

2 Terrestrial Communication Technology Research and Development

2-1 Next Generation Mobile Communications System to Realize Flexible Architecture and Spectrum Sharing

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The fifth mobile communication system is expected to be utilized as a communication infrastructure for emerging various applications. It will be operated under coordination of cellular operators who deploy access area universally and micro cell operators who deploy flexible access area in detail with specific performance for use scenarios. In this paper, its concept and necessary system architecture are proposed as well as functional verification using a prototype system. Also, issues on international roaming of mobile communications system are summarized.

1 Introduction

The requirements for a fifth generation mobile communications system (5G) have been defined as enhanced mobile broadband, ultra-low latency, and massive Machine Type Communications. The goals for 5G communication performance are much higher than those of conventional mobile communications systems, including a maximum transmission speed of 10 Gbps, a connection density of 1 million devices per square kilometer, and latency of around 1 millisecond[1]. Many new applications requiring 5G communication performance are expected to emerge in the coming age of the Internet of Things (IoT). Examples of these include on-demand transmission/viewing of high-definition video, self-driving assistance for motor vehicles and real-time remote control of robots, and the collection of sensor data required for daily life. While 5G is a mobile communications system, it is likely to become the technology that enables the aforementioned applications to be brought to fruition, as the need for communications in social infrastructure grows in the future.

Developing a single wireless system that satisfies all of the requirements of 5G communication performance will be difficult, so 5G systems will basically be composed of heterogeneous wireless networks that adaptively combine wireless systems with different communication capabilities. The approach centered on extensive access areas that has been the concept underpinning conventional mobile communications systems cannot be used to deploy access areas

that satisfy different service requirements. As such, it is necessary to deploy microcells meticulously tailored to the location and conditions using low-power base stations with different capabilities. A single mobile operator is unlikely to be able to undertake the development of this kind of network alone, so it will be necessary to establish the new 5G concept of multiple mobile operators cooperating organically based on uniform rules.

Those with the best understanding of the functions and capabilities required by individual services are the managers of those facilities and service providers. Accordingly, an effective approach to the use of microcells is to ensure that both microcells installed by mobile operators in the conventional way and microcells installed at the wishes of those facility managers/service providers are integrated as infrastructure in a way that guarantees a certain degree of reliability in respect of mobile communications system performance. In that situation, the ongoing operation of existing mobile communications systems by mobile operators should be guaranteed, so it would be desirable to keep interface expansion to the minimum necessary level, without impacting on the design concept of mobile communications systems, as far as possible.

Frequency allocations for mobile communications systems are already tight, so allocating frequencies for the operation of a large number of microcells would be problematic. At the ITU's World Radiocommunication Conference (WRC) in November 2015, participants agreed to include an item (Item 1.13) on the agenda for WRC-19

— to be held in 2019 — concerning the identification of frequency bands for the future development of international mobile telecommunications (IMT) in the 24.25–86 GHz range. As such, it is likely that some of the new frequencies for operating microcells will be in the millimeter wave range. The key feature of microcells is their small cell radius, so in this situation, cell placement is not expected to be as comprehensive as with conventional macrocells. From the perspective of radio wave propagation, there is considerable free space propagation loss in the millimeter wave range, so buildings and similar structures are likely to cause substantial attenuation. Consequently, as this reduces concerns about mutual interference due to sharing the millimeter wave range, there is a strong possibility that the need for stringent management of frequency allocations for base stations will disappear. However, it is not practical to manage frequency allocations individually for the plethora of microcells likely to be deployed. Given that it would therefore be preferable for microcells to share some frequency bands, research and development of the technological components required for this is necessary.

NICT has, for many years, been conducting research and development focused on control algorithms and system architecture for the basic technology of cognitive wireless networks, aiming to bring to fruition heterogeneous wireless networks that allow cooperation among mobile operators. Some technologies were demonstrated to be effective through real-world verification on a municipal scale[2] and support provided for areas affected by the Great East Japan Earthquake[3]–[5], among others, and were put to practical use in the form of a cognitive wireless router[6]. In addition, this work made a substantial contribution in such areas as the formulation of IEEE 1900.4[7][8], the world's first international standard for the fundamental architecture of cognitive wireless networks. Given that it was predicated on cooperation between separately managed wireless networks, it is likely that this research and development work by NICT was tremendously significant as research and development focused on basic technologies and, more recently, their practical application, as it corresponded with the aforementioned concept of 5G. However, these deliberations were conducted independently of the standards formulated by the Third Generation Partnership Project (3GPP), which focuses primarily on mobile communications systems. As such, when looking ahead to full-scale commercialization in the future, further deliberations will be required to map the technologies required

against the functions prescribed in the 3GPP standards, in accordance with the common interface. Accordingly, in light of the medium to long-term plan that began in April 2016, NICT is conducting research and development focused on technology for making the aforementioned 5G concept a reality, taking into account 3GPP's deliberations on a 5G standard.

