COOPERATIVE MODE BETWEEN MIMO AND BEAMFORMING SCHEMES IN WLANS

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Abstract

The multiple-input multiple-output (MIMO) and beamforming (BFM) techniques have become key techniques of wireless communications systems and are regarded as having significant roles in the development of single-user communication and multiuser communication performance. This paper shows their different advantages and disadvantages in terms of the data transmission rate and signal to noise ratio (SNR). The MIMO technique is the use of multiple antennas at both the transmitter and receiver to improve the performance of the data transmission rate while BFM increases the SNR performance. To fully deploy those advantages, we propose the integration of the MIMO and BFM techniques to improve the data transmission rate and SNR, the so-called cooperative mode. Furthermore, the proposed cooperative mode can improve the average throughput for both single-user and multi-user communications. The obtained simulation results reveal that the proposed concept provides a higher average throughput over both the MIMO and BFM techniques.

Keywords: MIMO, beamforming, cooperative, multi-user, single-user, WLANs

Introduction

Wireless communications have become a part of daily life as people need to give to, receive from, or exchange information with one another all the time. Accordingly, the growth of wireless technologies has exponentially increased and has been continually developed to support higher performance in terms of the transmission rate and quality. One of the most popular wireless systems is wireless local area networks (WLANs) based on the IEEE802.11 standard. The standard was firstly developed from IEEE802.11a supporting data transmission of only 54 Mbps with a small coverage (Jansons *et al.*, 2012; IEEE Standards Association, 1999a) Subsequently, the IEEE802. 11b, IEEE802. 11g, and IEEE802. 11n standards were established to support higher data rate transmission with wider coverage (Motorola, Inc., 2012; Sendra, *et al.*, 2011). Recently, attention has gone to the IEEE802.11ac and

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IEEE802.11ad standards as they are envisaged as providing a very high rate of data transmission for WLANs (IEEE Standards Association, 2012a, 2012b). Also, worldwide interoperability for microwave access (WIMAX) has been developed to support broadband technologies based on the IEEE802.16 standard providing high speed data transmission in some areas where a non-line of sight signal is dominant Pareit *et al*., 2012). All the above-mentioned standards for wireless communications originated with the aim of supporting an increase in the number of users, which is becoming relatively higher year by year. Also, the requirement for video steaming or transmitting huge packet sizes drives the ongoing developments.

From the beginning, the wireless technology standard was developed for a point-to-point communication, the so-called single-user system, in which a base station can communicate with 1 user at a time while someone else has to wait or use other channels; the system is able to provide a high signal-to-interference ratio (SIR). Unfortunately, this single-user system has a low channel capacity and throughput. Therefore, the later wireless technology standards e.g. IEEE802.11ac, IEEE802.11ad, IEEE802.16, or the LTE-A releases 12-15 were initiated for a point-to-multipoint communication, the so-called multi-user system. For this system, a base station can convey messages to numbers of users at the same time and on the same frequency. This alternative communication technology provides an increase in channel capacity and throughput. From the literature, a lot of research articles have demonstrated the advantages of multi-user communication over a single-user system in terms of the data transmission rate Nguyen *et al*., 2013; Li and Jafarkhani, 2013; Xiao and Sellathurai, 2010).

