INVITED PAPER *Special Section on Radio Access Technologies for 5G Mobile Communications System*

Development of Wireless Access and Flexible Networking Technologies for 5G Cellular Systems

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SUMMARY This paper discusses key technologies specific for fifth generation (5G) cellular systems which are expected to connect internet of things (IoT) based vertical sectors. Because services for 5G will be expanded drastically, from information transfer services to mission critical and massive connection IoT connection services for vertical sectors, and requirement for cellular systems becomes quite different compared to that of fourth generation (4G) systems, after explanation for the service and technical trends for 5G, key wireless access technologies will be discussed, especially, from the view point of what is new and how import. In addition to the introduction of new technologies for wireless access, flexibility of networking is also discussed because it can cope with QoS support services, especially to cope with end-to-end latency constraint conditions. Therefore, this paper also discuss flexible network configuration using mobile edge computing (MEC) based on software defined network (SDN) and network slicing.

key words: *5G cellular systems, massive MIMO, mobile edge computing, IoT, enhanced mobile broadband service*

1. Introduction

In cellular systems, generation is changed every 10 years; analog telephone system as the 1st generation (1G) started in around early 1980s, first digital telephone system as the 2nd generation (2G) in early 1990s, browser phone system as the 3rd generation (3G) in early 2000, and smartphone system as 4th generation (4G) system in around 2010. During these 30 years, although service quality in 1G to 3G systems was bottleneck in the entire networks, service quality of 4th generation system is no longer bottleneck. As a result, in the 5th generation (5G) which will be expected to start around the year 2020, the word "wireless bottleneck" will come to an end and the cellular system will enter to a new era with quite new features.

Since around 2010, the 5G system development was started, and its common understanding is that 5G should be sharply evolved from 4G; i.e., 1) its service is expanded from information transfer services to "connected" services [1]–[3] that connect vertical sectors [4] which are not connected to cellular systems yet, 2) more number of services, especially related to low latency-required services should be supported based on end-to-end quality of services (QoS) guaranteed services [5], and 3) dynamic control functionality is expanded to network in addition to the wireless access to cope with flexible end-to-end QoS support [5].

The first item means, 5G will actively introduce connection services for internet of things (IoT) in addition to the enhanced mobile broadband (eMBB) services [6]. Until 4G, cellular systems have supported mostly information transfer services, where information transferred from a server is transmitted from an access point to a terminal, and acknowledgment and some other control messages are fed back on the reverse link. Thus, main information stream in this case is transmitted on one way direction. In 5G on the other hand, internet of things (IoT) message is expected to be exchanged via cellular networks, for example, sensing data and control command are mutually exchanged for a control system [7]. In this case, ICT network including cellular network is no longer an information transfer system but it is a message exchange system between devices or between controller and controlled devices.

Moreover, although IoT connection might be considered as just an enlargement of devices supported by cellular networks, it is not really. More important point is that IoT connection means a connection of new systems which are not currently connected to cellular systems. In 5G Infrastructure Public Private Partnership (5G PPP) [8], such connected systems are called vertical systems. Some examples that belongs to the vertical sectors are, transportations including automotives [9] and train systems [10], and Industry 4.0 [11]/Industrial Internet [12] systems.

Among various IoT, massive connection IoT which is called massive machine-type communications (mMTC) in International Telecommunication Union Radiocommunication Sector (ITU-R), and mission critical IoT which is called ultra-reliable and low latency communications (URLLC) in ITU-R are the most important IoT communication services.

The second one is; more services will be evolved from best effort services to end-to-end quality of services (QoS) guaranteed services. In 4G systems, because the amount of radio resources is insufficient, services other than voice transmission is conducted based on best effort criteria. However, in 5G systems, because machines are connected, some of them will require low latency or short response time. Moreover, because radio resource for 5G may increase by the usage of centimeter and millimeter waves [13], total bandwidth will be increased by about 100 times compared to that for 4G systems. If so, it may be feasible to introduce more amount of QoS guaranteed services.

