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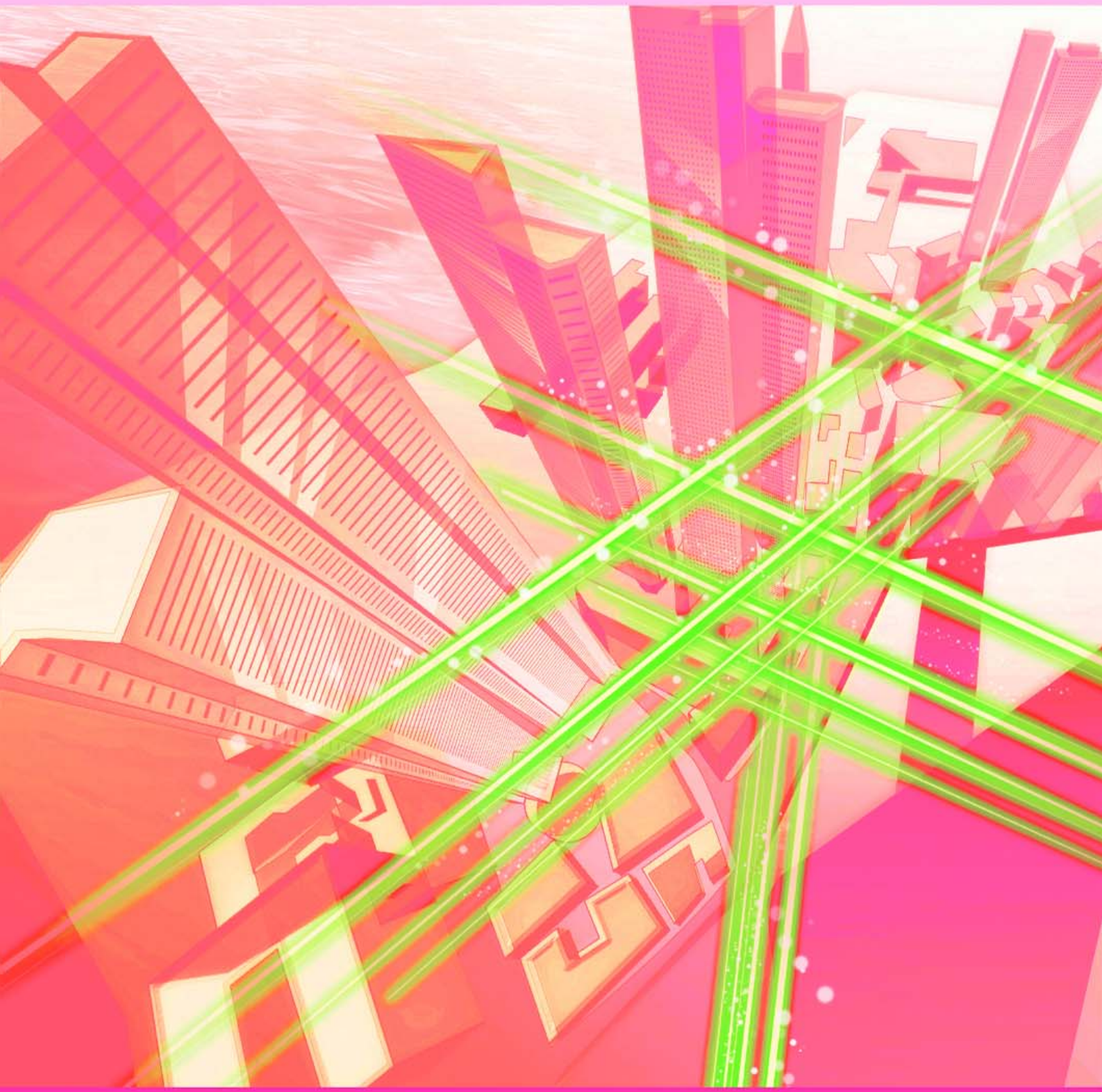

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Feature Articles: Wireless Access Technology to Meet Diverse Needs from IoT/M2M to Broadband

Regular Articles

Global Standardization Activities

External Awards/Papers Published in Technical Journals and Conference Proceedings

Enhancing Wireless Access Technologies Using Multiple Frequency Bands to Enable the Widest Range of Internet of Things Applications

Ryutaro Kawamura, Shuichi Yoshino, Masato Mizoguchi, and Takehiro Nakamura

Abstract

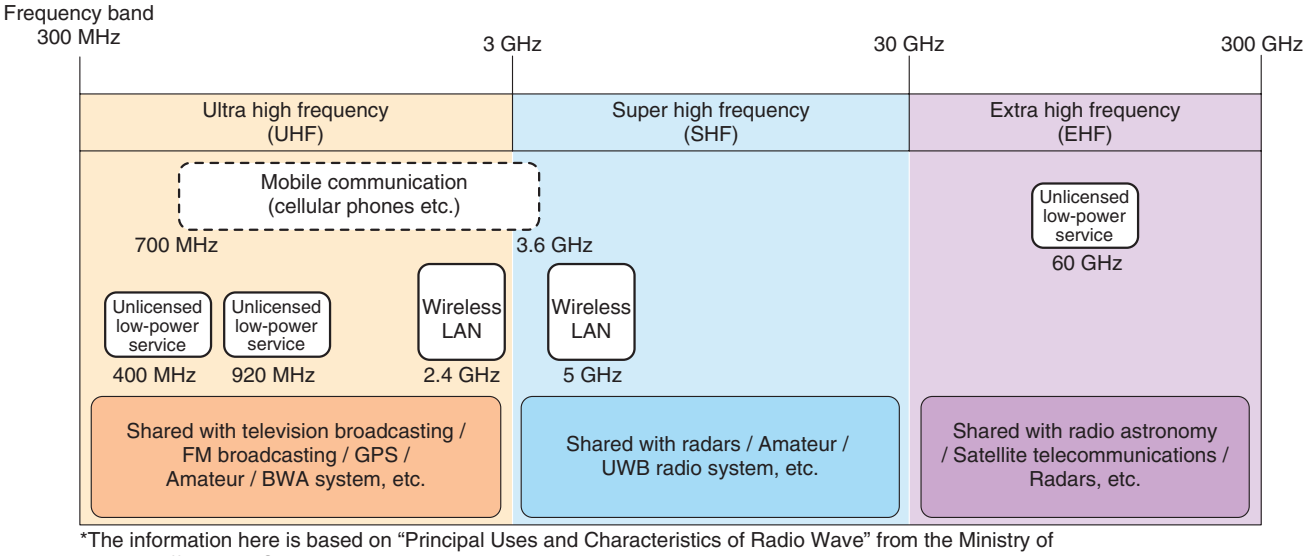
In the future vision of society, wireless communications will play a more critical role in every aspects of our lives, because the advent of the Internet of Things (IoT) is expanding the application of wireless technology beyond human usage such as mobile or smartphones to *thing* usage such as industrial applications. It is therefore essential to develop efficient wireless technologies for the wide variety of frequency bands available—from the efficient use of conventional bands to the use of pioneering EHF (extremely high frequency) bands (millimeter wave band). This article introduces such development efforts in three areas: 5G (fifth-generation mobile communications systems), wireless LAN (local area network), and wireless access for IoT.

Keywords: 5G, Wireless LAN, IoT

1. Introduction

The advances made in wireless technologies, facilitated by the widespread adoption of smartphones, tablets, and personal computers, have created an environment in which cellular phones and wireless local area network (LAN) services enable us to exchange and retrieve various kinds of information via networks anytime and anywhere, both indoors and outdoors, even while moving. Mobile services in Japan have been migrating to the fourth generation, and the number of total handsets amounts to more than 160 million [1], far exceeding the population. In addition, the annual shipment of wireless LAN devices surpassed 50 million in 2016 [2] and is expected to increase in the coming years. The aggregated traffic generated by wireless applications is increasing substantially and is being carried not only by mobile services provided by operators, but also by wireless LAN services in what is called off-loading. To accommodate the traffic increase, new wireless technologies for pioneering frequency bands are necessary in addition to those that can expand the capacity of existing mobile and wireless LAN services.

The Internet of Things (IoT) concept is driving the interconnection of devices in many places and is creating many opportunities for new wireless services including those in the areas of factory control, industrial machinery, transportation, agriculture, city planning, healthcare, security, consumer electronics, education, medical care, and countermeasures against disasters. The use cases and application environments for such services are obviously very diverse. For example, real-time communications are needed for



*The information here is based on "Principal Uses and Characteristics of Radio Wave" from the Ministry of Internal Affairs and Communications website.

BWA: broadband wireless access
FM: frequency modulation
GPS: Global Positioning System
UWB: ultra-wideband

Fig. 1. Principal uses of radio waves.

factory control and autonomous driving since their control functions must be implemented within the determined duration. Low power communications are needed in infrastructure monitoring and metering, since the devices that are scattered over a wide area need to be active for a number of years without having to frequently maintain them. Wireless technologies must offer a variety of quality and performance levels in addition to higher capacity.

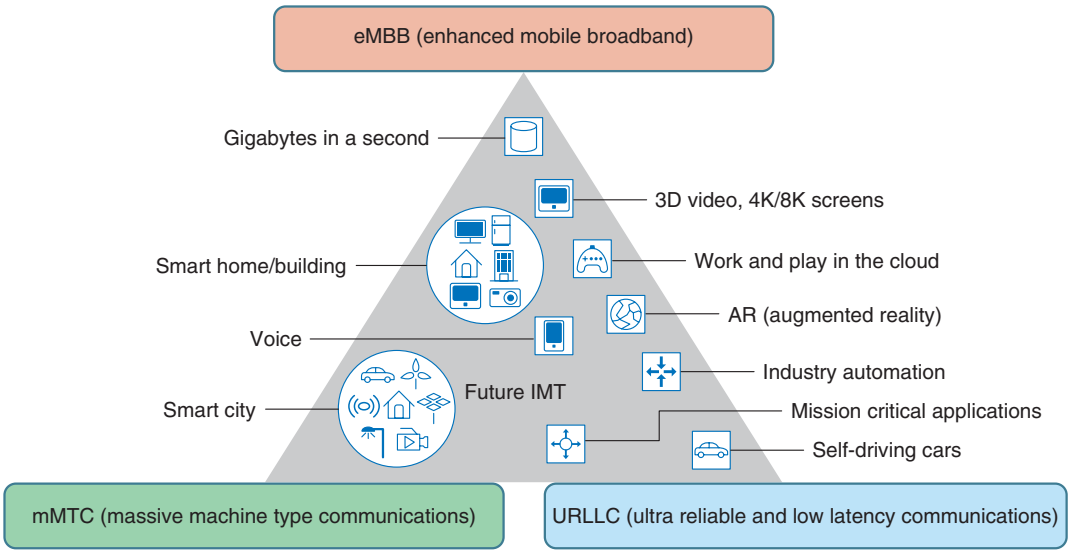
A wireless communication link is established by selecting a certain frequency band on which to transmit. The basic characteristics of a radio wave depend on its frequency. Technical standards set by governing organizations determine the allocation of frequency bands by the radio wave characteristics in order to make the best use of the frequency bands. The principal uses of the major frequency bands in Japan are illustrated in **Fig. 1**. In general, lower frequency bands are appropriate for wide area communications, since low-frequency radio waves can propagate well beyond the line-of-sight area. However, capacity is rather small.

In contrast, high frequency bands are appropriate for high capacity communications, but high-frequency radio waves have poor propagation performance. Applications should be assigned frequency bands that suit the service characteristics. UHF (ultra high frequency) and SHF (super high frequency) are the frequency bands that are most access-friendly in terms of propagation and capacity. Mobile services and wireless LAN services are allocated to those bands. It is expected that new technologies will be necessary to improve the frequency usage efficiency and to increase capacity in order to accommodate the increasing traffic. In addition, emerging IoT services, which have various quality and performance demands, have created the opportunity to pioneer the extreme high frequency (EHF) millimeter band.

Technology developments and standardization activities in a range of frequency bands have been progressing worldwide, and the NTT Group has been actively contributing to these efforts in order to meet the demands of our customers. The activities for fifth-generation mobile communications systems (5G), wireless LAN, and wireless access for IoT are described in the following sections.

2. 5G

In Japan, the first-generation mobile service started in 1979 and used analog technology. The second generation introduced digital technology and expanded



*Source: Recommendation ITU-R M.2083-0: "IMT Vision – Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond," 2015.

IMT: International Mobile Telecommunications

Fig. 2. Technical directions identified by the ITU-R recommendation.

mobile services substantially, while the third generation provided mobile data services to allow Internet access. The fourth generation enabled broadband data access, making mobile streaming services widely available. Today, research and development (R&D) activities for the fifth generation are progressing in order to increase capacity as well as to support emerging IoT applications.

In September 2015, the ITU (International Telecommunications Union) published a vision of 5G systems and identified three technical directions for R&D. These are indicated in **Fig. 2**, along with their relationship with the expected applications; eMBB (enhanced mobile broadband) supports broadband data access via larger capacity, mMTC (massive machine type communications) enables massive numbers of devices to be connected in a certain area, and URLLC (ultra reliable and low latency communications) achieves reliable data exchanges within short periods. 3GPP (3rd Generation Partnership Project), the standards organization for 5G services, has been developing detailed specifications of wireless technologies to suit the three directions. The article entitled "Standardization Status towards the Introduction of 5G in 2020" [3] in the Feature Articles in this issue details the latest stage in this study.

3. Advanced wireless LAN

Smart devices such as smartphones and tablets are usually equipped with wireless LAN functionality and are widely used in gathering places such as stadiums, airports, and shopping malls. In such environments, people can efficiently utilize the broadband wireless LAN services provided in addition to mobile services. Accordingly, there is a growing need to install wireless LAN access points in an extremely dense manner at various gathering places in order to provide more fast and reliable access even in crowded situations. With legacy wireless LAN technologies, service capacity is limited by the interference created by the high density of access points. The NTT laboratories have been contributing to the new technical specifications being developed to overcome this issue by developing more advanced antenna systems and intelligent control methods for multiple access points. The article in this issue entitled "New Trends in Wireless LAN and Cooperative Wireless LAN Technology" [4] details IEEE 802.11ax, the in-progress wireless LAN standard being developed by the Institute of Electrical and Electronics Engineers (IEEE). IEEE 802.11ax will improve the frequency usage efficiency of wireless LANs in dense installation environments. The article also introduces the cooperative wireless LAN, which reduces interference

by intelligent control and the use of distributed antenna systems, leading to improvements in the quality of wireless LAN services, especially 5G applications.

4. Wireless technology for emerging IoT applications

The use cases and environments of emerging IoT applications are rapidly diversifying, so the wireless technologies for them must advance in many directions. For example, it is expected that extremely wide coverage will be needed to connect the sensing devices of certain IoT services, as many will be placed where people cannot easily access them even for infrequent maintenance.

A number of new wireless technologies for the 920-MHz band have recently emerged worldwide that support IoT services needing wider coverage. The 920-MHz band is useful for this purpose, as such radio waves propagate further than those at 2.4 GHz. This band has until now been utilized by wireless LAN and Bluetooth*. The article entitled "Development Efforts on Wide Area Wireless Access to Accelerate Its Use for M2M" [5] details the activities of NTT laboratories involving wireless access technologies for the 920-MHz band.

IoT devices typically exchange small amounts of data. However, the capacity to handle much larger amounts of data is needed to support intelligent security services. For example, high quality moving images must be transferred to enable detection of infrastructure anomalies by using advanced data analysis schemes based on artificial intelligence algorithms. The greater frequency resources available in the EHF band are promising for developing new wireless technologies for such new bandwidth-demanding IoT applications.

Furthermore, it is expected that ultra-reliable and low latency wireless communications will be necessary to support connections to self-driving cars, as they must support data interaction for remote control and for obtaining prompt environmental information on other cars and roadside infrastructures. The article entitled "A Study on Wireless Technologies to Improve Communication Performance by Utilizing Multi-frequency Bands" [6] examines the activities of NTT laboratories in wireless access technologies for pioneering frequency bands to achieve greater capacity and higher reliability with lower latency.

5. Future developments

Recent advances in information technologies based on wireless communications have created abilities that will benefit all industry sectors by enabling them to apply information technologies to improve their existing workflows. Accordingly, wireless communication is expected to be a key part of the social infrastructure. NTT will continue its R&D activities on efficiently matching frequency bands to the new applications and creating new value in this emerging IoT-enabled world.

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* Bluetooth is a registered trademark of Bluetooth SIG Inc.

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Standardization Status towards the Introduction of 5G in 2020

Yoshihisa Kishiyama, Satoshi Nagata, and Takehiro Nakamura

Abstract

There is growing interest worldwide in the introduction of fifth-generation mobile communications systems (5G) by 2020 or earlier, and extensive efforts on 5G field experiments are being vigorously carried out in many countries and regions. 3GPP (3rd Generation Partnership Project), the standards organization for mobile communications systems, held the RAN (radio access network) Workshop on 5G in September 2015. Subsequently, discussions started on the standardization of new radio interfaces for 5G. This article outlines the approaches and the current status of standardization towards the introduction of 5G in 2020.

Keywords: 5G standardization, New RAT, wireless access

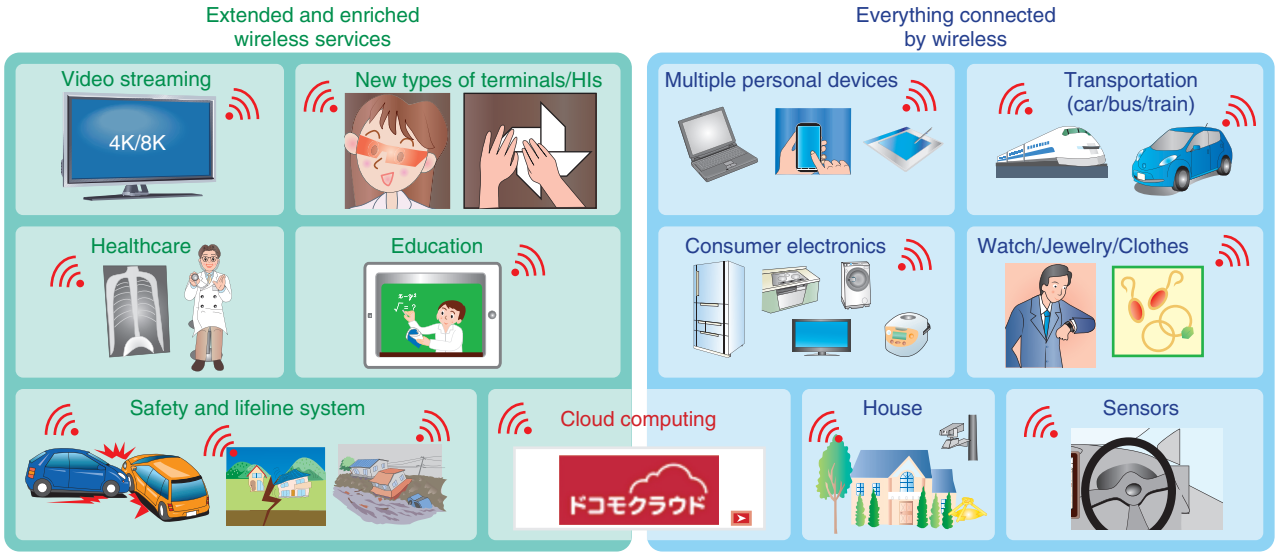
1. Introduction: Phased approach of 5G standardization

Wireless communications services in the era of fifth-generation mobile communications systems (5G) can be characterized by two major trends. One is enhanced mobile broadband (eMBB), which provides extreme broadband data transfer, and the other is Internet of Things (IoT), which connects everything to wireless networks. To achieve the services depicted in **Fig. 1**, two approaches for technical advancement are being considered: enhanced Long Term Evolution (eLTE), which denotes the continued evolution of 4G (LTE, LTE-Advanced, LTE-Advanced Pro), and New Radio Access Technology (New RAT), the introduction of the new 5G radio interface specification.

The former is an evolutionary approach that emphasizes backward compatibility with existing 4G systems. The latter is a clean slate approach to drastically improve performance; it emphasizes ultimate performance over backward compatibility. It is expected that 5G will be realized by some combination of eLTE and New RAT [1, 2].

A possible 5G deployment scenario that uses the NTT DOCOMO assumption about the combination of eLTE and New RAT is illustrated in **Fig. 2**. In the early stage of 5G deployment in 2020, eLTE and New RAT will be introduced in areas that require large capacity such as dense urban centers. Dual connectivity technology [1], which separates control and user data planes, will be used to enable cooperation between eLTE and New RAT to support sufficient coverage and mobility, while achieving high-speed and large-capacity mobile communications environments. In later stages, 5G will gradually be expanded from large cities to suburban and rural areas, under the assumption that new frequency bands such as millimeter wave bands, which are not used for current mobile communications, will be deployed as necessary.

To achieve the deployment of New RAT in 2020, the initial version of the specifications should be completed by mid-2018 at the latest. The standardization work therefore has to progress in accordance with the rather tight schedule. However, the International Telecommunications Union - Radiocommunications Sector (ITU-R), the organization that recommends international radio standards, wants the final interface specifications for supporting 5G (IMT-2020) to be completed by the end of 2019, allowing room for additional improvement of specifications.



HI: human interface

Fig. 1. Potential services available with 5G.

