TTC

TTC Ad Hoc Group on Future Mobile Networking

White Paper

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Preface

Recently, considerable research on future mobile networks, with a focus on 5G, has been conducted in Japan and other countries. In Japan, ARIB has been conducting active study mainly focusing on radio technologies for the year 2020 and beyond since 2013, and a white paper [1] on this subject was published in August 2014. The emphasis on future mobile networks is not only expected to result in the further development of radio technologies, but also lead to the full-scale implementation of IoT-based services and the provision of services that will enable new use cases.

In addition to taking into consideration the unique features of the Japanese mobile telecommunications market, TTC has done a survey of research and study trends in Japan and other countries, including the above-cited white paper on next-generation mobile communications systems that was prepared by ARIB, and has identified a number of technical issues that will need to be addressed before future mobile networks can be realized. TTC has conducted a survey of various component technologies that are being studied by research and standards development organizations all over the world, and has prepared of map of specific technologies that could serve as candidates for the resolution of the aforementioned issues. An effort has been made to consider trends in research on future mobile networks for 2020 and beyond. This white paper summarizes the study activities that were carried out during the half-a-year period between September 2014 and March 2015.

1 Scope

This white paper, which examines future scenarios for the year 2020 and beyond, and follows up on an ARIB study of next-generation mobile communications systems, presents a compilation of specific technical issues with the current core network, the mobile fronthaul and the mobile backhaul, and considers the trends with the technologies that are principal candidates for the resolution of these issues and assesses the direction that is being taken with future mobile networks.

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3 Terminology, abbreviations

5G	5th Generation
ANDSF	Access Network Discovery and Selection Function
ANQP	Access Network Query Protocol
AR	Augmented Reality
BBU	Base Band Unit
BPS	Bits Per Second
BS	Base Station
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CoMP	Coordinated Multipoint transmission / reception
CPRI	Common Public Radio Interface
C-RAN	Centralized Radio Access Network

CWDM	Coarse WDM
DBA	Dynamic Bandwidth Allocation
DML	Directly Modulated Laser
DMT	Discrete Multitone Modulation
DWDM	Dense WDM
E2E	End to End
EAP-SIM	Extended Authentication Protocol - SIM
EPC	Evolved Packet Core
EPON	Ethernet PON
EPS	Evolved Packet System
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FCAPS	Fault, Configuration, Accounting, Performance and Security
GPON	Gigabit PON
GW	Gateway
HW	Hardware
I2RS	Interface to the Routing System
IaaS	Infrastructure as a Service
ICN	Information Centric Network
ICT	Information and Communication Technology
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoE	Internet of Everything
IoT	Internet of Things
L1	Layer 1
L2	Layer 2
L3	Layer 3
LAA	Licensed Assisted Access
LB	Load Balancer
LMA	Local Mobility Anchor
LTE	Long Term Evolution
LTE-A	LTE-Advanced
LTE-U	LTE-Unlicensed
M2M	Machine to Machine
MAG	Mobility Access Gateway
MANO	Management and Orchestration
MBH	Mobile Backhaul
MCC	Mobile Country Code
M/dMU	Modulation / de Modulation Unit
MEC	Mobile Edge Computing
MFH	Mobile Fronthaul
MIMO	Multiple Input and Multiple Output
MME	Mobility Management Entity
MNC	Mobile Network Code
MNN	Mobile Network Node
MNO	Mobile Network Operator
MPTCP	Multi Path TCP
MS	Mobile Station
MTC	Machine Type Communication
MUX/DEMUX	Multiplexer / Demultiplexer
MVNO	Mobile Virtual Network Operator
NaaS	Network as a Service
NFV	Network Function Virtualization
NFVI	NFV Infrastructure
NW	Network
OAM	Operation, Administration and Maintenance
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operating Expense
OTN	Optical Transport Network
OTT	Over The TOP
P2MP	Point to Multipoint
P2P	Point to Point
PaaS	Platform as a Service

PON	Passive Optical Network
PSM	Power Saving Mode
QoE	Quality of Experience
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RAU	Radio Antenna Unit
RE	Radio Equipment
REC	Radio Equipment Controller
REST	Representational State Transfer
RRH	Remote Radio Head
SaMOG	S2a Mobility based On GTP and WLAN access to EPC
SBY	Standby
SDM	Space Division Multiplexing
SDN	Software Defined Networking
SIM	Subscriber Identity Module
SIPTO	Selected IP Traffic Offload
SLA	Service Level Agreement
SNS	Social Networking Service
T.B.D.	To Be Determined
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
TRX	Transmitter and receiver
UDWDM	Ultra Dense WDM
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VMM	Virtual Machine Monitor
VNF	Virtual Network Function
WDM	Wavelength Division Multiplexing

4 Future scenarios and issues of the current network

4.1 General

This chapter outlines possible scenarios and technical issues for the future mobile networks in 2020 and onwards. Each section is divided into three categories; Core Network, Mobile Backhaul and Mobile Fronthaul, as shown in the current network configuration in Figure.4.1-1.

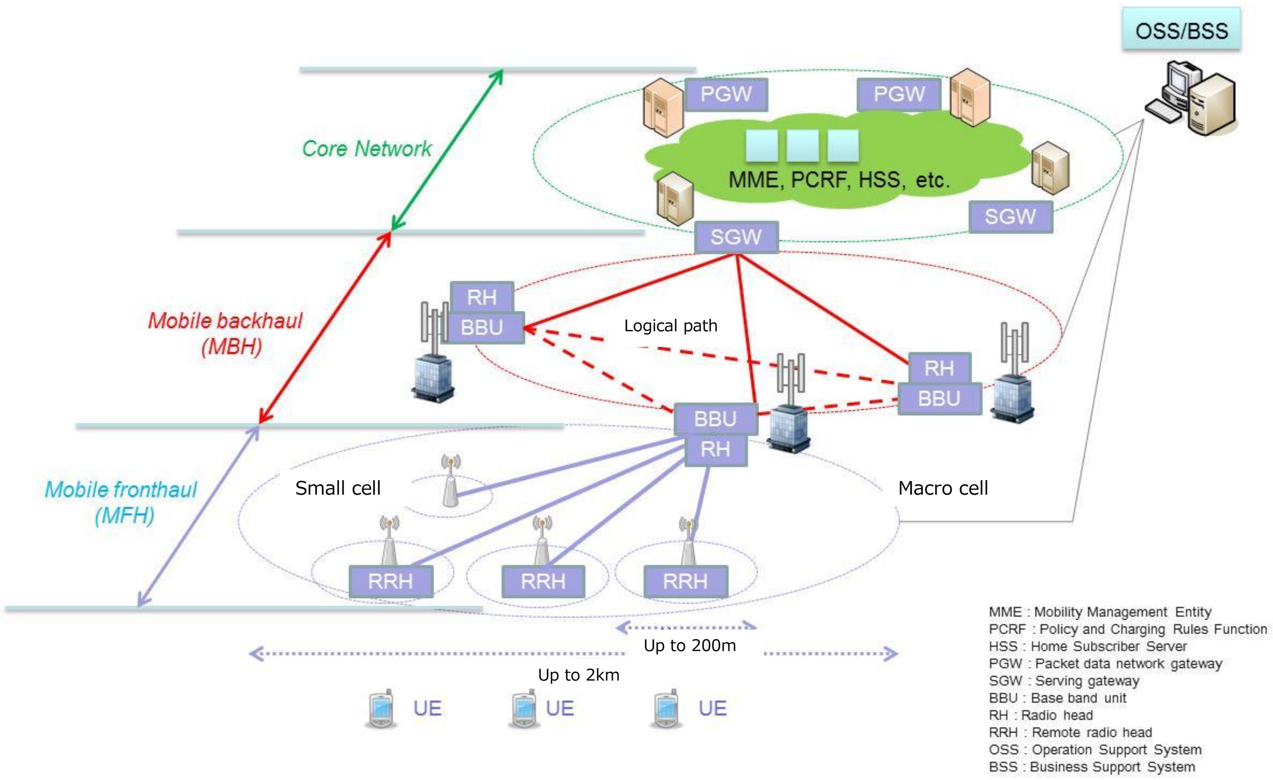


Figure.4.1-1: Network configuration overview

4.2 Ultra large capacity (U-plane)

4.2.1 Outline

According to [2], the data traffic for future mobile communications is expected to increase 1000 times. So it is expected to develop new technologies that can economically ensure the transmission rates of 10Gbps or more (at peak) and 100Mbps to 1000Mbps (all the time) on the terminal. To do so, it is necessary to establish technologies adopting dynamic network resource allocation according to traffic volume at Core Network, low-cost optical transceiver supporting 1Tbps at Mobile Backhaul, data compression and a PON method at Mobile Fronthaul, etc.

4.2.2 Future scenarios

According to [3], the traffic in mobile communication networks is increasing at an annual rate of 61% and projected to grow 1000 times in the future. Therefore, it is required to summarize the issues as to whether the future requirements can be supported by the current network architecture for mobile communications.

Figure.4.2.2-1 provides a VAN diagram outlining the requirements for future mobile communications. Compared with 4G, the future mobile communication requires larger capacity in the Extreme area, faster communication in areas such as Rural, Urban, Dense, etc. and expanded coverage in the isolated area.

Especially regarding the capacity increase, applications like AR (Augmented Reality) and real-time cloud access are assumed, with data rate requirements of 100 to 1000Mbps at any given time and around 10Gpbs at peak.

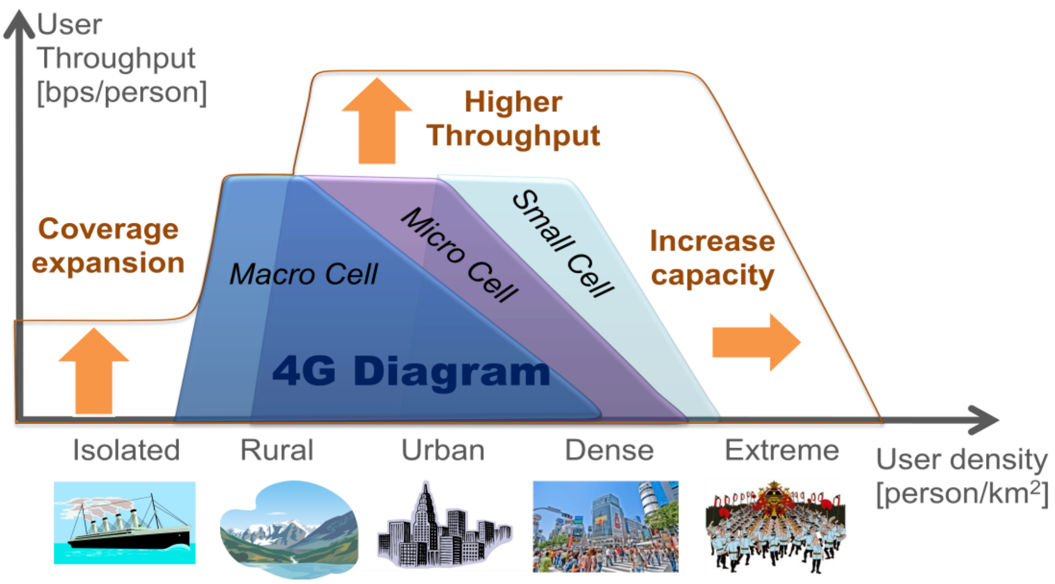


Figure.4.2.2-1: Requirements for future mobile communications

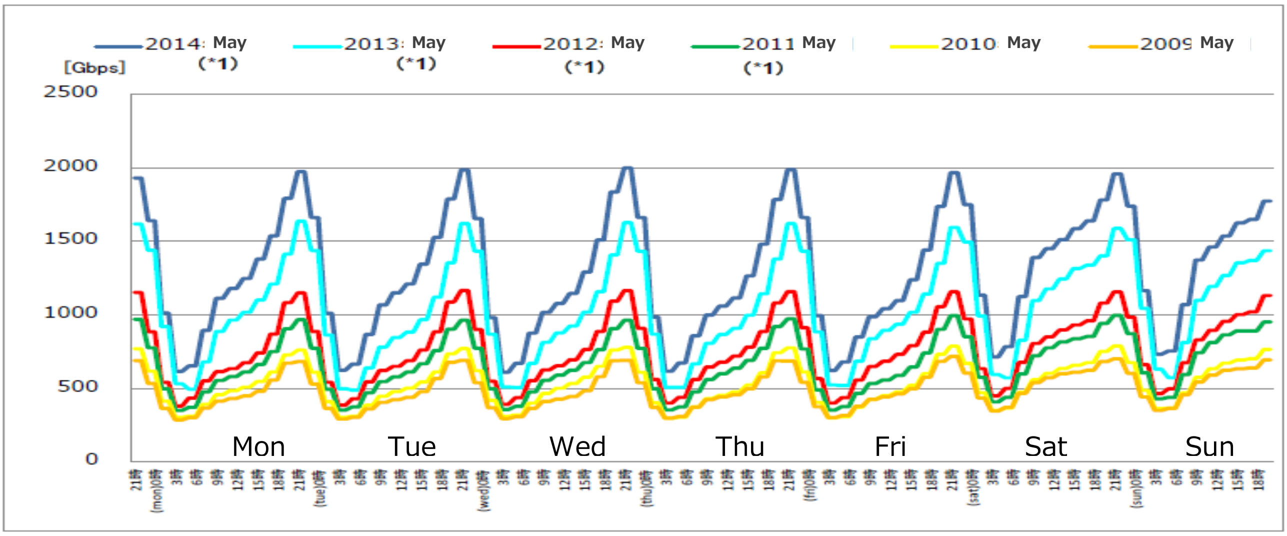
4.2.3 Technical issues in the current network

4.2.3.1 Core network

The main factors of mobile traffic increase are expected to include the increase in new applications such as AR and real-time cloud access as well as large amount of packets like video. At the same time, short-packet transmissions are also expected to increase due to M2M/IoT. Various types of packets (log/short packets, burst) need to be transmitted. In addition, traffic volume fluctuates greatly depending on the hour of day and sharply increases unexpectedly at a mass event or during a disaster.

Download

(Gbps)



Upload

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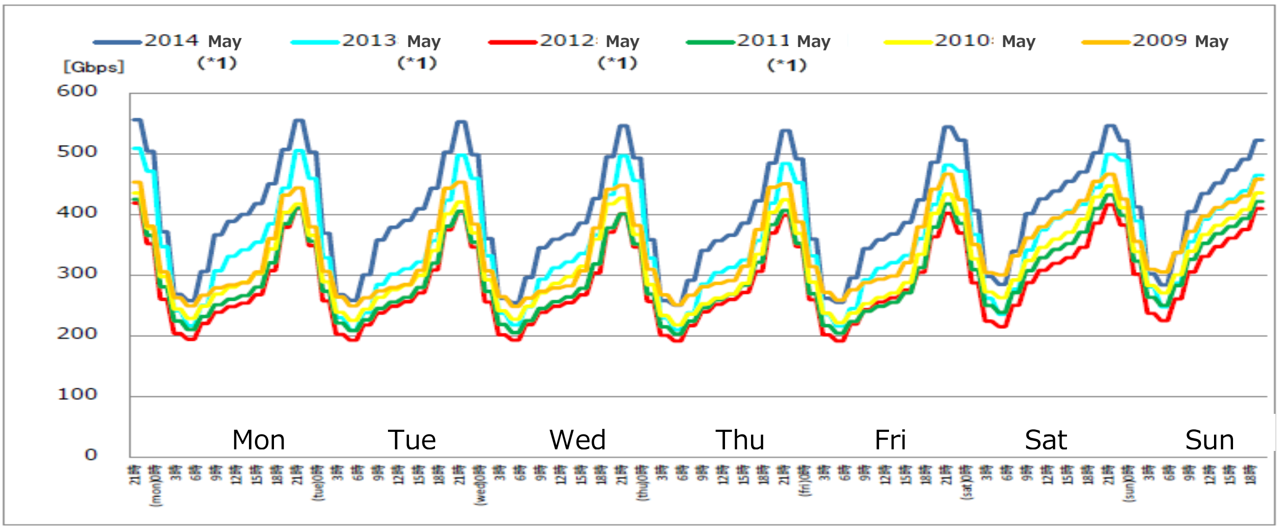


(*1) For the traffic from May 2011 to May 2014, a part of the traffic for communications with cellphone networks is excluded which was included in the traffic up to Nov 2010.

Figure.4.2.3.1-1: Traffic change based on the hour of day for broadband service subscribers (comparison over the past six years)

(Source: [4])

Not only the long-term traffic increase, but also diversified traffic types and a temporary increase cause the processing load of the U-plane Core Network equipment to increase. As the processing load of the Core Network equipment increases, more time is needed to process U-plane packets, resulting in data packet latency or congestion (rejection) and lower network reliability. On the other hand, adding core network equipment in anticipation of traffic growth would lead to increased facility costs.

To cope with this issue, a mechanism for dynamically allocating network resources according to traffic is needed. More specifically the followings need to be examined:

(1) Method for changing the radio access network, mobile network route or connection destination according to traffic

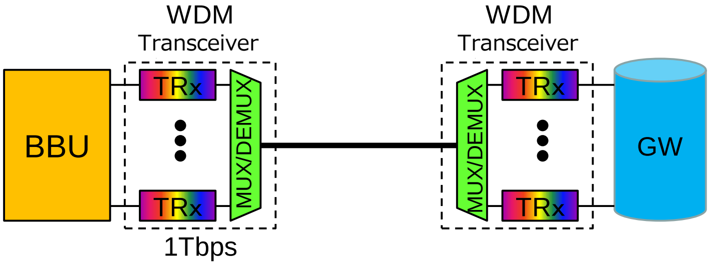
(2) Method for changing mobile network functions and resource allocation according to traffic

In addition, along with the increase in the number of M2M/IoT terminals, the memory size that needs to be retained to keep the connection in the idle state will become huge in the current EPC. In the future, it is possible to use a method for not continuously connecting specific M2M/IoT terminals that support intermittent connection and require low connection latency.

4.2.3.2 Mobile Backhaul

To aggregate a large number of fast lines, a transmission capacity of 100Gbps or greater is required even when the statistical multiplexing effect is taken into account. For instance, if one Mobile Fronthaul (small cell) supports a peak data rate of 10Gbps and 10,000 users with a usage rate of 0.01%, the capacity is 10Gbps. The number of small cells that can be deployed in one macro cell is about 100. So when the capacity per small cell is 10Gbps, a capacity up to 1Tbps needs to be considered for the Mobile Backhaul. Furthermore, as traffic increases, there is a concern about the increase in the number of transponders even when wavelength multiplexing is applied. Therefore, configuration study is also necessary in terms of high speed, large capacity and optical network.

At present, a technique for supporting 400Gbps with a single wave is being studied, but only up to 100Gbps has been achieved on a production level. A transmission rate of 1Tbps will be provided by parallel transmission using Wavelength Division Multiplexing (WDM). The configuration overview is provided in Figure.4.2.3.2-1. The WDM transceiver consists of optical transceiver and wavelength MUX/DEMUX. The table in the figure shows the number of required units to achieve 1Tbps with the existing transceiver.



Single unit	# of Ch	# of wavelength
10Gbps	100	100
40Gbps	25	100
100Gbps	10	40

Figure.4.2.3.2-1: Configuration of WDM transceiver to achieve 1Tbps

Only a single module cannot provide 1Tbps. Thus optical modules of 10Gbps/40Gbps/100Gbps have to be configured using multiple channels, which will cause the cost to increase sharply. Although the price is getting moderate thanks to the spread of 10Gbps/40Gbps optical transceivers, the price of 100Gbps optical transceiver is projected to soar even in 2010 based on the market trend. Therefore, although it is easy to configure with 100Gbps transceivers requiring less number of channels and wavelength, we will wait and hope for price decline when the product is prevalent in the future. The 40Gbps transceiver also requires a small number of channels, but the number of wavelength is the same as the 10Gbps transceiver. So either 10Gbps or 40Gbps will be selected depending on the equipment size, drive control methods according to traffic volume, etc. It is hoped that a 40Gbps transceiver with a single wavelength will be provided using high-speed electrical processing circuits.

4.2.3.3 Mobile Fronthaul

Figure.4.2.3.3-1 shows the configuration of the Mobile Fronthaul. Due to high-speed data rate of mobile terminals (great capacity at a cell), the capacity of the line used for the Mobile Fronthaul needs to be increased. For example, a transmission capacity of about 160Gbps (about 16 times) [1]is required to support 10Gbps terminals in the current CPRI-based Mobile Fronthaul.

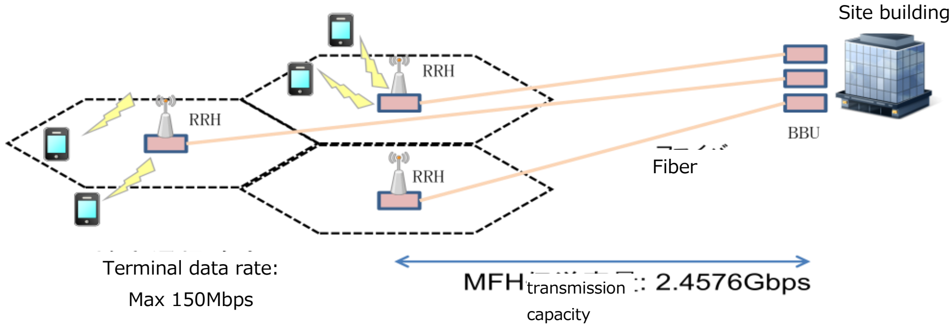


Figure.4.2.3.3-1: Configuration of Mobile Fronthaul

Furthermore, widespread deployment of small-size cells is expected to support high-speed and large-capacity mobile communications. In addition to macro cells with a radius of several kilometers, small cells with a radius of some dozens of hundreds of meters are being considered to be deployed together. For instance, assuming that a macro cell of 2km radius is replaced with small cells of 200m radius, the number of cells calculated based on the superficial area would increase 100 times. This brings up a concern about sharp increase of network cost due to increase in the number of links in the P2P configuration used for the current fronthaul.

Figure.4.2.3.3-2 and Figure.4.2.3.3-3 provide the number of links in the macro/small cell. If a macro cell (2km radius) is replaced with small cells (200m radius), the followings are expected.

- The number of small cells increases 100 times.
- Required fibbers and MFH optical transmission equipment also increase 100 times due to the increase in the number of small cells.
- The cost increase due to large capacity of MFH optical transmission equipment needs to be taken into account.

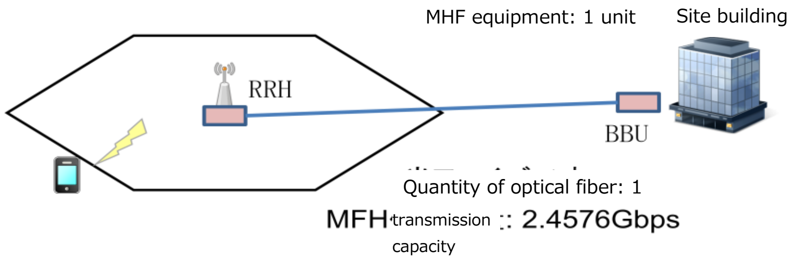


Figure.4.2.3.3-2: Number of links at macro cell

[1] Mobile fronthaul optical transmission capacity (20 MHz, 2x2 MIMO, CPRI transmission) when it is applied to LTE (DL: 150 Mbps) can be calculated using the following formula. Namely, for the communication rate of a UE, 16 times larger capacity for MFH capacity will be required.

$$20\text{MHz} \times 15(\text{sample width}) \times 1.536(\text{over sampling}) \times 2(\text{I/Q}) \times \frac{16}{15}(\text{control OH}) \times \frac{10}{8}(\text{8B10B}) \times 2(\text{2x2 MIMO}) = 2.4576\text{Gbps}$$

(Ref.: [5], 7.1.1)

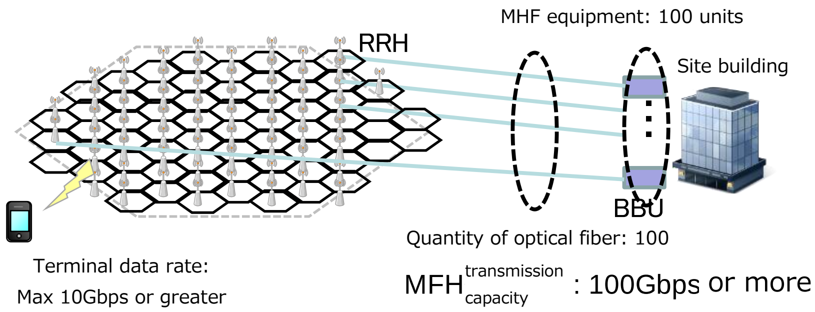


Figure.4.2.3.3-3: Number of links at small cell

Summarizing the issues for the Mobile Fronthaul based on the above discussion, the major issues are the followings: (1) Large-capacity transmission of 100Gbps or more and (2) Increase in the number of links.

(1) Regarding the large-capacity transmission of 100Gbps or more per cell, possible methods include reduction of transmission data amount and improved efficiency with transmission data compression. In the current CPRI transmission, however, radio signals in use cannot be identified at the optical layer, requiring all radio signals to be sent. The bandwidth in use also cannot be identified at the optical layer. So the calculation is made using the peak rate.

(2) Regarding the increase in the number of links, the number of fibers and equipment is expected to increase as long as the current P2P configuration is used, causing the cost to increase. Thus the system change to P2MP may need to be considered. A specific method for achieving this can be PON (TDM/WDM techniques, etc).

4.2.3.4 Common issues in the Mobile Backhaul/Fronthaul

Increase in the number of links at Mobile Backhaul/Fronthaul

The increase in the number of links due to small cell deployment (see 4.2.3.3) is also an issue in the Mobile Backhaul. Therefore, there is a concern about network cost due to increase in the number of links in the P2P configuration in both Mobile Backhaul and Fronthaul. The increase in the number of links also causes the number of equipment to increase, leading to huge power consumption. Thus it is necessary to study architecture to build economic and low-power Mobile Backhaul/Fronthaul.

4.2.3.5 Requirements for the future network

It is required to flexibly and economically support requirements such as a transmission capacity beyond 100Gbps, diversified traffic patterns and 100 times increase in the number of cells.

4.3 Load increase in C-plane C-plane

4.3.1 Outline

According to [1], about 100 times more terminals (compared with 2012) need to be accommodated to support M2M/IoT terminals in the future mobile network. The characteristics of the M2M/IoT terminals are different from the terminals operated by people in that M2M/IoT communications concentrate during specific hours of the day. Handover opportunities also increase as more small cells are deployed. Due to these factors, the C-Plane processing load for connection/disconnection, handover and paging may increase shapely in specific areas or during specific hours of the day in the Core Network. In addition, the architectures are expected to be diversified because M2M/IoT terminals to be accommodated are connected via the GW, etc. It is necessary to address a shortage of ID digits for terminal identification due to increase in the number of terminals and redefine terminal identification.