Of course, because path loth for upper centimeter and

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millimeter wave signal is so huge, it is applicable only to very small cell size. Fortunately, it can be resolved by introduction of a control-/user-plane (C/U) split introduced heterogeneous network with multiple radio access technology (multi-RAT) [14]–[16], in which most of the control message for each terminal is exchanged via a macrocell, and only user signal is exchanged via a microcell where a RAT that satisfies user requirement in the microcell is applied. Thus, 5G heterogeneous network is exactly the most important and advanced technical subject for 5G.

The third one is related to dynamic operation of networking to satisfy end-to-end QoS support, such as end-to-end latency satisfaction [5]. In 4G systems, short latency is required only for telephone (voice transmission services) which is several tenth ms determined by the sensitivity of human. As a result, a frame length for 4G wireless access is set to 10 ms. On the other hand, in the case of 5G, for mission critical IoT, latency of 10 ms is no longer sufficiently short, rather, end-to-end latency of 1 ms or less is necessary for some systems. When end-to-end latency is 1 ms, latency in wireless access systems should be definitely much shorter than 1 ms. Moreover, link distance dependent delay in a cloud network should also be much shorter than 1 ms. Generally speaking, because configuration of cloud networks is not open to public, it is impossible to control route based on the required latency.

In 5G systems in which very strict latency is required, mobile edge computing (MEC) [5], [17] will be introduced, by which a controller or a contents in a server is moved to an appropriate place that can satisfy user QoS requirement. In other words, network functionality for 5G should be extremely flexible compared to 4G networks.

In addition to the explained new issues, wireless access technology itself should also be enhanced in 5G [18]. The first one is massive multiple-input multiple-output (MIMO) technologies [19]–[21] for further enhancement of spatial spectral efficiency, as well as for its application to beamforming/beamtracking to achieve higher user rate. Moreover, waveform shaping techniques that suppresses out-of-band radiation like filter bank multi carrier (FBMC) technique [22] and sparse code multiple access (SCMA) [23] is also developed for flexible multiple access for massive connection IoT.

Thus, in this paper, after explanation of service and technology trends for 5G cellular systems as the background for 5G development, massive MIMO techniques, end-to-end latency reduction techniques, massive connection, and concept of extreme flexibility for 5G are explained as the most important technologies for 5G systems not only to improve performances from the viewpoint of wireless access but also to improve end-to-end performances determined by the network included configurations.

2. Service and Technology Trends for 5th Generation Cellular Systems

Figure 1 shows market expansion and related technologies

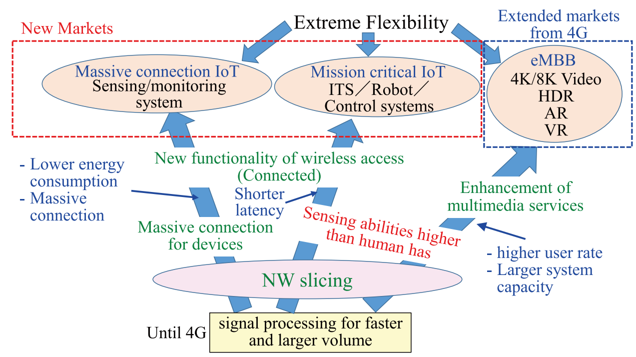

Fig. 1 Market expansion of 5G cellular systems.

for 5G cellular systems. Until 4G systems, broadband multimedia has been the main service in cellular systems. The multimedia service is based mostly on best effort criteria because latency is prescribed only in telephone support, and the other services are very tolerant to latency.

In 5G, mobile broadband services are still enhanced. Some examples are 4K/8K video, virtual reality (VR)/augmented reality (AR) and high dynamic range (HDR) technologies. These services are categorized as eMBB.

In 5G, mission critical IoT and massive connection IoT will be introduced as the connected services [5]. In the case of mission critical IoT, automotives, trains, factory machines, etc. are controlled via cellular networks and very strict end-to-end latency is required. In the case of massive connection IoT, on the other hand, although strict latency constraint is not imposed to and required data size for each transmission is not so large, massive amount of devices might require transmission at almost the same time. In this case, we have to consider the following two issues; reduction of overhead because data size is small, and the receiver has very high level flexibility in separating the simultaneously received signal, because the number of simultaneously received signals dynamically changes in time and space.

