System Model with Adaptive Modulation and Frequency Hopping in Wireless Networks

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***Abstract*—This article describes the features of the proposed system based on the 802.16 standard and orthogonal frequency division multiple access (OFDMA) with synergy of additional advanced technologies. The system enables dynamic subcarrier allocation to users. Subcarriers are allocated according to the quality of the received signal. Signal-to-noise ratio (SNR) per subcarriers is separately calculated for each user from the preambles placed in the beginning of the data frame. The proposed method performs adaptive modulation and coding (AMC) with frequency hopping (FH). The results are compared to the existing subcarrier permutations. They show greater system throughput at lower bit error rate (BER).**

Keywords— Adaptive modulation, dynamic resource allocation, frequency hopping, OFDMA, subcarrier scheduling

I. Introduction

Wireless networks enable nomadic or mobile access to Internet. However, data throughput and transmission quality in wireless networks are significantly lower than in fixed lines due to lack of bandwidth and complex conditions in the transmission media – air. Many advanced technologies such as orthogonal frequency division multiple access (OFDMA), multiple-input and multiple-output (MIMO), frequency hopping (FH), adaptive modulation or dynamic resource allocation, are used to solve this problem [1].

To exploit the available bandwidth and increase the data rate as much as possible, a solution for communication system is proposed and described in this paper. Based on channel quality information (CQI) feedback, the proposed solution dynamically selects the best available subcarriers for each user and conducts FH between the subcarriers of the same quality. Due to various conditions in their micro locations, each user receives subcarriers with different signal-to-noise ratio (SNR). SNR calculation and dynamic subcarrier assignment is done for each subcarrier and each user. Certain modulation coded (MC) group is determined for all subcarriers. A subcarrier based resource allocation algorithm (RAA) is embedded in the proposed solution to efficiently share resources among users according to the Quality of Service (QoS) requirements for specific service classes. To satisfy the aforementioned rules, the subcarrier assignment to each user starts from the best subcarriers first. The algorithm trades off between system throughput and fairness among users. However, the detailed description of RAA and QoS issues is beyond the scope of this paper. This paper describes the model of the system, and the proposed method is compared with the existing Full Usage of Subcarriers (FUSC) and Adaptive Modulation and Coding (AMC) subcarriers' permutations [2].

II. System Model

The data streams generated for the users go into transmitter where they are allocated to subcarriers based on the pre-defined rules within RAA. The RAA enables fair resource allocation among the users taking care of the data classes. Data are coded and modulated with FH. After packaging, data are prepared for sending through three independent channels. Sent data are received by three receivers, decoded and demodulated.

The main idea in system model design was to combine OFDM with FH. The 802.16 standard [2] has been used to enable results comparison with the existing systems. In practice FH should be done across 2048 subcarriers for all users currently present in the system. For simplicity reasons the number of subcarriers has been reduced to 256 and the corresponding number of users has been set to three to keep the condition that FH is done between lots of subcarriers. The OFDMA transmission system is used with 192 data subcarriers, 8 pilots, 256-point FFTs, cyclic prefix length ⅛ and channel bandwidth of 3.5 MHz. Seven MC groups are used for modulation and coding: OFDMA with BPSK ½, QPSK ½, QPSK ¾, 16QAM ½, 16QAM ¾, 64QAM ⅔ and 64QAM ¾. The coding is run as Forward Error Correction (FEC), consisting of a Reed-Solomon (RS) outer code concatenated with a rate-compatible inner convolutional code (CC).

The algorithm for dynamic FH is embedded in the system. FH happens if there is a free subcarrier of the same quality for an observed user. Frequency diversity is enhanced in this way, and, as FH is done exclusively among the same quality subcarriers, there is no reduction in transmission capacity and transmission rate of the system. Hopping pattern is not pre-defined for FH because it is determined dynamically based on the subcarriers' quality [3-5]. The authors [3] analyze the advantages of FH application in OFDM within LTE context, but with random FH. The papers [4, 5] compare the advantages of dynamic FH compared to random FH, assuming perfect signal measuring and no delay in signaling. Compared with the aforementioned models, the model described in this paper

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widens this approach with SNR calculation from the preambles. FH is not limited to the pre-defined set of subcarriers only. An additional condition is that FH is possible between the subcarriers of the same quality only, to prevent system capacity degradation.

As subcarriers are allotted to each user independently, it was necessary to develop an adequate RAA. The system allocates subcarriers to all users according to the data class. Subcarriers assignment starts from subcarriers with the best SNR values for each user, first for real time traffic and then for non-real time traffic [6].

