ARIB 2020 and Beyond Ad Hoc Group

White Paper

Mobile Communications Systems for 2020 and beyond

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Association of Radio Industries and Businesses (ARIB)

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Scope

This document summarizes the results of studies on system concepts and technical trends of mobile communications systems in 2020 and beyond. The study on system concepts includes market and user trends, traffic trends, cost and spectrum implications, usage scenarios, requirements and capabilities of mobile communications systems in 2020 and beyond. As for the study on technical trends, this document addresses radio access technologies and network technologies of mobile communications systems in 2020 and beyond.

Although this document mainly addresses radio aspects, non-radio aspects are also addressed to clearly depict a full picture of mobile communications systems in 2020 and beyond.

1 Introduction

Mobile communications systems have been playing prominent roles in the society over the last couple of decades, and against the backup of the recent boost in mobile data traffic, they are expected to play even more important roles in the years to come. This white paper entitled *"Mobile Communications Systems for 2020 and beyond"* was developed by "2020 and Beyond Ad Hoc (20B AH)"of Association of Radio Industries and Businesses (ARIB), Japan to describe vision for the terrestrial mobile communications systems planned to be commercialized in 2020 and beyond (See Annex C).

The paper first addresses the socio-economic environment surrounding 5G, including market and user trends, traffic trends, and spectrum implications in the 5G era. It then identifies the ever increasing roles of 5G and its typical usage scenarios. Cost implications, which are critical for wide-range deployment of 5G systems, are addressed in Chapter 5. New capabilities and the framework expected for 5G are shown in Chapter 8, where the capabilities of 5G are illustrated from a broad perspective, in particular, in comparison to IMT-advanced systems. Also in Chapter 8, several diagrams are proposed to address the capabilities of 5G. Then, a definition of "5G" from the perspective of radio access technologies is proposed in Chapter 9. In Annex A, which is entitled "5G Radio Access Technologies", numerous technologies in various categories required for 5G development are identified.

Throughout the paper, the term "5G" is tentatively used to denote the mobile communications systems to be commercialized in 2020 and beyond.

2. Objectives

The primary objective of the paper is to capture agreement on roles and expectations for 5G and to identify enabling technologies for 5G. The output of the paper will be made public by taking advantage of various occasions and fora in and outside Japan. It is also the objective of the paper to send messages and proposals to the industries, governments, and academia to promote and stimulate 5G development.

3. Market and User Trends of ICT

In this chapter, overall market and user trends of ICT in the 5G era are addressed without limiting its scope to the trends of 5G mobile communications systems. In the subsequent chapters, the discussion will be focused on 5G.

The world today is empowered by information: the opportunities created by ICT development are one of the main impacting factors on how the society has evolved in the past decades. Actually, the Internet has become an indispensable tool in everyday life. It is expected that ICT development will make further progress, resulting in creating the environment where everything can be done via the Internet in 2020 and beyond. In other words, the use of ICT will further increase and ICT will be applied to diversified services.

For example, ICT will be required to deal with a huge amount of data in a wide variety of applications, thereby fostering innovation in different industries, e.g. M2M, as shown in Fig. 3-1. M2M will allow wider and efficient deployment of infrastructure monitoring aimed at disaster prevention, environment conscious and innovative agriculture with saving water, tailored health monitoring, etc.

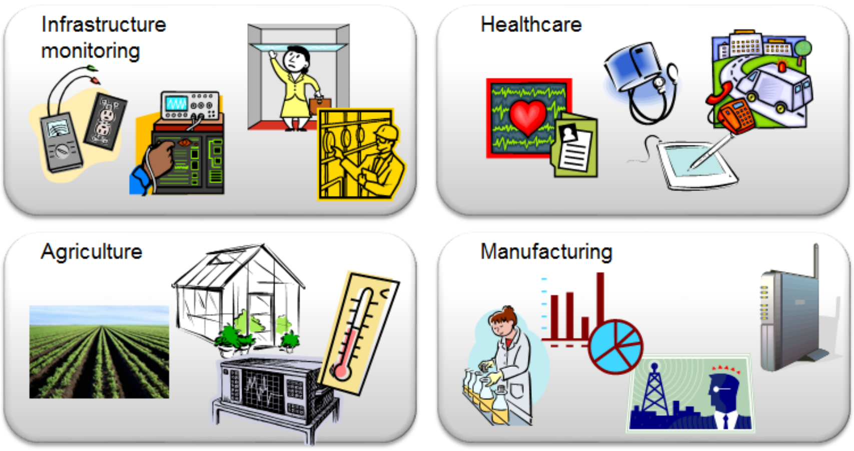


Fig. 3-1 ICT dealing with a huge amount of data coming from a wide variety of applications

ICT will also support flexible life styles, e.g. working, learning, shopping, creating community and interest groups as shown in Fig. 3-2. Younger generations now use the Internet for social networking, online gaming/education, and are enjoying/creating multi-media contents such as movies and music. Future trends of services and applications are generally shaped by the evolution of needs of new generations of users and entailing diversified life styles.

Fig. 3-2 ICT supporting flexible life styles

ICT will also need to address socio-economic requirements, such as disaster prevention and relief efforts, super-aging society, resource problems, and environmental problems as shown in Fig. 3-3.

Regarding the disaster prevention and relief efforts, our society has frequently suffered from natural disasters, such as earthquakes and eruptions. When a wide-scale disaster happens, infrastructure may be damaged and a huge number of people may suffer, e.g. losing their houses. Hence, disaster prevention and relief efforts by means of ICT are strongly demanded in our society.

Regarding the super-aging society, difference between the number of elderly and younger people is increasing in the developed countries. Fig. 3-4 shows the estimation of old-age dependency ratio in Japan. In such a society, working-age people will bear heavy burdens of taking care of elderly people, hence there will be demand for ICT to ease the burdens in medical/health care and nursing care.

With the increase in population and development of ICT on a global scale, energy consumption is expected to boost, and it may cause depletion of the underground resources. Therefore, ICT realized with low power consumption is critical.

Regarding the environmental problems, environmental destruction has still been observed and we need to prevent further environmental damage. Hence reduction of emission associated with transportation and electrical power generation is strongly demanded.

Fig. 3-3 Socio-economic requirements such as disaster prevention and relief efforts, super-aging society, resource problems, and environmental problems

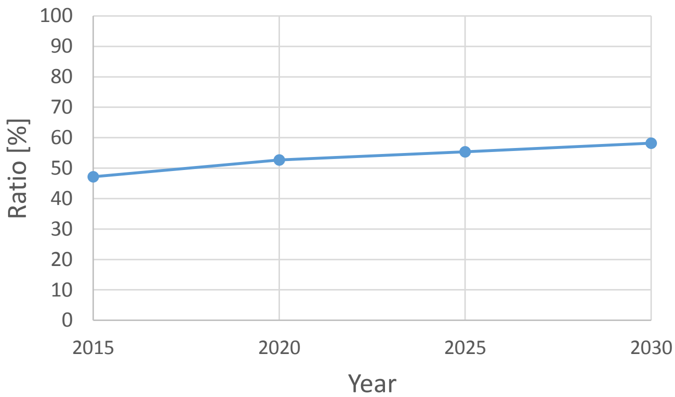


Fig. 3-4 Estimation of old-age dependency ratio in Japan (Age 65+ / Age 20-64) [1]

4. Traffic Trend

Over the past few years, there has been significant growth in the volume of mobile data traffic following the proliferation of smartphones and new mobile devices that support a wide range of applications and services. There is a general consensus in the industry that such growth will continue well into the future. Data traffic in super dense area, such as train stations, stadiums, shopping mall, is expected to become extremely high. The growth will also be accelerated by new types of communication services and involved devices, such as proximity services including device-to-device (D2D) communications and machine to machine communications (M2M).

4.1 Future trend of video data and video traffic

An enhancement of high definition video such as 8K Ultra High Definition (UHD) will be available around 2020. The number of pixels of visual contents increases accordingly as shown in Fig. 4-1. The increase in the number of pixels will not be directly translated into traffic volume, however, impact on traffic volume is inevitable. The provisional estimate of the total video communication traffic in 2020 carried over mobile and fixed systems is more than 2600 times the traffic in 2010 (see Annex D). This will have a certain impact on mobile traffic volume.

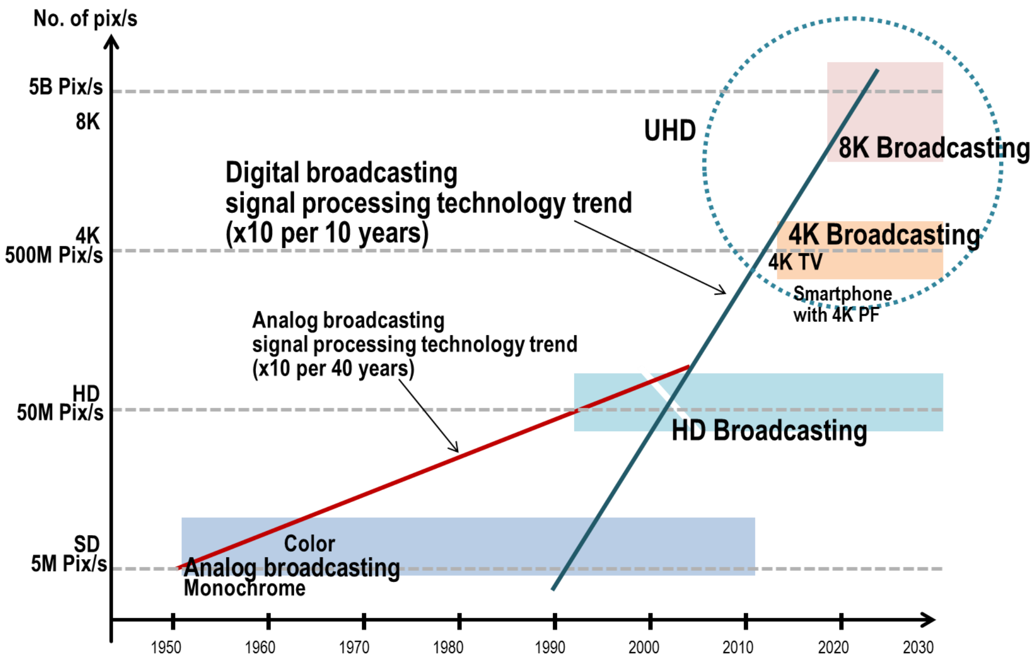


Fig. 4-1 Increase in information volume of visual content

4.2 Traffic variation and environmental dependency

Traffic volume varies greatly depending on time, locations, applications and devices, and as a result, traffic distribution becomes more and more uneven and not uniform these days. The trend of traffic non-uniformity will also be prevalent in the 5G era, when services will be more diversified and require richer contents, and traffic distribution will become denser. Regarding indoor/outdoor traffic ratio, it is reported that at least 80% of the total mobile traffic comes from indoor locations [2]. On the other hand, it is also well known that the indoor/outdoor traffic ratio highly varies depending on time and locations: outdoor traffic is dominant, e.g. during the daytime as shown in Fig. 4-2.

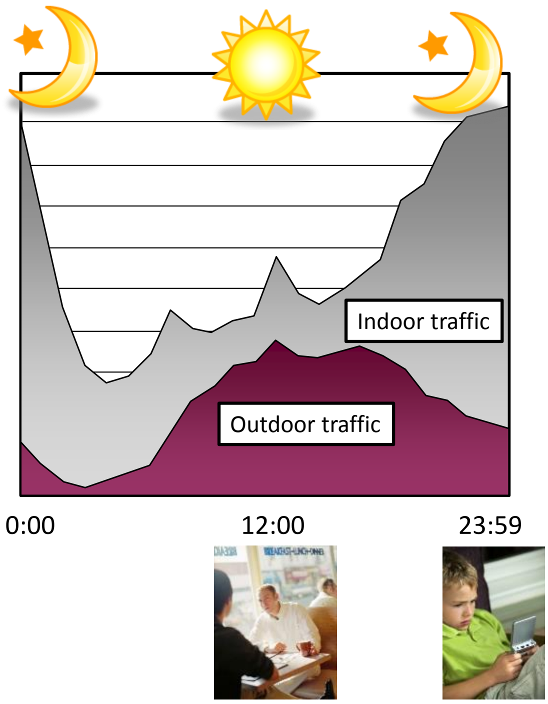


Fig. 4-2 Example of indoor/outdoor traffic variation during a day

4.3 Mobile traffic growth in the past and future

Regarding uplink/downlink traffic ratio, downlink traffic would continue to be dominant in many locations, however, the growth rate of uplink traffic is expected to be higher than that of downlink traffic, and such trend has been observed recently in Japan as explained below. In some crowded events such as sporting events and at concert venues, many photos and video are taken and uploaded simultaneously, therefore, traffic volume of uplink would be significantly high and may exceed that of downlink in some cases.

This tremendous increase in the volume of mobile data traffic was not foreseen before WRC-07. For instance, actual data traffic in 2010 was more than five times greater than some of the estimates in Report ITU-R M.2072. According to the recent report of MIC (Ministry of Internal Affairs and Communications) shown in Fig. 4-3-1 to Fig. 4-3-3, the growth rate of mobile traffic in the past 3 years was around 1.7 per year as a whole and downlink traffic accounted for nearly 90 percent of the total traffic. Growth rate of downlink traffic is around 1.7 per year while that of uplink is slightly higher and around 1.8 per year. The growth rate in busy hour around 23 o'clock also shows a similar tendency to that of the average traffic growth.

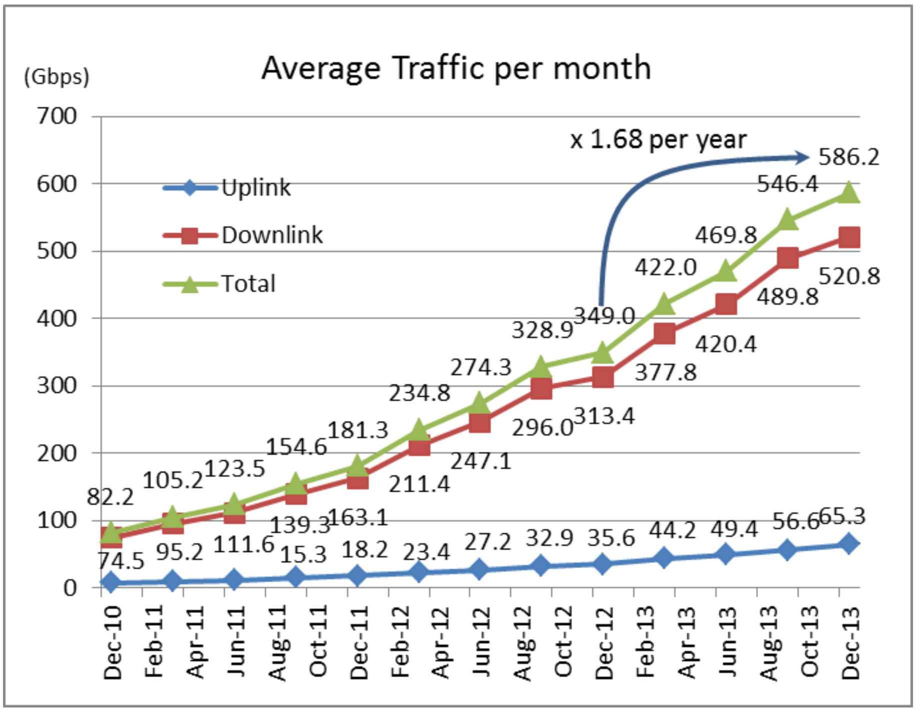


Fig. 4.3-1 Average traffic of mobile communications in Japan [3]

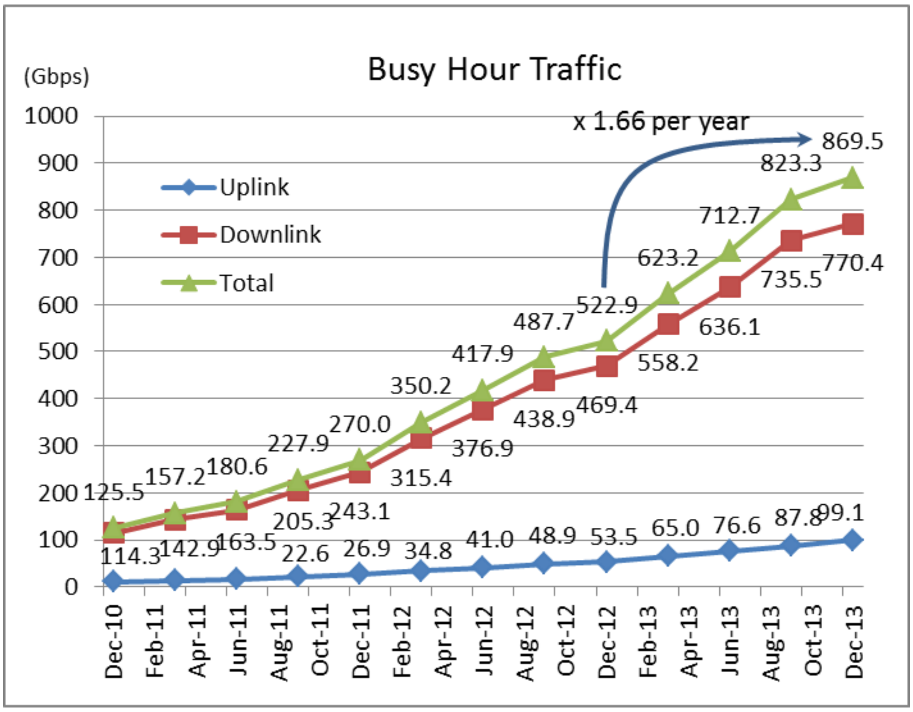


Fig. 4.3-2 Busy hour traffic of mobile communications in Japan [3]

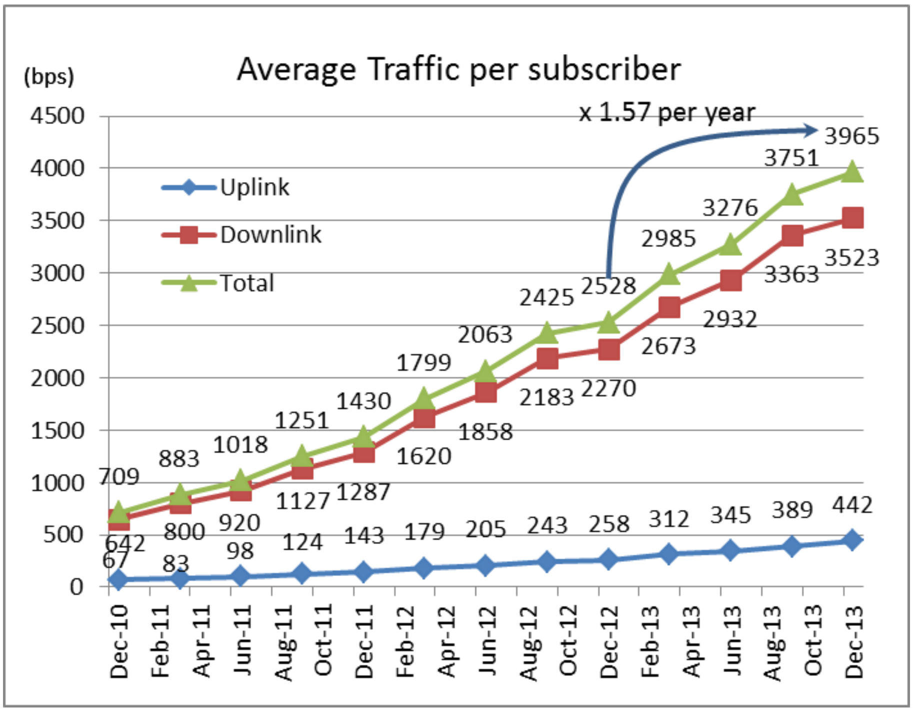


Fig. 4.3-3 Average traffic per subscriber of mobile communications in Japan [3]

Please note the traffic charts above show the total traffic of mobile data in Japan, excluding voice and Wi-Fi traffic.

Based on those mobile data traffic measured in the past, future traffic growth can be predicted as shown below.

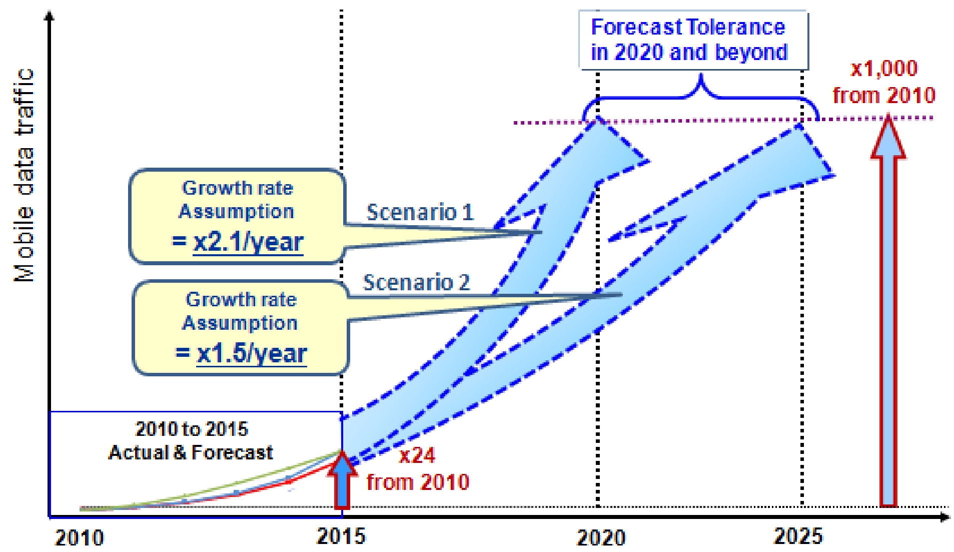


Fig. 4.3-4 Mobile data traffic growth forecast for 2020 and beyond - Example

Fig. 4-3-4 is an example of future mobile data forecast which takes into account both uplink and downlink traffic derived from the past statistics. In this chart, annual growth rates of the data traffic of 2.1 and 1.5 times are assumed, corresponding to an aggressive scenario and a conservative scenario respectively, which were actually observed in the last few years. With these assumed rates, the 1,000-fold traffic from 2010 will be reached in the timeframe between 2020 and 2025.

5. Cost Implications

5.1 Cost analysis of mobile network deployment

Despite huge growth of data traffic predicted for the coming future, the average revenue per user (ARPU) will not increase so drastically in the 5G era as compared to those in the previous generations. Therefore the total operational revenue is not likely to grow in proportion to the pace of 5G network expansion aiming to satisfy a wide variety of market needs including increased data traffic. In view of this background, cost reduction is one of the key factors in 5G network deployment.

Cost associated with mobile network deployment is roughly divided into two categories: capital expenditures (hereafter called CAPEX) and operational expenditures (hereafter called OPEX). According to the past experience in the previous generations, CAPEX and OPEX can be broken down into elements as shown below.

CAPEX

- Equipment cost

- Radio equipment (hardware and software)

- Supplementary equipment (i.e. batteries, air conditioner, transmission equipment, cubicles, etc.)

- Construction cost

- Network planning

- Site acquisition

- Civil works

Construction cost is the dominant part, and equipment cost represents only a fraction of CAPEX.

OPEX

- Site rental fee
- Electricity
- Operation and Maintenance
- Backhaul and front haul cost

5.2 Cost implication in the 5G era

At present, a large portion of capital expenditure associated with radio access network deployment is attributed to construction cost. As shown in the next section, as a result of emerging new technologies, downsizing of base stations using small cells and mass production, it is expected that equipment cost will go down. Reduction of construction cost will be increasingly important as well in the 5G era.

Therefore, every effort from a variety of perspectives should be made to minimize the construction cost. For example, in the U.S., there are wireless providers and companies that build cell phone towers, rooftop wireless sites, and other facilities required for radio access network deployment to be shared among mobile operators.

5.3 Factors contributing to cost reduction of 5G

The following are the factors which will have potential impact on CAPEX and/or OPEX reduction in the 5G systems. The individual impact on each factor will be referred to in the technology part of this white paper.

- Network Function Virtualization (NFV) of core and radio access networks.
- Global harmonization of spectrum
- Global compatibility of features and equipment (infrastructure and handsets).
- Mechanism to reduce construction cost including, but not limited to sharing of infrastructure.
- Flexible utilization of equipment including resource pooling.
- Smart OAM systems enabling the reduction of human resources required for network operation.
- Downsizing of base stations leading to less construction cost, less construction time and less space.
- Energy saving schemes for both infrastructure and handsets.
- Offloading of traffic to less costly network wherever available.

The following table shows potential elements which may contribute to cost reduction in the 5G radio networks. It should be noted there may be trade-off among these factors in terms of influence on OPEX and CAPEX. For more accurate description, detailed analysis would be required.

Table 5-1 Potential enablers for cost reduction

Key enabler	Contribution factors	Description	Cost Impact
MASS-SCALE MERIT	Support of major hit applications offered in worldwide market	*Capability of supporting popular applications (e.g. OTT, SNS, Multimedia) and common features for massive sales and mass-production for mega-markets.	* A large scale of production and sales contributes to lowering the unit price. (CAPEX)
	Global Compatibility	* Global standards and open interfaces will facilitate common design and inter-operability.	* Manufacturing cost will be reduced by scale of economy. (CAPEX) * Open standards and open interfaces facilitate inter-operability and easy roaming among multi-vendor systems without complicated conversion. (CAPEX)
		* Device conformance to the operation bands identified by 3GPP and ITU-R.	*Manufacturing cost of the radio devices will be reduced by scale of economy if the bands are harmonized. (CAPEX)
SCALABLE & OPTIMAL CONTROL	Scalability	* Capability to adjust capacity in a scalable manner according to variation of data volume and nature of traffic.	* System capability of scalable operation for accommodating required volume of data traffic and transport demands will help in reducing cost of communication systems.(CAPEX, OPEX)
	Optimal control	*Dynamic control/adjustment of system configuration parameters (e.g. transmission bandwidths, channels and transmission power) based on services and occasions.	* Tuning for optimal processing of variable data and signaling can save required resources and operation cost.(OPEX)
NETWORK VIRTUALIZATON	Resource sharing	*Functions of multiple nodes and multiple units will be realized by a common platform.	* The shared structure will reduce total cost compared with the case of discrete structure. (CAPEX)
	Flexible deployment	*Software-based virtual processing scheme has the capability of flexible and controllable operation and management.	* Small start, timely roll-out, agile change of system configuration will be available.(CAPEX) *Operational flexibility with virtualized entities supporting variable traffic and diverse services will be available. (OPEX)
CENTRALIZED	Centralized structure	*BBUs pooled in the central site in conjunction with the	*Required space for multiple cell sites will be reduced.