At the same time, in the realm of spectrum sharing, NICT has also been engaged in research and development of television white space technology (TVWS technology)[9]. It is technically difficult to control interference between television broadcasts, which involve high-power, one-way transmissions, and low-power, two-way wireless communications. The basis of TVWS technology is a central control system that uses a database to avoid interference, of the kind seen in regulations in many countries. However, further research and development is required, as a simpler, more effective system could likely be devised with a view to spectrum sharing by low-power microcells in 5G systems.

As well as introducing the concept of private areas in mobile communications systems as a means of making the aforementioned 5G concept a reality, this article proposes system architecture based on 3GPP that would facilitate the flexible installation of microcells in private areas and presents the results of performance tests using a prototype system. In addition, it summarizes the challenges posed to mobile communications systems by international roaming.

2 Microcell operation in private areas

2.1 Introduction of private areas and positioning of microcell mobile operators

Figure 1 shows the concept of cell deployment and device topology envisaged in future mobile communications systems. Cellular mobile operators are mobile operators that carry out subscriber management and deploy and operate macrocells — which have a wide communication range — themselves, as in the case of conventional mobile communications services. In addition to conventional macrocells, which have a communication range of up to 10 km or so, cellular mobile operators also deploy numerous microcells, which use new frequency bands such as millimeter wave bands and mostly have a communication range of no more than 100 m. Cellular mobile operators operate these microcells and macrocells in an integrated way.

In contrast, microcell mobile operators (mobile opera-

tors that deploy and operate microcells with a limited communication range, but do not necessarily carry out subscriber management) are facility managers and communications service providers, which provide mobile communications services to supplement coverage areas that cellular mobile operators cannot fully cover. Devices subscribed to a cellular mobile operator's service connect to and communicate via not only macrocell base stations or microcell base stations operated by the mobile operator to which they are subscribed, like Device A and Device B in Fig. 1, but also microcell base stations operated by microcell mobile operators (the Microcell Mobile Operator shown in green in Fig. 1). In addition, there are devices that microcell mobile operators manage themselves, which are not subscribed to the services of a cellular mobile operator and which only connect to and communicate via the microcell base stations managed by the microcell mobile operator in question, like Device C.

The cell deployment sites in mobile communications systems are examined on the basis of classification into two operational categories — public areas and private areas — as shown in Fig. 2[10]. Public areas are areas in which cellular mobile operators deploy communications services. Private areas, on the other hand, are areas in which cells managed by specific individuals or organizations are deployed; microcell mobile operators deploy cells in private

areas. In private areas, the owner or manager of the facility is likely to have the best understanding of the features and performance requirements of the wireless communications needed, so microcell deployment is based on the wishes of the owner. Conceivable examples of managed areas include companies, train stations, factories, underground shopping malls, universities, commercial facilities, and homes. Public areas cover the whole area, so public areas and private areas will usually overlap.

Private area microcells use the minimum necessary interface to connect to control devices belonging to cellular mobile operators. In addition, they provide cellular mobile operators with information about the location, capabilities (transmission speed, latency, etc.), frequency, and bandwidth of microcell base stations operating in private areas. This information is broadcast within the transmission area using the control channels of cellular mobile operators' macrocells. Devices gain information about the cells deployed by microcell mobile operators by receiving this information. Based on information about such matters as the type and status of the applications used, the load on network equipment, and wireless communication quality, devices then select and connect to the optimal cell from among those of both cellular mobile operators and microcell mobile operators in order to begin communicating.

