Massive MIMO Full-Duplex for High-Efficiency Next Generation WLAN Systems

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***Abstract*— In this paper, massive multiple-input multiple-output (massive MIMO) and full-duplex communications (FDC) are considered together for high efficiency next generation wireless LAN (WLAN) systems such as IEEE 802.11ax or beyond. The proposed scheme allocates different carrier sensing thresholds by applying the joint spatial division and reuse (JSDR) scheme and is able to enhance the efficiency of multi-user MIMO (MU-MIMO) protocols by reducing the protocol overhead. Finally, FDC is applied to improve the spectral efficiency of the WLAN systems.**

***Keywords*— WLAN, carrier sensing threshold, MU-MIMO protocol, Full-Duplex, massive MIMO**

I. Introduction

Recently, researches on the next generation wireless local area network (WLAN) systems are being actively conducted in order to accommodate the traffic increase in accordance with the rapidly increasing demands for mobile communication devices [1]. According to Mobidia data in 2013, Android data traffic on smartphones is composed of 33% of cellular traffic and 67% of Wi-Fi traffic in 2012, and becomes 27% and 73% in 2013 respectively [2], which shows the rapidly increasing data usage over WLAN. As the WLAN traffic increases as years go by, denser deployment of WLAN APs are required to meet such increasing traffic demands. Accordingly, the next generation WLAN systems, such as IEEE 802.11ax and beyond have drawn much interest to provide higher spectral efficiency in highly dense environments.

In this situation, among promising schemes for increasing the spectral efficiency are massive multiple-input and multiple-output (massive MIMO) which can provide numerous spatial resources for beamforming and interference cancellation [3] and full-duplex communication (FDC) which allows simultaneous transmission and reception of data using the same frequency band [4]. However, in order to apply such techniques to a WLAN system, an efficient carrier sensing scheme needs to be considered together and an efficient massive multi-user MIMO (MU-MIMO) protocol combined with FDC needs to be developed for highly dense environments.

In literature, efficient carrier sensing schemes, such as in [5-6], or full-duplex medium access control protocols, such as in [7], have been suggested. However, they consider a conventional AP having a single or a few antennas only and a joint design with an MU-MIMO protocol has not been suggested yet. In this paper, a new

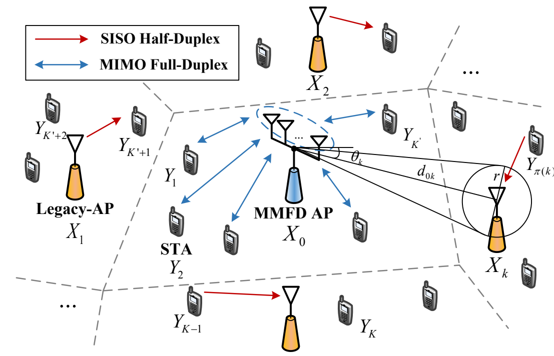

Figure 1. Network model

carrier sensing scheme, called joint spatial division and reuse (JSDR) to improve the efficiency of each AP in highly dense environments and a full-duplex MU-MIMO protocol is proposed to improve the spectral efficiency by using efficiently multiplexed signaling.

II. Proposed Joint Spatial Division and Reuse

Since the next generation WLAN systems need to provide high throughput in highly dense environments (many APs and many users per AP), it is required to utilize more number of antennas to fulfill the high throughput requirement. However, because APs are also dense, it is difficult to expect sufficient performance improvement if not combined with an advanced carrier sensing scheme. The authors proposed JSDR for an efficient carrier sensing scheme by utilizing many number of antennas in an AP [8] and it is further refined and improved in this paper. The JSDR scheme divides the total degree of freedom, which is the number of antennas in an AP, M, and assign $m \leq M$ dimensions to its STAs for data transmission and $M - m$ dimensions to create a null space to actively transmitting neighbor APs. Thus, the proposed JSDR enables an AP to operate and transmit and receive data by using its partial number of streams in cases where it needs to wait until neighboring APs become silent with the conventional carrier sensing scheme.

Fig. 1 shows the network model of this paper, in which a massive MIMO full-duplex (MMFD) WLAN AP X_0 denotes the AP with M antennas and the proposed JSDR and MMFD capability and legacy APs $\{X_1, X_2, \dots, X_L\}$ each with single antenna and the STAs $\{Y_1, Y_2, \dots, Y_K\}$ with up to two antennas are assumed to be uniformly distributed around the MMFD AP.

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Legacy APs transmit (downlink, DL) and receive (uplink, UL) data by using a half-duplex communications (HDC), and the MMFD AP simultaneously transmit and receive data by using an FDC as shown in Fig 1, where $Y_{\pi(l)}$ denotes the STA receiving data from the legacy AP X_l. Also the MMFD AP transmits data to the STAs denoted as $\{Y_1, Y_2, \dots, Y_{K'}\}$. The MIMO channel model considered in this paper is the one-ring scattering model similarly as in [9].