Key enabler	Contribution factors	Description	Cost Impact
CONTROL		transceivers and antenna system placed in distributed cells. *The operation can be controlled by a central processor.	(CAPEX) * Total electric power required for BBU operation and air-conditioning will be reduced. (OPEX)
	Central control and management	*Comprehensive control of pooled BBU, remote transceivers and antenna system under the central brain with a consistent policy and management.	*Integrated control with the reasonable set of resources and the minimum power operation result in reduction of operational cost. (OPEX)
	Smart OAM	*Central station covers and conducts radio network operation, call monitoring, and maintenance in an intelligent manner.	*System operation, maintenance and trouble-shooting can be conducted in a timely manner with minimum resources.(OPEX)
RADIO STATIONS	Wireless connections	*Non-wired free camping of radio stations and mobile terminals for radio networking, including nomadic stations for advanced D2D and wireless backhaul. *Autonomous plug-&-play by advanced SON.	* Agile construction with no wire-line and the flexible rollout will reduce construction cost. (CAPEX)
	Down Sizing	*Compact base station equipment installable in a limited space.	*Saving of site space, construction cost, and consumption power will be achieved. (CAPEX and OPEX)
RADIO DEVICES	Semiconductor device and module technologies for higher frequency	*Development of innovative RF devices (e.g. GaN, InP, GaAs, SiGe, CMOS) and module technologies for transceiver, PA, LNA, antenna to realize higher efficiency with smaller size, higher integration and longer-life operation in higher frequency bands (mmWave)	*Cost reduction of such RF devices and modules will be one of the key factors. (CAPEX and OPEX)
MULTI-RAT INTERWORK	RATs Interworking	*5G interwork with the existing radio access infrastructure (e.g. 3G, 4G, and RLAN) which satisfies requirements for the systems of previous generations.	* Interwork with the previous generation system(s) may lead to saving the 5G deployment cost. (CAPEX)

6. Spectrum Implications

As can be seen from Fig. 6-1, total radio spectrum bandwidth for UMTS/LTE (FDD) in Japan has been expanding steadily, which reflects rapid growth of traffic over the mobile communication systems and the results of every effort in satisfying the market demand. In the meantime, the number of logical frequency bands specified in 3GPP has also been increasing (see Fig. 6-2) as a consequence of worldwide explosion of UMTS/LTE.

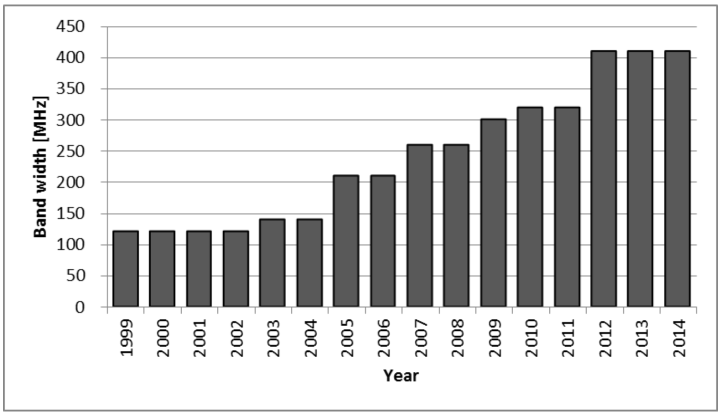


Fig. 6-1 Radio spectrum bandwidth of UMTS/LTE used in Japan [4]

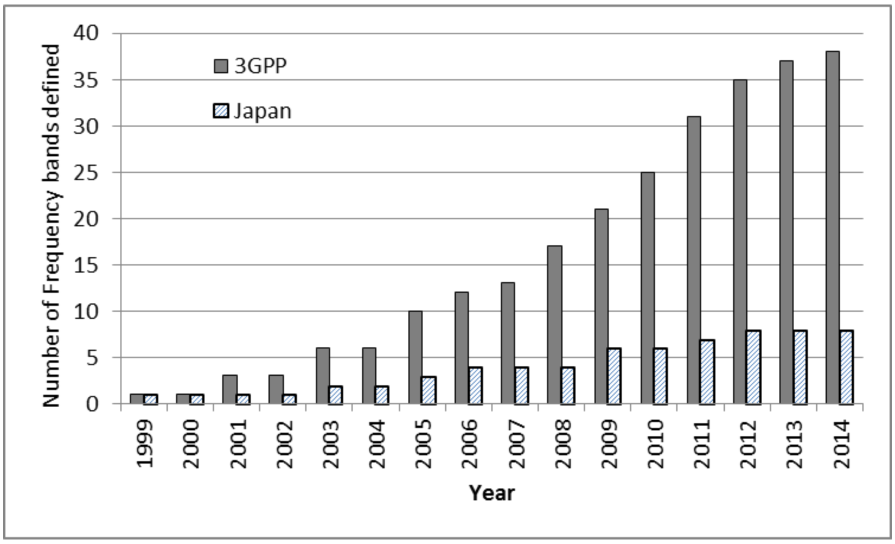


Fig. 6-2 The number of logical frequency bands specified in 3GPP [4]

Although both the gross total spectrum bandwidth identified for UMTS or LTE and the number of logical frequency bands in 3GPP have been increasing in a steady manner, it should be noted that some of these logical frequency bands specified in 3GPP overlap each other due to similar but not exactly the same frequency arrangements in each region or nation. This would imply that the systems now have a variety of frequency arrangements and that spectrum allocation is diversified or could be segmented.

Since the component carrier frequency bandwidth of UMTS was set as 5 MHz (or at most 20 MHz in LTE), most of the frequency bandwidths of one logical frequency band of UMTS (or LTE) are set around a few 10MHz as shown in Fig. 6-3. Accordingly, 'Carrier Aggregation' technology is being developed in 3GPP which aggregates component carriers and provide wider radio communication links to the users.

It can also be observed in Fig. 6-4 that frequency bandwidth of each frequency band correlates to its carrier frequency. The higher the carrier frequency, the wider bandwidth is available.

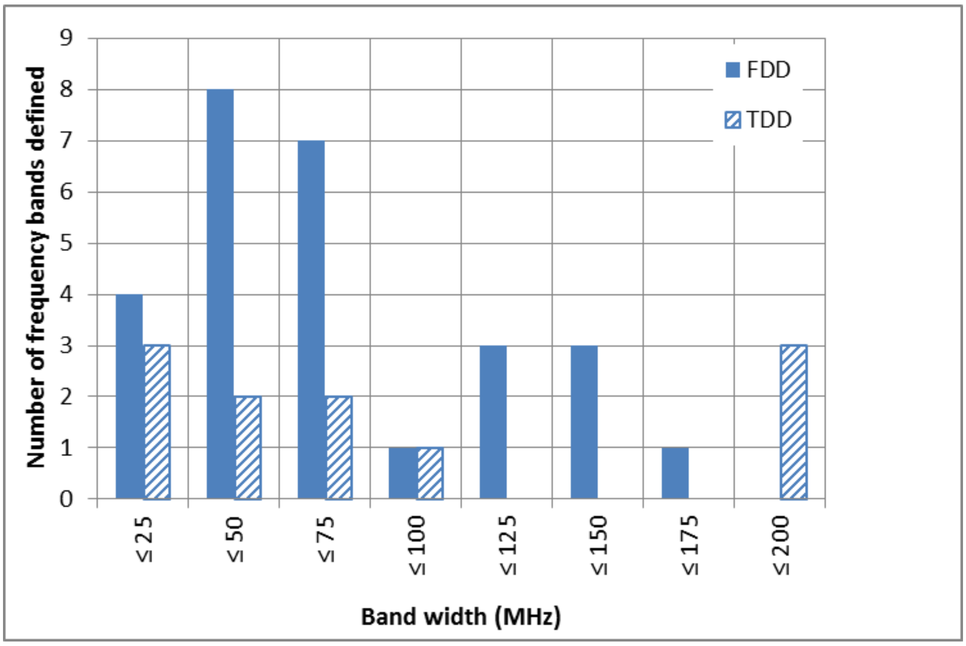


Fig. 6-3 Bandwidths of logical frequency bands specified in 3GPP [4]

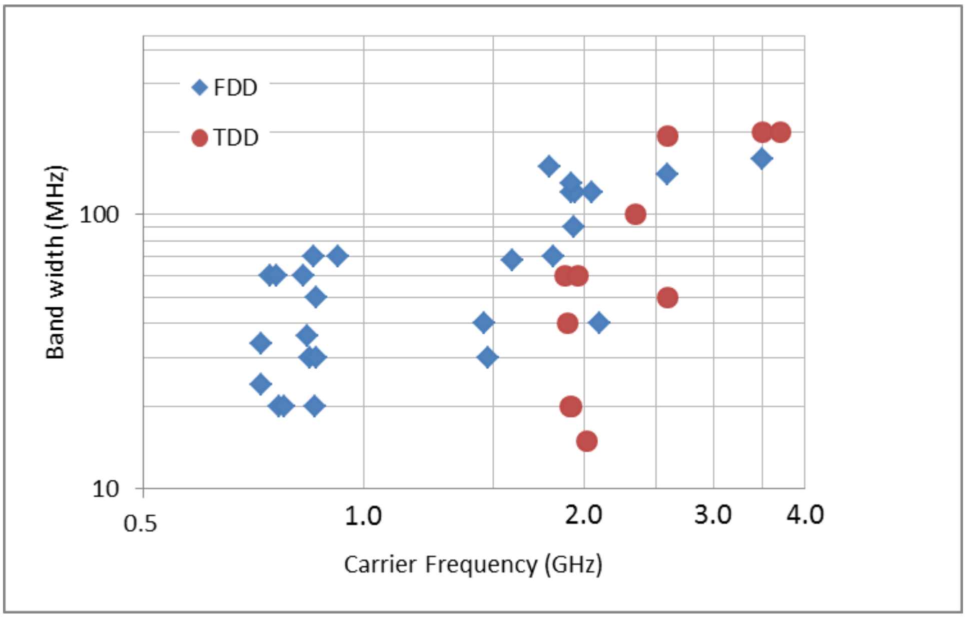


Fig. 6-4 Bandwidths and carrier frequency of logical frequency bands [4]

Considering the required capacity to satisfy the future traffic demand towards 2020 and beyond, the current frequency spectrum used for mobile communications systems is not sufficient, and thus wider range of frequency spectrum should be efficiently utilized in the 5G era, ranging from the existing lower frequency bands to the future higher frequency bands, e.g., up to millimeter waves. Formerly, such higher frequency bands, e.g. beyond 6 GHz, were not considered for the mobile communications systems due to their propagation characteristics. However, technical evolution in the 5G era such as combined usage of the lower and higher frequency bands will make such higher frequency bands useful, and thus such higher frequency bands and related technologies should be investigated for the future mobile communications systems.

Lower frequency bands, e.g., below 6GHz, will continue to be important also in the 5G era to provide basic coverage and mobility. In the future, wider spectrum bandwidths are generally required considering the future traffic demand in the mobile communications systems. Furthermore, the current frequency assignment is highly fragmented with multiple spectrum chunks over multiple frequency bands. Therefore, refarming of the existing spectrum allocations should be considered to enable utilization of wider contiguous spectrum as much as possible in the lower frequency bands.

On the other hand, higher frequency bands, e.g. beyond 6 GHz, also need to be investigated for future mobile communications systems to utilize much wider contiguous frequency spectrum since the bandwidths that can be obtained in the lower frequency bands are fundamentally limited. It is also desirable that future new spectrum bands in higher frequency are globally harmonized as much as possible to avoid possible market fragmentation and implementation complexity. In order to use unpaired frequency bands efficiently, new duplex schemes beyond the conventional ones are also of interest.

7. Typical Usage Scenarios, General Requirements and Roles of 5G

7.1 Typical usage scenarios of 5G

Fig. 7-1 shows typical usage scenarios of 5G.

From the socio-economic perspective, 5G will enhance user satisfaction for existing services. Navigation and autonomous driving provide more efficient and safer transportation. Richer contents such as multiuser UHD teleconferences, videos, music, and books are distributed over 5G networks. Home security and remote control of consumer electronics realize safe and comfort life. Collision avoidance and rescue from distress and accidents reduce the number of victims. Distance learning and virtual experience redress regional disparities of education. Prediction technology for disaster using M2M networks and robust infrastructure support the disaster relief. Remote medical examination provides routine preventive care.

In addition to the enhancement of user satisfaction for existing services, 5G induces completely new use cases as shown in Fig. 7-2. Smart citizen services realize knowledge creation and activity support. Shared experience provides virtual and perceptual touches with fidelity, reality and tactile sense. Automatic information sharing in proximity assists communication between unacquainted persons.

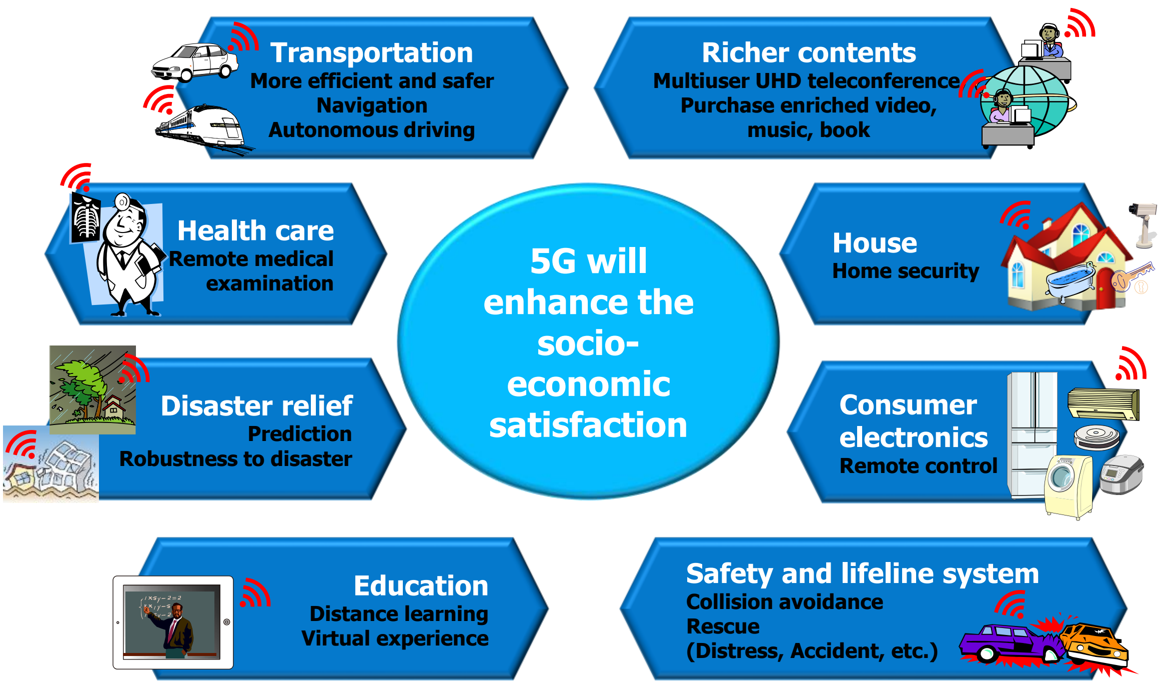


Fig. 7-1 Usage scenarios from socio-economic perspective

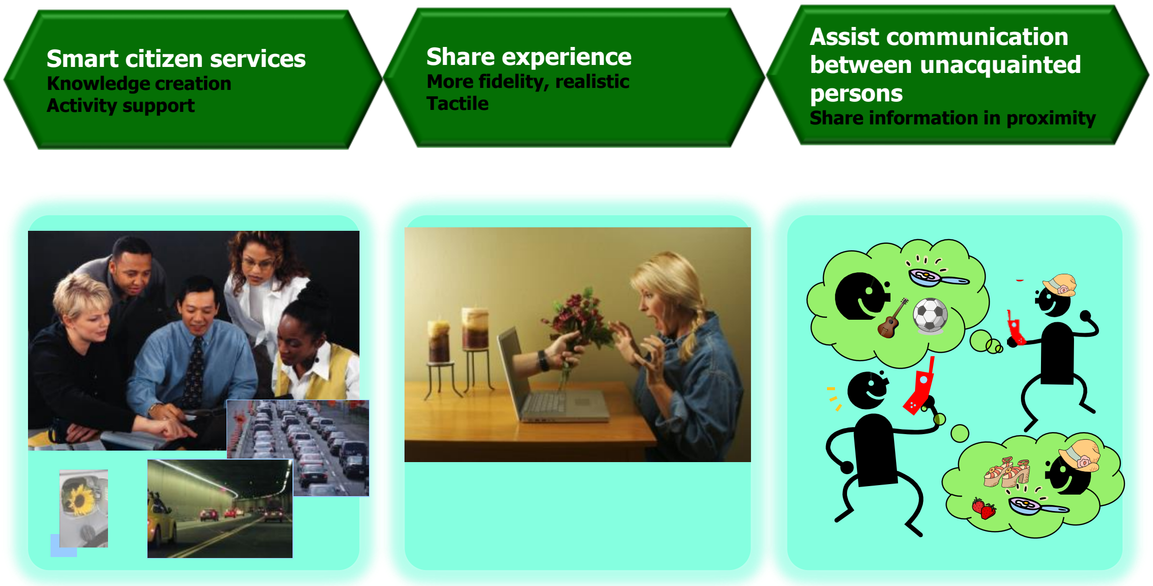


Fig. 7-2 Completely new use cases of 5G

Table 7-1 summarizes reasons why each usage scenario requires wireless access and the general requirements for 5G in terms of the difference from IMT-Advanced.

Table 7-1 Usage scenarios and their general requirements for 5G in terms of the difference from IMT-Advanced

Usage scenarios	Reasons why the usage scenario requires wireless access	General requirements for 5G (In terms of difference from IMT-Advanced)
Transportation (More efficient and safer, Navigation, Autonomous driving)	More efficient/safer navigation and autonomous driving will be realized by the communication on vehicle to vehicle and vehicle to roadside equipment.	For reliable connection, low latency, mobility, and guaranteed connectivity will be required.
Safety and lifeline system(Collision avoidance, Rescue)		
Richer contents (Multiuser UHD teleconferences, purchase enriched videos, music, books)	Richer contents such as videos, music, books, and multiuser UHD teleconferences will be provided in the mobile environment.	Considering two way communication, not only downlink capacity but also uplink capacity should be increased.
House (Home security)	Many sensors and controllers will be installed in home equipment. Due to the difficulty in wiring, such equipment tends to have a capability of wireless connection.	High density connectivity.
Consumer electronics (Remote control)		
Education (Distance learning Virtual experience)	Distance learning and virtual experience will be provided on wireless communication in the developing regions/countries.	Capacity and peak data rate are required to support rich contents.

Usage scenarios	Reasons why the usage scenario requires wireless access	General requirements for 5G (In terms of difference from IMT-Advanced)
Health care Disaster relief (Prediction, Robustness to disaster)	Sensors capturing physical conditions will upload the data to the server via wireless connection.	Data on physical conditions need to be uploaded anytime and anywhere. Hence connectivity is important.
Smart citizen services (Knowledge creation, Activity support)	Utilizing real-time knowledge created/derived from next generation hypermedia data, context relevant services are provided everywhere. Services would include support of business, social, health, sports, environment, and safety critical applications. Note: 'Citizen' here is used in its broadest sense and includes human and associated objects.	Large capacity, high density, and highly dependable ubiquitous access are required for mass usage. Interactive context relevant to real-time hypermedia services require low latency.
Share experience (More fidelity, realistic Tactile)	Tourists can share their experience during the travel with their family and friends in real time.	Capacity and peak data rate will be required to transmit rich contents including videos, sound, smell, and taste.
Assist communication between unacquainted persons	Mobile devices automatically exchange personal information over wireless connection, then the terminals search common experience, hobbies, and friends.	Low latency will be required to assist human communication.

7.2 Impacts of video communications in the 5G era

Today, ICT supports entertainment such as video streaming that can be viewed anytime, anywhere. In the 5G era, such entertainment will provide higher definition videos than today's 2K broadcasting. Since television will support 4K/8K beyond 2020, 4K/8K video streaming will also be needed. The following transmission rates should be supported for each format in case High Efficiency Video Coding (HEVC) is used for video streaming as in 4K/8K broadcasting.

- 40 Mbps for 4K (60 fps)
- 48 Mbps for 4K (120 fps)
- 100 Mbps for 8K (60 fps)
- 120 Mbps for 8K (120 fps)

In the meantime, ICT will also support Virtual Reality (VR) which will greatly enhance user experience with its imaging techniques. For instance, VR will be able to virtually take a user anywhere in the world. Scenery captured by image sensors installed at various places in the world will be transmitted through the mobile networks and will be displayed on a head mounted display (HMD). Consequently, users will experience the views as if they were on the spot.

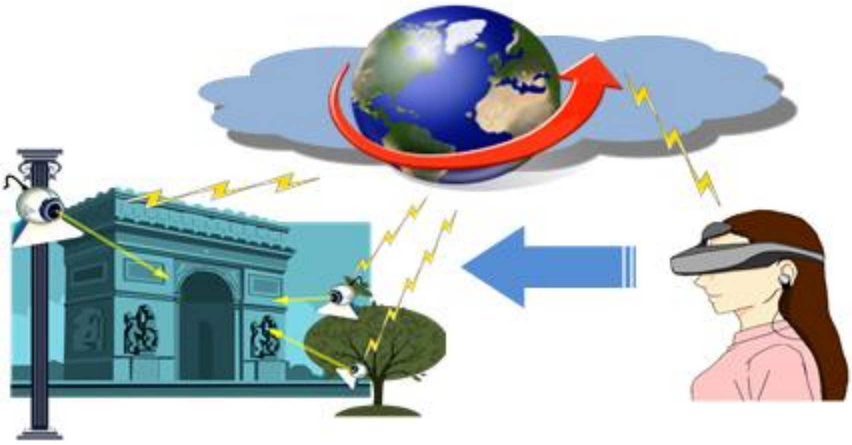


Fig. 7-3 Enhancement of user experience (virtual trip)

In order to realize virtual trips with reality, resolution of at least 8K with 120 fps is required. In the case of 3D, required information rate will be twice as high as that of 2D. Therefore, the data rate of 240 Mbps should be supported by the mobile networks if an image of the whole celestial sphere is to be transmitted. If an image of the desired spot can be projected in a relatively short time, an image of the half celestial sphere may be sufficient instead of the whole celestial sphere image. In this case, the data rate of 120 Mbps is required and the time delay should be minimized so that the view projected on HMD will be in accordance with the movements of the user's eyes. The HMD requests to send the image calculated from the angle that the sensor (e.g. gyro, accelerometer) in the HMD senses according to the movement of the person's eyes. Then, the remote cameras on the spot of interest will capture the new images and send them back to the HMD. Clearly, this process will cause some processing delay. In order to improve users' perception, the image should be displayed on the HMD within around 8 ms after the movement of the user's eyes. In practice, a maximum delay of 12 ms may be tolerable since the use of predictive algorithms can potentially provide a 4 ms margin. The non-network-related delay contributions in the current technology can be summarized as follows:

–	camera	4 ms
–	encoder and server	2 ms
–	decoder	1 ms
–	attitude sensor	1 ms
–	display	2 ms
		10 ms total

Therefore, it should be noted that for satisfying the total end to end requirement of 12 ms, the delay budget of network and data processing is critical and requires attention.

7.3 General requirements for 5G

In the 5G era, many new application services are expected to emerge to satisfy diverse needs and requirements of users by leveraging innovative multimedia applications and telecommunication technologies.

Fig. 7-4 indicates that, from users' perspectives, required capabilities vary depending on applications. Four typical applications are used to illustrate the different capabilities required by respective application.

(i) Video streaming
(ii) Virtual reality
(iii) M2M communication (i.e. sensors)
(iv) Autonomous driving (i.e. collision avoidance)

As users' requirements differ depending on applications, the network does not necessarily have to exhibit maximum performance capabilities, instead, the network resources should be used efficiently depending on applications.

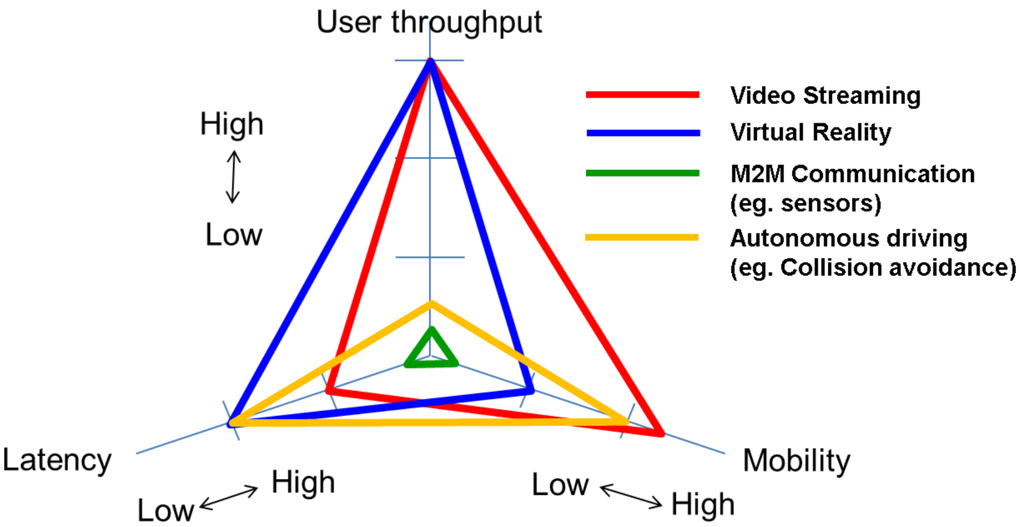


Fig. 7-4 Diversified required capabilities from users' perspectives depending on applications

8. Framework and Capabilities of 5G

8.1 General

This chapter first shows a diagram that highlights the difference of capabilities between 5G and IMT-Advanced/Enhanced IMT-Advanced. Then shows another diagram that describes maximum system capabilities of 5G. In the latter diagram, the capabilities consist of those quantitatively or qualitatively evolved from IMT-Advanced [5] and those genuine and new for 5G.

