Technologies for Next-generation Wireless LANs

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Abstract

This article reviews wireless local area networks (WLANs) as the most appropriate method to implement the home network services described in the previous articles. After surveying the trends for WLANs, we describe next-generation WLAN technologies including MIMO (multiple input multiple output) transmission, which uses multiple transmitting and receiving antennas. MIMO is the most attractive candidate for high-data-rate transmission and large communication capacity without expanding the signal bandwidth. We also describe various approaches to next-generation WLANs.

1. Introduction

With the expansion of broadband services, home networks that can connect a user terminal to a gateway, which is the entrance to the broadband service network, have become a very important research goal. The home network can generally be made as either (1) a wired system based on optical-fiber, coaxial, or twisted-pair cables, (2) a high-speed power line communication system [1] that utilizes the power lines present in most homes, or (3) a wireless local area network (WLAN). Among these methods, the WLAN is the simplest and most convenient because only a wireless access point is needed in order to cover most rooms in the home, and the network can be easily built without laying wiring. These benefits have triggered greater demand for WLAN equipment and its price has steadily fallen [2].

The data rate of broadband services is increasing year by year and has already surpassed 100 Mbit/s. This sets the next target for the WLAN. In this article, we review some next-generation WLAN technologies including MIMO (multiple input multiple output) transmission.

2. Trends in WLANs

Table 1 shows the frequency bands available for WLANs in Japan. WLANs that use them are mainly standardized by the Association of Radio Industries and Businesses (ARIB) [3] in Japan. The data rate has been increasing, as shown in **Fig. 1**. Several WLANs are outlined below.

2.1 2.4- and 5-GHz-band WLANs

WLANs in the microwave band are currently the most popular type. Their key feature is their relatively large service area, made possible by their low attenuation rate. Unfortunately, they suffer from fading: a lot of delayed waves overlap due to the multipath effect. Therefore, some techniques that can suppress the effect of fading are needed.

2.4-GHz-band WLANs are being standardized in the IEEE802 committee [4], an American standardization organization. ARIB standards (RCR STD-33 and ARIB STD-T66) were established on the basis of IEEE802.11 and 11b, which had been standardized in IEEE802. Because the 2.4-GHz band is the ISM (industrial, scientific, and medical) band and is also utilized by microwave ovens and medical equipment, these WLANs use spread spectrum modulation, which is robust against interference. IEEE802.11b has the same data rate (throughput) as Ethernet: its maximum data transmission rate is 11 Mbit/s. ARIB STD-T66 also corresponds to IEEE802.11g, which is

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Table 1. Main specifications of WLANs.

Frequency band (GHz)	Frequency bandwidth (GHz)	Modulation scheme	Transmission rate (Mbit/s)	Environment	Standard
2.4	2.471–2.497	DSSS, FHSS	1–11	Indoors/outdoors	RCR STD-33 (Japan)
	2.400–2.4835	DSSS, FHSS	1–11	Indoors/outdoors	ARIB STD-T66 (Japan) IEEE802.11, 11b, 11g (USA)
		OFDM	6–54		
5	4.9–5.0 5.03–5.091	OFDM	6–54	Indoors/outdoors	ARIB STD-T70, T71 (Japan) IEEE802.11j (USA)
	5.15–5.25	OFDM	6–54	Indoors only	ARIB STD-T70, T71, T72 (Japan)
	5.15–5.35	OFDM	6–54	Indoors only	IEEE802.11a (USA) HiperLAN2 (EU)
	5.47–5.725	OFDM	6–54	Indoors/outdoors	
19	19.485–19.565	QPSK	25	Indoors/outdoors	RCR STD-34 (Japan)
25	24.75–25.25 27.00–27.48	OFDM	6–54	Indoors/outdoors	ARIB STD-T83 (Japan)
60	59–66	GMSK	155.52	Indoors/outdoors	ARIB STD-T74 (Japan)