4.3.2 Future scenarios

Not only mobile phones but also various devices are connected to a network. The IoT technology that provides an environment for data exchange without human intervention as well as the M2M (Machine to Machine) communication where devices connected to a network communicate each other are advancing.

Furthermore, grouping the M2M/IoT terminals by service, area or local network connection is considered to be effective, and relevant studies are already being conducted at 3GPP. Fig.4.3.2-1 shows a case being examined at 3GPP.

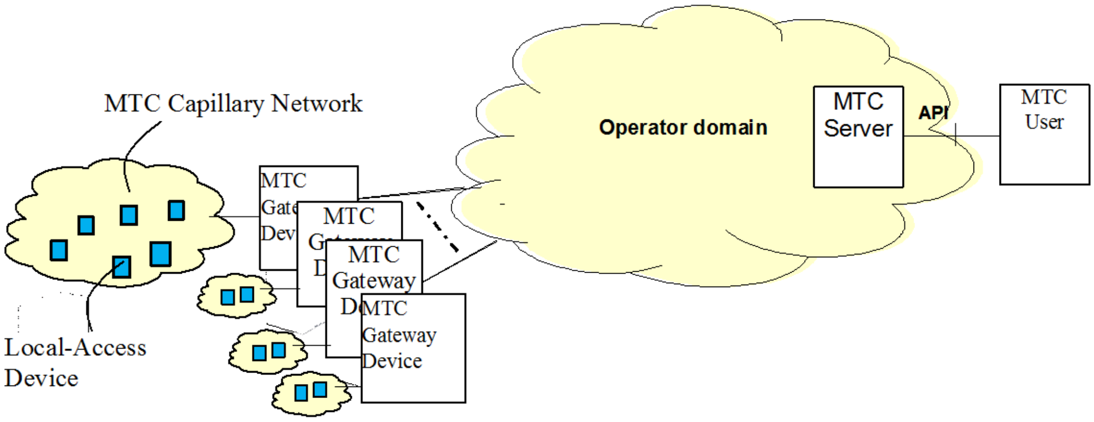


Figure.4.3.2-1: Examined case at 3GPP (Excerpt from [6])

The M2M/IoT terminals are indicated as Local-Access Device in Figure.4.3.2-1. As described above, the number of M2M/IoT terminals is expected to grow exponentially. In addition, considering diversified architectures that support local networks accommodating each M2M/IoT terminal, it is possible that the MTC service provider will directly manage each M2M/IoT terminal across multiple access lines. It is also necessary to thoroughly examine terminal identification to comprehensively manage a huge number of M2M/IoT terminals. See 4.3.3.2 for more discussion about terminal identification for mobile phones and M2M/IoT terminals.

4.3.3 Technical issues in the current network

4.3.3.1 Core Network

The M2M/IoT communications tend to concentrate at specific times of the day when small-sized data are intensively sent out from numerous terminals, which is a characteristic different from conventional communications. Thus concentrated control signals (C-Plane) cannot be processed with the conventional network resource managing/controlling techniques assuming human behaviors (e.g., mobile phones) that perform random communications to some extent, which may result in a network crash. Load is concentrated on equipment that processes C-Plane intensively (e.g., MME), causing various possible problems such as network disconnection, large delay and disruption of services like voice call. The mobile network control processes that are expected to increase greatly in the future at C-Plane are as follows:

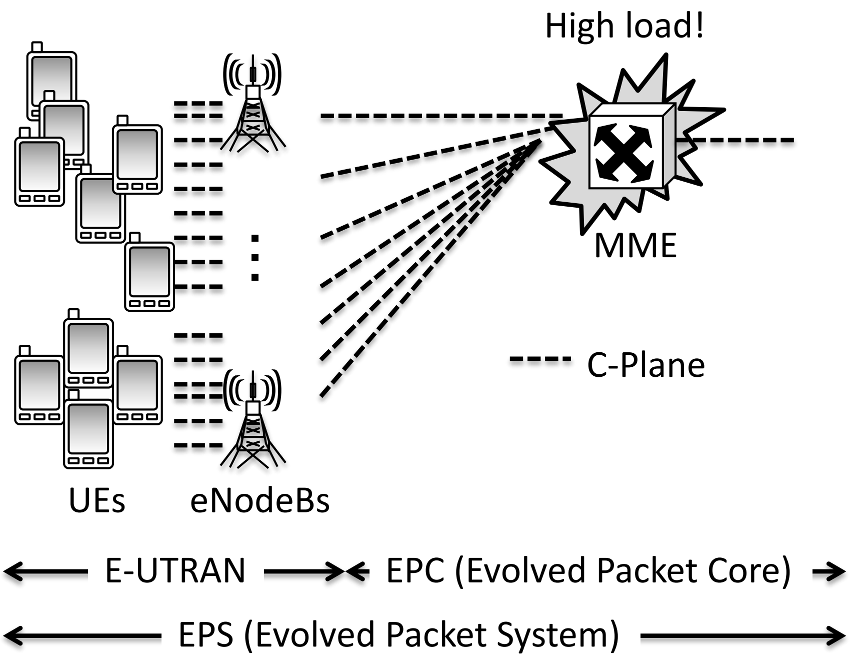


Figure.4.3.3.1-1: Load concentration at C-Plane

Connection/disconnection process

Load associated with the processes on the network required to connect/disconnect control connections and establish bearers during terminal communications. The conditions for connection/disconnection processing on the network include when a mobile terminal transitions from the Connected to Idle state as well as from Idle to Connected state. It is also applicable when multiple grouped communication terminals are collectively connected/disconnected. Processing load is concentrated in specific areas or at specific times of the day due to increase in the number of terminals performing frequent communications like sensors. This raises an issue of C-Plane process load concentration at the MME in the current system.

Handover process

Load associated with handover processes generated on the network when communication terminals move. The conditions for handover processing on the network include when a mobile terminal moves from one base station to another in Connected state. As small cells are deployed in the future, the handover frequency will increase, causing handover processing to concentrate in specific areas or during specific hours, which results in concentrated C-Plane processing load at core equipment like the MME and S-GW and the eNodeB

Paging process

In the mobile network, when new downlink traffic (incoming downlink data or voice) arrives for a communication terminal in standby state, a paging signal is sent. In response to the paging signal addressed to the mobile terminal, the terminal initiates a process to connect to the network to receive the traffic. This connection process involves establishment of a control connection and bearer. When communications with various types of M2M/IoT terminals increase in the future, the opportunities for a server at the center to send a PUSH notification is expected to increase, causing PUSH processing to concentrate in specific areas or at specific times of the day. This creates an issue of high C-Plance processing load at the MME and eNodeB. A technique such as smoothing PUSH notification timings according to the network load will be needed.

4.3.3.2 Terminal identifier (Identification)

The present mobile terminal is managed with an identification called IMSI associated with the SIM card. The structure of the IMSI is provided in Figure.4.3.3.2-1 which is defined in the numbering plan in the ITU-T E.212. It is assumed that each terminal belongs to a mobile operator identified by the MCC and MNC. The business model related to the M2M/IoT terminal is expected to be greatly diversified in the future, so the current device approval with the IMSI may become an obstruction in diversifying the business. In addition, according to the current 3GPP specification [7], the IMSI shall not exceed 15 digits, which may be insufficient to accommodate a huge number of M2M/IoT terminals. Therefore, it is necessary to study an efficient receiving technique that can identify a vast number of M2M/IoT terminals.

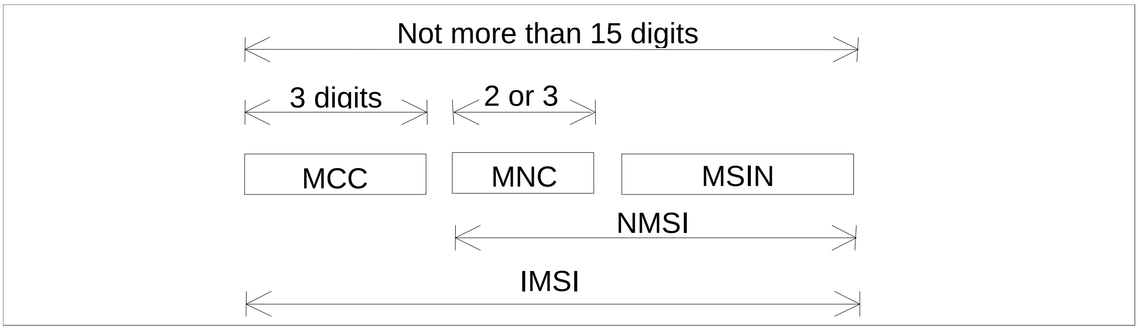


Figure.4.3.3.2-1: IMSI structure (Excerpt from [7])

4.4 Transport layer

4.4.1 Outline

Future mobile networks will be in heterogeneous environment using various frequency bands. However, in heterogeneous environment, due to insufficient support for end-to-end congestion control or multi-path communication, the existing TCP/IP communication will not be able to handle sudden change of bandwidth and latency due to frequent occurrence of handover. Also, it is expected that various applications will be created, hence applications with tolerance against changes on the different network side will operate. Building networks that meet requirements of all such applications is difficult in terms of technology and business, hence new transport layer appropriate for heterogeneous environment will be required.

4.4.2 Future scnenario

Future mobile networks will be heterogeneous networks where interconnections are made by various radio access technologies. Namely, the network configuration has overlayed small cells such as Pico cells (apx. 50 meters to apx. 500 meters of radius) and Femto cells (apx. 50 meters or less of radius) whose transmission power is low on Macro cell coverage. (Figure.4.4.2-1). When users move in such a heterogeneous network, they will go through a small cell in a short period. At that time, the quality (bandwidth/latency) of the accessed line will be changed discretely as they use multiple frequencies at the same time or the speed is switched to higher one. For example, when a user enters into a small cell, higher bandwidth is available than that of Macro cell area. However, since the cell coverage is small, the bandwidth becomes unavailable when the user moves out of the small cell.

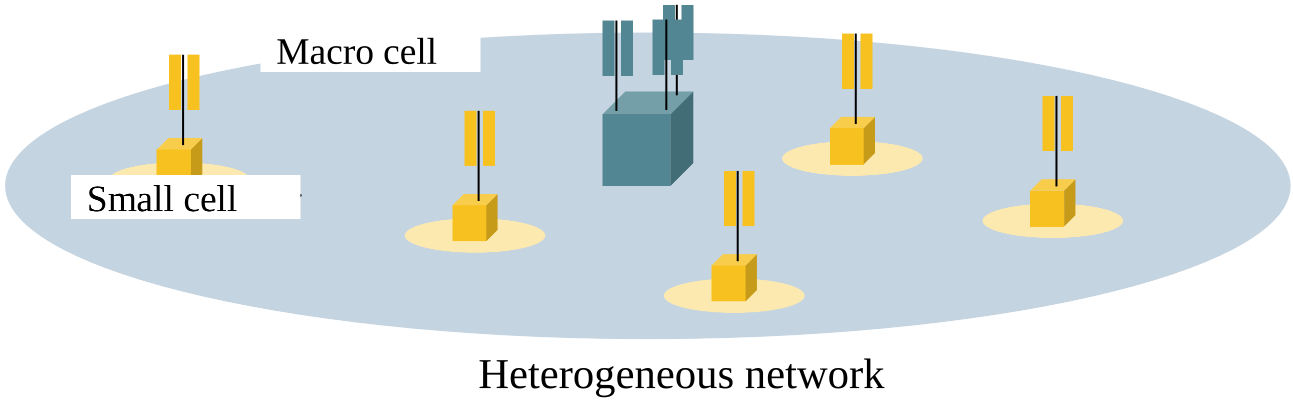
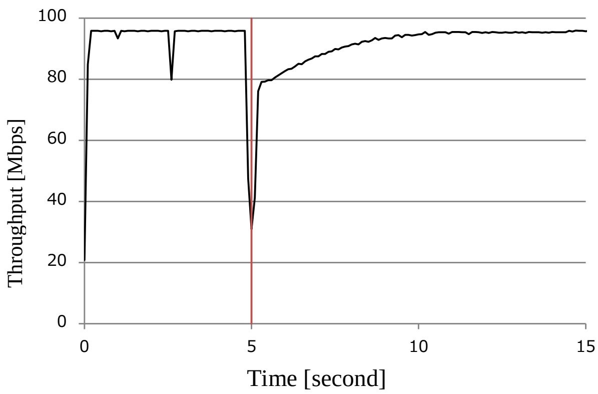


Figure.4.4.2-1 Heterogeneous network

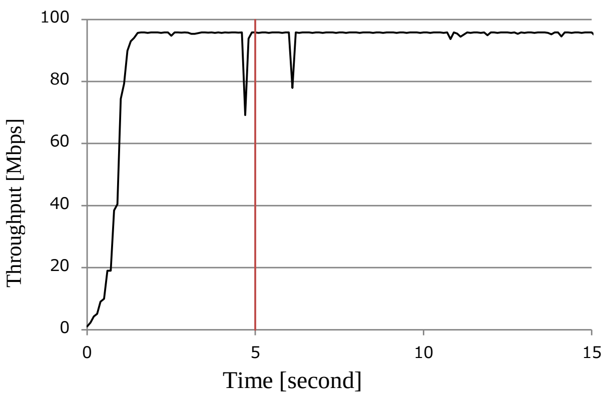
4.4.3 Technical issues of the current network

The current congestion control argorithm which uses TCP/IP is a control based on the window size, where control is repeated that basically widens the window size little by little and closes the window size in case contestion such as packet loss occurs. Currently, to handle this, TCP congestion control technology for radio access network is proposed and implemented, however, it is to solve the issue of high-latency/broadband line, but not to handle discrete quality change as heterogeneous network. CUBIC, which is a standard in Linux OS as of 2015, is also TCP to support high-latency/broadband line, however, it is not able to handle sudden change of quality.

To clarify the technical issue, an experiment to transfer a file between Linux PCs using iperf was performed. A wired line was used for connecting the PCs and the bandwidth was limited to 100 Mbps using network emulator. Figure.4.4.3-1 shows the result of increasing the transmission latency from 10 ms to 50 ms after five seconds after the start of file transfer and the contrary case using network emulator. The vertical axis is average throughput per 100 ms.



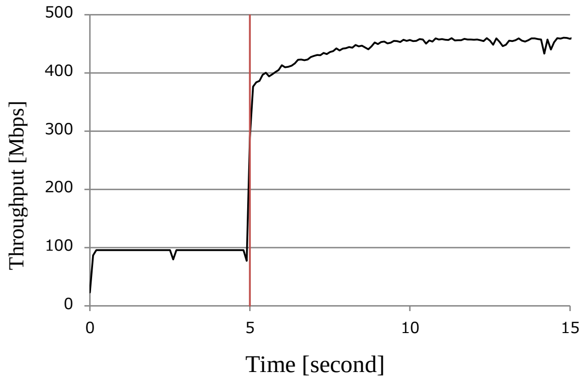
(a) Propagation latency was changed from 10 ms to 50 ms



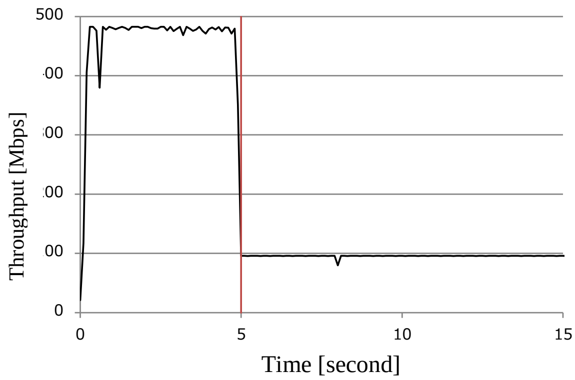
(b) Propagation latency was changed from 50 ms to 10 ms

Figure.4.4.3-1 Throughput change when latency was suddently changed

Also, Figure.4.4.3-2 shows grahps when latency was fixed to 10 ms and the bandwidth was changed from 100 Mbps to 500 Mbps under the same environment. From the results, it is known that when latency becomes low or bandwidth becomes small, quality change is immediately followed though packet loss occurs. On the other hand, when latency becomes high or bandwidth becomes large, it takes around five seconds to sufficiently use line quality. If walking speed of a person is 1.4 m/s, a UE moves appx. 7 m. Therefore, if there is only appx. 50 m of coverage, the user may not be able to use the line quality sufficiently but move out from the area.



(a) Bandwidth was changed from 100 Mbps to 500 Mbps



(b) Bandwidth was changed from 500 Mbps to 100 Mbps

Figure.4.4.3-2 Throughput change when bandwidth was suddently changed

MPTCP is a technology that enables high-speed communication by simultaneous use of multiple interfaces and seamless interface switching by using multiple paths. However, since there is overhead such as insertion of multiple path routes or negotiation of new TCP/IP path, its capability may not be sufficiently used in a heterogeneous network. Figure.4.4.3-3 shows average throughput when a file is downloaded by a terminal with Wi-Fi (802.11g) using iperf. At this time, let us assume that the UE is connected to a line of 1Gbps only for "a" second every 30 seconds. Two interfaces can be used seamlessly by MPTCP, however, if the connectin period "a" is less than 4 seconds, the line of 1 Gbps cannot be used. Namely, if the visiting period of small cell is less than 4 seconds, the user goes through the small cell without using its bandwidth even if it uses MPTCP. This time, the IP address of each PC is set to static, and considering negotiation at L2 and the allocated period of time for IP address in reality, MPTCP is not always applicable to heterogeneous network.

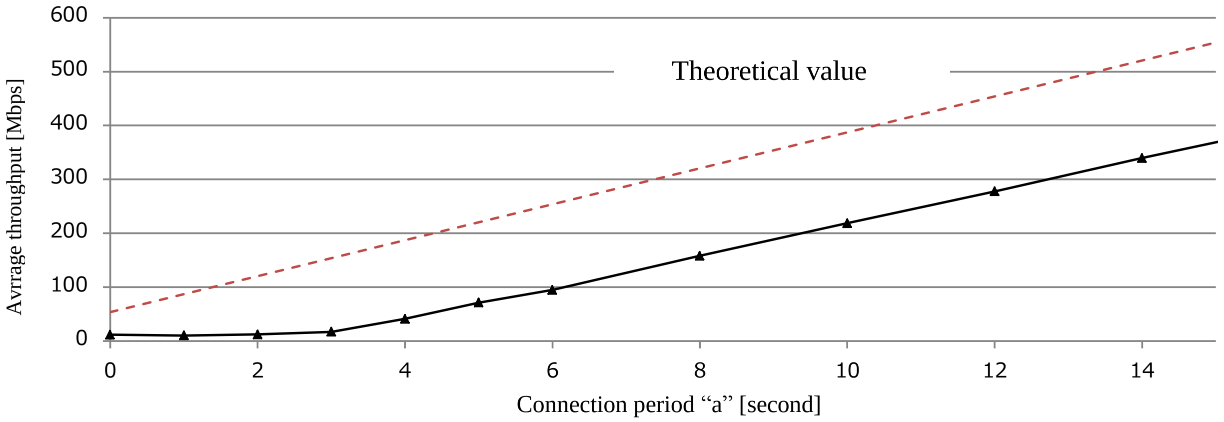


Figure.4.4.3-3 Throuput when MPTCP is used in an environment where two networks mixedly exist

Moreover, even if broadband line is provided for wireless line, it may not be effective depending on applications. Figure.4.4.3-4 shows the average throughput per second when YouTube is viewed using a dedicated application for Android. This application uses TCP/IP, however, the rate is limited to 500 kbps by control on the application side currently. Therefore, even when bandwidth higher than it is prepared, the application will not use it. Also, burst reception between 0 to 7 seconds is buffering to absorb jitter, hence playing the video is started after the quality such as line latency is measured first. Therefore, if line quality is changed in the middle, buffer overflow may occur, which may cause problem in playing a video. Thus, in future mobile networks where various terminals and applications are connected, there may be cases where providing lines of low latency and broadband for all the applications have no effect. Namely, it is important to provid line quality according to applications, and setting of line quality coordinated with applications will be important.

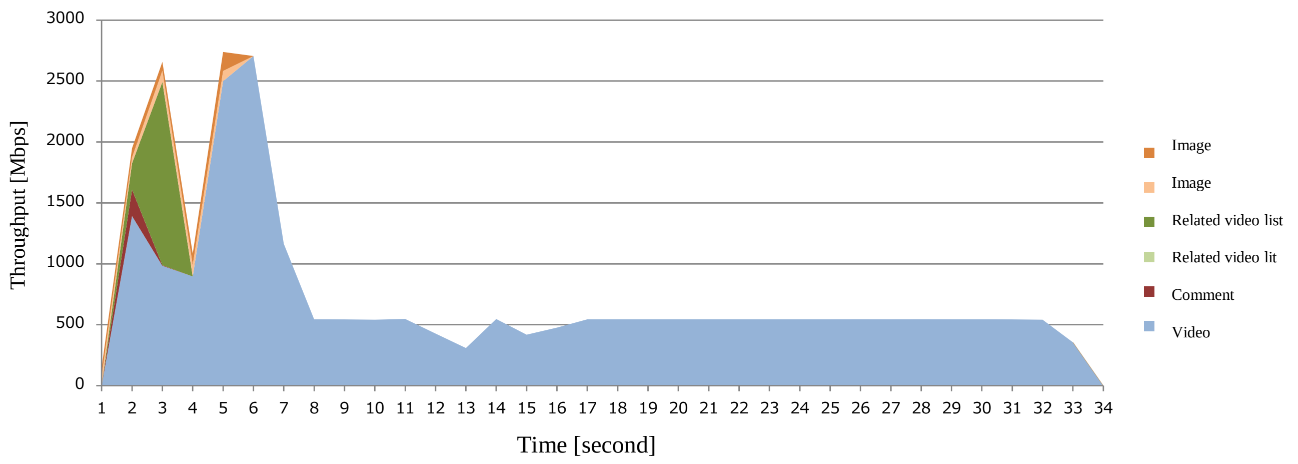


Figure.4.4.3-4 Average throughput per second when YouTube is viewed on Android terminal

4.4.4 Requirements for the future network

Based on the above issues to be considered for transport layer in a heterogeneous environment are follows:

- Control of transport layer that can follow frequent changes of line
- Provision of line quality that meet the requirements of applications

The roles of them are the roles of transport layer that is positioned between applications and networks, hence technologies that associate various terminals/applications and heterogeneous networks consisting of various access networks will be required.

For a technology to solve the abovemenitoned issues, not only the existing TCP/IP but also use of ICN (data aware networking technologies), which is getting attention in recent years, shall be considered also. One of the characteristics of ICN is decoupling of sender and recipient, which enables communication not dpending on current end-to-end session. Also, cross-layer technology with the technologies of lower layer than transport layer such as aggregation of multiple frequency bands with L2 like CA and network virtualization such as SDN shall be studied.

4.5 Ultra low latency

4.5.1 Outline

In the future mobile network, provision of new services requiring real-time performance is necessary, and support for a requirement of 1ms or less latency is being considered for E2E. Latency due to transmission distance is a physical amount determined uniquely, so it is required to establish technologies such as (1) minimized routing path with optimized layout for each transmission equipment, (2) reduction of processing latency for modulation/demodulation processing time, protocol conversion processing time, etc. and (3) study of overall network architecture that incorporates these technologies.

4.5.2 Future scenario

In the future mobile network, it is expected that new mobile services with very low latency will appear, which could not be provided with 4G. Specifically, an E2E latency requirement of 1ms is being considered for such applications as tactile communication, AR and auto-driving.

4.5.3 Technical issues of the current network

4.5.3.1 Core network

In the future mobile network, very severe requirements for network have to be met. The key challenges to be addressed are as follows:

(1) Physical latency due to distance

(2) Impact on network architecture

The latency due to distance depends on the medium (e.g., optical fiber), so further reduction needs to be considered from a network architecture perspective.

In the current EPC Architecture, the communication path is configured with the P-GW as anchor point. In order to support low latency communication, the anchor point needs to be put at a short distance from the communication terminal. As shown in Figure 4.5.3.1-1, the Local GW is deployed near the terminal as an anchor point to support the Home eNodeB in the LTE configuration. However, because the Local GW is fixed and cannot be relocated, the Local GW gets far from the terminal as the terminal moves, causing increased latency, while support for both fast mobility and low latency is required for services like V2V (Figure 4.5.3.1-1 is shown as an example. As UE1 moves from eNodeB 3 to eNodeB 2 and to eNodeB 1, the latency increases).

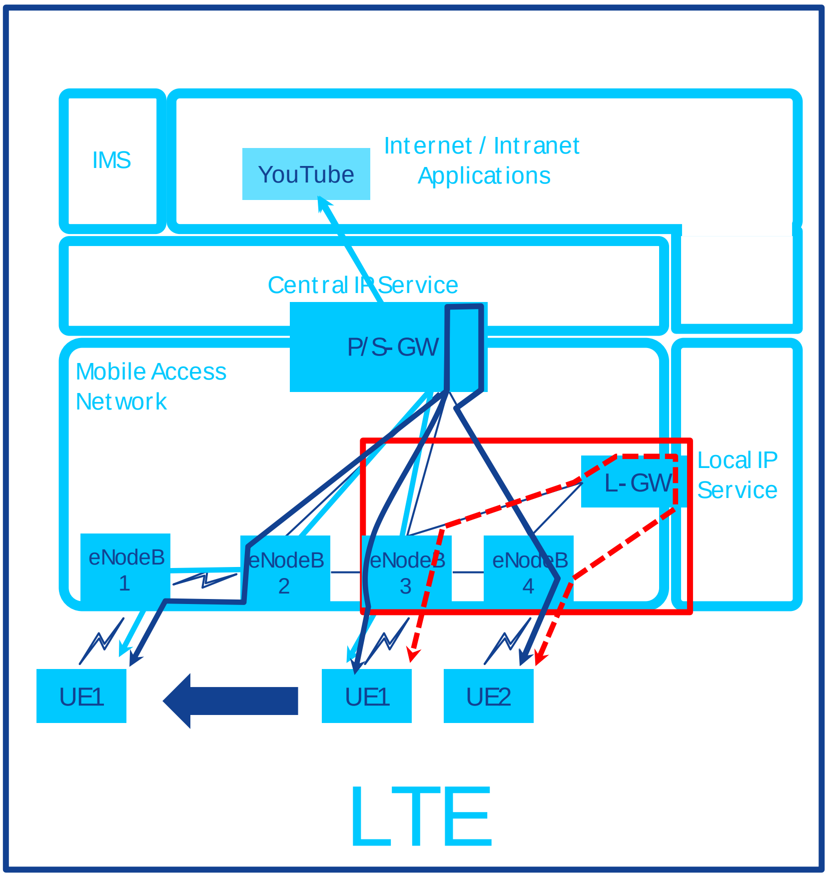


Figure 4.5.3.1-1: Issue point of 4G Network (LTE)

4.5.3.2 Mobile Backhaul/Fronthaul

Figure.4.5.3.2-1 shows the basic mobile network configuration, showing where and how long latency occurs in the RAN (Radio Access Network) in a detailed diagram. The upper part shows the conventional configuration without the

MFH. The lower part shows the configuration when the MFH is deployed. In this section, to provide generality, the functions of radio TRx in the BS are divided in two, considering the connection between the one part (e.g., modulation and demodulation unit (M/dMU) and the other part (e.g., RAU: radio antenna unit) as the MFH and the link for it as the MFH link. Likewise, the connection between the BS and the MNN (Mobile Network Node) is considered as the MBH and the link for it as the MBH link. Each RAT shall be applied for the radio link consisting of the radio TRx in the BS and the MS (mobile station) and the radio propagation space between them. It is assumed that each link is generally composed of TRx at both ends and transmission medium, with each TRx containing Lyer1 and Layer2 functions. There are some candidates for the demarcation point separating the TRx function in the MFH. The appropriate demarcation point to separate the TRx function may be selected according to requirements, etc. For example, industry's standards [8] and [9] specify the digital serial interface between the REC and the RE separated in the radio base station. The separated and remotely placed functions (partial radio TRxs) both provide original functions as radio TRx, so these functions and the MFH link can be considered the virtual radio TRx (practical TRx). For the same reason, both separated partial BS functions and the MFH link can be considered the virtual BS (practical base station). Thus, the MFH link can be translated as internal wiring for the radio TRx or base station.