Because mission of 5G is not only message transfer but also a message exchange for mission critical IoT and massive connection IoT, utilization of radio resource should be changed more dynamically compared to the conventional multimedia information transfer services.

In addition, to cope with diversified user requirements as well as its dynamic variation in space, "extreme flexibility" is set as the highest ranked keyword for 5G systems.

Figure 2 shows the relationship between 5G network technologies and connected services/systems/societies in the 5G era. In 5G, in addition to flexible wireless transmission and access technologies introduced until 4G era, system will extend their services to "connected services" that includes mission critical IoT and massive connection IoT, such as intelligent transport systems (ITS) [23], factory machine [24], etc.

Figure 3 shows the relationship between operations of AP, heterogeneous network and cloud network. Even in 4G systems, adaptive and flexible usage of spectrum in each

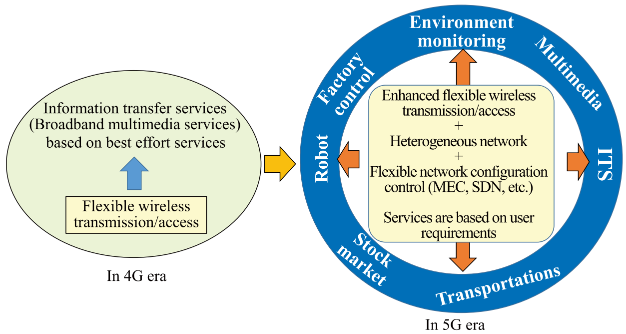

Fig. 2 Relationship between 5G network technologies and connected services/systems/societies in the 5G era.

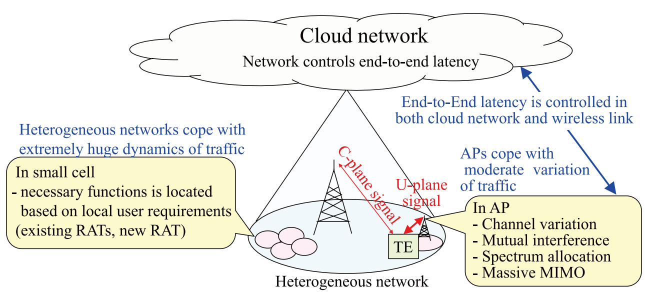

Fig. 3 Relationship between operation of AP, heterogeneous network and cloud network in 5G systems.

link is done using adaptive modulation and coding (AMC) and two dimensional radio resource management (RRM). In 5G, in addition to these techniques, massive MIMO further enhances the range of spectrum usage. However, flexibility range still stay in a moderate level.

Heterogeneous network using C/U split will drastically enhance flexibility range to an extreme level. As shown in Fig. 3, when user requirement in a local area becomes extraordinary, small cell with a necessary functionality is operated in such an area, for example, when broadband multimedia traffic in an area suddenly increases, microcells with high capacity are operated to mitigate traffic congestion, and when extremely low latency is required, microcell with a new RAT that satisfies this requirement are operated [25], [26].

When end-to-end latency is satisfied, in addition to the latency control in wireless access links, latency determined by the link distance in a cloud should also be controlled [5]. In 5G systems, latency in a cloud is controlled by MEC with the assistance of network softwarization and network slicing, in which network softwarizarion means to construct network functionality using software modules to achieve flexible and dynamic network support. As a result, responsibility for latency satisfaction should be appropriately shared between radio access and network.

Table 1 shows shift of requirements from 4G to 5G cellular systems. Although 4G support only information transfer services, 5G is required to further include mission critical and massive connection IoT in addition to eMBB. When IoT support is included in cellular systems, performance evaluation criteria is also changed. In the case of

Table 1 Shift of requirements from 4G to 5G.

Check point	Technical change from 4G to 5G (4G → 5G)	
Type of transmit information	Information Transfer	Connected services (mission critical/massive connection IoT are further introduced in addition to eMBB
Performance evaluation	Evaluated based on feeling of human (E2E latency ~ 10 ms)	Evaluated based on sensitivity of connected machines (E2E latency < 1 ms)
Extreme flexibility	Flexible management is supported by AMC and 2D scheduling, cell and network configurations are static.	The following items are further introduced in 5G to enhance system flexibility - 3D beamform - HetNet with multiple RATs - Flexible networking using MEC, SDN, network slicing

4G, because most severe constraint service requirement is based on the feeling of human sensitivity, latency of several tenth ms is sufficient. However, in 5G, service is enhanced to machine connection, for which QoS requirement is based on the sense of connected machines, and in this case, latency of 1 ms is or less would be necessary.