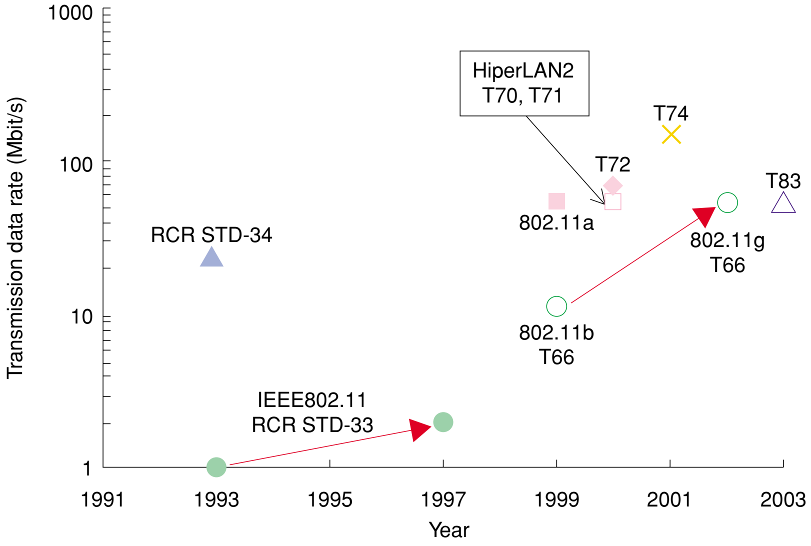


Fig. 1. Change of WLANs.

a WLAN that can co-exist with IEEE802.11b in the 2.4-GHz band and can achieve a maximum data transmission rate of 54 Mbit/s with orthogonal frequency division multiplexing (OFDM) modulation, which has excellent performance against multipath fading. ARIB STD-T66 is the preferred choice among Japanese WLAN standards and this equipment has the dominant market share.

There are three types of 5-GHz WLANs in the world: IEEE802.11a (ARIB STD-T71 in Japan) in the IEEE802 committee, HiperLAN2 in the European telecommunications standard institute (ETSI), and HiSWANa (ARIB STD-T70) in the Multimedia Mobile Access Communication (MMAC) Forum of Japan. These standardization organizations have established a liaison relationship and are cooperating in their study of the technical specifications on the physical layer. The first result is that coded-OFDM was chosen as the modulation method and basic parameters such as the guard interval and number of subcarriers have been unified.

The market for 5-GHz WLANs is currently much smaller than that for 2.4-GHz WLAN, but it is expected to grow in the near future because the frequency band for 5-GHz WLANs was expanded to 455 MHz in WRC-2003 (World Radio Communication Conference 2003).

2.2 19- and 25-GHz band WLANs

The 19-GHz-band WLAN (RCR STD-34) is a radio system based on time division multiple access (TDMA). It was the first to match the data rate of Ethernet. Because its main design goal was to eliminate the cables from a conventional LAN, the WLAN terminals were assumed to be fixed. Nevertheless, this system has had a major impact on the development of the present WLANs.

The 25-GHz band WLAN was allocated a bandwidth of about 1 GHz in the 25-/27-GHz bands (quasi-millimeter wave bands). The basic ideas behind using these frequency bands are to provide (1) high-speed wireless access, (2) systems capable of operating in various environments, such as offices, factories, homes, and public spaces including outdoors, (3) seamless connections, and (4) multimedia. The main feature of the 25-GHz-band WLAN is its ability to bundle multiple (up to six) signal channels. This means that the maximum data transmission rate is about 400 Mbit/s. The only current commercial offering is HiSWANb, which follows ARIB STD-T83. Except for the radio frequency, this system has the same technical specifications as HiSWANa, a 5-GHz WLAN. HiSWANb is expected to be used for applications that cannot be supported by 2.4- and 5-GHz-band WLANs.

2.3 60-GHz-band WLANs

One characteristic of millimeter-wave equipment is its small size. In addition, these systems can achieve higher data transmission rates than those using the microwave or quasi-millimeter wave bands because of the abundant frequency resources. The 60-GHz-band WLAN (ARIB STD-T74) provides a data transmission rate of 155.52 Mbit/s.

3. Technologies for next-generation WLANs

The frequency resources available for radio communication are generally limited, so it is critical to increase the frequency utilization efficiency in the microwave band. To this end, MIMO transmission, which offers significant improvements in frequency utilization efficiency, is being actively studied for WLAN application by various organizations.

3.1 MIMO transmission

Figure 2 shows a block diagram of MIMO transmission. The transmitter and receiver each have two or more antennas, and multiple communication paths (so-called “MIMO channels”) are established between them. Well-known MIMO transmission techniques include space division multiplexing (SDM), Eigenbeam SDM (E-SDM), and space division multiple access (SDMA).