Let $\mathbf{v}_1, \dots, \mathbf{v}_M$ denote the M dimensional normalized orthogonal basis vectors selected by the MMFD AP for efficient carrier sensing by maximizing the network throughput while nulling the interference from active neighbor APs. Each time the MMFD AP tries to transmit and receive data, it monitors the received signal by using its M antennas and solves the following optimization problem:

$$m^* = \max m \\ \text{s.t. } P_{CS}^{m}\left(\mathbf{v}_1, \dots, \mathbf{v}_M\right) \le \eta_{th}^{m},\ 0 \le m \le M, \tag{1}$$

where η_{th}^{m} is the carrier sensing threshold when an m dimensional subspace is used for its own transmission and reception. Here, $P_{CS}^{m}(\mathbf{v}_1, \dots, \mathbf{v}_M)$ denotes the minimum carrier sensing value measured from the subspace generated by the selected m vectors among $\mathbf{v}_1, \dots, \mathbf{v}_M$, i.e.

$$P_{CS}^{m}(\{\mathbf{v}_1, \dots, \mathbf{v}_M\}) = \min_{1 \le i_1 < \cdots < i_m \le M} \left\| \left[\mathbf{v}_{i_1}, \dots, \mathbf{v}_{i_m}\right]^H \mathbf{r} \right\|^2, \tag{2}$$

where $\|\mathbf{x}\| = \sqrt{x_1^2 + \cdots + x_M^2}$, $\mathbf{r}$ is the $M \times 1$ received signal vector at the MMFD AP, and $i_1, \dots, i_m$ are the selected m indices among the basis vectors, i.e. $\{i_1, \dots, i_m\} \subset \{1, \dots, M\}$. The carrier sensing thresholds, $\{\eta_{th}^{m}, \mathrm{m} = 1, \cdots, \mathrm{M}\}$, need to be carefully designed and one approach is presented in [8]. If the MMFD AP finds nonzero m^*, it starts to communicate with its scheduled STAs by using a full-duplex MU-MIMO protocol and the $M \times m^*$ beamforming precoders for simultaneously transmitting to the selected m^* target STAs should be in the subspace generated by $v_{i_1}, \dots, v_{i_{m^*}}$.

III. PROPOSED FULL-DUPLEX MU-MIMO PROTOCOL

In [10], a multiplexed pilot structure using code-division multiplexing (CDM) with a cyclic shift (CS) separation in the time-domain (TD) is proposed for an efficient DL MU-MIMO protocol and such a concept can be easily extended to the case

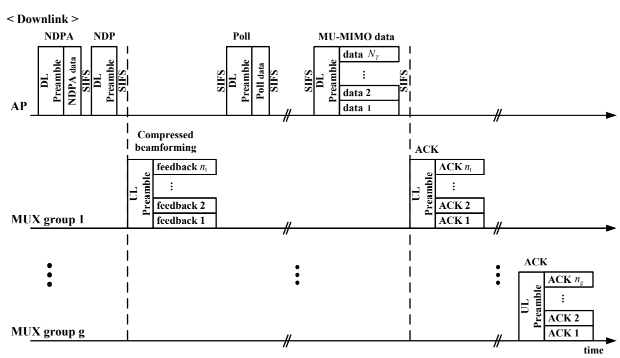

Figure 2. (a) DL MU-MIMO protocol

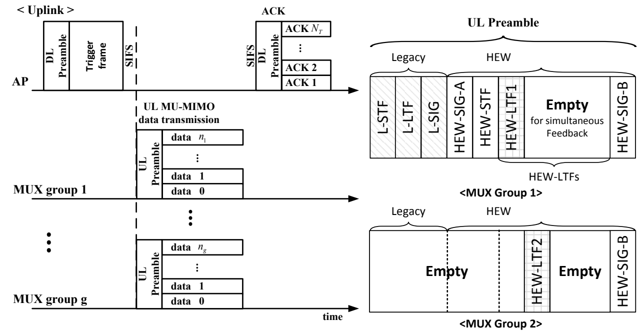

Figure 2. (b) UL MU-MIMO protocol

of UL MU-MIMO. Also, although a specific multiplexing method is not determined yet, similar concept is considered in the currently developing IEEE802.11ax standardization [11]. Thus, this paper adopts the DL MU-MIMO protocol in [10] and extend it to the UL MU-MIMO protocol as a baseline as shown in Fig. 2. Note that the long training fields (LTFs) in each MUX group users are multiplexed in the UL preamble part and the compressed feedback data or ACK data of the MUX group users are simultaneously transmitted and decoded by using the multiple antennas at the MMFD AP. Thus, the overhead caused from the compressed feedback or ACK can be significantly reduced. Similarly in the uplink, MUX group users simultaneously transmit the data and the MMFD AP transmits ACK to the MUX group users by multiplexing the preambles. Such MUX groups and some control parameters for them can be pre-determined at an association stage as in [10] so that a MUX group identifier is simply delivered to STAs in each MU-MIMO protocol or each user's identifier as well as some control parameters are delivered by using a trigger frame in each MU-MIMO protocol as considered in the IEEE 802.11ax standard [11].