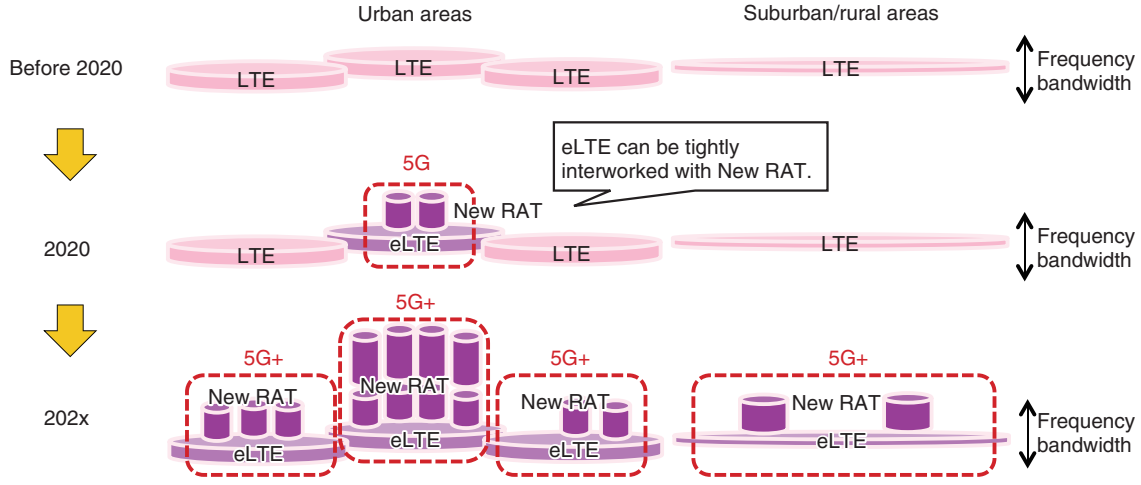


Fig. 2. 5G deployment scenario.

Accordingly, the consensus is to take the phased approach in 5G standardization for New RAT while incorporating the vision of achieving the early introduction of 5G as well as its subsequent evolution. In the phased approach, the initial specification (Phase 1) of New RAT has to be completed within a limited period of time. It is therefore important to establish the base design with an emphasis on forward compatibility instead of incorporating many new features. Specifically, it is realistic to design New RAT with a limited scope that focuses on the basic performance of eMBB to support 5G attributes such as high speed, large capacity, and low latency (**Fig. 3**). To augment wide area coverage, 4G and eLTE will continue to be used to support IoT services, which must connect many M2M (machine-to-machine) devices at low cost. In later stages, the final New RAT specification (Phase 2 and later) will include many new features and will be introduced gradually to support new unknown services in the era of 5G and IoT.

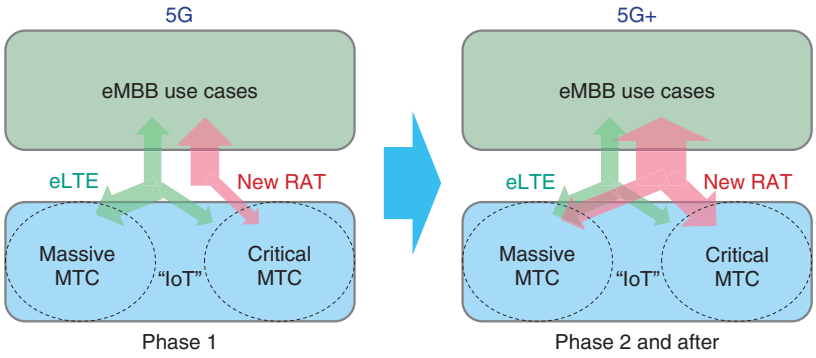


Fig. 3. 5G phased approach from use case perspective.

2. Standardization status of New RAT

Standardization is proceeding on various components and technologies associated with New RAT. We report here on the latest standardization efforts.

2.1 Frequency bands

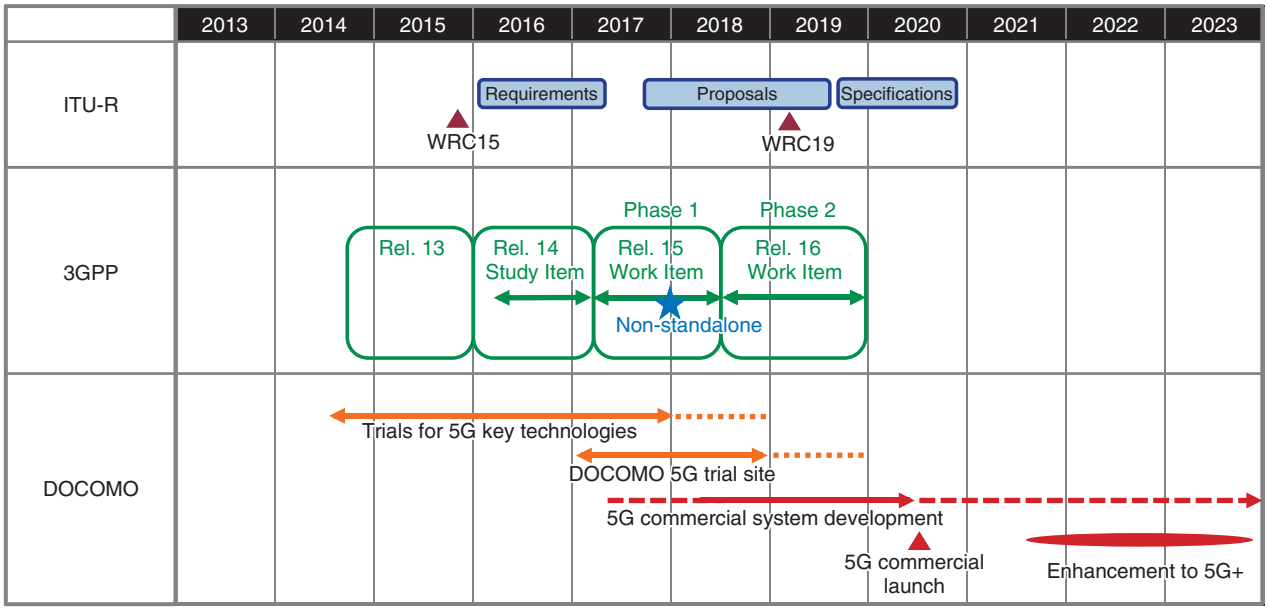
For 5G, the use of extremely wide frequency bands is being considered; they range from legacy low frequency bands to higher frequency bands, including millimeter wave, up to the maximum of 100 GHz. However, the frequency bands that will be available for commercial deployment in 2020, the target of Phase 1 specification, will be limited. During the RAN Workshop on 5G held by the 3rd Generation Partnership Project (3GPP) in September 2015, a discussion was held on whether to support frequency bands above 6 GHz, considering the strategies of operators and the usage of frequency bands in individual countries. While each operator and each country targeted different target frequency bands for 5G, the Federal Communications Commission (FCC) in the United States announced the allocation of frequency bands above 24 GHz to 5G [3]. The logic of supporting higher frequency bands (up to 50 GHz) in Phase 1 is gradually being accepted by the market. Thus in 3GPP, it was agreed that the scope of wireless technology in the Phase 1 specification (Release 15) should include frequencies both below and above 6 GHz [4].

2.2 Optimization for IoT-related services

Another topic of discussion in 3GPP concerns what features to include in the Phase 1 specification for optimization in terms of IoT-related services, for example, massive machine type communications (mMTC) and ultra-reliable and low latency communications (URLLC). Many opinions were exchanged during the 3GPP workshop. For example, some participants thought that Phase 1 should focus on eMBB and that the specification should consider eMBB, mMTC, and URLLC equally. Later, a number of companies cooperatively proposed that 3GPP complete the Phase 1 Work Items early, and as a result of extensive discussions, it was agreed that the Phase 1 specification would include eMBB and part of URLLC only in order to complete standardization early. However, the basic study according to the current Study Item includes the features for IoT as well as eMBB, and work is still in progress. Such features include channel coding schemes for small packets, and non-orthogonal multiple access schemes.

2.3 Support of standalone operation

The previous section mentioned NTT DOCOMO's assumption as to the combination of eLTE and New RAT for a deployment scenario. The dual connectivity technology enables MeNB (master evolved NodeB) to be used to provide the control plane function of eLTE and SeNB (secondary evolved NodeB) to be used only to provide the user plane function of New RAT. In this arrangement, New RAT can operate only within eLTE coverage, which is referred to as non-standalone operation. The benefit of this arrangement is that the specification of New RAT can be simplified since it does not need to provide the functions needed for standalone operation. Those functions include the support of broadcast information and an idle mode. A proposal was made for early completion of the Phase 1 Work Items, and based on



WRC: World Radiocommunication Conference

Fig. 4. 5G time plan.

that, an agreement was reached on the overall work plan to complete the Phase 1 physical layer specification for non-standalone operation by the end of 2017, three months earlier than the original plan [4].

2.4 Standardization schedule

An illustration of our assumed standardization schedule is shown in **Fig. 4**. The overall direction has been publicized in line with the phased approach agreed on in the 3GPP workshop. The core part of Phase 1 specifications will be completed by September 2018, and the core part of Phase 2 specifications, which satisfy the requirements of ITU-R, will be completed by December 2019 [5]. Furthermore, it was agreed that the Phase 1 physical layer specifications for non-standalone operation are to be completed by the end of 2017 [4].

3. Current status of New RAT study

The standardization of New RAT has been progressing in 3GPP, and research and development (R&D) of 5G radio technologies is underway as part of many national projects and by operators and equipment vendors worldwide. This section introduces two wireless technologies for New RAT: basic radio parameters with frame structures, and multi-antenna transmission technology. Standardization efforts and trials are also described.

3.1 Radio parameters with frame structures

To support a wide range of frequency bands and use cases for 5G, it is necessary to support multiple different numerologies, which are defined sets of radio parameters such as sub-carrier spacing and TTI (Transmission Time Interval). One effective approach is to design variable parameters based on the numerology of legacy LTE [1]. Of particular interest are the higher frequency bands targeted for 5G, which allow broader sub-carrier spacing than that possible with LTE. In the current study underway in 3GPP, the working assumptions to define scalable numerology based on LTE are as follows.

- The base of subcarrier spacing f_0 is 15 kHz (the same as that of LTE)
- Subcarrier spacing is defined as $f_{sc} = 2^m \times f_0$ (scalable in steps of powers of 2)

To realize the dynamic time division duplex (TDD) scheme, which can dynamically switch between uplink and downlink within the same carrier, the self-contained subframe that suits low latency retransmission control is being studied in order to overcome the issues posed by the quasi-fixed TDD scheme. A number of approaches have been discussed (**Fig. 5**). These include permanently allocating the head of a subframe to the downlink control signal and the tail

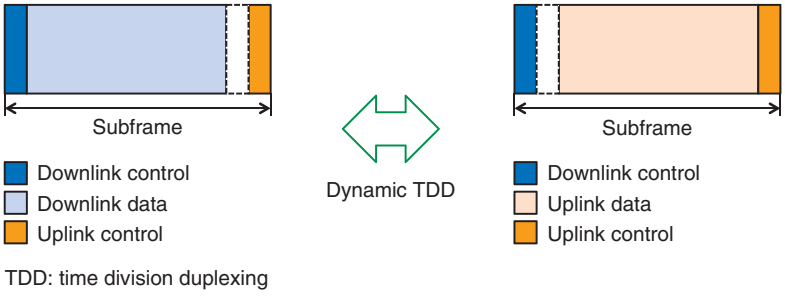


Fig. 5. Possible radio frame structure.

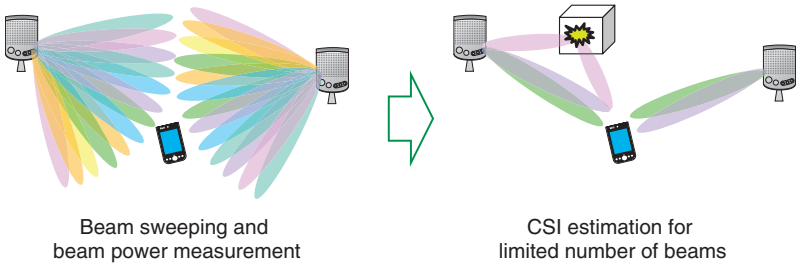


Fig. 6. Possible beamforming strategy for massive MIMO.

of the subframe to that of the uplink, and allocating the middle of the subframe to the data signal of both downlink and uplink, as well as to other reference signals.

3.2 Multi-antenna transmission technology

One of the key technologies enabling 5G to achieve drastic increases in capacity is massive multiple input multiple output (MIMO). It improves frequency usage efficiency through spatial multiplexing, and its beamforming gain helps to compensate for the propagation loss in higher frequency bands. The key issue in radio interface design is to efficiently support beam search, beam tracking, and diversity control of spatial multiplexing by controlling massive numbers of antenna devices with limited reference signals and low control overhead. Technical solutions have been proposed in order to address this issue, including the use of multiple hierarchical reference signals and beam control schemes suitable for analog-digital hybrid beamforming [6, 7].

The 5G experiment [8] conducted by NTT DOCOMO and Ericsson demonstrated highly efficient beam control by using multiple types of reference signals such as beam synchronization signals, a mobility reference signal (MRS) to measure the power of each beam, and a channel state information reference signal (CSI-RS) to measure channel quality for MIMO multiplexing (**Fig. 6**). First, a base station transmits synchronization signals and an MRS while rotating its beam direction, and a terminal receives those signals to establish synchronization and measures the MRS received power (MRSRP). The base station receives feedback from the terminal on MRSRP, selects the effective beam candidates for the terminal, and transmits the CSI-RS. The terminal receives the CSI-RS and derives the channel matrix to select the optimum combination of beams to maximize its throughput and to control the rank of MIMO multiplexing. This beam control scheme can be extended for multi-user MIMO and multi-point transmission. The 5G field experiment in the 15-GHz band conducted by NTT DOCOMO and Ericsson achieved an aggregated throughput of more than 20 Gbit/s by allocating four beams to two users at the same time in the frequency band of 800 MHz in an outdoor environment (**Fig. 7**).

BS: base station
UE: user equipment

Fig. 7. Experimental environment in which throughput over 20 Gbit/s was achieved.

4. Conclusion

In this article, the current status of 5G standardization was described together with the latest developments achieved in field trials. All the efforts mentioned herein are expected to provide a new area of services such as eMBB to provide high-speed and large-capacity broadband access, and IoT to connect everything to networks. NTT DOCOMO will continue to carry out advanced R&D and to contribute to standardization activities with the aim of achieving the initial deployment of 5G services in 2020, and the continued evolution of 5G (5G+) in later years.

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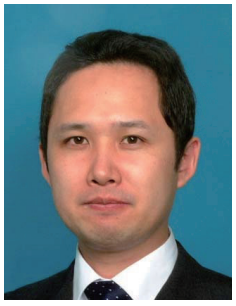

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New Trends in Wireless LAN and Cooperative Wireless LAN Technology

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Abstract

At NTT Access Network Service Systems Laboratories, we are researching and developing wireless local area network (LAN) technology, which is becoming more popular in homes, businesses, and public spaces. This article introduces standardization trends in wireless LAN technology, cooperative wireless LAN technology that solves interference issues in high-density wireless LAN environments such as stadiums, and integration of wireless LAN with cellular networks to realize 5G, the fifth-generation mobile communications system.

Keywords: wireless LAN, cooperative wireless LAN, 5G

1. Introduction

Wireless local area networks (LANs) can be used in a diverse range of applications including smartphones, game consoles, and drones. NTT has been strengthening the infrastructure for wireless LAN as our third access network platform following the fixed access network and mobile access network as part of our 2012 Medium-term Management Strategy. This has resulted in an increase in public wireless LAN area owners including businesses and local governments. As we look ahead to 2020, we can expect to see further expansion of wireless LANs in stadiums and other such venues. It is also expected that wireless LANs will be used for the fifth-generation mobile communications system (5G) that is being developed to cope with rapidly increasing levels of mobile traffic.

2. Wireless LAN standardization trends

The latest wireless LAN standard, IEEE* 802.11ac (11ac), supports high-speed communications over 1 Gbit/s, but in environments such as train stations and stadiums where there is a high density of wireless LAN devices, the throughput is liable to be impaired due to increased interference. To address this issue, the Task Group ax (TGax) was set up in the IEEE 802.11 Working Group, which is responsible for wireless LAN standardization, with the primary goal of improving throughput in high-density environments. TGax has been working on the standardization of IEEE 802.11ax (11ax) as a next-generation high-efficiency wireless LAN standard.

The main scope of TGax described in the Project Authorization Request, which is the prospectus of the task group, specifies that there must be at least one mode of operation such that the average throughput per user equipment in a high-density environment is at least four times higher than that of conventional equipment. Therefore, if this can be achieved, we can expect a great improvement in user experience

*IEEE: The Institute of Electrical and Electronics Engineers

compared with 11ac. The following approaches are being discussed in order to achieve the substantial improvements in frequency utilization efficiency that are needed to satisfy this requirement.

2.1 Multi-user transmission technology

Multi-user transmission is a technique whereby wireless signals for multiple terminals are transmitted together. In TGax, two approaches are considered—multi-user multiple input multiple output (MU-MIMO) and orthogonal frequency division multiple access (OFDMA). MU-MIMO is a technique that improves the transmission efficiency by performing spatial multiplexed transmission to multiple terminals using multiple antennas. OFDMA is a technique for flexibly and efficiently sharing frequency resources among multiple terminals. It has been introduced in standards such as Long Term Evolution (LTE) and is expected to be used in many wireless LAN devices due to its ease of implementation.

In 11ac, MU-MIMO is introduced only for the downlink, while for 11ax, both MU-MIMO and OFDMA will be adopted for the uplink as well as downlink. With the introduction of multi-user transmission in the uplink, it becomes possible for multiple terminals to transmit simultaneously in the uplink, which is expected to substantially improve the transmission efficiency. Due to the implementation of uplink multi-user transmission, TGax is discussing details such as the specifications of a new control frame called a trigger frame for the purpose of aligning the transmit timings between terminals.

2.2 Technology for improving spatial utilization efficiency of frequency resources

In a wireless LAN, the channel status is observed before transmitting packets to avoid collisions between packets, and if the received signal power is greater than a pre-defined threshold, the channel is regarded to be busy and the transmitter defers the transmission. In a conventional wireless LAN, the threshold value at which the channel is judged to be busy had been set to an excessively low value. In high-density wireless LAN environments, throughput degradation becomes more serious due to the increased occurrence of busy judgments, which eventually leads to fewer transmission opportunities. For 11ax, we are discussing how to address this issue by changing the conditions under which a channel is judged to be busy so that the space utilization efficiency of frequencies can be increased. Specifically, when the detected signal is a signal from another cell, transmission is permitted as long as certain conditions are met, thereby facilitating simultaneous transmissions in multiple cells and enabling high-density frequency re-use (**Fig. 1**). Discussions are also being held on determining a method to link the control of transmission power with the control of threshold values used to judge when a channel is busy.

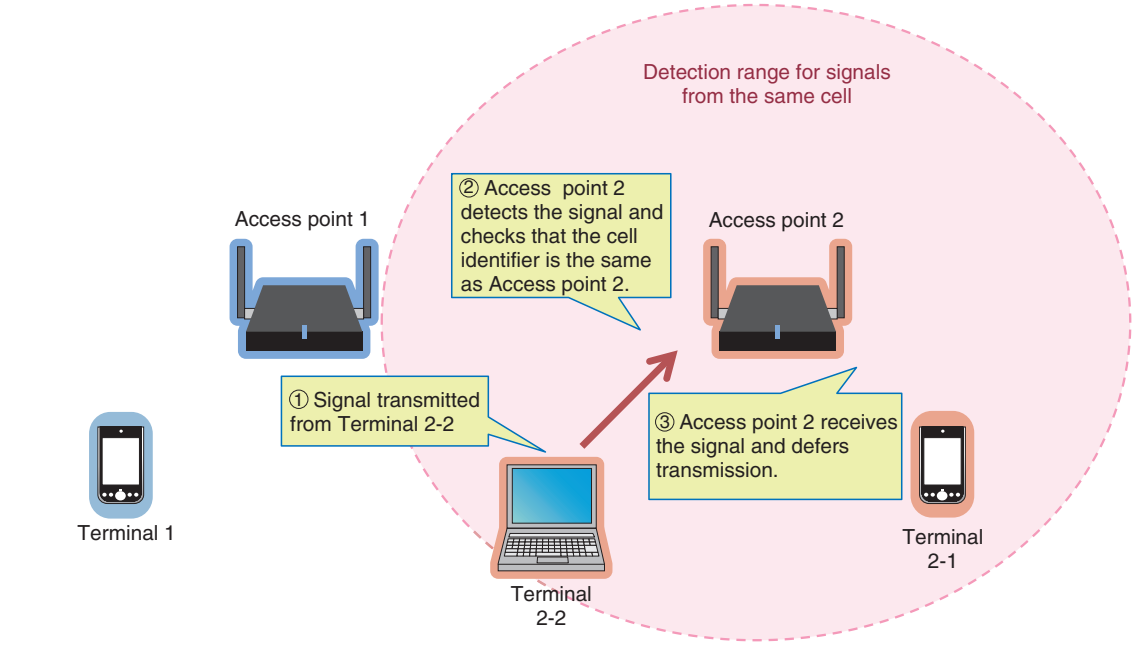
In addition, there is strong demand for outdoor use, so in 11ax, discussions are being held on matters such as finding a signal format that is highly robust against outdoor radio propagation characteristics and transmission modes that are specialized for long-distance transmission.

Standardization of IEEE 802.11ax is currently expected to be completed by the end of 2018. It is very likely that equipment conforming to the draft standard of 11ax will start to appear before completion of the standardization. It is assumed that equipment conforming to 11ax will become commonplace around 2020.

