Executive Summary

Japan led the world in mobile feature phone services, such as e-mail services via the internet, wide variety of information services by websites specifically designed for mobile phone screens, TV broadcasting service by One-Seg, and electronic payment services. With the advent of the 4th generation mobile communication system (4G), the people of Japan have gained access to a nationwide mobile broadband network. As users of smartphones are growing rapidly in Japan, services with rich content, such as HD video, e-books, music, and video games are widely provided. With these cutting-edge services, Japan has one of the most mature mobile communication markets which are able to enjoy the world leading mobile services.

As these new content-rich services have become more popular year after year, internet traffic has sharply increased along with the need for more network capacity and higher speeds. The services being offered are also diversifying, and both human-to-human and human-to-device communication is increasing. As network and sensor technology advances, device-to-device communication, what is called, the Internet of Things (IoT), is also expanding worldwide, leading to a further increase in traffic. This facilitates changes in ICT services for entertainment, transportation, industry/verticals, and emergency and disaster relief. Examples include artificial intelligence and adorable robots that assist people in their home and work lives, autonomous vehicles like unmanned taxis as well as vehicles that can provide mobility for senior citizens, and wearable devices that collect and analyze vital data to assist in health and medical services. These are just some of the services that are expected to be implemented in the near future as these trends continue to accelerate. However, the current 4G technologies, as well as its extension, may limit the growth of mobile services, especially when considering the needs of the 2020s. In order to accommodate the rapid growth with sufficient capacity and speed, there is strong global interest for research and development of the 5th generation mobile communication system, known as 5G.

The Fifth Generation Mobile Communications Promotion Forum (5GMF) was established in Japan on September 30, 2014 to actively promote 5G study in line with

trends both in Japan and abroad based on a roadmap on 5G implementation policy published by the government of Japan. This white paper discusses the expected many new uses of ICT in the 5G era by various industries, as well as the new businesses and markets that will be created and the expectations of the fuller lifestyle that it will bring to people everywhere. 5GMF has collected in this white paper the opinions and ideas of experts in industry, academia and government concerning their views of the future of applications, networks, and wireless technology related to 5G in order to provide a clear goal for the development of 5G.

More specifically, this white paper provides information on research into everyday uses of mobile applications, including use scenes in industry, transportation, education, logistics, medical, health and welfare services, safety, emergency, and disaster relief. The research presented looks at these mobile applications from many different viewpoints, clarifies the technical requirements for the mobile communication systems as a fundamental part of society. Additionally, it reports on high quality and cutting-edge services demanded by consumers, and results of research and analysis into the trends of society and markets. It also predicts on the use scene of the 2020s and applications that will be needed in that time frame. Then, based on these expected use scenes, key concepts of 5G, requirements, capabilities, architecture, and key technologies for 5G, and the desirable radio frequencies for 5G are discussed. Below is a description of some of the results about the main features of 5G that came out of this research.

5GMF proposes in this white paper two key concepts for 5G: “Satisfaction of End-to-End (E2E) quality” and “Extreme Flexibility.” "Satisfaction of E2E quality" means providing every user satisfactory access to any application, anytime, anywhere, and under any circumstance. “Extreme Flexibility” is the feature of communications systems which will allow 5G to always achieve E2E quality.

User demands and needs for E2E quality in the 5G era will be much more diverse when compared to previous generation systems. The dynamic ranges fluctuated by the temporal and spatial factors will also expand more dramatically. These changes determine a major requirement for 5G which is completely different from previous

generation systems, for which providing best effort quality was sufficient. Additionally, when thinking about radio access and network coordination concerning constrains of temporal factors, the minimum latency is determined by the path length between servers and terminals or controllers and controlled equipment in the network. Thus extreme flexibility cannot be realized by an individual radio access or core network on their own. Rather extreme flexibility through the coordination of networks will be needed in order to provide the dynamically diverse and fluctuating E2E quality that users will demand.