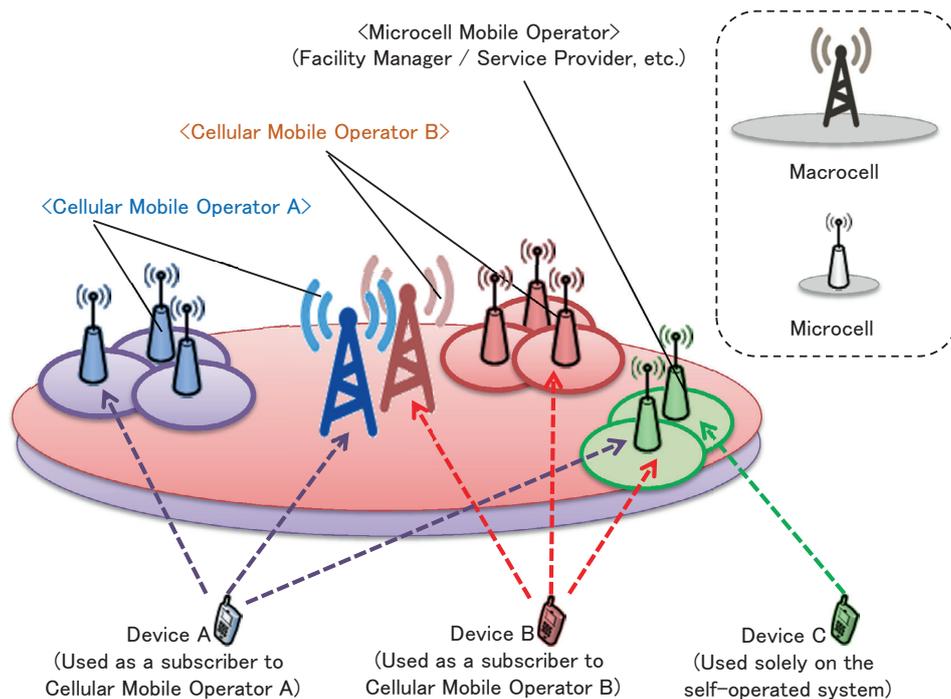


Fig. 1 Cell deployment and terminal topology in future mobile communications systems
(Devices subscribed to either A or B can connect to the green cells)

2.2 Creation of mobile communications businesses and the providers thereof

In this paper, the term “microcell mobile operator” indicates not only telecommunications operators, but also individuals and those who simply manage facilities. For example, if a railway operator or an organization managing a stadium wanted to offer broadband communications to passengers or spectators, it could deploy its own microcell in the station or stadium. Other possibilities include the installation of microcell base stations by a company on its premises or the installation of a microcell in an ordinary home after purchasing a base station at an electronics retailer.

Taking advantage of the fact that they can deploy cells in a flexible way, microcell mobile operators could play a complementary role in areas where it is difficult for cellular mobile operators to deploy cells. In particular, in terms of performance requirements other than broadband, namely low latency, highly reliable massive machine type communication, microcell mobile operators could proactively deploy cells with the necessary capabilities in places where cellular mobile operators have delayed deploying cells on the grounds of unprofitability.

A new system for allocating new frequencies to mobile communications systems — whether based on registration within a specific frequency band or without the need for

registration — could be introduced, rather than simply issuing licenses to specific mobile operators. This would make it easy for microcell mobile operators to install base stations, thereby encouraging the autonomous deployment of microcells and an expansion in wireless communications infrastructure.

Thus, cellular mobile operators could virtually incorporate cells deployed by microcell mobile operators to increase device connection areas and improve communication performance. At the same time, this would mean microcell mobile operators shouldering the burden of deploying communication areas with the necessary capabilities. Consequently, the concept of microcell mobile operators described in this article is not based on the idea of encroaching on the existing businesses of cellular mobile operators; rather, it focuses on the creation of new businesses that make daily life more convenient, while creating a win-win situation for both parties. If this concept of frequency use gains traction, frequencies will transition from being allocated to mobile operators to being shared, facilitating more effective use of radio wave resources, which can ultimately be expected to result in the expansion of business fields.