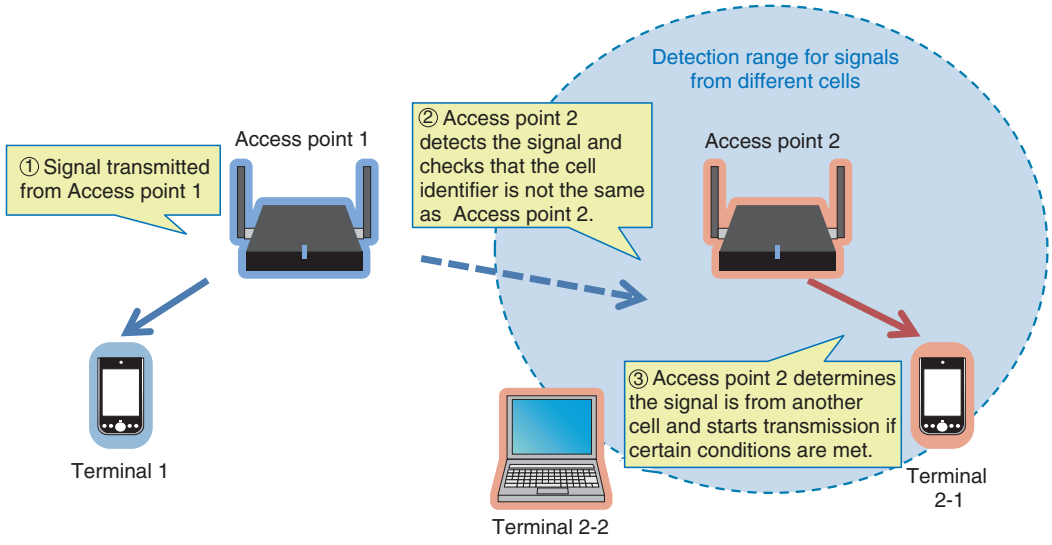
3. Cooperative wireless LAN technology for ultra-high-density wireless LAN services

In the 5G/11ax era, it is expected that the number of wireless LAN access points (APs) will further increase in order to cope with IoT (Internet of Things) and ultra-broadband services. However, since the frequency bandwidth used by wireless LANs is limited, in situations where APs are installed at high density, the number of cases where the same channel is shared by multiple APs in the same vicinity is increasing. Also, with the evolution of wireless LAN standards, we are seeing the expansion and diversification of radio parameters both in the frequency domain and in the spatial domain such as the frequency bandwidth, the number of spatial multiplexed streams, and the transmit power. In this sort of situation, it is difficult to obtain adequate performance by using autonomous distributed APs. To make efficient use of limited radio resources in order to accommodate more terminals and traffic, it is effective to perform centralized radio resource management by taking information about the surrounding radio environment into consideration.

Cooperative wireless LAN technology makes it possible to use radio resources with high efficiency by means of centralized control of the APs in order to provide carrier-grade communication quality. A radio resource management engine (RRME) that controls the AP performs centralized management of radio environment information obtained from the AP, and



(a) Example of channel judgment for signals transmitted from the same cell



(b) Example of channel judgment for signals transmitted from different cells

Fig. 1. Technology for improving spatial utilization efficiency of frequency resources.

sets suitable radio parameters for each AP so as to improve system throughput by avoiding throughput reductions caused by interference. In crowded places such as stadiums and train stations, the radio environment information acquired by each AP is collected, and the optimal radio parameters calculated by resource allocation based on the area throughput optimization policy (RATOP) algorithm [1] in the RRME are set in each AP so as to optimize the frequency and spatial resources. Consequently, the RRME can reduce interference and improve the throughput of the system (**Fig. 2**). In addition, it can prioritize the allocation of frequency bandwidth to APs carrying heavy traffic, enabling systems to be designed flexibly.

Also, by applying cooperative wireless LAN

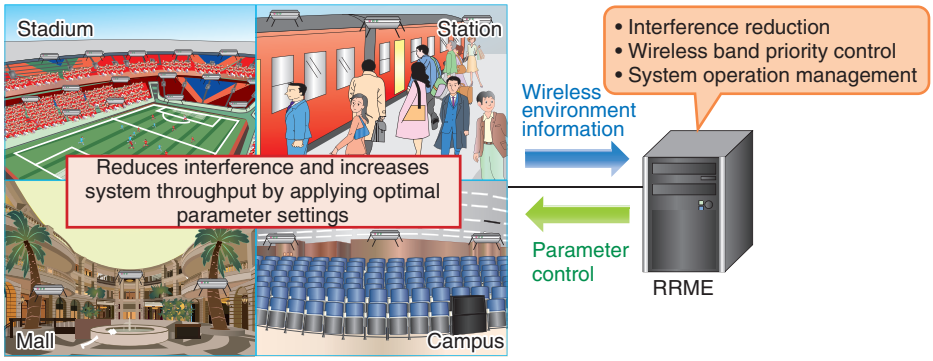


Fig. 2. Cooperative wireless LAN technology.

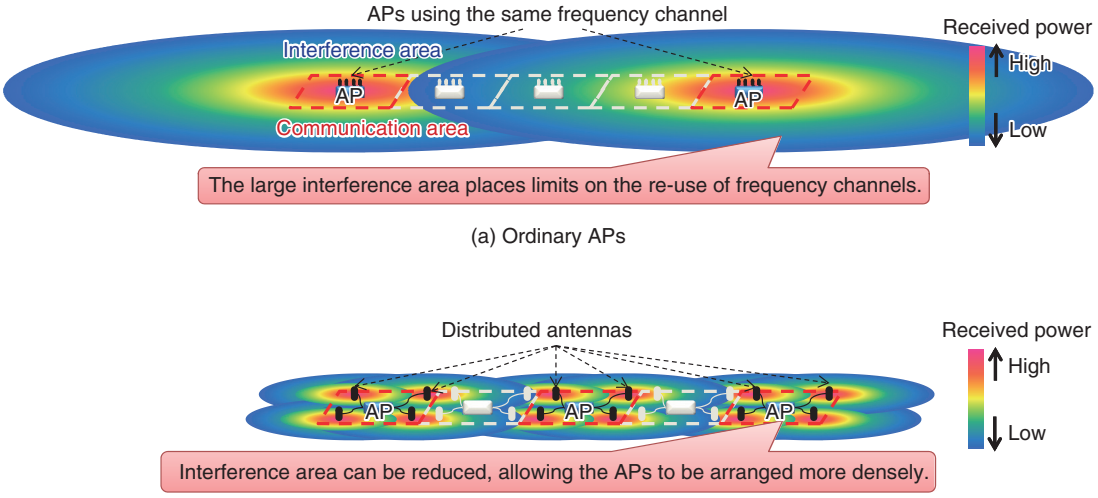


Fig. 3. Application of cooperative wireless LAN technology to distributed smart antennas.

technology to distributed smart antenna systems (D-SAS) where there are many parameters and the area design is very difficult (**Fig. 3**), it is possible to further increase the density of AP placement by optimizing the parameters of APs with D-SAS, enabling the implementation of high quality wireless LAN services with higher throughput.

4. Integration of wireless LAN into cellular networks

To accommodate increasing levels of mobile traffic, some traffic is being offloaded to wireless LANs. Since the frequency resources available for cellular communications are limited, active steps are being taken to use unlicensed frequencies in the 5-GHz band used by wireless LANs wherever possible. In 5G, a heterogeneous network is envisioned that combines multiple wireless access technologies [2], and it is expected that wireless LANs will increasingly be integrated with cellular networks as a type of wireless cell carrying user data.

To facilitate cooperation between wireless LANs and cellular networks, the 3GPP (3rd Generation Partnership Project) is standardizing LWA (LTE-WLAN Aggregation) and LWIP (LTE WLAN Radio Level Integration with IPsec Tunnel) [3] in order to implement integration at the radio access network level, allowing for seamless connections between wireless LANs and cellular networks. Additionally,

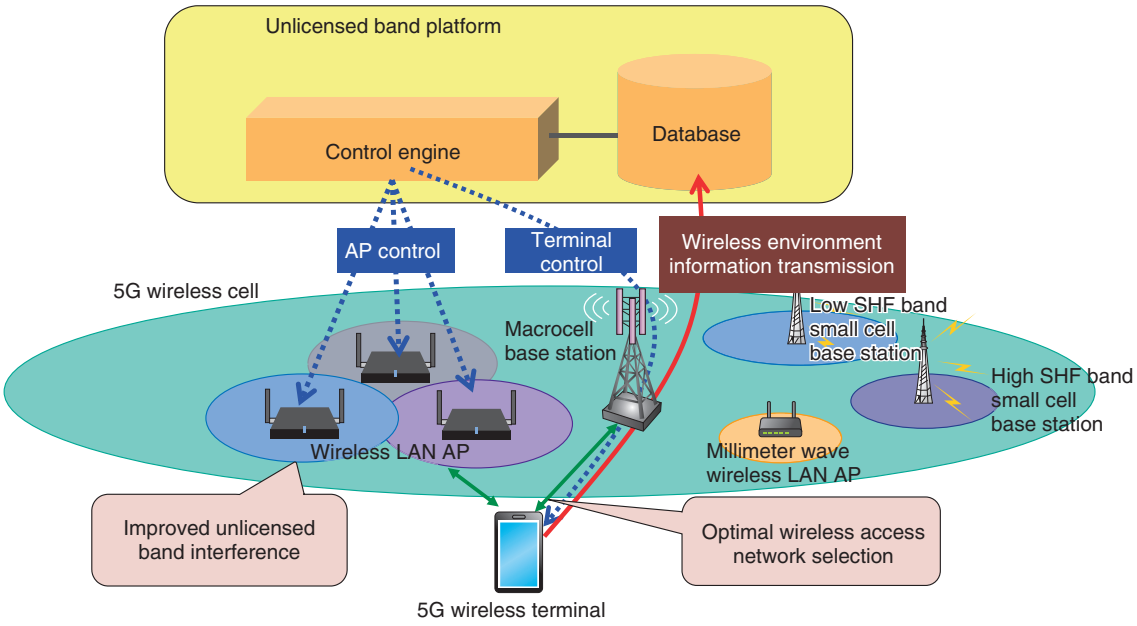


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Fig. 4. Unlicensed band platform technology.

traffic integration using multipath TCP (Transmission Control Protocol) [4] has been implemented as a method for the integrated use of wireless LANs and cellular networks without adding functionality to the cellular networks. The choice between a wireless LAN and a cellular network is set by ANDSF (Access Network Discovery and Selection Function) in 3GPP [5], which controls the selection of access networks from a cellular network. The integration of wireless LANs into cellular networks in 5G is probably based on these techniques but requires technology that can improve the user's quality of experience (QoE) in situations where wireless cells with diverse characteristics are arranged more densely.

Unlicensed band platform technology (**Fig. 4**) creates a database of information such as wireless environment information for unlicensed bands and cellular network quality information, and performs optimal control from the network side of the terminal attributes and AP settings according to a particular algorithm based on this information. Wireless resources can be used more efficiently by controlling the CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) wireless LAN access method via cellular networks. For example, to alleviate the hidden node and exposed node problems that typically occur in unlicensed band wireless systems, the platform collects information about transmission delays and the reception rate of wireless LAN beacon signals from terminals and APs. The control engine analyzes the relationships of hidden nodes and exposed nodes and improves the communication quality by optimizing the AP channel arrangement and the APs to which terminals are allocated in order to cancel out these hidden and exposed nodes [6]. With this technology, the aim is to achieve at least double the system throughput of current networks by systematically optimizing the diversity of wireless access technologies that constitute 5G (including wireless LAN) in order to improve the user's QoE.

5. Future prospects

NTT Access Network Service Systems Laboratories intends to continue developing wireless LANs as part of the social infrastructure by working on the standardization of high-efficiency wireless LANs, using cooperative wireless LAN technology to increase the system throughput, and carrying out research and development on the application of wireless LANs to 5G.

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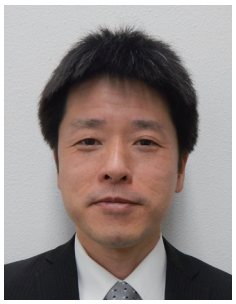

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Development Efforts on Wide Area Wireless Access to Accelerate Its Use for M2M

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Abstract

The Internet of Things (IoT), in which everything is connected to the Internet, has recently been attracting a lot of attention. NTT has been undertaking various initiatives such as research and development and field trials to realize IoT services. This article describes the requirements of IoT/M2M (machine-to-machine) services and outlines the low power wide area (LPWA) network. It also introduces a field trial utilizing the LPWA network implemented by NTT WEST and a wide-area and high-capacity radio relay system developed by NTT.

Keywords: IoT/M2M, LPWA, smart metering

1. Introduction

Machine-to-machine (M2M) communication systems have been attracting a lot of attention recently. The concept of the Internet of Things (IoT) involves connecting everything around us to the Internet [1]. The information that comes from these multiple components will be collected and analyzed in a network. This information will then be utilized as big data and is expected to lead to the creation of new value services.

In an IoT/M2M service, the terminals to be connected are dotted everywhere, and it is necessary to accommodate them efficiently. Examples are the smart metering of electric power and gas meters currently being introduced as well as agriculture sensors. Since their terminals will be widely dispersed, a wide-area but high-capacity network is necessary.

NTT WEST is working on the creation of IoT usage scenes and the development of new services in conjunction with partners in various fields. A key development is field trials with a low power wireless access (LPWA) network that adopts LoRaWAN[*1]. NTT Network Innovation Laboratories has developed a wide-area and high-capacity radio relay system for a smart metering service and has concluded tests on a liquefied petroleum (LP) gas centralized monitoring system.

2. Requirements of M2M services and overview of LPWA

M2M services clearly create different wireless loads from those of personal communication devices such as cellular phones. Most M2M service terminals cannot move independently and thus remain stationary for long periods. The typical communication environment expected for M2M services is depicted in **Fig. 1**. We assume the wireless environment has the following three requirements:

*1 LoRaWAN: An IoT communication standard formulated by members of the LoRa Alliance such as Semtech Corporation (semiconductor supplier) and IBM Corporation. LoRaWAN is a trademark of Semtech Corporation.

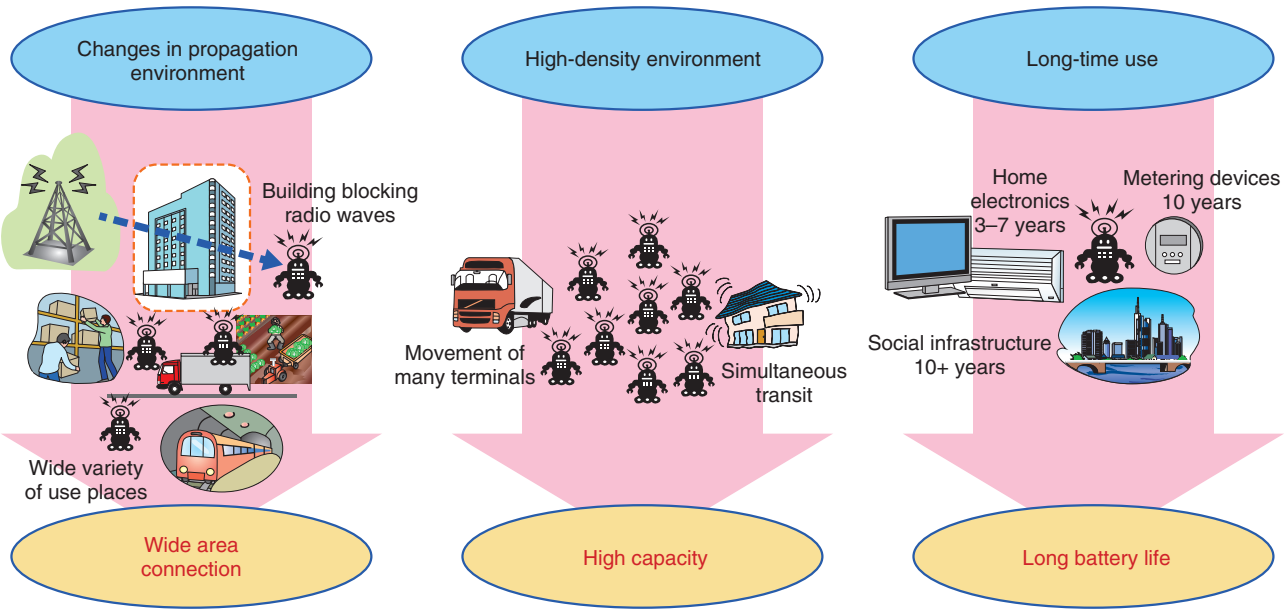

Fig. 1. Typical communication environment expected for IoT/M2M services.

1) Wide area: A terminal cannot be moved easily even if its wireless environment is inadequate. For example, the access point and terminal may not have a direct line of sight. Thus, communication must be established even in difficult circumstances.
2) High capacity: It is assumed that each access point may have to support many terminals that are likely to transmit simultaneously after a disaster. Therefore, it is necessary to be able to communicate with many terminals.
3) Long battery life: It is assumed that a terminal may have no AC (alternating current) power supply, or that some terminals will be hosted by the social infrastructure so that their operation will be managed over a decade-long period without replacing the battery. Therefore, a long battery life must be achieved while maintaining low power consumption.

To satisfy these requirements, wireless communication standards have been formulated to suit various usages [2]. For 3GPP (3rd Generation Partnership Project), standardization of Cat. NB1 and Cat. M were completed in 2016 as IoT standards, and development is now underway for their commercialization. LPWA using the sub-gigahertz band, which is the unlicensed band, is beginning to be used mainly in Europe and the United States. Since the sub-gigahertz band is lower than the 2.4-GHz band used in wireless LANs (local area networks), it has less attenuation and offers high diffraction performance, so it can cover a wide area with one base station. It can also achieve low power consumption of terminals and can accommodate many terminals. LoRaWAN [3] and Sigfox [4] are major LPWA networks currently being widely used in Europe. They are used for infrastructure monitoring and other services. In Japan, the Association of Radio Industries and Businesses (ARIB) issued standard STD-T108 [5] for the 920-MHz band as an unlicensed band in 2012. It is used by Wi-SUN (Wireless Smart Utility Network). NTT Network Innovation Laboratories has developed a 920-MHz band radio relay system for a smart metering service. The characteristics of the major LPWA networks are described below and summarized in **Table 1**.

(1) LoRaWAN

LoRaWAN achieves long distance communication of up to 2 km by using a variable transmission rate from 0.3 to 50 kbit/s. In addition, it offers high accommodation performance by multiplexing signals of different transmission rates using chirp spreading. Three protocols, Class A to C, are prescribed, but Class A is the main type being considered. Class A achieves a battery life of more than 10 years by eliminating the periodic reception operation of the terminal and sending downlink data together with the uplink response. Since downlink communication is

Table 1. Comparison of LPWA networks.

	LoRaWAN (Class A)	Sigfox	Radio relay system (NTT)
Transmission speed	0.3–50 kbit/s	100 bit/s	10 kbit/s
Transmission distance*1	About 2 km	About 3 km	About 1 km
High capacity technology	Multiplexes signals by using chirp spreading method	Multiplexes signals by randomly hopping frequencies	Reduces control signal by managing transmission timing
Response time	Uplink: several seconds Downlink: best effort*2	Uplink: several seconds Downlink: best effort*2	Uplink/Downlink: several seconds
Battery life	More than 10 years	More than 10 years	More than 10 years
Suitable service	Mainly uplink, or control only by downlink	Mainly uplink and very low frequency and low data volume	Bidirectional comm. with high response with similar uplink and downlink frequency

*1 Base station height: 30 m; Terminal installed outdoors; Deterioration rate: 0.1%
*2 Downlink data sent with response of uplink

best effort, it is assumed that it will be applied to services that mainly collect sensor information (such as infrastructure management, logistics, and agriculture) and services that realize control only through downlink communication.

(2) Sigfox

Sigfox achieves long distance communication of about 3 km by lowering the transmission rate to 100 bit/s. It achieves high accommodation performance by randomly hopping frequencies at the time of transmission and by multiplexing a large number of uplink data flows in the same frequency band. Furthermore, similar to Class A of LoRaWAN, the downlink communication is best effort, thereby realizing low power consumption of terminals. It is assumed that it is applied to services using uplink communication and very low frequency and low data volumes (such as state monitoring).

(3) Radio relay system

The radio relay system developed by NTT Network Innovation Laboratories is a specification guaranteeing the downlink response time. For this reason, it will be used for bidirectional communication, in which the frequencies of uplink communication and downlink communication are about the same and high response performance is required (services include smart metering, equipment control, etc.).

The communication requirements of M2M services are diverse. For example, for infrastructure management and environmental monitoring, the main traffic consists of uplink communication that collects sensor information. Also, in applications where a delay of more than several seconds is allowable, it is possible to perform downlink communication by responding to periodic uplink communication. Meanwhile, for smart metering, high-response bidirectional communication is necessary in order to acquire meter information, determine the state, and control the meter. To satisfy the communication requirements of these diverse M2M services, it is important to select and use the appropriate wireless system for each service from among the wireless systems available.

3. NTT WEST field trial

In these trials, NTT WEST provides an LPWA network that uses LoRaWAN, whose specifications have been formulated and promoted by the LoRa Alliance, with which approximately 400 IoT-related companies are affiliated [6]. A depiction of the trials is shown in **Fig. 2**. The trial partners prepare devices, sensors, platforms, and other elements on their own and connect them to the LPWA network provided by NTT WEST. The trials are being conducted in order to verify functions and operational requirements for IoT services on LoRaWAN and to create usage scenes of IoT services and verify business possibilities. Semtech Corporation (USA), which is in the process of formulating Japanese standards of LoRaWAN, is providing information on the outline and technical requirements of LoRaWAN.

