Broadband Wireless Access Technologies Using the Quasi-Millimeter Wave Band

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Abstract

This paper describes quasi-millimeter wave band wireless access systems for high-capacity broadband wireless communications. The 25- and 27-GHz bands have been allocated for nomadic wireless access systems in Japan to increase their system capacity and provide a transmission rate higher than 100 Mbit/s. After describing the application areas and regulatory requirements of the 25/27-GHz-band systems, we examine the experimental transmission performance of 25-GHz systems based on orthogonal frequency division multiplexing (OFDM). The issues to be resolved before 25/27-GHz-band systems become feasible are also discussed.

1. Introduction

The rapid growth of Internet and local area network (LAN) technologies is stimulating the demand of wireless LAN (WLAN) systems in offices, homes, and public areas. Frequency bands for WLANs are allocated worldwide in the 2.4- and 5-GHz bands, which allow WLANs a maximum transmission rate of 54 Mbit/s. On the other hand, fast Ethernet (100 Mbit/s) is common as the access lines for personal computers (PCs) and backbone networks in offices, and optical fibers now provide high-speed Internet access to homes. Due to the development of these fast access lines, Internet contents have become rich, and more and more users are accessing them. Consequently, there is an increasing demand for WLAN systems with greater system capacities and higher data rates. To meet the demand in Japan, a bandwidth of about 1 GHz has been allocated for nomadic wireless access (NWA) systems in the 25- and 27-GHz bands. The concept of the wireless systems using these quasi-millimeter wave bands is a straight extension of the 5-GHz WLAN systems like HiSWANa [1]-[3], IEEE802.11a [4], and HIPERLAN/2 [5]; that is, the recommended modulation scheme is orthogonal frequency division multiplexing (OFDM), and the channel bandwidth and spacing are the same as those of the 5-GHz WLAN systems. Consequently, quick deployment and cost-effective terminal development can be expected by using the base-band blocks of the 5-GHz systems. A 25/27-GHz-band system can provide high system capacity because a large number of channels are available in these bands. Another feature of 25/27-GHz-band systems is a high transmission rate of over 100 Mbit/s using channel bundling. The 25- and 27-GHz bands are also clear bands with much less interference from other systems than the 2.4-GHz band, which is the ISM (industrial, scientific and medical) band.

The radio performance at 25/27 GHz is completely different from that at lower frequencies, such as 5 GHz. For example, free space propagation loss and diffraction loss at higher frequencies are much greater than at lower frequencies. This means that wireless communication systems operating at higher frequencies generally cover a limited range and satisfactory communication can only be line of sight (LOS) or highly reflected short-range.

This paper describes the features and advantages of the broadband wireless access systems using the quasi-millimeter wave band. Section 2 introduces Japanese 25/27-GHz-band regulations for NWA sys-

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tems and their expected applications. Section 3 presents the OFDM radio performance at 25 GHz in indoor environments based on experimental results. Remaining issues to be dealt with are also discussed. Section 4 is a brief conclusion.

2. The 25/27-GHz bands in Japan

2.1 Concept and regulations

The basic concept of using the 25/27-GHz bands is 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.

Some expected applications of the wireless access systems using the quasi-millimeter wave band are shown in **Fig. 1**. (1) Nomadic wireless access (NWA) provides Internet access via access points (APs) deployed in public spaces, such as parks and roadsides, i.e., hotspots. (2) Wireless Internet access, which is similar to the fixed wireless access (FWA), provides a last-mile solution to homes and office buildings. Local distribution is another application in this category. This system distributes signals from a roof-top antenna to each room in an apartment building. (3) Inter-AP connections provide a wireless extension of the optical fiber network. (4) Homelinks connect PCs, audio-visual digital equipment, and other household appliances such as air conditioners and refrigerators in a home. (5) The office network is similar to a conventional office WLAN, but it has a higher speed and a higher capacity.