3.1.1 Space division multiplexing (SDM) transmission

In SDM, the transmitter transmits different signals from multiple antennas at the same time and at the same frequency. Ideally, it can achieve N times the data transmission rate of the SISO (single input single output) system over a widely dispersed wireless channel by using N transmitting and N receiving antennas at each side of the communication link without expanding the signal bandwidth.

This technology requires the received signals to be separated into the signals transmitted from each of the antennas at the receiver side; incomplete signal separation leads to multistream interference (MSI). Generally, the signal separation can be achieved by estimating the MIMO channel matrix **H**, which is expressed as the combination of all antennas between

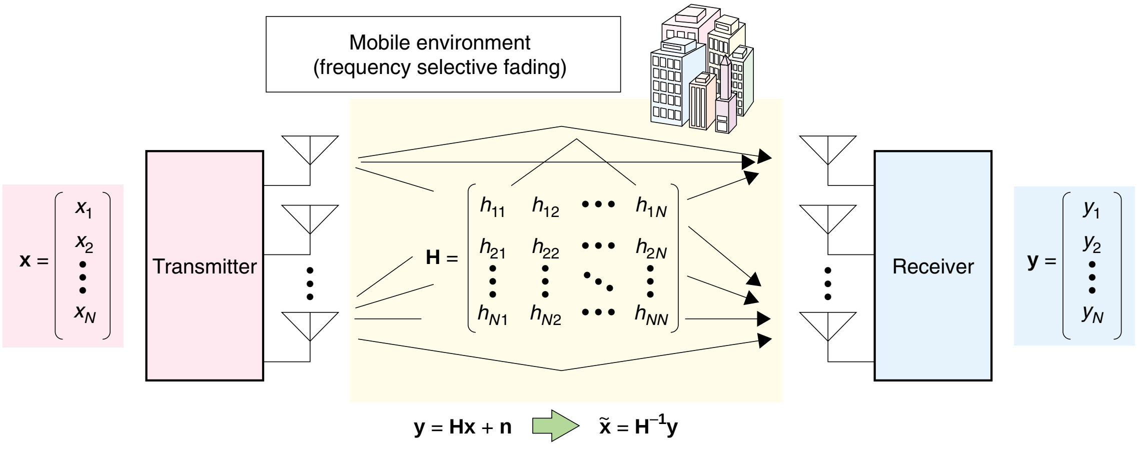


Fig. 2. MIMO transmission.

the transmitter and receiver, from the received known signal. There are four main signal separation algorithms: zero forcing (ZF), minimum mean square error (MMSE), vertical Bell Laboratories layered space-time (V-BLAST), and maximum likelihood detection (MLD). The ZF method, shown in Fig. 2, derives the transmitted signals $\mathbf{x}$ by multiplying the received signals $\mathbf{y}$ by the inverse matrix ($\mathbf{H}^{-1}$) of the above-mentioned estimated matrix $\mathbf{H}$. The ZF method has relatively low hardware requirements because of its simple circuit structure, but it has poorer error rate performance than the MLD method. The MLD method theoretically has the best transmission performance among all the signal separation algorithms, but its hardware requirements can be impractical because its signal processing complexity depends on the number of constellation points and the number of transmitting antennas. Signal separation algorithms for SDM, including those for application to OFDM-based WLANs, are being aggressively studied in various organizations, including NTT [5].

3.1.2 Eigenbeam-space division multiplexing (E-SDM) transmission

SDM places the signal processing technology at the receiver side because the transmitter cannot always gather MIMO channel information. On the other hand, the TDD (time division duplexing) approach offers a solution to this because the up and down links use the same frequency. Using this information, TDD-based SDM can offer a larger communication capacity (or higher transmission data rate) than the basic SDM.

Figure 3 shows the principle of E-SDM. E-SDM forms beams using eigen-vectors derived from singular value decomposition of the MIMO channel matrix **H**, which is known at the transmitter side, and can configure a spatially orthogonal MIMO channel, that is, a MIMO channel without crosstalk [6]. Therefore, E-SDM is expected to suppress the degradation in transmission quality caused by MSI, which is a serious problem in SDM systems.

