Journal of Advanced Research in Electronics Engineering and Technology
Volume 10, Issue 1 - 2023, Pg. No. 35-42
Peer Reviewed Journal

Research Article

Unlocking Collision-Free Communication: Self-Interference Cancellation in Random Access Multiuser MIMO

Hari Singh[1], Jasvinder Singh[2]

Shri Shankaracharya Technical Campus Bhilai.

INFO

Corresponding Author:
Hari Singh. Shri Shankaracharya Technical Campus Bhilai
E-mail Id:
hs9783407@gmail.com
Orcid Id:
https://orcid.org/0009-0004-2597-8491

How to cite this article:
Hari Singh, Jasvinder Singh. Unlocking Collision-Free Communication: Self-Interference Cancellation in Random Access Multiuser MIMO. *J Adv Res Electro Engi Tech* 2023; 10(1): 35-42.

Date of Submission: 2023-08-20
Date of Acceptance: 2023-09-25

ABSTRACT

This study suggests a method for MU-MIMO transmission's interference detection that makes use of periodic preamble signals in the frequency domain and the idea of full-duplex transmission when assuming idle antennas at the access point (AP). The proposed technique uses random access MU-MIMO, an asynchronous form of MU-MIMO, to provide collision detection (CD) of MU-MIMO. Asynchronous MU-MIMO causes numerous antennas in random access MU-MIMO to exist even when they are not being used for transmission. In order to prevent self-interference between AP antennas, full-duplex transmission allows idle antennas at the AP to receive preamble signals while the AP's transmit antennas send out the preamble signals. The interference can be identified by subtracting the brief preamble signal from the received signal following FFT processing, which is then multiplied by the predicted channel response. Additionally, to lessen the mutual coupling between the broadcast and receive antennas at the AP, we employ dual polarisation. The suggested approach may successfully identify collision from other user terminals (UTs) with OFDM signals when the interfering power from the interfering user terminal (IT) is greater than the noise power, as demonstrated by a computer simulation. Additionally, the potential usage of the suggested approach at the AP is described utilising the measurement data for the interfering power from IT at the AP and the intended user terminal (DT) in a real interior environment.

Keywords: Random Access Multiuser Mimo,Collision Detection, Short Preamble Signal, Self-Interference

Introduction

In order to meet the demands of cellular system offload, access points (APs) are being placed in wireless local area networks (WLANs) more frequently.[1] Since the service area a WLAN AP covers is regarded as a tiny cell, numerous APs must be placed in high traffic regions. However, when numerous user terminals (UTs) try to connect with an AP, collisions between UTs will happen since each APs have a limited number of frequency channels. Wired LAN systems can use the carrier sense multiple access/collision detection (CSMA/CD) access control mechanism to prevent such collisions by detecting them before packet transmission by observing voltage changes in the Ethernet connection.[2] The efficiency of this approach for wired LAN transmission is above 90%[3] because it incorporates proactive packet recognition and prompt retransmission. As a result, the problems with this approach have undergone extensive research.[4,5]

On the other hand, wireless LAN has implemented another access control method called CSMA/collision avoidance (CA).[6] In contrast to conventional LAN, wireless transmission makes it challenging to identify packet collisions. Therefore, the reply of acknowledgement (ACK) sent by a receiving station is used to determine the reception characteristics. Because retransmission cannot begin until ACK is determined, wireless LAN has a far worse transmission efficiency than cable LAN, with a value of less than 65% .[3] Therefore, achieving high transmission efficiency requires the usage of collision detection, which is employed in wired communication systems.

Schemes for detecting collisions come in two varieties. Single-user MIMO transmission is used in the first collision detection technique.[7,8] This technique makes use of the second antenna's idle state for 2 2 MIMO when the first antenna transmits brief preamble signals for temporal synchronisation with the UT. Dual polarised antennas, which are frequently employed in MIMO systems, can be used to cancel the self-interference between these two antennas at the access point (AP).[9,11] This concept is used in this paper to discuss multi-user MIMO systems.