In previous generation systems up to 4G, radio access networks were regarded as dominant bottleneck which determined the E2E quality of mobile applications and services, since the performance of radio access networks were limited by a number of constraints, such as radio propagation characteristics, available bandwidth, handset power, mobility, and so forth. In the 5G era, however, it is expected that most of these constraints will be greatly relaxed by the advancement of radio technologies. The performance of radio access networks alone is no longer the sole bottleneck; the performance of core networks will also be taken into account to satisfy E2E quality. Therefore, the technologies for radio access and core networks should be jointly studied and developed on an equal basis in order to realize "Extreme Flexibility".

This white paper identifies two key technologies necessary to support the wide range of use cases expected in the 5G era through "Extreme Flexibility". The first is an "Advanced Heterogeneous Network". The second is "Network Softwarization and Slicing".

Heterogeneous networks deployed with a single Radio Access Technology (RAT) that was standardized in 4G. However, due to the differences of user requirements for 5G services, depending on time and local geographic environments, the new RAT will need to be able to provide overall management with connections to already existing 2G, 3G, LTE, WLAN networks and be able to create new subnetworks in order to provide high level functions necessary to provide 5G users with the flexibility to access to a wide range of requested services anytime, anywhere.

This white paper proposes that the scope of integrated radio access networks be largely extended to include multiple technologies shown above and that the network,

realizing heterogeneity far beyond that in the previous heterogeneous networks, be called an “Advanced Heterogeneous Network”.

Network softwarization will greatly improve flexibility in design, implementation, deployment, operation and maintenance of network functions and components, and increased velocity of service delivery by making the best use of programmability. In addition, application of “Slicing” will increase the efficiency and dynamicity of 5G systems, since it enables just-in-time assembly of network functions and components for service delivery in concert with arrangement of advanced heterogeneous networks.

It is hoped that 5G standards will allow for wireless and wired networks to have the ability continue to handle growing demand for larger capacity and higher speeds as previous mobile communication systems have. It is expected that data traffic in the 2020s will be 1,000 times larger than that of 2010, meaning 5G standards will need to able to support this high level of data traffic. In addition, in order for users to be able to comfortably access rich, data-intensive content, 5G standards will need to support high speeds of more than 10Gbps.

Although transmission latency of 10s of milliseconds have already been realized by LTE/LTE-Advanced, new use cases in the 2020s such as haptic communication, robot control systems, and other control systems, will require lower latency in addition to other possible use cases that will require both low latency and high reliability. Based on these use cases, E2E latency will need to be on the order of milliseconds. Transmission latency over wireless sections of the network will especially need to be kept at less than 1 millisecond while maintaining 99.999% reliability.

Previous generations of mobile communication systems did not design for handling massive number of devices with simultaneous connections. 5G will need to meet this requirement due in part to the expected dramatic increase of IoT devices in the near future, for which 5G will be expected to support 100 times or more simultaneous connections than that currently supported.

Key technologies corresponding to these requirements will be utilized up to its maximum potential and will enable us to support new use scenes for the 2020s and beyond. Examples of these use scenes include: an air ambulance that can support surgery en route to a hospital, which will require a high capacity, low latency, and a

disaster resilient network; micro robots for use in next generation agriculture, requiring high capacity, massive number of devices with low power consumption; streaming HD video while moving at ultra-high speeds, which will require ultra-high speed mobility and high capacity; and experiencing sports events in the viewpoint of players through an HD 3D live feed, which will require high capacity, support of massive number of devices simultaneously connected, and low latency. 5G will provide the opportunity to provide these revolutionary services to everyone.

Using the above research as a base, the 5GMF has contributed to ITU and 3GPP in frequency coordination, standardization, and other related activities, built collaborative relationships with 5G related organizations internationally, and disseminated 5G related information to the relevant industry sector. Along with continuing to carry out these activities going forward, in order to support the successful implementation of 5G, 5GMF plans work with partners from Japan and abroad to hold 5G verification trials under the actual condition to attract the relevant industry to utilize 5G, to give demonstrations of 5G characteristics, to consider a platform where service providers will be able to easily offer 5G related services to their customers, and to acquire the necessary frequencies bands for 5G both domestically and internationally. These activities by 5GMF will accelerate the pace of actions needed to successfully implement 5G by the year 2020.