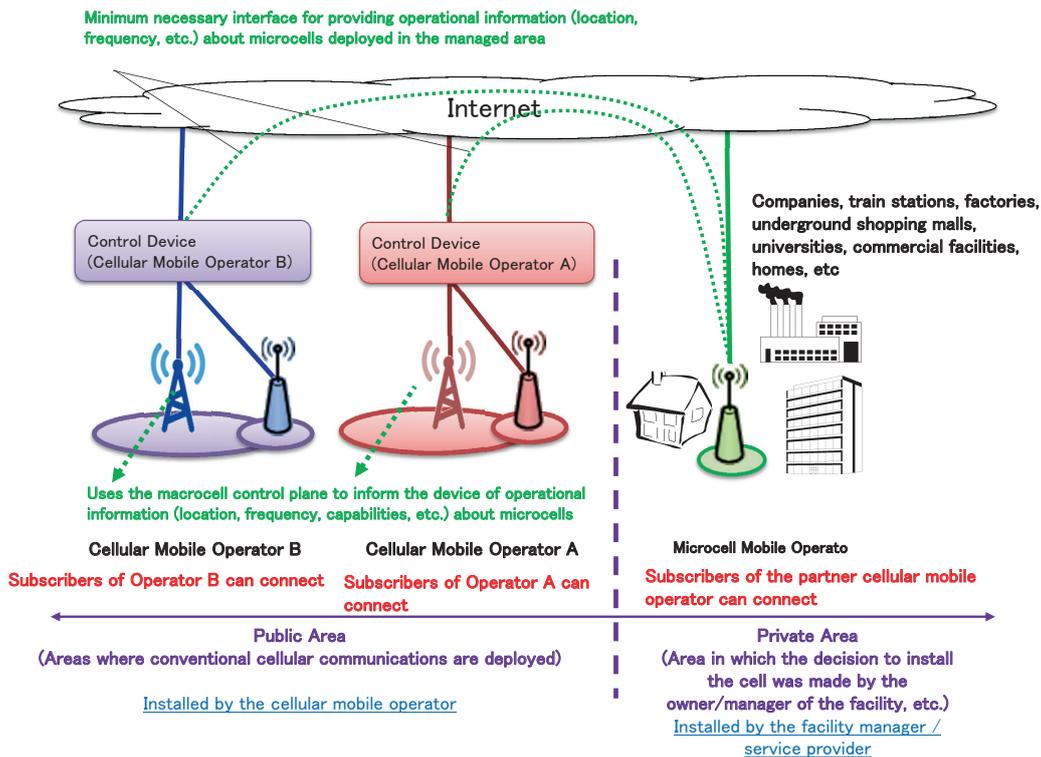


Fig. 2 Introduction of microcell mobile operators in private areas

3 Cooperative control system design and verification

To effectively utilize microcells, it is necessary to provide devices with operational information about microcells operating in a limited part of a private area, including their location, frequency, and communication performance; in addition, devices must be able to select and connect to them appropriately when needed. To achieve this, we propose a system that enables devices to use microcells effectively by providing cellular mobile operators with microcell operational information from microcell mobile operators and using cellular mobile operators' macrocells — with their extensive communication range — to broadcast that operational information.

We will examine the feasibility of the proposed system based on 3GPP standards and identify the technical challenges. In doing so, it will be necessary to actually create the requisite functions based on 3GPP standards in order to evaluate performance, but as the standards for 5G are still under discussion and have yet to be finalized, we decided to test the proposed system based on the 4G standards. While conducting these tests, we will make proposals for the functions required of 5G.

3.1 Outline of the proposed system

Figure 3 provides an outline of the proposed system. It uses the Cell Broadcast Service (CBS) prescribed by 3GPP as a means of transmitting information about the microcells operated by microcell mobile operators. The Microcell Operator Manager (MOM) is a component not prescribed by 3GPP, so we have defined it for the first time. We assume the MOM to be an item of equipment operated by micro-

cell mobile operators. The function of the MOM is to notify the Cell Broadcast Entry (CBE) of operational information concerning microcells operated by microcell mobile operators. As described below, this operational information consists of parameters such as frequency, channel number, and location. This is based on the assumption that each microcell has different operational information. The operational information is broadcast to devices from the cellular mobile operator's eNodeB via the CBE and CBC. The device selects the microcell mobile operator and cell based on that information and connects to the cell[10].

The CBS is created by the Cell Broadcast Center (CBC) and the CBE. Examples of use include earthquake early warning using the Earthquake and Tsunami Warning System (ETWS) prescribed by 3GPP[11][12]. In that case, the Japan Meteorological Agency's earthquake information distribution server, for example, would be the CBE, while the information distribution servers of mobile operators would be the CBCs. The CBC specifies that the information provided by the CBE should be transmitted through the MME by the applicable eNodeB cells.