The Japanese regulations for the 25/27-GHz bands are based on the above concept. **Table 1** summarizes the technical requirements for equipment using these bands. Channel bandwidth and spacing are 18 and 20 MHz, respectively, and the recommended modulation scheme is OFDM. A total of 47 channels are available in the 25- and 27-GHz bands. This means that many APs can be deployed in the same service area, resulting in a high system capacity in that area. Channel bundling is also allowed to obtain connection speeds higher than 100 Mbit/s. (Note that channel bundling is not allowed for 5-GHz-band WLANs in Japan due to a lack of channels.) The rules for 25- and 27-GHz

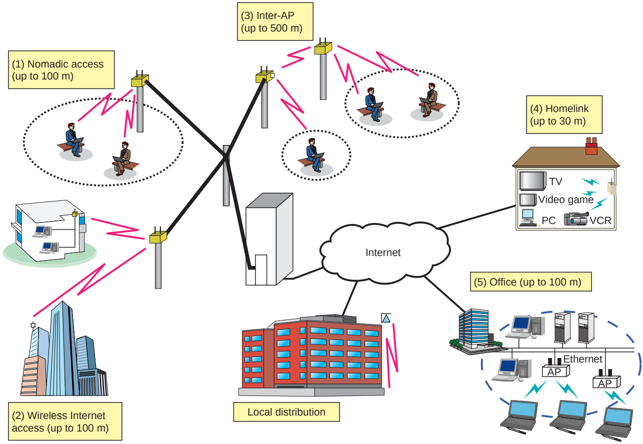

Fig. 1. Expected applications of wireless access systems using the quasi-millimeter wave band (AP: access point).

Table 1. Regulations for use of 25- and 27-GHz bands in Japan.

Frequency band	24.75-25.25 GHz	27.00-27.48 GHz
Target area	Communal spaces	Personal spaces
Modulation	OFDM is recommended	
Max. unit channel bandwidth	18 MHz	
Channel spacing	20 MHz	
Max. channel bundling	3	6
Max. transmission power	10 mW/MHz (OFDM 1-3 ch) 10 mW (OFDM 4-6 ch) 10 mW (non OFDM)	
Max. antenna gain	10 dBi	2.14 dBi

bands are based on different scenarios. The 25-GHz band will be used in communal spaces, such as roadsides, parks, libraries, and conference halls. The "hotspot" is envisioned as one of the main applications in these areas. Although the number of bundled channels is limited to three, transmission power of up to 10 mW/MHz and antenna gain of up to 10 dBi*1 are allowed, since the band must be able to support many users in a large area. On the other hand, the 27-GHz band will be used in personal spaces, such as homes and small offices. Users will be allowed up to six channels in the 27-GHz band because the main issue is high-speed transmission and not the number of users. The output power and antenna gain are limited to 10 mW (in total) and 2.14 dBi, respectively. These limitations imply that the coverage of 27-GHz band systems will be less than that of 25-GHz band systems.

The modulation scheme and channel plan of the 25/27-GHz bands are similar to those of 5-GHz band WLAN systems, which means that 25/27-GHz systems should use OFDM to combat severe multi-path fading and that the complex base-band circuits for the 5-GHz WLANs can be used to develop 25/27-GHz systems. The use of base-band circuits allows us to develop 25/27-GHz WLANs quickly and cost-effectively.

2.2 Demonstration

In this section, we introduce one practical application using the 25-GHz-band WLAN system. We demonstrated a broadband wireless connection between a train and station. This demonstration was organized by the Shikoku Bureau of Telecommunications of the Ministry of Public Management, Home Affairs, Posts and Telecommunications as part of the *e-Train2002* project. This application was an example of inter-AP connections and wireless Internet access. APs of the 25-GHz system were located on the platforms of several stations, and a mobile terminal (MT) was mounted in the cockpit of a JR Shikoku "Ishizuchi" express train (**Fig. 2**). The 25-GHz WLAN system was used to transfer an electronic newspaper, which was distributed via the Internet by a newspaper publishing company in Tokyo, to the file server in the train. About 500 MB of data was successfully transferred from the AP to the MT via the 36-Mbit/s broadband wireless connection using the 25-GHz system while the train was stopped at the station. The transferred data was stored in the file server in the train, and passengers could access the file server by using a conventional WLAN system such as IEEE802.11b. This demonstration showed the feasibility of applying the quasi-millimeter wave band system to connections to vehicles.

Fig. 2. Demonstration of a 25-GHz band WLAN system providing a broadband wireless connection between a train and a station.

