specific quality of service (QoS) request or application requirement over nth subcarrier, while denotes the total number of subcarriers in OFDM system. Subsequent literature review about the work done based on the model described above.

In [62], authors proposed a fuzzy rule base assisted adaptive coding and modulation scheme for OFDM systems. The proposed scheme adapts the pair of modulation and code rate being used during next transmission interval based on current CSI. In this way QAM and parallel concatenated Product codes were used as candidate modulation and coding schemes. The decision was taken by FRBS.

In [63], authors proposed a fuzzy rule base assisted adaptive coding and modulation scheme for OFDM systems. The proposed scheme adapts the pair of modulation and code rate being used during next transmission interval based on current CSI. In this way QAM and Convolutional codes were used as candidate modulation and coding schemes. The decision was taken by FRBS.

In [64], provided a comparison of FBRS based adaptive communication techniques in terms of the coding schemes used in [53], [54]. As a result, it was found that product codes may perform better than convolutional codes but at the cost of increased computational complexity at both transmitter and receiver end. The BER performance showed that product codes may achieve 2dB better performance.

In [65], authors presented an adaptive communication technique. In this technique Genetic Algorithm (GA) along with FRBS was used. Here FRBS was used to adapt the modulation and code pair while GA was used for adapting power vector for entire OFDM spectrum. The performance showed better results compared to alone adaptive coding and modulation using FRBS without adaptive power.

In [66], authors presented an adaptive communication technique. In this technique Differential Evolution (DE) along with FRBS was used. Here FRBS was used to

©2018 Journal of Communications

adapt the modulation and code pair while DE was used for adapting power vector for entire OFDM spectrum. The performance showed better results compared to alone adaptive coding and modulation using FRBS without adaptive power. It was demonstrated that DE based adaptive power was better than GA [65].

In [67], authors presented a real time adaptive communication technique. In this technique Gaussian Radial Basis Function, Neural Network (GRBF-NN), FRBS and Differential Evolution (DE) were used. Here FRBS was used to adapt the modulation and code pair while DE was used for adapting power vector for entire OFDM spectrum. GRBS-NN was trained by the examples generated by DE-FRBS engine. Where DE was used for generating random examples and FRBS was providing the outcome of the corresponding example. Once the network was trained, it could readily decide the appropriate power, code rate and modulation scheme for next transmission interval based on the weights that were already learnt. Hence made it suitable for real time applications.

The concept of adaptive communication is not just confined to OFDM systems but other systems may also get benefitted by them. For example, in [68] authors presented an adaptive modulation and coding (MODCOD) technique for digital video broadcast second generation (DVB-S2) satellite TV. The scheme was promising in terms of BER and QoS enhancement.

In [69]-[72], the concept of adaptive communication was investigated in OFDM based HYPERLANS. In this technique product codes were and QAM modulation was investigated under FRBS supervision.

IV. Conclusions

This paper presents a comprehensive review of adaptive communication techniques being investigated over past three decades or so. The concept of adaptive communication is being used in almost every generation of mobile communication like 3G, 4G and currently in 5G with a growing interest due to its promising nature in terms of enhanced data rates and reduced bit error rate (BER). Initially the concept was confined to adaptive modulation without coding. Then in next era people tried adaptive coding without modulation. Later the concept was combined and called adaptive coding and modulation (ACM). During past five years or so, concept of adaptive coding, modulation and loading (power) has been widely used. This is indeed a complex non-convex optimization problem. In this regard various algorithms/approaches were proposed and investigated. From the careful review, it is found that evolutionary/soft computing techniques are becoming more popular and promising compared to their classical complex optimization counterparts. In future, other transmission parameters may also be taken into consideration like bandwidth etc. The approach will be more benefitting for future communications like 5G networks with different communication patches like microwave and radio link adaptation etc. where the data rates and quality of service requirements are more than ever due to the enhanced number of supported users.

References

[1] I. Kalet, "The multitone channel," *IEEE Transactions on Communications*, vol. 37, pp. 119-124, February1989.