The relevant cells can be specified on the basis of cell IDs, which are identifiers for cells under the eNodeB; Tracking Area Identifiers (TAIs), which are device location registration units; or Emergency Areas (EAs), which are areas that can be arbitrarily defined by the mobile operator.

3.2 System architecture and control information

Figure 4 shows the proposed system architecture. A cellular mobile operator is composed of a Home Subscriber Server (HSS), a Mobility Management Entity (MME), a Packet Data Network Gateway (PGW), a Serving Gateway (SGW), an eNodeB, and a CBC. These are all components

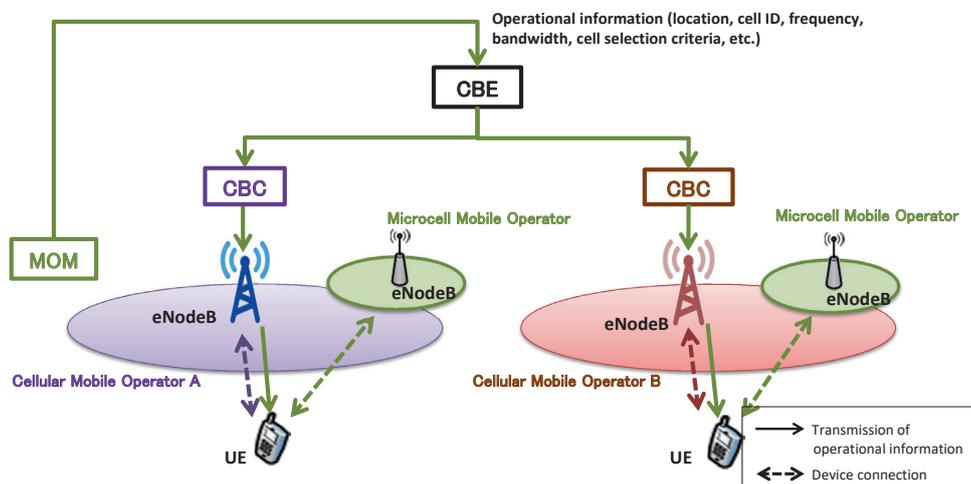


Fig. 3 Cooperation between cellular mobile operators and microcell mobile operators

prescribed by 3GPP.

On the other hand, a microcell mobile operator is composed of an MME, a PGW, an SGW, an eNodeB, and a MOM. As stated above, the MOM is a newly defined component.

We assume two situations involving device authentication by the microcell mobile operator: internal authentication by the microcell mobile operator and forwarding of authentication to the cellular mobile operator. Accordingly, while operating its own internal HSS, the microcell mobile operator also connects to the cellular mobile operator's

HSS. The decision about whether to use the internal or external HSS for device authentication is determined on the basis of the USIM ID and mobile operator ID mapping table held by the MME. As a result of this decision, authentication is assigned to one or other HSS. The HSS to which the MME connects is not necessarily that of a single cellular mobile operator; there may also be cases in which multiple cellular mobile operators are involved.