The first trial was conducted in Yasu City, Shiga Prefecture. The trial implemented agricultural remote control systems such as those for water supply management, water level, and temperature control utilizing multifunctional automatic water faucets. Due to large-scale farming and conversion of single cropping fields (rice paddies etc.) into multiple cropping

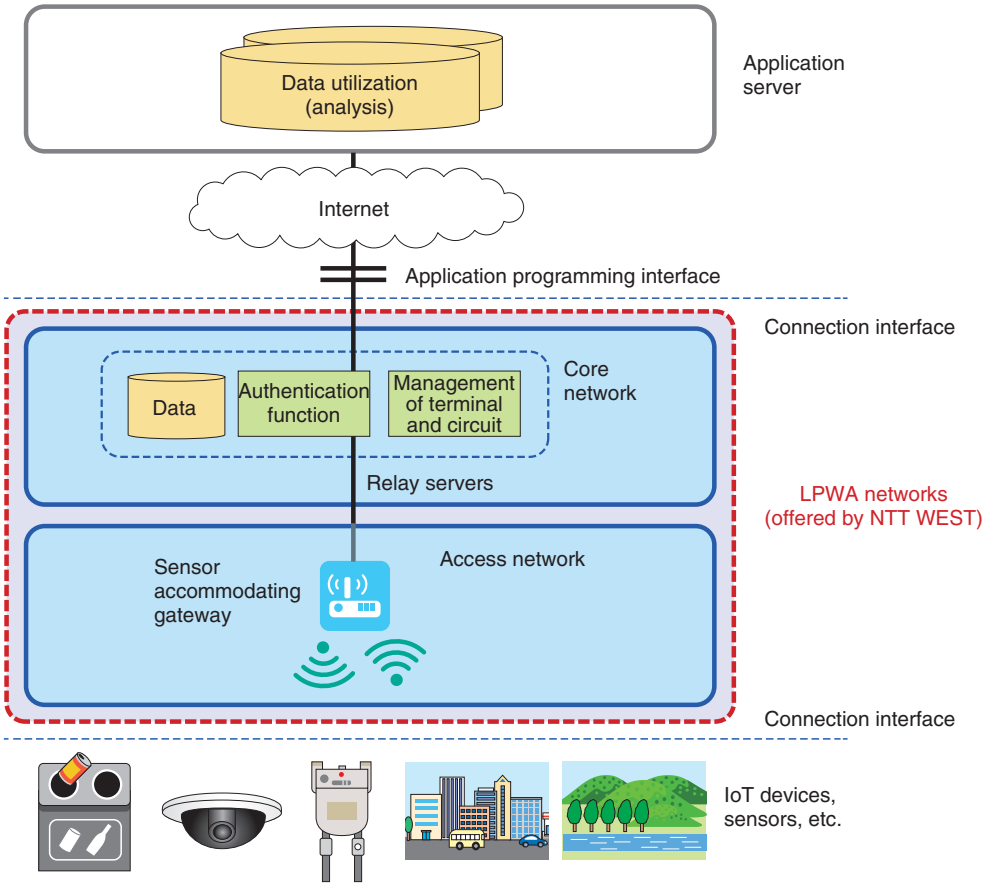

Fig. 2. Elements of field trial.

fields, labor saving in water management and demand-led water use have become necessary. In response to this situation, the feasibility of water management to suit different forms of agricultural management will be investigated. The intent of the communication carrier is to verify radio wave propagation characteristics and power saving compared to existing communication methods such as Wi-Fi*2.

4. Radio relay system suitable for smart metering

Smart metering systems that can automate monthly meter reading and enable visualization of electricity consumption in conjunction with HEMS (home energy management systems) are now being introduced by various electric power companies [7]. A gas smart metering system for the automation of gas meter reading and visualization of gas usage is being actively targeted. The U-Bus Air system has been standardized by the nonprofit organization Japan Utility Telemetering Association in order to achieve a gas smart metering system [8].

In response, we have developed a wide-area and high-capacity IoT/M2M radio relay system that suits the gas smart metering system. The system configuration is shown in **Fig. 3**. The system uses a multi-layer relay system; the lower layer utilizes the user network to connect directly with the user terminal such as the gas meter, and the relay layer is our developed radio relay system. The system offers a flexible area design in conjunction with the user network. Furthermore, since a large number of user terminals can be aggregated, it is possible to economically connect more user terminals to the server with one public line such as 3G or LTE (Long Term Evolution).

However, the following problems with the relay layer system need to be solved in order to satisfy the communication requirements of IoT/M2M.

1) Compatibility of a broadening area and high

*2 Wi-Fi is a registered trademark of Wi-Fi Alliance.

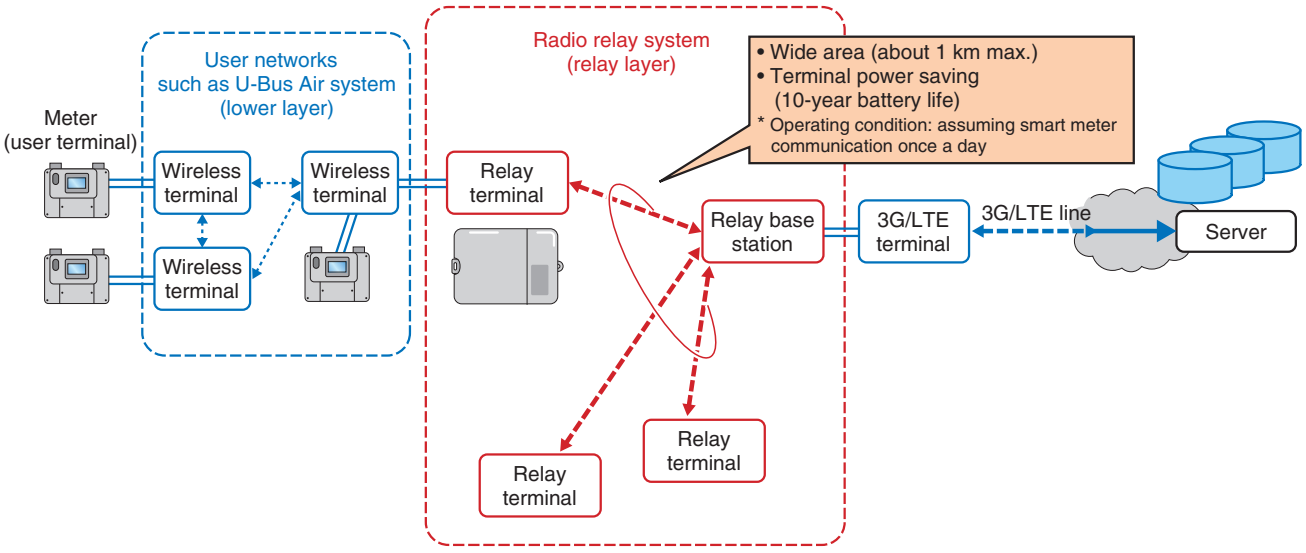

Fig. 3. System configuration of radio relay system.

capacity accommodation

2) Power savings from the relay terminals

In order to broaden the area of the relay layer, it is necessary to lower the transmission speed. The amount of data that can be transmitted decreases due to the lower transmission speed, so the accommodation capacity of the relay layer decreases. Furthermore, transmission and reception times of the relay terminal will increase due to the reduced transmission speed, which will increase the power consumption. For that reason, it is necessary to strike the right balance between a wide area, high capacity, and low power consumption.

Intermittent operation is required in order to maximize power savings. The radio relay system that performs intermittent operation normally needs to send and receive control signals in order to maintain synchronization between the relay base station and the relay terminal. However, as the number of relay terminals increases, interference due to control signals from the relay terminal increases. To avoid this interference, it is necessary to reduce the transmission frequency of the control signal from the relay terminal. However, if the transmission frequency of control signals is reduced, the transfer delay will increase and fewer applications will be supported.

In order to reduce the transmission frequency of the control signal without degrading the transfer delay, the radio relay system uses a method that enables the relay base station to manage the transmission timing of all subordinate relay terminals. As a result, interference can be reduced, so throughput is improved, as is capacity. Furthermore, since the transmission frequency of the control signal decreases, power saving of the relay terminal becomes possible.

Under the assumption that each user terminal generates communication traffic of 1 kbyte per day, each relay base station can support up to 2000 user terminals. Furthermore, each relay terminal can have a battery life of 10 years. As a result, the radio relay system can satisfy the requirements of the LP gas centralized monitoring service (wide area with low user density) and the urban gas smart metering service (with many gas meters). In addition to gas smart metering, it is also being applied to other M2M services that require interactivity such as social infrastructure control.

5. Future overview

NTT WEST is planning to consider the usage scenes of the LPWA network in various IoT services based on the network technology know-how obtained from the field trials. NTT Network Innovation Laboratories will continue its research and development activities to further enhance the wide area, high capacity, and power savings of radio relay systems, in order to enable them to be shared by various M2M services beyond gas smart metering (**Fig. 4**).

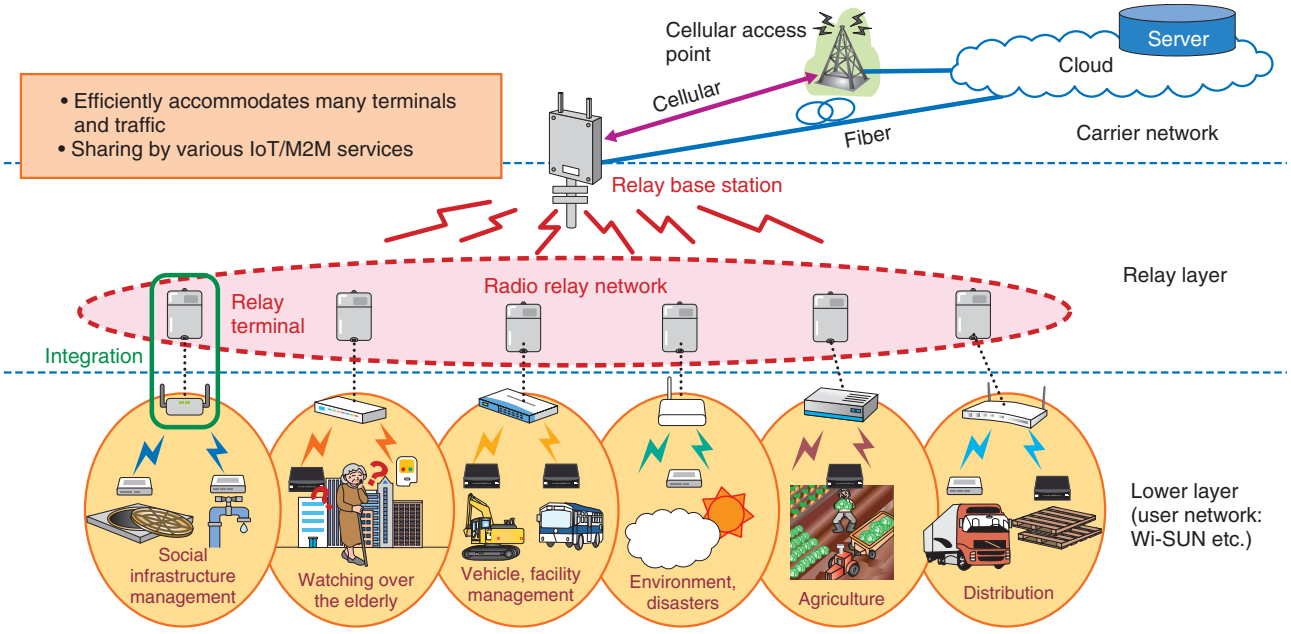

Fig. 4. Sharing by various M2M services.

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A Study on Wireless Technologies to Improve Communication Performance by Utilizing Multi-frequency Bands

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Abstract

The wireless access network for the Internet of Things must offer ultra-broadband communication in order to transfer broadband data such as video data to be displayed for user assistance. High-reliability and low-latency communication is also necessary to remotely and automatically control the instruments of vehicles and robots in real time. This article describes our study on wireless technologies designed to achieve ultra-broadband, high-reliability, and low-latency communications by utilizing new frequency bands.

Keywords: ultra-broadband, high-reliability/low-latency, multiband

1. Introduction

The Internet of Things (IoT) is expected to enable numerous applications including machine-to-machine (M2M) narrowband applications such as smart metering and environment sensing. It is also expected to enable M2M broadband applications such as utilization of stored video data for maintenance of outdoor infrastructures, as well as vehicle control and M2M control applications such as remote control of instruments. For example, to analyze driving data captured by cars as big data in cloud servers, an ultra-broadband wireless access system is necessary to achieve sufficiently short data transfer speeds. Moreover, high-reliability and low-latency communication will be required for autonomous vehicle driving systems that can respond to the environment surrounding the vehicle and control the vehicle in real time. This article describes a study on wireless technologies that promise the ultra-broadband, high-reliability, and low-latency communication desired for the IoT.

2. Ultra-broadband wireless access system

In this section, we explain the use cases, frequency band details, and specifications of the ultra-broadband wireless access system.

2.1 Use cases

Examples of leveraging ultra-broadband data are considered below and depicted in **Fig. 1**.

(1) Batch transfer of log data: broadband log data such as driving data of cars and video data recorded outdoors are transferred to the cloud network.

(2) Gathering information on the surrounding environment: information needed for automatic vehicle and robot control such as three-dimensional (3D) maps and pedestrian positioning information is provided from cloud servers just in time.

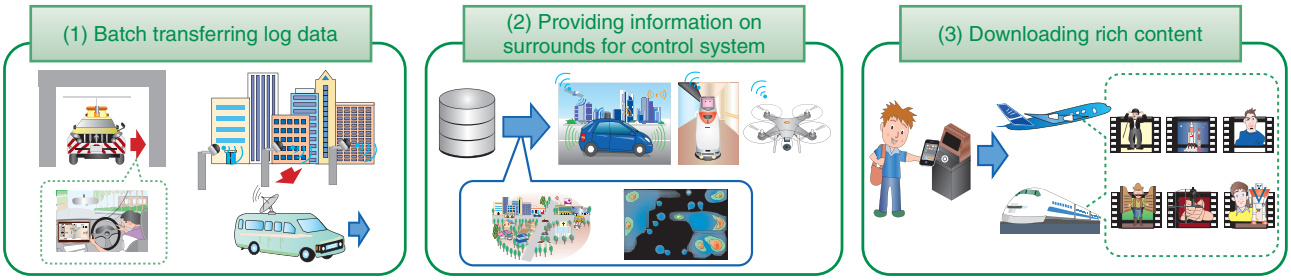


Fig. 1. Example of utilizing ultra-broadband data.

(3) Downloading rich content: rich content such as movie data and games is downloaded to user mobile devices when needed so that users can enjoy it without accessing the Internet, for example, on planes.

In these use cases, log data and database information saved on disk must be exchanged between the cloud database and the user anywhere and anytime through wireless networks. This requires disk-to-disk (D2D) communication, which until now has mainly been used to back up data on hard disks, between multiple devices and instruments that are far from each other through wireless networks. We set the target wireless transmission speed for this new D2D communication to 100 Gbit/s, which is 10 times faster than Wi-Fi*1.

2.2 60-GHz unlicensed band

We have adopted the 60-GHz unlicensed band as the frequency band for wireless transmission speeds of 100 Gbit/s. This unlicensed band has the advantage of easily forming ultra-high-speed wireless access links because the wireless access points can be placed freely, and the wireless function can be installed on any device without a license. The characteristics of the 60-GHz band are described below.

(1) Broadband bandwidth of more than 1 GHz
(2) High antenna directivity (antenna size is several centimeters)
(3) Short communication range (greater propagation loss and shielding than the microwave band)

The large bandwidth makes it possible to achieve the maximum transmission speed of 11.4 Gbit/s with a single stream [1]. For reference, the transmission speed of Wi-Fi is less than 1 Gbit/s [2]. By applying multiple-input multiple-output (MIMO) techniques, a transmission speed of 100 Gbit/s can be expected.

While the short communication range results in smaller communication coverage than that of the microwave band, the high antenna directivity enables interference signals from other stations to be reduced by both propagation loss and antenna directivity. Therefore, a stable wireless transmission speed of 100 Gbit/s is expected regardless of the other stations.

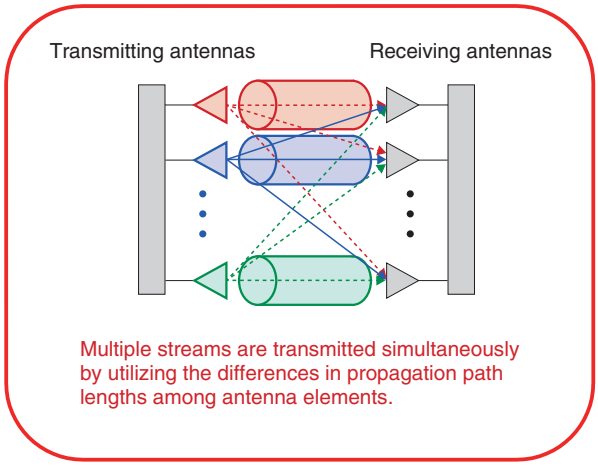


Fig. 2. System image: using short range MIMO techniques.

To achieve a transmission speed of 100 Gbit/s in the 60-GHz band, more than ten streams must be simultaneously transmitted via space division multiplexing because the maximum transmission speed with a single stream is 11.4 Gbit/s. We consider short range MIMO to be one of the most promising approaches to meet the requirements. The system image is shown in **Fig. 2**.

The MIMO technique is often used in multipath-rich environments, and with space division multiplexing, the number of streams can equal the number of

*1 Wi-Fi is a registered trademark of Wi-Fi Alliance.

Table 1. Standards for 60-GHz band.

	(For reference) LTE-advanced	(For reference) TransferJet	(For reference) IEEE802.11ac	IEEE802.11ad	IEEE802.15.3e	IEEE802.11ay
Frequency band	800 MHz/1.5 GHz /1.7 GHz/2 GHz /3.5 GHz	4.5 GHz	5 GHz	60 GHz		
Channel bandwidth (Without channel bonding)	1.4, 3, 5, 10, 15, 20 MHz	560 MHz	20 MHz	2.16 GHz		
Channel bonding (Channel bandwidth)	Available (*1)	Not available	Available (Up to 20 MHz x 8)	Not available	Available (Up to 2.16 GHz × 4)	Available (To be discussed)
MIMO (Number of transmitted streams)	Available (Up to 4)	Not available	Available (Up to 8)	Not available	Available (Up to 16)	Available (To be discussed)
Transmission speed	Up to 375 Mbit/s (*2)	560 Mbit/s	866 Mbit/s (*3) (Up to 6.93 Gbit/s)	Up to 4.6 Gbit/s (*4)	11.4 Gbit/s (*5) (Up to 138 Gbit/s)	About 100 Gbit/s (To be discussed)
Main use cases	Cellular	Close proximity communication	Spot	Short range	Close proximity communication (Higher speed than TransferJet)	Close proximity communication; Short range; Backhaul
Progress in standardization activities	Completed	Completed	Completed	Completed	To be completed in 2017	To be completed in 2019

*1: Carrier aggregation is also possible.
*2: Specifications of Premium4G services of NTT DOCOMO in September 2016.
*3: The user terminal is a smartphone, assuming that the number of antennas is 2 and channel bandwidth is 20 MHz x 4.
*4: When single-carrier physical layer is used.
*5: When single streams are transmitted.

multipath waves. However, general MIMO techniques cannot support more than ten streams because it is difficult to ensure more than ten multipath waves regardless of the propagation environment.

The short range MIMO technique is used in very close proximity environments in which the direct propagation path lengths between transmitter and receiver antennas are different from each other. The multiple streams can be simultaneously transmitted on direct paths by utilizing different phases on the propagation paths. When the linear antenna array is adopted as the MIMO antenna configuration, the carrier-to-interference ratio (CIR)[*2] degrades as the number of multiple streams increases. Moreover, the CIR strongly depends on the relative positioning of the transmitter and receiver, so the CIR significantly degrades when the positioning is not optimum.

To solve these problems, we are studying the use of two-dimensional antenna arrays and multiple MIMO configurations, the optimal design of those configurations, and adaptive selection of the MIMO configuration depending on the number of multiple streams and the positioning relationship at the time of use.

2.3 Standard specifications in 60-GHz band

The standard specifications in the 60-GHz band are introduced in this section. The key standards are listed in **Table 1**. IEEE802.15.3e is the next-generation standard specified by the Institute of Electrical and Electronics Engineers (IEEE). It has higher transmission speeds than TransferJet[*3] [3], and its target use is close proximity communication. IEEE802.11ad offers a higher transfer speed than Wi-Fi [2], and IEEE802.11ay is the next-generation standard with higher transmission speeds than IEEE802.11ad [4]. The standard IEEE802.11ad was completed in 2013, but IEEE802.15.3e and IEEE802.11ay are still in progress. All standards adopt the channel bandwidth of 2.16 GHz. Channel bonding[*4] and multiple stream transmission (with a MIMO function) will be standardized in IEEE802.15.3e and IEEE802.11ay. NTT

*2 CIR: Ratio of the received powers of desired signal to interference signal.
*3 TransferJet: Short range wireless technologies for close proximity communication. TransferJet is a trademark licensed by the TransferJet Consortium.
*4 Channel bonding: Combines multiple channels and transmits them as one.

Network Innovation Laboratories is active in contributing to IEEE802.15.3e and has proposed the MIMO function to achieve a transmission speed of 100 Gbit/s and a faster link setup of 0.2 seconds.

3. High-reliability and low-latency communications

The IoT is expected to support various social activities. Thus, high-reliability and low-latency communications will be demanded from the viewpoint of productivity and efficiency, especially in industrial fields. For monitoring and control systems in factories for example, the transfer of application data between servers and devices should be completed within the required time periods in order to acquire real-time sensing information from the field and to give appropriate feedback for control.

Proprietary industrial Ethernet specifications such as Ethernet for Control Automation Technology (EtherCAT)[*5], which combines a standardized physical layer and a proprietary MAC (media access control) layer, are available. Another approach that is progressing is Time-Sensitive Networking, which extends the present Ethernet specifications. In the automotive industry, automotive Ethernet standards are being discussed such as IEEE 802.3bw [5] for broadband low-latency communication for vehicle harnesses. Accordingly, wireless communications should match the expectations of high-reliability and low-latency communications.

3.1 Advanced ITS

The development of an advanced intelligent transport system (ITS) is continuing in Japan, and industry, government, and academia are promoting the development of autonomous vehicle driving technologies for 2030 [6]. Any autonomous vehicle driving system requires cooperative technologies such as predicting events using vehicle-to-vehicle/roadside wireless communications and artificial intelligence, as well as self-driving technologies such as collision avoidance using on- and off-board vehicle sensors. One cooperative ITS technology that has already been launched is the safe driving support service called ITS Connect, which uses the 760-MHz band in Japan.