The downlink for three users with three independent transmission channels is designed. The data rate varies dynamically in relation to the channel conditions. Stanford University Interim (SUI), SUI 3 channel model is used in the simulation. Channel transmission function and SNR value for subcarriers need to be determined for correct signal decoding and demodulation. Both parameters are calculated directly from the preambles and they are valid for the next frame. The unit and null preambles are in the beginning of each data frame [7]. Null preamble contains only noise, while the unit preamble contains both signal and noise power.

A perfect synchronization is assumed in the system. It is supposed that control bits are known to both transmitter and receiver. In comparison to the existing solutions, the information on signal reception from the preamble, which is needed for SNR calculation along all subcarriers, and the information on allocated subcarriers for each user have to be additionally communicated with this method.

III. SIMULATION EXPERIMENTS

Within the 802.16 standard, the channels are allocated to users in three main ways: FUSC, AMC and Partial Usage of Subcarriers (PUSC). In the suggested model there are no predefined groups of subcarriers' creation and channel matching. It is because the subcarriers are allocated directly to users based on their needs and the best SNR value conditioned on FH. Hence, a new subcarriers' selection and assignment procedure is proposed.

The suggested method is compared with FUSC and AMC subcarrier permutation. FUSC has been chosen because subcarriers are selected from the entire spectrum of subcarriers without SNR values assessment. With AMC the key to allot the subcarriers is average SNR calculation. Due to the mentioned reasons, both methods are interesting for comparison. PUSC method was not compared due to greater complexity in channel creation. However, the results of PUSC method would not significantly deviate from those obtained by FUSC application.

In case of FUSC, all data subcarriers are used to create various subchannels. Each subchannel consists of 48 data subcarriers. They are distributed evenly along the entire frequency band. Due to small number of users and data subcarriers in simulation, it was not possible to create groups with 48 subcarriers. Subcarriers in the simulation are taken evenly along available bandwidth, whereby 24 groups with 8 subcarriers are formed. Therefore, each 24^{th} subcarrier is taken. Such channels are allocated to the users according to the specified needs. Hence, groups with 8 subcarriers are created by applying the same analogy.

In AMC subcarrier permutation, nine adjacent subcarriers with eight data subcarriers and one pilot subcarrier form a bin. AMC subchannel can contain one bin over six adjacent symbols, two bins over three consecutive symbols or three bins over two adjacent symbols. The described analogy still holds. 24 groups are created with 8 data subcarriers, for relevant comparison along the entire frame. The average SNR value is determined for each user and for each group. The channels are allocated to the users for whom they have the highest SNR value.

The comparison between the proposed method with AMC and FUSC permutation schemes is described below in case of different channel quality for each user. The comparison is done on the basis of 300 frames and full system load. Incoming data is set to 4000 bits for real time traffic with non-real time data quantity necessary to achieve the full system capacity per each frame. The following conditions are set for the sake of easier view and results' comparison:

- the same thresholds are used for determining MC groups in all simulations
- when comparing system throughput, the difference in achieved BER values is not taken into account
- the results are shown for the full system load.

By setting optimal thresholds for each method (FUSC, AMC and the proposed) separately, the same BER would be achieved. As BER is the lowest with the proposed method, additional increase in transmission capacity would be achieved in the proposed method in relation to AMC and FUSC. However, as the same BER is impossible to accomplish in wide SNR area with all methods, results' comparison would be drastically reduced and unclear in that case.

To relate the achieved results with the applied method, the simulation comparison tests were conducted under maximum system load. Under normal working conditions (when the system is not overloaded), it is hard to replicate the same BER value achieved in the proposed method in AMC and FUSC methods because the best quality subcarriers are allocated first in the proposed method. If the system is not running under full load, the allocation of bad quality subcarriers does not happen at all. The comparison between the methods is done in a conservative way (BER is not uniform). The proposed method could have been even more dominant if the assumptions above had not been set.

The proposed system features are compared in three segments: resource allocation, achieved system throughput and BER.

Fig. 1 shows resource allocation between all three users with FUSC, AMC and proposed subcarrier permutation in case of different channel quality for every user. The results show the most even resource allocation between the users with the proposed method. The AMC method follows, while the resource allocation is the worst with the FUSC method.