8.2 Framework

One of the main goals of the 5G systems is to provide better user experience in wider area with a variety of user densities. Considering this aspect, user experience can be better represented by 'Typical User Throughput' (TUT) than, for example, the peak data rate. The diagram below illustrates the framework of the 5G systems which is characterized by 'Typical User Throughput (TUT) in *[bps/device]*' *(normalized by that of IMT-Advanced system in the figure*) and 'User density' in *[device/km2].*

TUT represents throughput per user/device under a typical condition, including user/device density. The typical condition should be set considering reasonable operation conditions, radio propagation conditions, user density as well as expected typical deployment of the system (See Annex B).

Typical user throughput can be kept constant for a certain range of user density by reducing the cell coverage area. It should be noted that the framework provided below does not restrict any possible deployment in practice, therefore, potentially, the 5G systems have the ability to provide higher user throughput to its users than what is illustrated, depending on the deployment conditions.

The following are the three main areas where the capabilities should be enhanced by 5G compared with that of IMT-Advanced;

(i) Coverage expansion in isolated areas, i.e. in rural areas or on a ship distant from land etc.

In the 5G era, it is essential to offer services in isolated or extremely sparsely populated areas in a more cost effective manner than IMT-Advanced. The result of the study carried out by MIC of Japan [6] indicates that dead zones of the existing mobile phone services in Japan will be halved by 2017, however, approx. 17,000 subscribers will still remain to be in the 'out of service' area. The 5G systems should cope with this coverage issue and provide stable and secure services.

(ii) Typical User Throughput improvement

In 5G RAT, the maximum available throughput per single radio link should be increased by a factor of 100. Together with proper deployment and operation of smaller cells in the system, this improved maximum throughput will lead to improvement of the typical user throughput as well, compared with that of the 4G systems.

(iii) Capacity augmentation.

When the user density exceeds a certain point, excessive interference from neighbouring cells would become a limiting factor to the system capacity. To cope with this capacity degradation, the 5G systems should adopt several technologies to properly control interference amongst these smaller cells.

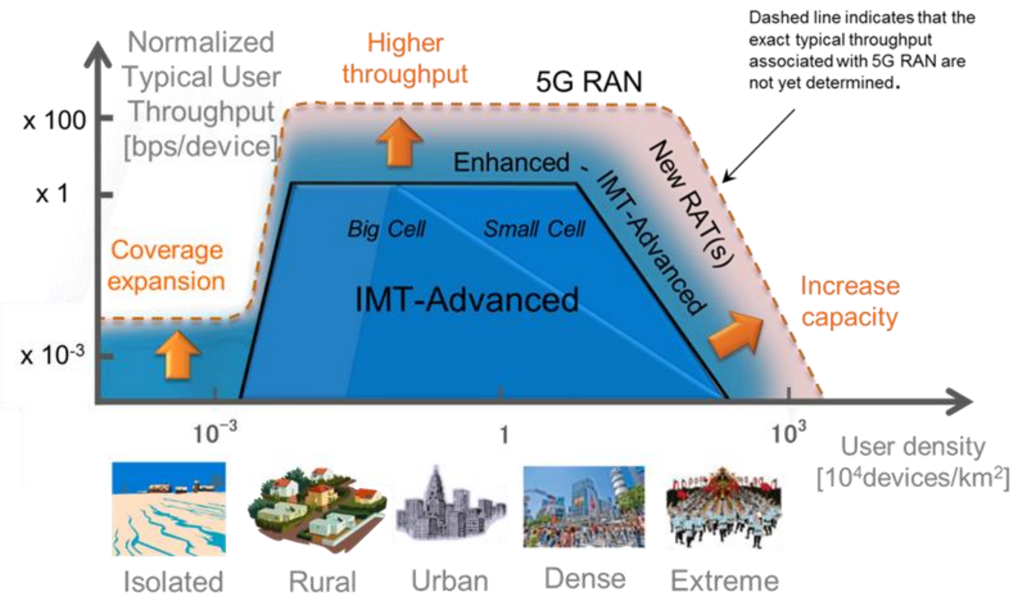


Fig. 8.2-1 Framework of 5G RAN

8.3 Maximum capability of 5G from system's perspective

8.3.1 Quantitatively or qualitatively evolved capabilities from IMT-Advanced

The diagram below describes the maximum system capabilities of 5G in comparison to that of IMT-Advanced. In the radar chart, six axes are selected, which are most appropriate to highlight the difference between the two systems. It should be noted that the chart represents the maximum capability, and each maximum capability element would be dependent on other capabilities. For example, the maximum number of connected devices per single cell in 5G would be kept the same as in Enhanced IMT-Advanced (probable evolution of IMT-Advanced). However, that should be available with larger capacity per area than that in Enhanced IMT-Advanced.

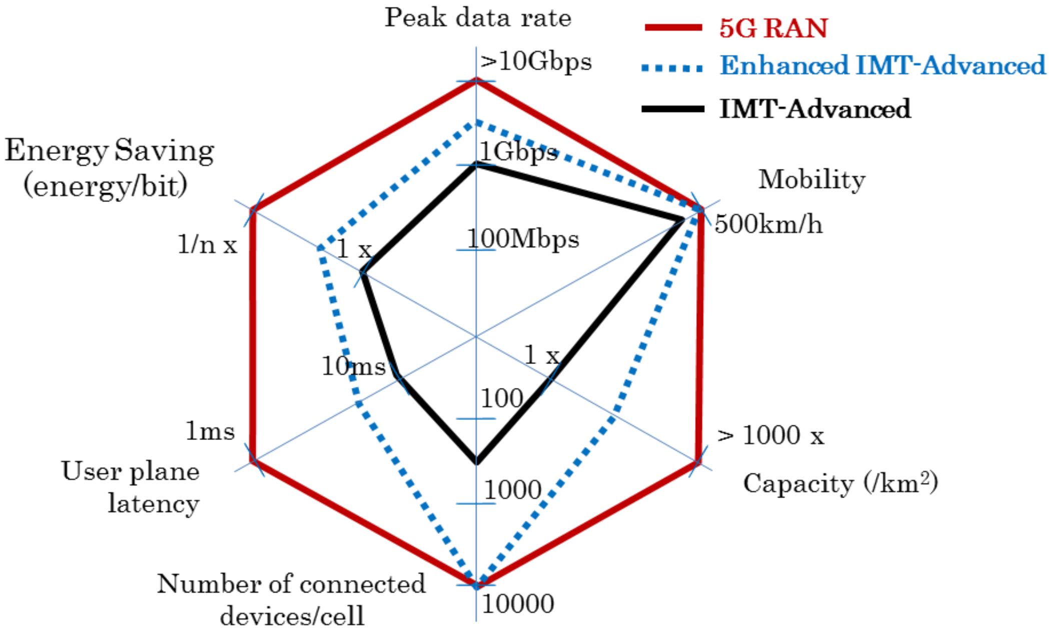


Fig. 8.3.1-1 Maximum system capabilities of 5G RAN

Enhancements to the 6 existing capabilities are shown in the radar chart, and their quantitative comparisons to IMT-advanced are explained below.

Capacity and peak data rate

To accommodate the soaring mobile traffic and increased number of devices in the 5G era, system capacity needs to be augmented with high peak data rate and massive device connectivity. The system capacity of 5G should be approx. 1000 times, in terms of bit/s/km^2, than that of IMT-Advanced. The peak data rate for 5G should be more than 10 Gbit/s while it is approx. 1 Gbit/s for IMT-Advanced. 5G needs new RAT(s) to realize such a very high peak data rate.

Number of connected devices

Massive device connectivity by the Internet of Things will emerge in the 5G era. It is forecasted that an increased number of devices, especially M2M sensors and actuators will be installed on top of the user handsets toward 2020 and beyond. According to some analysis [7], some tens of billions devices are estimated in the world in 2020, which would be higher than the number of world population. The number of connected devices for 5G can be approx. 100 times than that for IMT-Advanced. Enhanced IMT-Advanced might be able to accommodate such very large number of connected devices [8].

Latency

Some future real-time applications will impose very short latency. The user plane latency of 5G should be less than 1 ms while IMT-Advanced requires user plane latency of less than 10 ms. The definition of user plane latency is the same as that in Subsection 4.5.2 of [5]: "*the user plane latency (also known as transport delay) is defined as the one-way transit time between an SDU packet being available at the IP layer in the user terminal/base station and the availability of this packet (protocol data unit, PDU) at IP layer in the base station/user terminal*."

Mobility

Increased traffic demand is expected even in high-speed vehicular environments. 5G needs to offer higher data rates than IMT-Advanced in the high mobility environments of approx. 500 km/h. In light of the feasibility study of LTE-Advanced [9], Enhanced IMT-Advanced is also expected to support mobility of 500 km/h in certain frequency bands.

Energy efficiency

In order to make 5G a sustainable system, the total energy consumption of 5G should not significantly exceed that of current RAN. Therefore, energy consumption of 5G in terms of energy/bit needs to be much smaller than that of today. As for mobile terminals, 5G including new RAT(s) will require less power consumption to realize longer battery life. The demand for energy efficiency in Enhanced IMT-Advanced is smaller than that in 5G because of smaller system capacity.

Availability and reliability

Reliability for a certain service can be defined as an ensemble success rate or possibility to satisfy a set of service requirements at a certain condition. The service requirements can be user throughput, E2E latency or connection setup time, etc. They shall be specified depending on each service.

Availability is defined as the ratio of area (and period) in which the reliability or predefined service requirements are satisfied over the coverage area. The coverage area for some specific services (i.e. service coverage) could be smaller or larger than that of other services.

In the 5G era, ICT will play a role of lifeline systems, providing many services in daily life as well as during emergency. Examples of availability and reliability for certain capabilities are listed below.

- ✧ Availability of 99.999% (almost 100%) to satisfy ultra-low E2E latency requirement (e.g. less than 10 ms with the probability of 99.9% for each data transmission) in the coverage area dedicated to ultra-reliable M2M services such as drive assist and control of automobiles. Obviously such mission-critical systems should be fail safe and need to have room to tolerate delay to guarantee ultra-high safety even if the delay requirement is not met.
- ✧ Availability of 99.9% to satisfy the requirement of connection recovery in serious disasters (e.g. recovery within one hour after the disaster occurs) in order to discover and contact disaster victims at the early stages.
- ✧ Availability of 99% to satisfy the basic throughput requirement (e.g. 1 Mbps) in order to provide basic social services for citizens such as e-government.
- ✧ Availability of 90% to satisfy the high throughput requirement (e.g. 40 Mbps) in order to provide high-quality video services such as 4K video streaming (see section 7.2).

The quantitative values above need further studies. Some related information may be helpful to derive them.

- ✧ The penetration rate of public water supply is approx. 97.5% in Japan according to Ministry of Health, Labour and Welfare (MHLW) of Japan [10]. Because both mobile communications systems and public water supply are fundamental and important lifeline infrastructure, the figure could be used as a reference in terms of service availability of mobile communications systems.
- ✧ As a reference of required throughput, IMT-Advanced requires spectrum efficiency of 0.04 bps/Hz with location probability of 95% in pre-defined simulation assumption with high-speed environment [9].
- ✧ As a reference of E2E latency, the allowable latency for pre-cash warning is 20 ms [11].

8.3.2 Genuine and new capabilities of 5G

In addition to the enhanced capabilities from IMT-Advanced, 5G needs to have totally new capabilities to satisfy requirements for new sorts of applications. Such totally new capabilities of 5G are listed below.

Guaranteed connectivity to serve as lifeline system

5G needs to guarantee ubiquitous connectivity regardless of geographical locations. This can help ICT to be provided to everyone as a lifeline system.

Maximizing quality of experience (QoE)

5G needs to be controlled to maximize user perception considering user's specific conditions with limited network resources.

Flexibility to support more diversified application needs

New application services are expected to emerge to satisfy more diverse needs, and required capabilities from users' perspectives will vary depending on applications. Flexible and efficient use of network resources will be needed for 5G.

RAT capability for network virtualization

5G will integrate several radio access technologies (RATs) such as Enhanced IMT-Advanced and New RAT(s). By employing network virtualization, 5G can realize flexible and efficient use of network resources including multi-RAT to provide seamless communication experience to customers.

9. Definition of 5G

9.1 General

Current IMT-Advanced RAT will continue to be developed as Enhanced IMT-Advanced by adding some new features for enhancing its capabilities, while maintaining consistency in provided services to the mobile users, e.g. seamless geographical coverage. It is, however, foreseen that more and more system capabilities beyond those of Enhanced IMT-Advanced will be needed for mobile radio systems to fully satisfy users' demands in the year 2020 and beyond.

Such capabilities, among others, are listed in the order of priority;

- Capacity/User Throughput
- Latency
- Number of Connections

New RAT(s) will be required to achieve even larger gain than that of Enhanced IMT-Advanced with one or more emerging extremely high capabilities in a cost-effective manner, even by sacrificing compatibility and commonality with the IMT-Advanced system and its enhancements. Multiple New RATs, which will focus on other requirements, may be required to fully cover the emerging capabilities.

The New RAT(s) will focus on major 5G capabilities, e.g. larger gain in capacity and user throughput, which Enhanced IMT-Advanced cannot sufficiently provide. IMT-Advanced has evolved from IMT-2000, which was originally designed to provide mobile multimedia services by using the frequency ranges around 2 GHz. Its design was not intended to support such extremely higher capacity and user throughput with wider and contiguous bandwidth in higher frequency bands. Different design criteria, e.g. considering implementation complexity of carrier aggregation to support extremely wider bandwidth and severe phase noise in higher frequency ranges, such as mmWave, would be required for the design of the New RAT(s). On the other hand, the New RAT(s) may not focus on the scenarios and applications which Enhanced IMT-Advanced can sufficiently support. For example, the New RAT(s) may not support an extremely large cell size, which will require redundant options such as specific radio parameters or frame formats only for isolated areas and emergency cases. Some broadcast type services also may not be supported since they are required to guarantee reliability over the entire coverage area. Furthermore, the New RAT(s) may be optimized to the future higher frequency bands, e.g. beyond 6 GHz, and thus it would not be suitable for the frequency ranges around 2 GHz.

5G RAN as a whole will, therefore, be realized by the complementary interworking of its constituent RATs; Enhanced IMT-Advanced and New RAT(s), which satisfy all the requirements foreseen for mobile radio communications in the year 2020 and beyond.

The road towards 5G RAN is depicted in Fig. 9.1-1.

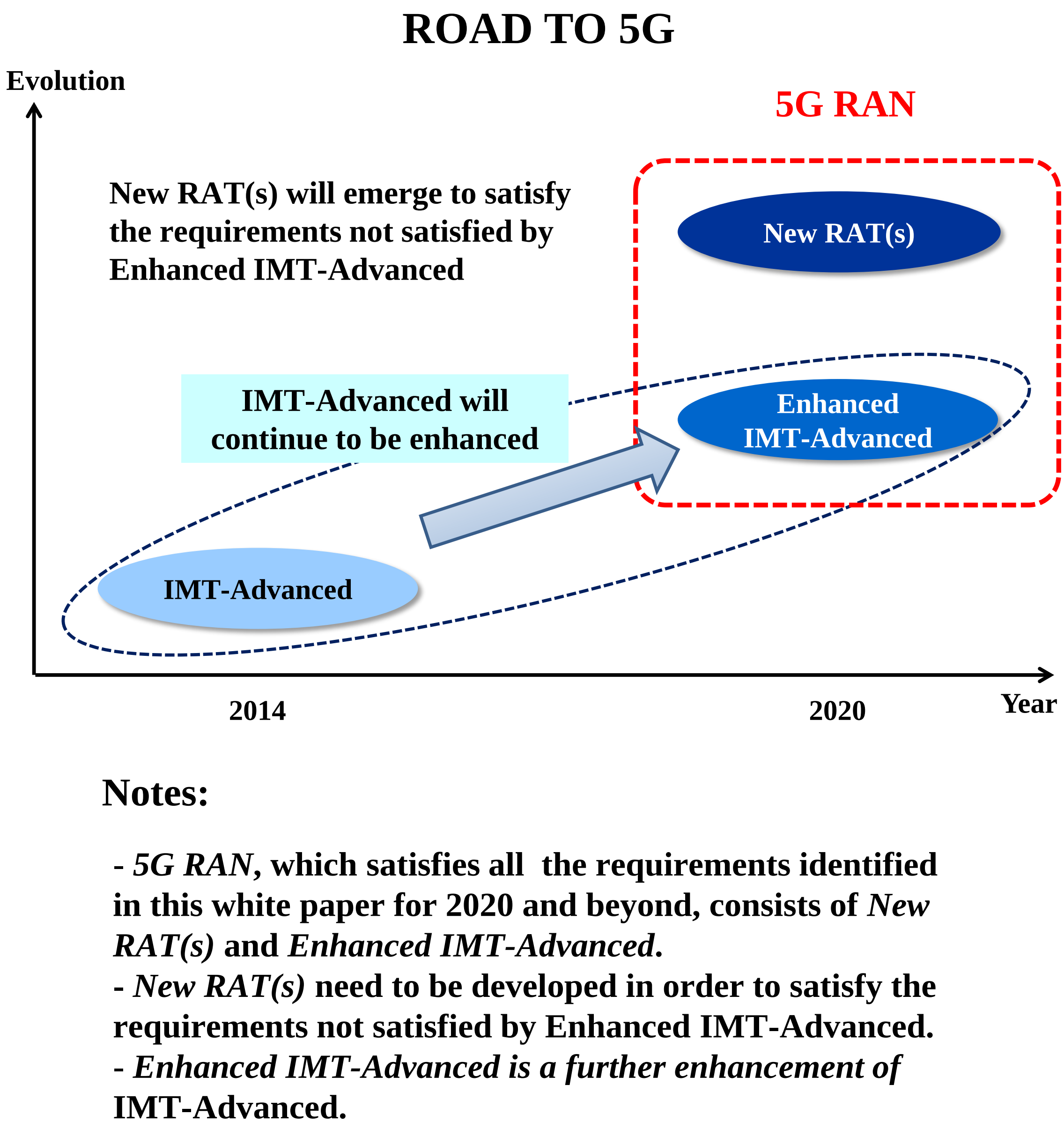


Fig. 9.1-1 Road to 5G

The first version of the New RAT(s) will need to be available in the year 2020, and they will continue to be enhanced. In 2020, the New RAT(s) will not replace Enhanced IMT-Advanced, although the future possibility could not be precluded at this time, because replace/not replace depends on technologies' availability in the future.

9.2 Interworking of 5G RAN

Fig. 9.2-1 depicts interworking of 5G RAN with other radio systems indicated before, where 5G RAN consists of two RAT groups; Enhanced IMT-Advanced and the New RAT(s). These two RAT groups independently work but also closely and complementarily interwork to provide the full capabilities of 5G RAN as a whole. 5G RAN also interworks with other RATs for users to be optimally and cost-effectively connected.

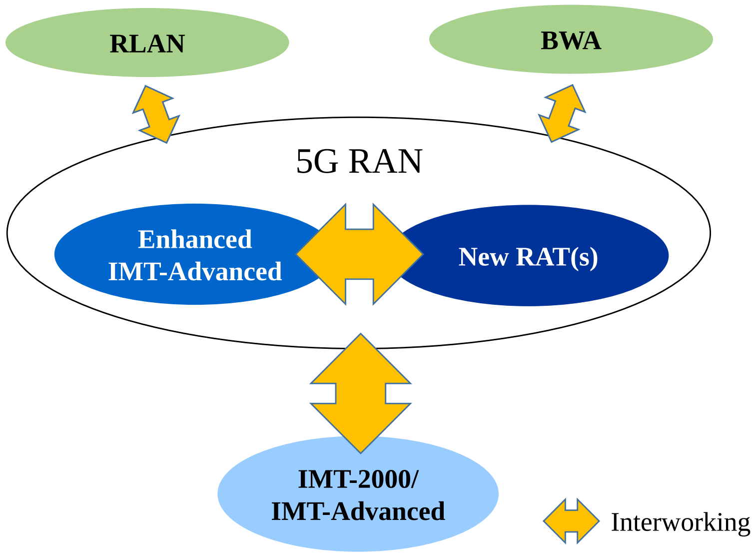


Fig. 9.2-1 Interwork of 5G RAN

Other radio systems are IMT-2000 and IMT-Advanced, RLAN [12], or BWA, including their possible future enhancements.

10. 5G Radio Access Technologies

10.1 General

In order to realize the 5G systems, advanced radio access technologies should be applied. In the following subsections, considerations on network architecture(s) of 5G and radio spectrum aspects are summarized, which could be the premise to develop 5G radio access technologies. Candidate radio access technologies to realize the 5G systems are enumerated in Annex A.

10.2 Network architecture(s)

Novel mobile network architecture will need to be structured to achieve the following:

- Massive capacity and massive device accommodation;
- Intelligently controlled virtual network to provide scalability and resource management;
- Integrated cloud network computing and aggregation to backhaul;
- Interworking with multiple RATs including data offload.

In the following chapters and subsections, some technical measures to achieve above goals are described as probable solutions.

10.2.1 Overall network concept and architecture

In the 5G era, the mobile telecommunication architecture should be evolved to provide substantially increased manageability and scalability in addition to massive-capabilities compared to those in the preceding generations. This can be achieved through the introduction of a centralized software-based network control structure for the mobile telecommunication network which supports various services. At the same time, the legacy network (e.g. 4G or 3G) structure may also be applicable as long as the expected quality of service, which satisfies the 5G performance requirements, can be delivered to the users.

Adaptive network solutions will be necessary for accommodating IMT evolution and innovative air interface technologies. Programmable operation, functional virtualization and network service technologies will reshape the entire mobile ecosystem, and 5G will facilitate creation of massive-scale services and applications.

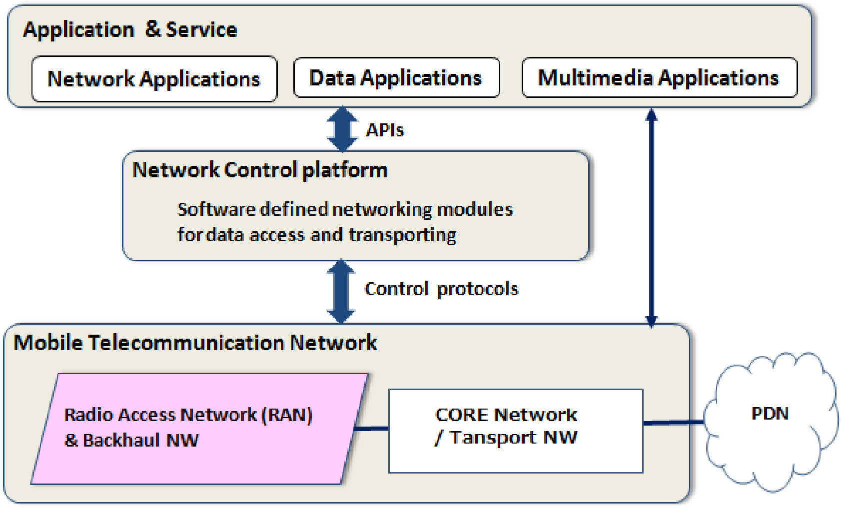


Fig. 10.2-1 Conceptual view of mobile network

Above picture shows a conceptual view of a future mobile network model consisting of three tiers based on the software-defined networking (SDN) approach.

The application and service domain is placed at the upper tier. Various types of services including system management support can be delivered to individual users, enterprises and mobile network operators. Network-related operations of applications are programmable from the network control tier.

Middle tier represents the network control platform which works for the upper applications to proceed networking control of application systems. This controller also works for the low tier mobile telecommunication network. Since the network control programs are configurable on a software definition basis, it can provide some advantages such as automatic, dynamic, flexible, intelligent, and scalable network operations. Control messages for data transportation networking protocols are carried via the interfaces.

Bottom tier represents mobile telecommunication network. This domain plays a role of end-to-end data transmission by the radio access network and core network. In the core network, some data processing functions, components and operational parameters can be virtually configured on a common platform as referred to as network function virtualization (NFV). The NFV scheme will provide a smart solution in conjunction with the SDN for flexible and optimal network control which are managed by the NFV operation system.

The approach of software-oriented network and cloud based services will provide the users with best quality of services (QoS) and experiences (QoE), and will also provide the operators with reduction of OPEX/CAPEX and energy saving.

10.2.2 Overview of 5G radio access network

The radio access network (RAN) and aggregated backhaul support the capabilities of data transport, radio transmission and reception. In the 5G era, these capabilities shall be much more enhanced for accommodating massive traffic capacity and device connectivity while providing enhanced quality of user experience. Many innovative technologies mentioned in Annex A will be introduced to improve the performance in the system for 2020 and beyond. Some of these technologies are illustrated in the figure below. It should be noted that the technologies in the figure are not exhaustive but just picked to illustrate some of the probable aspects of these radio access technologies.