[2] P. S. Chow, J. M. Cioffi, and J. A. C. Bingham, "A practical discrete multitone transceiver loading algorithm for data transmission over spectrally shaped channels," *IEEE Transactions on Communications*, vol. 48, pp. 772-775, 1995.

[3] A. Cyzlwik, "Adaptive OFDM for wideband radio channels," in *Proc. Global Telecommunications Conference*, vol. 1, pp. 713-718, November 1996.

[4] K. S. Sastry and M. S. P. Babu, "Fuzzy logic based adaptive modulation using non data aided SNR estimation for OFDM systems," *International Journal of Engineering Science and Technology*, vol. 2, no. 6, pp. 2384-2392, 2010.

[5] R. F. H. Fischer and J. B. Huber, "A new loading algorithm for discrete multitone transmission," in *Proc. IEEE Global Telecommunications Conference*, London, England, November 1996, vol. 1, pp. 724-728.

[6] S. Ye, R. S. Blum, and L. J. Cimini, "Adaptive modulation for variable rate OFDM systems with imperfect channel information," in *Proc. IEEE 55th Vehicular Technology Conference*, vol. 2, pp. 767-771, 2002.

[7] S. T. Chung and A. J. Goldsmith, "Degrees of freedom in adaptive modulation: a unified view," *IEEE Transactions on Communications*, vol. 49, pp. 1561-1571, 2001.

[8] S. Kant and T. L. Jensen, "Fast link adaptation for IEEE 802.11n," M.S. thesis, Aalborg University, 2007.

[9] A. Omar and A. R. Ali, "Adaptive channel characterization for wireless communication," in *Proc. IEEE Radio and Wireless Symposium*, 2008, pp. 543-546.

[10] H. Shatila, M. Khedr, and J. H. Reed, "Channel estimation for WiMAX systems using fuzzy logic cognitive radio," in *Proc. 6th IEEE and IFIP International Conference on Wireless and Optical Communications*, 2009, pp. 1-6.

[11] J. Faezah and K. Sabira, "Adaptive modulation for OFDM systems," *International Journal of Communication Networks and Information Security*, vol. 1, no. 2, pp. 1-8, 2009.

[12] H. Shatila, M. Khedr, and J. Reed, "Adaptive modulation and coding for WiMAX systems with vague channel state information using cognitive radio," SPECTS 2010, Ottawa, Canada, July 2010.

[13] T. H. Liew, C. H. Wong, and L. Hanzo, "Block turbo coded burst-by-burst adaptive modems," in *Proc. Microcoll'99*, Budapest, Hungary, 1999, pp. 59–62.

[14] T. Keller and L. Hanzo, "Adaptive modulation techniques for duplex OFDM transmission," *IEEE Transactions on Vehicular Technology*, vol. 49, no. 5, pp. 1893-1906, 2000.

[15] Y. Li and W. E. Ryan, "Mutual-Information-Based adaptive bit-loading algorithms for LDPC-Coded OFDM," *IEEE Transactions on Wireless Communications*, vol. 6, no. 5, pp. 1670-1680, May 2007.

[16] G. Caire, G. Taricco, and E. Biglieri, "Bit-Interleaved coded modulation," *IEEE Transactions on Information Theory*, vol. 44, no. 3, pp. 927-946, 1998.

©2018 Journal of Communications

[17] K. B. Song, A. Ekbal, S. T. Chung, and J. M. Cioffi, “Adaptive modulation and coding for bit-interleaved coded OFDM,” *IEEE Transactions on Wireless Communications*, vol. 5, no. 7, pp. 1685–1694, July 2006.

[18] C. Stierstorfer and R. F. H. Fischer, “Gray mapping for bit-interleaved coded modulation,” in *Proc. IEEE Vehicular Technology Conference*, Dublin, Ireland, April 2007, pp. 1703-1707.

[19] T. Tsugi and M. Itami, “A study on adaptive modulation of OFDM under impulsive power line channel,” in *Proc. IEEE International Symposium on Power Line Communications and Its Applications*, pp. 304- 309, April 2008.