However, multi-user communication is facing a problem of co-channel interference from neighbouring cells. Much of the literature has proposed ways to tackle this impairment, e.g. the utilization of an array antennas or frequency reuse techniques. The work presented in the following (Björnson *et al*., 2013; Smith *et al*., 2014; Addaci *et al*., 2014; Shariat *et al*., 2014) have demonstrated an increase in channel capacity and coverage employing an array of antennas at base stations. This is because the increases can provide a high value of directivity. Nowadays, a lot of attention has been paid to a multiple-antenna technology as it is low-cost and is not complicated. So far, the multiple-antenna technology has been reflected usually by the multiple-input-multiple-output (MIMO) or beamforming (BFM) technologies. These 2 unique technologies have different advantages and disadvantages. The MIMO technology allows numbers of users to send their information through a number of antenna elements at the same time. So, the system capacity and throughput can be greatly increased compared with the system employing only a single antenna element. However, the success of the MIMO technology totally depends on the knowledge of the communication channel which alters all the time. Moreover, the afore-mentioned impairment is more pronounced for long distance communication due to some phenomena, e.g. path loss, shadowing, or multipath fading, which make the communication channel crucially unpredictable. This degrades the system's capacity and throughput. On the other hand, the BFM technology provides higher stability for long distance communication as the system provides a high directivity gain in the desired direction. For this system, a user conveys the same information into a number of antennas which are properly weighted to coherently adjust the signal phase in order to be constructively combined at the destination. Unfortunately, the BFM technology cannot provide a high rate of data transmission.

As mentioned above, the MIMO and BFM technologies have different prominent points. From a previous work (Wongchampa *et al*., 2014), we have compared the data rate and average throughput with respect to the distance between the single-user MIMO (SU-MIMO) vs. the single-user BFM (SU-BFM) and the multi-user MIMO (MU-MIMO) vs. the multi-user BFM (MU-BFM) schemes when the number of users is 2 operating in multi-rate WLANs. The obtained results have shown that both techniques can improve the average throughput. The SU-BFM and MU-BFM schemes provide a higher data rate and throughput at long distance. On the other hand, the SU-MIMO and MU-MIMO schemes provide a better data transmission rate and throughput at a short distance.

Following both these advantages, this paper investigates a cooperative mode between MIMO and BFM in order to give the best performance for multiple-antenna systems. This paper proposes an idea for cooperation between the MIMO and BFM technologies without the use of a feedback signal. The key factor for switching modes between MIMO and BFM is the signal to noise ratio (SNR) at the user's device for multi-rate WLAN systems. This is because MIMO provides a better data rate when the received signal or SNR is strong or users stay near the base station while BFM gives better performance in terms of data rate when users move away from the base station. The remainder of this paper is as follows. After a brief introduction, section II shows the benefit of the MIMO and BFM technology in single-user and multi-user communications. Section III presents some simulation results. Section IV shows the proposed concept of the cooperative mode. Finally, Section V concludes the paper.

Benefits of MIMO and BFM in Single-user and Multi-user Communications

Wireless communications have been developed to respond to a user's needs such as a higher data transmission rate, higher capacity, higher reliability, and wider service coverage. Therefore, all standards for wireless communications have been developed from single-user to multi-user communications. Furthermore, the MIMO and BFM techniques have been used in wireless communications for increasing the data rate, throughput, signal to interference plus noise ratio (SINR), and capacity. This section shows the performance comparison between MIMO and BFM for single-user and multi-user communications.

A. Single-user Communications

Figure 1 shows the MIMO and BFM schemes for single-user communications. In these schemes, the access point (AP) transfers data to 1 user at a specific time or frequency. The MIMO technique is an antenna technologyin which multiple antennas are used at both the transmitter and receiver. Figure 1(a) shows the SU-MIMO scheme in which the AP is equipped with N antenna elements. Usually, those elements are linearly aligned. Furthermore, M is the number of antennas at a user terminal. The simulation assumed that the number of transmitting antennas at the AP and the receiving antennas at the user are the same ($N = M$). Then, another scheme applies the BFM technique into single-user communication, the so-called SU-BFM, as shown in Figure 1(b). We consider the case of a single user with a