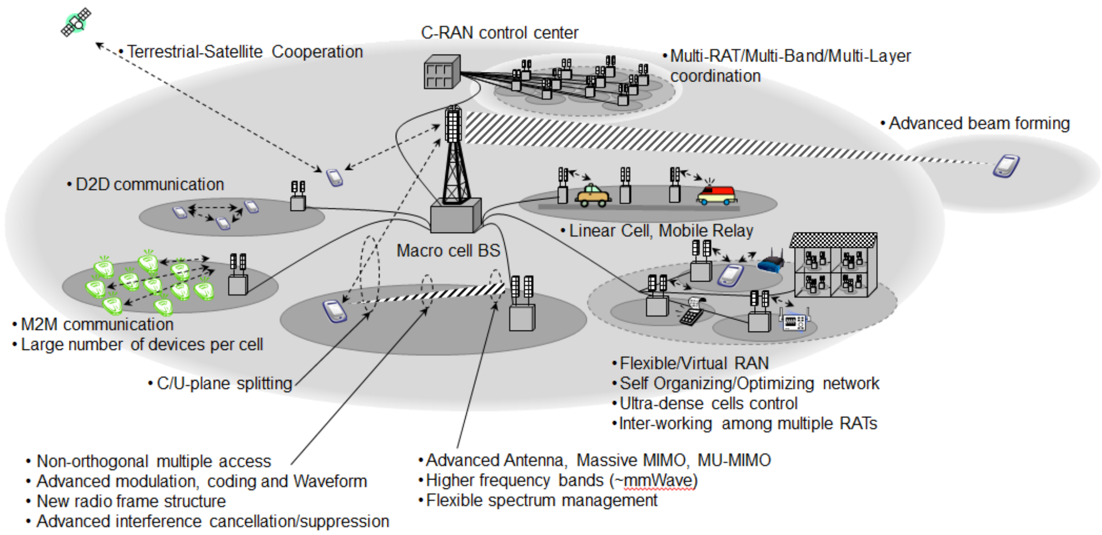


Fig. 10.2-2 Radio access technologies for the 5G systems

The 5G RAN coordinates multiple RATs, frequency bands, and heterogeneous network layers. The coordination can be centralized in the Cloud RAN (C-RAN) architecture or distributed in the Distributed RAN (D-RAN) architecture. RAN architectures are expected to be flat and flexible, and may even be virtualized. Cells are traditionally categorized as Macro, Micro, Pico, and Femto cells depending on the coverage radius. New coverage schemes using narrow beams may be considered as well. The wider radio frequency range including much higher frequency such as mmWave is used depending on the radio environment and deployment scenarios. The 5G RAN has the capability of interworking with some earlier generation systems such as 3G and 4G, and also with other land radio systems such as RLAN and BWA. Additionally, cooperation with satellite systems can be considered to cover isolated areas, for example. Some novel radio access technologies will need to be introduced such as new modulation/coding, interference reduction schemes, advanced antenna systems, flexible spectrum management. On the mobile terminal side, new network topologies can be organized among the UE devices, for example, by the enhanced networking of D2D communication.

10.3 Radio spectrum aspect

Encouraged by the exponential growth of the mobile traffic and the resulting spectrum exhaustion problem, the mobile industry has continued to make efforts to drastically improve the network capacity: one such effort is to continue to seek new spectrum on top of trying to aggregate channels of the already-allocated frequency bands, i.e. carrier aggregation (CA). Fig. 10.3-1 illustrates examples of corresponding UE configurations. Configuration on the left-hand side represents a CA-capable UE which combines component carriers and utilizes wider spectrum bandwidth by introducing a duplexer. This configuration results in excessive signal losses both in its transmitter chain and receiver chain, causing increased power consumption and impact on its physical dimensions. If wider spectrum bandwidth is available as shown on the right-hand side of the figure, it would provide a simpler UE architecture and more attractive attributes in terms of performance as well as physical dimensions.

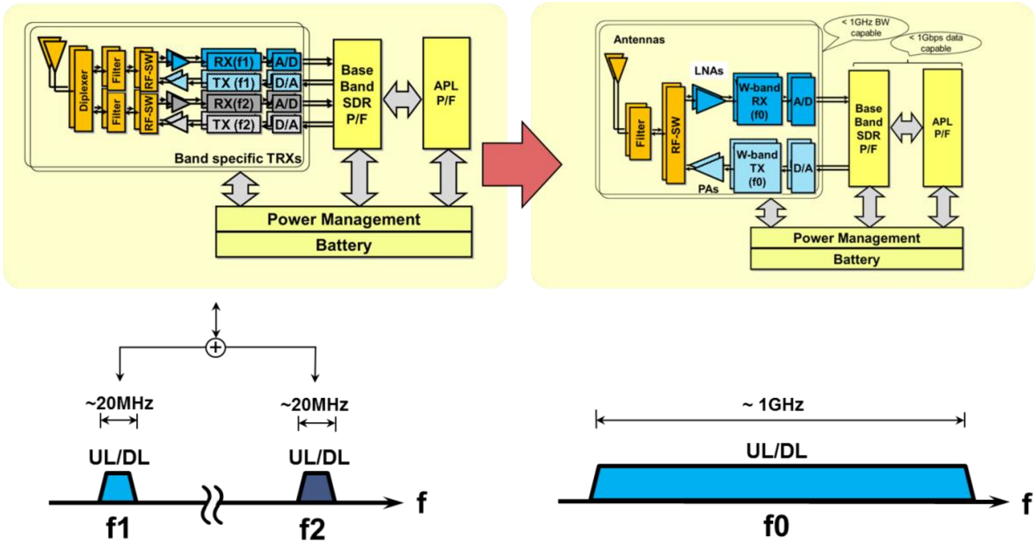


Fig. 10.3-1 Examples of UE configurations: CA-capable UE and wider single band UE

Given this background, one of the ways to achieve even higher network capacity is to take advantage of higher frequency bands that have not been considered for cellular systems in the past. The millimeter waves including centimeter waves, we call in this white paper "mmWave", are attracting increased attention of the industry simply because mmWave has several advantages in terms of 1) system densification due to shorter range with less interference, 2) bandwidth due to overwhelmingly broader bands, and 3) spectral efficiency enabled by advanced beam steering and massive MIMO. Needless to say, even though the use of mmWave is being examined as a candidate, the UHF bands which have been targeted by cellular services from the beginning should still be the key bands for the 5G systems.

Radio propagation characteristics have significant impact on the design of the radio system architecture. Compared to the UHF bands, other than free-space path loss, in the mmWave bands, further significant attenuation loss factors come into play, such as absorption losses by molecules of oxygen, water vapor and other gaseous atmospheric constituents. Millimeter wave propagation characteristics have been studied extensively for a very long time. Detailed calculations of those atmospheric absorptions were first published in the 1940s and the CCIR published a report on the topic [13]. As its descendant, ITU-R elaborated a recommendation in [14]. Rain loss depends on frequency and hourly precipitation as studied in [15]. Foliage losses at millimeter wave frequencies are also significant [16]. For non-line-of-sight (NLOS), radio wave propagates via reflection, diffraction or bending. As is the case for light waves, mmWave is subject more to shadowing and reflection than diffraction due to the nature of short wavelength. The short wavelength also causes diffusion at the reflection surface(s). However, direct reflection is normally the greatest contributor in NLOS [15].

Radio system designs for mmWave should take into account these propagation characteristics. The basic approach would be to avoid the particular frequency bands in mmWave which show significantly high attenuation, considering power efficiency both in base stations and user equipment.

11. Conclusion

This white paper entitled *"Mobile Communications Systems for 2020 and beyond"* was developed by "2020 and Beyond Ad Hoc (20B AH)" of Association of Radio Industries and Businesses (ARIB), Japan, in order to describe the terrestrial mobile communications systems to be commercialized in 2020 and beyond.

The paper addressed the socio-economic environment surrounding 5G, including market and user trends, traffic trends, cost and spectrum implications, as well as the framework and capability aspects of 5G. Based on the examination on the development road towards '5G', it was concluded that the radio access network (RAN) for IMT for 2020 and beyond as a whole will be realized by the complementary interworking of its constituent Radio Access Technologies (RATs), i.e., Enhanced IMT-Advanced and New RAT(s), which satisfy all the requirements foreseen for mobile radio communications in the year 2020 and beyond. As for the framework, 'Typical User Throughput' is considered one of the most important measures to characterize IMT for 2020 and beyond, focused on user experience in the wide range of user density.

Numerous technologies in various categories identified as effective 5G RAT(s) technologies are summarized in the list in Annex A.

Annex A Functions of 5G Radio Access Technologies

A.1 General

In the following subsections, candidate radio access technologies to realize 5G system are enumerated. Table-A.1-1 shows correlation between these candidate radio access technologies and 5G capabilities described in Chapter 8. It should be noted that in some cases, those technologies in each section (each row in Table A.1-1) may not support capabilities marked as 'x' but subset of the technologies involved in the section or combination of them with certain conditions or deployment may support the capability.

Table.A.1-1 Correlation between 5G RAT and 5G RAN features, capabilities

Radio Access Technology \ Feature, Capability		Coverage [8.2 (i)]	User Throughput [8.2 (ii)]	Peak Data Rate [8.3.1]	Mobility [8.3.1]	Capacity [8.2 (III), 8.3.1]	Connected devices [8.3.1]	Latency [8.3.1]	Energy [8.3.1]	Availability / Reliability [8.3.1]	Lifeline connection [8.3.2]	QoE [8.3.2]	Application diversity [8.3.2]	Virtualization [8.3.2]
A.2	Technologies to enhance the radio interface													
A.2.1	Advanced modulation, coding and multiple access schemes	x	x	x		x	x			x	x	x		
A.2.2	Multi-antenna and multi-site technologies	x	x	x	x	x			x					
A.2.3	Network densification		x		x	x			x	x				x
A.2.4	Flexible spectrum usage	x	x	x	x	x						x	x	
A.2.5	Simultaneous transmission and reception (STR)	x	x	x		x		x		x				
A.2.6	Other Technologies to enhance the radio interface	x	x						x		x	x		
A.3	Technologies to support wide range of emerging services													
A.3.1	Technologies to support the proximity services				x					x		x	x	
A.3.2	Technologies to support M2M						x	x	x	x	x	x	x	
A.4	Technologies to enhance user experience													
A.4.1	Cell edge enhancement	x	x			x	x							
A.4.2	Quality of service enhancement		x					x				x		
A.4.3	Low latency							x				x		
A.4.4	High reliability									x	x			
A.4.5	Radio Local Area Network (RLAN) interworking	x			x	x								
A.4.6	Context Aware											x	x	
A.4.7	Mobility Enhancement with Linear Cell				x								x	
A.5	Technologies to improve energy efficiency													

Radio Access Technology \ Feature, Capability		Coverage [8.2 (i)]	User Throughput [8.2 (ii)]	Peak Data Rate [8.3.1]	Mobility [8.3.1]	Capacity [8.2 (III), 8.3.1]	Connected devices [8.3.1]	Latency [8.3.1]	Energy [8.3.1]	Availability / Reliability [8.3.1]	Lifeline connection [8.3.2]	QoE [8.3.2]	Application diversity [8.3.2]	Virtualization [8.3.2]
A.5.1	Network-level power management					x			x					
A.5.2	Energy-efficient network deployment								x					
A.5.3	Other item					x			x					
A.6	Terminal Technologies													
A.6.1	Advanced receiver	x	x	x	x	x	x			x		x		
A.7	Network Technologies													
A.7.1	Technologies to enhance network architectures								x	x		x	x	x
A.7.2	Technologies to support ease of deployment and increase network reach	x			x						x		x	
A.7.3	Novel RAN architecture	x	x		x	x	x							
A.7.4	Cloud-RAN (C-RAN)		x						x			x		x
A.7.5	RAN sharing enhancement		x		x	x	x					x		
A.8	Technologies to enhance privacy and security											x	x	
A.9	Technical studies on millimeter wave and centimeter wave		x	x		x	x							

A.2 Technologies to enhance the radio interface

A.2.1 Advanced modulation, coding and multiple access schemes

A.2.1.1 Non-orthogonal multiple access

Future RAN systems must cope with increasing data traffic and a large number of connected users. It is required to achieve not only high system capacity but also high user throughput on a macro cell layer which cope with increasing data traffic and a large number of connected users. The technique employing non-orthogonal multiple access can achieve to assign radio resources to users immediately even if the radio resources are occupied by other users. The non-orthogonal multiple access techniques may employ both power levels and spreading codes in combination as mechanisms to facilitate the recovery of different data packets transmitted on common resources.

- Non-orthogonal multiple access (NOMA)

Non-orthogonal multiple access based on the use of power levels and advanced receivers has been introduced in [17]. Considering downlink operation with this technique, multiple downlink signals for different users are superimposed before transmission on common resources. The signals may be assigned different power levels to facilitate reception at the user. As for the uplink multiple access, the base station assigns the radio resources to multiple users so that the uplink signals are spatially-multiplexed on radio channel. The criteria for paired user selection may include conditions on the power levels arriving at the uplink receiver.

- Interleave Division Multiple Access (IDMA)

Interleave Division Multiple Access (IDMA) is a contention based access scheme in which very low-rate error control code words are applied and different interleaves are used to distinguish users. While it has been originally proposed as single-carrier transmission scheme, multi-carrier IDMA called OFDM-IDMA has been recently proposed, which successfully combines the advantages of OFDM and has higher throughput in a multipath environment compared to single-carrier IDMA. IDMA is suited to transmit small packet because it reduces the amount of require control signals used for frequency scheduling [18].

- Sparse code multiple access (SCMA)

The non-orthogonal multiple access may also be based primarily on spreading codes [19]. The sparse code multiple access (SCMA) scheme also uses a nonlinear spreading mechanism, and enables the non-orthogonal superposition technique. In the SCMA, FEC encoded binary domain data are directly mapped to sparse complex domain codewords selected from a predefined codebook set. The codewords are then mapped to OFDMA resource elements, for implementing the spreading process. Multiple user access is achievable by the application of codebooks to each layer or user and adding their respective contribution to the complex vector to be transmitted using the allocated OFDMA resource elements. A key characteristic of the sparse spreading codes is that the system resources can be overloaded such that the number of multiplex layers can be more than the spreading factor. The spreading codes can be optimized for shaping gain (by maximizing decoding decision distance over multiple dimensions) and can also use different power on the active tones.

With these non-orthogonal multiple access schemes mentioned above, it is essential to implement interference cancellation and/or suppression at the receiver in order to reduce the inter-user interference caused by the non-orthogonally multiplexing. For the NOMA scheme based on power level multiplexing, non-linear receiver algorithms such as successive interference cancellation (SIC), turbo equalization (iterative soft interference cancellation, and so on), are promising candidates to obtain significant non-orthogonal multiple access gain. For the SCMA, a codeword base MPA receiver can be seen in [19].

The capability of interference cancellation is required for the base station for the uplink and the user for the downlink to discriminate the desired signals. Moreover, for further enhancement of user throughput, channel dependent scheduling should be considered in the three-dimensional domains, i.e. time, frequency, and space.

A.2.1.2 Advanced modulation, coding and Waveform

To cope with the large traffic in the future, there is strong demand to improve the spectral efficiency. New signal waveform transmission schemes, e.g., Faster-Than Nyquist (FTN) transmission, Filter Bank Multi Carrier (FBMC) transmission, may be one of the potential radio access technologies under such an environment. Although the highly-sophisticated processing is required, some of these schemes may become one of the approaches with the potentiality to improve the spectral efficiency by increasing the data rate.

A.2.2 Multi-antenna and multi-site technologies

A.2.2.1 Multi-antenna technologies

(1) Narrow beamforming in rural area

5G RAN needs to serve very high throughput of users even in rural area. Use of small cells is able to improve throughput of congested users in urban area, whereas beamforming is effective to improve throughput of sparsely-scattered users in large cell coverage of rural area. By using adaptive narrow beamforming, transmission power can be highly concentrated on small area around static and/or moving user(s). The technologies to control large number of antenna elements, obtain accurate channel state information and track moving users are required to be investigated.

(2) Nonlinear precoding MU-MIMO

Multi-user MIMO (MU-MIMO) transmission is one of promising techniques for improving the spectral efficiency of both macro and small cell. The improvement of small cell spectral efficiency is mandatory necessary for offloading the large data traffic. Nonlinear precoding MU-MIMO, *e.g., Tomlinson Harashima precoding, Vector perturbation*, is more beneficial for small cell than current linear precoding MU-MIMO because the transmission performance of nonlinear precoding does not need severe user pairing required in the linear precoding MU-MIMO. This indicates the nonlinear precoding MU-MIMO can multiplex a larger number of users than the linear precoding, therefore, the nonlinear precoding MU-MIMO will successfully deal with the large data traffic of high load small cell.

Nonlinear precoding MU-MIMO can suppress the inter-user interference by the linear filtering similar to the current linear precoding. However, before the linear filtering, the nonlinear precoding can add a perturbation vector to extend the original constellation of modulation symbol as the multiples of constellation in the infinite lattice. By selecting the suitable perturbation vector, the transmit power increased by the linear filtering can be reduced. Any point in the infinite lattice can be recovered in the original constellation by the modulo operation. Therefore, from the viewpoint of the receiver algorithms at user terminal side, it is sufficient that each receiver applies the simple modulo operation to the received signal.

(3) Narrow-beam antenna

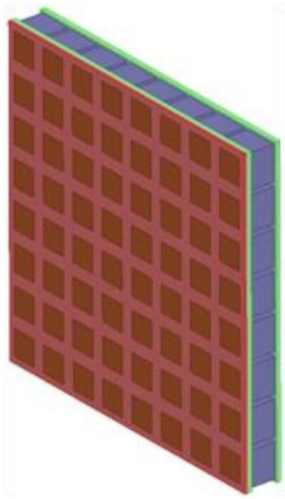


Fig. A.2.2-1 Several-tens elements array antenna

The current state-of-the-art MIMO scheme is typically based on closed loop spatial multiplexing using PMI (Precoding Matrix Indicator) feedback and SFBC (Space Frequency Block Code). For Enhanced IMT-Advanced, narrow beamforming using an antenna array consisting of several tens elements is utilized in a 3D MIMO scenario. In 3D MIMO, a beam pattern is controlled in both horizontal and vertical spatial dimension to avoid interference from neighboring cells.

(4) Enhanced MIMO for interference cancellation

In addition to the current MIMO scheme, the enhanced MIMO scheme will be introduced into the base stations and cancel/reduce the interference signal, which can be realized by analyzing the interference signals from the adjacent base stations and/or unconnected user equipment to the base station, This will be based on the same technology which is introduced to the current user equipment as IRS (Interference rejection combining).

This enhanced MIMO scheme improves not only the receiver sensitivity of the base stations, but also the system capacity by the reduction of the interference between cells. This improvement will be particularly effective and useful to solve the interference issues in the dense deployment of the small cell base stations.

(5) ABF Cell/Small Massive Antenna

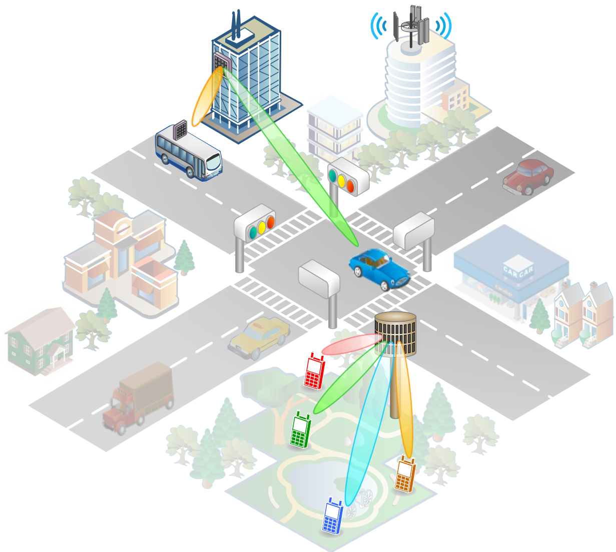


Fig. A.2.2-2 Small Massive Antenna／ ABF Cell

In the development of 5G, it is important to overcome propagation loss in higher frequency band, and to improve spatial user multiplexing performance for both mobile and static use cases. A new cell concept, Adaptive BeamForming (ABF) cell, will satisfy the aforementioned 5G requirements using massive antennas. In the adaptive BeamForming cell, massive antennas are used to provide flexible beam patterns, allowing expansion of a cell radius and MU-MIMO with higher capacity. The proposed cell is also designed for clustered mobile use cases. For example, within the proposed cell, commuter bus riders can use high data rate services during rush hour.

(6) High speed 3D beamforming

By tracking the narrowed beam very fast to vehicles or trains, very stable and high throughput communication can be realized in such a fast moving object by using high speed 3D beam forming. Especially to trains, even if the speed is very fast, the starting time, starting position and root of tracking can be easily predicted by the information which includes the time table, rail map and train position offered by the train control system, if the base stations have the interface to the system and they are well coordinated. Moreover this coordination will be very useful for the hand over system between base stations. So it might be more easily installed to the well-controlled trains.

A.2.2.2 Multi-site technologies

Multi-site technologies with beamforming

Multi-site transmission/reception technologies with beamforming are needed to prevent link loss due to shadowing and execute smooth handover. In the proposed ABF cell scenario, UE and a target cell need to find each other to establish a communication link with an optimize beam pattern. Therefore, UE or target cell search function needs to be improved or developed.

The technologies shall improve the following performances:

- Probability of handover failure, radio link failure
- Time required optimizing beams

A.2.3 Network densification

To address the challenge of able to provide extremely high traffic capacity and multi-Gbps data rates in specific scenarios, the introduction of ultra-dense network deployments is foreseen with nodes operating with very wide transmission bandwidths in higher-frequency bands relying on new RAT.

- Ultra-dense networks will consist of low-power access nodes being deployed with much higher density than the networks of today. In extreme cases, we foresee indoor deployments with access nodes in every room and outdoor deployments with access nodes at lamppost distance apart. To reliably support multi-Gbps data rates, ultra-dense networks should support minimum transmission bandwidths of several 100MHz with the possibility of an extension up to GHz-order bandwidth.
- Ultra-dense networks will primarily operate in the high frequency (typically above 20GHz). High frequency bands appear more suitable to the shorter-range communication of ultra-dense networks. Higher frequency bands make it easier to provide the very wide transmission bandwidth needed to reliably support multi-Gbps data rates. Ultra-dense networks will include advanced network solutions, such as integrated wireless multi-hop self-backhaul and advanced node coordination.
- Although they will operate in different spectrum and will most likely be based on new RAT, the ultra-dense networks should be well integrated with the overlaid cellular networks, providing a seamless user experience as devices move in and out of ultra-dense network coverage.

A key technical trend efficiently to deploy dense network is a Phantom cell concept [20], which is a network architecture concept splitting control (C)-plane and user data (U)-plane between macro-cell layer and small-cell layer in the overlaid cellular network using different frequency bands as shown in Fig. A.2.3-1. The C-plane is provided by a macro cell in a lower frequency band to maintain good connectivity and mobility. The macro cell also works as a normal cell supporting both C-plane and U-plane signaling. On the other hand, a broadband U-plane is provided by a small cell using a higher frequency band in order to boost the capacity and data rate. In the concept, there are variable motivations to be addressed for practical dense small cell deployments as follows.

- Small cell deployment without impact on mobility management
- Energy/cost efficient small cell operations
- Relaxing of cell planning effort and backhaul requirements
- Efficient small cell discovery

Phantom cell concept also includes functionality of inter-node carrier aggregation, i.e., dual connectivity, to relax the backhaul requirements between macro cell and small cell. In the 5G era, such network configuration splitting C-plane and U-plane will be the baseline to integrate future multi-layer networks using lower and higher frequency bands.

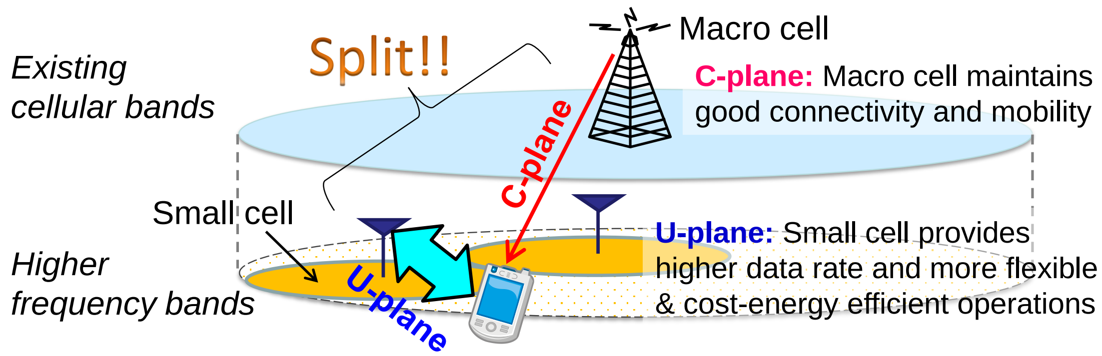


Figure A.2.3-1 Phantom cell concept with C/U-plane splitting.

A.2.4 Flexible spectrum usage

The mobile communication systems have been evolved by adapting new technologies to improve their spectrum efficiency, e.g. cellular concept, adaptive modulation and coding scheme and efficient radio resource management to alleviate the spectrum demand for mobile communications. Due to the ever increasing demand for mobile data communications, the spectrum demand is still increasing. The spectrum demand for mobile communications is forecasted 1000 to 2000 MHz by the year 2020 [21]. Since the radio spectrum resource is limited and scarce, it is getting more difficult to get new radio spectrum for mobile communication systems and/or to refarm radio spectrum in order to assign more spectrum to mobile communication systems within the framework of current spectrum usage scheme. Schemes and technologies for more "flexible" use of spectrum need to be developed to satisfy ever-increasing demands for spectrum.

The focus area of R&D is also shifting from the development of spectrally efficient technologies to that of flexible use of spectrum so that all the spectrum resources available can be fully exploited.

In the flexible use of spectrum, there are two major categories; (1) flexible spectrum use retaining the current spectrum regime (Sections A.2.4.1, A.2.4.2 and A.2.4.3) and (2) flexible spectrum use that needs changes to some extent in the spectrum regime (Sections A.2.4.4 and A.2.4.5).

In a single RAT, for example LTE, the RAT has conventionally used one of the multiple frequency bands, e.g. 800-900MHz, 1.5 GHz and 2GHz ranges, which are assigned to LTE/LTE-Advanced mobile communication systems. Recently, the technology has been developed so that the RAT can aggregate multiple frequency bands to obtain a logical broadband radio channel (Carrier Aggregation). In the future, the RAT will flexibly use/aggregate these frequency bands to fully exploit the different nature of these frequency bands to achieve higher efficiency of spectrum utilization. This technology is described in Section A.2.4.1.

The other approach to exploit advantages of the difference of the spectrum band is a heterogeneous network of different types of RATs, in which multiple RATs are aggregated as described in Section A.2.4.2. This approach flexibly manages multiple RATs to achieve high efficient spectrum use by exploiting both the difference of spectrum bands and systems. The first attempt of this approach has been used for offloading mobile communication traffic to a Wi-Fi which sometimes less utilizes the radio spectrum.