[20] O. Al-Askary, “Coding and iterative decoding of concatenated multi-level codes for the Rayleigh fading channel,” PhD thesis in Radio Communication Systems, KTH Information and Communication Technology, Stockholm, Sweden, 2006.

[21] S. Stiglmayr, M. Bossert, and E. Costa, “Adaptive coding and modulation in OFDM systems using BICM and rate-compatible punctured codes,” European Wireless, Invited Paper, pp. 1-7, Paris, France, April 2007.

[22] Y. Lei and A. Burr, “Adaptive modulation and code rate for turbo coded OFDM transmissions,” in *Proc. IEEE Vehicular Technology Conference*, 2007, pp. 2702-2706.

[23] C. Bockelmann, D. W ̈ubben, and K. D. Kammeyer, “Mutual information based rate adaptation for MIMO-OFDM system with finite signal alphabets,” in *Proc. International ITG Workshop on Smart Antennas*, Darmstadt, Germany, 2008, pp. 60-67.

[24] C. Bockelmann, D. W ̈ubben, and K. D. Kammeyer, “Rate enhancement of BICM-OFDM with adaptive coded modulation via a bisection approach,” in *Proc. IEEE 10th Workshop on Signal Processing Advances in Wireless Communications*, 2009, pp. 658-662.

[25] Y. Li and W. E. Ryan, “Mutual-Information-Based adaptive bit-loading algorithms for LDPC-Coded OFDM,” *IEEE Transactions on Wireless Communications*, vol. 6, no. 5, pp. 1670-1680, May 2007.

[26] F. Peng, J. Zhang, and W. E. Ryan, “Adaptive Modulation and Coding for IEEE 802.11n,” in *Proc. IEEE Wireless Communications and Networking Conference*, 2007, pp. 656-661.

[27] H. Zerrouk and M. Feham, “High throughput of WiMAX MIMO-OFDM including adaptive modulation and coding,” *International Journal of Computer Science and Information Security*, vol. 7, no. 1, 2010.

[28] C. Tarhini and T. Chahed, “AMC-aware QoS proposal for OFDMA based IEEE 802.16 WiMAX system,” in *Proc. IEEE Global Telecommunications Conference*, 2007, pp. 4780-4784.

[29] S. S. Das, F. M. Tariq, I. Rahman, F. B. Frederiksen, E. D. Carvalho, and R. Prasad, “Impact of nonlinear power amplifier on link adaptation algorithm of OFDM systems,” pp. 1303–1307, 2007.

[30] L. Leyssenne, J. M. Pham, P. Jarry, E. Kerherve, and D. Saias, “Analysis of temperature modulation on a sige power amplifier non- linearity,” pp. 1–4, 2006.

[31] S. Yun and C. M. Caramanis, “Multiclass support vector machines for adaptation in MIMO-OFDM wireless systems,” in *Proc. Allerton Conference on Communication, Control, and Computing*, 2009.

[32] R. C. Daniels and R. W. Heath, Online Adaptive Modulation and Coding with Support Vector Machines, 2012.

[33] R. C. Daniels, C. M. Caramanis, and R. W. Heath, “Adaptation in convolutionally coded MIMO-OFDM wireless systems through supervised learning and SNR ordering,” *IEEE Transactions on Vehicular Technology*, vol. 59, no. 1, pp. 114–126, January 2010.

[34] G. Xu and Y. Lu, “Channel and modulation selection based on support vector machines for cognitive radio,” in *Proc. International Conference on Wireless Communications, Networking and Mobile Computing*, Wuhan, 2006, pp. 1–4.

[35] I. C. Wong, Z. Shen, B. L. Evans, and J. G. Andrews, “A low complexity algorithm for proportional resource allocation in OFDMA systems,” in *Proc. IEEE Workshop on Signal Processing Systems*, Austin, TX, USA, 2004, pp. 1-6.

[36] H. Jianwei, V. G. Subramanian, R. Agrawal, and R. A. Berry, “Downlink scheduling and resource allocation for OFDM systems,” *IEEE Transactions on Wireless Communications*, vol. 8, no. 1, pp. 288-296, 2006.