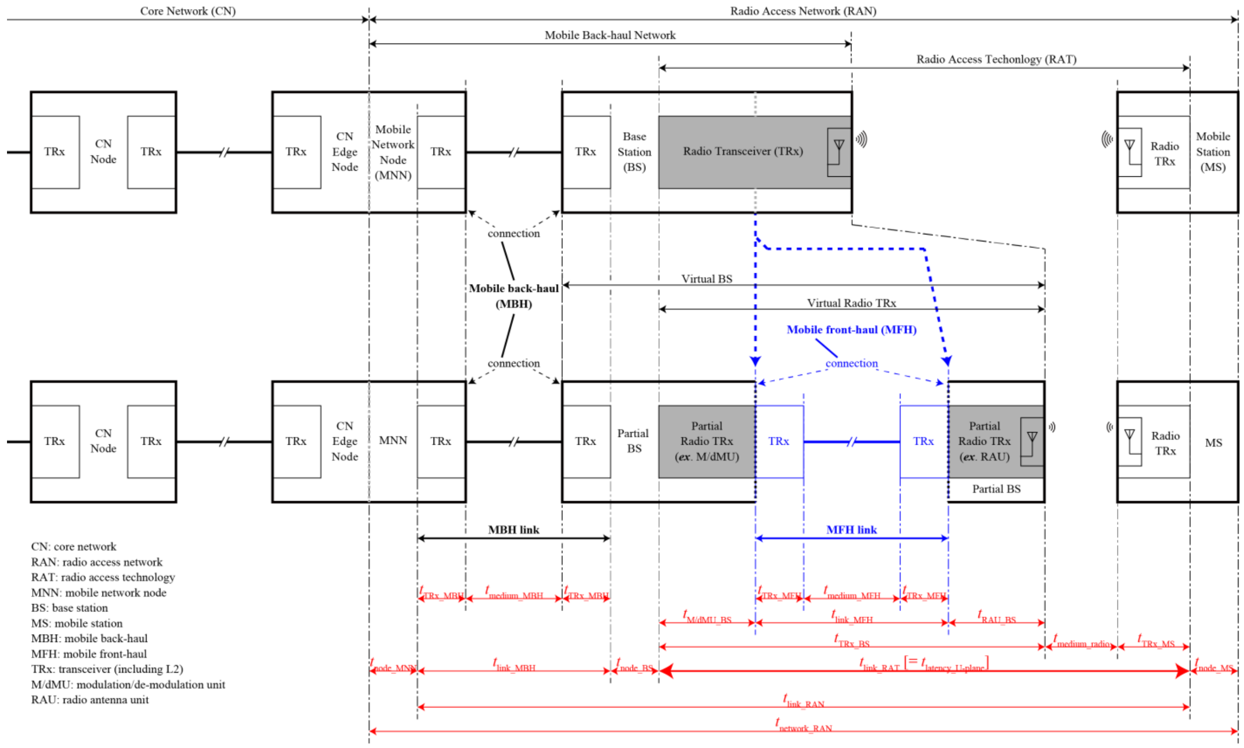


Figure.4.5.3.2-1: Basic configuration and latency for mobile network

According to Section 4.5 in [10] and Section 6.2.2 in [11], the user plane latency ($t_{latency\_U\text{-}plane}$) is considered to correspond to the link latency due to RAT (t_{link_RAT}) in Figure.4.5.3.2-1. This latency (t_{link_RAT}) consists of the processing latency of the radio TRx in the BS (t_{TRx_BS}), the propagation latency of the radio space (t_{medium_radio}) and the processing latency of the radio TRx in the MS (t_{TRx_MS}). If the MFH link is implemented, the processing latency of the radio TRx in the BS (t_{TRx_BS}) consists of the processing latency of functions in the radio TRx placed on the network side (t_{M/dMU_BS}), the latency of the MFH link (t_{link_MFH}) and the processing latency of functions in the radio TRx placed on the cell side (t_{RAU_BS}). Furthermore, the latency of the MFH link (t_{link_MFH}) consists of the processing latency of the MFH TRx placed on the network side (t_{TRx_MFH}), the propagation latency of the MFH link (t_{medium_MFH}) and the processing latency of functions in the MFH TRx placed on the cell side (t_{TRx_MFH}). In the current mobile network architecture, the core equipment is managed at a remote site from the base station. Thus, there has been a debate over the necessity to also take into account the processing latency of nodes other than TRx in the BS, the latency of the MBH link (t_{link_MBH}), etc. for the RAN link. The latency of the MBH link (t_{link_MBH}) can be further divided into the processing latency of the MBH

TRx placed in the MNN (t_{TRx_MBH}), the propagation latency of the MBH link (t_{medium_MBH}) and the processing latency of the MBH TRx placed in the BS (t_{TRx_MBH}). Note that the definition for the user plane latency is a subject of future study according to the note in Section 13.3 in [12].

For instance, if 1ms is required for E2E latency, the latency is equivalent to the transmission distance of 100km (round trip) based on the optical effective distance conversion. The physical latency due to distance (t_{medium_radio}, t_{medium_MFH}, t_{medium_MBH}) is generally physical amount determined in proportion to the propagation distance if the transmission medium (refractive index) is determined. Unless the routing path of the transmission medium constituting the MFH and MBH in the RAN is shortened or the transmission medium itself is improved or innovated, the latency cannot be reduced. Therefore it is necessary to appropriately deploy and place the devices in the RAN. Therefore after deducting the processing latency due to factors other than distance including the time necessary for flaming, multi-access, or protocol conversion process (t_{TRx_MS}, t_{RAU_BS}, t_{M/dMU_BS}, $2*t_{TRx\_MFH}$, $2*t_{TRx\_MBH}$) from the latency requirement for future mobile network, the derived value shall be converted to an effective transmission distance allocated to the RAN. Then the equipment in the RAN needs to be installed and placed, taking into account the installation conditions at the applicable area (e.g., geological and land-right restrictions, nature or heritage conservation restrictions, landscape restrictions, securing extra fiber length). For example, as processing latency due to non-distance factors, the processing latency at the MS (t_{TRx_MS}) and the BS ($t_{RAU\_BS} + t_{M/dMU\_BS}$) are assumed to be about 1.5 ms respectively according to Annex B.2 in [13]. This assumption does not meet the requirement of 1ms latency described above for future mobile applications, so some improvements need to be made. Based on the above, the issue is how processing latency due to factors other than distance can be reduced to cover a wider area with one RAN system. On the contrary, if the improvement of processing latency due to non-distance factors cannot be expected, the latency due to physical distance has to be reduced. When the latency allocated to physical latency is reduced, the area each RAN can cover gets small, requiring a large number of RAN systems to be deployed to secure the service area equivalent to (or greater than) the conventional. In that case, it is necessary to consider a core network architecture that can efficiently connect the nodes in the RAN.

4.6 Ultra energy (electric power) saving

4.6.1 Outline

In the future mobile network, there are concerns about increasing power consumption as a result of increased transmission rate and the number of devices in the Mobile Backhaul and Fronthaul. In light of the growing importance of energy issues such as global warming, development of new technologies is expected to achieve at least the level of 4G or a target of efficiency at one-tenth of the current rate. To do that, it is required to study technologies including equipment with high energy efficiency, active system control according to traffic fluctuation and a new Mobile Fronthaul transmission method in building a system or network.

4.6.2 Future scenario

In order to accommodate traffic expected to expand 1000 times, it is necessary to increase the number of network devices including packet switch and base station equipment. Especially, it is expected that more and more small cells and base stations using C-RAN configuration will be deployed with an aim to provide faster network with wider bandwidth and area expansion, leading to a sharp increase of the number of devices that constitute the Mobile Backhaul/Fronthaul. Thus, there is a concern about increased power consumption.

4.6.3 Technical issues of the current network

4.6.3.1 Mobile Backhaul

There are two major issues of power saving for the Mobile Backhaul.

As a result of faster data rates over radio and increased number of accommodations, the following issues exist between high-level concentrator SW (GW) and BBU:

- Increase in power consumption for optical transmission equipment due to faster optical transceiver and electric processing circuit

- Increase in wasted power consumption due to traffic differences by time of day as a result of expanded concentrator capacity

Communication capacity required for Mobile Backhaul

See 4.2.3.2.

Power consumption of optical transmission equipment with ultrahigh capacity

<Power consumption of optical transceiver>

The current product level of optical transceiver is as shown in Table.4.6.3.1-1(Reference: [14], [15], [16], [17]). Each type of transceiver listed in the table supports transmission distance of 40km.

Table.4.6.3.1-1: Optical transceiver types and power consumption

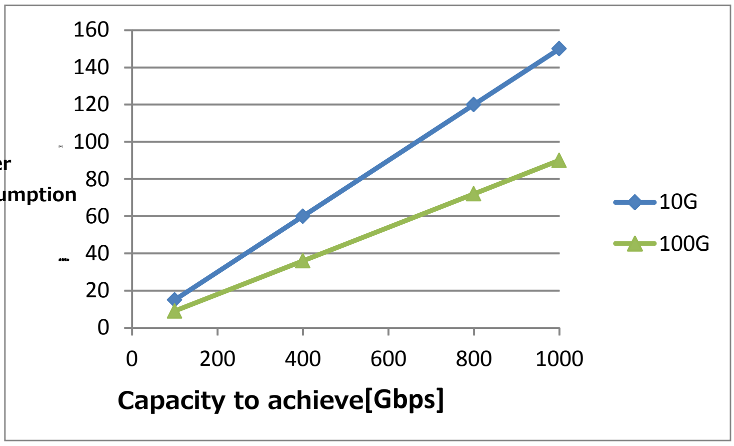
Transmission rate	Standard	Power consumption
Up to 1 Gbps	1000BASE-LH	≦1 W
Up to10 Gbps	10GBASE-ER	≦1.5 W
Up to100 Gbps	100GBASE-ER4	≦9 W
	Digital coherent	≦20 W (DSPonly)

The power consumption of the optical transceiver part in the transmission equipment can be calculated as follows:

Power consumption = (Capacity to achieve) / (Transmission capacity of transceiver unit) * (Power consumption of transceiver unit)

The calculation results are as shown in Figure.4.6.3.1-1. For instance, to achieve 1Tbps with less than 150W and about 100,000 macro cells and also provide redundant configuration, it would be 150W * 100,000 * 2 = 30MW.

For the Backhaul, there is a concern about increase in the number of transponders due to traffic expansion even in the case where wavelength multiplexing is applied. Therefore, fast, high-capacity and optical network configurations also need to be studied.

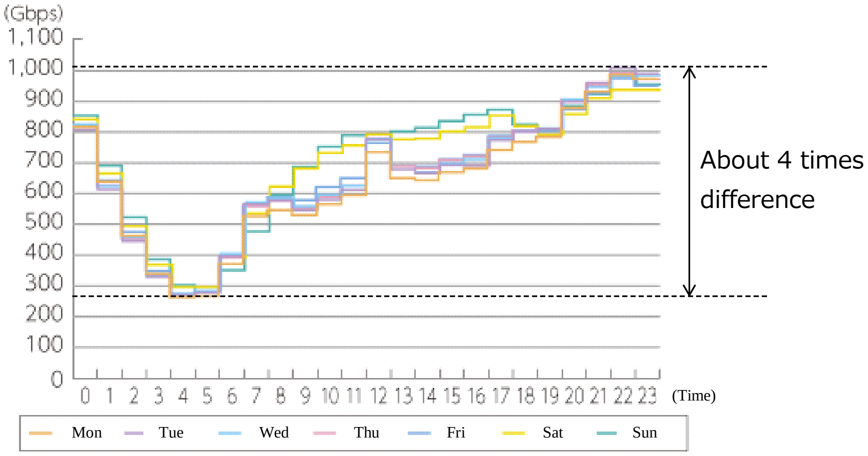


<Power consumption of electrical processing circuit (interface process)>

In addition, the power consumption of interface processing part of the existing switch equipment is about 30W per 10G-1 port. So the power consumption for the interface processing part to achieve 1Tbps is 3000W, which is 20 times greater than optical transceiver. And the consumption for the entire network is 600MW. Therefore, integration of electrical processing circuits (40G, 100G) is necessary to reduce the power consumption.

Wasted power consumption due to traffic fluctuations

Figure.4.6.3.1-2[18] shows fluctuations of mobile communication traffic by time of day. Actual traffic greatly varies depending on the hour of day, with about 4 times difference between the max and minimum according to the current statistics. Therefore, if operating at the max transmission rate all the time, power ends up being wastefully consumed. By applying variable control (drive control on a channel basis) according to traffic capacity, power consumption can be reduced. For instance, if a 40Gbps transceiver is configured, drive control is applied to 1ch to 25ch with a step of 40Gbps.



Source: Ministry of Internal Affairs and Communications, White paper on telecommunications for 2014

Figure.4.6.3.1-2: Fluctuations of mobile communication traffic by time of day

4.6.3.2 Mobile Fronthaul

Figure.4.6.3.2-1 shows the configuration of Mobile Fronthaul. The major power saving issues in the Mobile Fronthaul are as follows:

- The connection between the BBU and RRH complies with the CPRI standard and always uses a fixed rate regardless of actual traffic volume.

- Deployment of small cells (increase of the number of devices) increases the total power consumption.

- Faster optical transceivers, electrical processing circuits, etc. between the BBU and RRH due to higher data rate over radio increases power consumption.

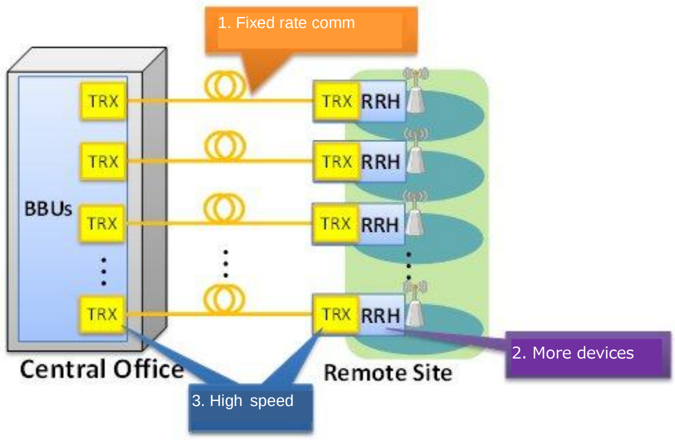


Figure.4.6.3.2-1: Mobile Fronthaul configuration and power saving issue

Power consumption due to fixed rate communication

As is the case in the Mobile Backhaul, mobile communication traffic fluctuations by time of day is also an issue in the Mobile Fronthaul. Especially, traffic fluctuations between cells are greater, which is likely to become more remarkable with small cell deployment. Therefore, the current standard and system design that use a fixed rate for communication causes wasted power consumption during the hours with light traffic.

Increase in total power consumption due to increased devices

For the future mobile network, small cell deployment is being considered to cope with further increase in traffic. This causes increased cells (i.e., increase in the number network devices that constitute a cell), which raises a concern about increase in total power consumption. Then, the impact of small cell deployment on the total power consumption for the Mobile Fronthaul has been estimated as follows.

Table.4.6.3.2-1 shows the estimate assumption. It was assumed that there are 100,000 macro cell sites with 6 sectors for the current network. For the future network, it was assumed that in addition to the current macro cells small cells are superimposed and there are 1 million 1-sector small cells. The equipment power consumption used for the estimate was determined in reference to the [14] document. In addition, two types of small cell transmission rate (1Gbps and 10Gbps) were examined. At that time, the power consumption of 10Gbps was calculated as 1.5 times of that of 1Gbps.

Table.4.6.3.2-1: Estimate conditions

	Current	Future
Cell config	MBH (Macro cell)	MBH (Macro cell) + MFH (Small cell)
# of cells	100,000	100,000 (Macro) + 1 million (Small)
# of sectors/cell	6 (Macro)	6 (Macro) 1 (Small)
Equipment power consumption	Macro: 4.5 KW (6 port BDE + 6 port BRE)	Macro: 4.5 KW Small: 1.2 KW (6 port BDE), 0.1 KW (1 port LRE)
Transmission rate	Macro: 1 Gbps	Macro: 1 Gbps Small: 1 Gbps or 10 Gbps

The power consumption for the current network ($P_{current}$) and the power consumption for the future mobile network (P_{future}) are calculated as follows. Where, N_{cell} is the number of cells, N_{sector} is the number of sectors per cell, P_{equip} is power consumption of equipment, and N_{port} is the number of ports on the equipment.

$$\begin{cases} P_{current} = N_{cell}(macro) * N_{sector}(macro) * \left(\dfrac{P_{equip}(BDE)}{N_{port}(BDE)} + \dfrac{P_{equip}(BRE)}{N_{port}(BRE)}\right) \\ P_{future} = P_{current} + N_{cell}(small) * N_{sector}(small) * \left(\dfrac{P_{equip}(BDE)}{N_{port}(BDE)} + \dfrac{P_{equip}(LRE)}{N_{port}(LRE)}\right)(* 1.5) \end{cases}$$

As a result of the calculation, the total power consumption for the Mobile Fronthaul is up to 900MW for the future network, twice that of the current network that is 450MW. Note that the power-generating capacity at a nuclear power station is about 500MW per plant.

Increase in power consumption of equipment due to higher data rate

The major factors for the power consumption for the Mobile Fronthaul include the optical transceiver part, the electrical processing circuit part and RF amplifier. As a result of higher data rate over radio, these devices need to be faster, which leads to increased power consumption.

The power consumption of optical transceiver is as shown in Table.4.6.3.1-1. For the optical transceiver, enough power saving is implemented on the level up to 10Gbps and therefore the impact is small. However, on the level of 100Gbps, power consumption increases sharply and the impact cannot be ignored considering the power consumption with small cell deployment. It is required to consider the impact of higher data rate on power increase also for the electrical processing circuit and RF amplifier. High frequency bands may be added in the future network, so the impact due to added frequency bands also needs to be examined.

4.6.4 Requirements for the future network

It is crucial to save power to curb the increase in power consumption for the entire network. In order to achieve the one-tenth efficiency, it is necessary to study technologies including equipment with high energy efficiency, active system control according to traffic fluctuations and new Mobile Fronthaul transmission methods in building a system or network.

For the Mobile Backhaul, the terminal speed will be 10Gbps, which requires a transmission capacity at least 100 times greater than the current one even when the statistical multiplexing effect is taken into account. If optical transceivers with 100Gbps-1Tbsp capability are implemented with the existing technologies, the power consumption will be 8 times greater than the current. Therefore, it is necessary to develop devices that achieve low power consumption using such techniques as integration. However, it is difficult to achieve the efficiency of one-tenth power reduction with just integration. So drive control according to traffic volume is required for transmission equipment (optical transceiver, interface circuit, etc).

For the Mobile Fronthaul, the power consumption is expected to double the current level due to small cell deployment. Therefore, to achieve the one-tenth efficiency for the whole communication system, power saving at one-twentieth of that of the current equipment is required. To do that, it is necessary to implement a configuration that can drastically control power consumption according to actual traffic volume or the number of connected UEs (when they are at a low level). In addition, the power consumption of optical transceiver soars when the transmission rate goes over 10Gbps. So in the future mobile network where the transmission rate over radio is higher at 10Gbps, a new transmission method, instead of CPRI, etc, is required to achieve the same level of reduction for the optical transmission rate as that of the radio transmission rate.

4.7 Ultra large-scale disaster/congestion/failure resilience

4.7.1 Outline

In the future mobile network, increase in traffic to be accommodated and expansion of accommodated terminals including IoT are expected and the importance as social infrastructure will be greater than ever. Therefore, the network needs to be more robust than ever against congestion and fault in the event of disaster. The existing network can only cope with congested traffic during disaster by temporarily managing network resources and therefore does not ensure sufficient network resources necessary during an emergency. It is necessary to take fundamental actions for the future network such as allowing for prompt enhancement.

4.7.2 Future scenario

Disaster resilience can be considered from congestion and failure resilience perspectives.

For congestion resilience, the traffic during the Great East Japan earthquake in 2011 was 50 to 60 times higher than normal with regard to voice communication via cellar phones. Concentrated service requests from base stations that cover a wide area causes resource shortage and congestion. Telecommunication carriers then implemented 80 to 95% traffic control [19]. It was extremely difficult for users to establish a voice communication. According to a survey result, people made a call about 12 times on average until they succeed and about 14 times on average until they give up in disaster-stricken areas[20].

For failure resilience, with regard to unexpected communication process disruption due to damage of network functions, the earthquake and tsunami caused collapse, flooding and washout of building facility, split and damage of undergrad cables, duct lines, etc., damage of utility poles, damage of aerial cables and collapse and washout of mobile base stations, which resulted in severe damage [19].

Although no specific numerical target levels are shared as a future scenario in terms of disaster resilience, the government and users both demand further enhancement of telecommunication networks based on the lessons learned from the Great East Japan earthquake described above.

4.7.3 Technical issues in the current network

4.7.3.1 Core network

The congestion issue is considered as follows:

Existing network

In the event of disaster (or public events like year-end and new-year events), mobile communication carriers generally secure necessary resources to maintain network functions and provide important communications (priority call, emergency call, etc.) by scarifying other less important communications. The network resource here is assumed to be the RACH capacity and signal-processing capability of network nodes.

Specifically, considering the RACH capacity as well as the fact that network node processing capacity is also used to reject signals, an “access control mechanism” has been mainly applied which prevents the terminal from originating calls in the first place. This is initiated at the terminal by the base station adding necessary information to the broadcast information for the terminal.

Various access control mechanisms have been examined according to a variety of use cases. They are divided into two major types; Access mechanism on a terminal basis and access mechanism for each call type. For the existing mechanisms, the former approach includes the mechanism that restricts all terminals in sequence and the mechanism that restricts only MTC terminals. The latter approach includes the mechanism that restricts only voice calls, the mechanism that restricts non-voice calls (i.e., only voice calls can be made) and the mechanism that only allows for specific originating calls on an application basis (this assumes a use case that only allows for Disaster Message Board and Disaster Voice Messaging Service)

Issue when continuing to rely on existing network functions in the future

The existing network functions only manage available network resources even during a large-scale disaster and cannot provide a fundamental solution that increases resources to cope with processing congestion. Unless some new functions are implemented in the future, user communications continue to be sacrificed.

If, however, network processing resources can be added during a large-scale disaster, more traffic can be connected. In the proof test for virtualization technology assuming a large-scale disaster as part of the “Research and development of dynamic control technology for mobile communication networks in times of large-scale disasters” [21] project commissioned by the Ministry of Internal Affairs and Communications, it was confirmed that the call connectivity rate improves from 1 in 20 times to 1 in 4 times by increasing the EPC resources 5 times within 30 minutes (Note: The test was conducted with a configuration that does not consider the impact of repeated calls).

Furthermore, it is expected that repeated calls will be eliminated and congestion will be settled soon by adding resources within a short time. Traffic begins to increase due to users’ safety confirmation about 5 minutes after disaster strikes. So a swift enhancement of network processing resources is required to prevent repeated calls.

As described above, the future challenge is to swiftly increase network processing resources within about 5 minutes. To achieve that, a procedure that further affects congestion nodes such as reattachment should be avoided.

The failure issue is considered as follow:

Existing network

Call state management and call processing are implemented in a single physical node in an inseparable way. Therefore, if the node fails, all the associated calls are disconnected.

Issue when continuing to rely on existing network functions in the future

Call state management and call processing should be implemented in physically separate nodes. By specially improving the failure resilience of the call state management node, the failure resilience of the network as a whole may be improved.

4.7.3.2 Mobile Backhaul/Fronthaul

It is necessary to build a network with high reliability that can secure communication lines, flexibly and dynamically responding to Backhaul node change and topology change in such events as base station outage.

4.7.4 Requirements for the future network

The system needs to smoothly reallocate resources as required among multiple nodes connected to WAN within 5-30 minutes without configuration change in neighboring nodes and user service disruption.

The system shall be able to perform call state management and call processing in different nodes.

4.8 Diversified types of terminal/traffic/operator

4.8.1 Outline

The future mobile network is expected to further permeate society than the conventional mobile network. Not only the conventional terminals like feature phones and smartphones that assume usage by people, but also a number of terminals assumed to be embedded in devices are expected to emerge, creating a variety of equipment. As a result, the traffic pattern may also be different. The end point of communication will be machines instead of people, and the number of terminals for M2M communication is expected to increase exponentially. Furthermore, the information exchange in M2M is expected to have a traffic pattern that differs significantly from the server-client data exchange in the conventional IP network. In addition, a variety of operators are expected to operate mobile networks. Thus, new challenges for the network are generated by diversification of terminal requirements, traffic patterns and mobile network operators.

4.8.2 Future scenario

For the traffic for conventional mobile terminals used by people, as high-definition terminals with a large screen and filming function become common, more and more various video contents are used as a medium and the OTT service is expanded, which increases video traffic. Furthermore, as M2M terminals get popular, the traffic of M2M terminals is expected to increase sharply.