For the full-duplex MU-MIMO transmission, the inter-user interference (IUI) from the UL transmitting users to the DL receiving users need be further considered. In this paper, an SIR-based full-duplex MU-MIMO protocol is proposed to minimize the IUI as depicted in Fig. 3. Here, SIR report group is further set and it can be delivered in the same way as for the MUX groups. In each full-duplex MU-MIMO protocol, the SIR group users calculate the desired signal power when the AP transmits the NDPA and NDP and the interference power from the MUX group users when they transmit the compressed beamforming feedback data. Then, the SIR group users report the SIR data when the AP transmits the trigger frame and the AP can receive them by using FDC. By using such reports, the AP can construct a SIR-table, similarly as in the conflict map [7], in an asynchronous manner and the overhead for the SIR report in each full-duplex MU-MIMO protocol is carefully designed by considering the environments such as the wireless channel and mobility. Whenever the AP determines the transmitting /receiving users for each full-duplex MU-MIMO protocol, the current value in the SIR-table is used not to select STAs causing IUI above a given threshold. Note that differently from [7], the proposed full-duplex MU-MIMO protocol does not need the scheduling preparation period.

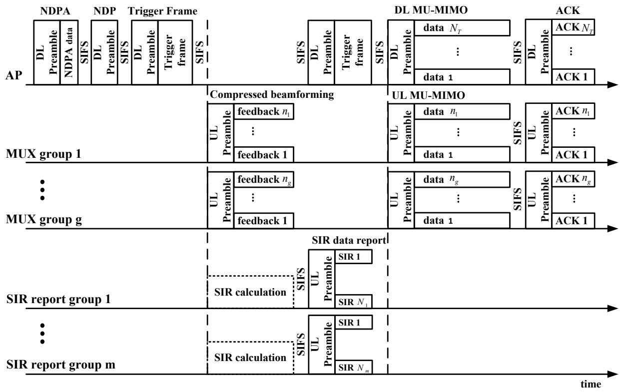

Figure 3. Proposed full-duplex MU-MIMO protocol.

IV. PERFORMANCE EVALUATION

For the performance evaluation, the transmit power of the MMFD and the legacy APs are set to 20dBm at the total bandwidth of 20MHz. The locations of the legacy APs and STAs are assumed to follow uniform PPPs with 10 APs and 25 STAs at each AP in the network size of 100m × 100m radius in average. We assume that all intended STAs always have enough data to transmit and require enough data for reception so that the MMFD AP can select STAs for both DL and UL data transfer with the same frame length. Also, we assume that the self-interference cancellation of the FDC at the MMFD AP is done by the MIMO full-duplex self-interference cancellation scheme in [12], in which 70dB of analog cancellation and 33dB of digital cancellation is available.

Fig. 4 shows the performance comparison among the conventional half-duplex MU-MIMO protocol (the baseline) and the proposed full-duplex MU-MIMO protocol when the number of antennas of the MMFD AP is 8 and 16, respectively. Here, the current fixed carrier sensing threshold of IEEE 802.11 system is used in Case 1 and the JSDR scheme is utilized in Case 2. From the results, it is shown that the proposed full-duplex MU-MIMO protocol overwhelms the conventional half-duplex one. By reducing the overhead in the protocol and utilizing the SIR table, the proposed scheme is much better than a full duplex MU-MIMO protocol without considering IUIs and is not much degraded compared to the case where such IUIs are assumed to be disappeared by Genie. It is also shown that applying the proposed JSDR can significantly improve the performance.

V. CONCLUSION

In this paper, an efficient full-duplex MU-MIMO protocol with an advanced carrier sensing scheme, JSDR, is proposed. The proposed scheme helps APs to operate frequently even in highly dense environment, reduces the protocol overhead by multiplexing, and successfully controls IUIs while using FDC. Performance evaluation confirms the superiority of the proposed scheme over conventional schemes

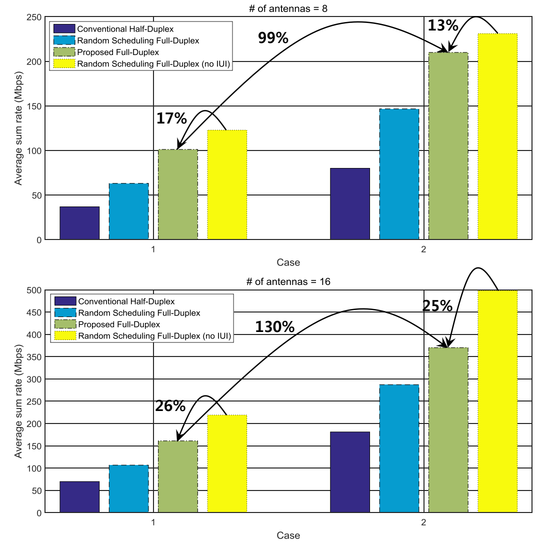

Figure 4. Performance evaluations.

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