In North America and Europe, a similar DSRC (Dedicated Short Range Communications) service will be introduced in the 5.9-GHz band in the next several years. Both of these systems adopt IEEE 802.11p wireless local area network (LAN) standards [1] for vehicle-to-vehicle/roadside communications.

Meanwhile, the development and standardization of cellular communication systems called LTE (Long Term Evolution) V2X [7] are also being discussed. Since LTE V2X can utilize the existing LTE cellular infrastructure, additional investment is minimal.

As shown in the case of the autonomous driving systems, a variety of wireless communication technologies in both licensed and unlicensed bands is being studied. Of course, existing wireless LANs are also promising radio access technologies (RATs) for these systems. The characteristics or performance of wireless communications depends on the radio environments such as the frequency band, the RAT adopted, network infrastructure availability, terminal device position, and radio channel conditions such as whether there is interference. Here, it is assumed that access point 1 with RAT-a running on band A and access point 2 with RAT-b running on band B are available (**Fig. 3**). Even if RAT-a has good performance (such as transmission speed or latency performance) as a RAT, its actual communication performance (such as throughput) will fall dramatically due to the presence of many terminals, heavy interference, or obstacles in the channel. In contrast, RAT-b offers lower ultimate performance but is more consistent. This suggests that establishing more reliable radio connections requires the optimal RAT to be selected from several candidates according to the multiband radio environments.

3.2 Multiband propagation evaluation technologies

NTT Network Innovation Laboratories is promoting the study of multiband propagation evaluation technologies and applied wireless access technologies. An overview is shown in **Fig. 4**. First, the radio propagation characteristics for each band (channel) are evaluated by simulating radio intensity and arrival time of multipath waves. For this, we consider 3D data of buildings and objects around the access points and terminal devices (Fig. 4(a)). Then the propagation results are combined to permit network simulations of different RATs for each band. These can evaluate overall system parameters such as processing latency and packet loss characteristics, taking into consideration the connection density of devices and other interference effects (Fig. 4(b)). These evaluation results make it possible to design multiband

*5 EtherCAT is a registered trademark and patented technology, licensed by Beckhoff Automation GmbH, Germany.

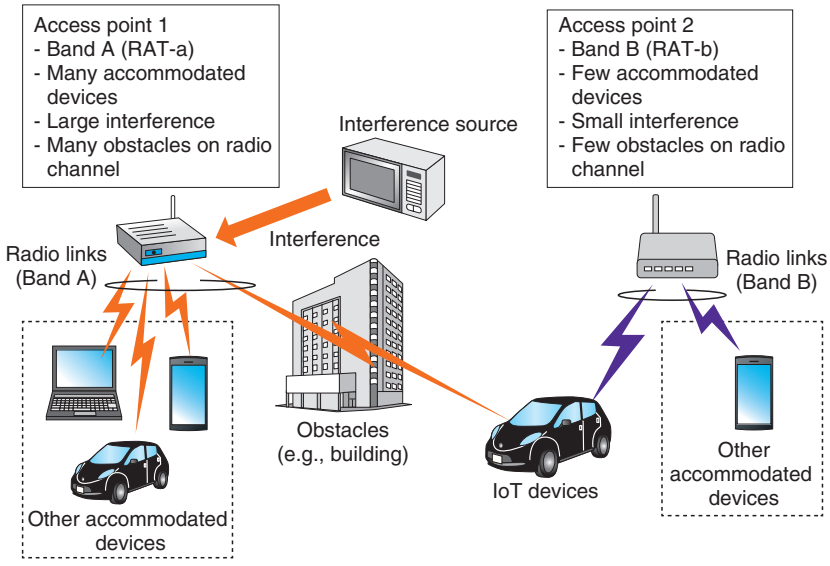
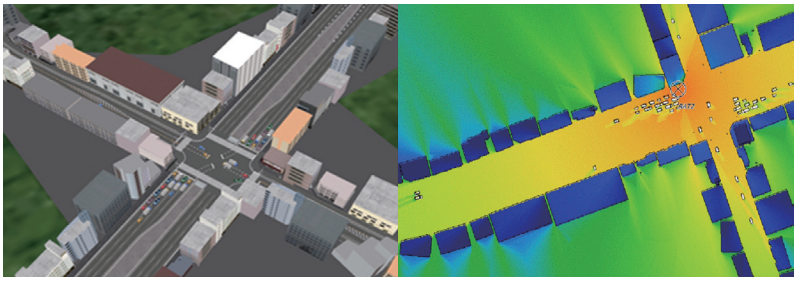
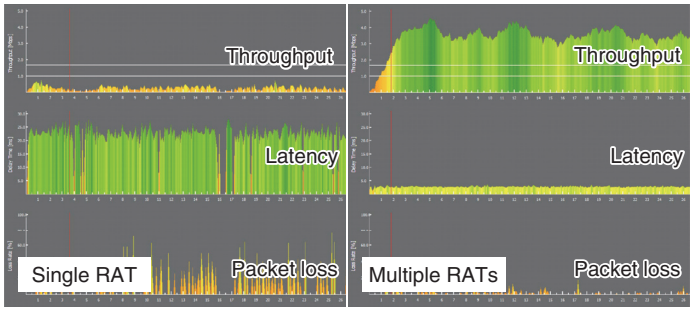


Fig. 3. Multiband utilization approach for high-reliability and low-latency communication.



(a) 3D model around intersections (left) and simulated results of radio intensity (right)



(b) Combined simulation for radio propagation and network performance

Fig. 4. Multiband propagation evaluation technologies.

wireless systems that make maximum use of multiple bands and the diversity in available RATs.

4. Conclusion

This article described work on wireless network technologies to realize ultra-broadband, high-reliability, and low-latency communication for the future

IoT. For ultra-broadband capacity, short range MIMO techniques are being applied to achieve the wireless transmission speed of 100 Gbit/s in the 60-GHz unlicensed band. The effective use of multi-frequency bands and RATs is being investigated to achieve high-reliability and low-latency communication, and a study is underway on multiband propagation evaluation technologies and applied wireless access technologies.

In the future IoT, both use-case scenarios and requirements will become more diversified. We aim to establish wireless technologies to meet these requirements.

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An Interpersonal Sentiment Quantification Method Applied to Work Relationship Prediction

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Abstract

For a business to be successful, it is important for people in the business to consider how other people feel, that is, to consider *interpersonal sentiment*. Our research goal is to quantitatively predict the strength of interpersonal sentiment by analyzing a small amount of data on office employees, for example, their gender or age group, and data on events such as giving positive feedback on work done and sexual or power harassment without directly asking someone about their change in sentiment. In this article, we propose an interpersonal-sentiment-changing model for this quantification and propose two new analysis methods for developing prediction formulas. These methods can be used even if 90% of data is missing and in environments in which it is difficult to gather data in a comparatively short time. We also implement two visualization systems to predict how interpersonal sentiment changes for each event based on actual office data.

Keywords: interpersonal-sentiment prediction, sparse regression, factor regression, visualization, missing data, personal relationships in offices

1. Introduction

For a business to be successful, it is important for the people involved to consider a mental model for work relationships. Let us consider one office scenario (**Fig. 1**). There are two people, a boss (Boss) and a subordinate (Mike). The relationship between the two is normally positive. One day, Boss yelled at Mike in front of everyone. Boss believed that being strict is important for guiding subordinates and gains a sense of superiority by acting in this manner toward Mike. However, Mike feels he is being harassed and feels contempt toward Boss. Thus, Boss and Mike have opposite interpersonal sentiments, and this affects the other people in the office. These unmatched emotions can negatively affect relationships if nothing is done. Therefore, it is important to make Boss aware that Mike feels contempt toward him in these instances. In other words, Mike's interpersonal sentiment for Boss can be predicted, and a function is needed that conveys Mike's sentiments to Boss.

In this article, we describe a way to predict the strength of interpersonal sentiment quantitatively. We statistically predict the strength of interpersonal sentiment by using as little data as possible about office employees, for example, just their gender or age group, without directly asking them whether or not their sentiment has changed. We describe related work and our motivation for this research in section 2. In section 3, we define the interpersonal sentiment discussed in this article. We give an overview of our approach in section 4. In section 5, we explain the proposed interpersonal-sentiment-changing model, and in section 6, we describe how to select investigation

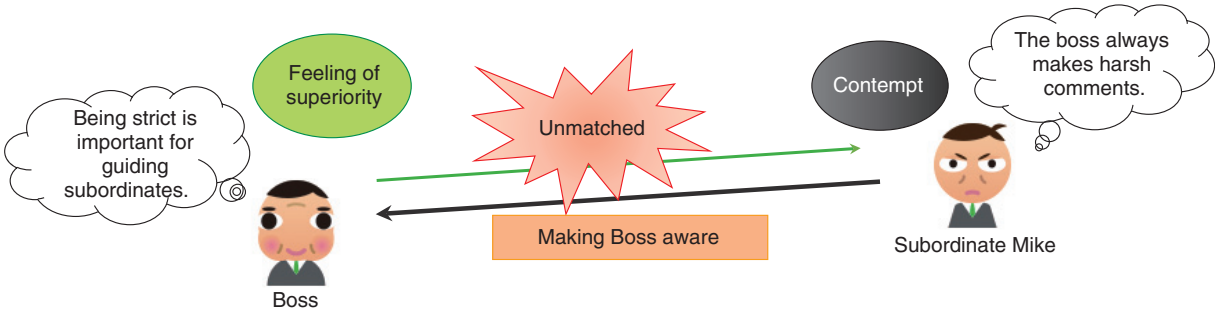


Fig. 1. One office scenario.

items in actual environments through statistical analysis using large-scale data. In section 7, we derive prediction formulas using data from target offices. We evaluate and discuss the estimation accuracy of interpersonal sentiment using these analysis methods. We explain two types of visualization systems for office managers and for office employees in section 8. Finally, we give concluding remarks in section 9.

2. Related work and motivation for this research

In order for businesses that focus on human relationships to succeed, the businesses cannot ignore mental information such as whether people like or dislike something. They also must focus their efforts on a wide range of people (e.g., office employees, students, and teachers) and develop practical interpersonal-sentiment-estimation tools. Interpersonal sentiment has been investigated from two viewpoints, psychological and engineering, and extensive research has been done on the effects of interpersonal sentiment on behavior in personal relationships, for example, parent-child interactions, conflict, negotiation, and leadership. A framework that can account for current findings and guide future research, called the emotions-as-social-information model, has been proposed [1, 2]. Many psychology studies have been conducted from micro- and internal viewpoints and have involved fragmentary trend analysis limited to female students or senior citizens.

There has also been extensive engineering research involving data analysis for automatically recording human behavior using sensors or radio frequency identifiers and web social data [3–5]. Emotion estimation has been investigated using voice and image data analyses [6–8]. Such research goals can be achieved through engineering technology with which people can superficially judge their own emotions by sight. That is, if a person smiles but is inwardly angry, engineering analysis is adequate in only detecting the smile. Thus, many engineering studies have been carried out from macro- and superficial viewpoints. However, the aspect of psychology has not been used in the engineering field.

As mentioned above, we aim to be able to use mental information in applications targeted for humans. However, many psychology studies involved have focused on trend analysis rather than quantification, so psychology research results are difficult to use in applications involving the controlling of human relationships in the workplace. There is currently a wide gap between psychology research and engineering research. We have combined psychology with engineering using statistics, and we use these statistics for sentiment quantification.

3. Interpersonal sentiment

In this article, we describe interpersonal sentiment as the way another person/other people feel. Interpersonal sentiment changes depending on events, and the sentiment has two main aspects, negative and positive. In psychology, interpersonal sentiment consists of several factors [9–13]. We focus on three such factors: like-dislike, respect-contempt, and relief-fear because they greatly concern office managers with regard to their subordinates.

4. Approach for predicting strength of interpersonal sentiment

We applied a four-step approach (explained below) and used the application candidates indicated in **Fig. 2**. With these candidates, we first clarify the interpersonal sentiment of one-to-one (1:1) relations in single and bi-directions. The application candidates

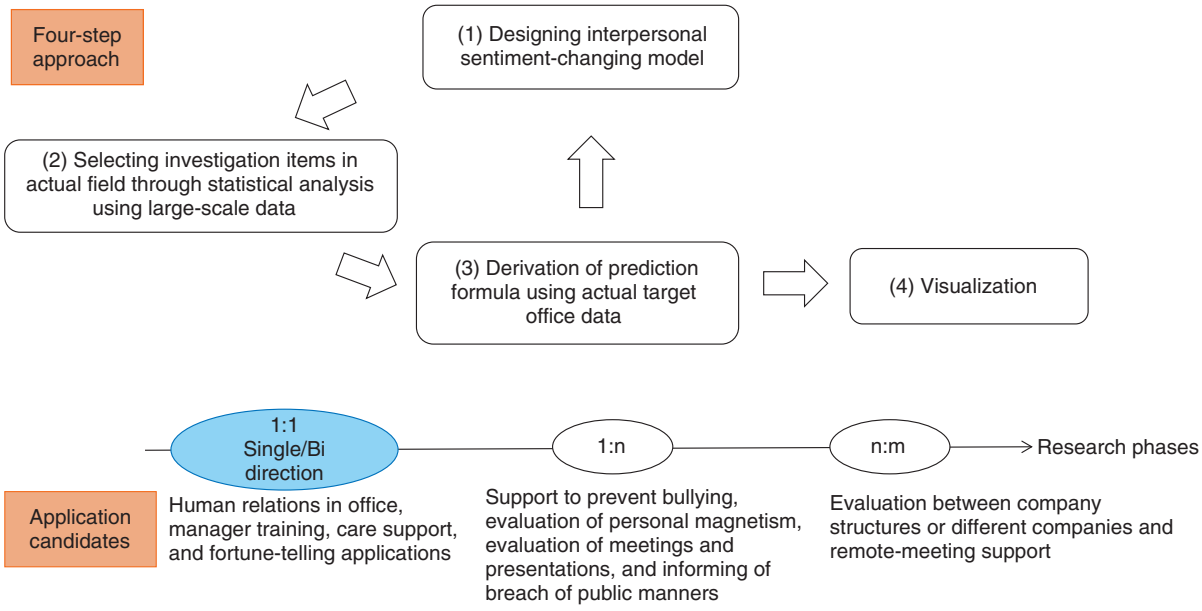


Fig. 2. Approach used in sentiment quantification.

are human relations in offices (target for this article), manager training, care support, and fortune-telling. The next phase involves clarification of interpersonal sentiment in one-to-many relationships (1:n), for example, teacher to students. The application candidates for this type of relationship are prevention of bullying, evaluation of personal magnetism, evaluation of meetings or lectures, and notifying people of breaches in public manners. In the final phase, the approach is expanded to many-to-many relationships (n:m), for example, department-to-department relations. The application candidates are evaluations between company structures or different companies, and remote-meeting support. In this study, we targeted the 1:1 relation of the first phase.

It has not been previously clarified which data are needed to predict the strength of interpersonal sentiment in actual work relationships. We used a statistical method in a top-down approach to identify what types of data are needed for the sentiment prediction. In this approach, we list every conceivable type of data and select from those that are useful (variables) using regression analysis. We follow the following four steps. Steps (1) to (3) are repeated several times to increase the prediction accuracy.

(1) Design of interpersonal-sentiment-changing model
(2) Selection of investigation items in actual offices through statistical analysis using large-scale data
(3) Derivation of prediction formula using actual target office data
(4) Visualization on personal computers (PCs) and smartphones

These steps are described in more detail in the following sections.

5. Design of interpersonal-sentiment-changing model

We developed a model reflecting how our interpersonal sentiments are constructed. A conceptual diagram for changing interpersonal sentiment depending on the event is shown in **Fig. 3**. The x-axis is the flow of time, and the y-axis is the strength of interpersonal sentiment y. In Fig. 3, we use the interpersonal sentiment factor of respect-contempt as an example. The strength of the sentiment is on a 5-point scale, where 1 represents great respect and 5 represents great contempt, with 3 being neutral.

Let us consider the scenario using Fig. 1. Two people, Boss and Mike, a subordinate, are in an office. They initially respect each other. When event A occurs in which Boss yells at Mike in front of everyone, Mike feels bad due to Boss' action (stage 1). The strength of interpersonal sentiment regarding respect-contempt before this event $y(t_A)$ decreases from 2 (respect) to 4 (contempt) after the event

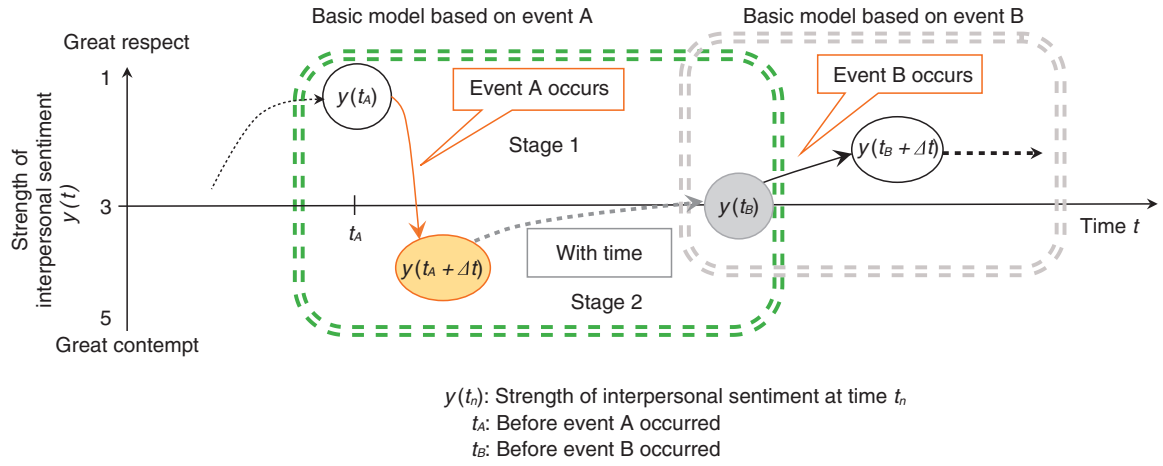


Fig. 3. Interpersonal-sentiment-changing model.

$y(t_A+\Delta t)$. However, with time, we usually cool down and return from contempt to a more positive sentiment, 3 (neutral), before the next event (event B) $y(t_B)$ (stage 2). In other words, Mike's sentiment toward Boss becomes stable over time. After a certain period, event B occurs with similar results to event A. Thus, we argue that stable interpersonal-sentiment results by repeating the combination of stages 1 and 2 several times. Thus, we consider the basic model as consisting of two stages depending on the event.

The prediction goals are as follows.

(1) Small number of variables needed for prediction

We use a regression formula for the interpersonal-sentiment prediction. The regression formula developed using general regression analysis has many variables. Therefore, when we calculate the prediction using the regression formula, we need to prepare the data for these variables. When considering the load for the formula user, we have to reduce the number of variables. Our goal is to have fewer than ten variables.

(2) Estimation accuracy

The estimation accuracy of interpersonal-sentiment strength should be approximately 60–70% with a +/– 0.5 margin of error when using a 5-point Likert scale to rate the three factors mentioned in section 3. We preliminarily interviewed office managers regarding prediction accuracy, and they said that achieving a level of accuracy of approximately 80% was not necessary at first because there has been no quantification of interpersonal sentiment in office environments. They wanted to detect signs of deteriorating situations in the workplace, even if they might be wrong. Therefore, prediction accuracy should be set to higher than 60% on a 5-point Likert scale, although the accuracy rate is 20% stochastically.

6. Selection of investigation items in actual offices through statistical analysis using large-scale data

In this section, we explain the process used to gather and analyze data.

6.1 Acquisition of large-scale data

We gathered calculation data based on our interpersonal-sentiment-changing model illustrated in Fig. 3. We gathered 130 potential explanatory variables for predicting interpersonal sentiment that were referred to in previous psychology and engineering research.

(1) Static variables of responses about oneself

- Gender, age group, marital status, with/without children, relatives living together, personality
- Occupation, number of employees in company and office, one's status in the office, one's value judgment of others

(2) Static variables of responses about others in the office

The others' statuses in the office, gender, age (older or younger), distance of desk from others (whether two people sit near each other), things in common (e.g., school, hometown, and experiences), how they spend private time, communication tools often used with others (e.g., LINE (social networking app), voice, or email) and duration (e.g., 10 minutes or 1 hour), and how much private information is shared

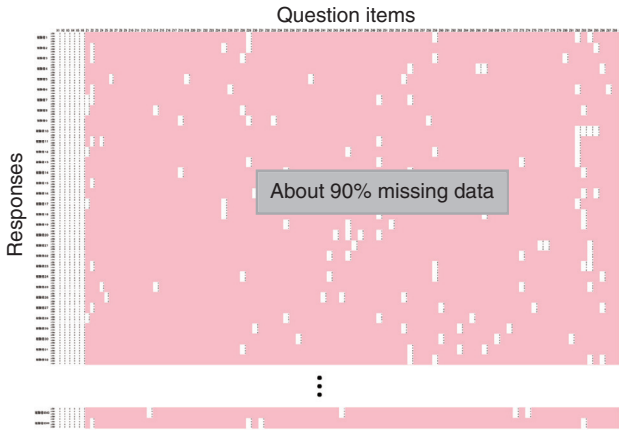


Fig. 4. Large amount of missing data.

via work email (e.g., if the other is on familiar terms, messages may contain private information such as an invitation to dinner or news about the family.).

(3) Interpersonal sentiment-related variables

- We included 83 types of events that may change interpersonal sentiment in the office, for example, power harassment or consoling others regarding work problems.
- Respondents' sentiment when the event occurred and its strength on a 5-point scale. We use Plutchik's eight primary emotions [14] as the measure of one's emotions, that is, rage, terror, vigilance, ecstasy, admiration, amazement, grief, and loathing.
- Respondents' condition such as health and deadlines
- Initial strength of interpersonal sentiment for each factor with regard to other office staff members
- First impressions of others

A large amount of data is needed for statistical analysis. We used a web questionnaire as an efficient data-gathering tool for the short term. The web questionnaire was conducted in January 2012. We obtained about 9000 responses.