The second solution uses the CSMA/collision notification (CN) protocol to approximate CSMA/CD for WLANs.[12] In CSMA/CN, the transmitter has two antennas: one for regular transmission and the other specifically for listening for notifications. When a receiver detects an interference signal while receiving a packet, it immediately alerts the transmitter. The transmitter stops transmitting when it notices a notification signal, opening the channel to nearby transmitters.[12]

The CSMA/CN technique uses a correlation calculation based on an earlier (training) signal received at the transmitter because the transmitter needs a second antenna to distinguish between its own transmit signal and the notification signal from the receiver. Another antenna determines whether a collision is detected when the notification signal arrives during the transmission of the own transmit signal because the correlation value between the received signal—ideally, just the notification signal plus noise—and the recognised training signal increases after the own transmit signal is cancelled.[12]

However, the CSMA/CN method has two problems. The correlation value with a small number of samples is actually very small because the power level of the notification signal is much lower than that of the own transmit signal at another antenna on the transmitter, making it challenging to detect collision in a real propagation environment using just the correlation value. Second, if there is no specific countermeasure for this effect, the received power at the amplifier gets saturated since the power of the own broadcast signal is significantly larger than the power of the notification signal from the receiver.[12] Along with these issues, feedback delay could still continue to happen even if the receiver instantly alerts the transmitter of a collision. By[7,8] these two issues have been improved.

This study proposes random access MU-MIMO[13] , a revolutionary asynchronous MU-MIMO transmission-based collision detection technique. In random access MU-MIMO, each user's transmission begins as soon as the data packet is ready for that user. As a result, asynchronous downlink transmission is used, and for users whose data packets are not prepared, null data is broadcast. This characteristic of random access MU-MIMO is used in this study, and instead of transmitting null data, idle antennas that don't transmit any signal can be set up.

Short preamble signals of OFDM based on IEEE802.11 map the signals to multiple subcarriers, and at the transmitter, IFFT transforms the signals in the frequency domain. Short preamble signals are detected at the receiver's beginning timing and the correlation is determined. After temporal synchronisation, the brief prelude signals are typically ignored. In contrast, the suggested method uses FFT processing to convert the brief preamble signals into the frequency domain.

The short preamble signal, which is multiplied by the estimated channel response using the received signal, can be used to identify interference coming from interfering user terminals (IT) by subtracting it. Through computer modelling, the usefulness of the suggested approach is demonstrated. Additionally, by assuming packet collision in a real interior setting, the interference power from the IT at the AP and intended user terminal (DT) is confirmed. It is shown that the proposed method may be used to detect collisions by examining the interfering signal power from IT to AP and DT.

The rest of this essay is structured as follows. The proposed approach is demonstrated in Section 2 utilizing random access MU-MIMO. In Section 3, computer simulation is used to illustrate the fundamental traits and efficacy of the suggested approach. The parameters of the interference power in a real indoor setting are described in Section 4 in order to confirm the viability of applying the suggested approach at the AP.

Proposed Method

Basic Concept of Proposed Method

In this paper, we consider an IEEE802.11n/ac-based wireless LAN system. When the number of antennas in the AP is N, and the number of antennas at the UTs is one, the AP makes a group with N users. Hereinafter, we assume that N is 4. In the case of wireless LAN, the process of carrier sense prohibits the transmission by other UTs. MIMO and MU-MIMO are introduced to the IEEE802.11n/ac-based wireless LAN. We focus on the interference signals due to packets that are synchronously transmitted from each UT, after each UT employs a carrier sense in the IEEE802.11n/ac-based wireless LAN.

Figure 1 shows the transmit sequence of conventional and random access MU-MIMO. In conventional MU-MIMO, all the packets of the synchronous transmitted multiuser group are generated, and the channel state information (CSI) between the AP and UTs is estimated. After acquisition of CSI, the conventional MU-MIMO downlink transmission starts. As shown in Figure 1, since the waiting time of the first generated packet in conventional MU-MIMO transmission is long, the transmission efficiency of conventional MU-MIMO is very low. On the other hand, random access MU-MIMO realizes asynchronous MU-MIMO. After one packet of the synchronous transmission multiuser group is generated, the CSI between the AP and all the UTs in multiuser group is immediately estimated. The data packets are (DATA1 and DATA2 in Figure 1) instantaneously transmitted in random access MU-MIMO. Therefore, since this procedure reduces not only the overhead of CSI estimation but also the transmission wait time for each data generation, random access MU-MIMO improves the transmission efficiency.[13]

