10-Gbit/s Wireless Link Technology Using the 120-GHz Band

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Abstract

The appearance of high-speed, large-capacity information-processing devices is driving the need for ultrahigh-speed wireless communications that can achieve nearly instantaneous transfer of large amounts of data. This article introduces a 120-GHz, millimeter-wave wireless link capable of 10-Gbit/s data transmission, which is a full order of magnitude faster than existing wireless communications technologies.

1. Rise in transmission speeds

As with computers, there seems to be no end to the increases in speed and capacity in information communications. **Figure 1** shows how transmission speeds have increased over time for long-distance optical backbone transmission, Ethernet LAN, and wireless techniques. It seems as if all three of these transmission techniques are converging on the same target, that is, transmission speeds from 10 to 100 Gbit/s. This result heralds the coming of an era in which wired communications using optical fiber and wireless communications will connect seamlessly at similar bit rates.

Figure 2 compares the transmission speeds of recent wired and wireless techniques for local area network (LAN) and personal area network (PAN) environments. Wired LAN/PANs using optical fiber have already been commercialized in Ethernet form at a bit rate of 10 Gbit/s. In contrast, the various versions of wireless LANs currently in use feature bit rates of only 20–50 Mbit/s, much lower than those of wired LAN/PANs. But the appearance of new techniques such as ultra-wide band (UWB) and millimeter-band wireless 1394 is expected to enable speeds of 1 Gbit/s in the near future.

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2. Benefits of 10-Gbit/s wireless links

We examined the need for 10-Gbit/s wireless links, which far exceed the transmission speeds of existing wireless techniques. At present, the market for fixed wireless access (FWA) is considered to be the most promising. This is because of the current state of corporate in-house LANs where the introduction of optical fiber networks is driving the broadband boom. Gigabit Ethernet (1 Gbit/s) is already widely used here, and the introduction of 10-Gigabit Ethernet (10GbE) to corporate in-house LANs can be expected in the coming years. But if such a 10GbE corporate LAN needed to be extended to an adjacent building, for example, it would take considerable time and expense to lay new optical fiber. If 10-Gbit/s wireless links were used, two separate 10GbE networks could be connected in a relatively short time at low cost.

10-Gbit/s wireless links are also expected to meet the demand for temporary broadband networks in natural-disaster recovery efforts, at event halls and venues, and in remote broadcasts. There is a particular need for circuit capacities of several gigabits per second for the uncompressed transmission of high-resolution moving pictures in high-definition television (HDTV) and digital cinema, but the maximum transmission speed of millimeter-wave wireless links typically in the 60-GHz band is only about 1.5 Gbit/s, which is insufficient for such moving-picture transmission. A 10-Gbit/s wireless link could play an active role at broadcast stations and conference sites where there is strong demand for the transmission of

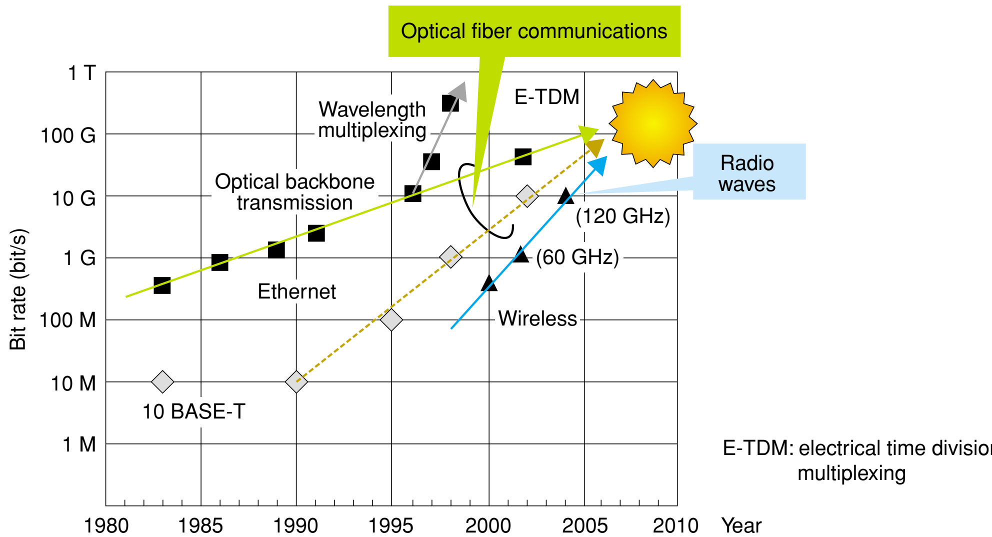

Fig. 1. Increase in bit rate for various transmission techniques.