6.2 Features of web questionnaire data and problem from viewpoint of statistical analysis

(1) Features

Sentiment is subjective; therefore, we have to prepare various choices in order to obtain the truest possible responses. In the first-impression investigation mentioned in section 6.1, we prepared a multiple-choice question asking respondents to choose 10 out of 94 items on what is important regarding first impressions. Each person reacts differently to words, so even if the same impression term was shown, for example, on the appearance of a good-looking man, we provided several words such as cool, cute, good, and smart. In our questionnaires, the respondents all chose the first 6 question items, and the other 4 were random throughout the remaining 88 items.

(2) Problem

As a result, 84 items were not chosen, resulting in a huge amount of missing data, about 90% (shaded region in **Fig. 4**). Therefore, the method of conventional statistical analysis makes analysis difficult.

6.3 Sparse factor regression analysis with large amount of missing data

We used a missing-data algorithm to estimate several of the regression-formula parameters. Regarding our data problem described in section 6.2, we have to determine why the data are missing. Rubin classified the following three types of missing-data mechanisms [15]. The analysis method differs depending on which mechanism is assumed. These mechanisms describe the relationships between measured variables and the probability of missing data.

(1) Missing completely at random (MCAR)

The MCAR mechanism means that data are missing independently of both observed and unobserved data.

(2) Missing at random (MAR)

The MAR mechanism means that when the observed data are given, data are missing independently of unobserved data.

(3) Missing Not at Random (MNAR)

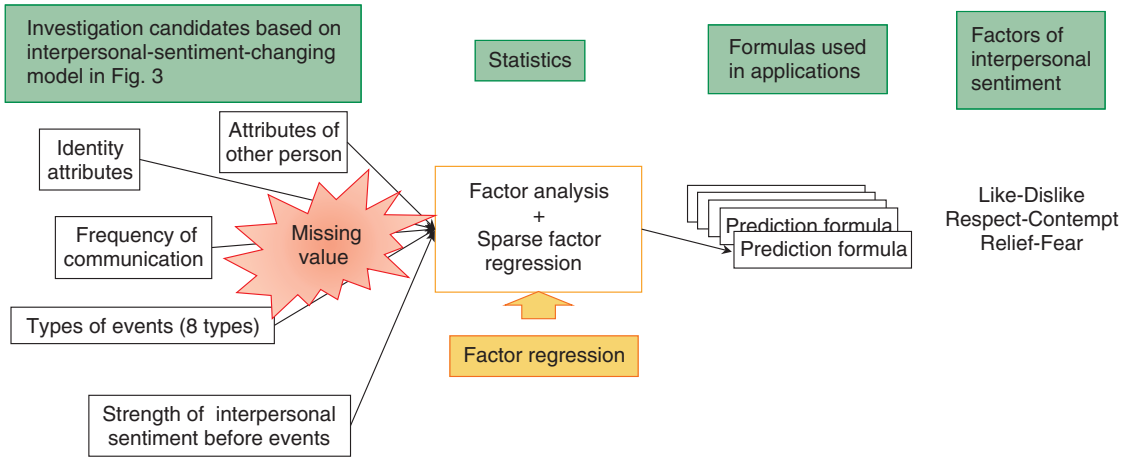


Fig. 5. Overview of factor regression.

The MNAR mechanism means that missing observations are related to values of unobserved data.

We assume that the missing data (unobserved data) are due to the variable not being chosen from the response. Therefore, we assume the MAR mechanism can be used. We conducted a factor analysis that can be used even if there is a large amount of missing data. Moreover, the factors not derived from factor analysis must be used in regression analysis. We want to minimize the number of useful explanatory variables for interpersonal-sentiment prediction discussed in section 5, even though we listed many candidate variables. Because variables (explanatory variables in regression analysis) may be used as input items in business, for example, in human-relation predictions in an office, having a large number of explanatory variables makes the prediction formula cumbersome and complicated.

The variables chosen from sparse regression modeling are used as the explanatory variables of the interpersonal-sentiment-prediction formula. The number of variables is small, which leads to better privacy protection in service systems because such systems do not need to keep user data that are not necessary for sentiment prediction. As the number of variables decreases, the input load decreases when using the prediction formula.

In this article, we focus on *sparse factor regression analysis*, and we describe the proposed analysis method based on a large amount of missing data as follows. Let the predictor and responses be x_n and y_n, respectively. In the factor regression model, prediction can be done directly by m latent factors f_n as follows:

$$x_n = \Lambda f_n + \xi_n,\ y_n = \Theta^T f_n + \varepsilon_n, \tag{1}$$

where Λ and Θ are factor loadings, and ξ_n and ε_n are error variables. The joint distribution (x_n, y_n) can be expressed as

$$\begin{pmatrix} x_n \\ y_n \end{pmatrix} = \begin{pmatrix} \mu \\ \alpha \end{pmatrix} + \begin{pmatrix} \Lambda \\ \Theta^T \end{pmatrix} f_n + \begin{pmatrix} \xi_n \\ \varepsilon_n \end{pmatrix}. \tag{2}$$

The above equation can be regarded as a standard *factor model*:

$$\tilde{x}_n = \tilde{\mu} + \tilde{\Lambda} f_n + \tilde{\xi}_n, \tag{3}$$

where $\tilde{x}_n = (x_n^T, y_n^T)^T$, $\tilde{\mu} = (\mu^T, \alpha^T)^T$, $\tilde{\Lambda} = (\Lambda^T, \Theta)^T$, and $\tilde{\xi}_n = (\xi_n^T, \varepsilon_n^T)^T$. Therefore, we can directly use an estimation algorithm of the factor-analysis model to obtain the solution. An efficient algorithm when a large amount of missing data is involved is detailed in previous papers [16, 17].

6.4 Evaluation results

We proposed the regression formulas for calculating $y(t_A+\Delta t)$ in Fig. 3 using the method described in section 6.3 (**Fig. 5**). There are several regression analysis models for obtaining prediction formulas (regression formulas). We used a linear regression model because it is easier to interpret with derived explanatory variables than a non-linear model. Moreover, when we create a graph of discrete values for each variable, the graph shape is not a curve fitting a non-linear model.

The regression formulas and their measured accuracy of interpersonal sentiment are listed in **Table 1**.

The strength of interpersonal sentiment y based on

Table 1. Regression formulas and accuracy rates of interpersonal sentiment factors.

Strength of interpersonal sentiment y
$y = b + a_1x_1 + a_2x_2 + a_3x_3 + \ldots + a_ix_i$

Factor of interpersonal sentiment	Accuracy (%)	Constant b	Coefficient a_i of explanatory variable x_i						
			a_1	a_2	a_3	a_4	a_5	a_6	a_7
Like/Dislike	62.6	3.8	–1.5	0.4	0.1	0.4			
Respect /Contempt	63.3	3.6	–1.2		0.2	0.2	0.1	0.2	
Relief /Fear	64.3	3.8	–1.5	–0.5	0.1	0.2	0.1		–0.2

Note: without segmentation

x_1: strength of interpersonal sentiment before event occurred; x_2: type of event; x_3: type of one's sentiment when event occurs; x_4: one's judgment value of others; x_5: personality; x_6: one's circumstances; x_7: relatives living together

the linear model shown on the y-axis in Fig. 3 is expressed as follows:

$$y = b + a_1x_1 + a_2x_2 + a_3x_3 + \ldots + a_ix_i, \qquad (4)$$

where b is a constant and a_i is a coefficient of explanatory variable x_i (input items of prediction formulas). Three factors of interpersonal sentiment are described in section 3. Our prediction goal was to have ten or fewer variables to reduce the formula user's load, as explained in section 5. In selecting explanatory variables, we first ensure that the absolute value of a_i is not close to zero since we are using sparse factor regression. Greater absolute values of a_i are useful to estimate y for each factor of interpersonal sentiment. The prediction accuracies listed in Table 1 are the averages of 5-fold cross-validation. We evaluated the prediction accuracy with and without segmentation of all data.

As a result, the prediction accuracy for all three factors was more than 60% without segmentation. We confirmed a prediction accuracy of approximately 70–80% when the data set was divided into several segments using explanatory variables of greater absolute values of a_i, types of events x_2, or initial strength of interpersonal sentiment before an event occurred x_1.

We also found that the approximately 60% accuracy was for all three factors involving only four to six variables (see Table 1, the number of a_i variables). The useful variables were x_1, the initial strength of interpersonal sentiment before an event occurred, x_2, types of events, and x_4, one's judgment value of others. That is, only up to ten input items at most can be obtained from the prediction formula in which the prediction accuracy is higher than 60%. Conversely, about 120 input candidate items out of the 130 items described in section 6.1 were not useful for predicting interpersonal sentiment.

7. Derivation of prediction formula using actual target office data

Here, we describe how we derived prediction formulas using actual data.

7.1 Problems in gathering data in actual office environment

Statistical analysis is generally necessary for large amounts of data to derive prediction formulas. However, there are two problems with the field data of actual target offices, as shown in **Fig. 6** and as follows.

(1) Problem 1

In an actual office, events in which interpersonal sentiments change do not occur frequently. Therefore, a long investigation period such as more than half a year is necessary to acquire an adequate amount of sample data for general statistical analysis.

During a long investigation period, however, personnel changes occur regarding those who are gathering data to develop the prediction formulas. Moreover, office workers who are the subjects of such an investigation bear a heavy burden; thus, the quality of gathered data decreases.

(2) Problem 2

We generally used Bayesian estimation for time-series and small-scale data. The derived prediction formulas using conventional Bayesian estimation consist of many variables. In conventional Bayesian estimation, Markov chain Monte Carlo (MCMC) methods can often be used. MCMC methods find an optimized answer from repeated computations.

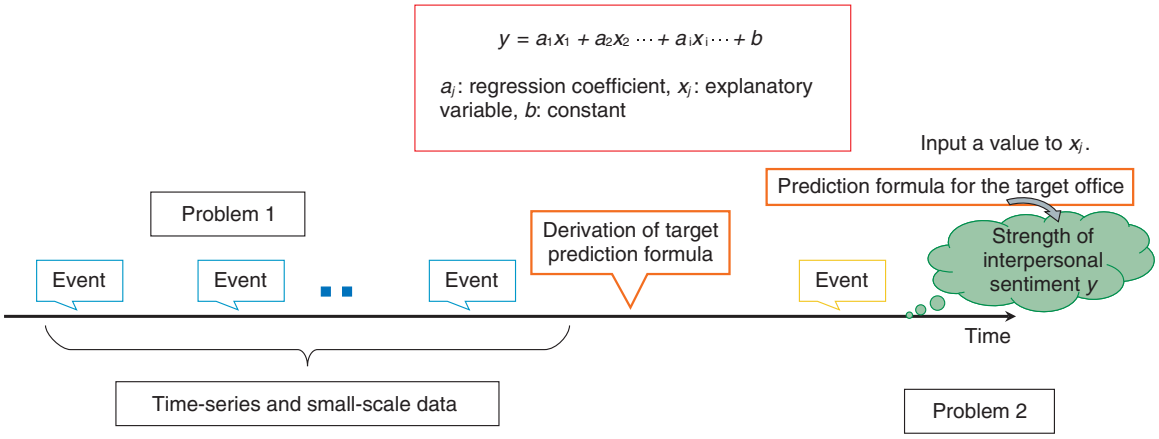


Fig. 6. Process of deriving prediction formula for actual office.

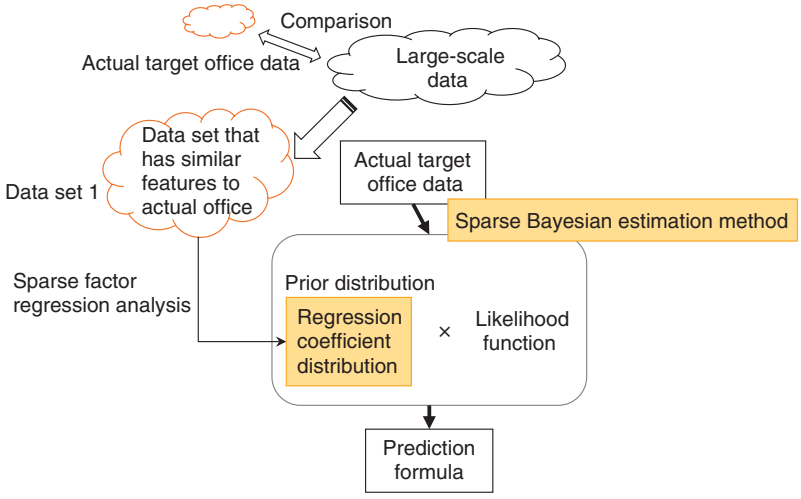


Fig. 7. Small-scale data analysis method using large-scale data.

However, they have heavy computational loads.

In contrast, when we want to minimize the number of variables of a prediction formula, we generally use sparse regression modeling. However, the conventional Bayesian estimation cannot use the standard lasso algorithm (sparse regression modeling).

7.2 Sparse Bayesian estimation method

In this subsection, we describe the method of sparse Bayesian estimation.

7.2.1 Prior distribution of Bayesian estimation using the analysis results of large-scale data

The proposed Bayesian estimation method is depicted in **Fig. 7**. To overcome problem 1, we use the analysis results of large-scale data through Bayesian estimation. As mentioned in section 7.1, conventional Bayesian estimation is useful to obtain an optimized answer from repeated computations such as with an MCMC method. To obtain an optimized answer with fewer repeated computations, it is important to set appropriate values to the prior distribution. To set the appropriate prior distribution, we propose using the analysis results of sparse factor regression analysis of a large-scale data set gathered from web questionnaires, as described in section 6.1. The data set involves the same kinds of jobs as in actual target offices. Bayesian estimation is generally used as a normal distribution for the prior distribution.

Our proposed method uses the regression coefficient distribution obtained from sparse regression analysis for the prior distribution of Bayesian estimation developed using data set 1 in Fig. 7.

7.2.2 Sparse Bayesian estimation method

To overcome problem 2, we use our method called the sparse Bayesian estimation method to carry out Bayesian estimation and sparse regression.

We focus on the logarithm of posterior distribution on Bayesian estimation used in sequential learning from a few events, which becomes a quadratic function. Bayesian estimation is unified sparse regression that can refine the variables of a prediction formula. We estimate the posterior mode instead of the posterior mean. The estimation of the posterior mode corresponds to the penalized maximum likelihood estimation. The prior distribution is assumed to be a multivariate-normal distribution; therefore, the posterior distribution is also a multivariate-normal distribution, which implies the standard algorithm used in the lasso-type estimation, for example, the coordinate descent algorithm, can be directly used.

The detailed algorithm is described below. The explanatory variables (e.g., gender and age) before an event are denoted as X, and the response variable (degree of connectiveness after the event) is denoted as Y. We conduct linear regression analysis to estimate Y from X, but the number of observations is often small. In this case, the estimator $\hat{\theta}$ may be unstable. To address this issue, we obtain a stable estimate by using $\hat{\theta}_{web}$, the estimator of parameter θ. Specifically, we use the following posterior distribution:

$$p(\theta|\hat{\theta}_{web}, Y, X) \propto p(Y|\theta, \hat{\theta}_{web}, X)p(\theta|\hat{\theta}_{web}). \quad (5)$$

Note that both likelihood function $p(Y|\theta, \hat{\theta}_{web}, X)$ and prior distribution $p(\theta|\hat{\theta}_{web})$ are multivariate-normal distributions; therefore, the posterior distribution is also a multivariate-normal distribution. The logarithm of likelihood function can then become quadratic.

We consider the sparse estimation of θ via L_1 regularization such as the lasso. Instead of using the negative log-likelihood $-\log p(Y|\theta, \hat{\theta}_{web})$, we use $-\log p(Y|\theta, \hat{\theta}_{web}) - \log p(\theta|\hat{\theta}_{web})$. As described above, $\log p(Y|\theta, \hat{\theta}_{web}) - \log p(\theta|\hat{\theta}_{web})$ takes a quadratic form with respect to θ. When we substitute the above quadratic function with the loss function of the lasso, we can directly use the standard algorithm of the lasso.

7.3 Diary method

We gathered the actual target office data using the diary method that we designed based on the interpersonal-sentiment-changing model shown in Fig. 3. Office employees had to keep a daily diary that includes information such as other staff members' names, events, and the changes in the strength of their interpersonal sentiments. Approximately 30 of the 130 candidate investigation items were selected through the sparse regression results described in section 6.4, including correction items for the target office.

The 30 investigation items were as follows.

(1) One-time investigation items
- Gender, age-group, marital status, with/without children, personality
- Types of occupation, one's status in the office, one's value judgment of others
- Strength of three factors mentioned in section 3 at the initial state for every office staff member

(2) Everyday investigation items
- An event that was selected from 83 types of events and Plutchik's eight emotions mentioned in section 6.1, a 5-point scale on the strength of factors for interpersonal sentiment, and respondents' condition and situation such as overall health and deadlines.
- Staff member's name involved in the event
- Strength of three factors for interpersonal sentiment mentioned in section 3 after the event for all office staff members.

The prediction was $y(t_A+\Delta t)$ as shown in Fig. 3, and the correct answer values of $y(t_A+\Delta t)$ are the strength of the three factors after the event.

The data obtained using the diary method to investigate human relations were gathered in four actual offices of an NTT Group company from Oct. 24 to Dec. 15, 2014. The data were input using an HTML (Hypertext Markup Language) interface. Since the interpersonal-sentiment data of office employees were very sensitive, the employees were allowed to answer the questionnaires in the privacy of their homes, as more accurate human-relation data could be gathered.

The basic analysis results of gathering data were as follows.

(1) Office staff (respondent) attributes
- Offices (departments): Marketing x 2, Development x 2; total of 4 offices
- Males: 17, females: 7
- Positions: department managers: 4, department chiefs: 2, staff members: 14, temporary staff

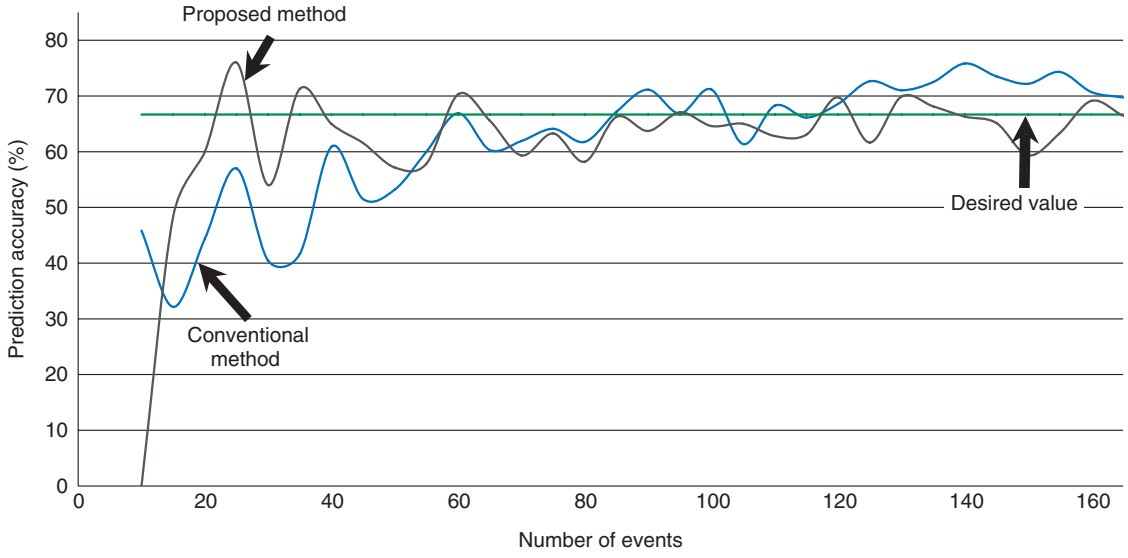


Fig. 8. Prediction accuracy of proposed and conventional methods regarding respect-contempt factor without segmentation.

members: 4

(2) Number of events that occurred over two months: 167
- Positive events: 136
- Negative events: 31

(3) Examples of main positive events
- Had a positive conversation (mainly marketing offices)
- Participated in the same event, drink party, or workshop (all offices)
- Helped someone with his/her work (all offices)

(4) Examples of main negative events
- Looked down on people (mainly marketing offices)
- Refused to take responsibility for problems (mainly development offices)
- Exhibited bad manners (mainly marketing offices)

7.4 Evaluation results and discussion

The evaluation results are shown in **Fig. 8**. The x-axis is the number of events, and the y-axis is the prediction accuracy. We analyzed 167 events that occurred during the two-month investigation period. The factor of interpersonal sentiment was respect-contempt. Data set 1 consisted of about 3100 data samples. The straight green line is the prediction accuracy using sparse factor regression analysis discussed in section 6.3 by using all 167 events. The blue line is the prediction accuracy using the conventional Bayesian estimation method, and the grey line is the prediction accuracy using the proposed sparse Bayesian estimation method. The weight coefficient τ of the initial distribution with the proposed sparse Bayesian estimation method was 1.0. The initial distribution with the conventional Bayesian estimation method was assumed to be uniform ($\tau = 0$).

We checked which of the two methods converged more quickly to the straight line of 67% (desired value) estimation accuracy. Calculations using both methods were started after ten events. The input items were sequentially input using both methods in the order the events occurred. The prediction accuracy of the two methods took an average of five times for two-fold cross-validation of the data of all 167 events.

Both methods began to converge from about 85 events. However, the estimation with the proposed method was more stable than that with the conventional method. That is, the proposed method had less dispersion in estimation accuracy than the conventional method. Therefore, the convergent start point of both methods was almost the same; however, the proposed method became stable faster than the conventional method. There were four useful variables: the initial strength of interpersonal sentiment before an event occurred, types of events, types of occupation, and personality.