The emerging approaches for higher spectrum use are those fall in Flexible Spectrum Access (FSA) as described in A.2.4.3 to A.2.4.5, in which a focus is brought into spectrum sharing with multiple radio communication systems to achieve higher spectrum usage rate, assuming that some spectrum bands are underutilized depending on time and geographical areas according to the results of spectrum occupancy measurements [22] [23]. Section A.2.4.3 addresses the shared use of license-exempt spectrum bands by mobile RAT such as LTE, which has been operated in frequency bands exclusive to public land mobile communications. Section A.2.4.4 provides overview of Dynamic Spectrum Access (DSA), in which several approaches are introduced to use spectrum in a more dynamic manner in time domain. Section A.2.4.5 addresses Licensed or Authorized Shared Access (LSA/ASA) in which spectrum sharing is allowed in orderly manner.

Section A.2.4.6 addresses a programmable radio frequency (RF) technology which supports the flexible use of spectrum.

A.2.4.1 Flexible spectrum management in a single RAT

(1) Heterogeneous network using various types of cell deployments

The network consisting of different types of cell in a single RAT, e.g. LTE, has been considered as heterogeneous network in 3GPP.

Considering 5G mobile systems in 2020 and beyond, in addition to conventional IMT frequency bands, the use of higher frequency bands (e.g. above 6GHz) is expected to accommodate huge traffic. Such higher frequency bands are suitable for smaller cell deployment due to its larger radio propagation loss. Therefore, the network will consist of several types of cells such as traditional high power macro-cell with conventional IMT frequency bands and lower power small cell with higher frequency bands, etc. In addition, such smaller cells are expected to be deployed densely to improve the area spectral efficiency while ensuring the coverage. In such heterogeneous network scenario including various types of cells, the flexible use of multiple frequency bands together with multiple cells deployments is needed.

Multiple cell deployment can be realized by centralized and distributed coordination, as shown in Fig. A.2.4-1. Such coordination helps cooperate to mitigate interference, improve the received signal power, or enhance the data rate.

Centralized coordination can be realized by the ideal backhaul such as high capacity optical fiber which carries baseband or RF signal. It connects remote antennas and a central baseband unit. Another way of centralized coordination can be realized by a non-ideal backhaul such as fiber optics to carry IP, or even copper (xDSL) line and wireless interface. It connects multiple small eNBs and centralized coordination entity.

Distributed coordination can be realized by a non-ideal backhaul. Multiple small eNBs are connected each other. In distributed coordination, self-organized coordination with intelligent distributed manner is quite important, although such self-organized coordination would also be required among central entities in centralized coordination.

To achieve high data rate while maintaining efficient mobility management, control / user plane splitting or separation needs to be considered as one of effective solutions.

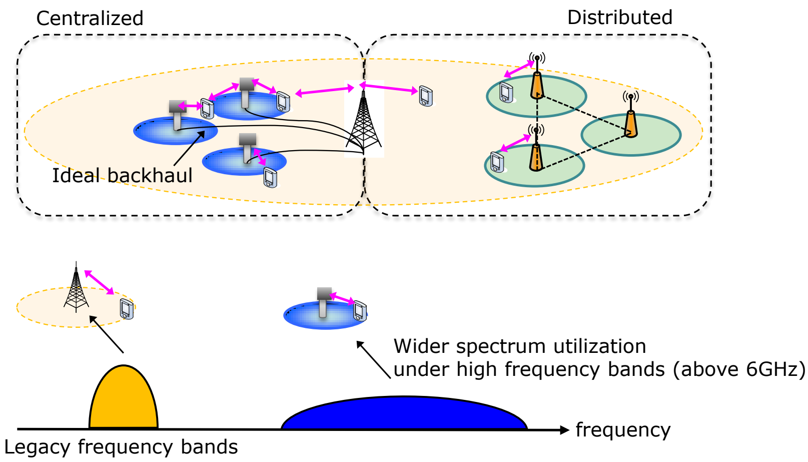


Fig. A.2.4-1 Multiple cell deployment

(2) Control- / User-Plane splitting for flexible spectrum use

With requirements of higher system capacity for cellular systems, denser deployment of access points in large cities has been widely introduced, mainly for achieving higher spectral efficiency. However, we have currently, another important restriction for cell size, i.e. the increase of user peak rate becomes difficult because transmit power cannot be increased although user rate is getting higher. The reduction of cell size is, therefore, no longer a parameter to control system capacity itself, but becomes a strict restriction to cope with dynamic range expansion of user rate in future mobile systems. On the other hand, terminal mobility management becomes more complex when cell size becomes smaller. Therefore, more dynamic cell size control while considering existence of higher mobility terminal becomes very important for future mobile systems. Introduction of control- and user-plane (C/U) splitting is widely discussed as a useful technique to cope with hierarchy cell configurations. In this scheme, macro- and micro-cells are introduced in a hierarchy cell structure, where control signals are exchanged over macro-cell links, and user data is exchanged over micro-cell links in a macro and microcell integrated scheme. This configuration will be beneficial especially when a millimeter wave system is introduced in future mobile systems, because the cell size for the millimeter wave system is extremely small, e.g. several meters to 10 m whereas the cell size for a macro cell is 100m or more. Because the situations of microcell systems in a macro cell can be recognized by a heterogeneous network and can be controlled by the control plane of macro cell, cooperative transmission as well as area information support of microcell systems are available via the macro cell networks. Therefore, such a C/U splitting control in heterogeneous networks will be very beneficial to construct extremely high speed wireless access networks.

A.2.4.2 Heterogeneous Network - Advanced interworking among multiple RATs

(1) Heterogeneous network using different types of RATs

Wi-Fi technology has widely been deployed and Wi-Gig technology will be deployed as well. These non-cellular radio access technologies are different from cellular access technologies. Although joint radio resource management (RRM) strategies and algorithms within cellular access technologies have been implemented, joint RRM strategies and algorithm between cellular and non-cellular access technologies have more possibility of the improvement.

Fig. 2.4-2 shows a heterogeneous network including different types of RATs. In order to cope with a huge amount of data from a wide variety of services which are forecasted in the year 2020 and beyond, such joint operations between multiple RATs in the heterogeneous network will be important in terms of efficient use of spectrum. Each RAT has different advantages in its service properties. Therefore, flexible integration of multiple RATs including 2G, 3G, LTE, Wi-Fi, Wi-Gig, and new RATs, if any, will also be important to accommodate wide range of service properties. In addition, to use the legacy/evolution of the existing RATs would minimize the total cost of deployment and/or standardization. The networks customized for service, application, user and/or location can flexibly be provided with the coordination of multiple RATs, taking into account traffic, user distribution, user needs/preference. Usability should also be improved by automatic network coordination since users need not care which RAT they are currently connected over, e.g. LTE, Wi-Fi, or Wi-Gig, etc.

Coordination of multiple RATs can be realized by centralized and distributed coordination. Such coordination helps cooperation to improve QoS of users. Similar to the case within a single cellular system, control / user plane splitting among different RATs can be considered as one of the effective solutions to achieve high data rate while maintaining efficient mobility management.

In addition, a lot of uncoordinated network and air interface resources would be available in a multiple RAT operation scenario, especially with Wi-Fi. Such uncoordinated network may be appear or disappear according to the users' use case scenarios i.e. the scenario that individual users and/or organizations set up Wi-Fi access points by themselves would be a typical one among other scenarios. Therefore, to coordinate "uncoordinated networks" is a promising area in improving system capacity and user experience in multi-RAT capable networks and terminals. Such improvement can be realized by distributed coordination, such as self-organized network with an intelligent distributed manner. It can be realized by the network control based coordination and terminal-driven network coordination with also the possibility of network assistance.

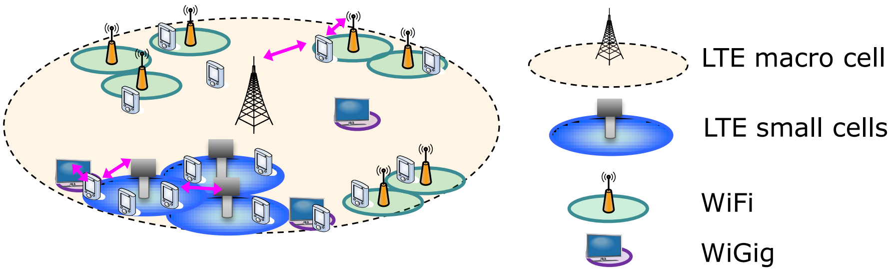


Fig. A.2.4-2 Heterogeneous network including different types of RATs

(2) Evolution of the heterogeneous network

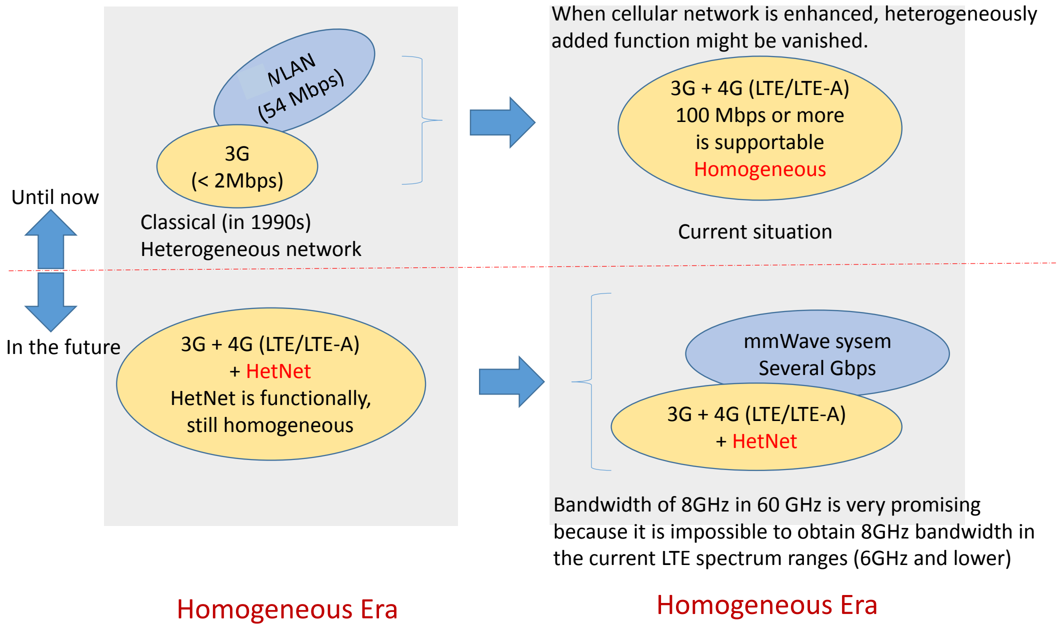


Fig. A.2.4-3 Future network evolution through heterogeneous networking

Fig. A.2.4-3 shows a future network evolution from a viewpoint of heterogeneous networking. In the beginning of the year 2000, when heterogeneous networking was proposed, integration of wireless LAN and cellular systems was the most promising combination for heterogeneous networks, because peak user rate for cellular systems is limited to 2 Mbps whereas Radio LAN (R-LAN), e.g. Wi-Fi can support up to 54 Mbps in those days. However, as the enhancement of functionality in cellular networks, combination of cellular and wireless LAN is no longer promising because homogeneous network that consists of 3G and/or 4G, e.g. LTE or LTE-Advanced can cover user data rate supported by the R-LAN systems. Therefore, in future heterogeneous networks, the systems that are designed based on completely different priorities would be combined. A possible combination would be the introduction of millimeter wave systems that has a spectrum bandwidth of more than 8 GHz into cellular systems, because contiguous bandwidth of more than 8 GHz is completely impossible to be assigned to the future mobile systems in the spectrum range below 6 GHz.

A.2.4.3 Application of mobile RAT to license-exempt bands

The alternative approach to cope with the shortage of spectrum resources due to traffic explosion in high capacity 5G era, is the use of spectrum in license-exempt bands, e.g. Industry-Science-Medical (ISM) band in 2.4 GHz. There will be a pressing need for additional spectrum resource other than licensed spectrum since the amount of available licensed spectrum for exclusive use is limited and costly. Therefore, the use of license-exempt spectrum bands for data offloading will be one of the key features in terms of flexible spectrum usage in the year 2020 and beyond.

Even though the data offloading of a cellular system via an R-LAN, e.g. Wi-Fi system has been widely achieved as an application of license-exempt spectrum utilization, more integrated approach will be required in the year 2020 and beyond, i.e. the application of the same radio access technology for licensed spectrum bands to the license-exempt bands. This would be one of the promising enhancements for future IMT system(s).

For example, utilization of license-exempt spectrum bands with assistance of the existing cellular system in licensed spectrum may increase the total system capacity, since the license-exempt spectrum bands having a wide variety of properties, e.g., the different nature of interference from other systems, and radio propagation property (path loss, Doppler frequency, etc.), can flexibly be used based on the wide range of applications and services.

The benefits of license-exempt spectrum utilization would be to offer 1) potentially better frequency efficiency and coverage, and 2) cost-effective operation for mobile operators.

On the other hand, there are different technical and/or operational restrictions for the use of license-exempt spectrum bands in different countries. The technical enhancements, e.g., "listen before talk", may therefore be required in order for the cellular system to be used in the license-exempt spectrum bands. In addition, coexistence with other legacy RATs in the license-exempt spectrum bands also needs to be considered as a new technical challenge.

A.2.4.4 Dynamic Spectrum Access (DSA)

The spectrum demand for mobile communications is forecasted to further grow due to their huge data traffic. The spectrum resources have been assigned exclusively to specific radio services in a predefined and static manner. The recent spectrum survey reveals that there is a variation in the use of spectrum both in a temporal and geographical domain, depending on radio services. The use of radio spectrum resources in more dynamic manner has been studied in both regulatory, industry and academic arenas.

Dynamic Spectrum Access (DSA) encompasses various methods to use spectrum dynamically [24], as depicted in Fig. A.2.4-4.

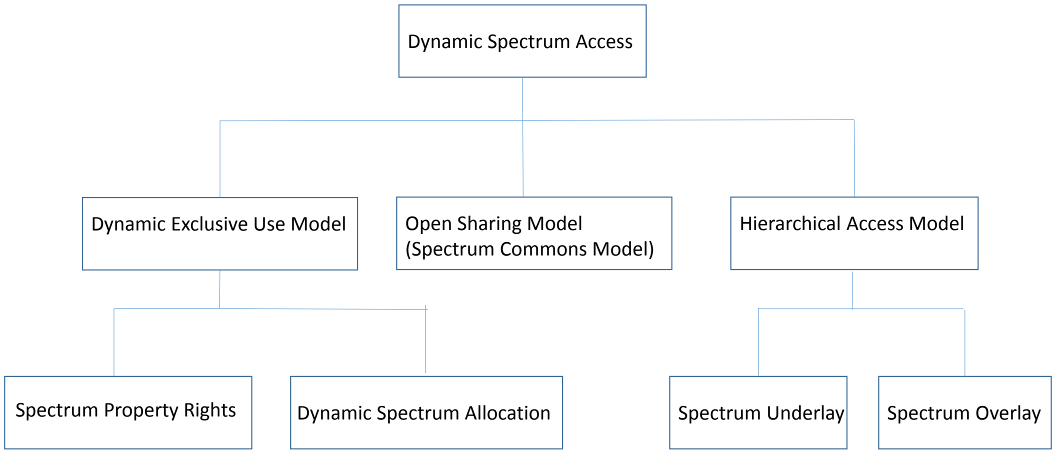


Fig. A.2.4-4 A taxonomy of Dynamic Spectrum Access

Dynamic Exclusive Use Model maintains basic regulatory framework in that spectrum bands are licensed to radio services for exclusive use. This model is further categorized into two categories; *Spectrum Property Rights* and *Dynamic Spectrum Allocation*.

Spectrum Property Rights model allows licensees to sell and trade spectrum as well as to choose Radio Access Technology (RAT) by licensee's decision, while most of the present "Command and Control" regimes only allow licensees to use particular frequency bands for particular radio systems. This approach is dynamic in that the licensees may choose a radio communication system dynamically according to the market demands, without getting a new permission from authorities.

Dynamic Spectrum Allocation is another approach to improve spectrum efficiency by dynamic spectrum assignment with exploiting the temporal and geographical difference of traffic of radio communication systems.

Open Sharing model is also known as *spectrum commons*, which employs open sharing among users who have an equal access right to spectrum. This model originally comes from the experience of R-LAN, e.g. Wi-Fi operation in license exempt ISM band. The application of mobile radio systems to the license exempt band is delineated in Section A.2.4.3.

The *Hierarchical Access model* is based on the spectrum access structure of two different layers; primary and secondary users. This approach is also called "vertical sharing" model. Under this model, secondary users are only allowed to access spectrum under the condition that they do not give any harmful interference to the primary users. This scheme further has two major approaches; *Spectrum Underlay,* e.g. Ultra Wide Band (UWB) and *Spectrum Overlay*, i.e. opportunistic spectrum access although there are some approaches in-between.

Dynamic Spectrum Access becomes feasible and practical with the aid of Cognitive Radio capabilities, such as the cognition of radio environments for interference avoidance.

Some elements in the flexible spectrum use of Dynamic Spectrum Access approaches would be introduced in 5G RAN in order to further improve spectrum efficiency.

A.2.4.5 Licensed or Authorized Shared Access (LSA/ASA)

In a circumstance where radio systems run out of its available range in a certain frequency band, spectrum sharing approach may be effective measure to be introduced. Shared spectrum access method has several schemes in which two or more users or wireless applications are authorized to utilize the same span of frequency bands on a non-exclusive basis in a defined sharing arrangement along with any other possibility for multiple users to access the radio spectrum without having exclusive rights.

Licensed Shared Access (LSA) is an effective shared spectrum access scheme to achieve spectrum sharing between the incumbent holder(s) and LSA licensee. The LSA enables spectrum sharing flexibly when and where the operation of incumbent user is vacant or very limited at a time in an area. The LSA facilitates introduction of new spectrum users in that spectrum band while maintaining the incumbent services by ensuring a certain level of guarantee in terms of spectrum access and protection against harmful interference for both the incumbent(s) and LSA licensee(s), thereby allowing them to provide a predictable quality of service under the control. This scheme contributes to efficient spectrum utilization on the time, space and frequency domains. ([25], [26])

An example of LSA architecture is described in [27] where the key functional components are listed as follows:

- LSA Repository:

It is database with relevant information (i.e. spatial, frequency, time) on spectrum use by the incumbents. That is required to deliver information and associated conditions.

- LSA Controller:

It manages the access to the spectrum made available to the LSA licensee based on sharing rules, policy and information on the incumbent's use provided by the LSA repository. It computes LSA spectrum availability based on LSA repository and on the rules.

- Operations, Administration, and maintenance (OA&M):

It translates the LSA Controller message into radio resource management (RRM) commands on the LSA spectrum availability over the underlying incumbent spectrum.

Above LSA control architecture enables unlock of the incumbent spectrum dynamically or in some statistical manner depending on the operational availability and negotiation terms with the incumbent band operation. That can fulfill the cell capacity requirement under the predictable QoS assurance simultaneously.

In some scenario, for example, the LSA scheme can work effectively in conjunction with carrier aggregation (CA) between a licensed band and another LSA band when it is available for non-wasteful spectrum usage.

A.2.4.6 Programmable radio frequency (RF)

A totally programmable access point (AP) in which RF signal processing is also programmable enables 5G RAN to realize flexible interworking of various wireless systems such as LTE, Wi-Fi and so on. The AP needs to realize wide-range programmability of frequency bands from UHF band to millimeter wave band and transmission power from several ten milli-watts to several ten watts. Moreover, it needs to be equipped with self-monitoring functions that can guarantee the accurate realization of configured parameters and can avoid spurious emission due to change of parameters. One of the subjects of future investigation is digital circuit realization of frequency-tunable functions, which can exclude the imperfection of the analogue devices and can reduce both sizes and power consumption of AP, provided future evolution of the semiconductor process.

A.2.5 Simultaneous transmission and reception (STR)

Frequency Division Duplex (FDD) has, until now, been the dominating duplex scheme for cellular communication and will clearly continue to be very important, especially for macro deployments.

However, the importance of Time Division Duplex (TDD) can be expected to increase in the future, especially in light of an expected increased importance of very dense network deployments with low-power network nodes outdoor on street level or indoor. The expected much larger transmission bandwidths of future wireless access, with bandwidth of at least several 100 MHz in higher frequency bands being considered, will also increase the relevance of TDD due to the difficulty of finding sufficiently large paired-spectrum allocations.

It should also be noted that the increased interest for direct device-to-device (D2D) communication makes TDD more relevant.

Current TDD-based cellular technologies assume a relatively static assignment of transmission resources to the two transmission directions. Future TDD should allow for much more dynamic assignment of resources to the different transmission directions in order to enable more efficient utilization of radio resources.

Simultaneous transmission and reception (STR) or full duplex radio is a technology to improve the spectrum efficiency significantly, i.e. theoretically doubling the spectrum efficiency.

STR or full duplex radio implies transmission and reception taking place on the same frequency at the same time with the interference from the transmitter being suppressed by different means. In principle, this interference suppression is straightforward as the interfering signal is fully known to the receiver. However, in practice the cancellation is very difficult due to the extreme power difference between the target and interfering signals at the receiver side. In order to relax the dynamic requirements on A/D converters, the experiments/demonstrations of full duplex has relied on a combination of over-the-air suppression, analog suppression/cancellation and digital suppression/cancellation.

At current technology level, STR or full duplex radio communication is not commercially feasible except, perhaps, in case of very specific scenarios. However, with future implementation advancements, STR or full duplex radio may be applicable to more scenarios. Thus, the possibility for later introduction of STR or full duplex radio should be taken into account in the design of future radio-access technology even if it is not realizable in the early introduction of such technology.

It can be concluded that:

- FDD based on paired spectrum will continue to be important, especially for spectrum targeting high-power macro deployments.
- The importance of TDD will increase, especially for higher frequency bands

targeting more dense deployments of low-power network nodes. Future TDD technologies should preferably allow for dynamic assignment of resources to the different transmission directions.

- Future radio-access technologies should preferably be designed to allow for the introduction of STR or full-duplex when implementation so allows.

A.2.6 Other Technologies to enhance the radio interface

A.2.6.1 Programmable Air Interface

5G system is expected to support a much broader range of deployment and application scenarios than the previous generation wireless systems. On one hand, people expect to watch and exchange high quality video over mobile broadband networks, at home or in vehicles, without any perceptible experience degradations (e.g. buffering delays, stalls). On another hand, a huge proliferation of IoT devices may be connected via these same networks for the purpose of issuing small messages for periodic or event based reporting. Air interface adaptation will enable the 5G system to serve contrasting applications efficiently.

Flexible configuration of air interface elements can be achieved dynamically by a radio interface controller. Characteristics of air interface may be adapted depending on the operational environments or link conditions in a similar manner to the adaptive modulation and coding (AMC). Also, the air interface may be adjusted or customized to serve different type of service applications in different use cases. By introducing the air interface adaptation control, it enables efficient use of the resources such as frequency spectrum, time, transmission power and the total energy. This approach also contributes to reduce the interference risk on neighbor cells and the coexisting systems, while maintaining the desired level of service qualities for user experience.

Adaptation candidates may include configurable elements such as the waveform and modulation, coding scheme, frame structure, re-transmission scheme, access scheme, and multiple RAT selection.

Configurable elements for adaptation candidate may include those of the waveform and modulation(e.g. OFDM, SCM, FBMC, FTN), frame structure (e.g. Multiple level TTI), coding scheme, transmission and re-transmission scheme, multiple access scheme (e.g. dedicated channel resource, shared channel resource, contention/non-contention based), and multiple RATs group (e.g. 5G air-interface, 4G, 3G, RLAN).

Those elements may be configurable by an adaptation mechanism with signaling exchange between UEs and the air interface control entity in the network, which is working on the PHY, MAC, RRM and IP layer. For example, at the initial step for access procedure, the UE capability information is sent to the network side, and the air-interface components selection is ordered to the UE from the network side based on some measurement metrics (e.g. CQI). Those physical components of fundamental air-interface may be explicitly controlled by signaling exchanges in the protocol, while supplemental attributes and the associated parameters may be invoked in implicit manner.

A.2.6.2 Further enhancement of traffic adaptation

Dynamic traffic adaptation is to enhance capacity for the small cells overlaid by macro layer and a user-centric resource allocation, i.e. the user perceived throughput, can be achieved by effectively and dynamically change the transmission directions according to the time instance of the downlink and uplink traffic load. The dynamic traffic adaptation can maximize the traffic adaptation gain under the condition regarded as the isolated small cell, e.g. the condition where the small cell base station and user equipment (UEs) are within the same indoor building.

As challenge to apply the dynamic traffic adaptation to the outdoor small cells in high load case, interference mitigation techniques need to be studied to mitigate cross-link interference between small cells due to the different transmission directions among small cells. The type of cross-link interference includes co-channel small cells for the same operator, adjacent channel small cells of the same operator, and adjacent channel small cells of different operators. Furthermore, to realize traffic adaptation in the dense small cell networks, further enhancement of interference mitigation techniques needs to be studied including small cell coordination between small cells, and downlink/uplink power control.

A.2.6.3 Flexible backhaul

Currently, fixed backhaul solution such as wired backhaul (e.g. optical fiber, cable) or wireless backhaul is costly and inefficient in some typical scenarios. Affordable cost and high reliability flexible backhaul solution is required for covering traffic hot spot in nomadic manner.

Flexible backhaul solution, based on the IMT radio access technology, can satisfy various requirements such as point to point, point to multi-point system. It is a key technology having benefits of higher spectrum efficiency, and convenience of maintenance. Also, it facilitates network availability with the available resources to achieve high capacity, low latency and high reliability for wireless backhauling.

Concept of flexible backhaul:

It is a complete solution to improve transmission capability of mobile backhaul with scalable and dynamic network topology, through flexibly utilizing the available system resources and dynamic resource allocation to meet the network transmission requirement with affordable cost. The wireless self-backhaul realizes fiber-like access to the fixed network.