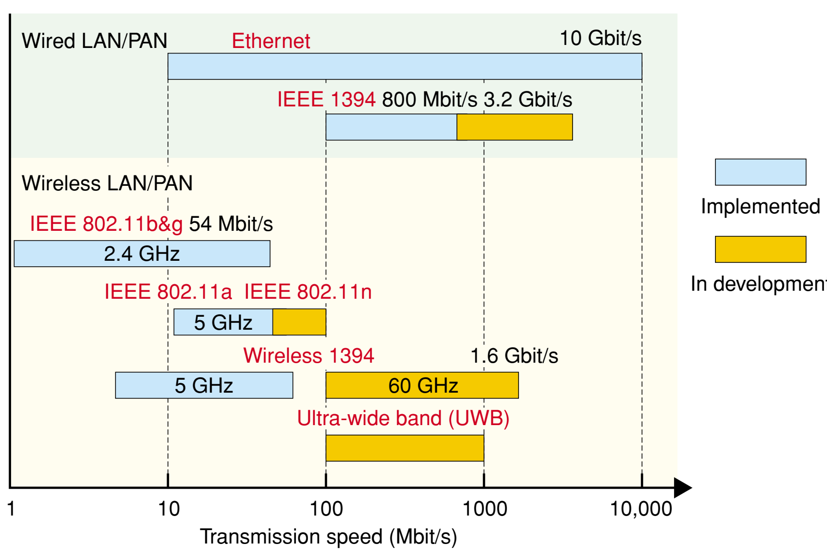

Fig. 2. Development of high-speed LAN.

large amounts of moving-picture data.

Another application of 10-Gbit/s wireless links is in the storage area network (SAN) field where large files and applications are stored on centralized servers to simplify their management and sharing. In corporate in-house networks, efforts are being made to enable individual terminals to instantaneously download data as needed from these servers. Here, the introduction of 10-Gbit/s wireless links to a SAN configured by 10GbE would enable each terminal to download large amounts of data at speeds equivalent to those of an optical-fiber connection without having to use a cable.

10-Gbit/s wireless links can also be considered for hotspot-like applications such as downloading movie files in a movie-rental service. The transmission of the 4.7 gigabytes of data stored on a DVD, for example, takes nearly seven minutes over Fast Ethernet (100 Mbit/s) but would take only about four seconds over a 10-Gbit/s wireless link. In the future, the use of 10-Gbit/s wireless links might make scenarios like the instantaneous exchange of large amounts of data between two passersby a reality (**Fig. 3**).