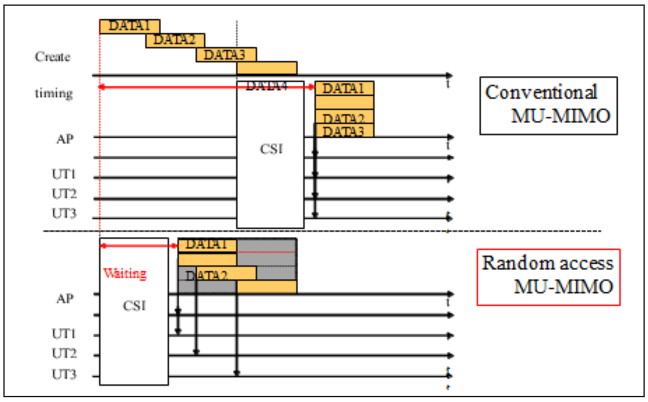

Figure 1. Transmission sequence by conventional and asynchronous MU-MIMO.

As can be seen in Figure 1, for the random access MU-MIMO, the proposed method utilizes the fact that the number of data packets for a certain period is less than the number of idle antennas, which are not necessarily required for transmission at the AP. Figure 2 shows an example of the data sequence in random access MU-MIMO transmission and a basic idea of the proposed method. As can be seen in Figure 2a, the data packets are transmitted after gathering the downlink signals. Hence, the proposed method focuses on this feature, and the receive antennas are prepared to detect self-interference cancellation between the AP antennas. As can be seen in Figure 2, only Data 1 and 2 for UT 1 and 2 are transmitted. Hence, at least two antennas are required for MU-MIMO transmission. In the proposed method, the antennas #3 and #4 at the AP are used for collision detection. Since at least three, two, and one antenna are required at the AP in the periods 2, 3, and 4, respectively, as shown in Figure 2a, the unused antennas are prepared for realizing collision detection.

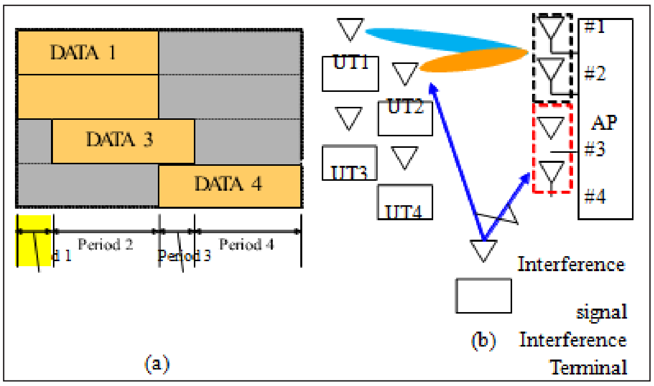

Figure 2. Concept of the proposed method

Detailed Principle of Proposed Method

Figure 3 shows the waveforms before and after applying the proposed method. As can be seen in Figure 3, the preamble signals are transmitted for synchronization and estimation of CSI before transmitting the data signals; the short preamble signal is utilized for detecting the initial timing of the data packet.

From Figure 4, it is seen that the short preamble signal is adopted in the IEEE802.11n-based wireless LAN system. At the transmitter, the signals are mapped for only twelve subcarriers in order to generate a periodic signal in the time domain[6], following this IFFT processing, the signal is transmitted. At the receiver, timing synchronization based on the calculated correlation value between the received signal, y(t), and the short preamble signal in the time domain between the known transmitted and received signals, $s_p(t)$, is employed. Note that the correlation calculation is completely different from that in[12], because this calculation is employed for finding the initial timing of the data packet. The correlation between these signals, ρ, is denoted as

$$\rho = \frac{\sum_{t=1}^{L} s_p^*(t)\, y(t)}{\sqrt{\sum_{t=1}^{L} |s_p(t)|^2 \sum_{t=1}^{L} |y(t)|^2}},$$

where L is the number of symbols for which correlation calculation is conducted (for IEEE802.11n-based OFDM signals, L = 160)[6]. The correlation value, ρ, is maximized at the initial timing of the short preamble signals.