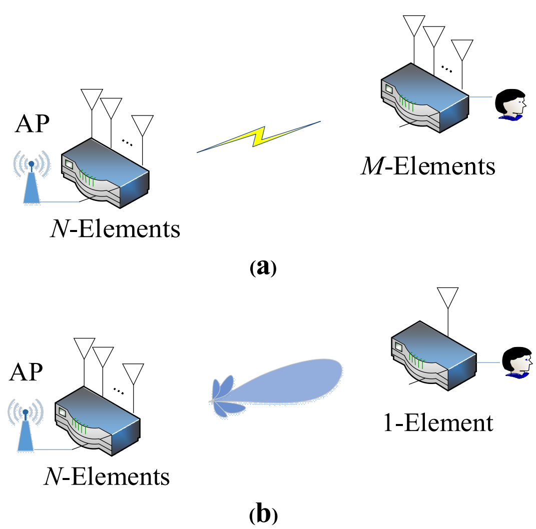

Figure 1. Single-user communications employing (a) MIMO and (b) BFM

single antenna element employed at the user. The number of antenna elements at the AP is more than 1 ($N > 1$) which is linearly aligned.

For the simulation, we assume that all users are uniformly distributed and they adaptively select their data rates based on their average SNR. In addition, the system parameters from the literature (IEEE Standards Association , 1999b; Jin *et al*., 2011) were adopted. Then, the average SNR at a user's device with distance *d* from the AP can be expressed as

$$SNR = SNR_0 - 44.2 - (10 \times PLe) \log d \qquad (1)$$

where SNR_0 is the transmitted SNR for each antenna. The path loss at 1 meter is also set to 44.2 dB and *PLe* is the path loss exponent which is 4. Also, *d* is the distance between the user and the AP.

In wireless communications, the users exploit a high SNR as they are close to the AP. On the other hand, the SNR is degraded when users are moving away from the AP. The performances in terms of the data rate for the SU- MIMO and SU- BFM when employing N = 2 and N = 4 through the computer simulation are shown in Figures 2 and 3, respectively. From the results, the SU-MIMO (solid line) provides a higher data rate compared with the SU-BFM (dash line) when the system SNR is high. Conversely, at a low SNR, the results obtained from employing the SU-BFM provide a higher data rate compared with the cases of the SU- MIMO. Figure 3 shows the similar simulation, but $N = 4$ at the AP. As expected, the SU-MIMO provides a better data rate than the SU- BFM when the system experiences a high SNR. This is because the MIMO technique can increase the

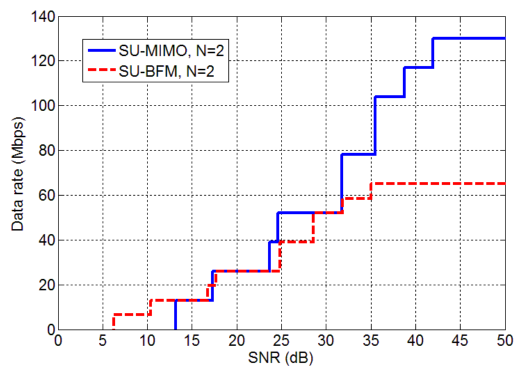

Figure 2. Data rate vs. SNR for the SU-MIMO and SU-BFM with $N = 2$

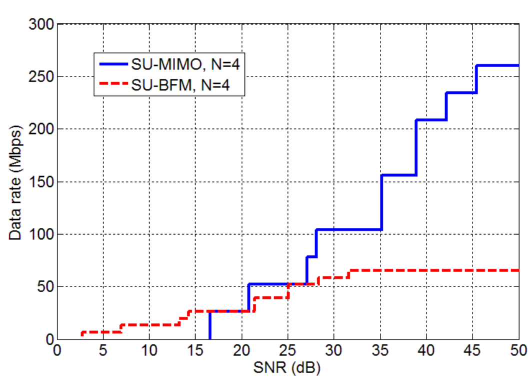

Figure 3. Data rate vs. SNR for the SU-MIMO and SU-BFM with $N = 4$

spectrum efficiency and improve the data rate performance. On the other hand, the SU-BFM provides a better performance in terms of the data rate when staying with a low SNR situation. This is because the BFM technique has a high directive gain. So, it works well for long distance communication (low SNR). In addition, the feedback channel for MIMO is dramatically degraded when the users stay at a long distance.