In general, a connection topology like sensor network is assumed for M2M terminals, with possible use cases such as management, monitoring and remote control of production facilities, lifelines, building and housing, vending machines and heavy equipment. The device mobility is relatively low and both the occurrence frequency and data volume of each traffic tend to be small, but the number of terminal connections per unit area becomes very large. From 2020 and onward, along with the advancement toward IoT and IoE incorporating M2M, the terminals and applications to be accommodated will further diversify. It is also expected that there will be many new players in the mobile service industry as MVNO.

4.8.3 Technical issues of the current network

4.8.3.1 Core network

Accommodation of terminals and traffic with various requirements

For M2M terminals, it is expected users operate devices for a long time without being conscious of battery charge and replacement in the use cases like smart meter. There is a requirement of 10-year battery life with only built-in power supply, operating the terminal in the sleep mode most of the time. PSM is adopted in 3GPP ([22], [23]), but such M2M terminals cannot be called from the network. So the issue is to maintain long battery life while supporting mode change so that the terminals can be called from the network when necessary (e.g. emergency events). Such M2M terminals are assumed in use cases with low mobility. In such cases as IoT where a variety of things communicate each other, it is expected that communication modules will be attached to wearable terminals, pets and distributed cargo and built into wheeled vehicles. In addition to the M2M device requirement stated above, additional requirements including support for high mobility need to be met, which requires optimization for each use case.

In order to efficiently accommodate numerous M2M terminals, it is considered to be necessary to implement policy control, addressing, etc. on a group basis for M2M terminals, which are different from normal mobile terminals. Relevant studies are being conducted at 3GPP [24].

Regarding the traffic pattern of M2M terminals, C-plane traffic is relatively higher than U-plane traffic. It is inefficient to accommodate them in the existing core network that is designed to accommodate the normal mobile terminal traffic. Furthermore, the usage fee operators can charge is very low for M2M terminals compared with normal mobile terminals because their data capacity per traffic is small, which may put pressure on operators' profit. Also, for the normal mobile terminals, the traffic pattern may greatly change due to various video contents used as a medium and new services/applications using tactile communication, AR, etc. Thus, there should be another network configuration that is fundamentally different in terms of design concept, which then raises an issue of huge capital investment.

Flexibility improvement for NW function release

Along with diversification of applications including M2M/IoT, the number of MVNOs is expected to increase to further improve the convenience of users. The network has to be flexible to release sufficient resources for necessary core network functions to MVNOs. In meeting a number of release requirements, there will be a various function requirements for each MVNO, which requires scalability to meet new requirements.

4.8.4 Requirements for the future network

While high-volume traffic like video is increasing, we need to cope with M2M/IoT traffic and MVNOs increase. It is necessary to provide required functions according to the characteristic of terminal/traffic/operator as well as a network virtualization platform where network resources can be logically configured. The LINP (Logically Isolated Network Partitions) concept to virtualize network resources and logically configure a virtual network according to various services is defined in an ITU-T recommendation [25], providing a valid framework to resolve each issue described above.

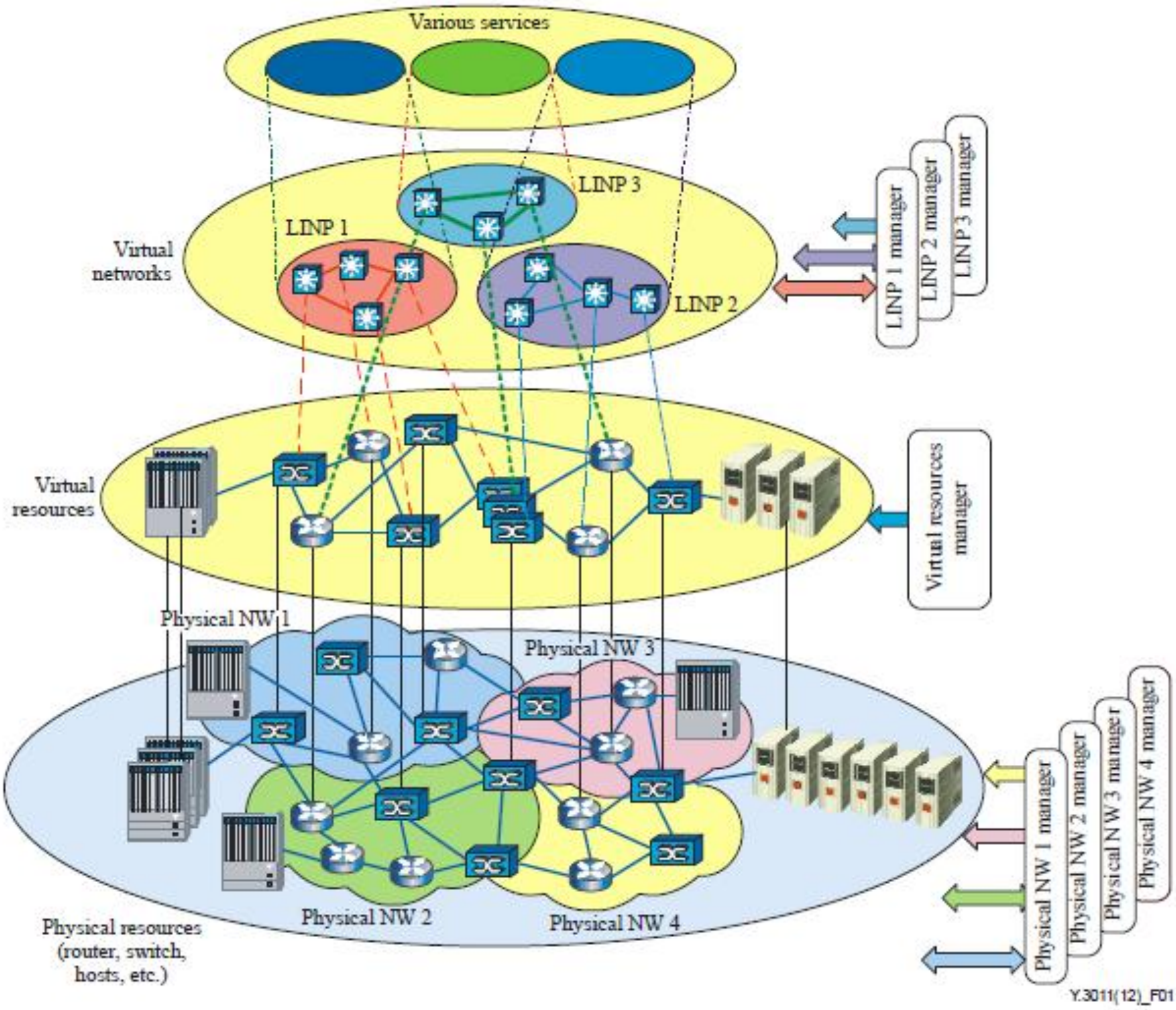


Figure.4.8.4-1: Conceptual architecture for network virtualization

(Source: [25])

4.9 Interworking with other RATs

4.9.1 Outline

Since radio frequency resources are limited and MNOs will have to bear more costs due to an increase in the number of cells per unit area, it is foreseen that the future mobile network will become a multi-RAT environment where the existing RAT cells and wireless LAN networks will be integrated and used. Accordingly, in addition to the integration and management of various RATs for higher efficiency, the heterogeneous network of RATs with various characteristics will need to assist in optimal cell selection for better quality of user experience in the network. Additionally, since all RATs may not be accommodated in a single network, communication interworking through the internet will be another important issue.

4.9.2 Future scenario

In order to accommodate 1,000 times more volume of traffic than the present, the frequency usage efficiency (bps/Hz/cell), frequency bandwidth (Hz) and number of cells per unit area (cell/km2) will need to be decupled. As of the year 2014, approx. 610MHz of frequency bandwidth is allocated to mobile networks and others and approx. 350MHz is allocated to wireless LAN networks, which is 960MHz allocation in total. According to [26], the Ministry of Internal Affairs and Communications has stated that they will aim in the 2020’s to allocate 2700MHz of frequency bandwidth to wireless LAN networks and others out of 2900MHz to be used for mobile communications in 6 GHz and lower frequency bands (see Figure. 4.9.2-1). Accordingly, frequencies available to wireless LAN and others can be expected to be nearly tripled. If more frequency bandwidth is needed, 6 GHz and higher frequency bands will be expected to be used. Therefore, the frequency bandwidth allocated to a single RAT will not be enough to secure the bandwidth required for the future mobile networks. The bandwidth for wireless LAN will need to be used together with new RATs available in 6GHz and higher frequency bands in an integrated manner.

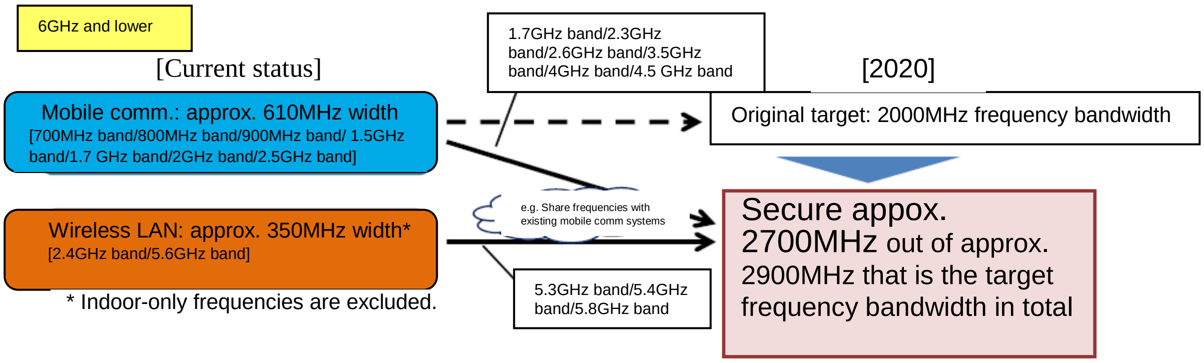


Figure.4.9.2-1 Frequency allocation status and plans in Japan

(Reference: [26])

Regarding the number of cells per unit area, mobile operators will have cost issues because an increase in the number of cells due to Small Cell will cause an increase in the CAPEX/OPEX related to MBH/MFH and BTS. Since it is not realistic in terms of cost to update all existing cells for the future mobile networks, a heterogeneous network will need to be built in parallel with the utilization of the existing RATs (e.g. LTE) and wireless LAN cells. This will need multi-RAT interworking.

4.9.3 Technical issues in the current network

4.9.3.1 Core networks

Even at present, data offloading to wireless LAN is actively encouraged in urban and other areas with tight traffic. In those areas, optimal RAT selection and RAT interworking (e.g. seamless connection between wireless LAN and mobile) are already offered. As shown in Figure.4.9.3.1-1, the details of interworking between wireless LAN and mobile vary depending on the layer, from tight interworking between the networks to loose interworking with a weak impact on the networks. Various interworking technologies standardized in 3GPP and others have been practically applied.

As shown in Table.4.9.3.1-1, there are two main types of cells to be targeted for multi-RAT interworking: cells in cellular technology and cells in IEEE 802.11 wireless LAN technology. Depending on the development of each technology and expansion of frequency band, the types of cells to be interworked in the future mobile network will be increased. In addition to the RAT mentioned here, sensor network system RAT may be integrated in the future in order to accommodate IoT terminals for example. Basically, the existing interworking technologies will be applicable to the future mobile networks, however, in Multi-RAT environment in the future mobile networks, the diversity of the attributes of the cells to be interworked will be increased than current ones, which is a characteristic change. Since cells with high frequency band such as millimeter wave will be used, cells that are smaller/narrower and faster than the current ones will be integrated in the heterogeneous networks. Also, the operator of each RAT is not always a single one, hence the quality of backhaul lines and provided services may be different depending on the cells. Moreover, in the future mobile networks, new requirements such as ultra-low latency will be defined, however, it may not be realized in all the cells, hence cells that meet the requirements and that cannot meet the requirements may be mixed. Due to the abovementioned increase in the diversity of RATs, new functions will be required for the network architecture. Specifically, provision of integrated management function of Multi-RAT and support function of optimal RAT selection are considered, for examples.

What has been described above is mainly about RAT interworking in a mobile network. However, there will be more requests about communications outside the mobile network, that is, with terminals/servers connected to the internet, too. In order to improve the quality, that is, reduce the communication latency and increase the communication capacity while tracking the mobility of terminals/servers, e.g. seamless move, is ensured, communication interworking (including connections between mobile networks and the internet) will be required. It is important to resolve the following issues for this interworking.

- Highly reliable seamless handover to remove the failure range and communication latency that are increased by connecting to the internet only in a specific location
- Seamless access through the communication system on the second and third layers of the OSI7 hierarchy model (for IoT terminals and others that are different from the existing mobile terminals)
- Aggregation of various types of RATs: Apply link aggregation (e.g. Carrier Aggregation, Dual Connectivity in 3GPP (see [27])) and multipath communication (e.g. MPTCP) to various types of RATs and increase the communication speed.

Additionally, RAT selection changes depending on the traffic changes in the network under communication, RAT selection depending on the application, etc. will be issues to be resolved for mobile communication interworking through the internet as well as in mobile networks.

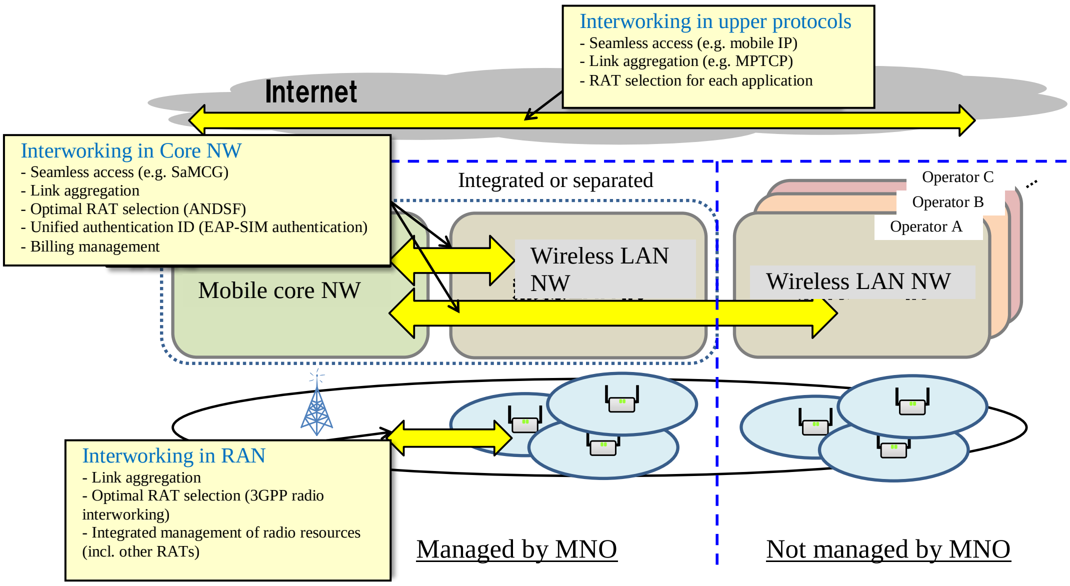


Figure.4.9.3.1-1 Interworking between Mobile and Wireless LAN

Table.4.9.3.1-1 Main targets for multi-RAT interworking

Category		RAT	Frequency band	Cell radius	Rate
Cellular	Licensed band	LTE/LTE-A	< 3GHz	Dozens of meters - dozens of kilometers	< 3Gbps
			3.5GHz	Dozens of meters – several hundred meters	
		5G	< 6GHz,	T.B.D.	Up to 10Gbps
			> 6GHz (e.g. millimeter waves)	T.B.D.	
	Unlicensed band	LTE-U(LAA)	Possibly 5GHz band	Approx. dozens of meters – 100 meters	T.B.D.
Wireless LAN		IEEE 802.11 a/b/g/n/ac (Wi-Fi)	2.4GHz, 5GHz,	Approx. dozens of meters – 100 meters	A few Mbps - 6.9 Gbps
		IEEE 802.11ad (WiGig)	60GHz	Approx. 10m	A few Mbps - 6.9 Gbps
		IEEE 802.11ax	2.4GHz, 5GHz	T.B.D.	T.B.D.
		IEEE 802.11ah	<1GHz	T.B.D.	T.B.D.

4.9.4 Requirements for the future network

4.9.4.1 Integrated management of the Multi-RAT

Mobile operators will need to manage various RATs of cells. In order to efficiently manage those cells and make full use of resources, a function will need to be provided to manage multiple RATs in an integrated manner. There are two main types of integrated management: (a) Inter-RAT interface conversion and (b) Inter-RAT cooperative transmission/load balancing (see Figure. 4.9.4.1-1).

(a) Inter-RAT interface conversion: It is preferred in terms of simplified core network facility management to be able to accommodate not only the 5G RAT but also the existing RATs (e.g. IMT-2000) and other RATs (e.g. wireless LAN) in an integrated interface to the mobile core network. Additionally, this interface is expected to have flexible scalability for new RATs to be provided in the future.

(b) Inter-RAT cooperative transmission/load balancing: Inter-RAT cooperative transmission (e.g. improvement of wireless LANs' mutual interference by control on the mobile side), MAC layer-level inter-RAT cooperative scheduling, etc. in the overlapping coverage and load balancing among RATs can be considered to secure more accommodation capacity than when RATs are individually deployed. Architecture with consideration of BTS-to-BTS connections will be required, depending on how the cooperation should be.

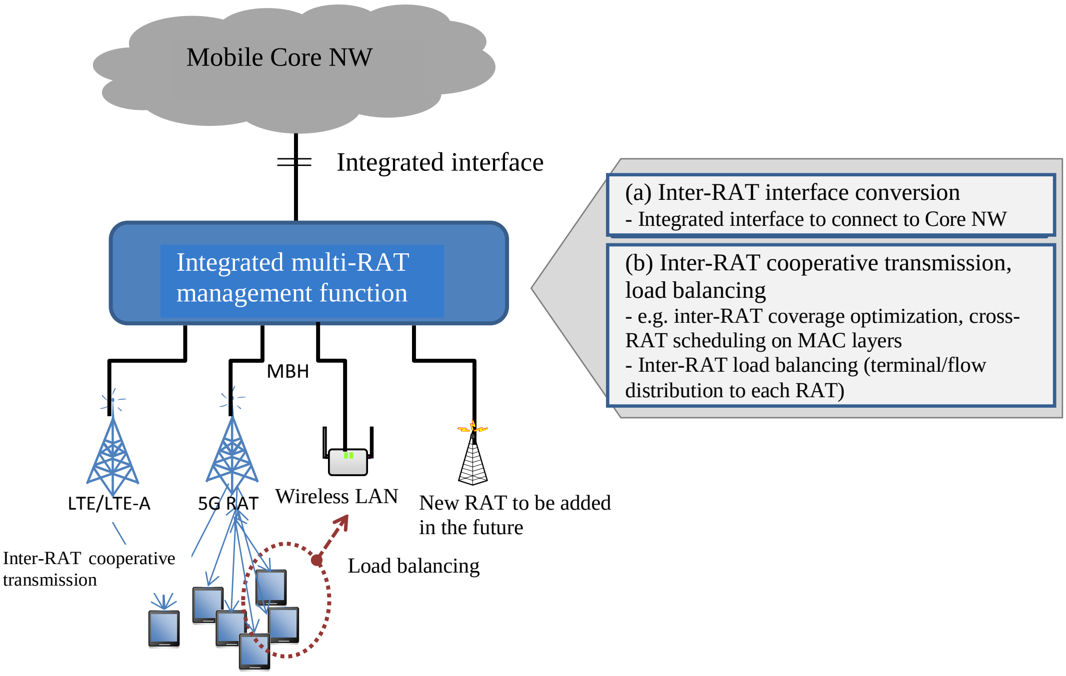


Figure.4.9.4.1-1 Integrated multi-RAT management

4.9.4.2 Support for optimal RAT selection

Networks need to provide a function to support the optimal use of various RATs to maximize the quality of user experience in a heterogeneous network environment where those RATs are used based on the situation. It has been enough to support the selection between wireless LAN and mobile, and since wireless LAN is basically faster and cheaper, prioritizing wireless LAN has been satisfactory in many cases. However, since Small Cell will increase the number of handover occurrences and there will be more cell attributes in the future mobile networks, it will be mandatory to make an immediate and optimal selection of a cell to be used depending on the characteristics of the application. It would be effective for terminal-driven or network-driven RAT selection to collect the information on the radio quality, usage rate of radio resources, backhaul bandwidth and quality, offered services and others on the network side and provide terminals with information to be used for RAT selection or instruct terminals to select a RAT. The existing technology also provides each RAT with information and a NW selection policy, e.g. beacon signals and ANQP (see [28]) are used to obtain network information in wireless LAN and ANDSF as a 3GPP technology (see [29]) is used to distribute a network selection policy. Multi-RAT would be efficiently used and highly scalable in the future networks if information is provided and RAT selection is controlled in the networks in a method and standard common to RATs (see Figure. 4.9.4.2-1). Standardization across RATs will be important.

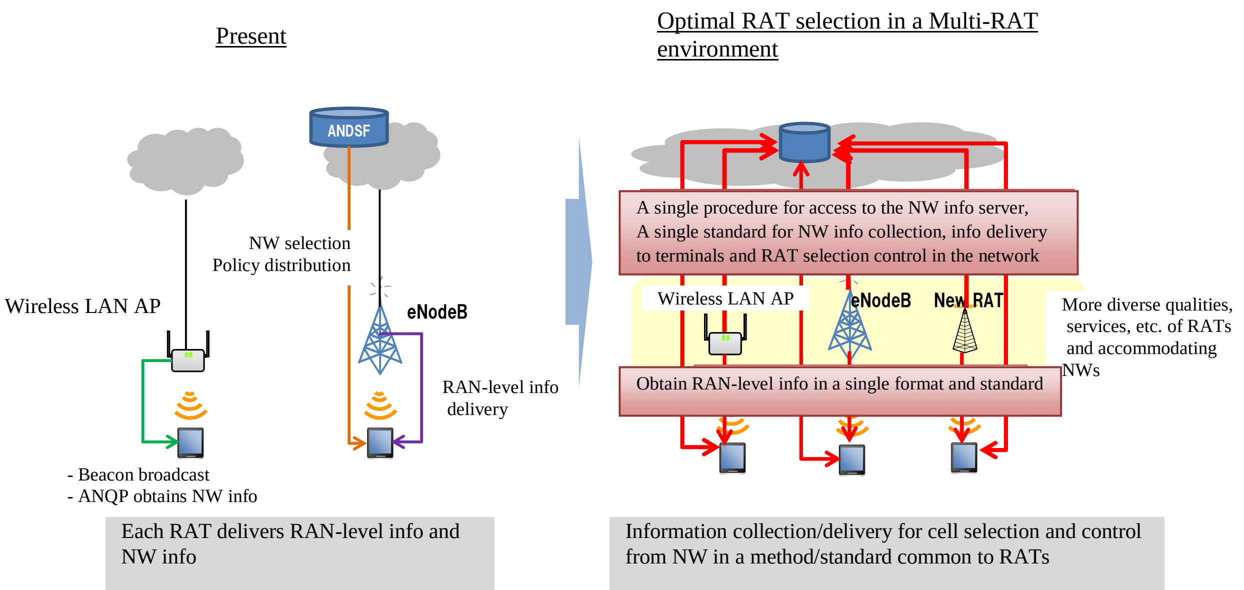


Figure.4.9.4.2-1 Support for selection among multiple RATs

4.9.4.3 Communication interworking through the internet

In this section, requirements for communication interworking between RATs of mobile network and the internet regarding Highly reliable seamless handover and Aggregation of various types of RATs in order to improve the quality in terms of lower communication latency and increase of communication capacity for applications while seamless mobility on the networks including the internet is ensured.

- Highly reliable seamless handover: It will resolve the issue of resistance against failures and eliminate the issue of increase in communication latency that may occur because access points with the internet are limited to specific locations. As for the move to the other RAT within a mobile network of a terminal, seamless communication is possible thanks to the interworking between LMA on the network side and MAG on the RAT side. However, for a connection with the internet, if any failure occurs at LMA where the terminal is connected in the upper stream or at a location close to such a LMA, the connection already established with the internet will be lost. Also, if a terminal moves to a RAT that belongs to a different LMA or if the user on the other end of the communication moves to a network away from the relevant LMA, latency will be increased. Seamless handover function by interworking among networks and multiple RATs including some changes to LMA that will solve these issues will be required.

- Aggregation of various types of RATs: In addition to interworking within a mobile network such as link aggregation and multiple-path communications using Multi-RAT, improvement in communication quality using multiple paths including the internet lines will be required. Similarly to the abovementioned notification of quality on the backhaul side from the network, mechanism such as notification of quality of the internet access point from the network side and notification of quality from the terminal side can be considered.

4.10 Security

4.10.1 Outline

Security will be positioned in more importantly in the future networks. For building a network, the way of thinking “security by design,” which considers security from the stage of design, will be important. As a point greatly different from the networks so far, virtualization of networks and computer resources shall be considered. Though some of the security issues are expected to be resolved by such virtualization, new security issues may occur. In this section, future scenario and issues regarding security are suggested.

4.10.2 Future scenario

In the future, mobile networks will be a part of important social platform more than now, and life of people will greatly depend on them. As the degree of dependency on such a platform is increased, cyber attack against the platform will be more complex and sophisticated. Also, to aim higher availability, efficiency, and flexibility of networks and computer resources, network/hardware virtualization technologies such as SDN and network function virtualization technologies such as NFV will be prerequisites for mobile networks. For introducing SDN/NFV, following security issues shall be considered.

4.10.3 Technical issues of the current network

4.10.3.1 Security issues regarding network/hardware virtualization

For network/hardware virtualization technologies, flexible management of networks and computer resources can be realized by newly introducing control layer since handling networks and computers abstractly is possible. By this, it is expected that security issues so far will be resolved, however, it is necessary to consider new threats also at the same time. Namely, as far as the newly introduced control layer works normally, it will contribute to security enhancement, however, in case the control layer is captured by an attacker, it may lead to a ruinous damage. Therefore, it is important to ensure the security of SDN controller, orchestrator in NFV, and hypervisor or VMM for a virtual machine.

4.10.3.2 Security issues under the environment of the multi-tenant operator administrator

An NFV environment needs general-purpose NFVI providers that are assumed to be a combination of IaaS, NaaS and PaaS providers. One example is an MVNO that rents an NMO’s infrastructure to offer services. MVNO will develop its service form where it only provides networks to various combinations such as interworking with the upper-level services. Under such an environment, the assumption will be greatly different from that of the current networks where services have been provided upon vertically integrating the network infrastructure services. This means that in many cases, network operators/administrators will not be the same as service operators/administrators because network and services will be separately provided. When there are two or more administrators, mutual authentication and delegation of authority need to be smooth and safe among administrators.