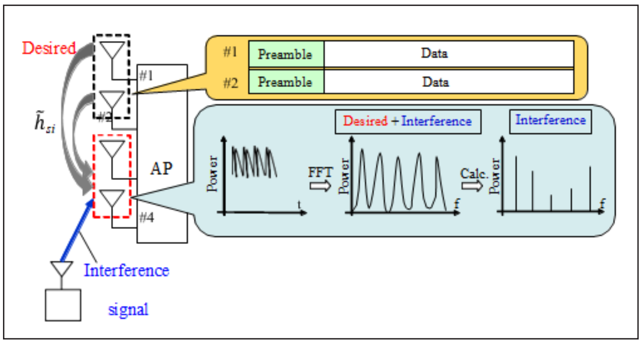

Figure 3. Waveforms before and after applying the proposed method

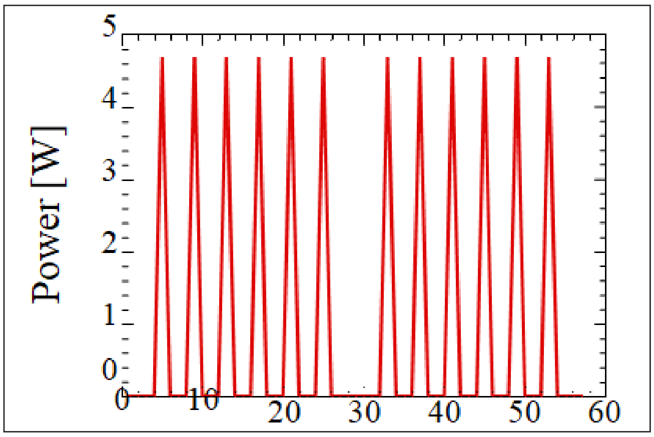

Figure 4. Short preamble signal

In a typical wireless LAN system, the short preamble is not used after timing synchronization. In contrast, in the proposed method, the short preamble is used after FFT processing. When the interference signals arrive at the AP, the received signal at the k-th subcarrier after FFT, $r_p(k)$, is denoted as

$$r_P(k) = \sum_{i=1}^{M} h_{s_i}(k)x_i(k) + h_I(k)s_I(k) + n(k),$$

where $h_{s_i}(k)$ is the self-interference channel response between the i-th transmit and the receive antenna of the AP at the k-th subcarrier. $h_I(k)$ is the channel response between IT and the receive antenna of the AP at the k-th subcarrier. $x_i(k)$ is the product of the transmitted signal of the i-th transmit antenna of the AP and the weight vector, which is generated by block diagonalization algorithm. $s_I(k)$ and n(k) denote the interference signal, which assumes the short preamble signal, and the thermal noise at the k-th subcarrier, respectively. M is the number of self-interference signals at the receive antennas. Here, the transmitted signals, which are short preamble signals, are already known, and $\tilde{h}_{s_i}$ denotes the estimated channel response of h_{s_i}. The channel response, $h_{s_i}(k)$, can be assumed to be obtained between the idle time at the AP in advance, because the propagation characteristic between the Antenna #1 and #2 at the AP could be not changed and $h_{s_i}(k)$ will be regarded as the static channel. The channel response of the interference signal, $h_I(k)$, is estimated as

$$r_P(k) - \sum_{i=1}^{M} \tilde{h}_{s_i}(k)x_i(k) \approx h_I(k)s_I(k) + n(k).$$

The interference detection can be realized by using Equation (3) while the transmission is employed.

Effectiveness of the Proposed Method by Computer Simulation

Through this computer simulation, in which IEEE802.11n/ac-based OFDM signal is assumed, the effectiveness of the proposed method is verified by evaluating the characteristics of self-interference reduction and detection of interference from ITs. Table 1 shows the simulation parameters. As can be seen in Table 1, when considering the self-interference signal between AP antennas, the average signal to noise power ratio (average SNR) is set to be 45 dB from the previous measurement[7], and we confirmed that the fading caused by self-interference between AP antennas can be negligible due to its large power, even if people work around the AP.[8] On the other hand, the propagation of interference signal is assumed to be Rayleigh fading. In the simulation, the signal to interference power ratio (SIR) is changed from 0 to 50 dB. The other basic parameters are the same as that for the IEEE802.11n/ac standard with 20 MHz mode. When $\tilde{h}_{s_i}(k)$ denotes the estimated channel response between the AP antennas and ρh (t) denotes the time variation of channel response, h_{s_i}, the channel response between the i-th transmit and a receive antenna of the AP is denoted as

$$h_{s_i}(k) = \rho h(t)\tilde{h}_{s_i}(k) + \sqrt{1 - \rho^2(t)}\,h_{iid}(k). \qquad (4)$$

From the results in [8], ρh (t) is set to be 0.9999 in the evaluation.