B. Multi-user Communications

Figure 4 shows the MIMO and BFM schemes in multi-user communications. The systems independently transmit data from the AP to a number of users at the same time

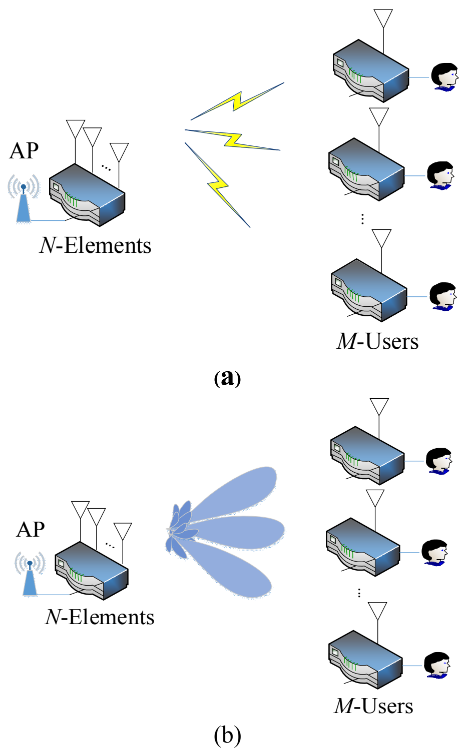

Figure 4. Multi-user communications employing (a) MIMO and (b) BFM

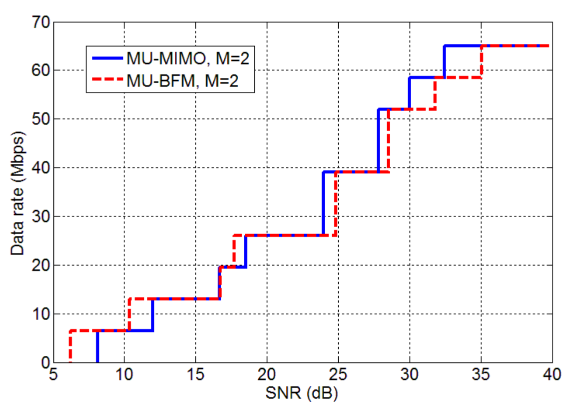

Figure 5. Data rate vs. SNR for the MU-MIMO and MU-BFM with *M*=2

and at the same frequency. The MU-MIMO scheme is shown in Figure 4(a). For this case, we consider a single antenna employed at each user. The number of transmitting antennas (N) at the AP is equal to the number of receiving users, N = M. The MU-BFM scheme shown in Figure 4(b) employing the transmitting antennas at the AP can perform the BFM and its main lobe can be directed to each user. In this case, the number of antenna at each user is 1. The number of users (M) and the number of transmitting antennas (N) are the same as the ones for the MU-MIMO scheme.

In the simulation results, the data rate and SNR between the MU-MIMO vs. MU-BFM when the number of users M = 2 and M = 4 are shown in Figures 5 and 6, respectively. Please note that the data rate is considered per 1 user. From the results, the MU-MIMO provides a higher data rate than the MU-BFM at a high SNR, but at the longer distance or low SNR, the MU-BFM outperforms the MU-MIMO.

From the simulation results, we have compared the performance of wireless communications with the utilization of the SU-MIMO, SU-BFM, MU-MIMO, and MU-BFM schemes in terms of data rate with respect to the SNR. The results have revealed that both the SU- MIMO and MU- MIMO provide a higher data rate compared with the case of the SU-BFM and MU-BFM at a high SNR. But both the SU-BFM and MU-BFM provide a higher data rate than the SU-MIMO and MU-MIMO at a low SNR. Both single-user and multi- user communications have the same results. So, the MIMO and BFM techniques have different benefits. In the next section, we propose a concept of the cooperative mode between MIMO and BFM.