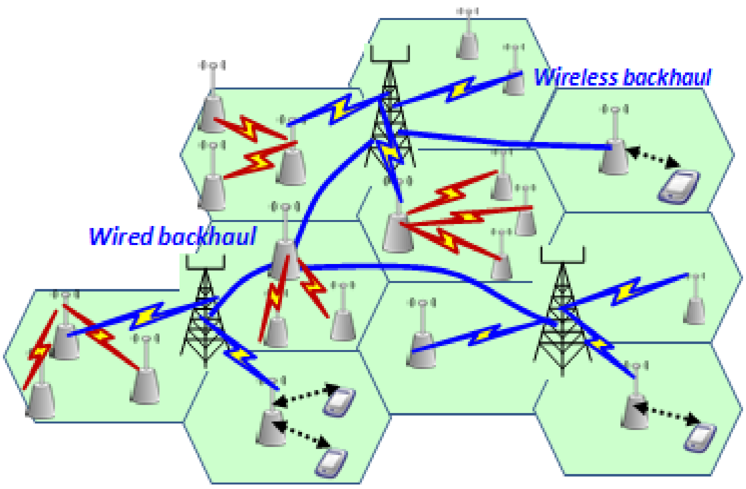


Fig. A.2.6-1 Flexible backhaul

Key features of flexible backhaul are noted below:

Flexible system resources : flexibly utilizing any system resources including wired resources, wireless resources (e.g. mmWave) and the hybrid resources, in order to increase the resource utilization efficiency

Dynamic network topology: adjusting mobile network topology and backhaul transmission nodes dynamically in order to cover the varying traffic and to meet the transmission capability. Plug-and-play capability is essential to deployment where such nodes will need to access and self-organize available spectrum blocks.

Dynamic resource scheduling : exploiting the freedom degree of network resources in terms of frequency, space, power, and time, in order to maximize the transmission capability of access network aggregated to the backhaul.

A.2.6.4 Terrestrial-Satellite Cooperation

As 5G is to provide lifeline communication, it is important for 5G to cover everywhere including mountainous region, ocean, etc. The satellite communication is more efficient for the coverage enhancement in such isolated areas. In addition, especially on serious natural disaster occasions, the satellite communication will be the important alternative to terrestrial system. Hence, terrestrial-satellite cooperation is expected in 5G.

The technology enablers for terrestrial-satellite cooperation are:

- Cognitive radio which selects appropriate systems (terrestrial or satellite) automatically
- A high degree of commonality between the terrestrial and satellite radio interfaces

A.3 Technologies to support wide range of emerging services

A.3.1 Technologies to support the proximity services

The popularity of proximity services is anticipated to grow dramatically in the 5G era. D2D communication can be a powerful enabler of such location based, or location aware services which will be also useful in provisional or nomadic scenes as well. As the typical applications, some telecommunications in traffic safety, public safety, and general proximity services are favored with D2D direct communication owing to its potential contributions to higher spectrum efficiency, coverage extension, and significant reduction of latency in the air interface compared with the case of the conventional communication via the network infrastructure. For example of proximity services, in front of a shop in a shopping area, AR applications may benefit from metadata delivery over inter-device links connecting the user with nearby points of interest which are enabled with transceivers.

In addition, D2D communication can be used for various devices as well as smartphones and tablet devices. For the various devices, such as home appliances and vehicles, the direct communication among terminals could conduct the future life style, traffic safety, and so on.

Grouping of D2D devices for the purpose of cooperation may be determined by devices themselves on an ad-hoc basis protocol exchanging in some level, or may be network-assisted. Under the network control, D2D will offer carrier-grade reliability to local communication services since the network can manage the D2D traffic in the available band. Hence D2D can improve user experience of proximity services.

From the technical point of view, there are several challenges, such as interference management (between cellular signal and D2D signal, between D2D signals), new frame design with a flexible UL/DL pattern which itself will enable support for more flexible adaptation to different scenarios: e.g. UL and DL traffic imbalance, self-backhauling, easier device-to-device communication and faster dormancy for lower energy consumption.

A.3.2 Technologies to support M2M

Machine to Machine (M2M) communications impose a key challenge on 5G radio access in order to enable the accommodation of a massive number of connected devices with a wide range of requirements. Thus, the support of massive device connectivity for future Internet of Things (IoT) is a fundamental requirement of 5G as also explained in Section 8.3.1. Besides massive device connectivity, there would be other requirements specific to particular M2M use cases, such as super long battery life and ultra-high reliability. Hereafter, technical issues and solutions corresponding to three major requirements related to M2M use cases are presented as shown in Fig. A.3.2-1. Note that such a variety of M2M requirements may be supported by a single new RAT or multiple new RATs together with Enhanced LTE RAT.

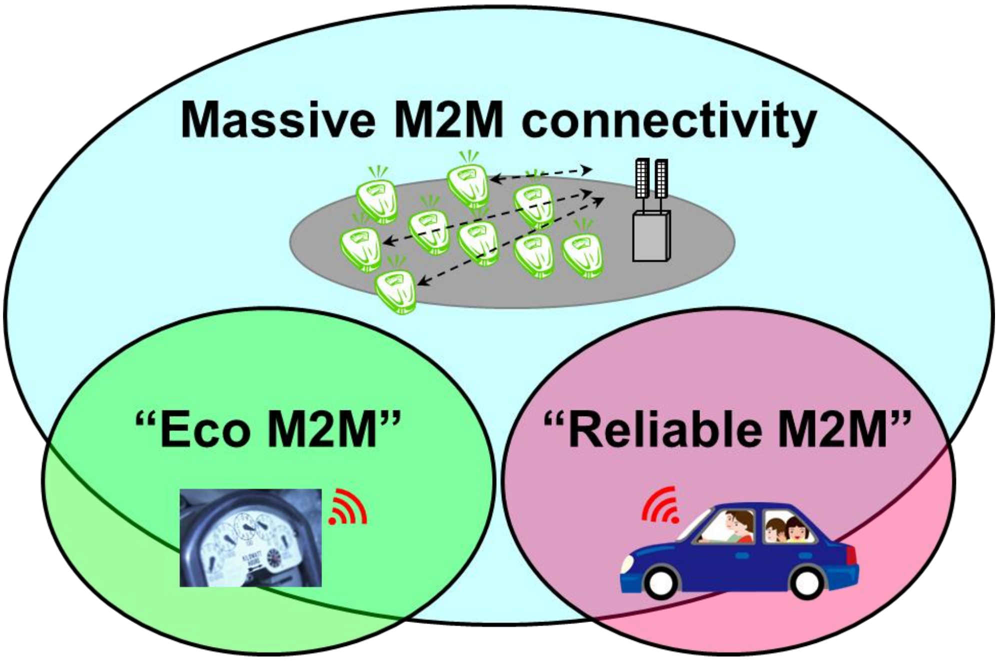


Fig. A.3.2-1 Three major requirements of M2M use cases

■ Massive M2M connectivity

The support of massive device connectivity is a fundamental requirement for 5G radio access taking into account the variability of requirements of M2M use cases. Possible technical issues regarding massive M2M connectivity are as follows.

- Radio capacity for massive device connections
- Reduction of signaling impact on core network
- Efficient support of various Quality of Experience (QoE)
- Efficient support of small payloads, e.g., signaling traffic
- Efficient support of large number of simultaneous accesses
- Efficient support of variable communication triggers such as proximity-triggered communications

In order to address such a variety of technical issues, a set of solutions would be required as summarized in Table A.3.2-1.

Table A.3.2-1 Technical issues and solutions for massive M2M connectivity

Technical issues	Possible solutions
Radio capacity for massive device connections	General capacity enhancing technologies such as NOMA, massive MIMO, etc.
Reduction of signaling impact to core network	Efficient device grouping, flexible RAN architecture, etc.
Efficient support of various Quality of user Experience (QoE)	Efficient QoE aware scheduling and related L1/L2 protocol design
Efficient support of small payloads, e.g., signaling traffic	Low signaling overhead for small payloads, e.g., transmission without channel state information (CSI) feedback, etc.
Efficient support of large number of simultaneous accesses	Efficient paging and random access schemes
Efficient support of variable communication triggers such as proximity-triggered communications	Efficient device discovery, etc.

■ Support for super long battery life for specific M2M devices (Eco M2M)

As explained in Section 8.3.1, longer battery life for mobile terminals is a general requirement of 5G radio access, and some specific M2M devices such as sensors and smart meters may require extremely longer battery life, e.g., up to 10 years. Such “Eco M2M” use cases typically require lower device cost and have lower data rate per device. A long range of coverage, e.g., up to deep in house, may also be required in some usage scenarios. In order to address such technical issues, a set of solutions would be required as summarized in Table A.3.2-2.

Table A.3.2-2 Technical issues and solutions for "Eco M2M" use cases

Technical issues	Possible solutions
Long battery life, e.g., up to 10 years	Small Tx power capability, efficient long DRX mechanism, energy aware scheduling, etc.
Lower device cost	- Huge economy of scale (ecosystem) like LTE - Lower data rate capability, relaxation of RF bandwidth and requirements, etc.
Coverage extension	Repetition and lower coding rate, narrowband transmission, beamforming technology, etc.

■ Support for ultra-reliable M2M/D2D use cases (Reliable M2M)

As explained in Section 7.1 and 7.3, some M2M or device-to-device (D2D) use cases such as transportation and safety/lifeline system will require very high reliability while supporting the required latency and mobility. Such M2M usage cases should be available immediately when needed. In order to address such technical issues, a set of solutions would be required as summarized in Table A.3.2-3.

Table A.3.2-3 Technical issues and solutions for "Reliable M2M" use cases

Technical issues	Possible solutions
Ultra high reliability	Robust transmission technologies such as diversity, enhanced channel coding, hybrid ARQ, error detection scheme, etc.
Ultra low latency	- Short Tx time interval (TTI) and round trip delay (RTD) - Fast radio access establishment including efficient discovery, etc.
High possibility of availability	Use of licensed spectrum, multi-level diversity, etc.

A.4 Technologies to enhance user experience

A.4.1 Cell edge enhancement

Large area scheduling

Large area scheduling is a data scheduling over large geographical area and long time duration. On downloading large amount of data or updating applications, which need no quick response from network, a user of poor channel quality and/or in heavy-traffic environment had better to wait until the situation improves in order to increase spectrum efficiency. Therefore, the large area scheduling can increase system spectrum efficiency drastically by controlling data transmission based on the future channel quality assumed by behavior prediction of users. Technologies for accurate behavior prediction and efficient data-forwarding between base stations need to be investigated.

A.4.2 Quality of service enhancement

QoE based radio resource management

The advanced radio resource management (RRM) should be able to handle variety of application traffic in different required communication quality and data size. From the viewpoint of enhancing quality of service (QoS) for RRM, users' quality of experience (QoE) can be introduced as an enhanced RRM metric. The QoE is "the overall acceptability of an application or service, as perceived subjectively by the end-user" as is defined by ITU. The QoE based RRM can contribute in the radio access aspects to make the RAN more users friendly, namely various applications on many UEs can run with sufficient quality.

Programmable Air Interface for QoS enhancement

In order to enhance Quality of service aspect, some of the functions such as Programmable Air Interface technologies described in section A.2.6.1 would be useful. As for the parameter selection or configuration control to improve Quality of Experience, Deep Packet Inspection, i.e. setting these parameters by analyzing packet headers of higher layers, could also be applied in addition to the ordinal statistical traffic measures.

A.4.3 Low latency

Novel Air Interface

Significant reduction in air interface latency can be achieved by novel physical and higher layer concepts. This prepares the grounds for an inbuilt-support of interference management and efficient device-to-device communications, machine-type communications and self-backhauling.

Regarding adaptive or optimized latency control, flexible configuration setting /

parameter set selection in Layer1 and Layer 2 protocols considering required service properties or content attributes would be useful as well.

Programmable Air Interface

Programmable air I/f (may implement frame structures and protocols supporting low u-plane latency), Radio access virtualization (minimizes impact from c-plane latency (cell follows user)), Alternative multiple access approaches.

A.4.4 High reliability

Several radio access technologies described in section A.2, such as technologies for multi-antenna control or Control- / User-Plane splitting with small cell deployment, would provide stable connectivity and sustained high throughput for certain scenarios. Technologies providing lower communication latency captured in section A.4.3 would be important in some use cases as well. In some cases, eg. secured communications between devices to control machines or vehicles would be another important aspect considering the communication reliability as a whole. As such, depends on the required level of communication reliability, proper radio access technologies and their control parameter should be set.

A.4.5 Radio Local Area Network (RLAN) interworking

Integration of both novel and existing access technologies is the key concept of 5G, which will not be a completely new radio technology, but an integration of novel with existing access technologies such as LTE-Advanced and RLAN (Wi-Fi). With different RATs - an evolution of what we know now and revolutionary technologies tied to meet more extreme requirements for 5G - and different cell sizes one can aim at designing a scalable system that is able to connect huge amount of low-cost sensors, provide broadband upload, and enable omnipresent connectivity and virtually zero latency where and when it is needed.

A.4.6 Context Aware

Information has become so broadly available that we will now experience an increasing need to filter and deliver it to end users. As an example, technicians repairing complex devices would obtain tailored instructions on their glasses, which are overlaid in real-time with what they can see in reality. An uptake of augmented reality applications will require decent guaranteed data rates, most likely in conjunction with ultra-low latency. A context-aware provisioning of resources and network functionality will be essential.

A.4.7 Mobility Enhancement with Linear Cell

Linear Cell

Deploying "linear cell", where cells are placed along the road or railway line, is one solution to achieve higher throughput and greater coverage area than that of today.

In order to achieve high throughput transmission for mobile users, a tradeoff among the size of a cell, transmission frequency and frequency of handovers needs to be considered. It is clear that high throughput transmission can be achieved at high radio frequency at the cost of reduced cell radius. As the result of reduced size of cells, frequent handovers are required. Since commuter buses or trains move in the same direction, if narrow cells are placed linearly along the direction of users' movements, handover between cells can be achieved efficiently.

Massive antennas, spatial multiplexing and beam tracking can be utilized for forming the linear cells, and they can bring further expansion in throughput and capacity to the high-mobility users.

Leaky coaxial cables (LCX) are also used to form the linear cells in some deployments to cover the blind zones such as tunnels and subways. Although LCX is not considered as a cost effective solution for a general deployment, the enhancement supporting MIMO capability (LCX-MIMO) may bring further expansion in throughput and capacity to the high-mobility users.

A.5 Technologies to improve energy efficiency

Increased cost and energy efficiency will be of major importance in 5G design. On the infrastructure side, energy and cost efficiency may be increased through flat network architecture, a more efficient resource usage, and fully self-configuring and self-optimizing radio access and network architecture. Energy efficiency on the device side will be especially needed in sensor networks or in general machine type communication where a multitude of small devices is used for gathering large amounts of data. While cost reduction may be driven by the economy of scale, the energy efficiency needs to be assisted by the design of the infrastructure, devices and the principles of next generation mobile communications system.

A.5.1 Network-level power management

A.5.1.1 Inter-Base Station Energy Saving

While energy saving on the base station level is important to enable a base station to utilize its physical resources in the most efficient way, note that much higher energy savings can be achieved when relations between multiple base stations are considered appropriately. Such inter-base station energy saving could, for example, allow coordination of base stations to optimize energy saving decisions by leveraging actual knowledge of capacity and coverage demand. Such coordination involves the exchange of certain information among base stations, including load, coverage, and interference, and a collective decision for the energy saving state of particular network elements.

A typical scenario is inter-base station energy saving in urban areas. Here, the network is designed to accommodate peak-hour traffic conditions by positioning cells relatively closely, forming dense arrangements for frequency reuse and capacity increase purposes. An example of establishing such an energy saving configuration is illustrated in Figure A.5.1-1.

The objective is to match the capacity demand with the energy consumption at all times. This is ensured by a dynamic load and energy state arrangement, which balances extra load on a determined optimal set of base stations, thus maintaining minimum energy consumption. Base station hardware is designed to minimize the power consumption in sleep mode. To ensure that the operators' quality-of-service targets are always met, a complementary process can determine the optimal cell or site to wake-up to adapt to increasing load conditions, while introducing minimal additional energy consumption.

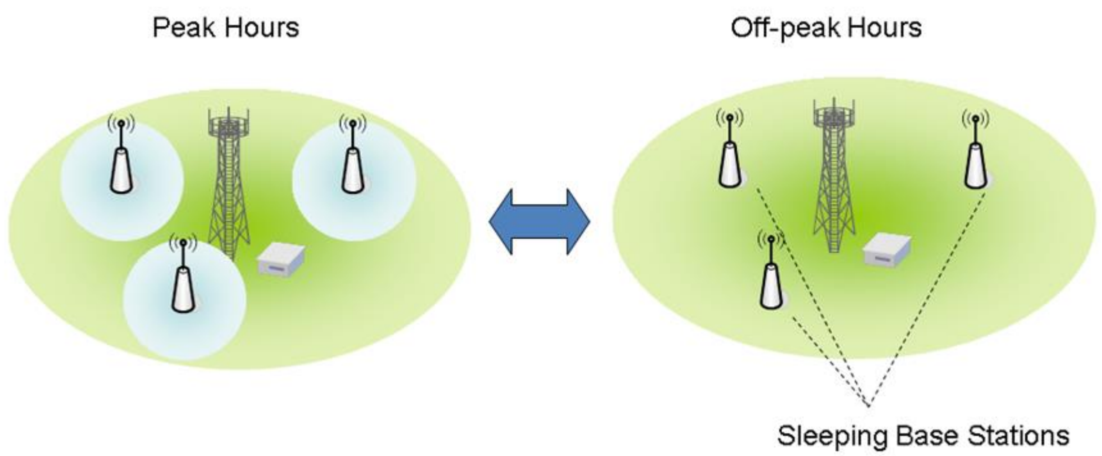


Fig.A.5.1-1 Inter-Base Station Energy Saving

A.5.2 Energy-efficient network deployment

A.5.2.1 Minimization of CRS transmission

Under the network with the high density small cells, each small cell tends to have typically low average but high burst load. In this case, cell-specific reference signal (CRS) is always transmitted from small cells regardless downlink data traffic so that it could be one of the main reasons of the interference and the network energy consumption. Therefore, if CRS could be stopped in the absence of downlink data, this could contribute to improve the network energy efficiency.

A.5.2.2 Energy Efficient Small Cell Activation for Heterogeneous Networks

This is an intelligent cell activation mechanism, which considers the energy saving gains obtained based on the amount of traffic load offloaded from the macro cell to small cells, while avoiding QoS degradation of the UE. The main idea is to offload traffic to small cells in energy saving mode, only when there is significant energy saving gains achievable from the process, thereby minimizing the total energy consumption of the network. It is considered the activation of small cells, always assuming the presence of overlaid macro cells providing coverage. This could be one of the preferred modes of deployment for network operators, since it provides flexible energy saving operation of the network without the probability of introducing coverage holes in the network.

A.5.3 Other item

A.5.3.1 Energy-efficient network configuration using natural energy

5G RAN needs to be a sustainable and "green" system while achieving very high traffic capacity (1,000 or more times larger than 4G). Therefore, the reduction of energy consumption is a very big problem for 5G RAN. In order to solve the problem, the power consumption of network infrastructure such as transmission power and power consumption of digital circuits needs to be reduced. At the same time, more efficient electricity infrastructure by using smart grid and so on is also very promising. 5G RAN could realize drastic reduction of energy consumption by efficiently using both network and electricity infrastructures. For example, a system utilizing small cell nodes with power supply from natural energy such as solar panels and rechargeable batteries can be a candidate of such a high energy-efficiency system. The distributed solar panels not only enable effective use of solar energy and reduction of transmission electricity loss but also realize more disaster-resistant system. In order to provide stable communication quality in spite of instability of power supply from natural energy, it is required to control ON/OFF switching and transmission power of each node by considering remaining battery power as well as traffic distribution and load balance.

A.6 Terminal Technologies

A.6.1 Advanced receiver

With rapidly increasing demand to further improve capacity and user throughput, an advanced receiver can cope with this demand from the receiver point of view. In the higher-order MIMO technologies, the cancellation or suppression of self-interference due to inter-stream interference is applicable without any assistance from the network. Furthermore, severe intra-cell/inter-cell interference should also be mitigated at a terminal side especially in the dense small cell deployment. In this case, a network-assisted intra-cell/inter-cell interference cancellation or suppression has a potential capability of achieving significant throughput gain. Non-linear detection such as turbo equalization (iterative soft interference cancellation) or maximum likelihood detection (MLD) is expected as a candidate for the advanced receiver. The advanced receiver can contribute to increase of the number of MIMO streams and spatially-multiplexed users, and thereby the capacity and user throughput are enhanced.

A.7 Network Technologies

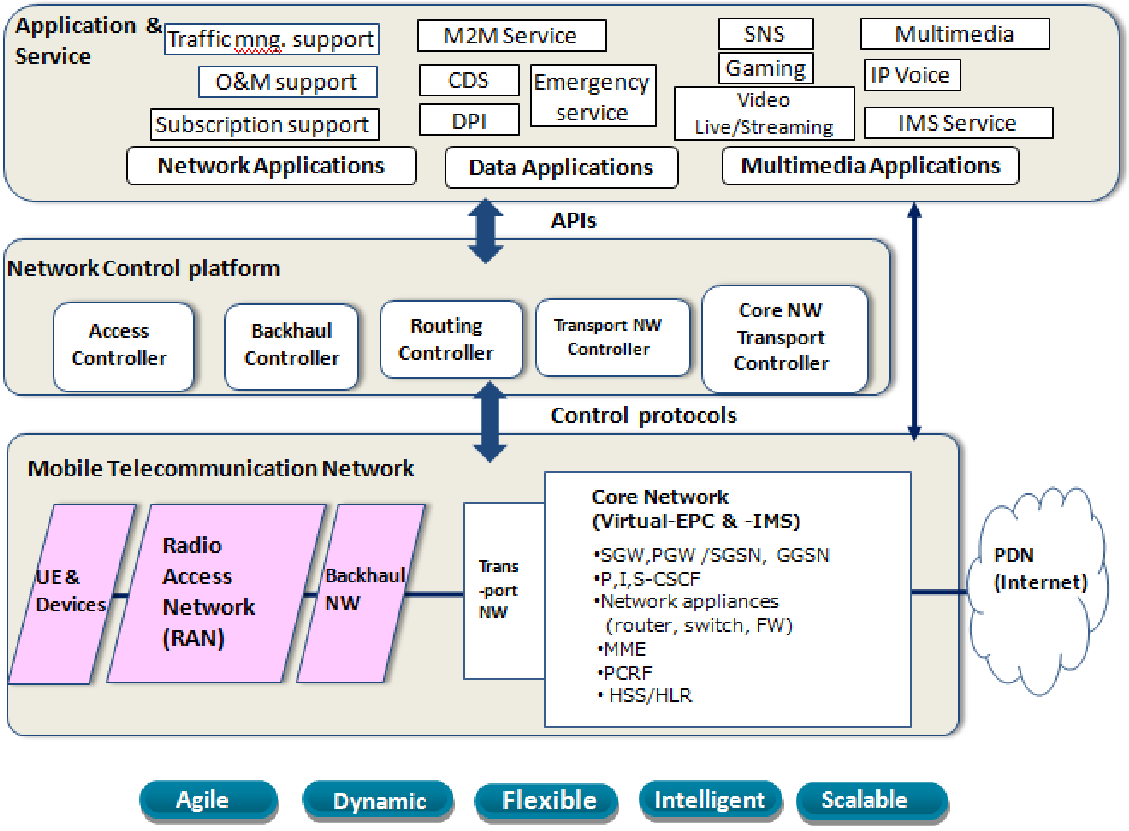
Following subsections describe innovative network technologies to provide the novel mobile telecommunication capabilities.

A.7.1 Technologies to enhance network architectures

This section describes overall network architecture encompassing the radio access network (RAN) which will be able to provide autonomous resource management. Such a network adaptation can be achieved well with Software-Defined Networking (SDN) based concept and Network Function Virtualization (NFV) based configuration. Those innovations for advanced network will cultivate potential capabilities of intelligent operation by reducing complexity of the network. In following subsections, those approaches are described.

A.7.1.1 Software oriented network control

The picture below shows a conceptual model of overall network view.



Abbreviations:

API	: Application Programming Interface	CDS:	: Contents Delivery Service
CSCF	: Call Session Control Function	DPI	: Deep Packet Inspection
EPC	: Evolved Packet Core	GGSN	: Gateway GPRS Support Node
HLR	: Home Location Register	HSS	: Home Subscriber Server
PCRF	: Policy and Charging Rules Function	IMS	: IP Multimedia Subsystem
MME	: Mobility Management Entity	P-GW	: PDN Gateway
SNS	: Social Networking Service	SGSN	: Serving GPRS Support Node
S-GW	: Serving Gateway		

Fig. A.7.1-1 Future network conceptual model - example

As noted briefly in another section, the upper tier represents the application and service domain which works on higher layer which would also include the transport layer as well. This domain encompasses a variety of applications for network operation support, reliable data provision, and multimedia services. Operation management and system control of those diverse services could be combined, scheduled, and organized by the orchestration management system.

Bottom tier represents the infrastructure of mobile telecommunication network that transports data from end to end by processing data in low layers from the physical layer up to the transport layer. Data processing is conducted on the user plane via the associated protocols of the control plane, which are working on the radio access network (RAN) and the core network. The RAN, UE devices, and the backhaul blocks are the major focus of this white paper document, as those include the radio access components of 5G radio access technologies (RATs).

The middle tier represents a centralized control platform, which is composed of some software modules for network control. This platform plays a role of network control by sending the protocol control messages onto the infrastructure user-plane blocks downwards, while sending the network related management instructions to the upper application and service domain via application programming interfaces (APIs). The SDN controller may manage the user packet transport path in end-to-end; from the multiple base stations to the application servers passing through appropriate processing network nodes by means of its routing control depending on the associated service policy per the user, the terminal device, and/or the application, etc.

This style of SDN structure and the enhancement will contribute to conduct sophisticated network management that will enlarge capability and intelligence of the network including RAN by the external programming instructions working on a software based network control platform.

A.7.1.2 NFV based network virtualization

The software defined network controlling approach is suited well to the network function virtualization (NFV) for virtual operation. In the NFV architectural framework, the virtual network functions (VNFs) are configured upon a virtual platform of the NFV Infrastructure (NFVI). Those VNFs may be key functional nodes of the core network nodes and even the base station element (e.g. Baseband processing unit (BBU), the Switch (SW), and the control unit) of RAN. Functional chain of those nodes and the upper operation supporting system can be managed by the NFV Management and Orchestration (NFV MANO) system.