[37] P. Trifonov and E. Costa, “Adaptive data transmission in downlink MIMO-OFDM systems with pre-equalization,” *IEEE International Conference on Communications*, St. Petersburg, 2007, pp. 1036-1041.

[38] Y. B. Reddy, N. Gajendar, T. Portia, and M. Damian, “Computationally efficient resource allocation in OFDM systems: Genetic algorithm approach,” in *Proc. Fourth International Conference on Information Technology*, LA, 2007, pp. 36-41.

[39] K. Gunaseelan, R. Venkateswari, and A. Kandaswamy, “A novel efficient resource allocation algorithm for multiuser OFDM systems,” *IETE Tech Review*, pp. 201-206, 2008.

[40] M. I. Rahman, S. S. Das, Y. Wang, F. B. Frederiksen, and R. Prasad, “Bit and power loading approach for broadband multi-antenna OFDM system,” *IEEE Transactions on Communications*, pp. 1689-1693, 2007.

[41] I. Ahmed and S. P. Majumder, “Adaptive resource allocation based on modified Genetic Algorithm and particle swarm optimization for multiuser OFDM systems,” in *Proc. International Conference on Electrical and Computer Engineering*, Dhaka, Bangladesh, 2008, pp. 211-216.

[42] I. Chatzifotis, K. Tsagkaris, and P. Demestichas, “Ant colony optimization for subcarrier allocation in OFDMA-based wireless system,” in *Proc. ICT-Mobile Summit 2009 Conference Proceedings*, Santander, Spain, 2009, pp. 1-9.

[43] J. Xu and J. Seo, “Adaptive subcarrier and power allocation with fairness for multi-user space time block coded OFDM system,” *Wireless Personal Communications*, vol. 53, no. 2, pp. 163-177, 2010.

[44] B. Liu, M. Jiang, and D. Yuan, “Adaptive resource allocation in multiuser OFDM system based on genetic algorithm,” in *Proc. International Conference on Communications and Mobile Computing*, Jinan, China, 2009, vol. 1, pp. 270-273.

[45] Y. Fuwa, E. Okamoto, and Y. Iwanami, “Resource allocation scheme with proportional fairness for multi-user downlink MIMO-OFDMA systems,” in *Proc. 9th*

International Symposium on Communications and Information Technology, Japan, 2009, pp. 588-593.

[46] C. K. Chakravarthy and P. Reddy, "Particle swarm optimization based approach for resource allocation and scheduling in OFDMA systems," *International Journal of Communications, Network and System Sciences*, vol. 3, pp. 466-471, 2010.

[47] N. Sharma and K. R. Anupama, "A novel genetic algorithm for adaptive resource allocation in MIMO-OFDM systems with proportional rate constraint," *Wireless Personal Communication Springer Link*, vol. 61, no. 1, pp. 113-128, 2010.

[48] M. S. Al-Janabi, C. C. Tsimenidis, B. S. Sharif, and S. Y. Le Goff, "Bit and power allocation strategy for AMC-based MIMO-OFDMA WiMAX systems," in *Proc. 6th International Conference on Wireless and Mobile Computing, Networking and Communications*. Newcastle, UK, 2010, pp. 575-579.

[49] E. Chriaa, M. Quzineb, and B. Sanso, "Genetic algorithm for efficient real-time subcarrier and bit allocation for multiuser OFDM transmission," *International Journal of Research and Reviews in Computer Science*, 2011.

[50] V. D. Papoutsis and S. A. Kotsopoulos, "Chunk-Based resource allocation in distributed MISO-OFDMA systems with fairness guarantee," *IEEE Communications Letters*, vol. 15, no. 4, pp. 377-379, April 2011.

[51] S. S. Das, E. D. Carvalho, and R. Prasad, "Performance analysis of OFDM systems with adaptive sub carrier bandwidth," *IEEE Transactions on Wireless Communications*, vol. 7, no. 4, pp. 1117-1122, April 2008.

[52] H. Saki and M. Shikh-Bahaei, "Cross-Layer resource allocation for video streaming over OFDMA cognitive radio networks," *IEEE Transactions on Multimedia*, vol. 17, no. 3, pp. 333-345, 2015.