4.10.3.3 Security issues due to complex architecture

It would be difficult for operating personnel to create a drawing of and visually check physical and logical configurations in a network hardware virtualized environment because they do not correspond to each other on a one-on-one basis. To resolve the situation, computer-aided operation, automated network configuration of machines, automated configuration verification of services and other technologies would be introduced. This issue could be more complicated if it is in a multi-operator/administrator environment. For example, a configuration could not be made as per expectations or it could be vulnerable to cyber attacks from malicious tenants.

4.10.4 For resolving the issues

To resolve such issues, technologies will be required to ensure security overall upon linking the security management of the account machine system, which has been performed so far. First, in order to ensure the security of computer resources, it will be necessary to be based on Secure Boot with tamper-resistant devices as a starting point of reliability. Then, using the security status as the next original point, hypervisor shall be booted securely and the chain of reliability shall be connected to VNF. Also, since it may be attacked after the activation, a technology to verify the safety periodically (attestation) will be required. To ensure the security chain using attestation, not only verification from inside the host but also remote attestation will be mandatory. Moreover, chains will be required such as ensuring security as orchestrator by security interworking among multiple hypervisors and ensuring security by interworking of multiple orchestrators. There are security issues as follows specifically:

- Chain of trust/relationship building technologies and their underlying Secure Boot and remote attestation
- Define trusted domains with the same policy attached
- Share information and build a trusting relationship between trusted domains

4.11 Network operations

4.11.1 Outline

Accompanying the advance of high speed, high capacity, and low latency of mobile networks, great innovation and new solutions will be required also for the network operations.

In the mobile communications, shift from feature phones to smart phones with high functions and high performance is progressing, and the hurdle of development of application on them has been lowered, hence the number of applications in the market is increasing. Also, expansion of MVNO business and increase in IoT and M2M communications are expected, hence as a result of them, various new functions and new services are featured rapidly, which leads to fiercer competitions of communication service provision. From now on, accompanying the advance and higher speed of radio technologies, higher functions and higher performance of terminals are expected, therefore how rapidly such new functions and new services can be provided is a key.

Since high reliability as a social infrastructure as well as high network performance will be expected, it will be mandatory to make efforts for e.g. no service downtime. It will also be important to offer a future mobile network service with high performance and reliability at a low cost.

4.11.2 Future scenario of the network management

Virtualization is getting attention in terms of networks, as one of promising technologies to build future mobile networks. Virtualized network functions will be logically and dynamically configured and activated as applications on a server. Applications and infrastructure need to support the following and others:

- Componentized/virtualized functions, and a combination of those functions
- Standardized technologies, utilization of open-standard technologies
- Simplified/automated deployment
- Operational work saved by integrated management

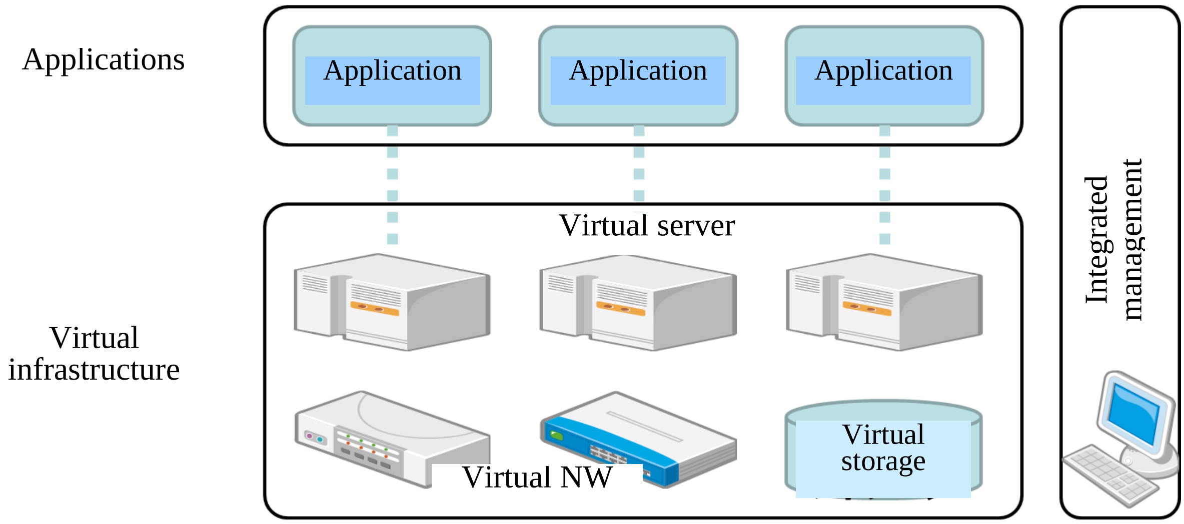


Figure.4.11.2-1 Image of a virtualized network

Introducing this network virtualization technology can be expected to produce the following effects:

- Physical construction workload as an overhead in terms of schedule can be reduced or removed.
- A testing period can be shortened because it is easier to minimize the difference between development and commercial environments
- Agile development, e.g. consecutive function addition/troubleshooting, can be expected to shorten periods.
- Resources can be dynamically and logically added, depending on how widely new services are used.
- If a new service is not popular, its resources can be reused for other services by making it smaller or discontinuing it.

The above effects are expected to contribute to the creation of an environment to help with the more prompt provision of new functions/services.

At the same time, it is expected that network virtualization will be effective for cost reduction in terms of software-enabled network functions and universal use of hardware. Also, from software-enabled network functions, automation of network operations is expected, which will be effective to reduce OPEX and to avoid human errors.

Based on the above, as for the operations of future mobile networks, issues regarding agility, no downtime, realization of new functions, cost, and automated, flexible and simple operations are assumed.

4.11.3 Issues about agility

Ensuring agility of new function/service offering

In general, when a new function or service is launched, an application is developed so that it can work on UEs (however, application development is not required for some functions/services) and equipment required for the function/service offering is procured and physical construction work is performed for the network. However, also for the applications to offer a new function/service on the network side, specific environment (infrastructures including hardware and networks) was required to run the applications in many cases, hence dependency between such applications and infrastructure was high, therefore it was difficult to independently arrange an infrastructure, which required substantial construction period, in advance. Such construction period has been blocking prompt offering of new functions and new service. Network virtualization is recently a focus of attention as a technology to enable the building of common and general-purpose infrastructure leading to a reduction in the construction period. As mentioned in other chapters of this white paper, this technology is under consideration in various standardization bodies.

No service downtime

Basically, having a redundant configuration cannot be avoided as a measure against HW failures.

When there is a HW failure in a redundant system, only its backup system is operational. Therefore, it is needed to ensure the reliability of the backup system.

A network in a virtual environment will need N distribution in the LB configuration or a scenario to automatically add new SBY when there is a failure in ACT.

This function is under study as an auto-healing function in NFV. Improvement/application of this function will need to be studied in the future.

Regarding the recovery form a failure (especially a failure due to e.g. attached burst), the current durability against burst depends on the lowest performance node of MME, S/P-GW, AAA, Diameter and other related nodes. Due to this, it takes time to make connections at a time after the failure. Flexible and dynamic CPU resource allocation with virtualization is expected to improve the recovery capability by several percent to tens of percent.

This function is under study as an auto-scaling function in NFV. Improvement/application of auto-scaling, resource equalization/replacement, etc. with this function will need to be studied in the future.

In addition, it is important to improve the quality of alarms that help to immediately identify a failure spot. It is important for core NW management to make a recovery in a shorter time and ensure the reliability after immediately identifying a failure spot.

Offering a new function e.g. with virtualization

File updates to introduce a new function to a network usually do not have an impact on commercial services (e.g. by updating several nodes per night). It is expected to automate in-service file updates, by using the NFV file update function in a virtual environment to dynamically transfer traffic from one node to another in a short time for day and night file updates. It is needed in the network to implement the NFV auto-test function and reduce the time taken to check the normality of file updates.

CORBA and other protocols as an interface to OAM cause high inter-system dependency. It is cost-consuming to implement them and they disturb the implementation of standardized OAM. It will be needed to consider the use of the industry-standard REST-IF protocol that is used in OpenStack and others.

International standardization activities that are currently ongoing at 3GPP:

1. NFV as a study item: A technical report on it is under preparation and it is studied together with ETSI NFV, TMF and OPNFV. (The architecture, use cases and procedure of each use case are the main topics.)
2. Other than NFV:

1) Work item to reduce the workload on maintenance personnel by optimizing the alarm definitions as alarm quality improvements
2) Study item to simplify the rules by re-extracting requirements from the current OAM specification as Application and Partitioning of Itf-N

4.11.4 Issues of cost

The existing centralized architecture for operational management can be considered as the main factor to increase the network management cost.

As shown in Figure.4.11.4-1, the existing operational management system is generally centralized to remotely manage the FACPS of various facilities. Since most of original information is maintained in the facilities, the operational management system collects the information through regular polling or event notification from the facilities.

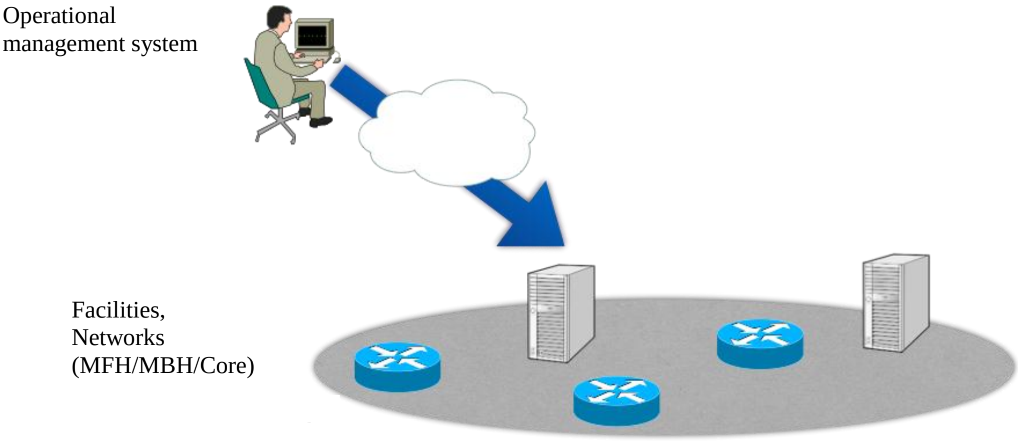


Figure.4.11.4-1 Existing centralized network management

Reduction in CAPEX for network management

- It is foreseen that it will be getting more difficult to maintain/improve the quality in the existing operational method, because the volume of operational management information has been getting larger due to more complicated and diverse network facility types and functions whereas the quality expected in network services has been getting higher. Since the operational management system may be drastically changed or expanded to maintain the quality of network services, there is a concern about an increase in the costs for the operational system.
- Factors for the CAPEX increase
  - More data to be monitored/managed (larger size of the related database and operational management system)
  - Larger and more complicated system due to a part of response to the following factors for the OPEX increase

Reduction in OPEX for network management

- It is assumed that the efforts will be made with a combination of an operational management system and a network configuration to enable flexible system modifications leading to a reduction (5GPPP's target: 20% or more) in the network operation cost in the management framework enabling prompt software deployment after HW addition/replacement.
- Factors for the OPEX increase
  - More workload for failure recovery support and more difficult verification in a testing environment, with more complicated network functions

- ➢ Decreased reliability (increased failure rate) with more general-purpose facilities
- ➢ More frequent requests for configuration modifications (MVNO, XaaS)
- ➢ Support for various types of data (M2M, IoT, Flash Crowd, Content (4K, 8K), Latency Sensitive)

Studying a new operational management architecture to help with a reduction of (cost) restrictions attached to the existing architecture, and to be more specific, the following three can be considered in relation to the above factors for the cost increase.

- Improvement in how to deploy the operational management functions (FCAPS) and their related operational data (e.g. distributed deployment)
- More sophisticated operational data analysis technologies (e.g. more scalability, failure sign detection)
- More flexibility in configuration modifications and programming

4.11.5 Flexible and simplified network operation

Flexible and immediate network operation

As network functions are more enhanced and virtualization technology is introduced, it is expected that types and functions of mobile networking facilities will be further complicated and increased. At the same time, accompanying increase of MVNOs and expansion of IoT and M2M areas, usage forms of mobile networks will be varied and service demand by users will be varied also, then it will be more difficult to respond to them promptly. As described in [30], in this network environment, it would be necessary to introduce a set of technologies to enable network resources to be directly programmed, combined, controlled and managed.

As described in [31], especially when virtualized network technology is introduced, it will be important to manage the lifecycle of NW functions as software and to optimally deploy network resources so that the service scale can be changed as soon as maintenance personnel makes a request.

Automated network operation

Operation will need to be automated because the future mobile network will be faster and more powerful and more sophisticated SLA management will be required.

For example, in ETSI NFV-ISG, [32] and [33] state that capacity adjustments, software updates and responses to detected failures need to be automated. In addition, [34] states that for in-system network management, a management system that can efficiently operate and be maintained and that can support additional services and an increase in communications, especially a system that can efficiently and effectively process management data and information and convert it to related information or knowledge for delivery to the administrator, is needed as a high-level requirement.

The above operational automation can be expected to reduce OPEX and human errors.

Standardized network protocols

For introducing network protocol due to specifications by a new standardization and others, it is difficult to support them with the existing facility, hence in addition to preparation for new protocol standards, development and introduction of supporting equipment will be issues also. As for future mobile networking, it is still under preparation for requirements by each standardization body, and necessity of needed network protocol has not been clarified, however, in IETF for example, tunneling protocol in overlay network using network virtualization is under study (Reference: [35], [36]). Also for accommodation of networks with different management policies using virtualization technology, it will be one of the requirements for future mobile networking, hence use of such protocols will be effective.

5 Survey of component technologies

5.1 General

The global survey and analysis on the research activities of the 5th generation mobile communication network were done. The key relevant component technologies are listed here. Table 5.1-1 shows them with the surveyed organization.

Table.5.1-1 Key relevant component technologies with the surveyed organizations

Section number	Classification	Technology	Associated technology	Surveyed organization
5.2.1	Core network system technologies	Mobility/Network access management technologies	Mobility management	ITU-T
			Extension identifier	ITU-T
5.2.2		Data aware networking technologies		ITU-T
				4G Americas
				NetWorld2020
5.2.3		Context aware networking technology		4G Americas
5.2.4		User profile management technologies	User profile management	Wireless World Research Forum (WWRF)
			Terminal virtualization	NetWorld2020
5.2.5		Edge computing	Mobile Edge Computing	ETSI ISG MEC
5.3.1	SDN technologies	Network virtualization technology		ITU-T
5.3.2		Service chaining technology		IETF
5.3.3		U/C-plane separation technologies	I2RS, SDN	IETF
			SDN controller	ONF
			EPC virtualization technology	The Institute of Electronics, Information and Communication Engineers (IEICE)
5.4.1	NFV technologies	Slicing technology		ITU-T
5.4.2		Auto-scale in/out technologies	Auto-scale in/out technology	ETSI ISG NFV
			Efficient operation of resources	Wireless World Research Forum (WWRF)
5.4.3		Communication technology between VMs	NVO3, SDN	IETF
5.4.4		XaaS technology		ETSI ISG NFV
5.4.5		MANO architecture	Virtualization network management	3GPP
			MANO technology (Life cycle management)	ETSI ISG NFV
			MANO technology (Resource allocation change)	ETSI ISG NFV
5.4.6		Auto-healing technology		ETSI ISG NFV
5.4.7		Service orchestration technologies	NW virtualization, integrated network management	ITU-T
			Service orchestration technology	ITU-T
			Service orchestration technology	ETSI ISG NFV

5.4.8		SDN/NFV integration technologies	SDN/NFV integration technology	IETF
			SDN/NFV integration technology	ARIB 2020 and Beyond Ad Hoc
			Secure boot, attestation, remote attestation, trust chain	ETSI
5.5.1	MBH system technologies	High reliability technology	Carrier-grade Ethernet system	MEF (Metro Ethernet Forum)
5.5.2		Clock synchronization technology	Clock distribution system (limited to UDWDM-OFDM)	IEEE/OSA
5.6.1	MFH technologies	C-RAN transmission technologies	MFH transmission system (Change of functional allocations between RRH & BBU: Layer 1 should be in RRH.)	IEICE
			RU/DU functional splitting	NGMN
5.6.2		Data compression technology	Radio data dynamic compression technology	IEEE/OSA
5.6.3		TDM-PON technologies	Bandwidth allocation control (DBA: Dynamic Bandwidth Allocation)	IEEE/OSA
			Bandwidth allocation control	IEEE ICC
			Radio data compression	IEEE ICC
			C-RAN functional splitting	IEEE ICC
5.7.1	Optical transmission technologies	Modulation technologies	DMT system	IEICE
			UDWDM-OFDM system	IEEE/OSA
5.7.2		Space Division Multiplexing technology	MC-SMF transmission system (Multi Core-Single Mode Fiber)	IEEE
5.7.3		Wavelength Division Multiplexing technology	Flexible grid allocation system	IEEE
5.8.1	Other technologies	NW power saving technologies	Optical switching system	ITU-T
			Sleep function	ITU-T
			Traffic control (minimum)	ITU-T
5.8.2		Economic incentive technology	SLA management, etc.	ITU-T
5.8.3		Integrated network management		ITU-T
5.8.4		NW optimization	Optimum control of resource allocations	ITU-T
			Optimum control of network functions	ITU-T
5.8.5		Reliability improvement technology		ITU-T
5.8.6		Security technologies		ITU-T
				Wireless World Research Forum (WWRF)

5.2 Core network system technologies

5.2.1 Mobility/Network access management technologies

Component technology	Mobility management
(1) Features	Huge amount of nodes (communication devices) shall be able to easily move at high speed and in large scale in various kinds of networks (e.g., networks for mobile phones and wireless LAN, etc.) where they move dynamically. Also, regardless of the mobility characteristics of nodes, mobile service shall be supported.
(2) Issues to be solved by this technology	It is difficult to easily offer services combining cells of multiple types and RAT/WiFi of multiple types to users.
(3) Benefits of this technology	By providing access optimized to radio approach status of terminals, service connectivity will be improved.
(4) Maturity level of this technology/ issues to be worked out	Provision of various radio access for terminals and introduction of optimized management system
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

Component technology	Extension identifier
(1) Features	Configuration of new identifiers that can scalably support mobility and data access shall be provided
(2) Issues to be solved by this technology	Support for control combining cells of multiple types and RAT/WiFi of multiple types. Support for inter-domain move and various terminals.
(3) Benefits of this technology	By defining new identification structure to enable networking between host and data efficiently, dynamic mapping of ID and dynamic mapping between data and host IDs are possible.
(4) Maturity level of this technology/ issues to be worked out	The overview has already been described in Y.3031.
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001, Y.3031

5.2.2 Data aware networking technologies

Component technology	Data awareness tetworking technology
(1) Features	It shall be possible to process massive amount of data optimally and efficiently. For the purpose, access method has been designed considering the location of the data in the center. However, in the future networks, access method will be established not focusing on the location but on the data itself.
(2) Issues to be solved by this technology	Since access method was set considering the location of data in the center, access procedure was complicated, which increased access duration.
(3) Benefits of this technology	Reduction of time required for data access, and simplification of the procedure
(4) Maturity level of this technology/ issues to be worked out	The overview has already been described in Y.3033.
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001, Y.3033

Component technology	Data aware networking technology
(1) Features	Communication will be made not with addressing based on the location but with the content name, etc., without the need to know where the communication counterpart is. In addition, end-to-end communication is not needed because contents are assumed to be cached.
(2) Issues to be solved by this technology	The technology will adapt to the situation where the main purpose of communication has changed from voice call and other one-on-one communications to data distribution/acquisition.
(3) Benefits of this technology	Streamlined distribution and optimized resources/facilities can be expected.
(4) Maturity level of this technology/ issues to be worked out	Ideas under consideration
(5) Organization for this study	4G Americas
(6) Reference	4G Americas, 4G Americas' Recommendations on 5G Requirements and Solutions, OCT 2014

Component technology	Data aware networking technology
(1) Features	Networking based not on the location but on the name will be realized. Communication will be made by naming contents, users, devices, etc. and dynamically linking them.
(2) Issues to be solved by this technology	Since the communication architecture is not based on the location, mobility management is essentially not needed. Multicast is made easily, too.
(3) Benefits of this technology	Possible to efficiently distribute information. In addition, delay in distribution will be smaller with content acquisition from a cache near the user.
(4) Maturity level of this technology/ issues to be worked out	Ideas under consideration
(5) Organization for this study	NetWorld2020
(6) Reference	NetWorld2020 ETP 5G: Challenges, Research Priorities, and Recommendations

5.2.3 Context aware networking technology

Component technology	Context aware networking technology
(1) Features	Environment where the network autonomously offers optimal services by mapping service attributes to functions based on the network environment, subscriber and device information, application requirements, operator policies, etc.
(2) Issues to be solved by this technology	Resource deployment can meet various requirements, as compared to the offering of similar communication services not based on the characteristics.
(3) Benefits of this technology	Dynamic service offering based on the characteristics of the device/application. Optimization of CAPEX.
(4) Maturity level of this technology/ issues to be worked out	An issue has been raised with the security about context collection on the user side.
(5) Organization for this study	4G Americas
(6) Reference	4G Americas, 4G Americas' Recommendations on 5G Requirements and Solutions, OCT 2014

5.2.4 User profile management technologies

Component technology	User profile management
(1) Features	The concept of User Profile is that users use the three classifications (Private/Professional/Casual) of Virtual Identity (VID). They have been studied in the ETSI, 3GPP, Liberty Alliance, W3C, etc., and SSO by identity providers, decentralized Open ID (however, any authentication methods not defined), Generic User Profile (ETSI STF342), etc. have been defined.
(2) Issues to be solved by this technology	The concepts are: - Profile Management Framework integrated by a Personalization & Identity provider for the same Profile Management (for 3rd parties and others, too) - User Profile expansion in an application and
(3) Benefits of this technology	It will be easy to offer M2M and other new services and to manage multiple User Profiles e.g. in an application.
(4) Maturity level of this technology/ issues to be worked out	The study in ETSI, which was similar to that conducted originally by TISPAN, was documented in the GS INS series. ITS standardized the technology in TS 102 941. Identity Management is under study in ITU-T SG17, too.
(5) Organization for this study	Wireless World Research Forum (WWRF)
(6) Reference	WWRF Outlook 3 (User Profiles, Personalization & Privacy)

Component technology	Terminal virtualization
(1) Features	A terminal that is logically divided to offer multiple separate services
(2) Issues to be solved by this technology	Currently, different terminals are used to set different security policies and uses (e.g. for work and personal use), which is not convenient.
(3) Benefits of this technology	Offering of a function needed for the user to simultaneously access multiple services or access networks. For example, a terminal will be able to be logically divided for work and personal use in the BYOD environment, too.
(4) Maturity level of this technology/ issues to be worked out	Ideas under consideration
(5) Organization for this study	NetWorld2020
(6) Reference	NetWorld2020 ETP 5G: Challenges, Research Priorities, and Recommendations

5.2.5 Edge computing technology

Component technology	Mobile edge computing technology
(1) Features	Technology to install platform that has IT and cloud computing capability on radio access networks close to mobile subscribers. Also, the technology provides API for the third party to use this platform function.
(2) Issues to be solved by this technology	This technology provides mobile subscribers with simple, secure and flexible access. It is a measure to solve degradation of response due to mobile traffic increase.
(3) Benefits of this technology	This technology will improve responsibility to mobile subscribers and accelerate contents, service and application. Similar to the direct access to real-time radio network information (subscriber location, cell load, etc.) that is used for application and services to provide context-related services, this technology will enable provision of service environment of broad band with extremely low latency for application developers and contents providers.
(4) Maturity level of this technology/ issues to be worked out	White paper was issued (in September 2014).
(5) Organization for this study	ETSI ISG MEC
(6) Reference	ETSI ISG MEC White paper

5.3 SDN technologies

5.3.1 Network virtualization technology

Component technology	Network virtualization technology
(1) Features	A technology that makes multiple networks that are logically independent out of one physical network resource. Also, this technology is able to handle multiple physical network resources as one network resource by virtually multiplexing them.
(2) Issues to be solved by this technology	Difficult to flexibly respond to various requirements of networking functions needed for various service applications
(3) Benefits of this technology	More streamlined and flexible network management Quick introduction of new functions/services ensured
(4) Maturity level of this technology/ issues to be worked out	High-level requirements and architecture have been defined.
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3300

5.3.2 Service chaining Technology

Component technology	Service chaining technology
(1) Features	Definition of a protocol for service chaining (SDN control), including the method for marking service attributes (providing metadata)
(2) Issues to be solved by this technology	Realization of flexible service chaining, enabling both fully central (SDN) network control and partial & decentralized control
(3) Benefits of this technology	Currently it is restricted to simple sorting based on the static marking information only, but this technology is expected to make it possible to define a flexible behavior depending on the application in the network.
(4) Maturity level of this technology/ issues to be worked out	Although defining the protocol is not yet completed, it is under relatively detailed discussion. Since it is an individual protocol, there is a concern that the granularity is too fine as an ad-hoc item. It is preferable to refer to it.
(5) Organization for this study	IETF
(6) Reference	draft-boucadair-sfc-requirements， RFC 7364, RFC 7365

5.3.3 U/C-plane Separation Technologies

Component technology	I2RS, SDN
(1) Features	Definition of a protocol for SDN-like control mainly about routing
(2) Issues to be solved by this technology	Realization of SDN-like management and control about (IP) routing and forwarding
(3) Benefits of this technology	This SDN approach is expected to make it possible to openly program routing, forwarding and other functions that are basically assumed to autonomously operate with distributed protocols.
(4) Maturity level of this technology/ issues to be worked out	The architecture, use cases, etc. are under discussion.
(5) Organization for this study	IETF
(6) Reference	draft-ietf-i2rs-architecture， RFC 7364, RFC 7365

Component technology	SDN controller
(1) Features	Central management of traffic in mobile networks in a virtual manner

(2) Issues to be solved by this technology	- Load balancing - Content filtering - Policy management and implementation - Disaster measures and recovery - Mobile traffic offloading and roaming - Optimal NW capacity allocation based on the content - Traffic optimization
(3) Benefits of this technology	Optimal control of the above (e.g. load balancing, content filtering, traffic optimization) enabled by central management
(4) Maturity level of this technology/ issues to be worked out	The concept has just been described in white papers. The details of control and scalability need to be verified.
(5) Organization for this study	ONF
(6) Reference	ONF White Paper "Software-Defined Networking : The New Norm for Networks"