Proposed Cooperative Mode

In the previous section, the simulation results show that the MIMO and BFM techniques have different advantages and disadvantages. Therefore, this paper proposes a cooperative mode to give the best performance for WLANs. This section proposes the concept of the cooperative mode which chooses the best performance for both the MIMO and BFM schemes, as shown in Figure 7. The configuration of the proposed cooperative mode for WLANs consists of a transmitter and a receiver. The transmitter will select the MIMO or BFM technique from the data rate of the user according to its SNR value to maintain the good data rate at all times.

The proposed cooperative mode is employed for single-user communications (SU-MIMO and SU-BFM) with N = 2 and N = 4 shown in Figure 8. Then, Figure 9 shows the proposed concept for the MU-MIMO and MU-BFM with M = 2 and M = 4. From the results, the cooperative mode in both figures are similar. Employing the M = 4 elements provides a higher SNR compared with the case of the M = 2 elements. This is because employing a higher antenna element provides a higher degree of freedom. Also, the proposed cooperative mode can improve the overall SNR and data rate due to the system being able

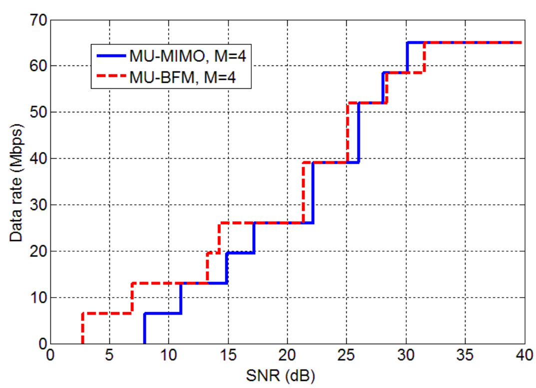

Figure 6. Data rate vs. SNR for the MU-MIMO and MU-BFM with M=4

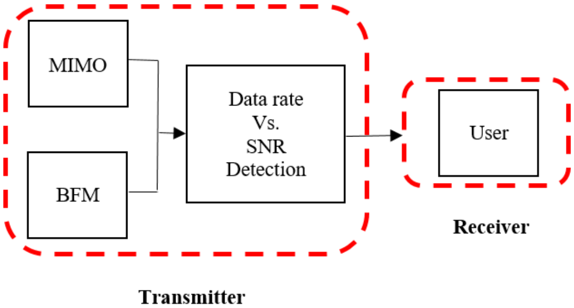

Figure 7. Configuration of proposed cooperative mode for WLANs

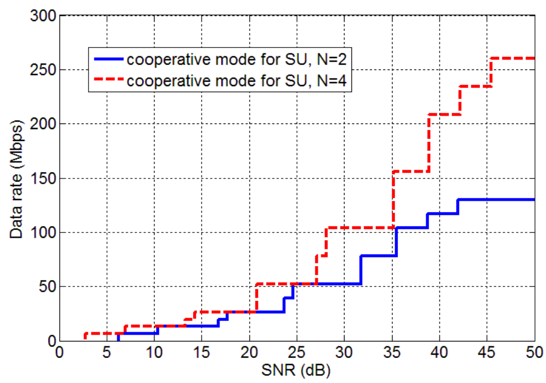

Figure 8. Cooperative mode between MIMO and BFM for single-user communications employing $N = 2$ and $N = 4$

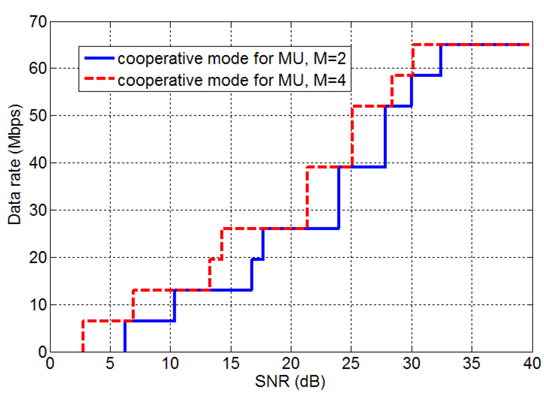

Figure 9. Cooperative mode between MIMO and BFM for multi- users communications employing M = 2 and M = 4

to choose the best values at all times (between MIMO and BFM).