Moreover, although flexibility in 4G is mainly supported by the wireless access and network side is almost static, flexibility in 5G becomes more flexible: In wireless access side in 5G, in addition to three dimensional beamforming and beam tracking techniques in wireless access side, heterogeneous network with multiple RAT is introduced to cope with extremely huge variation of spatial user requirements. Furthermore, in the network side, network configuration is also dynamically controlled using MEC and network slicing, thereby end-to-end QoS is jointly controlled by the wireless access and network.

Based on the understanding, 5G specific technologies will be explained in more detail in the following sections.

3. Wireless Access Technologies for 5G Cellular Systems

3.1 Massive MIMO and Its Applications to Beamforming Antenna to Mitigate Near-Far Problems

Massive MIMO [19]–[21] in which huge number of antenna element is integrated in AP, is one of the most important technologies for 5G systems. In 5G systems, conventionally used spectrum in the range of lower than 6 GHz and new bands in above 6 GHz will be used. For above 6 GHz band, WRC-15 decided to invite studies of sharing and compatibility between 5G and existing services in the band 24.25–86 GHz [13]. In massive MIMO [27] cases, when the number of antenna elements is quite high, 100 or more, due to channel hardening effect [28], Gram matrix for the channel can be approximated by a diagonal matrix, thereby suppressing computation complexity to calculate inverse-matrix of Gram matrix used in the MIMO signal separation. As a result, the number of computation for massive MIMO is reasonable even if the number of antennas is quite huge. Actually, in this case, very good performances are reported [28], and it is especially good when the operated spectrum is in the range of 24.25 GHz or more because quite a large number of antenna element can be included in a specific area of antenna module

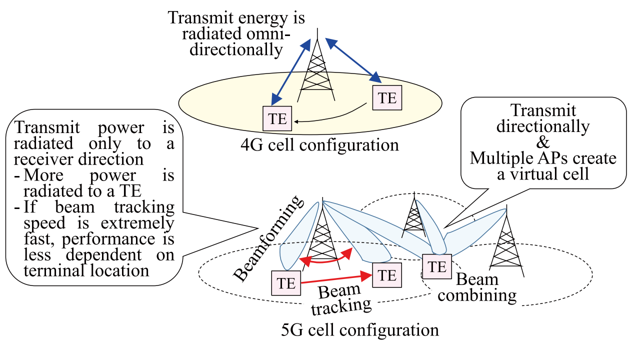

Fig. 4 Cell configuration for 4G and virtual cell configuration in 5G.

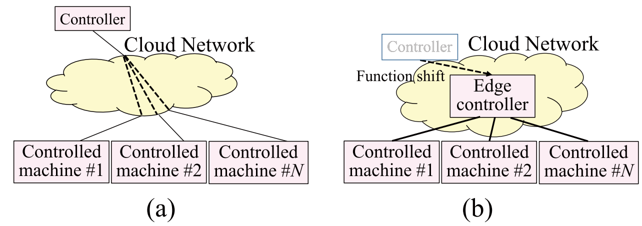

Fig. 5 Configuration of a control system for (a) conventional scheme and (b) MEC used 5G system.

[29]–[31]. When operated spectrum is selected from below 6 GHz band, on the other hand, because antenna distance in a MIMO antenna module is not short, the number of included antenna elements tends to be below 100, in which case it is quite hard to approximate Gram matrix for the channel as a diagonal matrix [32]. This type of MIMO configuration is categorized as a large MIMO (10 to 100 of antenna elements). In this case, it is necessary for the MIMO signal separation to reduce the number of computation even if Gram matrix is non-diagonal. Recently, normalized matched filter belief used Gaussian belief propagation (GaBP) algorithm is proposed to suppress the impact of ill convergence behavior of iterative detection due to lack of channel hardening effect in large MIMO cases [32].