3.1.3 SDMA technology

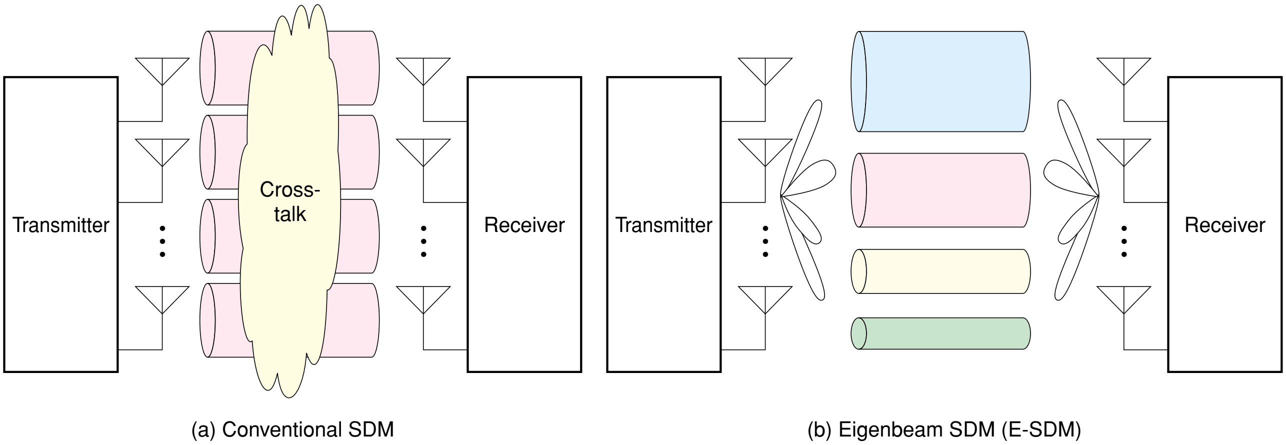
Most WLAN networks have many WLAN terminals within the communication area (or cell) configured by an access point and these terminals share the communication capacity of the access point through time, frequency, or code sharing.

SDMA [7] is another multiple access method. To accommodate a group of users (WLAN terminals) using the same frequency within the same cell simultaneously, the access point constructs a spatially independent MIMO channel to each user and transmits signals to the users in parallel (**Fig. 4**). Consequently, SDMA can greatly improve the frequency utilization efficiency.

When SDMA is applied to the MIMO channel, the following advantages are obtained: (1) higher reception diversity gain can be achieved by increasing the number of antennas and (2) higher communication capacity is expected when used in combination with SDM because of the greater suppression of MSI. Given these advantages, SDMA has been attracting attention recently.

3.2 Other technologies

Error correcting codes are also expected to be needed in the next-generation WLAN. Turbo code [8] and low-density parity check (LDPC) code [9] have recently been attracting attention as error correcting codes whose performance can approach the "Shannon limit", the limit up to which data can be transmitted without errors. Turbo code is already being



(a) Conventional SDM

(b) Eigenbeam SDM (E-SDM)

Fig. 3. Principle of E-SDM.

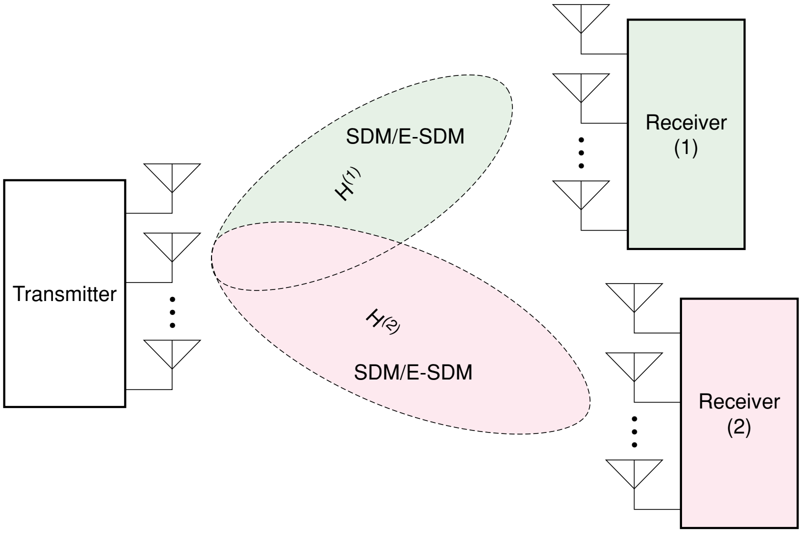


Fig. 4. Principle of SDMA.