Next, we estimated the accuracy enhancement regarding the respect-contempt factor. We focused on the regression coefficient of all data using our diary

method. The explanatory variables of a large regression coefficient were gender (= 0.2) and event type (= 0.4). In this article, we have focused on event type, which were segmented into positive and negative events. There were 136 positive events and 31 negative events out of the total 167 events. There were too few negative events for our sparse Bayesian estimation method; therefore, we used the 136 positive events. After data cleansing, we analyzed 111 positive events. The prediction accuracy takes an average of five times for two-fold cross-validation of office data for the 111 positive events. The prediction accuracy was 77%—about 10% higher—by segmentation. Thus, we achieved our prediction goals of obtaining more than 60% prediction accuracy and having ten or fewer variables.

The proposed method converged at about 60 events, and the conventional method converged at about 80 events. That is, the proposed method converged with about one-fourth fewer events than the conventional method. The diary method we used required 30 days to gather the data on 60 events. Thus, we obtained a prediction formula after at least 20 days of learning using the proposed method. This 20-day learning period is sufficient for practical use.

8. Visualization on PCs and smartphones

To our knowledge, no studies have been done on the visualization of human personal relationships from a psychological point of view. We implemented two types of visualization systems. One is for office managers or human resources staff, and the other is for general office staff.

8.1 Visualization system for office managers

We attempted to visualize the change in the prediction of invisible interpersonal sentiment as a tool for managers. We implemented a visualization system as shown in **Fig. 9**. We prepared two types of visualization displays, a single (Fig. 9(a)) and a comparative visualization screen (Fig. 9(b)). We assumed an actual office scenario in which interpersonal sentiment changes and is easy to visualize in an actual office. In this visualization system, the privacy of responses and an interface for observers were not considered. We will investigate these issues as future work. The comparative visualization display (b) has the same functionality as display (a). The difference is that the interpersonal-sentiment variation in two different departments can be compared for the same events. For example, we can see the difference in interpersonal-sentiment variation between an engineering department and a marketing department.

The system requirements for visualization are as follows.

Operating system (OS): Mac OS X 10.8.4, HTTP (Hypertext Transfer Protocol) server: Apache 2.2.22, runtime: JDK (Java Development Kit) 7.0_45, browser: Firefox 25, processor: 1.3-GHz dual core Intel Core i5, memory: 4-GB 1600-MHz LPDDR3, storage: 256 GB.

8.2 Visualization system for office staff

In this section, we describe the system to visualize how an office staff member is feeling. The visualization target is the sentiment of a person, so it is very sensitive. It is necessary to carefully investigate changing interpersonal sentiments, depending on who observes the human relations that are visualized. It may be necessary in some cases, for example, when the information made visible is viewed by individual office workers in the workplace, to add minor falsifications of the true predicted values tuned to improve human relations, or to refrain from showing direct information about the people involved in order to protect privacy. To prevent information displayed from being seen by others in the workplace, we implemented the system on smartphones; therefore, users can input data in a private space.

The following components are involved in the visualization process.

First, the gender, age, and position of the person we want to visualize in the organization have to be set. To simplify the relationship information, we decided to allow only the following two types of individuals to be set:

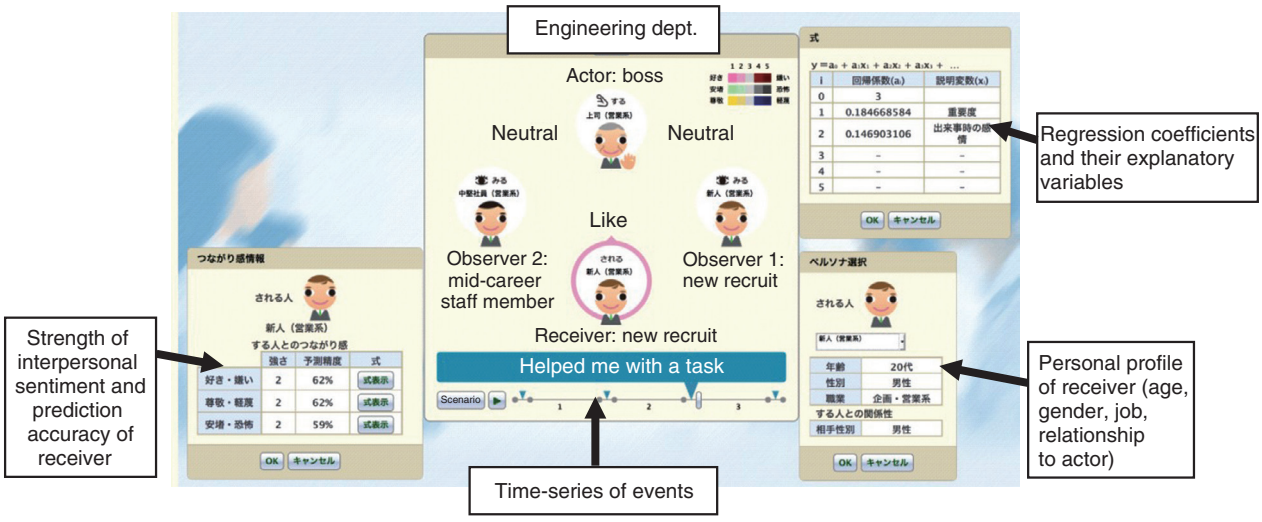
(1) One who provoked an event
(2) One who is affected by having witnessed the event

The prediction of the sentiments between the two set individuals was executed by using the formula mentioned in section 7.2. The data collected from the diary method during in-context experiments were used.

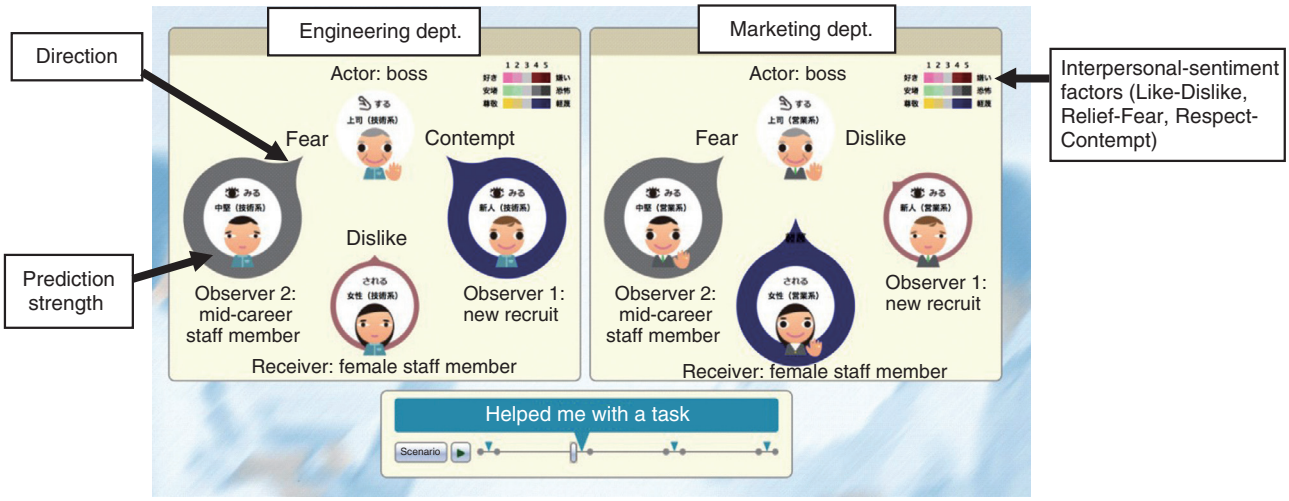
The visualization system was designed as an application for smartphones and implemented on a smartphone. The specifications of the smartphone were as follows.

Smartphone: AQUOS SERIE mini SHV31, central processing unit (CPU): MSM9874AB 2.3-GHz Quad-core, memory: 2 GB, storage: 16 GB, OS: Android 4.4.

In consideration of client-side processing constraints



(a) Single display



(b) Comparative display

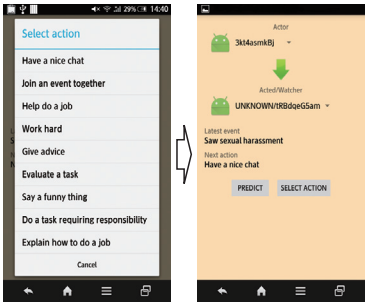
Fig. 9. Visualization for office managers.

and the high privacy level of manipulated data and results, we implemented the proposed sparse Bayesian estimation method mentioned in section 7.2 using R language, and events or user information files were run or stored on an Apache server.

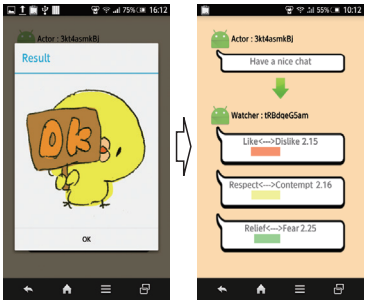
The server specifications were as follows.

CPU: Intel Core i5-2400 3.1-GHz Quad-core, memory: 8 GB, storage: 128 GB, OS: Windows 10 Pro 64 bit, HTTP: Apache 2.4.17.

The displayed images are shown in **Fig. 10**. The display combined actual and predicted data; the predicted data were displayed after displaying the actual data collected as the training data set. Specifically, relationships should be expressed through a quiz-style interface such as "Here is the current relationship status; choose the next action and see how the relationship turns out" (Fig. 10(a)). A warning may be displayed when a prediction mismatch occurs (chosen action leads to relationship deterioration). The scenario illustrates the case of monitoring the relationship between colleagues or between full-time and temporary employees. Therefore, the application is suitable for both managerial and subordinate positions. For example, it is possible to input an event such as one that may lead to power harassment, whether you are the *actor* (the person who provoked



(a) Next-action-selection displays



(b) Prediction result display
(general feeling on left, details on right)

Fig. 10. Visualization for office workers.

the event), the *receiver* (the person who suffered from the event), or the *observer* (the person who observed the event). The interface to visualize the prediction of the relationship depending on an event can be a quiz-style interface such as the one mentioned above: "Here is the current relationship status; choose the next action and see how the relationship turns out." The major functionalities are as follows.

- Input the identification of the person(s) whose relationship you care about.
- Input the related event.
- For the user interface, only the top ten most frequent events are displayed first.
- For screen size and readability, the event category is selected first; then five to ten concrete events are listed.
- Select what action you think would be appropriate next to improve the relationship.
- Display the quiz results and prediction accuracy for reference by pressing the relationship-prediction button (Fig. 10(b)).

We used simple sentiments to more easily understand the prediction results, that is, whether the selected next action would be a positive choice. We have conducted demonstrations of this system many times, and it was well received based on the opinions of attendees.

9. Conclusion

The utilization of mental data is important for a business to be successful. In this article, we explained an interpersonal-sentiment-changing model and proposed two analysis methods to quantitatively estimate changes in interpersonal sentiments in an office by using psychological research and statistical data. The first proposed method is a data analysis method that assumes the MAR mechanism, even if about 90% of data is missing. This method is also simultaneously used for sparse regression modeling and factor regression analysis. The second method was a sparse Bayesian estimation method for time-series and small-scale data. For appropriating prior distribution of the method, we used large-scale data that had similar attributes to actual workers in the target offices. The large-scale data were gathered using web questionnaires, and the small-scale data of actual target offices were gathered using a diary method.

With these methods, we achieved a prediction accuracy of more than 60% without segmentation and ten or fewer variables. When we segmented a data set using a variable of a large regression coefficient, the prediction accuracy increased by about 10%.

We finally implemented two types of visualization systems for office managers and for office staff members. Managers can monitor a subordinate's human relations on a PC, and staff members can monitor relations on smartphones. We demonstrated the visualization systems using actual office data. The demonstrations were well received based on the comments of attendees.

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Trademark notes

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Report on WTSA-16 (World Telecommunication Standardization Assembly 2016)

Yoshinori Goto, Kazuhiro Takaya, Noriyuki Araki, and Hideyuki Iwata

Abstract

The World Telecommunication Standardization Assembly was held from October 25 to November 3 in 2016 in Yasmine Hammamet, Tunisia. This article gives an overview of the meeting along with information about the main topics that were discussed.

Keywords: WTSA, IMT, digital object architecture

1. Introduction

The World Telecommunication Standardization Assembly (WTSA) is the highest decision-making body of the International Telecommunication Union Telecommunication Standardization Sector (ITU-T), which oversees telecommunication standardization in the ITU. The assembly convenes every four years (**Fig. 1**). Decision-making organizations above WTSA include the Plenipotentiary Conference and the Council (**Fig. 2**). WTSA formulates the action policies of ITU-T, organizes Study Groups (SGs), and appoints the chairs and vice-chairs of SGs and the Telecommunication Standardization Advisory Group (TSAG).

The SGs are the key organizations engaged in ITU-T's standardization activities. Since discussions at this level require a high level of technical expertise, experts from private companies play an important role. In contrast, most topics discussed in WTSA concern policy or organizational operation matters. Consequently, government officials play a larger role, although technical knowledge is required when discussing what topics should be addressed by the SGs. A feature of WTSA is, therefore, that its discussions require collaboration between government and the private sector.

The outcomes of the discussions in WTSA usually take the form of resolution documents. Unlike the ITU Constitution, ITU Convention, or ITU Administrative Regulations (Radio Regulations and International Telecommunication Regulations), which are treated as international law, these documents are not legally binding. However, since they define the policies governing ITU-T activities, they are not only of great importance in and of themselves but also serve as guidelines for the working methods adopted by ITU-T.

Under its plenary, WTSA forms five committees (**Fig. 3**), each of which discusses specific topics. Particularly important are COM3, which studies working methods, and COM4, which discusses the work program.

2. SG restructuring

The restructuring of SGs is the most important issue to be addressed by WTSA. ITU-T currently has 11 SGs. To improve the efficiency of ITU-T operations, it was proposed that some SGs with decreasing workloads should be merged with other SGs. Specifically, the merger of SG9 (cable television (CATV)) and SG15/SG16, and the merger of SG11 (protocols and testing) and SG13, were considered.

Fig. 1. Scenes from the conference.

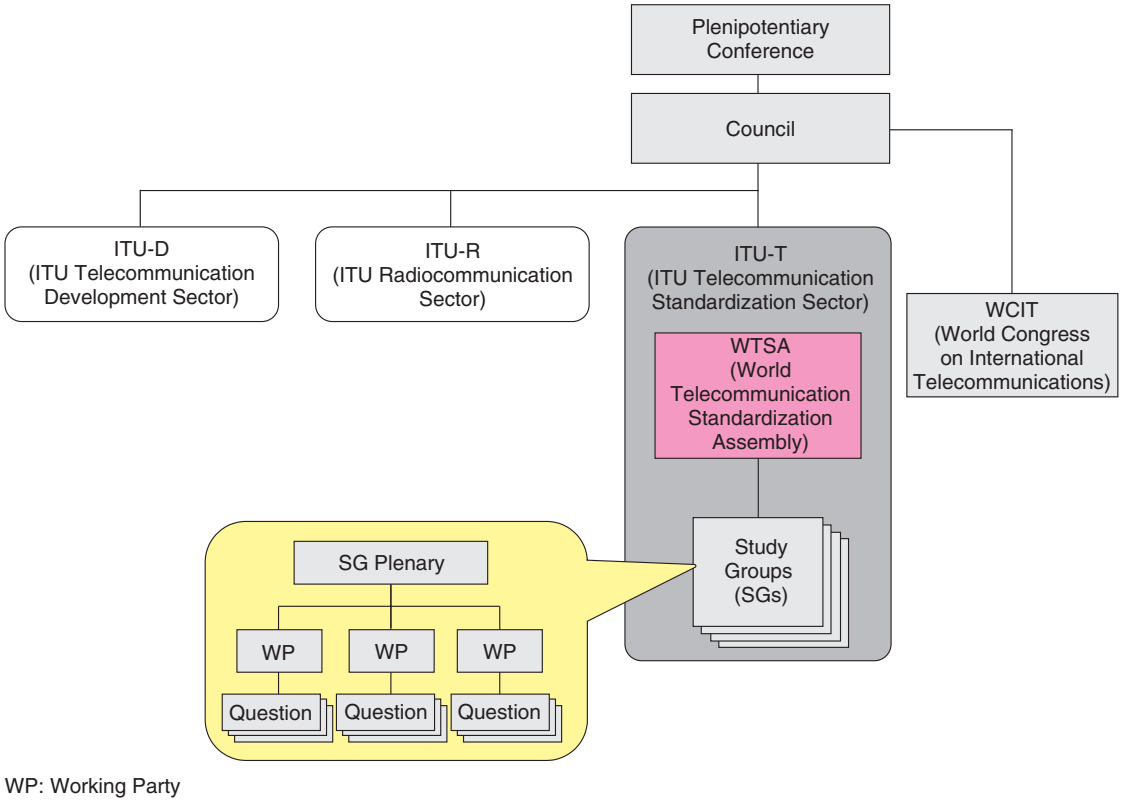
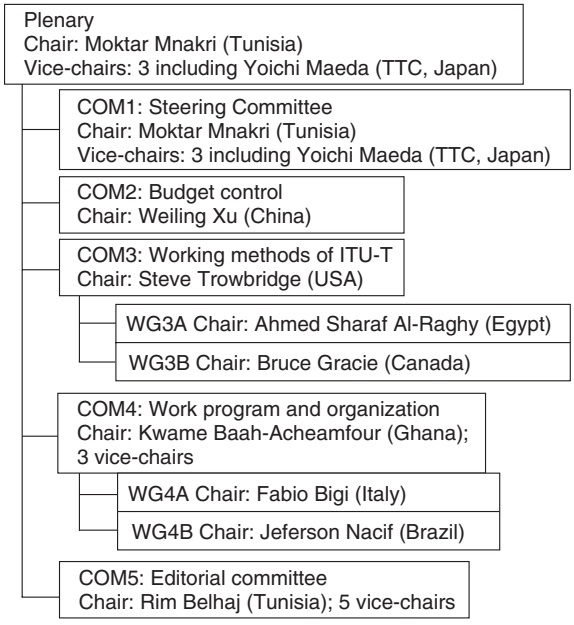


Fig. 2. Position of WTSA within the ITU structure.

Members from the USA, Canada, and CEPT (European Conference of Postal and Telecommunications Administrations) proposed the merger of SG11 and SG13, but the Regional Commonwealth in the field of Communications (RCC; Russia and other countries in the region) and the Asia-Pacific Telecommunity (APT) proposed to retain SG11 as a separate entity. Support for this merger from Member States was insufficient, so it was agreed to retain SG11 as an independent study group.



TTC: Telecommunication Technology Committee

Fig. 3. WTSA structure.

Initially, no organizations other than APT expressed a desire to keep SG9. However, when Japan argued for the retention of SG9 based on the peculiarities of the standardization of CATV, which is subject to regulations that are different from other regulations applied to the telecommunications industry, Russia changed its stance to support the continuation of SG9. With this as a trigger, nations in the Middle Eastern and African regions also changed their positions to support the retention of SG9. There was an extended discussion between these parties and the USA and the member European nations, which proposed for SG9 to be merged. On October 29, the latter backed off and agreed to the retention of SG9.

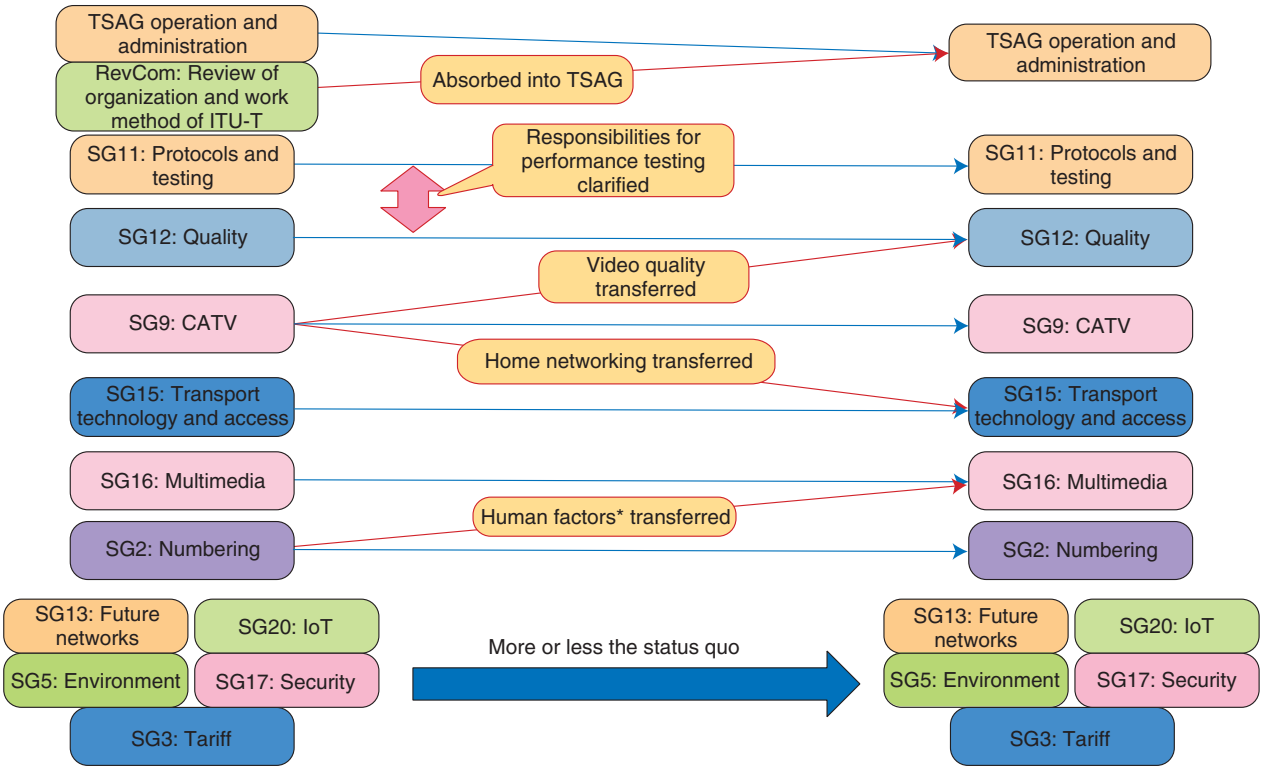
Although it was decided to retain SG9, the USA and European nations insisted on transferring SG9's question on quality to SG12 and the question on home networking to SG15. The developing nations that supported the retention of SG9 had no strong opinion on this matter. In particular, while the African nations supported the retention of SG9, they requested the transfer of the question on quality. The chair of COM4, which was in charge of SG restructuring at this WTSA, was a Ghanaian. He tried to push the transfer of the question through, but Japan resisted his attempt by expressing a reservation (an act of retaining the right to restart a specific discussion), claiming that there was a problem in the manner in which the discussion had proceeded. In the end, it was agreed to transfer the questions on quality and home networking, but the responsibilities of the related SGs were rearranged to enable these SGs to take those actions deemed necessary.