In addition to channel capacity enhancement property by the massive MIMO, massive MIMO is also effective when it is used as a high gain beamforming antennas [33]. On the top of Fig. 4, a conventional (4G) cell configuration is shown. From an access point (AP), a signal is transmitted omni-directionally, and each terminal equipment (TE) receives the signal at any point in a cell. On the bottom of Fig. 4, application of beamforming antenna and virtual cell concept is shown [33], [34]. In 5G systems, transmit signal from each AP will be radiated using a beamforming antenna to each TE in many cases because of the following reasons;

Until 4G, optimization of a receiver is almost done. However, in 5G, its peak user rate will be still increased by 10 times or more, which means we need to further increase transmit power density. Of course, it is not preferable to further increase transmit power, which means the only thing we can do is to enlarge transmit antenna gain using beam forming antennas.

Fortunately, when higher frequency is utilized, we can accommodate more antenna elements in an antenna module [31]. When beamforming is employed in the transmitter side, signal is radiated with higher spatial power density, and can mitigate near-far problem of the performances [31].

One more important issue for beamforming is, because beam width becomes narrower for higher number of antenna elements, it is less probable to occur inter-user interference. With almost the same reason, Doppler spread in the received signal becomes smaller, although Doppler shift is still determined by the terminal velocity and direction of the arrived signal.

With these considerations, massive MIMO will be the most important key technical subject area to enhance spectral efficiency, to mitigate performance difference between terminals located closer to an AP and terminals in the cell edge, and to microscopically control each user's transmission quality.

As for realization of massive MIMO antennas, in addition to all digital antennas, analog-digital hybrid combined antenna [20] is developed from the view point of lower energy consumption.

3.2 Reduction of End-to-End Latency

End-to-end latency satisfaction is a new criterion in 5G, because several tenth ms of latency in wireless access is sufficiently short for telephone based on the sensitivity of human being. That is why, latency in 4G wireless access is set to be several tenth ms. However, when IoT connection is introduced in 5G, several tenth ms of latency is no longer short enough for machine control. That is why shorter latency, i.e., 1 ms of end-to-end delay is discussed in 5G system developments.

Figure 5 shows a configuration of a control system for (a) conventional scheme and (b) MEC used 5G system. When a controller and controlled machines are connected via a cloud network, end-to-end latency might be longer than that required by the connected devices. In other words, to accurately satisfy a required latency conditions, a controller should be located closer to the controlled machine. In the MEC employed 5G systems [5], a controller functionality is shifted to an edge controller that is located closer to the controlled machine as shown in the right side in Fig. 5(b).

In addition to the MEC, network slicing and network softwarization are included in the network to further enhance flexibility of networking.

Figure 6 shows a configuration of networks that include network softwarization, network slicing and MEC [5]. For flexible and dynamic operation of 5G networks as well as prompt delivery of new services with lower equipment and operation costs, network softwarization using software defined network (SDN) technology will be introduced in the 5G network. Moreover, based on the required functionalities for each service, the network is dynamically sliced to create an optimal network functionality for each service depending on the actual user requirements and network operation

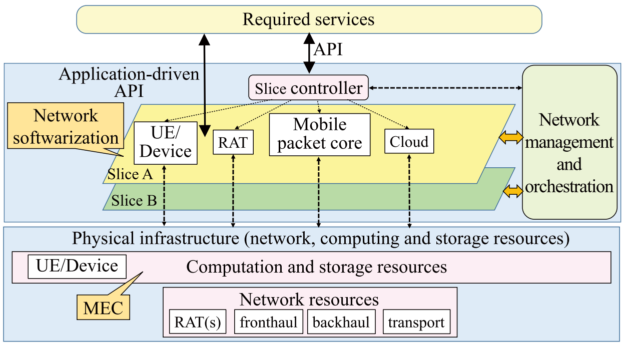

Fig. 6 Configuration of network that includes network softwarization, network slicing and MEC.

conditions. On top of that, MEC is dynamically operated.

Until 4G era, because improvement of wireless access functionality was the most important issue, network improvement was mainly focus on creating almost static all IP networks. In the 5G era, development of cellular network is then shifted to a new era, from almost static all IP networks to dynamically operated all IP networks in which end-to-end QoS for services will be supported. Thus, development of dynamically operated all IP networks is one of the most important key issues for 5G system development.