The simulation process is summarized as follows:

[Step[1]] The desired signal and the interference signal with the OFDM signal format are created and added.

[Step[2]] The short preamble signal is detected from the signal by the sliding correlation.

[Step[3]] The interference signal is estimated and detected.

Table 1. Simulation parameters.

Number of Trial	10001
Number of transmit antennas (NT)	2
Number of receive antennas (NR)	1
Number of desired user terminals (NU)	2
Number of interference user terminals (NIT)	1
Average SNR	45 dB
Average SIR	050 dB
Propagation path of interference sinal	Rayleigh fading
Bandwidth	20 MHz
Number of FFT points	64

Figure 5 and 6 show the received power of interference from IT in the frequency domain, and these are estimated by the proposed method by assuming that the SIR is 10 and 45 dB. The received power is not transmitted when there is self-interference between the AP antennas; only the interference signal from the IT arrives at the receiver of the AP. The estimated and ideal interfering powers are plotted in these figures. When considering low SIR, as shown in Figure 5, the interference power versus subcarrier number for the estimated interfering power is almost identical to that for the ideal interfering power. Although the estimation seems to be possible when the SIR is 10 dB (in Figure 5), we can observe that the estimation error with SIR = 45 dB is much larger than that with SIR = 10 dB.

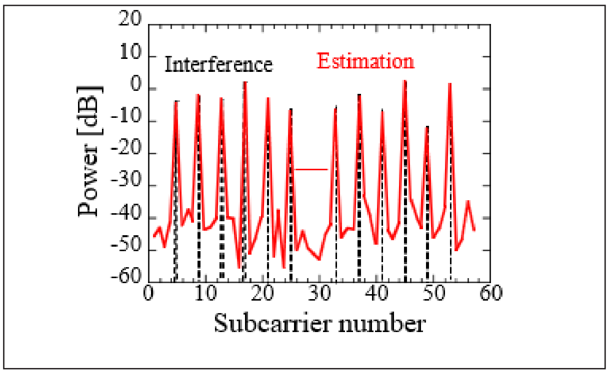

Figure 5. Power versus subcarrier number (SIR = 10 [dB])

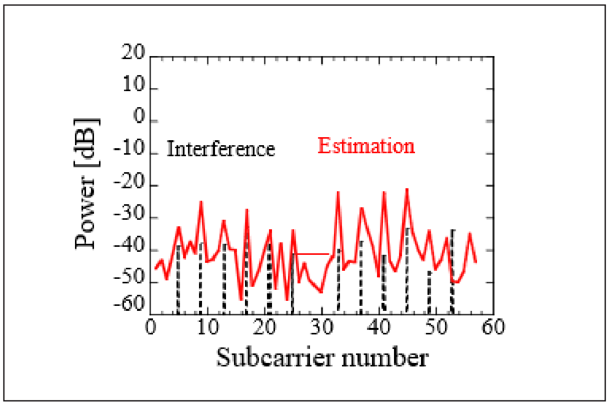

Figure 6. Power versus subcarrier number (SIR = 45 [dB])

In order to evaluate how to estimate the interference signal when considering low SIR, the interference channel response is estimated by using Equations (2) and (4). If the multiplication of interference signal and short preamble signal is denoted as $\tilde{h}_I(k)\tilde{s}_p(k)$, the estimated equation is denoted as

$$\tilde{h}_I(k)\tilde{s}_p(k) \approx r_p(k) - \sum_{i=1}^{M} \tilde{h}_{s_i}(k)s_i(k).$$

The estimation error on the interference power by the proposed method is evaluated.

The estimation error is denoted as

$$\text{Estimation Error} = 20 \log_{10} \frac{|h_I(k)s_p(k)|}{|\tilde{h}_I(k)\tilde{s}_p(k)|}, \quad (6)$$

where $|h_I(k)s_p(k)|$ and $|h_I(k)\tilde{s}_p(k)|$ denote the ideal and estimated interference power, respectively.