[53] H. Saki, A. Shojaeifard, and M. Shikh-Bahaei, "Cross-layer resource allocation for video streaming over OFDMA cognitive radio networks with imperfect cross-link CSI," in *Proc. International Conference on Computing, Networking and Communications*, 2014.

[54] Z. Abbas, N. Javaid, A. Javaid, Z. A. Khan, M. A. Khan, and U. Qasim, "An adaptive transmission scheme in wireless sensor networks," *World Applied Sciences Journal*, 2013.

[55] C. K. Huynh and W. C. Lee, "Optimal solution for channel selection and power allocation for TVWS-Based smart metering system," *Wireless Pers. Commun.*, vol. 85, no. 3, pp. 1653–1668, 2015.

[56] K. Singh, "Fuzzy logic based modified adaptive modulation implementation for performance enhancement in OFDM systems," *International Journal of Intelligent Systems and Applications*, vol. 8, no. 5, pp. 49-54, 2016.

[57] F. Mustafa and P. Lohiya, "Survey of optimum resource allocation in OFDM communication system," in *Proc. National Conference on Emerging Trends in Advanced Communication Technologies*, 2015, pp. 10-13.

[58] F. Mustafa and P. Lohiya, "Optimization of resource allocation in OFDM communication system for different modulation technique using FRBS and PSO," *Sensor Netw Data Commun*, 2015.

[59] A. M. Haider and M. K. Ibrahim, "Efficient dynamic resource allocation in OFDMA systems by firefly pack algorithm," *International Journal of Computer Network and Information Security*, vol. 9, no. 3, pp. 1-10, 2017.

[60] M. K. Ibrahim and A. M. Haider, "Adaptive OFDMA resource allocation using modified multi-dimension genetic algorithm," *Iraq Journal of Electrical and Electronic Engineering*, vol. 12, no. 1, pp. 103-113, 2016.

[61] Atta-ur-Rahman, I. M. Qureshi, and A. N. Malik, "A fuzzy rule base assisted adaptive coding and modulation scheme for OFDM systems," *J. Basic Appl. Sci. Res*., vol. 2, no. 5, pp. 4843-4853, 2012.

[62] Atta-ur-Rahman, I. M. Qureshi, and M. Z. Muzaffar, "Adaptive coding and modulation for OFDM systems using product codes and fuzzy rule base system," *International Journal of Computer Applications*, vol. 35, no. 4, pp. 41-48, December 2011.

[63] Atta-ur-Rahman, I. M. Qureshi, M. Z. Muzaffar, and M. T. Naseem, "FRBS based rate enhancement scheme for OFDM systems using product codes," in *Proc. 15th International Multi-topic Conference*, Islamabad, Pakistan, December 13-15, 2012, pp. 339-344.

[64] Atta-ur-Rahman and I. M. Qureshi, "Comparison of coding schemes over FRBS aided AOFDM systems," *Journal of Networking and Innovative Computing*, vol. 1, pp. 183-193, 2013.

[65] Atta-ur-Rahman, I. M. Qureshi, and A. N. Malik, "Adaptive resource allocation in OFDM systems using GA and fuzzy rule base system," *World Applied Sciences Journal*, vol. 18, no. 6, pp. 836-844, 2012.

[66] Atta-ur-Rahman, I. M. Qureshi, A. N. Malik, and M. T. Naseem, "Dynamic resource allocation for OFDM systems using DE and fuzzy rule base system," *Journal of Intelligent & Fuzzy Systems*, vol. 26, no. 4, pp. 2035-2046, 2014.

[67] Atta-ur-Rahman, I. M. Qureshi, A. N. Malik, and M. T. Naseem, "A real time adaptive resource allocation scheme for OFDM systems using GRBF-Neural networks and fuzzy rule base system," *International Arab Journal of Information Technology*, vol. 11, no. 6, pp. 593-601, 2014.