In addition, 5GMF expects that the results of the research reported in this white paper will support ongoing and new research and development, standards activities, and radio frequency allocation coordination, as well as strengthening and extending international partnerships, and will promote to build collaborative relationship with a variety of industries in order to make the best use of 5G in user scenarios for entertainment, transportation, industry/verticals and emergency and disaster relief.

Abstract of the White Paper

1. Market and User Trends related to 5G (Chapter 3)

This chapter, in addition to gathering information on ICT usage, broken down by age group, type of content, and type of device, and relevant industries and services, attempts to predict future trends in order to understand what the communication environment will be, and thus what mobile communication services will be in demand, in 5G era.

Trends indicate that internet use will increase broadly across all ages and that young people, especially women, will increasingly access the internet through mobile devices. Unlike in the recent past that internet was accessed through personal computers and similar devices, more and more people are accessing the internet through their smartphones, tablets, and wearable devices. In addition, many kinds of devices, such as new types of sensors, robots, including drones, and cars, are also increasingly connected to the internet.

Once 5G is introduced, many new services will be launched: artificial intelligence and adorable robots to assist people in their daily lives, and in industrial services, autonomous vehicles such as driverless taxis and elder care support vehicles, and wearable devices that will track and analyze vital data to provide information for health services.

In addition, people will be able to access real time geographic information with traffic jams or road construction information through maps that are updated dynamically. Plus, not only information but also objects and devices will become more sharable as information when the times and locations they are available to be borrowed can be accessed dynamically, as well. Finally, as fintech becomes more advanced and its user base increases, support for the introduction of new financial services will also occur.

2. Traffic Trend (Chapter 4) and Cost Implications (Chapter 5)

This chapter introduces the most up to date analysis of data traffic. Data traffic has been increasing dramatically over a period of several years, and research and analysis shows these trends will continue over the next decade, as well. Additionally, communication networks that will connect all things and all services will be used, which is assumed will also certainly create new traffic.

Accordingly, 5G will add to this sharp increase in traffic, and as a new type of communication systems, it is important that it is able to handle these new patterns of traffic when its introduction will certainly bring into existence.

After analyzing communication systems construction and operating costs, household mobile communication expenditure trends, and telecommunication carriers projected revenue, it concludes that these projected increase in traffic will not necessarily lead to an increase in business. Population surveys shows population shifts, both in terms of location and time of day, especially the large changes in daytime and night time populations. The amount of connections between people and things means the future of mobile commination systems will be used in a much broader way than they are today. In order to satisfy these demands, it is necessary to build a network that is both flexible and extendable.

3. 5G Key Concepts (Chapter 6)

5GMF proposes in this white paper two key concepts for 5G: “Satisfaction of End-to-End (E2E) quality” and “Extreme Flexibility.” "Satisfaction of E2E quality" means providing every user satisfactory access to any application, anytime, anywhere, and under any circumstance. “Extreme Flexibility” is the feature of communications system which will allow 5G to always achieve E2E quality.

5GMF believes the key technologies for 5G include an advanced heterogeneous network, network softwarization, and slicing.

5G will not be made up of a single network, rather it will use advanced heterogeneous networks, 5G radio access technologies (RAT), and connecting to already existing 2G, 3G, LTE, WLAN networks via RAT to create an integrated system that can provide support for a variety of services with flexibility. Additionally, with network softwarization, network devices, and components can be designed, introduced, maintained, and administered with easily updated programmable software as well as ensuring that network devices and components can easily and flexibly be used and maintained.

In addition, using the ITU-R vision report M.2083-0 as a base, typical use cases (high reliability, ultra-low latency communications, massive communications, advanced mobile broadband) with examples of what technology and requirements will be needed

to make these use cases a reality is discussed.