In this study, the number of trials was 10,001. Figure 7 shows the estimation error versus SIR. The median values are plotted for each SIR for all the trials by changing the channel response. As can be seen in Figure 7, the estimation error is less than 1 dB, when the SIR is less than 30 dB.Hence, the proposed method can successfully cancel the self-interference between AP antennas and estimate the interference with small power.

Interference Power Characteristics in an Actual Indoor Environment

We carried out indoor measurement using IEEE802.11n/ac-based OFDM signals, in order to verify how serious the problem of interference is for the DT, when considering the collision detection at the AP. Figure 8 and Table 2 show the measurement environment and parameters, respectively. In this measurement, the interfering power from IT to AP and DTs is verified by assuming packet collision in an actual indoor environment. Hence, in this measurement, IT is a transmit antenna, and AP and DT are receive antennas. The OFDM signal has been measured in an actual indoor environment. The received power was analyzed by the measured OFDM signal. The proposed method is employed by the measured received signals in Section 2.

The size of the room is 6.2 × 7.5 m and AP and DTs are located in a corridor (outside the room). The center frequency and transmit power are 2.55 GHz and 21 dBm, respectively. The other basic measurement parameters are the same as that for the IEEE802.11ac standard signal format. The short preamble signals are obtained by sliding correlation at each measurement point. In order to avoid specific characteristics in the measurement, the transmitter is moved with an interval of 0.5 wavelengths by using a position controller, and 17 measurement points are obtained for each transmit location.

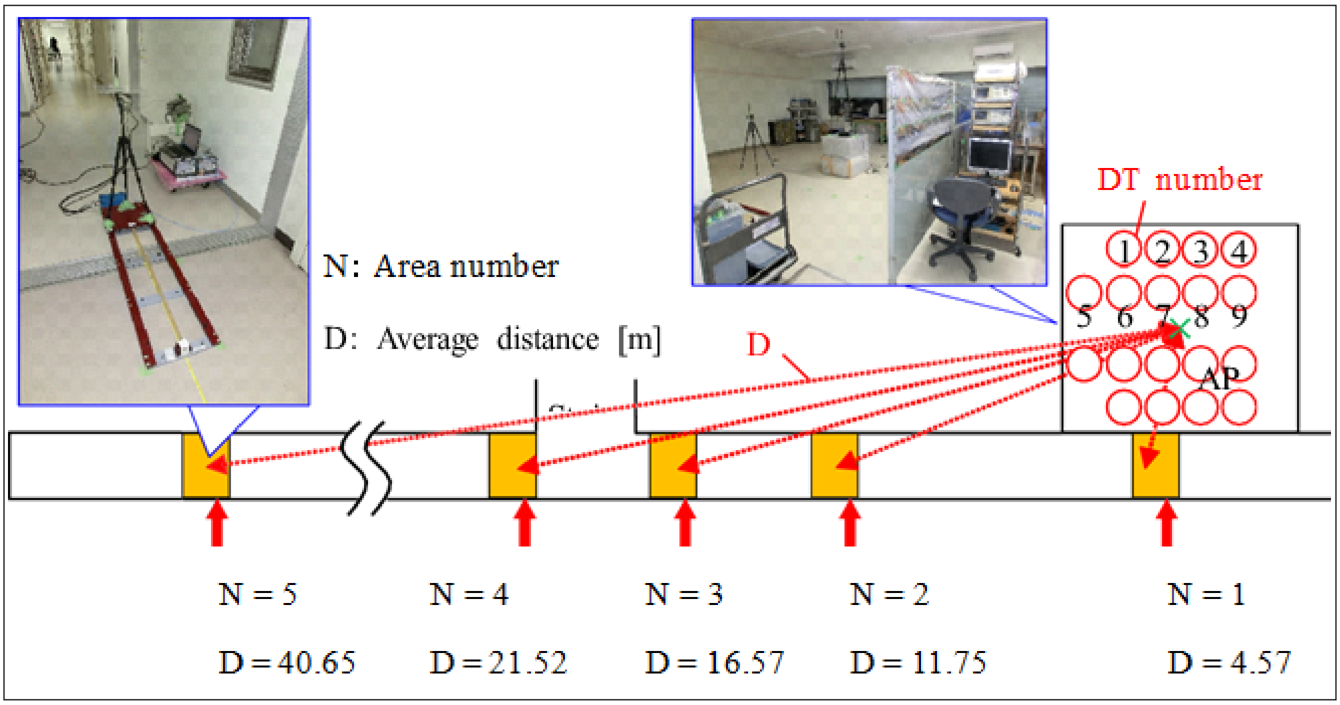

Figure 8. Measurement environment

Table 2. Measurement conditions.