In data communication in RAN side, the packet data traffic aspect of newly emerging services may be much different from those of conventional data services. By virtue of the NFV approach, the processing power of each node resource associated with the service can be designed and allocated appropriately. Also, the NFV framework will contribute to optimal management of functional node operation that is beneficial for reduction of CAPEX, OPEX, energy consumption, and for agile rollout of the system.

The NFV like virtual configuration, scalable, flexible architecture, and the management capability will be enhanced towards the future mobile system on a software basis.

The flat layer structure based on the NFV will provide the industry with the open system services such as IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service).

Following sections describe network structures and the technologies, which may be applied to 5G Radio Access Network (RAN) and the Backhaul network.

A.7.2 Technologies to support ease of deployment and increase network reach

5G network deployment approaches should consider integration with multiple radio access technologies. Diverse network topologies may be configured by the cell sites or user terminal devices under unified management control entity.

A.7.2.1 Multi-radio access and multi-mode

In the 5G radio system, a set of integrated radio-access technologies jointly enables the long-term networked society. The new technology components include both cases of evolution of the existing radio-access technologiess and new complementary radio-access technologies.

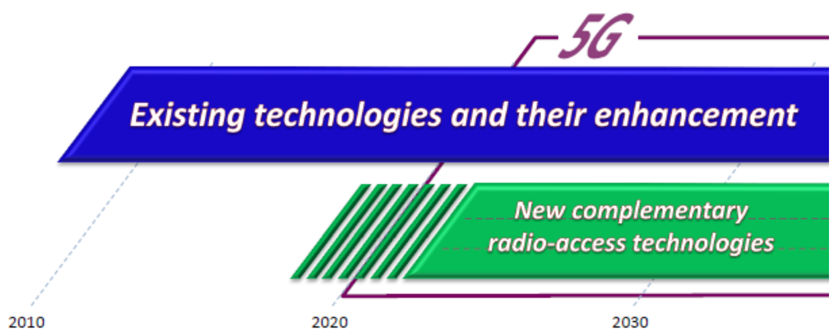


Fig. A.7.2-1 Multi-radio access and multi-mode

This 5G system enables Multiple Radio access integration and the possible interworking with 3G/4G/BWA/RLAN. The set of integrated radio access technologies jointly enables the long-term network society. This may be supported by flexible

Multi-RAT RRM as well as the service aware traffic steering and seamless handover between simultaneously connected RATs. An improved capability to scale the system by adding new RATs is also anticipated. To achieve these capabilities, a unified radio controller (URC) is required. The URC has following coordination roles:

- 5G RAN centric Coordination with other complementary access technologies
- Multi-RAT Coordination
- Multi-Band Coordination
- Multi-Layered Functions Coordination
- Seamless Handover of Inter-RAT, and Inter-Band

A.7.2.2 Mesh and Grouping

Mobile relay operation may be realized as an extensional mode of the device cooperated ad-hoc communication and device mesh networking. Inter-device link can provide an opportunity to route some traffic over device mesh networks. The device mesh network routing can be configured by an advanced algorithm like the Selected IP Traffic Offload (SIPT) basis for example, where the usage of the primary air-link between infrastructure and devices may be avoided by finding another optimal route instead.

A.7.2.3 Mobile relay

Group mobility with mobile relay:

Mobile terminals on the transportation, e.g. commuter buses and trains, handover simultaneously. High signaling load due to handover of such mobile terminals is frequently generated if commuter buses or trains move in the area where many small cells are placed. However, it might be possible to reduce signaling load if a mobile relay is introduced and the group mobility concept, which manages mobility of mobile terminals connected to the mobile relay node, is used. In order to realize the group mobility operation with the mobile relay, the mobility management function for the mobile relay node and the connected mobile terminals needs to be implemented in RAN and core network.

A.7.3 Novel RAN architecture

A.7.3.1 Multi-layer / Multi-band cells

In order to achieve all the requirements for the wide area coverage, spot coverage, and higher capacity accommodation with higher throughput, the cell size based categorization and the heterogeneous operation may be introduced. Different types of cell may be deployed in overlaid layers with multiple cell and multiple carrier band in order to satisfy multiple requirements such as coverage and capacity simultaneously in the overlapped operation area. Different type of radio technologies may have to be applied in these different types of cell and frequency bands. One example of multiple cell deployment is described below.

- Coverage cell:
  This cell is C-plane responsible cell and an optional U-plane. This cell covers wide range and higher mobility user. The transmission performance may be limited by inter-cell interference. The existing radio access technologies or the enhancements will be available in this cell operation. Within this wide coverage area, mobile relay operation and the enhanced D2D communication are available.
  Cell profile - e.g. Carrier frequency is below 3GHz. The bandwidth is less than 20MHz for example.
- Efficiency cell:
  This cell is U-plane responsible cell and an optional C-plane, and will further improve the spectral efficiency in higher/wider frequency bands assuming the same PHY parameters as the coverage cell. In this cell operation, the existing radio access technologies or its enhancements will be used for efficient data offloading. The transmission performance may be limited by inter-cell interference.
  Cell profile -e.g. Carrier frequency is around 3 to 10GHz. The bandwidth is about 40-100MHz, for example.
- Capacity cell:
  This cell is U-plane responsible cell for higher capacity and throughput in a local area or spot operation in higher/wider frequency bands than the coverage and middle cell. The transmission performance may be limited by surrounding noise in the local area. New radio access technologies may need to be applied on this high frequency capacity cell.
  Cell profile -e.g. Carrier frequency is above 10GHz and below 60GHz. Carrier bandwidth is wider than 100 or 200MHz, for example.

Smaller cells may also handle the offload traffic data from the larger cell(s).

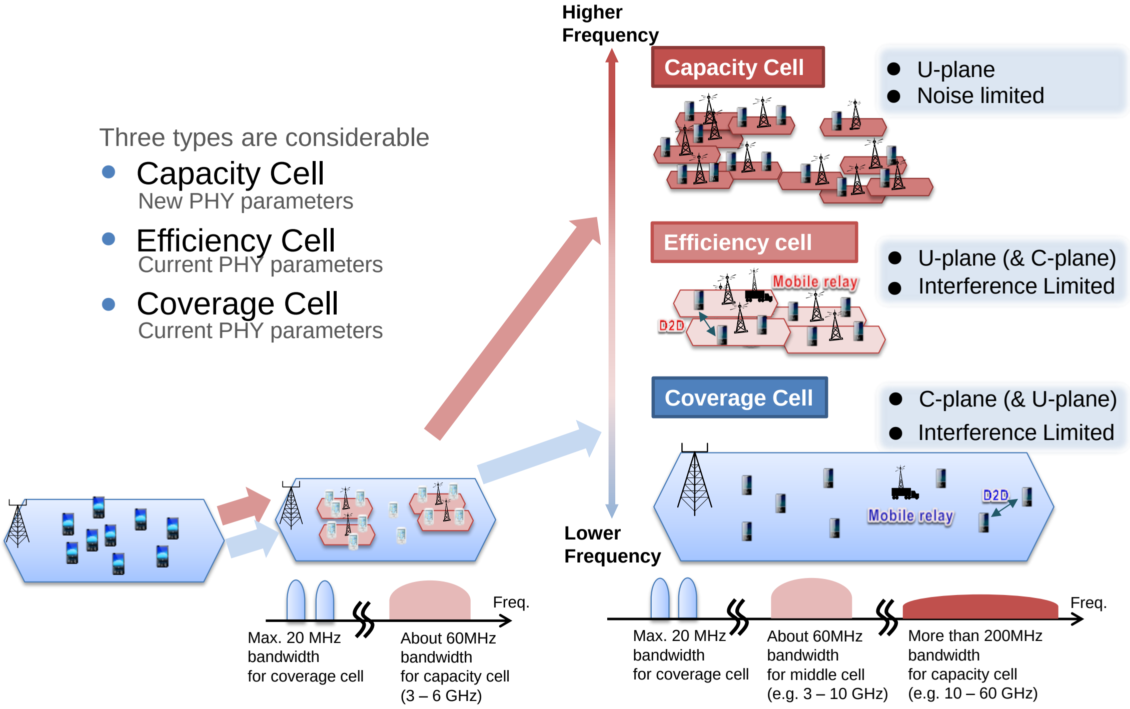


Fig. A.7.3-1 (a) Multiple type cells

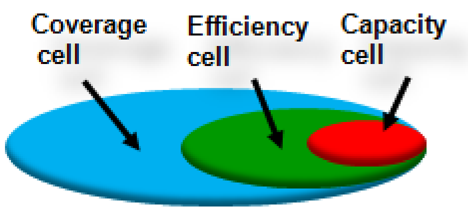


Fig. A.7.3-1 (b) Multi-layer/Multi-band cells overlay

A.7.4 Cloud-RAN (C-RAN)

Radio cell operation system may be unified in a central cloud RAN management controller referred to as Cloud RAN (C-RAN). Radio cell processing functions are integrated in the intelligent computing architecture, while the antennas and radio transceiveres are deployed around the distributed cells. The C-RAN platform consists of a number of baseband processing units (BBU) working in the layers from PHY, MAC RLC, PDCP and RRC, and the switching units, cloud computing processor,, and the fiber units typically. This cloud structure may be implemented on the virtual platform of NFV framework.

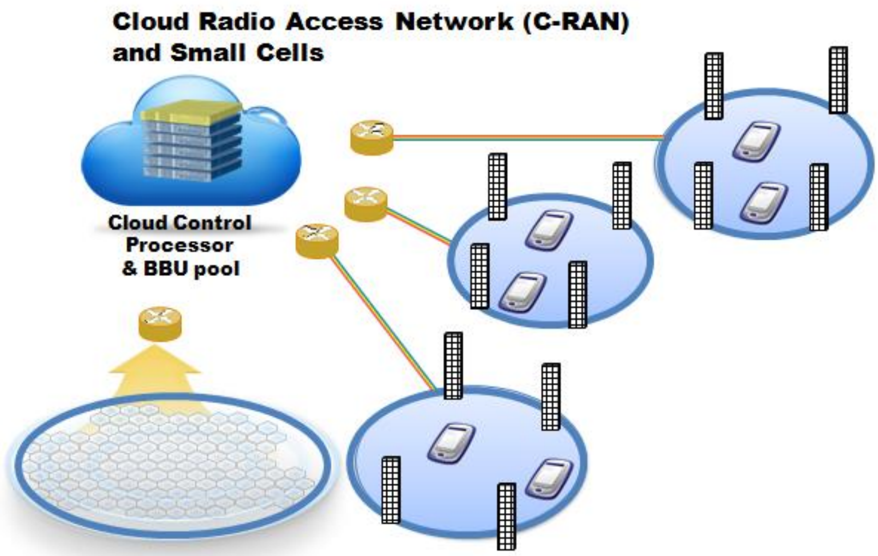


Fig. A.7.4-1 Cloud RAN (C-RAN)

This approach of cloud baseband integrated processing has some capabilities as follows, including but not limited to:

- Hierarchical cellular architecture where high density user data access is covered by small cells and the control signals are processed in the C-RAN platform. (e.g. Joint operation of RAN cells and backhaul node is available under the C-RAN.)
- Unified traffic steering, mobility manegement, multiple RATs management, and call manegment (e.g. 5G coordination control of IMT-advanced RAT and New-RAT is available in the BBU opeation)
- Joint radio resource management for uniform performance over multiple cells (e.g. cell edge gain improvement with joint radio transmission by coordinatd scheduling and power control)
- Flexibile cell site deployment under managment of the centralized self-organizatoin network technology. (e.g. plug-and-play camping of addtional cell site)
- Enable "virtual multi-transceiver" approach as a virtual radio access with multiple transceivers. The radio transmission link can be dynamically configured to meet the QoS requirement by optimal grouping of transmitters and receivers activated in multiple cells and multiple UEs.

As a result, the C-RAN architecture can serve to provide better user experience everywhere in the service area., under the integrated cloud control platform.

In the following subsections, a few examples of C-RAN application to the radio network are described.

A.7.4.1 Joint operation of RAN and Backhaul

In order to accommodate higher traffic amount encountered in dense urban area and to realize scalable configuration for efficient resource utilization, a joint radio network of small cells and the backhaul node in a hierarchical structure will provide a smart solution. A key management platform exists in the C-RAN with its centralized processing to enable interworking of the backhaul mode and small cell operations.

This RAN hierarchy structure consists of following layered radio network entities:

- C-RAN central control platform

Enables a consolidated interwork management of the small cells and backhaul node by virtue of centralized processing for the coordination and cooperation. This platform also provides a capability of interworking with other C-RAN platform.

- Backhaul layer:

Reinforcement will be required in the backhaul aggregation network due to the further increasing data traffic encountered in urban area and hot spot. The backhaul span lines from cell sites may be fixed fiber, or wireless radio to realize flexible deployment with affordable cost.

- Radio access layer:

Any number of small cells is deployed in high traffic area and hot spots.

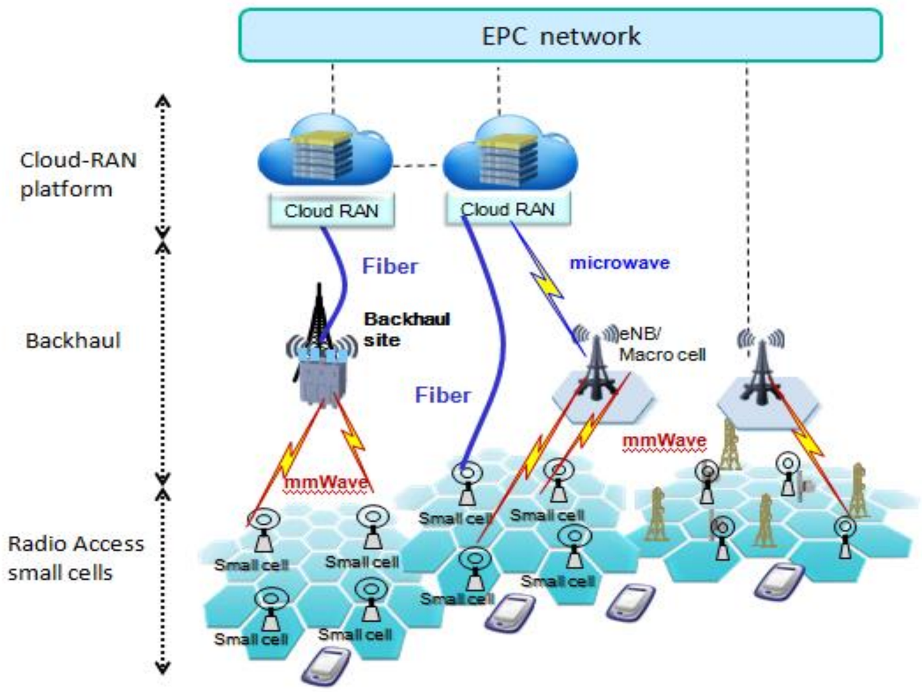


Fig. A.7.4-2 RAN and Backhaul joint operation model

This hierarchy architecture is beneficial to enable the consolidated management of multiple small cells while saving the required network resources.

A.7.4.2 Coordination of Multi-RAT and Multi-cell

The C-RAN central processor provides some solutions for multi-RAT and multi-cell coordination.

This C-RAN controller enbales consolidated operation of multiple RATs. For example, the integrated contrrol of New-RAT with IMT-enhanced RAT will be available for those data processing in combinatoin under an efficient interwork manegement of the C-RAN and the BBU control.

In the multi-cell coordination under the C-RAN supervise, the joint-transmission/reception scheduling coordinattion of UE or multi-point BSs are optimally controlled and adjusted in a C-RAN management in order to provide a performance gain and uniform quality around cells.

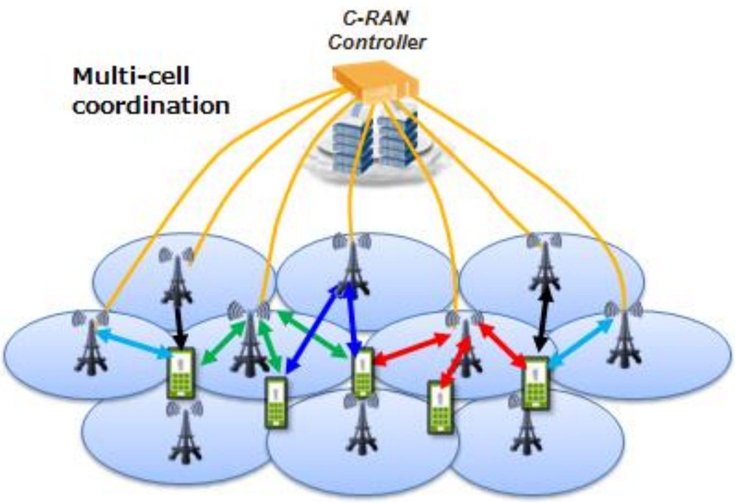


Fig. A.7.4-3 Multi-cell control under C-RAN

RAN tarffic sterring prosessor may be implemented in the C-RAN central computing platform to achieve optimal traffic balancing among multiple cells efficiently under C-RAN, depening on the traffic load of each cell. That system may work depending on the concerned cell loading metric and the call blocking rate to manage the UE hand over to another neighboring cell. The control procedure and criteria to achieve uniform traffic loading are highly dependent of the policy of operator. This scheme will contribute to provide fair data service performance for users throughout multiple cells on a real-time basis, although the C-RAN based operation is not a sole solution for the traffic load balancing.

A.7.4.3 Virtual multi-transceiver

The C-RAN architecture enables the "virtual multi-transceiver" approach to mobile access. The data links can be dynamically configured to meet different QoS requirements through the optimization of both transmitter and receiver sets in real-time, by means of C-RAN, multiple transceiver configuration, and UE direct communication additionally. This radio access virtualization can help realizing the joint-layer optimization where radio resources are efficiently utilized.

Virtual multi-transceiver processing is capable of implementing joint transmission (JT) and joint processing (JP) at the same time to realize a synergy among a large number of pooled transmit / receive points. This pooled hardware resource includes radios and antennas belonging to both infrastructure access points and mobile devices. The processing can vastly improve the channel condition of users that would be categorized as cell edge in a non-cooperative network. In this case, users can share almost equal spectrum efficiency at any place of a cell maximizing both the capacity and user experience. This is analogous to lighting which minimizes visible shadowing in indoor environments.

Considering transmission point pooling and the application of JT/JP schemes in C-RAN, a new virtualized cell generation concept can be introduced. With the virtual multi- transceiver, radio resource allocations may be dynamic in the dimension of transmit points as well as time and frequency. A logical cell can be dynamically formed anywhere that the hyper transceiver has the capability to put it. In principle, it is not necessary to limit the use of a cell-ID to a single transmit point. Multiple transmit points may also share the same higher layer protocol stack, e.g. MAC/RLC/PDCP.

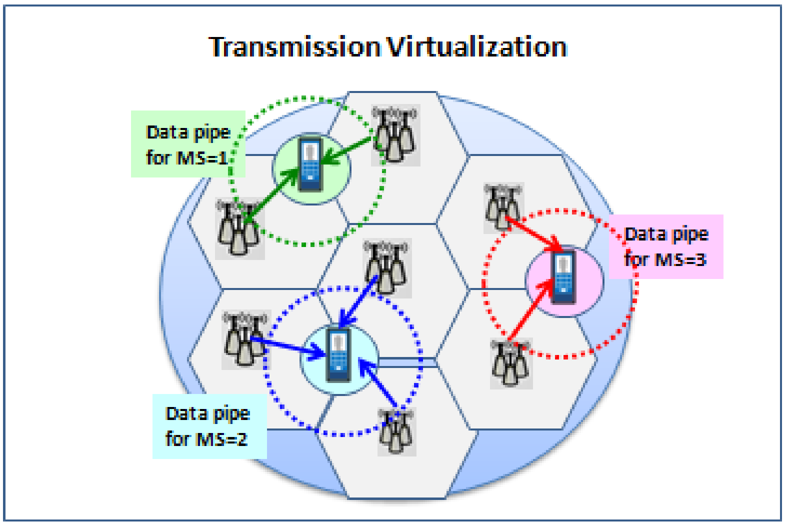


Fig. A.7.4-4(1) Virtual multi-transceiver

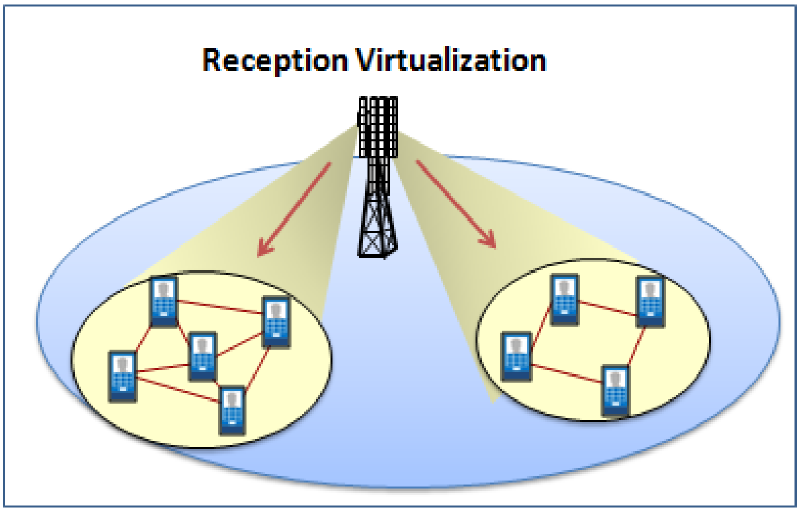


Fig. A.7.4-4(2) Virtual multi-transceiver

A.7.5 RAN sharing enhancement

Traffic load balancing between neighboring cells in a mobile radio system has been one of the key technologies for efficient and flexible/dynamic use of limited resources of infrastructure and spectrum. Several technologies have been developed and applied to a mobile radio system operated by a single operator, in order to offload traffic in a flexible manner. In future mobile radio systems, flexible resource usage can be enhanced to the case where multiple operators share the common Radio Access Network (RAN) for exploiting the scarce spectrum resource and the flexible use of network.

RAN sharing may be defined as any arrangement by which multiple operators share the capacity of a physical network. That applies to the case of two or more MNOs pooling their network infrastructure by leasing capacity each other, as well as the case in which a network owner leases capacity to one or more mobile virtual network operators (MVNOs).

The RAN sharing refers specifically to the sharing of radio access network assets, and can be classified to either passive or active sharing. In the case of passive RAN sharing, operators share only the cell sites. In the active RAN sharing, it extends the capability widely to the sharing of transport infrastructure, radio spectrum and baseband processing resources.

For example, it enables optimal traffic balance among some cells shared by multiple operators and the associated public land mobile networks (PLMNs), depending on the data traffic amount observed in each cell. When the loading of an individual cell exceeds an overload level, the RAN sharing control system will reduce traffic in the concerned cell of multiple operators by re-allocating some UE connections to another cell where more capacity room exists for additional traffic under a traffic sharing agreement. That will help reducing excessive traffic load encountered in a cell and in the connected PLMNs of operators, and will contribute to provide the traffic load balance in an agreed level among the multiple operators.

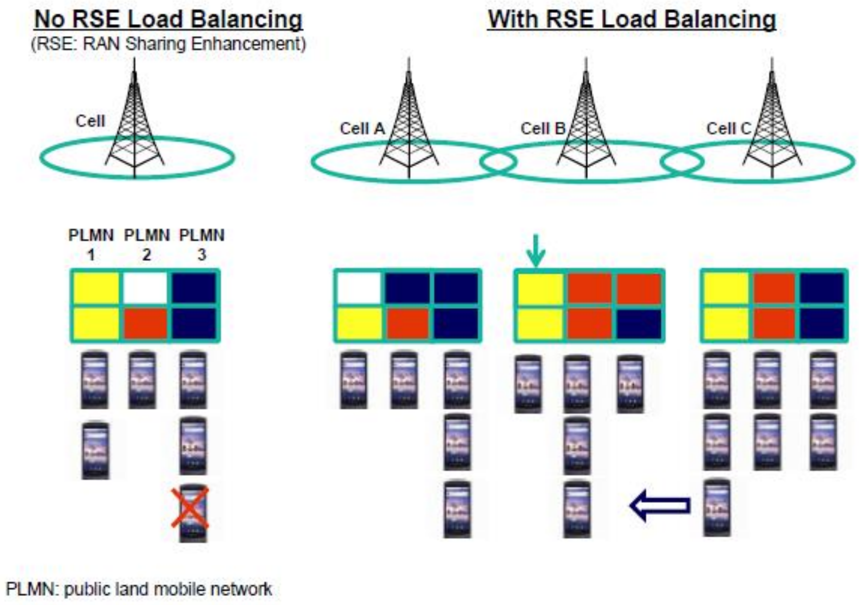


Fig.A.7.5-1 RSE Load Balance control

Following are potential benefits of the RAN sharing enhancement.

- CAPEX and OPEX savings: The primary benefit of RAN sharing for operators is the cost saving in planning, rolling out, maintaining and upgrading their networks. Network owners can subsidize their costs by leasing capacity to MVNOs, while MVNOs benefit from having not deployed and maintained their own infrastructure.
- New revenue sources: Virtualization of radio resources allows network owners to package and lease radio spectrum more flexibly in smaller units than has previously been possible. As a result, network owners can offer much possibility for MVNOs.
- Service-centric networks: Sharing of network infrastructure will encourage a shift from competition on a basis of network coverage to competition on a basis of features and services.
- Environmental benefits: RAN sharing is a greener option than traditional single-operator networks since the sharing of equipment and sites facilitates

operators to reduce their energy consumption and minimize environmental impact by deploying fewer antenna masts. Active RAN sharing enables pooling of baseband processing resources, resulting in further energy savings particularly during periods of low load.

A.8 Technologies to enhance privacy and security

As '5G' must support variety of services with wider footprint, it should serve robust and secure communication links in every level of its connection links. Depends on the service aspect or use cases to be applied, different level of robustness or security would be required considering sensible balance between these performance and cost, processing delay, power consumption effect etc. These aspects are so important and should further be investigated.