3. OFDM radio performance at 25 GHz

The OFDM radio performance at 25/27 GHz is

*1 dBi: decibel with reference to isotropic antenna. absolute gain, isotropic gain.

completely different from that at lower frequencies. Because of free-space attenuation and decreased wall penetration, wireless communication systems operating at higher frequencies generally have a limited range and the shadowing effect is much greater than in the 2.4- and 5-GHz bands. Fading effects are also different from those of the lower frequencies. This means that satisfactory communication can only be achieved via line of sight (LOS) or over a short range in the case of multiple reflections. We performed an experiment to investigate the OFDM radio performance at 25 GHz.

3.1 Experimental setup

Figure 3 shows a photograph of our experimental 25-GHz-band equipment based on the Japanese WLAN standard “HiSWANb” [6]. The equipment was constructed from 5-GHz-band test equipment and up- and down-converters for the 25-GHz bands. The 5-GHz OFDM signals generated in the 5-GHz transmitter were converted into 25-GHz signals and radiated into the air. The received 25-GHz signals were down-converted to the 5-GHz band and demodulated in the 5-GHz receiver. The modulation was OFDM, and the sub-carrier modulations were BPSK (binary phase shift keying), QPSK (quadrature phase shift keying), and 16QAM. The forward error correction (FEC) was a convolution coding and Viterbi decoding (K=7, R=1/2, 9/16, 3/4). The maximum data rate was 36 Mbit/s (16QAM, R=3/4). The AP had two radio frequency (RF) front-ends and two modems with a diversity function. The MT had no diversity function.

Fig. 3. Experimental equipment for measuring OFDM radio performance measurement in the 25-GHz band.

The measurement was carried out in an office (**Fig. 4**). The office floor plan was 38 m × 23 m, and the ceiling was 2.8 m high. The walls were made of steel, and the floor and ceiling were covered with carpet and plaster board, respectively. The office contained about 90 desks, which were separated by steel bookshelves or cloth partitions about 1.2 m high. There were six reinforced-concrete pillars in the room.

An AP was placed in one corner of the room with its antenna at a height of 2.5 m. The AP antenna was oriented towards the center of the room, and its beam width was 40°. The measurements were carried out at the 40 MT positions shown in Fig. 4. The MT antenna was placed 1.2 m above the floor and was elevated at an angle of 6.5°. The beam width and gain of the MT antenna were 13° and 20 dBi, respectively. Transmitter output power was 3.5 dBm, and the sub-carrier modulation was 16QAM, R=3/4.

3.2 Measurement results

In the first step of the measurement, we found the three strongest signals at each MT position by rotating the MT antenna. The LOS signal was the strongest or second-strongest signal at almost all MT positions. A reflected signal was the strongest at nine MT positions near the walls.

We measured the packet error rate (PER) for these three signals at each MT position. Figure 4 also maps the PER performance for the strongest signal. The height of each cylinder indicates the received signal level at each MT position and the arrows show the signal arrival directions. The blue cylinders indicate error-free reception (i.e., PER=0), while the yellow and red ones indicate PER≦0.01 and PER>0.01, respectively. The gray cylinder indicates a spot where a connection could not be established. A PER of better than 0.01 was obtained at all MT positions except two. These two positions were outside the AP antenna’s beam. The PER performance with the second- or third-strongest signal at each MT position was not better than that of the strongest signal. Thus, the PER performance depended on the received signal level, and did not depend on whether the signal was LOS.

Figure 5 shows the measured PER performance as a function of received signal level. The solid line shows the PER performance for an additive white Gaussian noise (AWGN) environment, and the squares show the measured performance at each MT position. In this office environment, the PER perfor-

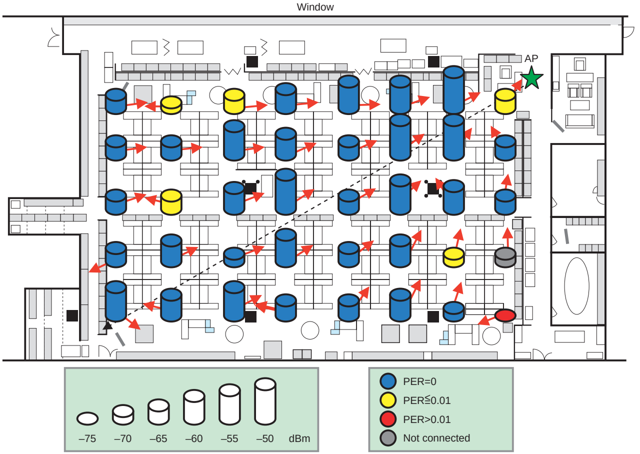

Fig. 4. Floor plan (38 × 23 m) and measured packet error rate (PER), received signal level, and signal arrival direction. (16QAM, R=3/4)