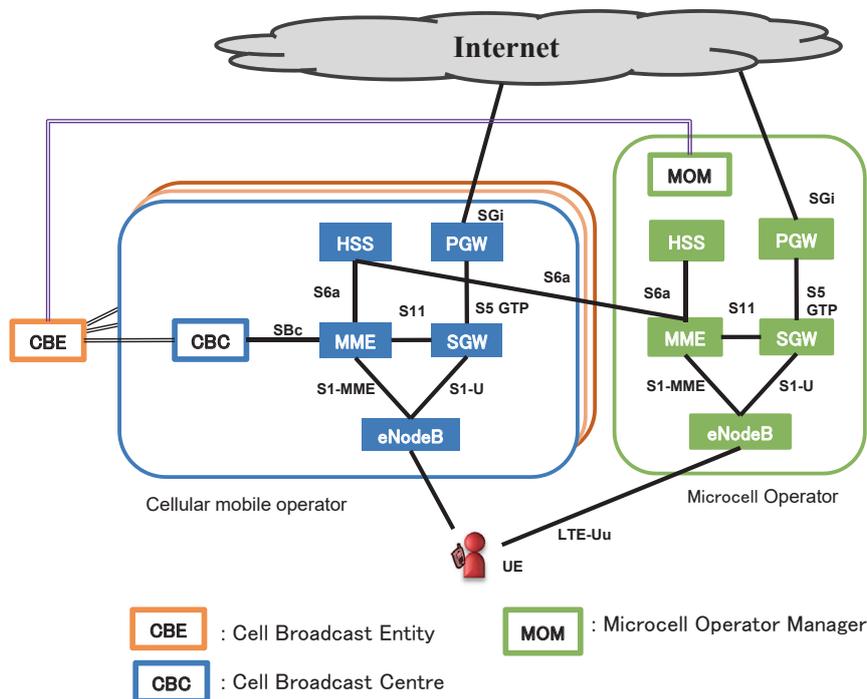


Fig. 4 System architecture for transmitting microcell operational information using the Cell Broadcast Service

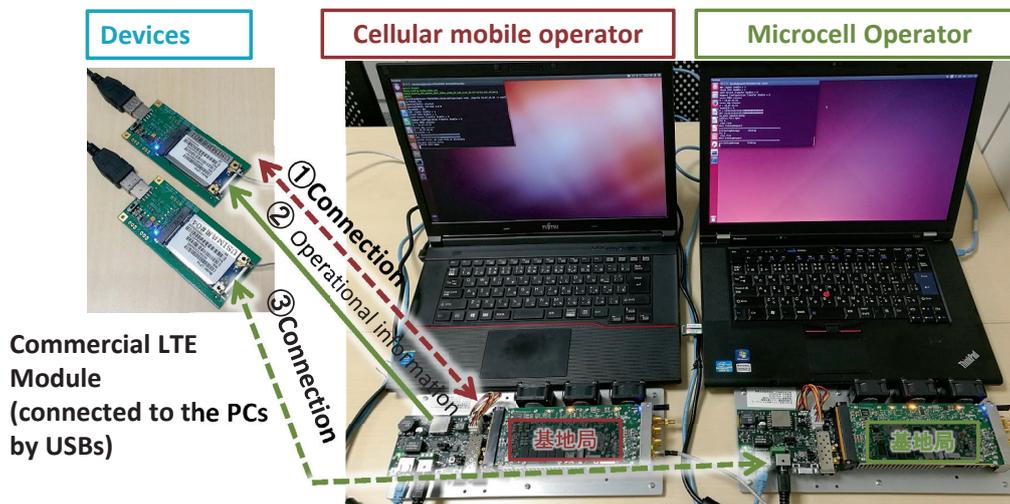


Fig. 5 Development of a prototype for evaluating how the proposed system functions

3.3 Prototype production and evaluation of its functions

Figure 5 shows the prototype produced on the basis of the system architecture in Fig. 4. In this prototype system, we constructed a simulated network with one cellular mobile operator and one microcell mobile operator.

On the PCs, we ran core network functions, including CBC and MOM, for the respective mobile operator networks. We assumed that the CBE is implemented outside the cellular operators as shown in Fig. 4 because this arrangement does not affect system evaluations. However, in reality, we implemented the CBE on the PC where the core network functions of the cellular operator are running. One base station was operating on each mobile operator network. Each base station was allocated a non-overlapping frequency band in the 2.6 GHz band. The devices were commercially available LTE modules compatible with the aforementioned frequency band as laptop computers, which we connected to laptop computers by USB. We used RF cables to connect the base stations with the LTE modules.

Using this prototype apparatus, we confirmed what happened when we ran the system, following the procedure below. The macrocell is the cellular mobile operator’s cell, while the microcell is the microcell mobile operator’s cell.

- (1) The device connects to the macrocell
- (2) The microcell begins operating, and operational information is broadcast from the macrocell and

received by the device

- (3) The device connects to the microcell

When we shut off the microcell’s operations, the device disconnected from the microcell and reconnected automatically to the macrocell.

As a result of this function test, we were able to confirm that the microcell mobile operator’s operational information was transmitted by the cellular mobile operator to the device via the CBS and that this was the catalyst for the device’s successful connection to the microcell.

4 Challenges posed to mobile communications systems by international roaming

The frequencies used for mobile communications systems differ from one country’s system to another. Under existing mobile communications systems, devices are compatible with all possible frequency bands, so they can connect to wireless systems operating on other frequencies, even when in other countries, and are therefore capable of using roaming services, in many cases. However, in the 5G era, a very wide range of frequency bands — including the millimeter wave range — will become candidates for use and there is a possibility that wireless systems based on different standards will be put into operation, to fulfill the functional requirements of enhanced mobile broadband, low latency, and massive Machine Type Communications.