Next, we present the simulation results of the proposed cooperative mode between MIMO and BFM for single-user and multi-users communications in terms of the average throughput. The system throughput is considered based on the IEEE 802. 11 network which employs the distributed coordination function. We assumed that the system is at the best scenario in which the channel is perfect without any error. The formula of throughput for IEEE802. 11 standards was derived in (IEEE Standards Association, 1999b). The scenarios of the simulations are assumed for the MIMO, BFM, and cooperative schemes. Please note that random distribution for 100 users is given in the simulation.

Figures 10 and 11 show the average throughput when varying the payload size for single-user and multi-user communications, respectively. There is a comparison of the cases for the MIMO and BFM schemes, and the cooperative mode. As we can see, the proposed cooperative mode provides a higher average throughput compared with the MIMO and BFM techniques. This is because the cooperative mode can select the operating mode based on the system SNR. The system will employ MIMO when experiencing high SNR at a short distance but will select BFM when the users move away from the AP and are faced with a low SNR. Accordingly, the system is able to keep good values at all times.

Conclusions

This paper has introduced the concept of the cooperative mode. The cooperative mode is an

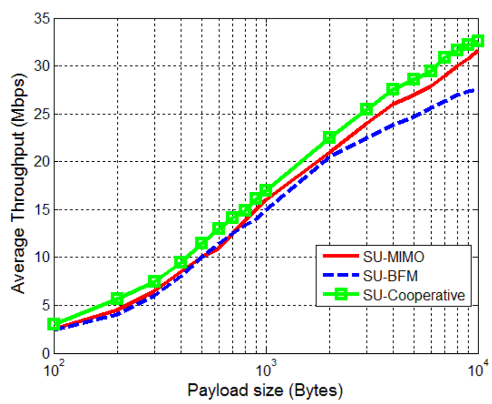

Figure 10. Average throughput vs. payload size for single-user communications

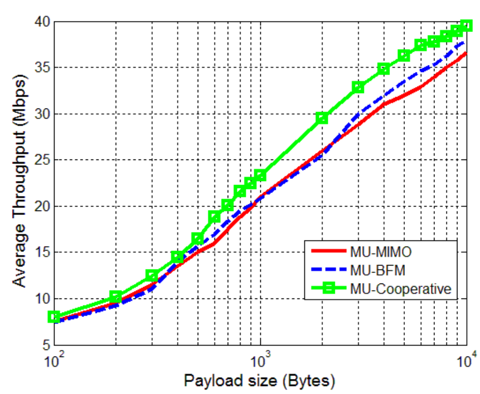

Figure 11. Average throughput vs. payload size for multi-user communications

integration between the MIMO and BFM techniques for improving the performance of single-user and multi-user communications. Also, we have compared the performance of WLANs with the utilization of the SU-MIMO, SU-BFM, MU-MIMO, and MU-BFM schemes in terms of the data transmission rate vs. the SNR. The results obtained from computer simulation have revealed that both the SU-MIMO and MU-MIMO provide a higher data rate at a high SNR compared with the case of the SU-BFM and MU-BFM. However, at a low SNR, both the SU-BFM and MU-BFM provide a higher data rate. Also, we can see that there is a tradeoff between the utilization of the MIMO and BFM (both SU- and MU-) schemes. The proposed cooperative mode is a combination of the advantages of the MIMO and BFM techniques. The simulation results have shown that the proposed cooperative mode can increase the average throughput in all simulation cases.

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