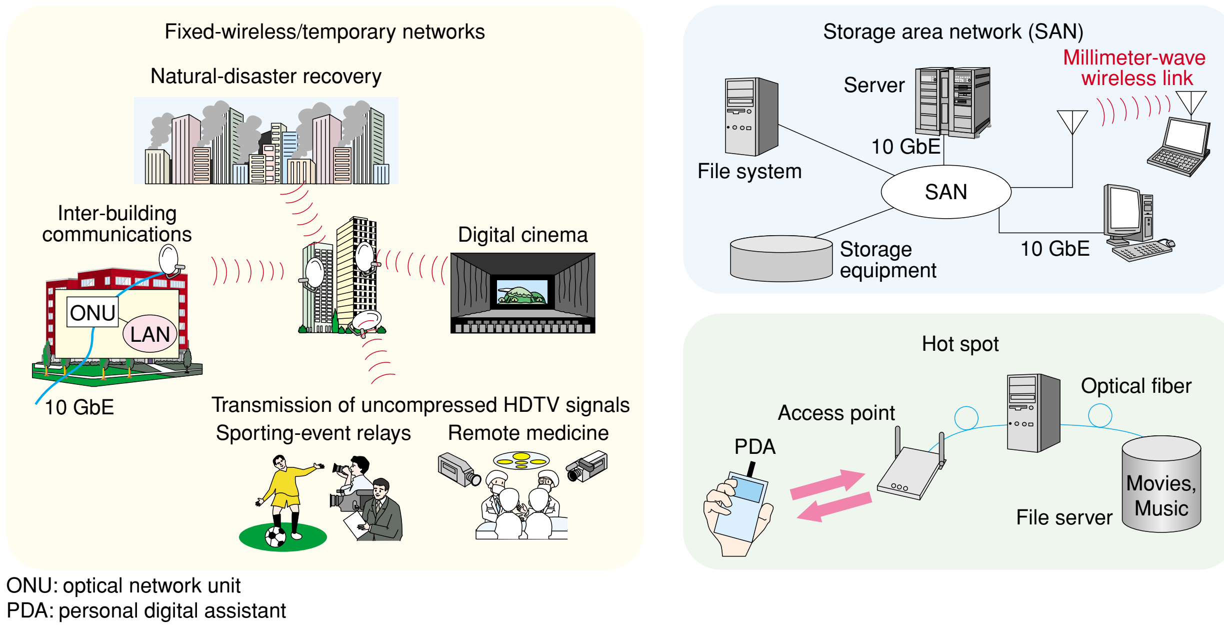

Fig. 3. Application examples of 10-Gbit/s wireless links.

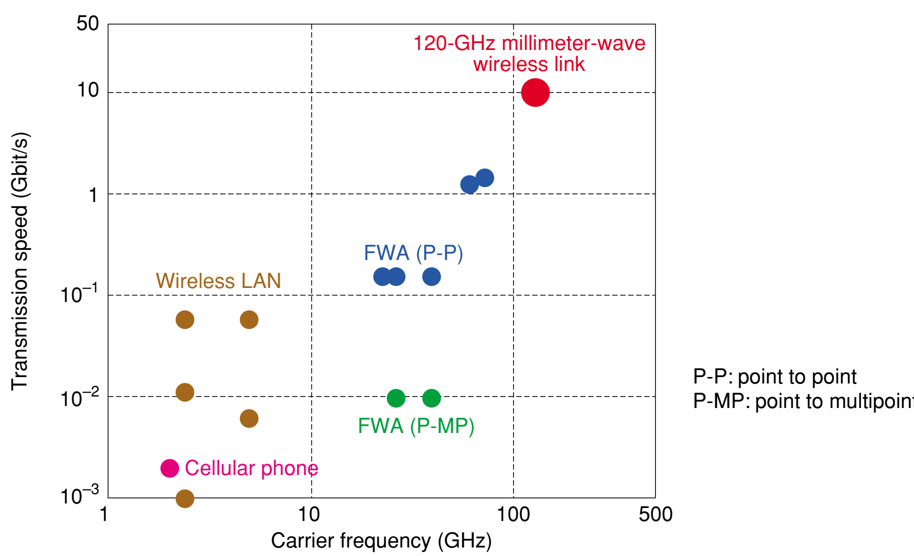

Fig. 4. Relationship between transmission speed and carrier frequency in various wireless communication systems.

3. Why 120 GHz?

To achieve 10-Gbit/s transmission speeds, we chose to use the 120-GHz electromagnetic-wave band as a carrier. This band has never before been used for this purpose. Why use such a high radio frequency above 100 GHz? The answer lies in the relationship between transmission speed and carrier frequency in wireless communications, as shown in **Fig. 4**. Examining the plots for transmission speed versus carrier frequency starting with 2-GHz cellular phones and then continuing with the previously described wireless LAN and 60–70-GHz FWA, we see that carrier frequencies of over 100 GHz would be effective for achieving bit rates in excess of 10 Gbit/s.