4. 5G typical use scenarios (Chapter 7)

5GMF surveyed and analyzed market and user trends to understand the following use scenarios: 1) entertainment, 2) transportation 3) industry/verticals 4) emergency and disaster relief.

Entertainment use scenarios include those that create high level user experiences to allow those who enjoy spectator sports, games, travel, and other forms of leisure activities to be able to have more fulfilling experiences than today. Users will even have the ability to access mobile networks easily in locations where many people gather together or to collaborate with a variety of people and devices over long distances.

Transportation use scenarios include a high level of services supporting people and things while they are moving. The use scenarios include autonomous cars that drive without any attendance of a human, drive assistance that provides passengers a pleasant drive through providing information to avoid traffic jams and other dangers and route direction that helps people move easily at a busy event. The use scenarios also include enhancing user experiences on devices even in high speed vehicles, from cars to magnetic levitation train, and user guidance systems to provide concrete navigation and actions for users by the collection of data from different sensors and analyzing this information.

Industrial/vertical use scenarios include applying ICT in other industry, such as manufacturing factories and agricultural fields, that will create innovative and inventive ways of working, and increases in sophistication in manufacturing process. Through the use of ICT in various industry sector, compared to previous trends in industry, productivity will be increased, new business models or new value will be crated. Though using sensor networks and big data analysis and low latency feedback to actuators, new business opportunities of drones, sensors, and industrial robots will be developed, as well.

Emergency and disaster relief use scenarios include providing high level first aid and other needed functions during an emergency. It will be realized that providing emergency help during a traffic accident, supporting communications for first responders during a disaster, locating missing individuals, providing information for evacuation routes, and supporting the efforts of rescue workers in disaster areas.

5G systems do not always need to achieve its maximum performance. 5G systems will be determined based on individual use scene requirement. These requirements will change dynamically depending on the time, location, and situation. Therefore, the network needs to be optimized for each individual use scene. It is effective for this optimization approach to utilize advanced heterogeneous networks, which coordinate the different RAT systematically. In addition, end to end connections, including to fixed networks, need to be flexible in order to accommodate different use scenes as well as their dynamic changes, making network softwarization and slicing key technologies for 5G.

5. Radio and Network technology used to deploy 5G (Chapters 8 -12)

In order to realize extreme flexibility of 5G, it is required to utilize any frequency bands from low frequency bands to high frequency bands depending on their characteristics.

5GMF has analyzed which frequency bands are most desirable for 5G, especially in the 6GHz to 100GHz bands. The first stage of this research is the analysis from the viewpoint of 5G, the second stage is the evaluation from the viewpoint of interacting with other systems, and the third stage is the evaluation from the viewpoint of international cooperation. This white paper has presented a list of desired frequency bands as a result of second stage research.

Regarding research on 5G RAT, 5GMF has shown some of the current promising technologies. These new technologies have been sorted and organized in order to understand how they will be used to support the necessary requirements of 5G, including high speeds, high capacity, massive number of devices with simultaneous connections, and high reliability and efficiency. The ITU-R, 3GPP, and other international organizations will be able to use this research to concretely decide on what needs to be tested and what standards will define 5G. These technologies and standards can then be quantitatively tested for practical use with the expectation that standards which can be reasonably met by the market will be quickly decided and published.

Regarding network technology for 5G, 5GMF describes technologies to implement extreme flexibility and to enable wide variety of services to be provided. Network Function Virtualization (NFV)/Software Defined Networking (SDN) technology has

been developed with the goal of promoting network virtualization. Network softwarization is the overall industry trend including NFV and SDN and it will be one of the main technologies to promote network flexibility. There are four focus areas where these technological trends are to be further explored: network softwarization, network management technology, fronthaul/backhaul, and mobile edge computing. An overview of technologies in each area is given, followed by thorough discussion and how to implement these technologies as well as possible use cases in 5G and beyond, as well.