Component technology	**EPC virtualization technology**
(1) Features	System to take control with the OF-mpc protocol, equipped with the 3GPP-defined interface as well as with an SDN controller and multiple switches in the S-GW/P-GW
(2) Issues to be solved by this technology	There is much higher traffic volume for some hours/in some areas, caused by traffic changes affected by the time/geographical location. A technology is needed to help with flexible response to traffic changes and to enable static IP address routing in the mobile networks to be flexibly changed.
(3) Benefits of this technology	Efficient use of resources leading to a reduction in costs and power consumption
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] SDN-based mobile networks have been prototyped. A reduction in the S-GW/P-GW traffic volumes and other benefits have been verified in simulations with a path that only offloads video signaling. [Issue] Integration of SDN controllers
(5) Organization for this study	IEICE
(6) Reference	Tutorial BT-1-5 for NEC/2014 Communication Society Conference

5.4 NFV technologies

5.4.1 Slicing technologies

Component technology	**Slicing technology**
(1) Features	Network virtualization technology to improve the usability of networks by dividing (slicing) a network into multiple virtual networks and enabling each network to be separately managed.
(2) Issues to be solved by this technology	Needed to physically add new facilities when building a new network
(3) Benefits of this technology	Efficient use of limited physical network resources, leading to a reduction in CAPEX.
(4) Maturity level of this technology/ issues to be worked out	Requirements are already described in .3011.
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001, Y.3011, Y.3012

5.4.2 Auto-scale in/out technologies

Component technology	Auto-scale in/out technology
(1) Features	Resource will be optimally deployed based on the real-time monitoring of resource consumption in the virtual network.
(2) Issues to be solved by this technology	Automatic optimization of network resource deployment
(3) Benefits of this technology	Easy to change the size and layout of resources in the virtualized NW. Automatic and real-time network resource optimization controlled by software, based on the actual traffic status and service requirements.
(4) Maturity level of this technology/ issues to be worked out	Requirements in ETSI ISG NFV Phase1 will be standardized in the relevant SDO. Phase2 might have a revision.
(5) Organization for this study	ETSI ISG NFV
(6) Reference	ETSI ISG NFV / Network Functions Virtualisation – Introductory White Paper

Component technology	Efficient operation of resources
(1) Features	Assumption of time varying traffic distribution: - During the busy hour, 20% of voice and 25% of non-voice - 50GBps/km^2 of throughput is needed in a highly dense region. - 2.08Gbit/s/RAN node (2.09Tbit/s/IP-Backbone) is needed in the transport NW.
(2) Issues to be solved by this technology	Proposal of applying Dynamic Resource Management and Self Configuration/ Self Optimization to Core Network to respond to local traffic changes and an increase in the number of node connections
(3) Benefits of this technology	A failure can be prevented from bursting e.g. due to local traffic changes.
(4) Maturity level of this technology/ issues to be worked out	Dynamic Resource Management can be realized by applying NFV and other technologies. Using wireless backhaul or others is under consideration in the transport field.
(5) Organization for this study	Wireless World Research Forum (WWRF)
(6) Reference	WWRF Outlook 7 (Requirements and vision for NG-Wireless)

5.4.3 Communication technologies between VMs

Component technology	NVO3, SDN
(1) Features	Tunneling protocol to create an overlay between VM or other entities
(2) Issues to be solved by this technology	Realization of: - Appropriate forwarding (e.g. load balancing) in an underlay, based on the overlay flow - Flexible ID space where VM migration is considered, too
(3) Benefits of this technology	The scale of a service-chained virtual network is expected to be maintained, which is difficult to realize with the existing tunneling technology only.
(4) Maturity level of this technology/ issues to be worked out	The maturity level is high because the details are being fixed. Since it is an individual protocol, there is a concern that the granularity is too fine as an ad-hoc item.
(5) Organization for this study	IETF
(6) Reference	IETF/RFC 7364, RFC 7365

5.4.4 XaaS technologies

Component technology	XaaS technologies
(1) Features	Provision of a single platform that can be used for various services and by multiple network users
(2) Issues to be solved by this technology	More flexible cancellation of a NW function

(3) Benefits of this technology	Various services (e.g. IaaS, PaaS, SaaS) offered and resources shared among multiple network users (e.g. service providers, MVNO users) in a platform generated by comprehensively virtualizing the core NW, leading to an reduction in facilities costs
(4) Maturity level of this technology/ issues to be worked out	Requirements in ETSI ISG NFV Phase1 will be standardized in the relevant SDO. Phase2 might have a revision.
(5) Organization for this study	ETSI ISG NFV
(6) Reference	ETSI ISG NFV / Network Functions Virtualisation – Introductory White Paper

5.4.5 MANO Architecture

Component technology	**Virtualized NW management**
(1) Features	Study of management of virtualized 3GPP networks
(2) Issues to be solved by this technology	Summarization of how the NW management architecture and functions relate to each other in the virtualized NW, existing (non-virtualized) NW and a combination of them
(3) Benefits of this technology	Migration to the virtualization environment is expected to be made easy because it will likely be possible to manage virtualized 3GPP networks in a method unified by standardization and a combination of virtualized and existing networks will be considered, too.
(4) Maturity level of this technology/ issues to be worked out	This technology started to be studied in August 2014. The version number of the technical report summarizing what was studied is 0.3.0 as of January 2015.
(5) Organization for this study	3GPP
(6) Reference	3GPP SA WG5 / TR 32.842 (http://www.3gpp.org/DynaReport/32842.htm)

Component technology	**MANO (Life cycle management)**
(1) Features	Lifecycle of software functions in the hierarchical network is managed by the operation management system.
(2) Issues to be solved by this technology	Reduction in time taken to create a service
(3) Benefits of this technology	Time required to offer (add/modify) a service reduced with the comprehensively virtualized core NW and the integrated operation management system
(4) Maturity level of this technology/ issues to be worked out	Requirements in ETSI ISG NFV Phase1 will be standardized in the relevant SDO. Phase2 might have a revision.
(5) Organization for this study	ETSI ISG NFV
(6) Reference	ETSI ISG NFV / Network Functions Virtualisation – Introductory White Paper and – Update White Paper"

Component technology	**MANO (Resource deployment change)**
(1) Features	Flexibility in changing the resource layout in the network will be enhanced by network virtualization.
(2) Issues to be solved by this technology	Realization of flexible network operations that meet the needs of maintenance personnel
(3) Benefits of this technology	Easy to change the scale and layout of resources in the virtualized NW. Possible to quickly change the service scale based on the situation and plan as requested by maintenance personnel.
(4) Maturity level of this technology/ issues to be worked out	Requirements in ETSI ISG NFV Phase1 will be standardized in the relevant SDO. Phase2 might have a revision.
(5) Organization for this study	ETSI ISG NFV
(6) Reference	ETSI ISG NFV / Network Functions Virtualisation – Introductory White Paper

5.4.6 Auto-healing technology

Component technology	Auto-healing technology
(1) Features	Resiliency and stability will be provided so that no single point of failure shall cause failures of entire NW and offering and continuity of services shall be ensured.
(2) Issues to be solved by this technology	Improvement of fault tolerance
(3) Benefits of this technology	NW made more reliable with flexible changes in the layout of services and resources during a HW failure in the virtualized NW
(4) Maturity level of this technology/ issues to be worked out	Requirements in ETSI ISG NFV Phase1 will be standardized in the relevant SDO. Phase2 might have a revision.
(5) Organization for this study	ETSI ISG NFV
(6) Reference	Network Functions Virtualisation – Update White Paper

5.4.7 Service orchestration technologies

Component technology	NW virtualization , Integrated network management
(1) Features	Acceptance of various network services with different traffic characteristics and behaviors (e.g. small data sent from a huge number of terminals, very high-precision image signals sent to a specific location). In addition, connections made from a huge number of devices (e.g. sensor terminals) to the network.
(2) Issues to be solved by this technology	Efficient accommodation of terminals with different requirements (terminals different in mobility and delay tolerance). Quick introduction of new functions/services ensured
(3) Benefits of this technology	Accommodation of various terminals/services different in network characteristics. Reduction in time taken to introduce a new function/service
(4) Maturity level of this technology/ issues to be worked out	Realization of requirements/architecture
(5) Organization for this study	ITU-T
(6) Reference	Y.3001: Future networks: Objectives and design goals

Component technology	Service orchestration technology
(1) Features	Functional flexibility to support new services that are launched upon request of users. Due to the impossibility of realizing a network meeting any user’s requirements both at present and in the future, a technology enabling dynamic changes in network functions will be developed to make up for it.
(2) Issues to be solved by this technology	There is a restriction in the NW’s function offering, and in order to launch a new service, development, construction, etc. are needed e.g. to add new facilities. New services need be carefully introduced so that they will not have an impact on the existing services.
(3) Benefits of this technology	Easy to quickly offer a new service because it will be possible to add new functions flexibly to the existing network infrastructure
(4) Maturity level of this technology/ issues to be worked out	Realization of requirements/architecture
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

Component technology	Service orchestration technology
(1) Features	General-purpose equipment will be applied due to the reduction in the existing equipment.

(2) Issues to be solved by this technology	Reduction in CAPEX/OPEX (incl. power consumption)
(3) Benefits of this technology	CAPEX/OPEX and power consumption will be reduced due to the reduction in core NW equipment and use of general-purpose products
(4) Maturity level of this technology/ issues to be worked out	Requirements in ETSI ISG NFV Phase1 will be standardized in the relevant SDO. Phase2 might have a revision.
(5) Organization for this study	ETSI ISG NFV
(6) Reference	ETSI ISG NFV / Network Functions Virtualisation – Introductory White Paper

5.4.8 SDN/NFV integration technologies

Component technology	**SDN/NFV integration technology**
(1) Features	Research issues and solutions about SDN and NFV
(2) Issues to be solved by this technology	Four issues (Policy-based management, Analytics for visibility and orchestration, Security and service verification, Virtual Network Function (VNF) performance modeling to facilitate transition to NFV) have been raised. However, it is still in the phase of raising issues.
(3) Benefits of this technology	Difficult to list specific effects because a specific technology has not yet been confirmed.
(4) Maturity level of this technology/ issues to be worked out	Discussion has just started as a research issue. It has not yet been sufficiently discussed.
(5) Organization for this study	IETF
(6) Reference	draft-ietf-i2rs-architecture， RFC 7364, RFC 7365， draft-boucadair-sfc-requirements

Component technology	**SDN/NFV integration technology**
(1) Features	- SW-driven network control with SDN, NFV-based virtualization of NW functions - Functional node chain and upper operation support system, managed by NFV MANO (Management and Orchestration)
(2) Issues to be solved by this technology	More expected in 5G to: - Build an efficient network to respond to various services (e.g. IoT) - Quickly deploy new services - Improve the reliability
(3) Benefits of this technology	- NW complexity mitigated and operations sophisticated by the SDN/NFV configuration - System rollout made easy with NFV - CAPEX, OPEX and energy consumption reduced by setting up a common platform
(4) Maturity level of this technology/ issues to be worked out	- Some parts of SDN and NFV are already in practical use.
(5) Organization for this study	ARIB 2020 and Beyond AdHoc
(6) Reference	ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond", Version 1.0.0, [A7.1]

Component technology	**Secure boot, attestation, remote-attestation, trust chain**
(1) Features	- Technology to verify that the pre-defined configuration is used to start up a virtual machine. - Technology to verify that running machines are not improperly manipulated. - Technology to ensure a safe system by connecting devices that are safely running
(2) Issues to be solved by this technology	External attacks to the system. If hardware and networks are assumed to be virtualized with NFV/SDN, there will be a threat of the type that has not been

	considered before.
(3) Benefits of this technology	Services can be safely offered.
(4) Maturity level of this technology/ issues to be worked out	[Maturity] Secure Boot and other individual technologies are getting matured whereas e.g. analyzing a threat to the system has not yet started. [Issue] Both the architecture and individual implementation need to be verified.
(5) Organization for this study	ETSI
(6) Reference	ETSI GS NFV-SEC 003 V1.1.1 (2014-12) Network Functions Virtualisation (NFV); NFV Security; Security and Trust Guidance

5.5 MBH system technologies

5.5.1 High reliability technology

Component technology	**Carrier-grade Ethernet system**
(1) Features	The MEF creates the carrier-grade Ethernet technique specification applicable to communication networks provided by carriers as an MEF standard, by adding OAM, etc. to the Ethernet technology specified in IEEE802.3. As part of the effort, the MEF has standardized the carrier-grade Ethernet technology for mobile backhaul as part of the MEF22 series.
(2) Issues to be solved by this technology	Contribution to cost reduction for mobile backhaul construction by applying the carrier-grade Ethernet technology widely used in core/access networks of carriers to mobile backhaul networks.
(3) Benefits of this technology	Because carrier-grade Ethernet is able to respond to the change of transmission capacity and the number of nodes with QoS, and also because its boundary of responsibility is clear and it has service management completely, it is possible to build efficient and highly reliable mobile backhaul network at low cost.
(4) Maturity level of this technology/ issues to be worked out	Current MEF22.1 is created based on 4G (LTE), and its Amendment 1 supports small cells. Because functions such as transmission capacity, etc. are specified in accordance with core networks, the technology can be supported at an early stage once the 5G specification is determined in 3GPP.
(5) Organization for this study	MEF (Metro Ethernet Forum)
(6) Reference	MEF22.1 Overview, MEF22.1, MEF22.1 Amendment 1

5.5.2 Clock synchronization technology

Component technology	**Clock distribution system (limited to UDWDM-OFDM)**
(1) Features	Technology to distribute/generate sync clock necessary to accommodate synchronous Ethernet in the UDWDM-OFDMA system, one of the mobile backhaul solutions in the future.
(2) Issues to be solved by this technology	In addition to basic sync functions such as handoff between base stations and carrier frequency accuracy, system-level synchronization is necessary for OFDM. In recent years, the clock distribution/generation technology for single-wavelength direct detection OFDM system has been presented. However, there are still some issues for multi wavelength such as inhibit of beats causing spectrum efficiency degradation.
(3) Benefits of this technology	In this paper, by applying SSB (Single Sideband Modulation) and the envelop detection technique that does not require and DSP, sync clock 50MHz can be distributed and generated under 30Gbps, 24.56GHz and 40Km transmission conditions, which can contribute to application to mobile backhaul.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] At a stage of theory verification at lab (according to document) [Issue] Standardization of distribution/generation method

(5) Organization for this study	IEEE/OSA
(6) Reference	Novel Synchronous Clock Distribution and Recovery for High-Speed UDWDM-OFDMA-based Mobile Backhaul

5.6 MFH system technologies

5.6.1 C-RAN transmission technology

Component technology	**MFH transmission system (Reference point change: Layer 1 processing at APs)**
(1) Features	Retain the coding function, move Layer 1 process to remote AP, split data for each OFDM symbol for transmission.
(2) Issues to be solved by this technology	With the optical remote method using CPRI, the MFH data rate gets huge, making implementation difficult financially.
(3) Benefits of this technology	Reduction of transmission delay in MFH
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] At a stage of method proposal [Issue] Method comparison is necessary
(5) Organization for this study	Institute of Electronics, Information and Communication Engineers
(6) Reference	NEC/2014 IEICE Society Conference (Tutorial BT-1-3)

Component technology	**RU/DU functional splitting**
(1) Features	Functional split points for RU (RRH) and DU (BBU) in the C-RAN configuration are studied and redefined.
(2) Issues to be solved by this technology	The objective is to optimize the tradeoff between DU-RU data communication band and C-RAN advantages (maximized CoMP effect, resource share, concentrated load, etc), and 5 types of split point are being studied.
(3) Benefits of this technology	There is a tradeoff between advantages (effect) and disadvantages depending on the selection of functional split points. For example, in the case of the conventional split points (RF: AD/DA, compression, DU: L1, L2, L3), while great benefit can be obtained from C-RAN, high-capacity data communication bandwidth is required. On the other hand, if the split point is set between L1 and L2, although the bandwidth can be reduced, the C-RAN benefit becomes small.
(4) Maturity level of this technology/ issues to be worked out	There has been no method presented that can achieve both data communication band reduction and maximization of C-RAN benefit. Other split points are also available, so further comparison study is required.
(5) Organization for this study	NGMN (Next Generation Mobile Network)
(6) Reference	NGMN / “Suggestions on potential solutions to C-RAN”, 4.2.3 Allocation of signal processing functions between RU and DU/DU cloud

5.6.2 Data compression technologies

Component technology	**Wireless data compression technologies**
(1) Features	IQ data compression shall be processed according to the frequency bandwidth used for wireless signals.
(2) Issues to be solved by this technology	Ultra high-speed and huge number of line connections in mobile front-haul cause steep rise in the cost. General base-band signal transfer is based on the fixed rate, unsuitable for application of shared network TDM-PON.
(3) Benefits of this technology	Statistical multiplexing effect can be expected with dynamic compression of wireless signals, which can increase the effectiveness of TDM-PON applied to mobile front-backhaul.

(4) Maturity level of this technology/ issues to be worked out	[Maturity level] At a stage of theory verification for compression function on the assumption that wireless band allocation information is obtained (according to document). [Issue] Standardization of compression method
(5) Organization for this study	IEEE/OSA
(6) Reference	Optical Fiber Communication Conference 2014 (OFC2014) Tu3F.4

5.6.3 TDM-PON technology

Component technology	**Bandwidth allocation control (DBA: Dynamic Bandwidth Allocation)**
(1) Features	Mobile scheduling information shall be obtained from the BBU to reflect it in bandwidth allocation control for TDM-PON.
(2) Issues to be solved by this technology	Ultra high-speed and huge number of line connections in mobile front-haul cause steep rise in the cost. If existing TDM-PON is applied to mobile front-haul, the delay requirement (<1ms) is not satisfied.
(3) Benefits of this technology	The number of line connections and cost can be reduced by applying TDM-PON that satisfies the delay requirement.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] At a stage of theory verification test with pseudo traffic at a fixed rate on the assumption that mobile scheduling information is obtained (according to document) [Issue] Method to obtain actual mobile scheduling and traffic information
(5) Organization for this study	IEEE/OSA
(6) Reference	Optical Fiber Communication Conference 2014 (OFC2014) Tu3F.3

Component technology	**Bandwidth allocation control**
(1) Features	Mobile scheduling information shall be obtained from the BBU to reflect it in bandwidth allocation control for TDM-PON. IQ data compression shall be processed according to the frequency bandwidth used for wireless signals. Functions are split between the BBU and the RRH.
(2) Issues to be solved by this technology	Ultra high-speed and huge number of line connections in mobile front-haul cause steep rise in the cost. If the existing TDM-PON is applied to mobile front-haul, there will be problems of lower latency and wider bandwidth.
(3) Benefits of this technology	The number of line connections and cost can be reduced by applying TDM-PON that satisfies the delay requirement.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] At a stage of theory verification test, while presenting conventional technologies mainly sorting out issues (according to document) [Issue] Standardization of the technology
(5) Organization for this study	IEEE ICC
(6) Reference	Operator Perspective on Next-Generation Optical Access for Future Radio Access

Component technology	**Wireless data compression**
(1) Features	IQ data compression shall be processed according to the frequency bandwidth used for wireless signals.
(2) Issues to be solved by this technology	Ultra high-speed and huge number of line connections in mobile front-haul cause steep rise in the cost. General base-band signal transfer is based on the fixed rate, unsuitable for application of shared network TDM-PON.
(3) Benefits of this technology	Statistical multiplexing effect can be expected with dynamic compression of wireless signals, which can increase the effectiveness of TDM-PON applied to

	mobile front-backhaul.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] At a stage of theory verification test for compression function on the assumption that wireless bandwidth allocation information is obtained (according to document) [Issue] Standardization of compression method
(5) Organization for this study	IEEE ICC
(6) Reference	Operator Perspective on Next-Generation Optical Access for Future Radio Access

Component technology	**C-RAN functional splitting**
(1) Features	Functions shall be split between the BBU and the RRH.
(2) Issues to be solved by this technology	Ultra high-speed and huge number of line connections in mobile front-haul cause steep rise in the cost. General base-band signal transfer is based on the fixed rate, unsuitable for application of shared network TDM-PON.
(3) Benefits of this technology	Statistical multiplexing effect can be expected with dynamic compression of wireless signals, which can increase the effectiveness of TDM-PON applied to mobile front-backhaul.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] At a stage of theory verification test for compression function on the assumption that wireless bandwidth allocation information is obtained (according to document) [Issue] Standardization of compression method
(5) Organization for this study	IEEE ICC
(6) Reference	Operator Perspective on Next-Generation Optical Access for Future Radio Access

5.7 Optical transmission technology

5.7.1 Modulation technologies

Component technology	**DMT system**
(1) Features	DMT modulating multiple subcarriers, only with the strength element without using the phase element. Each subcarrier's modulation level dependent on the transmission quality.
(2) Issues to be solved by this technology	TDM-PON has a delay issue and WDM-PON is not economical.
(3) Benefits of this technology	Possible to reduce costs in ultra high speed transmission in MFH
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] Experimental verification is underway for DML transmission (100 Gbps or more for 10 km). DML itself is a technology used for ADSL. [Issue] Comparison with other methods needed
(5) Organization for this study	IEICE
(6) Reference	Fujitsu/Tutorial BT-1-4 for 2014 Communication Society Conference

Component technology	**UDWDM-OFDM system**
(1) Features	Single Sideband Modulation method that enables the distribution and reproduction of a synchronous 50MHz clock
(2) Issues to be solved by this technology	OFDM needs system-level synchronization as well as basic synchronization functions such as BTS-to-BTS hand-off and carrier frequency accuracy. Although a clock distribution and reproduction technology has recently been presented in the OFDM system that directly demodulates single-wavelengths,

	there are some issue with wavelength multiplexing, including the need to reduce beats that cause a reduction in the spectral efficiency.
(3) Benefits of this technology	When SSB (Single Sideband) modulation and envelope demodulation with no need for DSP are applied, a synchronous 50MHz clock can be distributed and reproduced in transmission of 30Gbps, 24.56GHz and 40km in the UDWDM-OFDMA system. This can be expected to be applied to the mobile backhaul.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] According to the reference, the principle is being verified in the lab. [Issue] Standardization of the distribution and reproduction method
(5) Organization for this study	IEEE/OSA
(6) Reference	Novel Synchronous Clock Distribution and Recovery for High-Speed UDWDM-OFDMA-based Mobile Backhaul

5.7.2 Space Division Multiplex technology

Component technology	**MC-SMF transmission system (Multi core - Single mode fiber)**
(1) Features	Research report on the space division multiplexing transmission system, summarizing advantages and disadvantages of MC-SM (Multi-Core Single-Mode) transmission, SC-FM(Single-Core Few-Modes) transmission and MC-FM transmission compared to SC-SM transmission
(2) Issues to be solved by this technology	MC-SM and SC-FM are more advantageous as near-future solutions because it has been reported that they enable long-distance transmission. However, the core density per fiber could easily reach the limit.
(3) Benefits of this technology	MIMO technology-based MC-FM transmission is expected to help with capacity expansion in the future.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] The results of long-distance transmission show that MC-SM is equivalent to SC-SM. Although the distance that is experimentally verified in long-distance transmission with MC-FM is only approx. one hundredth of that enabled with SC-SM, successful results have already been reported on the transmission up to the distance (40km) required for access. [Issue] Still in the lab level. Any field testing has not been reported. Since new fiber installation is needed for practical use, infrastructure costs are another issue.
(5) Organization for this study	IEEE
(6) Reference	[Organization studying this technology] Prysmian Group [Reference] ECOC 2014 Tu.4.1.1 Next-Generation Fibers for Space-Division-Multiplexed Transmissions

5.7.3 Wavelength Division Multiplex technology

Component technology	**Flexible grid allocation system**
(1) Features	A technology to use frequency bands more efficiently with not fixed but variable allocation of wavelength division multiplexing grids has been presented in future mobile fronthaul solutions (“CWDM-like” transmission/reception method as a short-term solution and “DWDM-like” transmission/reception method as a long-term solution) and a future mobile backhaul solution (DWDM system).
(2) Issues to be solved by this technology	CWDM is a technology that can be applied to the fronthaul. But since it is for dual-core bidirectional transmission, FTTH facilities based on single-core bidirectional transmission cannot be applied (installed fibers cannot be reused). In DWDM (Dense Wavelength Division Multiplexing) technology applied to core networks, 90 wavelengths are multiply transmitted, with wavelength division multiplexing grids divided in fixed units of 50GHz. However, since 50GHz of intervals include margins and even 37.5GHz enables transmission, further multiplexing could be possible.