In selecting a particular frequency, we must also consider the problems of radio-wave propagation and radio-wave regulation (frequency allocation). **Figure 5** shows attenuation characteristics for radio and optical waves under various atmospheric and rainfall conditions. In the range from 10 GHz to 1 THz, the atmospheric attenuation of radio waves increases as

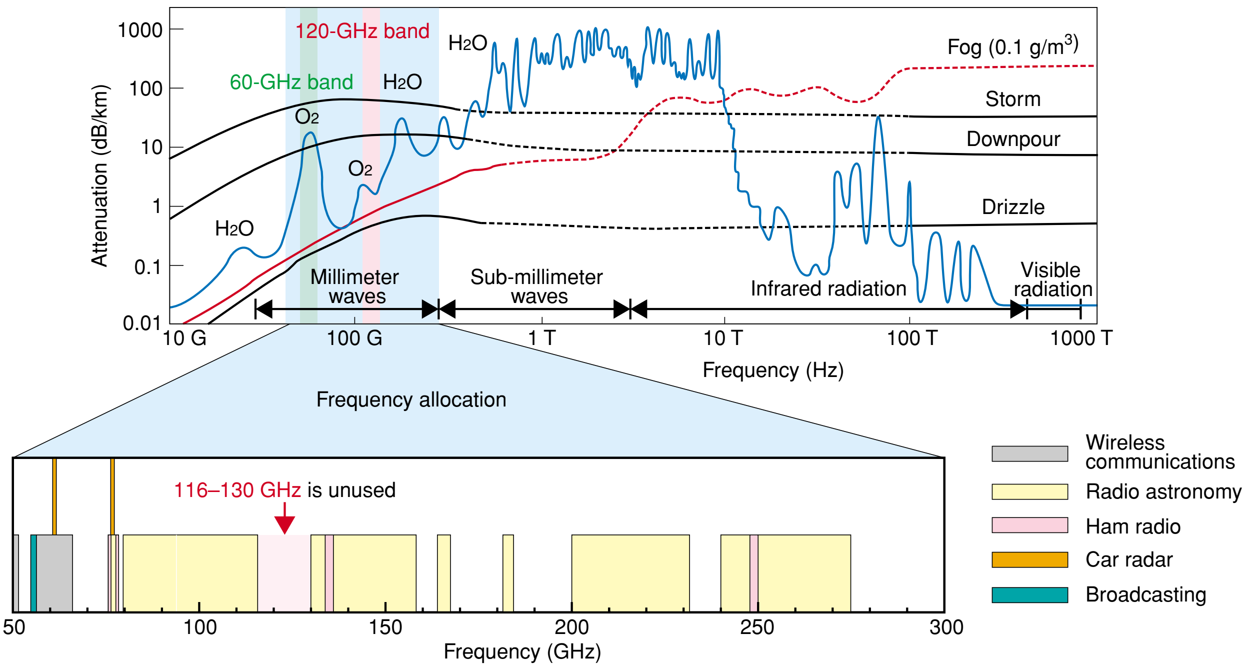

Fig. 5. Millimeter-wave propagation characteristics and frequency allocation in Japan.

frequency rises and reaches 10 dB/km at 200 GHz and above. Absorption bands due to oxygen and water molecules can also be seen at 60 and 200 GHz and elsewhere. The 120-GHz band, however, lies in a valley between such absorption bands, so it is a frequency region with relatively little atmospheric attenuation. Millimeter waves, though, are known to suffer from large attenuation during rainfall, and even in the 120-GHz band, attenuation can reach 50 dB/km during severe rainfall caused by storms. Such large attenuation during severe rainfall, however, is not limited to the 120-GHz band. It is essentially constant for millimeter waves above 60 GHz.

Given that radio-wave frequencies are a limited resource, they are regulated in Japan by the Radio Law to ensure fair and efficient use. Figure 5 also shows the frequency allocation in Japan in the 50–300-GHz range. Radio waves in the 50–90-GHz range are widely used for wireless communications, radar, and other applications, but above 100 GHz, they are allocated only to radio astronomy and ham radio. There are also a number of unused regions including the one from 116 to 130 GHz.

