Experimental verification of wireless LAN with distributed smart antenna system (D-SAS) in a train environment

Koichi Ishihara, Yasushi Takatori, Jun Mashino, Satoshi Suyama, and Yukihiko Okumura

1 NTT Access Network Service Systems Laboratories, NTT Corporation, 1–1 Hikarino-oka, Yokosuka-shi, Kanagawa 239–0847, Japan
2 5G Laboratories, NTT DOCOMO, INC., 3–6 Hikarino-oka, Yokosuka-shi, Kanagawa 239–8536, Japan

Abstract: For high-density wireless LAN environment, the interference among overlapped basic service sets (OBSSs) is a serious problem. To address this issue, we have proposed distributed smart antenna system (D-SAS) for wireless LAN, which suppresses the interference among OBSSs and improves the throughput. We have also developed the prototype of wireless LAN access point (AP) with D-SAS and demonstrated the system throughput with stadium environment. In this letter, we evaluate the performance of the developed wireless LAN AP with D-SAS on a train environment and describe that throughput with D-SAS is superior to that with the conventional centralized antennas. It was found that the developed D-SAS AP provides twice system throughput larger than the conventional AP with centralized antennas.

Keywords: distributed smart antenna system (D-SAS), train, interference, overlapping basic service sets (OBSSs)

Classification: Terrestrial Wireless Communication/Broadcasting Technologies

References

[1] M.S. Afaqui, E. Garcia-Villegas, and E. Lopez-Aguilera, “IEEE 802.11ax: Challenges and Requirements for Future High Efficiency WiFi,” IEEE Wireless Commun., vol. 24, no. 3, pp. 130–137, June 2017. DOI: 10.1109/mwc.2016.1600089wc

[2] K. Ishihara, T. Murakami, H. Abeysekera, M. Akimoto, and Y. Takatori, “Distributed smart antenna system for high-density WLAN system,” Electron. Lett., vol. 54, no. 6, pp. 336–338, March 2018. DOI: 10.1049/el.2017.4081

[3] Y. Okumura, S. Suyama, J. Mashino, and K. Muraoka, “Recent activities of 5G experimental trials on massive MIMO technologies and 5G system trials toward new services creation,” IEICE Trans. Commun., vol. E102-B, pp. 1352–1362, Aug. 2019. DOI: 10.1587/transcom.2018tt0002

[4] Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: Enhancements for very high throughput for operation in bands below 6
1 Introduction

Wireless local area network (LAN) systems have recently seen explosive growth since various smart devices such as smartphones deploy wireless LAN chips to enable swift wireless access anywhere. Therefore, the number of access points (APs) also increases and APs are densely arranged so as to afford enough connectively for wireless LAN devices. However, since the frequency resources available for wireless LAN systems are limited, APs have to share their frequency channel with some others in dense AP environments. As a result, overlapping basic service sets (OBSSs) give rise to interference and the throughput degrades [1].

To address this problem, we have proposed a distributed smart antenna system (D-SAS) [2] for a wireless LAN, which suppresses the interference between OBSSs and improves the throughput in high-density wireless LAN environments. We have also developed the prototype of wireless LAN AP with D-SAS and demonstrated the system throughput of the proposed scheme with stadium experiment. Recently, the wireless LAN APs are also installed in public transportations such as train and used by passengers for various internet services. In 5G and beyond era, the network architecture of the moving cell that 5G cellular system is used for mobile backhaul between base station and transportation and wireless LAN is used for passengers in the transportation is also considered for one of the new service scenarios [3]. The advantage of wireless LAN is that it can be adopted to the transportations with lower initial cost and users already has the devices with it. However, wider frequency bandwidth is required for a lot of passengers and the inside of the transportation is also dense environment for wireless LAN. Furthermore, wireless LAN is used for not only in trains but also platforms. Consequently, the number of available frequency channels is restricted, resulting in the throughput degradation due to the interference from the other BSSs. Therefore, D-SAS is also effective in this scenario.

In this letter, we introduce the experimental evaluation of the developed wireless LAN AP with D-SAS on a train and describe that throughput with D-SAS is superior to that with the conventional centralized antennas. It was found that the developed D-SAS AP provides twice system throughput larger than the conventional AP with centralized antennas.

2 Block diagram and procedure of the developed D-SAS

Fig. 1 illustrates the block diagram of the developed wireless LAN AP with D-SAS. D-SAS has 4 switching devices (SWs) and 4 attenuators (ATTs), which are connected to RF ports of the wireless LAN module. Each ATT adjusts RF signal power at each signal stream and each SW selects an antenna element from 4 antenna elements, which are managed by control signals from the wireless module at each packet type and station (STA). The antenna gain of each element is 6 dBi. Two external antenna
sets are symmetrically located by using RF cables, where the distance between the AP and the antenna set is 6 m and the beam directivity of each set is made inward. The other two antenna sets are implemented within the AP and the beam directivity of each set is made outward. Since 16 antenna elements are grouped into 4 antenna sets, each antenna set is geographically distributed although antennas of the same set are co-located.