(3) Benefits of this technology	Reference [A]: The following solutions are proposed: (Short-term solution) Technology to enable single-core bidirectional transmission by using two wavelengths with 20nm of space between them for transmission and reception, as a “CWDM-like” transmission/reception method (Long-term solution evolved from the above solution) “DWDM-like” transmission/reception method to enable passive and automatic wavelength assignment by using “Self-seeded Reflective Semiconductor Optical Amplifier (RSOAs)” They can be expected to be applied to the mobile fronthaul. Reference [B]: If technologies including WSS (Wavelength Selective Switch) to enable an arbitrary selection of wavelength division multiplexing grids are developed, those grids can be variable, not fixed to 50GHz. This can be expected to be applied to the mobile fronthaul, as more efficient high-capacity transmission.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] Researches and discussion are being summarized. [Issue] Practicality
(5) Organization for this study	IEEE
(6) Reference	[A] Orange Labs Networks /ECOC2014 Tu.4.2.1 Things You Should Know About Fronthaul [B] British Telecom./ECOC2014 Mo3.1.1 Core Networks in the Flexgrid Era

5.8 Any other technologies

5.8.1 NW power saving technologies

Component technology	**Optical switching system**
(1) Features	Energy efficiency shall be maximized by effectively utilizing device/equipment/network-level technologies and satisfy user’s requests with minimum traffic. Device/equipment/network-level technologies shall interact with each other to save network energy, rather than operating independently.
(2) Issues to be solved by this technology	Consumption power increase due to increased traffic volume. 24-hour operation causes heat generation and increases consumption power.
(3) Benefits of this technology	Power can be saved by switching from electronic to optical switches.
(4) Maturity level of this technology/ issues to be worked out	The overview has been stated in Y.3021
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001, Y.3021

Component technology	**Sleep function**
(1) Features	Energy efficiency shall be maximized by effectively utilizing device/equipment/network-level technologies and satisfy users’ requests with minimum traffic.
(2) Issues to be solved by this technology	Consumption power increase due to increased traffic volume. 24-hour operation causes heat generation and increases consumption power.
(3) Benefits of this technology	Power can be saved by implementing a sleep function into network equipment.
(4) Maturity level of this technology/ issues to be worked out	The overview has been stated in Y.3021
(5) Organization for this	ITU-T

study	
(6) Reference	ITU-T Y.3001, Y.3021

Component technology	**Traffic control (minimum)**
(1) Features	Energy efficiency shall be maximized by effectively utilizing device/equipment/network-level technologies and satisfy users' requests with minimum traffic.
(2) Issues to be solved by this technology	Consumption power increase due to increased traffic volume. 24-hour operation causes heat generation and increases consumption power.
(3) Benefits of this technology	Power can be saved by minimizing traffic volume using cache.
(4) Maturity level of this technology/ issues to be worked out	The overview has been stated in Y.3021
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001, Y.3021

5.8.2 Economic incentive technology

Component technology	**SLA management, etc**
(1) Features	Designing shall be done to provide a sustainable competitive environment in order to solve conflicts of economic interests among various stakeholders including users, various providers, governmental institutions, and intellectual property right holders.
(2) Issues to be solved by this technology	Development of new network technologies due to financial reasons that are not practically applied or sustainable.
(3) Benefits of this technology	Network that evolves sustainably can be constructed by giving economic incentives to all ICT stake holders.
(4) Maturity level of this technology/ issues to be worked out	Crystallization of requirements/architecture
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

5.8.3 Integrated network management

Component technology	**Integrated network management**
(1) Features	Management mechanism that can be efficiently operated and maintained as well as deal with increase of services and communication. Especially, it can efficiently and effectively process information including control data, convert the information into relevant information or knowledge and send it to administrators.
(2) Issues to be solved by this technology	Management systems exist separately for each network component, which results in poor operation efficiency. In addition, network management operation capability depends on operators' level of skill, which requires transmission of know-how.
(3) Benefits of this technology	Simplified network management, flexibility and OPEX reduction. Efficient transmission of operators' knowledge, etc.
(4) Maturity level of this technology/ issues to be worked out	Crystallization of requirements/architecture
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

5.8.4 NW optimization

Component technology	Optimum control of resource allocations
(1) Features	Network equipment performance shall be optimized based on service requirements and user's requests to provide sufficient performance. Diverse optimization in the network shall be possible taking into account various physical limitations of network equipment. Device-level (ratio control for optical and electrical transmission layers) and system-level (encrypted layer control) shall be optimized for optimal resource allocation control.
(2) Issues to be solved by this technology	In facility planning, excessive facility may be planned taking max users/traffic into account.
(3) Benefits of this technology	Excessive CAPEX is saved by installing optimal network equipment in accordance with user's actual requests.
(4) Maturity level of this technology/ issues to be worked out	Crystallization of requirements/architecture
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

Component technology	Optimum control of network functions
(1) Features	Network equipment performance shall be optimized based on service requirements and user's requests to provide sufficient performance. Diverse optimization in the network shall be possible taking into account various physical limitations of network equipment. Optimization for path, topology, access point, cache/storage and computer functions.
(2) Issues to be solved by this technology	In facility planning, excessive facility may be planned taking max users/traffic into account.
(3) Benefits of this technology	Excessive CAPEX is saved by installing optimal network equipment in accordance with user's actual requests.
(4) Maturity level of this technology/ issues to be worked out	Crystallization of requirements/architecture
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

5.8.5 Reliability improvement technology

Component technology	Reliability improvement technologies
(1) Features	Design, operation and development shall be performed to provide fault tolerance and high reliability even in difficult situations.
(2) Issues to be solved by this technology	The challenge is to provide network service for mission-critical services
(3) Benefits of this technology	Further improvement of network reliability, security for providing service to wide-ranging users and ensured privacy.
(4) Maturity level of this technology/ issues to be worked out	Need to address the challenge in each technology area.
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

5.8.6 Security technologies

Component technology	Security technologies
(1) Features	Safety and users' privacy need to be considered in design. Security to be realized with middle-level access control (user identification, authentication)

(2) Issues to be solved by this technology	Identification of online users and protection of personal information. A safe and secure online environment needs to be offered to users including children, handicapped people and minority groups.
(3) Benefits of this technology	- More reliable networks - Security and privacy secured to offer services to various users
(4) Maturity level of this technology/ issues to be worked out	This issue needs to be addressed in each technical area.
(5) Organization for this study	ITU-T
(6) Reference	ITU-T Y.3001

Component technology	**Security technologies**
(1) Features	Security-related measures are needed to respond to increasing privacy-related concerns due to evolving ICT and devices that are getting smaller and more sophisticated.
(2) Issues to be solved by this technology	The following is important as the basic concept of security in design: - Not a reactive (but proactive) approach to issues - As the default setting - Not as an add-on function - Securing of privacy without any degradation - Privacy secured on an E2E basis - Transparent and visible method for securing privacy - User Friendly
(3) Benefits of this technology	Design considering the securing of security will make it possible to secure the reliability of networks.
(4) Maturity level of this technology/ issues to be worked out	In the EU, ENISA (mainly Network and Information Security (NIS) Platform) and other bodies are working on it.
(5) Organization for this study	Wireless World Research Forum (WWRF)
(6) Reference	WWRF Outlook 11 (Cyber Security in Future Internet)

6 Compilation and mapping of issues and component technologies

6.1 Compilation of issues

6.1.1 Core network

Issues involving the core network are as follows:

・**Ultra large capacity U-plane:** It is expected that the load placed on U-plane core network equipment will increase over time due to gradual long-term growth in traffic volumes, the growing diversity in the types of data traffic and the effects of short-term spikes in traffic levels. When an increased load is placed on core network equipments, the U-plane packet processing time increases. This may cause increased data packet latency or congestion (loss), and as a result, network reliability may decrease.

・**Load increase in C-plane:** M2M/IoT communications are considered different from conventional communications in respects such as the tendency at certain times for many devices to send bursts of small packets within a short period of time. As conventional traffic control is not able to handle such bursts of C-plane signals, this can lead to problems such as large latency or an interruption in voice service.

An additional consideration is the anticipated proliferation in M2M/IoT business models. Regarding the 15 digit IMSI number used to authenticate individual devices, its ability to accommodate the expected huge number of M2M/IoT terminals is being called into question.

・**Issues in the transport layer:**

In a heterogeneous environment, conventional TCP/IP communications are not able to handle sudden changes in bandwidth and latency caused by frequent handovers. And to accommodate a variety of new applications that are expected to rise, it will be necessary for the network to have a new transport layer that can cope with the varying requirements for an increasingly heterogeneous environment.

・**Ultra low latency:** It is expected that new services and applications such as tactile communication, AR, and M2M that need real-time control will require ultra low E2E network latency, which cannot be realized with current technologies. This latency issue will need to be addressed by means such as shortening the physical communication path or changing the network architecture.

・**Ultra large scale disaster/congestion/failure resilience:** With the network congestion that occurs following an ultra large scale disaster, the need to reduce convergence time by providing the necessary additional resources within a short time period and thereby eliminating the need for repeat calls is an issue.

・**Various types of terminals/traffics/operators and network management:**
As efficiency is an issue when trying to accommodate various types of terminal equipment and traffic in the same core network because of the different management methods and traffic characteristics, it is necessary to study network architecture to find ways to efficiently accommodate M2M, IoT, IoE, and other types of terminals that have different traffic characteristics. There is also a need for the study of network flexibility and extensibility to enable the provision of the necessary network functions and sufficient network resources for an ever more diverse range of MVNO services and applications.

・**Interworking with other RATs:** The following challenges may be encountered when seeking to interwork with other RATs to achieve the targeted total bandwidth for future mobile systems:

- As the result of limiting Internet connections to a specific number of points, the prevention of failures and latency increases that interfere with the achievement of highly reliable, seamless handovers.
- The achievement of seamless access and smooth communication access to a large number of IoT terminals and similar units
- The application of link aggregation or multi-path communication between different types of RATs
- Unifying traffic flows by bringing together different types of RATs, thereby improving communication speeds

6.1.2 Mobile Backhaul

There are the following three issues with the mobile backhaul:

・**Ultra large capacity U-plane:** Even after taking the effects of statistical multiplexing into account, ultra large capacity circuits with capacities exceeding 100Gbps will be needed to accommodate a large number of high-speed lines. For example, 10Gbps of capacity is needed for a single mobile fronthaul (small cell) with a peak rate of 10Gbps, 10,000 users, and a use rate of 0.01 %. The maximum allowable number of small cells per macro cell is about 100. If the required capacity is 10Gbps for each small cell, the maximum required backhaul capacity will reach 1Tbps. So, N-times expansion and the associated increase in costs are issues with 10Gbps/40Gbps/100Gbps units.

・**Ultra low latency:** With the current mobile network architecture, as the core network and the base stations are in different locations and must be managed as such, latency arising as the result of transmission distance and equipment processing latency in MBH/MFH will need to be considered.

・**Ultra power saving:** Due to the increase in the number of devices that will be needed to accommodate a growing number of links, power consumption will be enormous. For example, a transceiver capable of 1Tbps will use less than 150W on its own, but with 100,000 base stations the total power consumption will amount to 30MW, when taking redundancy into account. So, it will be necessary to study architecture how to economically build a mobile front/backhaul that consumes less power. For the electric processing circuit (interface circuit) to handle 1Tbps the current 10Gbps processing circuit will need about 30W and the total power consumption will reach about 600MW. Therefore, an issue will be how to reduce power consumption for N-times scale equipment and reduce the amount of power consumed by equipment that is not in use.

6.1.3 Mobile Fronthaul

・**Ultra large capacity U-plane:** There will be an issue of how to increase circuit capacity for the mobile fronthaul (increasing cell capacity) to accommodate the ever greater data transfer rates of mobile terminals. For example, the current mobile fronthaul utilizing CPRI needs a bandwidth of more than 100Gbps to achieve 10Gbps at the terminal side. The introduction of the use of small cells will result in an approximate hundredfold increase in the total number of cells. Soaring network costs due to the need to accommodate a corresponding number of one-to-one (P2P) mobile fronthaul connections will be a concern.

・**Ultra low latency:** With the current network architecture, since core equipment is installed in the separate location from base stations, latency due to the transmission distance and equipments in the mobile backhaul/fronthaul should be studied.

・**Ultra power saving:** The connection between the BBU and the RRHs is based on the CPRI standard, and communication is done with an always-on state and at a fixed rate regardless of the actual amount of traffic. Total power consumption will increase as the result of the introduction of small cells (increasing number of devices). The power consumption of individual devices will increase by growing speed of optical transceiver between BBU & RRH and the electric circuits, etc. due to an increase in radio data rate.

・**Ultra large scale disaster/congestion/failure resilience:** In the event of a base station failure, there will be the need to be able to secure the communication circuits by dynamically and flexibly changing the backhaul nodes and topology.

6.2 Compilation of Component Technologies

6.2.1 Core Network

Key component technologies related to core network are as follows:

・**Mobility/Network access management technologies:** It is the technology to improve service connectivity by optimizing the radio access environment for terminals and/or applications, and support mobile services regardless of node's mobility performance. They include technologies that allow for improved interworking between RATs. And for the various approaches used with different terminals, there is an aim to define a new identifier for scalable support of mobility and data access.

・**Data aware networking:** To reduce data access time and to simplify the process, a data centric access means is used whereby communication is based on the name, etc. of the contents. Without needing to know the location of the caller, this technology allows dynamic communication connections by linking names of contents, users, devices, etc.

・**Context aware networking:** An environment for the autonomous provision of optimum services by network's mapping attributes to network functions based on network environment, customer information, device information, application requirements, operator policy, etc.

・**User profile management:** A technology to partition a terminal logically with virtual identity to provide multiple separated services to one terminal, by enabling easy management of multiple User Profiles for the new services as well as applications such as M2M/IoT. This involves the concept of user profile management by means of three virtual identity (VID) classifications (private/professional/casual).

・**Edge computing:** A technology to establish a platform with IT and cloud computing capabilities in a radio access network close to subscribers. Also, this technology provides an API for third parties to use this platform functions.

・**SDN - network virtualization:** A technology for creating multiple logically independent networks from one physical network resource. By means of virtual multiplexing, it also enables the handling of multiple physical network resources as a single network resource by virtual multiplexing.

・**SDN - service chaining:** A technology that is currently restricted to simple sorting based just on static marking information. By realizing flexible service chaining according to marking (meta-data) based on service attributes, it will eventually enable not only full central network control (SDN) but also distributed control.

・**SDN - U/C separation:** A technology that makes it possible by SDN approach to openly program routing, forwarding and other functions that are basically assumed to operate autonomously with distributed protocols. It has been studied in IETF I2RS, SDN, etc. SDN controller - is one of technologies to enable central management of mobile traffic for optimal control of load balancing, content filtering, traffic optimization, etc. It can flexibly handle time- or geography-based fluctuations in traffic by concentrating on specific time periods and/or geographical regions, and can flexibly change a fixed IP address routing in the mobile network. By enabling the efficient use of resources, this can reduce cost and power consumption.

・**SDN - slicing:** A network virtualization technology that improves the usability of a network by dividing it into multiple virtual networks and enabling each network to be managed separately

・**SDN - Auto-scale in/out:** A technology that optimally deploys resources based on the real-time monitoring of resource consumption in a virtual network. As the size and layout of resources are easy to change in a virtual network, network resources can be controlled in real time by software, based on the actual traffic status and service requirements.

・**NFV - Communication between VMs:** A tunneling protocol for creating an overlay between VMs or other entities. Based on the overlay flow, it can realize appropriate forwarding (e.g. load balancing) by an underlay and flexibility of ID Space by taking VM migration into consideration.

・**NFV- XaaS:** A technology to provide a single platform that can be used for various services and by multiple network users. It can reduce facility costs by providing a variety of services such as IaaS, PaaS, SaaS, etc. and sharing resources with multiple network users (e.g. service providers, MVNO users) on a platform generated by comprehensively virtualizing the core network.

・**NFV - MANO architecture:**
A technology for the operation and management of a virtualized network, an existing (non-virtualized) network, or a combination of the two. With a virtualized network, since it is easy to change resource size and layout, it can quickly change the scale of service based on status, plans, and the requests from maintenance personnel.

・**NFV - auto-healing:**
A technology that provides resiliency and stability, guaranteeing that no single point of failure can cause the entire network to fail and lead to a discontinuation of service. Using a virtualized network, it can improve network reliability by flexibly changing the layout of services and resources following a hardware failure.

・**NFV - service orchestration:**
A technology that accommodates various network services with different traffic characteristics and behaviors, making it possible to connect a huge number of devices such as sensor terminals to the network. It can enable a dynamic change of network functions. By enabling the flexible addition of new functions to the existing network infrastructure, new services can be introduced easily and quickly. It can reduce CAPEX and OPEX, and also power consumption, by consolidating many core network equipment types onto industry standard high volume servers, switches and storage.

・**NFV - SDN/NFV integration:**
A technology that verifies whether a virtual machine (VM) has started up correctly as programmed beforehand and has not been falsified. It ensures system security by inter-connecting safely operating equipment. It uses software-driven network control technology based on SDN and network function virtualization technology based on NFV. Since NFV MANO (management and orchestration) manages functional chains of nodes and higher layer operation support systems, SDN/NFV architecture can reduce network complexity and enhance network operation. NFV enables easy system roll-out, and CAPEX, OPEX and power consumption can be reduced by using a common platform.

6.2.2 Mobile Backhaul

Key component technologies related to the mobile backhaul are as follows:

・**Frame processing:** The MEF has established carrier-grade Ethernet technical specifications by applying OAM, etc. to IEEE802.3 based Ethernet technology. As a part of its activities, MEF has standardized carrier-grade Ethernet technology for mobile backhaul as the MEF22 series.

・**Space division multiplexing (SDM):** SDM can be realized with a single optical fiber having multiple cores, not a regular single-mode optical fiber. When the number of available wavelengths in an optical fiber is insufficient, the number of fibers can be increased. This is still in the development stage and a practical means for manufacturing and deploying these fibers has not yet been devised.

・**Wavelength division multiplexing:** A technology that makes efficient use of bandwidth by allocating variable wavelength grid, not fixed wavelength grid, in DWDM system. A flexible grid has been realized through the development of WSS. This is useful when a transmission line is shared with other base station circuits.

・**NW power saving:** A technology that coordinates between devices/equipment/network-level technology so they work together efficiently and thereby reduce power consumption. For example, a line concentration switch can be replaced with an optical switch. An optical transceiver is equipped with a sleep function so that it works only when there is actual traffic.

・**NW optimization:** A network optimization technology that takes the various physical performance limits of network equipment into consideration. For example, it can keep CAPEX within acceptable limits by enabling the installation of network equipment in a configuration that best suits actual user needs. For example, resources (switches, optical transceivers, etc.) having the right capacity can be installed and utilized.

6.2.3 Mobile Fronthaul

・**C-RAN transmission:** A BS architecture that brings together base band unit (BBU) resources from multiple cells, and antennas and radio transceivers are located in a remote location, away from the BBUs. This can reduce CAPX/OPEX by gathering together all available BBU resources, and allows for highly sophisticated CoMP and virtual multi transceiver applications.

・**Data compression:** A technology for the dynamic compression of IQ data based on the wireless signal bandwidth. Statistical multiplexing can be expected to be effective with the dynamic compression of radio signals, which increases the effectiveness of TDM-PON when it is utilized with the mobile fronthaul.

・**TDM - PON:** A technology that makes it cost effective to connect many RRHs and one BBU using currently installed optical fibers with time division multiplexing over PON. Since latency increases when TDM-PON technology is applied to the mobile fronthaul, DBA technology will need to be developed to handle scheduling for radio segments.

・**Modulation/demodulation:** A technology of modulation and demodulation that can economically realize ultra-high-speed transmissions in the mobile fronthaul

・**Space division multiplexing (SDM):** A technology to employ multi core optical fiber, as opposed to single mode optical fiber. When the number of available wavelengths is insufficient, the number of optical fibers will need to be added. Since this is still under development, manufacturing and construction costs could be an issue.

・**Wavelength division multiplexing (WDM):** A technology that can realize ultra-high-speed optical transmissions, either through the use of a “CWDM-like” transmission/reception method (a short term solution) or a “DWDM-like” transmission/reception method (a long term solution). Further improvements of wave-length multiplexing can be obtained through the application of flexible grid technology.

・**NW power saving:** A technology that reduces power consumption by coordinating the operation of devices/equipment/network-level technology. For example, a line concentration switch can be created using an optical switch. Another example is the equipping of an optical transceiver with a sleep function, so that it operates only when there is data traffic.

6.3 Mapping of relevant component technologies to resolve technical issues

6.3.1 Core network

Table 6.3.1-1 maps the various issues and component technologies, and indicates which technologies present good solutions to specific issues. A check mark in the table indicates that the corresponding component technology (see section 5) has been judged to be an effective solution. This is not meant to imply, however, that unchecked items have no value as a potential solution.

Table.6.3.1-1 Mapping of relevant component technologies to resolve technical issues – Core network (1/4)

Issues	Descrip-tions	Core network system technologies					SDN technologies			NFV technologies							
		Mobili-ty/Net-work access mgt.	Data aware net-work-ing	Context aware net-work-ing	User profile mgt.	Edge comput-ing	Net-work virtuali-zation	Service chain-ing	U/C separa-tion	Slicing	Auto-scale in/out	Comm-unica-tion be-tween VMs	XaaS	MANO architec-ture	Auto-healing	Service orches-tration	SDN/ NFV integra-tion
Ultra-large capacity U-plane	Load increase in U-plane					✓	✓							✓			
Load increase in C-plane	Increased number of sessions/ bearers								✓		✓			✓			
	Increased number of ID/identi-fiers	✓		✓	✓												
	Signalling increase								✓		✓			✓			✓

Table.6.3.1-2 Mapping of relevant component technologies to resolve technical issues – Core network (2/4)

Issues	Descriptions	Core network system technologies					SDN technologies			NFV technologies							
		Mobility/Network access mgt.	Data aware networking	Context aware networking	User profile mgt.	Edge computing	Network virtualization	Service chaining	U/C separation	Slicing	Auto-scale in/out	Communication between VMs	XaaS	MANO architecture	Auto-healing	Service orchestration	SDN/NFV integration
Ultra low latency	Latency due to physical distance		✓			✓											
Issues on transport layer	Frequent circuit change/ coping with various applications		✓														
Ultra large scale disaster/ congestion/failure resilience	Flexible congestion control & load distribution						✓				✓				✓		
Various types of terminal/ traffics/ operators and NW mgt.	Accommodate various terminals/ traffics with different requirements.			✓	✓											✓	
	Improving openness of NW functions									✓			✓				

Table.6.3.1-3 Mapping of relevant component technologies to resolve technical issues – Core network (3/4)

Issues	Descrip-tions	Core network system technologies					SDN technologies			NFV technologies							
		Mobili-ty/Net-work access mgt	Data aware net-work-ing	Context aware net-work-ing	User profile mgt.	Edge comput-ing	Net-work virtuali-zation	Service chain-ing	U/C separa-tion	Slicing	Auto-scale in/out	Comm-unica-tion be-tween VMs	XaaS	MANO architec-ture	Auto-healing	Service orches-tration	SDN/ NFV integra-tion
Inter-working (IW) with other RATs	Optimum RAT selection, high reliable seamless handovers, seamless access, IW between hetero-geneous RATs	✓															
Swift-ness	Guaran-teed swift introduce-tion of new functions and services							✓					✓			✓	
	Zero down time service						✓				✓				✓		
	New functions by vertualiza-tion, etc.												✓			✓	✓

Table.6.3.1-4 Mapping of relevant component technologies to resolve technical issues – Core network (4/4)

Issues	Descrip-tions	Core network system technologies					SDN technologies			NFV technologies							
		Mobili-ty/Net-work access mgt	Data aware net-work-ing	Context aware net-work-ing	User profile mgt.	Edge comput-ing	Net-work virtuali-zation	Service chain-ing	U/C separa-tion	Slicing	Auto-scale in/out	Comm-unica-tion be-tween VMs	XaaS	MANO architec-ture	Auto-healing	Service orches-tration	SDN/ NFV integra-tion
Cost	CAPEX reduction in NW mgt.								✓	✓			✓				
	OPEX reduction in NW mgt.						✓				✓				✓		
Flexibili-ty & optimiza-tion	Flexible & simplified NW opera-tions						✓				✓			✓			

6.3.2 Mobile Backhaul

Table 6.3.2-1 maps the various issues and component technologies, and indicates which technologies present good solutions to specific issues. A check mark in the table indicates that the corresponding component technology (see section 5) has been judged to be an effective solution.

Table.6.3.2-1 Mapping of relevant component technologies to resolve technical issues – Mobile Backhaul

Issues		New technologies				
		Frame processing	Space division multiplexing	Wave length multiplexing	NW power saving	NW optimization
Ultra large capacity U-plane	N-times extention		✓	✓		
	Cost increase	✓				✓
Ultra low latency						✓
Ultra large power saving	Power consumtion increase by N-times	✓			✓	
	Wasted power				✓	✓

6.3.3 Mobile Fronthaul

Table 6.3.3-1 maps the various issues and component technologies, and indicates which technologies present good solutions to specific issues. A check mark in the table indicates that the corresponding component technology (see section 5) has been judged to be an effective solution.

Table.6.3.3-1 Mapping of relevant component technologies to resolve technical issues – Mobile Fronthaul

Issues		C-RAN transmission	Data compress-ion	TDM-PON	Modulation	Space division multiplexing	Wavelength multiplex-ing	NW power saving
Ultra large capacity U-plane	N-times extention	✓	✓		✓	✓	✓	
	Cost increase	✓	✓	✓	✓			
Ultra low latency								
Ultra power saving								✓
Ultra large scale disaster/ congestion/failure resiliences		✓						

7 Considerations

Through this study, we have arrived at the following findings:

- To realize ultra low latency, new technologies will need to be introduced for use in the core network. At the same time, there are some physical restrictions with network node placement and the routing of the transmission medium for the mobile front/backhaul. It will be necessary at some future point to re-evaluate whether the desired benefits can be obtained from the introduction of the new technologies and whether there are any restrictions to where the network nodes can be located.

- Providing the ultra large capacity needed to accommodate the anticipated explosive increase in the number of IoT terminals while reducing CAPEX and OPEX (including power saving costs) for the core network and mobile front/backhaul will not be easy if one relies solely on the continued use of currently available commercial network technologies and introduction of virtualization technologies. If a quantitative analysis reveals that there is no means other than the introduction of new technology to address these issues, a thorough study of these new technologies will need to be carried out at an early stage.

- The required flexibility in processing power and the allocation of functions can be obtained through the use of existing technologies if resource allocation time is not an issue. New technology should be introduced to reduce the resource allocation time. It will be necessary at a later date to re-evaluate the requirements to judge whether the anticipated benefits justify the introduction of the new technology.

- It can be expected that the introduction of network virtualization technologies will enhance network management. While the impact of virtualization on the core network's functional architecture will be rather limited, this will play a key role in meeting the requirements for the optimization of the core network's performance (capacity, latency, etc.), congestion resilience and power saving efficiency.

Core network

As described in section 4, this study of future scenarios and issues with the current network has shown that the core network will play a central role in the future realization of an ideal mobile network. In addition to already apparent issues such as the load increases in the U- and C-planes, newly identified issues involving such topics as ultra low latency and network management will need to be addressed.

SDN and NFV virtualization technologies have already been shown to be effective, and further attention should be paid to resolving issues with new technologies such as data-aware networking, context-aware networking and mobile edge computing (MEC).

Mobile Backhaul

Even with statistical multiplexing, the mobile backhaul will need to have a capacity of around 1Tbps. To efficiently bring the mobile backhaul's power consumption down to one tenth of the current level, it will be necessary to control the supply of power for driving transmission equipment such as optical transceivers and interface circuits based on the amount of traffic. To keep devices reasonably compact and hold down electric power consumption, further progress in device integration will be essential.

Therefore, new cost-effective technologies that reduce power consumption and optimize capacity control based on traffic levels will need to be introduced.

Mobile Fronthaul

To hold down costs associated with the increase of network capacity and rising electric power consumption, further study should be devoted to means for optimizing the network architecture, including possible changes to how functions are allocated between a BBU and RRHs.

There are two important issues that need to be considered:

- how to handle a cell that has a capacity in excess of 100Gbps

- how to efficiently hold down costs and power consumption with a large number of small cells (approximately 100 times as many cells as with the current system)

For example, to reduce power consumption for the complete communication system to one-tenth of the current level, it would be necessary to lower the power consumed by all mobile fronthaul equipment to one-twentieth of the current level. Therefore, the current CPRI, etc. will need to be replaced with a new transmission methodology and/or a means for optimizing network control to reduce the entire communication system's power consumption will need to be devised.

A solution that extends beyond the mobile fronthaul will be needed for the handling of ultra large disasters, network congestion, and equipment failures.

8 Conclusion and proposal

This document's compilation of the various technical issues that will need to be addressed with the current core network and the mobile front/backhaul is based on the following scenarios that have been drawn up for 2020 and beyond:

- Data traffic will continue to increase in the years leading up to 2020 and beyond.
- In line with the rapid increase in the number of M2M/IoT terminals, the number of connections will continue to increase.
- Traffic levels will fluctuate widely from hour to hour due to variety in the types of services that will be on offer.
- There will be a need to accommodate a greater variety of access technologies.
- The advent of ultra low latency real-time control services such as tactile communication, V2X, AR, and M2M can be anticipated.