Transmitting Signal	IEEE802.11 Based OFDM Signal
Center frequency	2.55 GHz
Transmit power	21 dBm
High of AP	2.4 m
High of IT and DT	1.2 m

Figure 9 shows the interference to noise power ratio (INR) versus the distance from IT to AP at the AP position. The INR is obtained by averaging 17 measurement points. The broken line indicates the threshold value, which is obtained by the estimation error with 1 dB in Figure 7, because the INR is 15 dB when SIR and SNR are 30 and 45 dB, respectively. When the INR is greater than the threshold value, the proposed method can detect the interference while cancelling the self-interference between AP antennas. Moreover, Figure 10 shows that the INR versus distance from IT to AP is identical in this measurement. As can be seen in Figure 10, the interference can be detected at a distance of 16 m from the AP. Since the tendency of INR among AP and DTs are similar, the AP instead of DTs can successfully estimate the interfering power from IT when considering a room with small size.

On the other hand, it is verified from Figure 10 that DT receives the interference but AP cannot receive interference when the distance is greater than 16 m. Figure 11 shows the SIR of DTs versus distance from IT to AP. As can be seen in Figure 11, in such a scenario, collision cannot be detected at the AP but the received power from AP to DT is much higher than that from IT and DT. Therefore, the communication between DT and AP is not a serious problem.