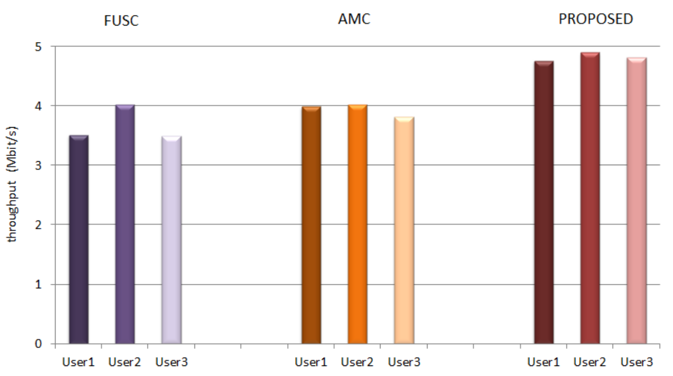

Fig. 1. Users throughput in the FUSC, AMC and proposed method in case of significant diference in channel quality (SNR $_{User\ 1}$ = 15 dB, SNR $_{User\ 2}$ = 30 dB, SNR $_{User\ 3}$ = 19 dB).

Fig. 2 illustrates the comparison between the proposed method with AMC and FUSC permutation schemes for overall system throughput under different channel quality for every user. The results show visible domination of the proposed method at the lower SNR values and at the greater differences in the quality of transmission channels between the users. The system throughput at low SNR average values (15, 30, 19) is 18% higher than in AMC, and 24% higher than in FUSC permutation. The obtained results have theoretical foundation because the proposed method does calculations and allocations at the level of subcarriers which enables better adaptability to bad conditions in the transmission channel. At greater SNR values all three methods produce similar results because the subcarriers are of better quality and the allocation principle is not crucial.

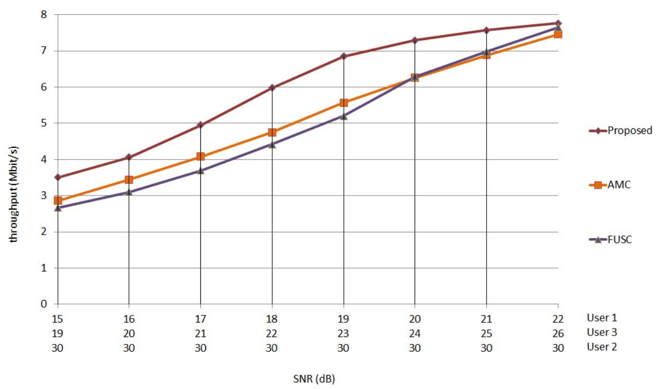

Fig. 2. System throughput for AMC, FUSC and the proposed method

Fig. 3 illustrates BER curves for AMC, FUSC and the proposed method at varying average SNR Value. The latter has the fewest mistakes in data transmission because the SNR value is determined for each single subcarrier. FUSC permutation method does not condition to allocate groups of subcarriers (subchannels) to users based on the SNR value criteria. Hence, its results are the worst. AMC subcarrier allocation of subcarriers (subchannels) is based on the average SNR value for observed group of subcarriers. Due to SNR values' averaging, AMC has fewer mistakes in data transmission than FUSC but far more mistakes than the proposed method.

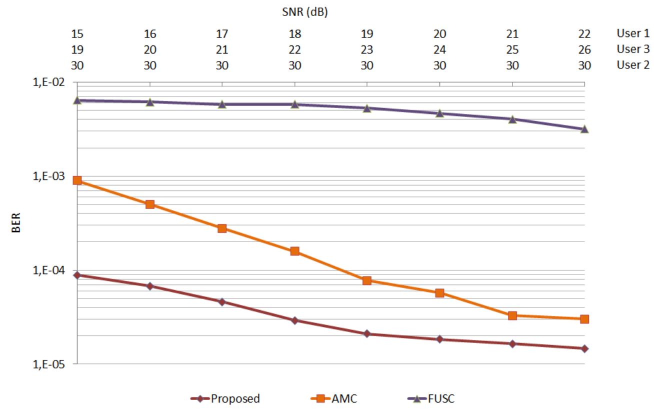

Fig. 3. BER curves for varying SNR for AMC, FUSC and proposed method

IV. Conclusion

Compared to AMC and FUSC permutations, the proposed method enables greater system throughput under poor channel conditions because the resources are allocated to the users based on the best SNR value, FH and adaptive modulation and coding. Besides transmission capacity increase, lower BER values are also achieved for the same reasons. Better characteristics of the proposed method are, among others, accomplished due to the needs for greater data quantity transmission. Control data signalization should include SNR value at the level of subcarriers and dynamically determined pattern for FH. The next research goal is to reduce signalization data overhead.

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