used in third-generation mobile communication systems such as W-CDMA (wideband code division multiple access) and cdma2000, and its high error correction performance has been verified. LDPC code theoretically approaches to within 0.3 dB of the Shannon limit. Consequently, error correcting codes will be essential to achieve QoS (quality of service) functions in broadband multimedia wireless communication.

4. Approaches to the next-generation WLAN

Various approaches to the next-generation WLAN are being advanced around the world. Here we introduce two activities.

4.1 IEEE802.11n system

The IEEE802 committee established TGn (Task Group n) in September 2003, which is now studying the technical specifications of the next-generation WLAN. The goals of TGn are to guarantee backward compatibility with IEEE802.11a and 11g and to achieve throughputs of more than 100 Mbit/s at the service access point in the media access control layer (MAC-SAP). Aiming to complete technical specifications in 2006, TGn is presently examining technical proposals collected from TGn members. MIMO is also being studied as a core technology for the IEEE802.11n system [10]. NTT is a member of TGn.

4.2 Millimeter-wave radio system

NICT (Japan's National Institute of Information and Communications Technology) established a study group to investigate millimeter-wave wireless access systems in January 2004 [11]. This group aims to make a system that can support broadcast service and bi-directional communication in apartment buildings. The millimeter-wave band has a useable frequency bandwidth of more than 1 GHz, making it possible to achieve gigabit-per-second-class transmission systems. Therefore, millimeter-wave WLANs are expected to provide IEEE1394 and Gigabit Ethernet (GbE) interfaces that are impossible for microwave (2.4 and 5 GHz) and quasi-millimeter wave (19 and 25 GHz) WLANs.

5. Conclusions

Technologies for next-generation WLANs are being aggressively studied and developed by various organizations. In particular, MIMO transmission techniques are expected to improve the frequency utilization efficiency and achieve over-100-Mbit/s transmission by radio. We hope these technologies are applied not only to home networks, but also to various wireless communications, including fourth generation mobile communications.

References

[1] T. Matsuzaki, A. Sugimoto, and T. Shikama, "Perspective on High Speed Power Line Communication," Mitsubishi Electric Technical Report, Vol. 78, No. 7, pp.2-6, 2004 (in Japanese).
[2] M. Umehira, "Research and Development of Broadband Wireless Access Technologies," NTT Technical Review, Vol. 2, No. 1, pp. 12-20, 2004.
[3] See for example, http://www.arib.or.jp/
[4] T. Ichikawa, Y. Kojima, and T. Sakata, "Activities of Wi-Fi Alliance

to Promote Interoperability of Wireless LANs," NTT Technical Review, Vol. 2, No. 5, pp. 40-43, 2004.
[5] T. Sugiyama, S. Kurosaki, D. Uchida, and Y. Asai, "SDM-COFDM Technologies for Broadband Wireless Access over 100 Mbit/s," NTT Technical Review, Vol. 2, No. 1, pp. 21-28, 2004.
[6] K. Miyashita, T. Nishimura, T. Ohgane, Y. Ogawa, Y. Takatori, and K. Cho, "Eigenbeam-Space Division Multiplexing (E-SDM) in a MIMO Channel," Technical Report of IEICE, RCS2002-53, pp. 13-18, 2002 (in Japanese).
[7] T. Nishimura, T. Ohgane, Y. Ogawa, Y. Takatori, and K. Cho, "Evaluation of E-SDM Performance in the Presence of Channel Estimation Error," Technical Report of IEICE, RCS2001-155, pp. 23-30, 2001 (in Japanese).
[8] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near Shannon limit error-correcting coding and decoding: Turbo-Codes," Proc. ICC'93, pp. 1064-1070, 1993.
[9] D. MacKay, "Good error correcting codes based on very sparse matrices," IEEE Trans. Inform. Theory, IT-45, pp. 399-431, 1999.
[10] See for example, http://www.ieee.org/
[11] See for example, http://www2.nict.go.jp/

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