3.3 Massive Connection Concept

In 5G era, anything existing around our life space will be connected. Compared to the number of smart phones, the number of IoT device is at least 100 times more [7]. Services that connect such huge amount of devices are called massive connection. First, problem for massive connection is, data size is quite small, thereby the amount of overhead tend to be relatively large. Because overhead ratio in each packet should be as small as possible, random access that does not have extra overhead for radio resource allocation is considered to be the most suitable access scheme. Secondly, because data transmission occurrence for each transmission is sparse in time, the number of simultaneous transmission users dynamically changes [7], [35], [36], i.e., in some cases, there is no simultaneous transmission whereas in some other cases, large number of simultaneous transmission may occur. Thus, signal transmission schemes that accept moderate level of mutual interference are proposed for massive connection IoT to obtain larger number of available channels, in which interference cancelation combined with some adaptive reception techniques are employed to appropriately separate simultaneously transmitted signals [37]. Some examples are non-orthogonal multiple access based scheme [38] and sparse code multiple access (SCMA) based scheme [39]. To further enhance flexibility to cope with simultaneous transmission devices, MIMO combined scheme is also proposed [40].

3.4 Support of Extreme Flexibility

Even until 4G, flexibility has been the most important concept for wireless access systems, because it is mandatory for wireless access systems to perfectly compensate for channel variation as well as to suppress the impact of interference. In 3G, adaptive modulation and coding [41] was introduced to mitigate the impact of channel variation on the received signal quality. In 4G era, user diversity concept called two dimensional scheduling [42] was introduced in the RRM, and MIMO technology that actively utilize nature of wireless channel dynamics was introduced. As a result, wireless channel variation is no longer a cause of performance degradation, and wireless transmission/access techniques have wide dynamic range of flexibility in coping with channel quality variation even until 4G era.

However, dynamic range for 4G is still insufficient to cope with extreme variation of user traffic, especially when a big special event happens. Thus, to commercially operate 5G by the time for Tokyo Olympic 2020, 5G technologies that can cope with such dynamic traffic are planned to be developed.

Multiple RAT heterogeneous network is exactly one of the most suitable technology to cope with this requirement. Actually, heterogeneous network is already specified in 4G. However, RAT used in the subnetwork in 4G heterogeneous network is just the same as that used in macro cell, and only difference is the transmit power, because heterogeneous network for 4G is designed to cope with spatial dynamic variation of total traffic. In 5G, on the other hand, in addition to coping with spatial total traffic variation, types of services (low latency, low power, etc.) are also considered as the cause of local dynamics, and if necessary, new RAT that can cope with the given requirement will be included in the subnetworks.

Because dynamic range of flexibility in 5G is extremely high compared to that of 4G, Fifth Generation Mobile Communication Promotion Forum (5GMF) has set “extreme flexibility” as the most important conceptual keyword for 5G technical developments.

4. Conclusions

In this paper, after explanation on service and technology trend as the back ground for the development of 5G cellular systems, key wireless access related technics are explained.

The most important challenge for 5G system is the expansion of cellular services, which is not simply the expansion to the connections of IoT devices but to the connections of IoT systems included in vertical sectors for cellular systems. For this change, QoS is determined not only by the human sensitivity but also by the mechanics sensitivity. As a result, end-to-end latency conditions for 5G becomes severer, around 1 ms. However, there are many machines that require end-to-end latency of shorter than 1 ms. Thus, 1 ms of end-to-end latency should be considered as the starting point of QoS for 5G cellular systems and it will be improved further in the future.

Next point to claim is, due to strict end-to-end latency conditions, network flexibility in addition to the wireless access flexibility becomes mandatory for 5G cellular systems. Because end-to-end QoS requirement would be getting tighter, network functionality should also be more flexible in the future.

As for wireless access technologies, they should be polished more to reduce service divergence due to locations of devices. Moreover, for massive connections, wireless access system should be extremely flexible to variation of the number of simultaneously connected devices in massive IoT services.

Anyway, 5G that will be started in early 2020 will be drastically new systems and 5G connected world hope to be highly convenient and comfortable.

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