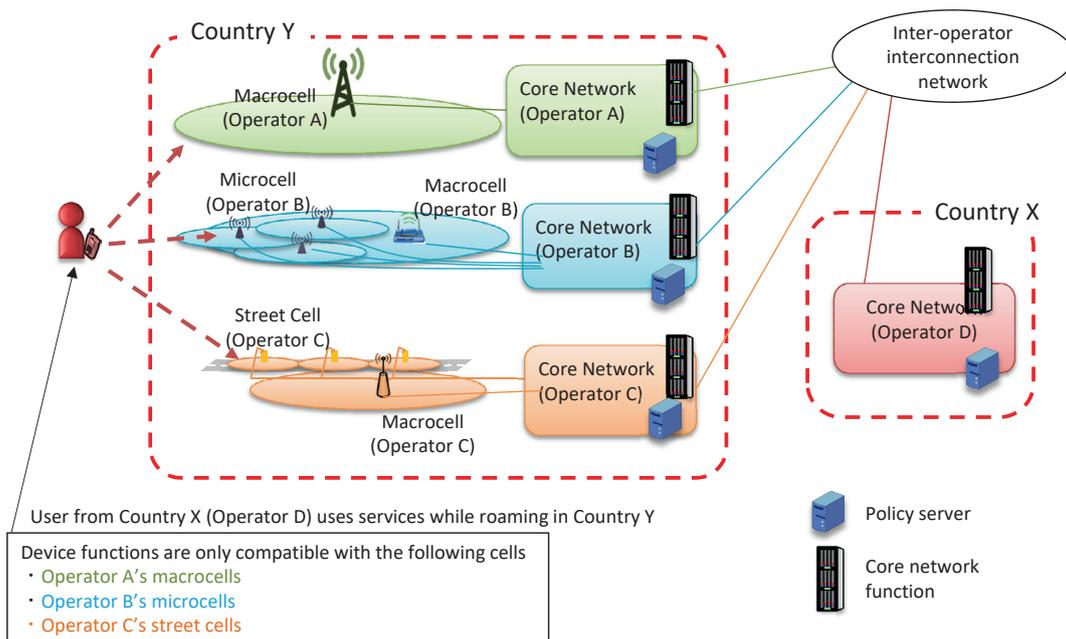


Fig. 6 Challenges posed to mobile communications systems by roaming

In that situation, it will be unlikely that devices will generally have the ability to access all wireless systems.

Figure 6 shows a typical example of a mobile communications system during roaming. Let us consider the case of a user subscribed to Operator D in Country X, who uses a communications system after moving to Country Y. In Country Y, Operators A, B, and C deploy wireless communications services, but Operator A operates macrocells only, Operator B macrocells and microcells, and Operator C macrocells and street cells. Street cells are a series of contiguous microcells laid out in a straight line. In this case, the device is assumed to be compatible only with Operator A's macrocells, Operator B's microcells, and Operator C's street cells. Under the current roaming system, a device can only connect to one of the operators (either Operator A, B, or C) at a time and cannot simultaneously use cells deployed by several different operators. However, the need might arise to connect to both a macrocell and a street cell, depending on the requirements of the applications used at the same time.

The following functions would be required to resolve this issue.

- Core network and device functions that simultaneously accept roaming connections to multiple operators
- Optimal operator and cell selection functions, based on the frequency of the cells operated by each operator and the wireless access technology
- Functions enabling cells operated by different operators to be integrated in the upper layer as needed for communication

We have proposed a system that satisfies these functional requirements and are currently using prototype apparatus to examine how it runs[13].

5 Conclusions

This article explained the need to build infrastructure in mobile communications systems in the 5G era that will facilitate cooperation among not only cellular mobile operators with extensive area coverage, but also microcell mobile operators, which can flexibly and meticulously deploy specialized coverage offering a particular level of communication performance tailored to specific usage scenarios. In addition, it used a prototype to evaluate the proposed system for this. Furthermore, it pointed out the problems faced in international roaming, given that use of

a wider range of frequency bands is envisaged, and indicated the need for future research and development.

Some of the proposals in this article have been submitted to 3GPP SA2 and we plan to continue activities aimed at bringing next-generation mobile communications systems to fruition.

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