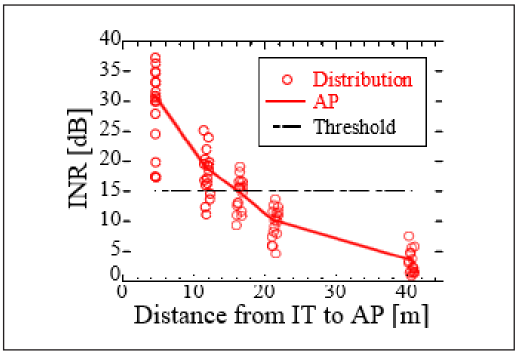

Figure 9. INR versus distance from IT to AP

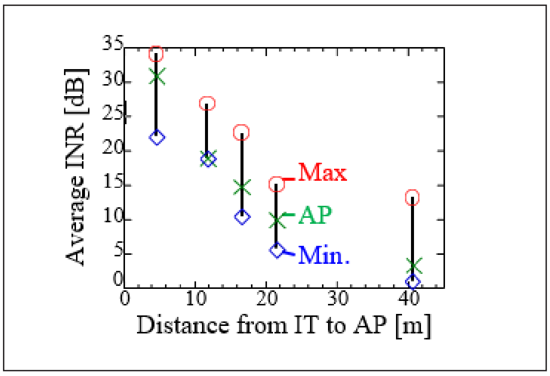

Figure 10. Average INR versus distance from IT to AP

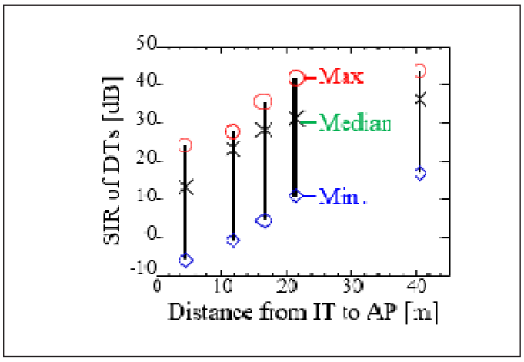

Figure 11. Range of SIR at 0.7s

Conclusions

This study proposes random access MU-MIMO, an asynchronous MU-MIMO-based collision detection technique. When addressing random access MU-MIMO, this technique makes use of the fact that idle antennas—those not actively transmitting signals—can be used to detect interference and receive it. As a result, idle AP antennas can receive preamble signals while AP antennas used for transmission send out preamble signals; this is known as full-duplex transmission and eliminates self-interference between AP antennas. The interference can be identified by subtracting the brief preamble signal from the received signal following FFT processing, which is then multiplied by the predicted channel response. Through the use of computer modelling, IEEE 802 is used. When the SIR is less than 30 dB, it is confirmed that the estimation error on the interference power is less than 1 dB. As a result, the suggested approach can accurately estimate interference with low power and cancel self-interference between AP antennas. Additionally, we performed indoor measurements utilising IEEE802.11n/ac-based OFDM signals to confirm the severity of the interference issue for the DT when taking into account the AP's collision detection. The interference power is shown to be accurately estimated by the suggested method even when the interference power is low, and it is demonstrated that collision detection at the AP is realised from the measurement.

The effectiveness of interference detection is assessed in this research as the foundational investigation for the suggested strategy. However, the bit error rate should be assessed in order to gauge the overall system performance. Future research will examine the evaluation using the BER while taking into account the overall system performance.

References

1. Nakamura, T.; Nagata, S.; Benjebbour, A.; Kishiyama, Y. Trends in Small Cell Enhancements in LTE Advanced.
2. IEEE Commun. Mag. 2013, 51, 98–105.IEEE. IEEE 802.3 Standard for Information Technology-Specific Requirements—Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications; IEEE: Piscataway, NJ, USA, 2008.
3. Hiraguri, T.; Nishimori, K.; Ogawa, T.; Kataoka, R.; Yoshino, H.; Makio, H. Access control scheme for collision detection utilizing MIMO transmission. IEICE Commun. Express 2013, 2, 129–134.
4. Abeysekera, B.A.H.S.; Matsuda, T.; Takine, T. Dynamic contention window control mechanism to achieve fairness between uplink and downlink flows in IEEE 802.11 wireless LANs. IEEE Trans. Wirel. Commun. 2008, 7, 3517–3525.
5. Hiraguri, T.; Ogawa, T.; Nagata, K.; Ueno, T.; Jinno, K.; Nishimori, K. Queuing Schemes for Improving Downlink Throughput on WLANs. J. Springer Wirel. Pers. Commun. 2012, doi:10.1007/s11277-012-0741-0.
6. IEEE. IEEE 802.11 Standard for Local and Metropolitan Area Networks Part 11: Wireless LAN Medium Access
7. Control (MAC) and Physical Layer (PHY) Specifications; IEEE: Piscataway, NJ, USA, 2012.
8. Kawahara, M.; Nishimori, K.; Kataoka, R.; Hiraguri, T.; Hideo, H. Interference detection using wireless LAN based MIMO transmission. In Proceedings of the 2013 Asia-Pacific Microwave Conference (APMC), Seoul, Korea, 5–8 November 2013; pp. 1000–1002.
9. Kawahara, M.; Nishimori, K.; Hiraguri, T.; Makino,

H. A new propagation model for collision detection using MIMO transmission in wireless LAN systems. In Proceedings of the 2014 IEEE International Workshop on Electromagnetics, POS1.17, Sapporo, Japan, 4–6 August 2014.
10. Erceg, V.; Soma, P.; Baum, D.S.; Catreux, S. Multiple-Input Multiple-Output Fixed Wireless Radio Channel Measurements and Modeling Using Dual-Polarized Antennas at 2.5 GHz. IEEE Trans. Wirel. Commun. 2004, 3, 2288–2298.
11. Nishimori, K.; Honma, N.; Murakami, T.; Hiraguri, T. Effectiveness of relay MIMO transmission by measured outdoor channel state information. IEEE Trans. Antennas Propag. 2012, 60, 615–623.
12. Kataoka, R.; Nishimori, K.; Kawahara, M.; Hiraguri, T.; Makino, H. Interference detection method using wireless LAN based MIMO transmission. IEICE Commun. Express 2013, 2, 307–312.
13. Sen, S.; Choudhury, R.R.; Nelakuditi, S. CSMA/CN: Carrier sense multiple access with collision notification.
14. IEEE/ACM Trans. Netw. 2012, 20, 544–556.
15. Morino, Y.; Ogawa, T.; Nishimori, K.; Hiraguri, T. A Study of Synchronous Random Access System for MU-MIMO; IEICE Technical Report, CS2014-33; IEICE: Kagoshima, Japan, 2014.