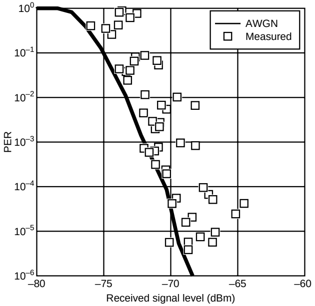

Fig. 5. PER performance.

mance fell by about 4 dB at PER=0.01 compared with the AWGN environment. The degradation agreed well with simulation results. **Figure 6** shows the relationship between the degradation from the AWGN performance and the delay spread of each measurement. The delay spread was from 20 to 100 ns. However, the PER degradation was not related to the delay spread itself, as shown in this figure. Spectrum distortion severely degraded the PER performance.

Figure 7 shows the cumulative probability of the received signal level. The circles, crosses, and triangles show the probabilities for the first-, second-, and third-strongest signals, respectively. The strongest signal covered 98% of the room with a received level greater than –70 dBm, which gave a PER of better than 0.01, as shown in Fig. 5. The second- and third-strongest signals covered 85% and 65%, respectively, with a PER < 0.01.

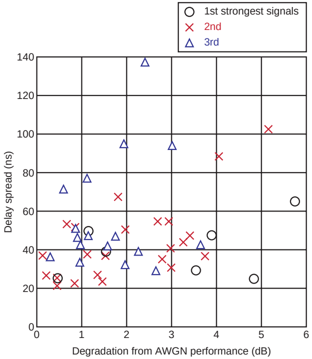

Fig. 6. Relationship between the degradation from the AWGN performance and measured delay spread.

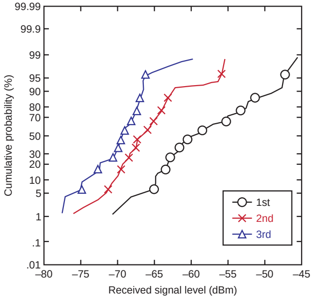

Fig. 7. Cumulative probability of received signal level.

Table 2. Estimated coverage for 8-dBi MT antenna.

%

	1st	2nd	3rd
BPSK, R=1/2	100	96	75
QPSK, R=1/2	95	45	4
16QAM, R=9/16	50	8	2
16QAM, R=1/2	45	6	1

3.3 Discussion

For the above measurements, we employed a high-gain directional antenna (20 dBi) as the MT antenna. Omni-directional or sector antennas are easy to use in practical situations. The beam width of the MT antenna was about 13 degrees, so we would have needed about 30 sectors to cover 360 degrees. Unfortunately, antennas should have no more than 6 or 8 sectors if they are to be practical, so the antenna's gain was limited to about 8 dBi. **Table 2** shows the coverage for several modulation modes estimated by adjusting the MT antenna's gain. One AP covers 45% at 16QAM, R=3/4 by using the strongest signal, and placing multiple APs in a room is no problem for 25-GHz WLAN systems to provide a high system capacity. Thus, our experimental results suggest that three or more APs could cover the whole area of the room. If the strongest signal gets lost, we will able to use the second-strongest signal. However, it might provide only a low data rate when using a modulation scheme such as BPSK, R=1/2.

WLAN systems operating in the quasi-millimeter wave band generally have a limited range and must employ directional antennas to increase the system gain because of the large propagation loss of the 25/27-GHz-band signals. As a result, shadowing by human bodies or other obstacles severely degrades their performance. On the other hand, the 5-GHz band WLAN system has a larger range and suffers less fading. A frequency diversity technique in the 5- and 25/27-GHz bands can be used to achieve high capacity as well as high link availability because both systems can use common base-band blocks.

4. Conclusion

In this paper, we discussed the feasibility of broadband wireless access systems using the 25- and 27-GHz bands that have been allocated for nomadic wireless access systems in Japan. The systems can provide a high system capacity by making the best use of their wide bandwidth. The shadowing effect in the quasi-millimeter wave band is much greater than at lower frequencies, and a dual-band system using the 5- and 25-GHz bands is one possible solution to this problem. Achieving a compact mobile terminal like a WLAN card is still an issue for a practical broadband wireless access system using the quasi-millimeter wave band.

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