It will be noted that 5G research and pre-standardization activities within the relevant domestic and global organizations are ongoing. A survey of the main technologies that are candidates for inclusion in the 5G platform has been carried out by the relevant standards development organizations (SDOs) and research organizations of countries that have been playing a leading role in this effort, and useful insights into key technical issues and technologies have been obtained. Although it will also be noted that the definition or interpretation of "5G" differs depending on the organization; as such, there is not yet a unified definition of 5G.

This study has gathered information on the following important technologies and key technical issues.

(1) Based on a monolithic network architecture, the current mobile network has passed through the eras of 2G, 3G and 4G and the core network has steadily evolved by adding the functions needed to accommodate the changing requirements of services and radio access technologies. However, as discussed in this white paper, in the future the network side will need the capability to efficiently accommodate a greater variety of traffic and connect with a wide variety and huge number of M2M/IoT terminals.

(2) In the core network, a new setup will be necessary to efficiently accommodate multiple architectures that are optimized each for specific needs and conditions, and further efforts to integrate network and component technologies based on the promising NFV and SDN technologies will need to be made.

(3) Currently, the main communication services on offer are voice, multimedia services such as video, and SNS and other types of messaging services, while in mobile communications IMS is utilized for both fixed and mobile networks for the commercial provision of IP multi-media services. This technical survey has not uncovered any new study activities in Japan or other countries focusing on communication services for 2020 and beyond or new systems required for such services.

(4) Regarding the mobile front/backhaul, this study has identified a number of technical issues associated with the rising traffic volumes in the U-plane. While it has been essential to have ultra large capacity for both the mobile fronthaul and the mobile backhaul, this requirement will need to be mitigated through the continued enhancement of transmission technologies, and studies will need to be conducted that take the entire network into account when examining topics such as the appropriate layout of functions. It also has become clear that power consumption is becoming a serious issue for the mobile fronthaul because of the increase in capacity and the introduction of small cells, and it will be necessary to study new technology and architecture to resolve this.

(5) Taking the network management point of view, it is commonly known that relatively new technologies such as SDN, NFV, and virtualization are to be deployed on a large scale, and that scalable and flexible network management technologies are indispensable to the mitigation of network management costs associated with short service life-cycles and the handling of excessively large amounts of management data. These issues are acknowledged both domestically and globally. Network security issues will also need to be studied due to the complexity of a network architecture that utilizes virtualization and other technologies.

TTC has prepared this summary of the technical issues related to mobile networks for 2020 and beyond, and has done a domestic and international survey of potential solutions. Based on the results of this study, TTC will continue to study these issues in collaboration with the relevant organizations, and is considering activities such as the following:

- A quantitative assessment of the issues identified in this document
- The application of the component technologies discussed here
- Discussion and study of a complete new end-to-end architecture, including the radio system and the requirements for the entire system

TTC would like to emphasize that it will be much more important for a study of a unified network management approach for future mobile networks to be done from a comprehensive standpoint that considers not only radio system technologies but also the core network, the transmission network and the service network. TTC also wishes to affirm that it will continue to actively monitor trends in domestic and international 5G activities. TTC would like not only to accelerate the pace of global standardization activities related to5G, but also be a main driver in promoting research into the types of services, network architecture, and component technologies that society will need for 2020 and beyond.

Annex A Radio technologies

A.1 Radio transmission technologies

A.1.1 Multi-element technologies

Component technology	**Massive MIMO**
(1) Features	Massive MIMO with 256 antenna elements Reduced latency with sampling frequency at 2n times of 30.72 MHz
(2) Issues to be solved by this technology	• Transmission loss increase due to a high frequency band • Latency increase due to high speed data
(3) Benefits of this technology	Enabling more than 10 Gbps transmission in the 11GHz band
(4) Maturity level of this technology/ issues to be worked out	[Level of maturity] In the technical report, 10Gbps transmission has been achieved in the test trial. 30Gbps transmission is still at the feasibility study by computer simulation. [Issues】 Transmission power decrease
(5) Organization for this study	IEICE
(6) Reference	NTT DOCOMO/IEICE Technical ReportRCS2013-232

A.2 Radio system technologies

A.2.1 C-RAN technology

Component technology	DU virtualization
(1) Features	Digital Units ((DU) (Baseband Unit (BBU)) virtualization in the C-RAN architecture has been studied from an implementation point of view. There are two definitions: • DU sub-cloud (cluster) • DU Cloud with using GPP (General Purpose Processor)
(2) Issues to be solved by this technology	No description.
(3) Benefits of this technology	[DU sub-cloud】 It can maximize cost reduction by DU virtualization. [DU Cloud with using GPP] It enables efficiency improvement of wireless signaling processing and cost reduction by GPP (packet processing and Core network & L2/L3 processing).
(4) Maturity level of this technology/ issues to be worked out	The concept has been proposed, but the optimization will be For Further Study (FFS).
(5) Organization for this study	NGMN (Next Generation Mobile Network)
(6) Reference	NGMN / "Suggestions on potential solutions to C-RAN", 4.2.1 DU and DU Cloud

Component technology	RU remote monitoring method
(1) Features	Remote power supply method and remote monitoring method have been studied as a RU (RRH) implementation solution in the C-RAN architecture.
(2) Issues to be solved by this technology	In the C-RAN architecture, the method to supply power to RU remotely and the method to monitor and perform maintenance remotely are needed to study.
(3) Benefits of this technology	[Remote power supply] • Power supply in the wide area • Power supply backup and management • Easy method to protect from theft [Remote monitoring method] • Reducing monitoring cost by centralized monitoring
(4) Maturity level of this technology/ issues to be worked out	No description
(5) Organization for this study	NGMN (Next Generation Mobile Network)
(6) Reference	NGMN / "Suggestions on potential solutions to C-RAN", 4.2.4 RU and remote sites

Component technology	Method to build MFH economically
(1) Features	Ring topology, using OTN, applying WDM to PON architecture, and etc. have been studied to build Mobile Front Haul.
(2) Issues to be solved by this technology	Equipment cost increases if the network is configured by the exising 1:1 connection. This is because of increased capacity and number of links.
(3) Benefits of this technology	It enables economical network deployments.
(4) Maturity level of this technology/ issues to be worked out	It is necessary to compare cost efficiency for each network configuration.
(5) Organization for this	NGMN (Next Generation Mobile Network)

study	
(6) Reference	NGMN / "Suggestions on potential solutions to C-RAN", 4.2.5 Front Haul network solutions for C-RAN

Component technology	**C-RAN architecture**
(1) Features	C-RAN is an architecture, where BBUs (Base Band Units) of Multiple cells are concentrated as a common resource, and on the other hand, antenna & radio transceiver are in the each relevant remote cell.
(2) Issues to be solved by this technology	In the 5G network, many small add-on cells need to be introduced per macro-cell to cope with the ever growing traffic. So, CAPEX/OPEX of base station will be increased accordingly. CAPEX/OPEX should be reduced to a reasonable range.
(3) Benefits of this technology	• CAPEX/OPEX reduction by resource concentration • Advanced "Coordinated multipoint transmission/reception" (CoMP) technology will be available.
(4) Maturity level of this technology/ issues to be worked out	• C-RAN technology has already been commercially developed. • The Radio on Fiber (RoF) transmission with large capacity and low latency by CPRI is used in the current C-RAN, and ideal backhaul such as dark optical fiber is needed. The latency requirement limits the maximum length of optical fiber. (For example, up to 20 km).
(5) Organization for this study	ARIB 2020 and Beyond Ad Hoc
(6) Reference	ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond", Version 1.0.0, [A7.4]

A.2.2 HetNet technologies

Component technology	**UDN (Ultra-Dense Networks)**
(1) Features	It is a group of technologies to accommodate densely deployed small access nodes efficiently in the (overlay macro) area. • New RATs for high frequency bands • Coordinated multipoint (CoMP) transmission and reception techniques between small cells • How to handle traffic load in a wireless backhaul node • Etc.
(2) Issues to be solved by this technology	It should solve the following problems of decreased capacity due to increasing number of nodes in a (overlay) macro area: • Deterioration of frequency utilization efficiency due to increasing interference between cells • Increasing overhead of mobility management signallings, and deteriorating robustness due to increasing number of Hand Overs (HOs),
(3) Benefits of this technology	CoMP can contribute to improvement of capacity, etc. by achieving load distribution, minimizing the number of HO failures, reducing power consumption, reducing maintenance cost and providing efficient wireless backhaul.
(4) Maturity level of this technology/ issues to be worked out	3GPP has the following WIs for the EPC enhancement. • Cope with a high-density integrated cell by deploying small cells • Efficient Mobility Management due to congestion of signallings to a single local point
(5) Organization for this study	METIS
(6) Reference	METIS/Deliverable D6.2 Initial report on horizontal topics, first results and 5G system concept

Component technology	Coverage optimization (Multi-layer/Multi-band cells)
(1) Features	It can realize the optimum cell coverage according to traffic demand by overlaying multiple cells with various cell sizes. For example: • Coverage Cell: Mainly for C-plane, on the other hand, it is optional for U-plane. Frequency less than 3GHz is used. • Efficiency Cell: Mainly for U-plane, on the other hand, it is optional for C-plane. Frequency Band between 3GHz and 10GHz is used. • Capacity Cell: For U-plane. Frequency above 10 GHz is used.
(2) Issues to be solved by this technology	Traffic generation is not geographically uniform, but it is often localized. So, it is necessary to make optimum cell design for actual demand.
(3) Benefits of this technology	By optimization of coverage, it can improve CAPEX.
(4) Maturity level of this technology/ issues to be worked out	Method of overlaying simple cells has already been at the commercial service level. Highly sophisticated coordination between cells is FFS.
(5) Organization for this study	ARIB 2020 and Beyond Ad Hoc
(6) Reference	ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond", Version 1.0.0

Component technology	Summary of LTE-A HetNet systems implemented by FiWi Access NW
(1) Features	Listing up study items to realize LTE-A HetNet with the Fiber Wireless (FiWi) Access Networks: • Both of WDM PON and E-PON, or Wireless LAN are considered to compose Fiber Wireless (FiWi) Access Networks. Fiber Wireless (FiWi) Access Network. FiWi should be studied to realize LTE-A NetNet.
(2) Issues to be solved by this technology	1. Back-Haul infrastructure with large capacity and low latency: There is a mismatch between the following two: • Requirement from wireless part, • Performance of backhaul interconnecting base stations to realize CoMP. Latency is a key performance indicator (KPI) for CoMP. 2. Existing PONs for fixed broadband access should be commonly used with the Back-Haul for small cells: 3. Mobility management supported by user terminals: It performs traffic steering to route to a suitable cell and to provide a service with a suitable RAT. 4. Real-time development of failure recovery algorithm: It is an important technology to reduce OPEX/CAPEX. 5. Development of the intelligent WiFi off-load strategy: It is important to utilize WiFi as RAT effectively. 6. To cope with M2M communication and Smart-Grid application: It should be adapted to M2M communications. 7. How to accommodate Context awareness communications with D2D: • Optimum combination between LTE Direct with D2D communication and WiFi Direct via base station • How to form D2D group
(3) Benefits of this technology	• It can realize large capacity access network, and reduce CAPEX/OPEX. • It can accommodate more applications.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] Its purpose is to raise technical problems, so it does not show any solution. [Problems] LTE-A HetNet is the major target here. But there may be some possible other problems than described here in the future mobile access network, in which LTE-A HetNet is not the only technology.

(5) Organization for this study	IEEE ICC
(6) Reference	FiWi Access Networks: Future Research Challenges and Moonshot Perspectives

A.2.3 RAN sharing technologies

Component technology	**Common RAN**
(1) Features	• It divides an existing RAN into multiple virtual RANs by virtualization. And it can rent them to tenants. • It can also apply virtualization technologies not only to RAN parts but also to Back-Haul parts.
(2) Issues to be solved by this technology	• It should reduce CAPEX, which may be increased by using small cells. • It should reduce cost by virtualizing RAN on the cloud computing system.
(3) Benefits of this technology	It can reduce CAPEX/OPEX by sharing equipments.
(4) Maturity level of this technology/ issues to be worked out	Still at the conceptual stage
(5) Organization for this study	NetWorld2020
(6) Reference	NetWorld2020 ETP 5G: Challenges, Research Priorities, and Recommendations

Component technology	**Sharing RAN technology**
(1) Features	• When a RAN is shared by multiple MVNOs, radio resource allocation per cell to each MVNO is made by optimum load balancing based on its traffic demand. RSE (RAN Sharing Enhancement) Controller offloads UEs to cells with unused resources.
(2) Issues to be solved by this technology	• In 5G, since traffic capacity increase is expected, it will be necessary to increase the number of cells per area with small cells. • CAPEX/OPEX should be reduced.
(3) Benefits of this technology	• Effective reduction of CAPEX/OPEX by sharing equipments • Power saving
(4) Maturity level of this technology/ issues to be worked out	Partcially commercial development
(5) Organization for this study	ARIB 2020 and Beyond AdHoc
(6) Reference	ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond", Version 1.0.0, [A7.5]

A.2.4 SDN technologies

Component technology	**SDN controller**
(1) Features	It performs a virtual centralized operation to control Wireless Access networks by SDN Controller.
(2) Issues to be solved by this technology	It should solve a problem of interference between wireless access cells.
(3) Benefits of this technology	• Efficient avoidance of interference between wireless access cells • More efficient utilization of radio resource
(4) Maturity level of this	Since it describes the technology just at the conceptual level in the whitepaper,

technology/ issues to be worked out	actual control and scheduler should be verified.
(5) Organization for this study	ONF
(6) Reference	ONF White Paper "Software-Defined Networking : The New Norm for Networks" ONF Solution Brief "OpenFlow™-Enabled Mobile and Wireless Networks"

A.2.5 SON technologies

Component technology	**ANR, MRO, CCO ANR, MRO, CCO**
(1) Features	ANR: Automatic Neighbor Relation - renewal of list of neighboring cells for HO with priority level MRO: Mobility Robustness Optimization – Renew offset by a certain frequency of HO failures CCO: Coverage and Capacity Optimization – Setting optimum transmission power with information such as user throughput
(2) Issues to be solved by this technology	Load increase by small cells and communication quality deterioration between micro cell and small cell.
(3) Benefits of this technology	It can give a good balance between cost reduction for development & operation and stable high quality of service.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level] It is still in feasibility study by computer simulation in the technical papers. [Problem] Definition under multi-vendor environment and procedures
(5) Organization for this study	IEICE
(6) Reference	NEC/IEICE Technical Report RCS2013-234

Component technology	**Optimized system for coverage/ HO**
(1) Features	Coverage optimization: To change cell size by dynamic transmission power control. HO optimization: Automatic adjustment in threshold level, margin, timing etc.
(2) Issues to be solved by this technology	It increases OPEX due to complex system parameter adjustments.
(3) Benefits of this technology	It can provide a good trade-off between cost reduction for development & operation, and stable high QoS.
(4) Maturity level of this technology/ issues to be worked out	Maturity level: It is still a feasibility study by computer simulation in the technical papers. Problem: It should be verified in real environment.
(5) Organization for this study	IEICE
(6) Reference	KDDI/IEICE Technical Report RCS2013-233

A.2.6 Edge computing technologies

Component technology	**Network performance improvement technologies with data cache**
(1) Features	It is Software-Defined PON Back-Haul architecture, by installing a controller to allocate band-widths and manage data cache.
(2) Issues to be solved by this technology	PON has been studied for a solution to accommodate expected high speed traffic transmission such as high-definition (HD) video streaming. On the other hand, data caching has been studied to reduce ever-growing traffic.
(3) Benefits of this technology	Software-defined PON is expected to provide 50% latency improvement and 30% performance improvement in video requests.
(4) Maturity level of this technology/ issues to be worked out	[Maturity level]: It is still at the computer simulation stage. [Issue] —
(5) Organization for this study	[Organization to study]: IEEE/OSA and NEC Laboratories America

(6) Reference	[Reference]: Joint Bandwidth Provisioning and Cache Management for Video Distribution in Software-Defined Passive Optical Networks

A.2.7 Mobile Relay technologies

Component technology	**Mobile Relay**
(1) Features	It can reduce signaling overheads by introducing moving cells to cover moving vehicles such as buses or trains.
(2) Issues to be solved by this technology	In the case of great many active users in a high-speed moving vehicle, huge amount of simultaneous HO signallings are generated.
(3) Benefits of this technology	• Easy deployment of network and improvement of deployment speed • Reduction of mobility management signallings • Reduction of CAPEX/OPEX。
(4) Maturity level of this technology/ issues to be worked out	It has been studied in 3GPP (TR 36.836).
(5) Organization for this study	ARIB 2020 and Beyond Ad Hoc
(6) Reference	ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond", Version 1.0.0, [A7.2.3]

A.2.8 Device to Device (D2D) Proximity Communication technologies

Component technology	D2D Proximity Communication
(1) Features	The D2D concept is built around the idea of enabling two or more mobile devices in proximity of each other to establish direct local links. A mobile device outside of the cell can communicate with a mobile device within the cell. To improve communication reliability, the same data is transmitted over two different routes via conventional network and D2D direct communication, or the data is transmitted by switching the route to adapt to the environmental condition.
(2) Issues to be solved by this technology	In the current communication system, even if the corresponding device is in close proximity to the calling device, the communication link via network is established. It is a resource waste. So, D2D is introduced to utilize network resource efficiently.
(3) Benefits of this technology	(1) It can reduce cost of Back Haul Network by traffic offload. (2) It can improve communication reliability by providing two routes, conventional route via network and D2D direct route. (3) It can increase traffic capacity per area. (4) It can reduce End-to-End data transmission latency. (5) It can improve coverage.
(4) Maturity level of this technology/ issues to be worked out	METIS has not produced any technical report on it. On the other hand, 3GPP has been working on its technical specifications in Release 12/13.
(5) Organization for this study	METIS
(6) Reference	METIS/Initial report on horizontal topics, first results and 5G system concept.

Component technology	**Extension of Device-to Device proximity communication**
(1) Features	The concept of the D2D proximity communication, which includes licensed frequency band, is extended further to cover other usages.
(2) Issues to be solved by this technology	Further optimization of Device-to Device proximity communication and transfer Extension with relaying between conventional coverage devices Enabling communication efficiency by unifying multiple device

	communications.
(3) Benefits of this technology	It can be an optimum implementation scenario for radio resource. It can be a communication means in the isolated area caused by neotwork failure.
(4) Maturity level of this technology/ issues to be worked out	From the beginning of the 5G study, it has been studied as a main solution but not an additional component.
(5) Organization for this study	4G Americas
(6) Reference	4G Americas, 4G Americas' Recommendations on 5G Requirements and Solutions, OCT 2014

Component technology	**Mesh Network**
(1) Features	It is a mesh network between devices. A part of traffic is transmitted over the direct link between devices. The routing can be set up by SIPTO-like algorithm.
(2) Issues to be solved by this technology	It is required to restore or extend network immediately for out of service area due to disaster or failure.
(3) Benefits of this technology	Easy network deployment, and faster deployment
(4) Maturity level of this technology/ issues to be worked out	Mesh network itself is an existing technology, but it has not been studied for applying as a part of mobile system yet.
(5) Organization for this study	ARIB 2020 and Beyond Ad Hoc
(6) Reference	ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond", Version 1.0.0, [A7.2.2]

A.2.9 Coordination technology between Radio Access Technologies (RATs)

Component technology	**Unified management of multi-RATs by Single Radio Controller (SRC)**
(1) Features	Single Radio Controller (SRC) controls multiple RATs, and it controls multiple RATs via the same single Core Network (CN) Interface.
(2) Issues to be solved by this technology	• Efficient frequency spectrum utilization • QoE provisioning without RAT dependency • Enabling easy interoperability between RATs • Simplified network management
(3) Benefits of this technology	It can easily perform traffic load distribution, and it can improve frequency spectrum utilization and User Experience.
(4) Maturity level of this technology/ issues to be worked out	Still at the conceptual stage. It is assumed that C-RAN will be introduced.
(5) Organization for this study	Wireless World Research Forum (WWRF)
(6) Reference	WWRF Outlook 9 (Multi-RAT Network Architecture)

Component technology	**Unified management of radio resources by Unified Radio Controller (URC)**
(1) Features	It can unify various heterogeneous Wireless Access methods such as 3G/4G, WiFi. The Unified Radio Controller (URC) can control unified radio resources.
(2) Issues to be solved by this technology	Since a single RAT has limited capacity for ever-increasing traffic from the points of cost and frequency spectrum, existing RATs and other RATs such as Wireless LAN, etc. should be utilized to complement lack of capacity.
(3) Benefits of this technology	Improve traffic capacity by multi-band and multi RATs. CAPEX/OPEX reduction by using the existing access methods。 Improve QoE by seamless Handover (HO) between heterogeneous networks
(4) Maturity level of this technology/ issues to be	3GPP includes non-3GPP access accommodation, but further enhancement toward 5G will be needed. It is FFS.

worked out	
(5) Organization for this study	ARIB 2020 and Beyond Ad Hoc
(6) Reference	ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond", Version 1.0.0, [A7.2.1]

(Note) Although the above mentioned two technologies (SRC and URC) are defined in the different oraganizations, both concepts are similar. There are some differences: URC is defined for radio resource control, on the other hand, SRC includes unification of CN interface.

Component technology	Multi-RAT integration
(1) Features	Seamless integration of different types of wireless systems
(2) Issues to be solved by this technology	• Improve User Experience for 5G Use Cases • Improve operation efficiency for 5G Use Cases
(3) Benefits of this technology	Guaranteeing service level and/or interference avoidance for coverage increase and accommodating ever-growing number of customers
(4) Maturity level of this technology/ issues to be worked out	Extension of the current 3G/LTE-WiFi Integration
(5) Organization for this study	4G Americas
(6) Reference	4G Americas, 4G Americas' Recommendations on 5G Requirements and Solutions, OCT 2014

Component technology	Mobile Backhaul access integration
(1) Features	It can integrate Mobile Backhaul Radio and Access Radio from both aspects of frequency and system.
(2) Issues to be solved by this technology	It can mitigate inefficiency due to the division into Back-Haul Radio and Access Radio, by coping with demand of increasing radio needs for Back Haul links with extension of small cell utilizations.
(3) Benefits of this technology	It can improve E2E performance and QoS by enhancing utilization efficiency of system and radio.
(4) Maturity level of this technology/ issues to be worked out	It is for further investigation.
(5) Organization for this study	4G Americas
(6) Reference	4G Americas, 4G Americas' Recommendations on 5G Requirements and Solutions, OCT 2014

Component technology	Coordination technologies between radio systems (Phantom Cell and WiFi)
(1) Features	Multi-Domain Radio Resource Management (MD-RRM) can provide information on user’s mobility with optimum system selection and service. • It can perform scheduling of radio resources for Cellular system and Wireless LAN in real-time mode, based on information on user’s mobility with optimum system selection and service, provided by MD-RRM.
(2) Issues to be solved by this technology	To maximize utilization of limited radio resources for higher speed and higher capacity.
(3) Benefits of this technology	It enables to provide high throughput according to the traffic load to the Access Points of Wireless LAN.
(4) Maturity level of this technology/ issues to be worked out	[At the maturity level] It is still at the stage to confirm its efficiency by computer simulation in the technical papers. [Issues] It should be confirmed its efficiency by the trial test.
(5) Organization for this study	IEICE
(6) Reference	NTT DOCOMO/ IEICE Technical Report RCS2013-237

A.2.10 Other radio technologies

Component technology	URC (Ultra-Reliable Communication)
(1) Features	It guarantees stable and reliable connectivity.
(2) Issues to be solved by this technology	It can guarantee high reliability for connectivity and availability even under severe conditions. It needs to support the various connectivity requirements for the following different communication-types: • Always connected communication-type like cloud computing with small amount of data and low data speed or latency requirement • Latency critical communications such as V2V, V2X, etc.
(3) Benefits of this technology	By solving the above mentioned issues, it can guarantee the following stable connections: • Accommodating 10 - 100 times more number of connected devices than now, • Prolonging device battery life 10 times more than now, • Reducing E2E latency to one-fifth of the present system.
(4) Maturity level of this technology/ issues to be worked out	Although actual solutions have not been described, it is mentioned that activities at 3GPP (for example, Public Safety (R12)) or IEEE are quite limited.
(5) Organization for this study	METIS
(6) Reference	METIS/Deliverable D6.2 Initial report on horizontal topics, first results and 5G system concept

Annex B Member list of the TTC Ad Hoc group on Future Mobile Networking

	Role	Company/Organization	Name
1	Leader	NTT DOCOMO INC	Takatoshi Okagawa
2	Sub-leader	KDDI Corporation	Michiaki Hayashi
3	Member	NTC Corporation	Koji Sato
4	Member	NTT COMWARE CORPORATION	Kei-ichi Sasaki
5	Member	NTT DOCOMO INC	Atsushi Minokuchi
6	Member	Oki Electric Industry Co. Ltd.	Masayuki Kashima
7	Member	KDDI Corporation	Atsushi Tagami
8	Member		Akira Yamada
9	Member	Cyber Creative Institute Co., Ltd.	Kenji Nakanishi
10	Member	SHARP Corporation	Tetsuro Moriwaki
11	Member	National Institute of Information and Communications Technology (NICT)	Toshiaki Kuri
12	Member		Nozomu Nishinaga
13	Member	SOFTBANK Mobile Corp.	Daisuke Yokota
14	Member	NEC Corporation	Takanori Iwai
15	Member		Takashi Egawa
16	Member		Kenji Obata
17	Member		Toshiyuki Tamura
18	Member		Hideo Himeno
19	Member	NTT	Hiroshi Ou
20	Member		Jun-ichi Kani
21	Member		Kenichi Kawamura
22	Member		Arata Koike
23	Member	Nokia Networks Japan	Kiyohisa Wakabayashi
24	Member	Hitachi Ltd.	Yoshinori Ishikawa
25	Member	Fujitsu Ltd.	Shinichiro Aikawa
26	Member		Ryuichi Takechi
27	Member	Mitsubishi Electric Corp	Masatoshi Katayama
28	Member		Takashi Nishitani
29	Member		Fumiki Hasegawa
30	Member		Tetsushi Matsuda
31	Special Member	University of Tokyo	Akihiro Nakao
32	TTC Strategy Committee Member	KDDI Corporation	Masaaki Koga
33	TTC Strategy Committee Member	NTT	Kenichi Hiraki
34	TTC Strategy Committee Member	Fujitsu Ltd.	Mitsuhiro Azuma
35	TTC Secretariat	TTC	Masanori Goto
36	TTC Secretariat		Koichi Onohara