A.9 Technical studies on millimeter wave and centimeter wave

Ultra dense deployments with high traffic and low latency requirement will encourage new revolutionary technologies to emerge in 5G era. The introduction of new radio access technologies (New RATs) for the higher frequency bands, i.e., centimeter to millimeter wave, is the key element of 5G systems.

New PHY (with modified OFDM numerology or based on single carrier), MAC and higher layer concepts should be required for the new RAT(s) to meet such requirement. The new RAT(s) will allow a significant reduction in air interface latency and prepare the grounds for an inbuilt-support of interference management and efficient device-to-device communications, machine-type communications and self-backhauling. A lot of different traffic use cases shall be supported for variety of 5G applications; therefore flexible resource adaptation such as dynamic UL/DL allocation is expected to be important.

A.9.1 Propagation properties in higher frequency bands

The utilization of millimeter wave bands will open the door to an abundance of spectrum, but the very different propagation properties in these bands bring up challenges that require novel forms of network deployment, infrastructure and management. The millimeter waves (mmWave) communication is a promising solution for wireless backhaul of future small nodes (also including multi hop backhauling), but we also see a large potential in using not only centimeter but also millimeter wave band for access links in very dense small cell deployments. The propagation characteristics in high frequency ranges are such that transmission should be done through a few selected paths (without relying on scattered energy), clearly the strongest one being the line-of-sight (LOS) path. Main challenges in the design of a system for such bands are related to overcoming radio wave propagation rather than increasing spectral efficiency. As compared to channels at below 6 GHz bands, mmWave band channels carry the following unique propagation characters:

- Free-space path loss – As antenna size shrinks with frequency, free-space path loss decreases with respect to the electromagnetic wavelength.
- Reflection loss – Coarse reflection surfaces may not appear to be specular to mmWave signals, which will cause scattering and diffusion in addition to reflection, although high reflectivity and large surface scattering can lead to large signals [17].
- Diffraction loss – The quasi-optical character leads to high diffraction loss at mmWave bands.

These characters lead to (1) much smaller number of the path clusters at mmWave band than that of at below 6 GHz bands and (2) high blockage probability at mmWave band. Figure A.9-1 compares the number of significant path clusters for a cell with collocated LTE band at 2.5 GHz and mmWave band at 28 GHz, generated by the channel modelling architecture proposed in [28]. The small number of clusters and the blockage issue at mmWave band can be observed. Note that this channel modeling architecture generally applies for all microwave frequency bands (300 MHz – 3 THz). The figure takes 28 GHz as an example for demonstration and ease of calibration purpose (many available channel measurement data are at 28 GHz band [29]).

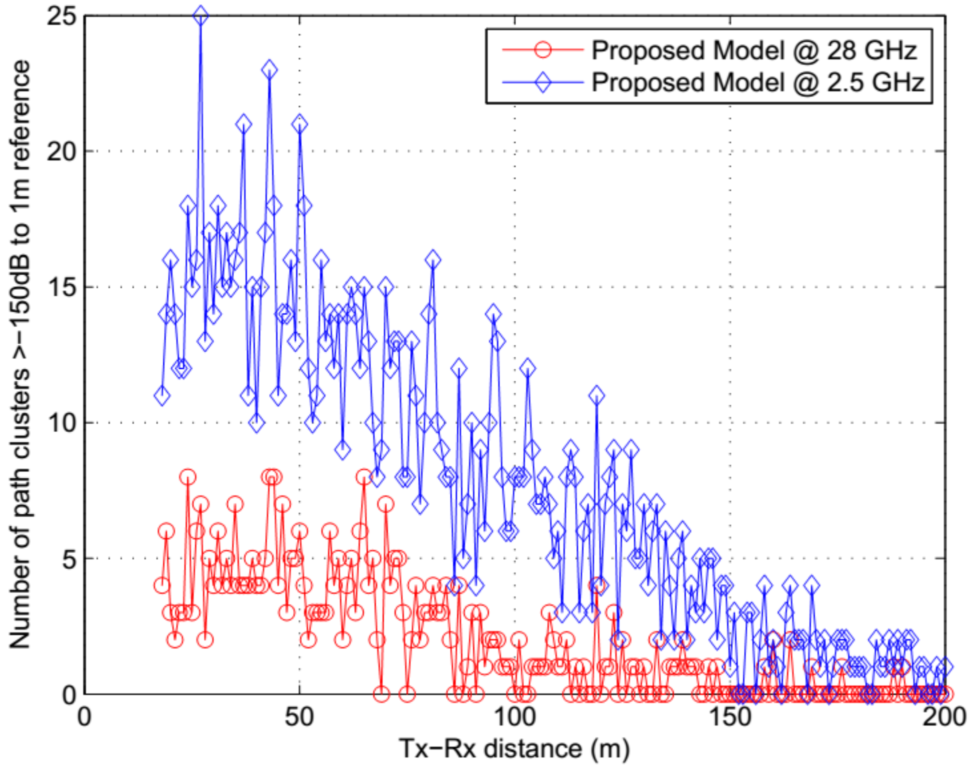


Fig. A. 9-1 Number of path clusters for cell with co-located LTE band and mmWave band.

The system is noise limited in mmWave due to its large path loss rather than interference limited in lower frequency. Thus a relatively simple air interface would suffice the needs in the new RAT for mmWave. Higher data rate is achieved simply by wider carrier bandwidth rather than relying on the spectrum efficient high rank MIMO. This is aligned with the implication that higher the frequency band is, wider the available contiguous spectrum is. This also helps to satisfy the low latency requirement by easing the handling of interference and high order transmission.

For mmWave bands, the size of antenna modules is expected very small even for a large number of antenna elements. A new antenna array technology for mmWave such as chip scale phase array is expected technically feasible towards 2020 and beyond. Such multi-element antenna modules can be used for efficient beam steering techniques to enable communication in a band where radio waves behave like rays of light. Therefore the mmWave system relies on the beam forming gain and ultra-dense deployment to achieve the 5G capacity target.

A.9.2 Semiconductor technologies for higher frequency bands

For millimeter wave device, a compound semiconductor process such as GaAs is superior in performances such as noise of receiver, output power of transmitter and phase noise of signal source in general. RF devices using compound semiconductor process have been developed and already put in practical use for high speed wireless communication in millimeter-wave region. On the other hands, RF performances of a recent Si process such as RF-CMOS or SiGe-BiCMOS accomplishes remarkable development and the research and development about the application to millimeter-wave radar and wireless communication of the Si process are widely carried out. And RF devices using the Si process begin to be gradually applied to commercial products. The Si process has characteristics of lower wafer-cost, higher integration, and higher functionality by integration with digital circuits in comparison with the compound semiconductor process. However it is inferior in RF performances.

Therefore, there is trade-off among the appropriate processes from the viewpoint of cost, size and RF performances. In the 5G system, all Si-RFIC will be desired for cost and size reduction. However, future miniaturization of the Si process causes degradation of RF output power due to drop of breakdown voltage. Fig. A.9-2 shows saturation power (Psat) of millimeter-wave power amplifiers (PA), that were published in technical papers and conference digests [30] - [134]. It is clear that the PAs fabricated by compound semiconductor perform higher Psat than SiGe/CMOS PAs. Therefore, in the case of the requirement for high output power of transmitter, a combination of Si and GaAs devices will be desired.

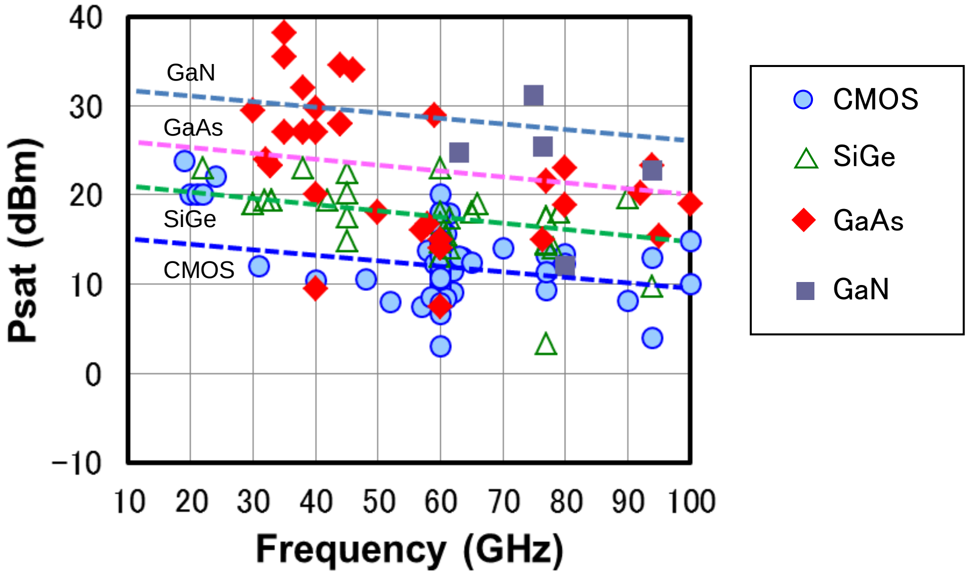


Fig.A.9-2 Saturation power (Psat) of millimeter-wave PA [30] - [134]

Annex B Typical User Throughput

B.1 General

Typical User Throughput (TUT) represents throughput per user or device under a typical condition, including user or device density. The typical condition should be set considering reasonable operation conditions, radio propagation conditions, user density as well as expected typical deployment of the system. To set the typical conditions, several pieces of useful information are collected in the following subsections.

Regarding the user density, population densities in different situations shown in Table B.1-1 give several scenarios for user density of from 10-4 to 103 [x 104 person/km2] which range corresponds to the horizontal axis of Fig.8.2-1. Assuming number of devices per person as 0.5 to 2 as mentioned in [135], device density could be attained from the population density in Table B.1-1 by multiplying the number of devices per person. It would be worthwhile to note that devices per person could be even larger than two considering possible wearable sensors or devices in '5G' era.

Under these user or device density conditions, 5G RAT should provide required Typical User Throughput (TUT).

Table B.1-1 Population density in different regions or scenarios

Target area or situations	Population density [x 10^4 person/km^2]	Remarks
Alaska state, USA	0.5 x 10^{-4}	1.2 person/$mile^2$, as of 2010 [136]
USA	3.5 x 10^{-3}	As of 2013 [137]
Hokkaido, Japan	0.7 x 10^{-2}	As of 2009 [138]
Japan	0.35 x 10^{-1}	As of 2013 [137]
Fukuoka, Japan	1.02 x 10^{-1}	5.07 million persons 4847 km^2, As of 2010 [139]
Tokyo metropolitan area (Special 23 wards area)	1.44 x 10^{0}	8.97 million persons 623 km^2, As of 2010 [140]
Kwun Tong District, Hong Kong	0.57 x 10^{1}	As of 2013 [141]
Events in National stadium of Japan	0.76 x 10^{2}	Capacity: 54,224 people Land area: 71,707m^2 [142]
Crowded outdoor event scenario (eg. Fireworks event, Outdoor concert etc.)	0.6 x 10^{3}	Based on the maximum crowd density of 6 to 9.2 person per square meter [143] [144]

B.2 Consideration of deriving Typical User Throughput

In order to derive sensible requirement of 'Typical User Throughput (TUT)', variety of possible deployment considering typical use cases should be investigated. Afterwards typical upper layer configurations and radio configurations for physical layers would be derived. It should be noted that even for the same user/device density (per unit area), typical deployment for LTE-Advanced/LTE and 5G RAT may be different and it would be sometimes tricky to compare these TUTs as a simple comparison.

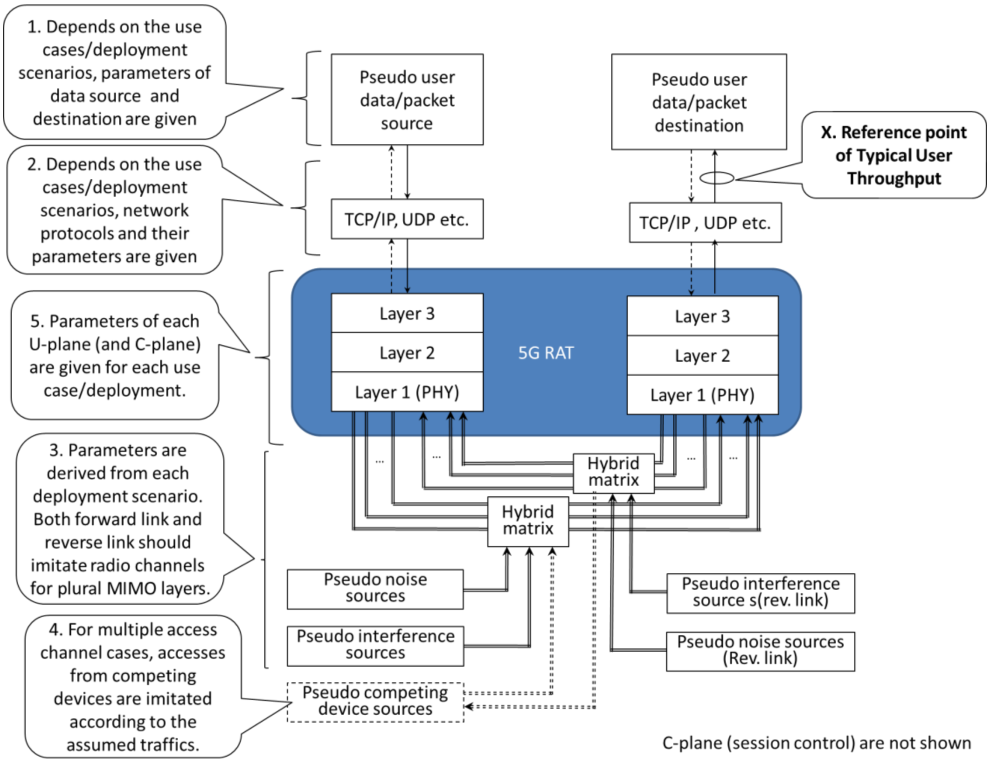


Fig. B-1 Reference configuration defining Typical User Throughput

Fig. B-1 shows possible definition of TUT as well as its measurement configuration. Reference point of TUT should be set at the output or input of a network protocol layer in the receiving entity (Represented X in Fig.B-1). It should be noted that the figure focuses on user plane and control plane is not shown there. Overall conditions to define TUT for certain scenario will be attained by the following procedure;

1. Depends on the use cases or deployment scenarios, pseudo user data/packet source and pseudo user data/packet destination entities are set and their actual parameters, eg. Peak and average packet data rate, duration of active and inactive period etc. will be defined.
2. Network protocols (eg. TCP/IP or UDP) and their parameters are also defined for each use case in question.
3. Regarding the radio channels, it should imitate typical propagation conditions

such as desired signal strength, relative noise level and co-channel/adjacent channel interference from other transmitter chains (eg. Other user devices in the same geographic area) considering corresponding user/device density in question. Reverse link channel should also be provided in case ARQ or hybrid ARQ type connections is applied.

4. For the case of multiple access channel with probable collision, accesses from competing devices are imitated by pseudo competing device sources according to the assumed traffics.
5. As for 5G RAT, parameters for each U-plane stratum, they will be defined so as to afford required TUT for each propagation conditions as well as network protocol parameters derived from the use case or deployment scenario considered.

B.3 Related performance requirements and test scenarios specified for LTE-Advanced (Information for future investigations)

For LTE-Advanced, several performance requirements and test scenarios related to data transmission are defined in 3GPP in order to ensure that actual system complies with the requirements of IMT-Advanced.

- Demodulation performance requirements:

Demodulation performance requirements for the physical channels are specified in [145], [146], [147] and [148]. These requirements are specified under the specified measurement channels and the propagation conditions with the specified uplink or downlink channel. These requirements are set in order to ensure the minimum requirements and defined by the relative throughput to the corresponding maximum (peak) throughput (such as 70% of the maximum throughput) under specified radio channel propagation condition with predefined received signal strength and interference signal levels.

- Sustained downlink data rate provided by lower layers:

Sustained downlink data rate provided by lower layers (Layer 1) are specified in [145] and [146]. The sustained downlink data rate shall be verified in terms of the success rate of delivered service data unit(s) by Layer 2. The test case below specifies the RF conditions and the required success rate of delivered TB by Layer 1 to meet the sustained data rate requirement. The requirements are set by the relative throughput to the maximum (peak) throughput but in this case, the relative term is 95% with stable radio channel propagation conditions with relatively higher and enough received signal power.

- Deployment configurations

For the case of "Home enhanced Node B", which is a small base station to be deployed in uncoordinated manner, study results of its deployment configurations are captured in [149] and [150]. Depends on the expected use cases or scenarios, deployment configuration may differ however once the configurations are set, radio propagation conditions or radio signal strength and interference level at each radio signal receiver in certain position in each service area could be identified and derived.

- Upper layer signals

Total throughput will be affected by configurations and communication parameters set in upper layers as well. As a part of conformance tests for LTE-Advanced UE, 'IP test model' is defined in [151] and [152]. It contains definitions of "IP user data", "Configuration of Sockets" etc.

Annex C Roadmap towards 5G

Fig. C-1 below represents a roadmap towards '5G' elaborated in [153], which gives a whole picture of '5G' related activities to realize '5G' system towards year of 2020 and beyond. As can be seen in the figure, the present white paper will provide a good basis for investigations in the next stage towards '5G'.

Note: In July 2014, the Round-table Conference on Radio Policy Vision held by Ministry of Internal Affairs and Communications published its interim report. In the report, variety of observations and suggestions on the radio policy are captured as interim outcomes from the conference up to June. Fruition of '5G' is one of the major topics in the conference and the report provides roadmap towards '5G' as shown in Fig. C-1. The conference will finalize the report in December 2014 and future radio policy will be elaborated based on the report.

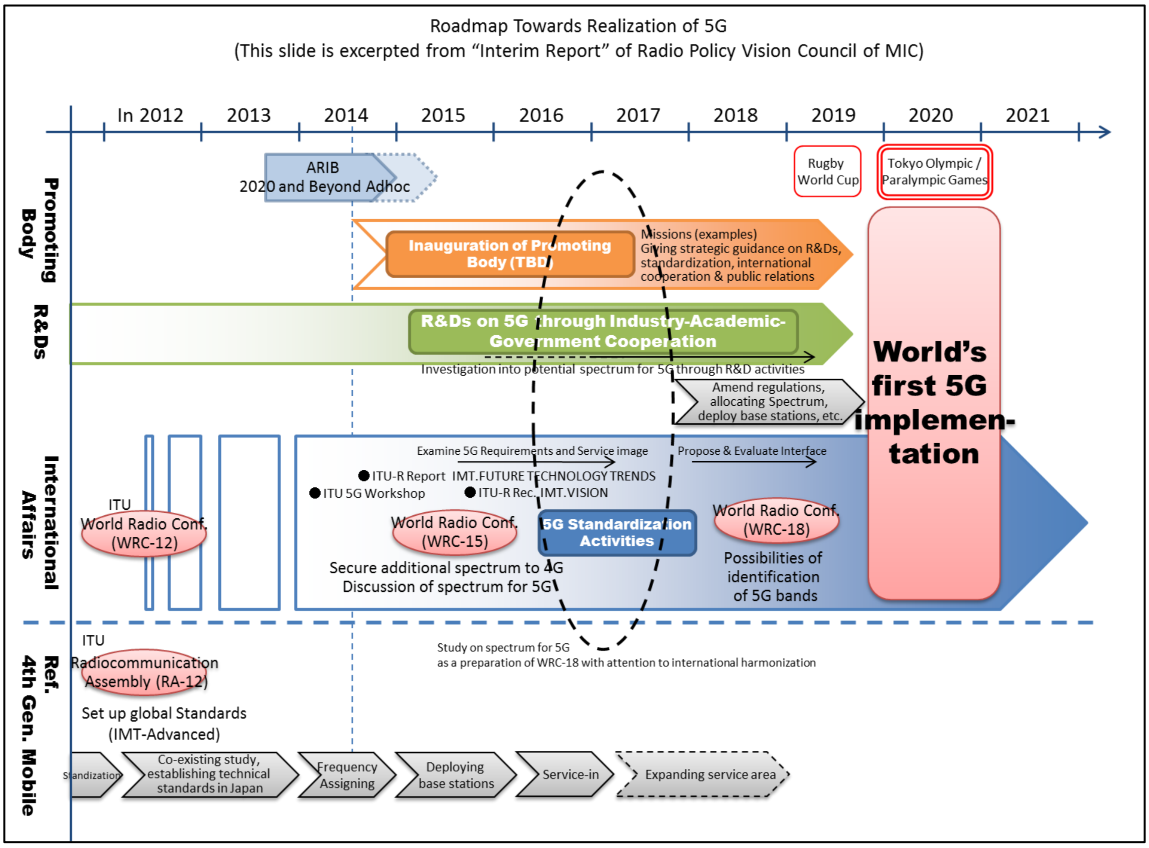


Fig. C-1 Roadmap towards realization of 5G [153]

Annex D Provisional Estimate of Video Communication Traffic

A provisional estimate of the traffic trend based on a pure demand, which excludes traffic controls such as throughput limitation, can be calculated by assuming its use cases. Estimation in the lightest use case is carried out as follows;

Assumptions:
4K video transmission becomes common in year 2020.
Usage in one-person households;

- A person uses a personal computer or a tablet to watch 4K video streaming or to download 4K video contents for two hours a day.
- In addition, a person uses a smartphone to watch 4K video streaming or to download 4K video contents for one hour a day

Transmission rates;

- 48Mbps for the personal computer and tablet
- 10Mbps for the smartphone (high compression codec is assumed for mobile devices)

Traffic amount per month in a household;
Monthly traffic per one-person households
= (48[Mbps]*2[hour]+10[Mbps]*1[hour])*60[sec]*60[min]*30[day]*0.125[byte/bit]
= 918000 [Mbytes]
= 0.918 [Tbytes]

Therefore,

Total traffic per month in Japan
= (Monthly traffic per one-person households)*(Total households of Japan [154])
= 0.918*53000000
= 48654000 [Tbytes]

In the year 2010, monthly total traffic in Japan was 18572 [Tbytes] [3].

Therefore,

Increase ratio of year 2020 to 2010
= 48654000/18572
= 2619

As a result of the above calculations, the provisional estimate of the video traffic in 2020 which is based on market demand is more than 2600 times the video traffic in 2010. Since the assumptions used for these calculations are based on the minimum family structure and do not include business scenes in the office, the increase ratio should actually be much larger than this result.

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Terminology, abbreviations

3D-Beamforming	3-Dimension Beamforming
3D-MIMO	3-Dimension MIMO
3GPP	Third Generation Partnership Project
ABF	Adaptive Beamforming
A/D	Analogue to Digital
AP	Access Point
API	Application programming interface
AR	Augmented Reality
ARQ	Automatic Repeat Request
ASA	Authorized Shared Access
BBU	Baseband processing unit
BiCMOS	Bipolar and CMOS (technology)
BWA	Broadband Wireless Access
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CMOS	Complementary Metal Oxide Semi-conductor
cmWave	centimeter waves
CP	Cyclic-prefix
C-plane	Control-plane
CQI	Channel Quality Indicator (Indication)
CRAN	Cloud RAN
CRS	Cell-specific reference signal
CSI	Channel Quality Information
D2D	Device-to-Device
DL	Downlink
DPI	Deep Packet Inspection
DRAN	Distributed RAN
DSA	Dynamic Spectrum Access
eNB	Evolved Node B or E-UTRAN NodeB
EPC	Evolved Packet Core
FBMC	Filter Bank Multi-Carrier
FDD	Frequency Division Duplex
FEC	Forward Error Correction

FTN	Faster Than Nyquist
GaAs	Gallium arsenide
GaN	Galium nitride
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
ID	Identifier
IDMA	Interleave Division Multiple Access
IMT	International Mobile Telecommunications
IoT	Internet of Things
IOTA	Isotropic orthogonal transform algorithm
IP	Internet Protocol
IRS	Interference rejection combining
ISM	Industry-Science-Medical
ITU	International Telecommunication Union
JP	Joint processing
JT	Joint transmission
L1	Layer 1
L2	Layer 2
MIC	Ministry of Internal Affairs and Communication
LOS	Line-of-sight
LSA	Licensed Shared Access
LTE	Long Term Evolution
M2M	Machine-to-machine
MAC	Media (Medium) Access Controller
MIMO	Multi Input Multi Output
MLD	Maximum likelihood detection
mmWave	millimeter waves
MNO	Mobile virtual network operator
MPA	Message Passing Algorithm
MU-MIMO	Multi-user MIMO
MVNO	Mobile virtual network operator
NFV	Network Function Virtualization
NLOS	Non-Line-of-Sight
NOMA	Non-orthogonal multiple access

OA&M	Operations, Administration, and maintenance
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditure
PA	Power Amplifier
PaaS	Platform as a Service
PDCP	Packet Data Convergence Protocol
PHY	Physical layer
PLMN	Public land mobile network
PMI	Precoding Matrix Indicator
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
RAT	Radio Access Technology
RAN	Radio Access Network
RF	Radio Frequency
RFIC	RF Integrated circuit
RLAN	Radio Local Area Network
RLC	Radio Link Control
RRC	Radio Resource Control
RRM	Radio Resource Management
RSE	RAN sharing enhancement
RTD	Round Trip Delay
SaaS	Software as a Service
SCMA	Sparse code multiple access
SDN	Software-Defined Networking
SFBC	Space Frequency Block Code
Si	Silicon
SIC	Successive Interference Cancellation
SiGe	Silicon Germanium
SIPT	Selected IP Traffic Offload
STR	Simultaneous Transmission and Reception
SW	Switch
TCP	Transmission Control Protocol

TDD	Time Division Duplex
TTI	Transmission Time Interval
TUT	Typical User Throughput
UE	User Equipment
UHD	Ultra high definition television
UHF	Ultra High Frequency
UL	Uplink
UMTS	Universal Mobile Telecommunication System
U-plane	User-Plane
URC	Unified radio controller
UWB	Ultra Wide Band
VNF	Virtual network function
Wi-Fi	Wireless Fidelity
Wi-Gig	Wireless Gigabit
WRC	World Radiocommunication Conference
xDSL	x (A: Asymmetric, H: High Speed, V: Very High Speed) Digital Subscriber Line

Change history

Ver.	Date	Contents
1.0.0	2014/10/8	First version.