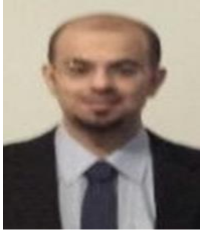
[68] Atta-ur-Rahman, I. M. Qureshi, A. N. Malik, and M. T. Naseem, "QoS and rate enhancement in DVB-S2 using fuzzy rule base system," *Journal of Intelligent & Fuzzy Systems*, vol. 30, no. 1, pp. 801-810, 2016.

[69] Atta-ur-Rahman, I. M. Qureshi, M. T. Naseem, and M. Z. Muzaffar, "A GA-FRBS based rate enhancement scheme for OFDM based HYPERLANS," in *Proc. 10th IEEE International Conference on Frontiers of Information Technology*. Islamabad, Pakistan, pp. 153-158, December 17-19, 2012.

[70] Atta-ur-Rahman, "Applications of softcomputing in adaptive communication," *International Journal Control Theory and Applications*, vol. 10, no. 18, pp. 81-93, 2017.

[71] Atta-ur-Rahman, "Applications of hybrid intelligent systems in adaptive communications," in *Modeling, Analysis and Applications of Nature-Inspired Metaheuristic Algorithms*, 1st, Chapter: 10, pp. 183-217, Publisher: IGI Global, 2017.

[72] Atta-ur-Rahman, I. M. Qureshi, M. Z. Muzaffar, and M. T. Naseem, "Adaptive resource allocation for OFDM systems using fuzzy rule base system water-filling principle and product codes," in *Proc. Intelligent Systems Design and Applications*, Brunei Darussalam, December 10-13, 2012, pp. 811-816.



Abdullah Alqahtani Dr. Abdullah Alqahtani is holding BS, MS and PhD in computer science and information system. He is currently working as Assistant professor as well as Vice Dean for Postgraduate Studies and Scientific Research at department of Computer Information System, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University, Dammam, KSA. His main research interests include privacy, decision support systems, e-services, e-business, e-government, database design and development, system modeling, web-based information systems, intelligent decision support systems, data mining; business intelligence and system evaluation.

Nahier Aldhafferi is holding BS, MS and PhD in Information Technology from New England University, Australia. He is currently working as Assistant professor as well as Vice Dean of Academic Affairs at department of Computer Information System, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University, Dammam, KSA. His research interests are social media and privacy, data mining, security and intelligent systems.

Atta-ur-Rahman is currently working at Department of Computer Science, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University (Former University of Dammam), Dammam, KSA as Assistant Professor. Before that he was Associate Professor and Deputy Director at BIIT (Pakistan) where he served for 11 years. Dr. Atta has completed his BS degree in Computer Science from University of The Punjab, Lahore, Pakistan; MS degree in EE from International Islamic University, Islamabad, Pakistan and PhD degree in Electronic Engineering from ISRA University, Islamabad Campus, Pakistan in years 2004, 2008 and 2012, respectively. His research interests include digital signal processing, information and coding theory, digital image watermarking, wireless/digital communication, AI and soft/evolutionary computing.

Kiran Sultan is currently associated with Department of Computer and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia. She did her PhD from Air University, Islamabad, Pakistan in 2013 with major research area Signal Processing in Relay-assisted Cognitive Radio Networks. Previously, she did her Masters and Bachelors from UET Taxila in 2008 and 2003 respectively. Her research interests include Cognitive Radio Networks, Cooperative Communication, Detection and Estimation, Evolutionary Algorithms, Soft Computing and Internet of Things.

Mohammad Aftab Alam Khan received the B. Tech and M. Tech degrees in Electronics & Communication Engineering in 2005 and 2009 respectively from India. He is currently a Lecturer in College of Computer Science & Information Technology, Imam Abdulrahman Bin Faisal University (previously known as University of Dammam), Saudi Arabia since 2011. He is a member of Member of Computer Science Teachers Association (CSTA) and International Association of Computer Science and Information Technology (IACSIT) since 2012. His main research work focuses on Wireless Communication, Signal Processing, Image Processing and Microstrip Patch Antenna. He has 13 years of teaching experience and 9 years of research experience.