4. Configuration of wireless link

There have been no examples to date of using a millimeter-wave band above 100 GHz for Gbit/s-class high-speed wireless communications. One reason for this is that transistors and other electronic components that can operate at such high frequencies account for only part of the required circuitry, so it is still difficult to obtain all the components needed for wireless transmission of this type. In response to this problem, we have been testing the introduction of photonics technology for the generation, modulation, and transmission of 120-GHz millimeter-wave signals [1]. This technology, which was developed in the field of optical-fiber communications, can generally accommodate a broader band of signals than electronic technology. It is relatively easy for photonics technology to process signals having a frequency above 100 GHz.

Figure 6 shows the configuration of a 120-GHz wireless link. First, a 125-GHz intensity-modulated optical signal is generated using an optical millimeter-wave signal generator. Then, this 125-GHz optical signal is modulated with a data signal having a maximum bit rate of 10 Gbit/s by an optical modulator, and the resulting optical signal is amplified and input to a photonic emitter. A uni-traveling-carrier photodiode (UTC-PD) [2] known for its high speed and high output characteristics is used to perform optoelectronic conversion on this optical signal, which is then amplified by a millimeter-wave amplifier using a high electron-mobility transistor (HEMT) [3] and radiated from an antenna [4]. The millimeter-wave signal that reaches a receiver's antenna is then ampli-

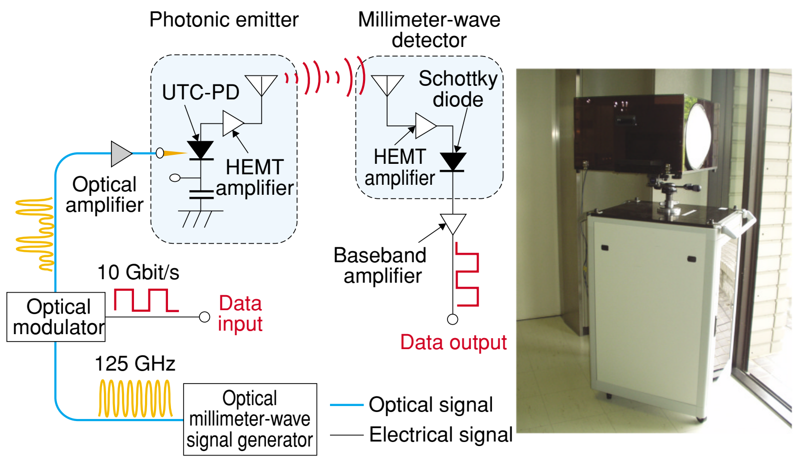

Fig. 6. Configuration of a 120-GHz millimeter-wave wireless link and a photograph of the transmitter.

fied and subjected to envelope detection using an ultrahigh-speed Schottky diode. The figure also shows a photograph of the millimeter-wave wireless transmitter that we developed. A maximum transmission distance of 1 km can be achieved by using a Gaussian optics lens antenna having high directivity for both the transmitter and receiver.

5. Future outlook

On July 8, 2004, we received a license from the Kanto Bureau of Telecommunications of the Ministry of Public Management, Home Affairs, Posts and Telecommunications for an experimental station using the millimeter-wave communication equipment described above. This is the first license given in Japan for a radio experimental station in a frequency region above 100 GHz. In the future, we plan to perform both laboratory and field experiments to evaluate propagation characteristics in various environments with the aim of making a practical working system. We also plan to take up the challenge of developing the electromagnetic region from 300 GHz to 1 THz by using the same photonics approach as described here.

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He received the B.S. and M.S. degrees in chemistry from the University of Tokyo, Tokyo in 1992 and 1994, respectively. Since joining NTT in 1994, he has worked on development of LSI interconnection, microelectromechanical systems, and the design and integration of millimeter-wave devices. He is currently developing 120-GHz-band wireless links using photonic technology. He received the 2002 Asia Pacific Microwave Conference APMC Prize and the 2004 YRP Award. He is a member of IEEE and IEICE.