When the STA is associated with the AP, the scheme measures the received signal power at all the antennas $P_u = \{P_{u,1}, P_{u,2}, \ldots, P_{u,16}\}$, where $P_{u,m}$ is the received signal strength indication (RSSI) at the $m$th antenna element. Then, the largest RSSI values at each RF port of the wireless LAN are selected and each ATT value is adjusted to coincide with the target received power. The AP measures the RSSI value at the STA every $T$ period. If the difference from previous measurement value is larger than the threshold, antenna selection and ATT adjustment are carried out again via the above procedure so that the scheme can select optimum antennas and adjust ATT values at each STA in accordance with STA mobility and channel variation.

In the developed AP with D-SAS, when the broadcast control frames such as beacon and request-to-send/clear-to-send (RTS/CTS) are transmitted or carrier sense is carried out at the AP, antennas of different sets, e.g., one antenna from each antenna set, are selected and used and each ATT is set to the value where the AP or each STA can decode the control frames. This is done because the information carried by control frames should be shared with all the wireless LAN devices within the basic service set to avoid signal collision.
Note that this prototype AP complies with IEEE 802.11ac [4] and can associate with the commercial STAs without any modification.

3 Experimental setup

Fig. 2 shows experimental setup in a train environment. This experiment was conducted on The Tobu Skytree Line, which was supported by TOBU RAILWAY CO., LTD. Two APs (AP#1 and AP#2) with D-SAS were located on the center of 2nd and 3rd cars, respectively. For comparison, two conventional APs with four centralized omnidirectional antennas with 2.5 dBi were also located on the same places. 20 units of Galaxy S8 [5] were used as STAs and each one was respectively put on the attached table at the sheet as shown in Fig. 2. We measured TCP downlink throughput at each STA using the IxChariot [6]. The channel bandwidth of each AP was set to 40 MHz, and the primary channel indexes at AP#1 and AP#2 were set to Ch. 36 and 44, respectively.

![Fig. 2. Experimental setup on the train.](image)

4 Experimental results

Fig. 3(a) shows the cumulative distribute function (CDF) of throughput per STA. The figure shows that the median of the throughput per STA with D-SAS AP and the conventional one are respectively 18.3 and 6.3 Mbit/s. Therefore, the 50th percentile throughput of D-SAS AP is 2.9 times larger than that of the conventional one. The figure also shows that throughput of 90% of STAs associated with D-SAS AP is superior to that with the conventional one. In wireless LAN, carrier sense multiple access with collision avoidance (CSMA/CA) is adopted. When the conventional APs with co-located antennas are densely located, the transmission opportunity is restricted due to interference between BSSs resulting in the throughput degradation. Although it is conceivable that the transmit power from the AP can be reduced to suppress interference, throughput is degraded due to the decrease of the received signal power. In contrast, the AP with D-SAS distributes antennas in the car to shorten the distance between AP antennas and STAs and sets the optimum antennas and ATT values for each STA. Thus, excessive transmit signals can be
reduced without the need to become less than the required received power for the STAs in the BSS and interference to the AP and STAs in the other BSS can be suppressed. On the train, in spite of some metal walls between BSSs, the AP with the conventional centralized antennas restricts the transmission opportunity while the other AP transmits signals. On the other hand, both APs with D-SAS can avoid the reduction of the transmission opportunity caused by interference signals from the other car whose power is more than the carrier sense threshold, resulting in the throughput improvement. Fig. 3(b) shows the system throughput. This shows that the throughput of D-SAS AP and the conventional one are respectively 383.4 and 213.3 Mbit/s and the system throughput with D-SAS is 1.8 times larger than that with the conventional one. This means the AP with D-SAS provides almost more than the number of APs, i.e., twice, the throughput of a conventional AP with centralized antennas.

![Fig. 3. Experimental results obtained for the AP with D-SAS and the conventional on the train.](image)

5 Conclusion

This letter described D-SAS we propose for wireless LANs and showed experimental results obtained with a prototype on a train. The proposed scheme dynamically selects the best antennas for each packet by high-speed switching and reduces interference from each AP while service area is maintained even in a train. We confirmed that the system throughput of our developed D-SAS AP is 1.8 times larger than that of the conventional AP with centralized antennas.

Acknowledgments

This paper includes a part of results of “The research and development project for realization of the fifth-generation mobile communications system” commissioned by The Ministry of Internal Affairs and Communications, Japan.