Other agreements include the transfer of the question on human factors from SG2 to SG16 and the merger of the Review Committee, which had been studying the reorganization of ITU-T, into TSAG. The results of SG restructuring were laid out in Resolution 2. An overview of SG restructuring is shown in **Fig. 4**.

3. Appointments of chairs and vice-chairs

The chairs and vice-chairs appointed are listed in **Table 1**. New chairs were appointed for SGs 2, 5, 9, 11, 16, and 17. These appointments took regional balance into consideration, so no more than one chair was appointed from the same nation except for Japan, which has two chairs (SG3 and SG9).

Resolution 35 contains provisions on the appointments of chairs and vice-chairs. This WTSA revised some of the provisions to limit the number of vice-chairs from the same region to three in each SG. In view of the trend of there being too many vice-chairs



* Human factors: Issues related to improving the quality of life through international telecommunications
RevCom: Review Committee

Fig. 4. Overview of SG restructuring.

Table 1. Officers appointed (Chairs and Vice-chairs).

SGs	Chairs	Vice-chairs
TSAG	Bruce Gracie (Canada)	8
SG2 (Numbering, administration)	Phil Rushton (UK)	8
SG3 (Tariff)	Seiichi Tsugawa (KDDI, Japan)	13
SG5 (Environment)	Maria Victoria Sukenik (Argentina)	9 including Kazuhiro Takaya (NTT, Japan)
SG9 (CATV)	Satoshi Miyaji (KDDI, Japan)	3
SG11 (Protocols and testing)	Andrey Kucheryavy (Russia)	8
SG12 (Quality)	Kwame Baah - Acheamfour (Ghana)	12
SG13 (Future networks)	Leo Lehmann (Switzerland)	10 including Yoshinori Goto (NTT, Japan)
SG15 (Transport technology and access)	Steve Trowbridge (USA)	10 including Noriyuki Araki (NTT, Japan)
SG16 (Multimedia)	Zhong Luo (China)	7 including Hideki Yamamoto (OKI, Japan)
SG17 (Security)	Heung Youl Youm (South Korea)	9 including Masaru Miyake (KDDI, Japan)
SG20 (IoT)	Nasser Al Marzouqi (UAE)	13 including Takafumi Hashitani (Fujitsu, Japan)

appointed from developing countries, the intention of this revision was to enhance the quality of vice-chairs by applying some restrictions. At first, some members proposed limiting the number of vice-chairs from the same region to two, but in view of the fact that several Asian nations such as Japan, China, and Korea are more active than others, the number was raised to three. For TSAG, the number of vice-chairs

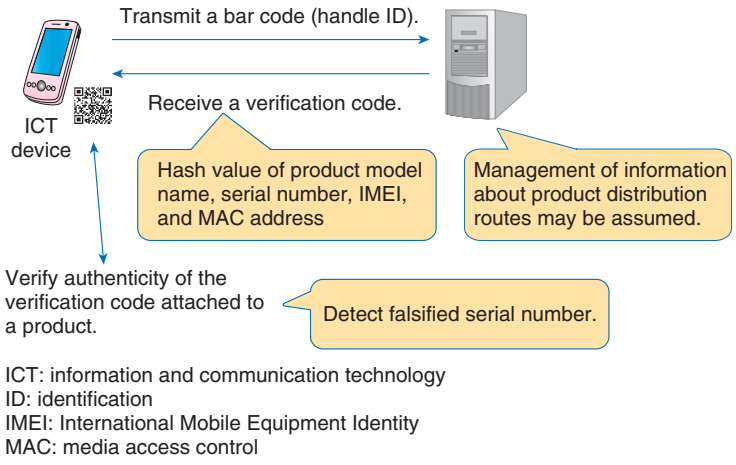


Fig. 5. Overview of DOA.

from a single region is limited to two.

In recent years, as elsewhere, the increased participation of women in the field of standardization has been noticeable. For example, the chair of SG5 is an Argentinean woman. Some expressed the need to seek a gender balance in the appointments of chairs and vice-chairs. In Japan, it will be necessary to foster the greater participation of women in the area of standardization activities.

4. Promotion of study on IMT and cooperation with open source communities

International Mobile Telecommunications (IMT) is a standardization topic concerning mobile communications. It is a unique technical field where wireless and wired technologies converge. Expectation has been growing recently for the development of a fifth-generation mobile communication network called IMT-2020. IMT is being studied not only by ITU but by a variety of standardization bodies. In order to accelerate the standardization of the non-wireless part of IMT-2020, ITU-T established the Focus Group on IMT-2020 (FG-IMT2020) in May 2015. It has been analyzing existing standards, studying existing technologies such as front/backhaul networks and software implementation of networks, collaborating with open source communities, and promoting prototyping.

Since collaboration with ITU-R (ITU Radiocommunication Sector), which is responsible for wireless technology, is important when studying IMT, collaboration with different ITU sectors was defined in Resolution 38. Advances in the activities of FG-IMT2020 have led to the formulation of a new resolution, which clarified the tasks of related SGs in addition to collaboration between ITU sectors in order to accelerate the study on IMT. As a replacement to existing Resolution 38, this resolution strengthens the content of Resolution 38.

FG-IMT2020 is studying the possibility of cooperating with open source communities to gain their participation in standardization efforts. The cooperation between standardization groups and open source communities is expected to expand in many areas beyond IMT. With this trend taken into consideration, a new resolution was adopted to strengthen cooperation with open source communities.

5. DOA and countermeasures against counterfeit products

Considerable time was spent at WTSA-16 discussing how to incorporate issues related to digital object architecture (DOA) and its applications into resolutions. The DOA is a system used to identify the serial number and other details of a product based on a two-dimensional bar code. It can be used to detect imitation (counterfeit) products and manage the distribution channels of products (**Fig. 5**).

Imitation communication devices such as mobile phones are said to be spreading particularly quickly in developing countries. They represent a variety of problems, including infringement of intellectual property rights and lack of due attention to safety and environmental protection. Some products are actually

authentic but have been stolen with their serial numbers overwritten. However, it is necessary to note that other than illicitly modified products, stolen products have been properly certified at point of manufacture, and thus their problems are slightly different from those of imitation products. SG11 is studying what countermeasures can be taken to combat imitation products and is proposing solutions, including one that uses an International Mobile Equipment Identity (IMEI) database. An IMEI is assigned to each mobile terminal. Another solution it proposes is the use of the DOA.

The DOA is referred to in a number of resolutions in this WTSA: Resolution 50 (cybersecurity), Resolution 60 (identifications for Internet of Things), Resolution 78 (e-health), a new resolution related to imitation products, and a new resolution related to stolen mobile devices. The discussion centered on whether to accept the DOA in these resolutions. There were two opposing parties. One party, consisting of the USA and European nations, argued that the DOA was just an example of implementation technologies, and that adopting it in resolutions without studying its technical details is tantamount to denying the existence of similar technologies that have been adopted in recommendations.

The other party, consisting of Russia and the African nations, stated that the DOA was highly generic and useful technology and insisted on promoting its study by explicitly referring to it in resolutions. This division was partly due to differences between the two parties in the interpretation of Resolution 188 of the Plenipotentiary Conference, which refers to Recommendation ITU-T X.1255, which stated that it was based on the DOA.

This matter was assigned to COM4, which discussed it in both formal and informal meetings. Although a draft compromise with some modifications to the description of the DOA was informally proposed, no conclusion was reached. The matter was carried over to the next plenary conference. On the night of November 2, with only two days left for the conference, this matter was included in a new draft resolution on imitation products. When modifications to the description of the DOA recurred, the chair made a hurried attempt to approve the draft resolution. The USA and European nations opposed this attempt and raised a point of order, which was a motion of objection.

The dispute over the DOA has several possible causes. First, a top-down approach of adopting a resolution in a plenary meeting was attempted in an effort to deal with a technical issue that should more properly be addressed by technical experts holding detailed discussions in SGs. Second, a Memorandum of Understanding existed between ITU and the DONA (Digital Object Numbering Authority) Foundation, which is promoting the DOA. Third, there was a competition between member groups to obtain leadership in Internet-related technologies.

6. Discussions on the Internet

At the previous WTSA in 2012, there was great interest in international governance of the Internet because the conference was to be followed immediately by the World Congress on International Telecommunications (WCIT), which is in charge of making revisions to the International Telecommunication Regulations (ITR). At WTSA-16, discussions on the Internet were not as intense as before because there was still no schedule for the next WCIT. The African nations proposed a draft resolution promoting a study on levying a tax on over-the-top (OTT) providers. This was because telecommunication carriers in developing countries are seeing their revenues dwindle due to the expansion of OTT, and they want to recover them through taxation. While it is evident that there is competition between OTT providers and telecommunication carriers, some argued that taxation was not an appropriate matter for ITU-T, a body dedicated to technical discussions, because responsibility for taxation lies with the sovereign governments of individual nations. In the end, the new draft resolution was not adopted. The only decision that was made was to request SG2 and SG3 to study management and financial matters related to numbering resources.

The Middle Eastern nations and the RCC proposed a resolution relating to ITU-T's participation in another revision of the ITR. Although the Council was studying revision of the ITR, it had made no decision on specific directions for the revision. Since the ITR has a major impact on ITU-T, some insisted on holding discussions on this matter within ITU-T by adopting a new resolution. In the end, WTSA adopted a resolution to study the ITR through TSAG based on the resolutions of the Plenipotentiary Conference and the Council.

In addition to the above, Resolution 52 on countermeasures against spam, Resolution 64 on the transition to IPv6 (Internet Protocol version 6), and Resolution 69 demanding unlimited access to Internet resources, were updated.

7. Future prospects

At this WTSA, there was a sharp division of opinions, including those on the DOA, between developed and developing countries, leading to intense disputes not seen in recent years. However, with new people appointed to chairmanships and vice-chairmanships in many SGs, ITU-T will undertake its activities over the next four years with updated missions adapted to the current circumstances of the telecommunications industry. We will contribute to the global expansion of NTT technologies.

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External Awards

FY2016 Award of Director-General for Industrial Science and Technology Policy and Environment Bureau, METI, to Recognize Contributions to Industrial Standardization

Winner: Hisashi Izumita, NTT Access Network Service Systems Laboratories
Date: October 6, 2016
Organization: Ministry of Economy, Trade and Industry (METI)

For his contributions to international standardization on the International Electrotechnical Commission (IEC) Technical Committee 86 (Fibre optics).

Excellent Presentation

Winner: Masaya Nohara, Yoko Ono, Mikayo Iwata, Masahiko Hayashi, and Takeshi Komatsu, NTT Device Technology Laboratories
Date: December 7, 2016
Organization: EcoDesign Products & Service (EcoDePS) Symposium 2016

For "Proposal and Basic Performance of New Concept Batteries which Consist of Fertilizer Components."
Published as: M. Nohara, Y. Ono, M. Iwata, M. Hayashi, and T. Komatsu, "Proposal and Basic Performance of New Concept Batteries which Consist of Fertilizer Components," EcoDePS 2016, Tokyo, Japan, Dec. 2016.

2016 IEICE Communications Society OCS Young Researchers Award

Winner: Masanori Nakamura, NTT Network Innovation Laboratories
Date: December 20, 2016
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Communications Society, Technical Committee on Optical Communication Systems (OCS)

For "A Construction Method and Basic Characteristic Evaluation of Optical 8-dimensional Modulation Using Square-QAM."
Published as: M. Nakamura, M. Yoshida, K. Yonenaga, and A. Hirano, "A Construction Method and Basic Characteristic Evaluation of Optical 8-dimensional Modulation Using Square-QAM," IEICE Tech. Rep., Vol. 115, No. 276, OCS2015-53, pp. 59–64, 2015.

Microsoft Most Valuable Professional Award (Data Platform Category)

Winner: Tsuyoshi Ozawa, NTT Software Innovation Center
Date: January 1, 2017
Organization: Microsoft Corporation

For his contributions to open source software projects concerning Apache Hadoop and enhancement of the Apache Hadoop ecosystem.

*Microsoft is a registered trademark of Microsoft Corporation in the United States and/or other countries. Apache Hadoop is a registered trademark of the Apache Software Foundation in the United States and/or other countries.

Young Scientist Presentation Award

Winner: Megumi Kurosu, NTT Basic Research Laboratories
Date: March 14, 2017 (awards ceremony to be held)
Organization: The Japan Society of Applied Physics (JSAP)

For "Dispersion Effects on Phonon Temporal Waveforms in a Phononic Crystal Waveguide."
Published as: M. Kurosu, D. Hatanaka, K. Onomitsu, and H. Yamaguchi, "Dispersion Effects on Phonon Temporal Waveforms in a Phononic Crystal Waveguide," The 77th JSAP Autumn Meeting, Niigata, Japan, Sept. 2016.

Young Scientist Presentation Award

Winner: Takuya Ikuta, NTT Basic Research Laboratories
Date: March 14, 2017 (awards ceremony to be held)
Organization: The Japan Society of Applied Physics (JSAP)

For "Implementation of Quantum State Tomography for High-dimensional Time-bin Entanglements."
Published as: T. Ikuta and H. Takesue, "Implementation of Quantum State Tomography for High-dimensional Time-bin Entanglements," The 77th JSAP Autumn Meeting, Niigata, Japan, Sept. 2016.

Papers Published in Technical Journals and Conference Proceedings

Channel Model Considering Frequency Dependency Based on Propagation Measurements with Multiple Frequencies for 5G Systems

M. Sasaki, M. Inomata, W. Yamada, N. Kita, T. Onizawa, and M. Nakatsugawa

Proc. of the European Wireless 2016, pp. 15–20, Oulu, Finland, May 2016.

A path loss model is described and the frequency dependency characteristics of path loss are presented. The characteristics are obtained from measurement results in multiple frequency bands, including those above 6 GHz. In order to analyze the frequency dependency, measurements are carried out with multiple frequency bands from 0.8 GHz to 37.1 GHz. The measurement environments are a street canyon and an indoor office, which respectively correspond to an urban micro cell and an indoor hot spot of mobile communication system scenarios. On the basis of the obtained measurement results, path loss characteristics are clarified and path loss models are proposed for the street canyon and indoor office environments. The models validity is also verified.

Path Loss Characteristics between Different Floors from 0.8 to 37 GHz in Indoor Office Environments

M. Sasaki, M. Inomata, W. Yamada, N. Kita, T. Onizawa, M. Nakatsugawa, K. Kitao, and T. Imai

Proc. of ISAP 2016 (International Symposium on Antennas and Propagation), pp. 66–67, Okinawa, Japan, October 2016.

This paper describes analytical results obtained for floor penetration loss characteristics and their frequency dependency by measuring in multiple frequency bands, including those above 6 GHz, in an indoor office environment. Measurement and analysis results show that the floor penetration loss depends on two dominant components: paths through floors and outside buildings. It was clarified that the characteristics of these paths determine the frequency dependency of the floor penetration loss.

Contextual Analysis on Geminate/Singleton Identification Difficulties for L2 Learners of Japanese Based on Perceptual Features

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It is widely known that Japanese geminate/singleton consonant identification is one of the biggest problems for L2 learners. We have been analyzing identification error characteristics based on their perceptually motivated features.

Ancilla-driven Instantaneous Quantum Polynomial Time Circuit for Quantum Supremacy

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Physical Review A, Vol. 94, 062336, December 2016.

Instantaneous quantum polynomial time (IQP) is a model of (probably) nonuniversal quantum computation. Since it has been proven that IQP circuits are unlikely to be simulated classically up to a multiplicative error and an error in the l_1 norm, IQP is considered as one of the promising classes that demonstrates quantum supremacy. Although IQP circuits can be realized more easily than a universal quantum computer, demonstrating quantum supremacy is still difficult. It is therefore desired to find subclasses of IQP that are easy to implement. In this paper, by imposing some restrictions on IQP, we propose ancilla-driven IQP (ADIQP) as the subclass of commuting quantum computation suitable for many experimental settings. We show that even though ADIQP circuits are strictly weaker than IQP circuits in a sense, they are also hard to simulate classically up to a multiplicative error and an error in the l_1 norm. Moreover, the properties of ADIQP make it easy to investigate the verifiability of ADIQP circuits and the difficulties in realizing ADIQP circuits.

Vibration of the Feet Soles Inducing a Walk Sensation Expands Peripersonal Space

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Transactions of the Virtual Reality Society of Japan, Vol. 21, No. 4, pp. 627–633, December 2016 (in Japanese).

The representation of peripersonal space is remapped by body actions such as integrating tactile stimuli from the body's surface with multisensory stimuli presented within a limited distance from the body. Previous research showed that the boundaries of peripersonal space extend while walking when listening to a looming sound, but it is unclear whether the boundaries change when a sensation of walking is induced with no physical body motion. Here, we examine the change using a technique to induce a sensation of pseudo-walking by presenting vibrotactile stimuli of the sound of recorded footsteps at the soles of the feet. Experiments were performed to compare the reaction times to detect a vibrotactile stimulus on the chest while listening to a sound looming toward the body, taken as a proxy of the peripersonal space boundary. Experimental evaluations showed that the peripersonal space seems to expand when a sensation of pseudo-walking was clearly induced.

Resource Allocation Method of Service Chaining for Guaranteeing Minimum Bandwidth and High Resource Utilization

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Service chaining (SC) is a method for realizing a service by transferring flows among several service functions (SFs) that process packets. A route among SFs is called a service path (SP). Service chaining is being developed to reduce costs, increase flexibility, and shorten time-to-market. SC technologies are expected to be applied to carrier networks so that large communication carriers benefit from them. We assume that SPs process the traffic of services that treat all users in the same way such as an Internet access service for home users. An SP processes flows from several users. We do not assume that each SP is assigned to a user. Because a carrier network

accommodates many users, each service will be heavily utilized. Therefore, it is assumed that the amount of traffic of a service is larger than the resource of an SF apparatus. Several SPs are required to process the traffic. SPs are supposed to meet two requirements. One is guaranteeing minimum bandwidth. The other is reducing the number of SF apparatuses, i.e., high resource utilization. Resource utilization depends on the combination of the resource quantities of SF apparatuses. Network operators have to determine the bandwidth of each SP within the range from the minimum bandwidth to the resource quantities of SF apparatuses to maximize resource utilization. Methods for determining the bandwidth of each SP have not been proposed for meeting the two requirements. Therefore, we propose a resource allocation method for this purpose. The proposed method determines the bandwidth of each SP on the basis of the combination of the resource quantities of SF apparatuses for guaranteeing the minimum bandwidth and maximizing resource utilization and allocates necessary resources to each SP. We also evaluate the proposed method and confirm that it can guarantee the minimum bandwidth of SPs and achieve high resource utilization regardless of the combination of resource quantities of SF apparatuses. Although SF apparatuses are generally produced without considering the combinations of resource quantities of SF apparatuses in SPs, the proposed method can provide more options for selecting SF apparatuses.

Visual Area V5/hMT+ Contributes to Perception of Tactile Motion Direction: a TMS Study

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Human imaging studies have reported activations associated with tactile motion perception in visual motion area V5/hMT+, the primary somatosensory cortex (SI), and the posterior parietal cortex (PPC; Brodmann areas 7/40). However, such studies cannot establish whether these areas are causally involved in tactile motion perception. We delivered double-pulse transcranial magnetic stimulation (TMS) while moving a single tactile point across the fingertip, and used signal detection theory to quantify perceptual sensitivity to motion direction. TMS over both SI and V5/hMT+, but not the PPC site, significantly reduced tactile direction discrimination. Our results show that V5/hMT+ plays a causal role in tactile direction processing, and strengthen the case for V5/hMT+ serving multimodal motion perception. Further, our findings are consistent with a serial model of cortical tactile processing, in which higher-order perceptual processing depends upon information received from SI. By contrast, our results do not provide clear evidence that the PPC site we targeted (Brodmann areas 7/40) contributes to tactile direction perception.

Ad-hoc Mobile Network Architecture Using Distributed P-GW on Unlicensed Bands for LTE

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Proc. of IEEE CCNC 2017 (the 14th IEEE Annual Consumer Communications & Networking Conference), Las Vegas, NV, USA, pp. 749–754, January 2017.

Data traffic has been increasing rapidly in recent years on mobile networks. Several methods using unlicensed bands for LTE are proposed to increase wireless capacity. Stand-alone unlicensed LTE is also proposed as a technology that provides LTE service with only unlicensed bands. In this paper, we propose distributed P-GW systems for stand-alone unlicensed LTE base stations that can provide future mobile services by using an ad-hoc network architecture. Additionally, we evaluate the effectiveness of our proposal in terms of network load, handover latency, and user data plane latency in comparison with the full Cloud EPC model and IPsec model. We reveal that the proposed architecture has an advantage in terms of network loads and end-to-end latency and has an issue with handover latency.
