Future Generation Spectrum Standardization for 5G and Internet of Things

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Abstract**—**Spectrum designing, and standardization of network systems are utmost concerns in realizing the full vision and benefits of forthcoming generations. Moreover, such measures could promote the innovation and competition of new spectrum approaches and services. Future generations will deliver high quality services beyond the expectations and limitations of the present features of conventional mobile broadband services. Therefore, spectrum enhancement will be indispensable to meet this evolution. Two leading and important technologies, namely, Internet of Things (IoT) and mobile communication, are expected to drive innovation. In the perspective of 5G, the spectrum of the future generation will reach up to 300 GHz, while in the perspective of IoT, the range would reach up to 6 GHz to meet future spectrum requirement. The current study delineated the major differences between previous generations and 5G. We included a substantially proposed spectrum for future generation, test trial ranges of spectrum, high band frequencies under consideration, and sharing schemes. Then, we culminate this study with the effective ranges to achieve a harmonized spectrum.

Index Terms**—**5G, Fifth generation, spectrum, sharing, internet of things (IoT)

I. Introduction

In this decade, 5G is attracting attention from organizations and countries based on the strength of its key capabilities, rendering 5G a game changer technology. 5G is an active area of research standardization and evaluation. First, we present a brief comparison between 5G and previous generations. In the past three decades, mobile and wireless communications have transformed the ways people communicate. 4G network technology replaced 3G and offered faster speed for users for media streaming, browsing, and downloading of data. 4G connectivity was reliable and delivered higher speeds than previous generations. Currently, 4G LTE technology has the best performance, speed, and connectivity for mobile Internet experience up to 10 times better than 3G. LTE continues to grow faster, as various edges require improvement before transferring to 5G. The next generation technology is being designed by successional 4GLTE. After the deployment of 5G, the technology will deal with all user connectivity issues wherever one travels, regardless of the number of devices connected in the same place at the same time. High frequency bands will be used in 5G, which uses higher frequency signals than 4G, due to a high spectrum range of approximately up to 300 GHz. Future 5G spectrum will include 28, 37, and 39 GHz bands. [1]The Internet and mobile communication have grown rapidly since their early stages and with the acceleration of connected technologies and appliances. The goal is to achieve bigger accomplishments with the technology and to continue such target. (See ref. Fig. 1) Fig. 1 represents the revolution of LTE technology from the startup analog system to 5G.

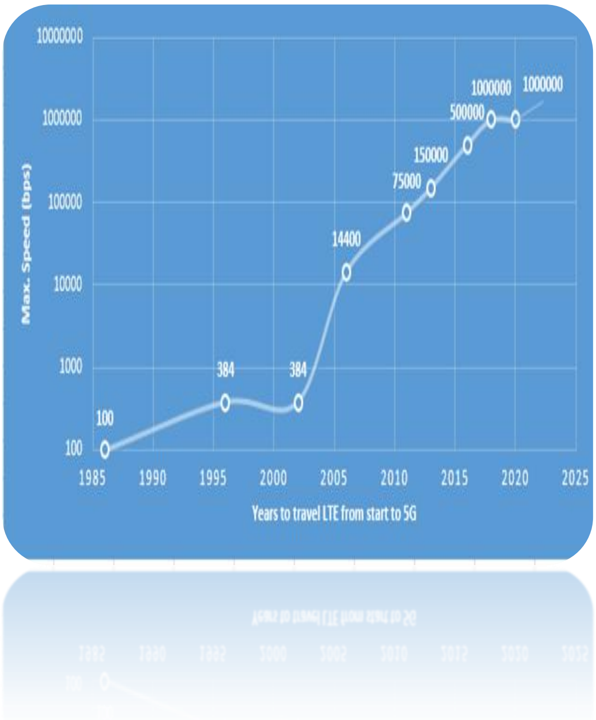

Fig. 1. Road bridge to 5G

5G architecture will build upon different technologies, including 4G, LTE, and other previous networks, with supporting 1–10 Gbits/sec bandwidth and 1 ms latency. The dream of downloading substantial data in only a few seconds is coming true. A comparison between 4G and 5G shows the impressive change from the present and future technology (see Table I).

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TABLE I. COMPARISON OF 4G AND 5G

Comparison	4G	5G
Downloading Speed	200Mbps average Theoretical 300Mbps	10-50Gbps Test environment 1Tbps
Latency	50 milliseconds	1 millisecond
Spectrum Frequency	800 MHz,1.8GHZ,2.6Ghz	700MHz,2.3GHz,3.4GHz,3.6-3.8 GHz, 24GHz and higher
Bandwidth	200mbps	>1gbps
Data Speed	1 GB	10Gb
Spectrum efficiency	30 b/s Hz	120 b/s Hz

5G is approaching high-performance ratings and will play a vital role in advancing and improving technology to match the needs of the present time.

II. 5G SPECTRUM

Spectrum standardization is currently an important issue in the standardization of 5G technology. Standardization features of 5G define additional throughput; reduced latency; and improved performance, coverage, and low cost. According to current research, spectrum standardization is expected to range from 0 to 100 GHz in 5G and may even reach up to 300 GHz in the case of mm wave [1] scenarios. In the context of 5G scenarios, global researchers and institutions consider research projects in 5G, such as China IMT [2], METIS [3], PCAST [4] Fire [5], and Fire+ [6]. Current studies on 5G in spectrum standardization indicate that a spectrum below 6 Ghz will be the best resource related to performance in the near future [7]. According to spectrum demands, one of the most important questiosns is the calculation of the spectrum demand (Ref, Fig. 2). Apart from these current methodologies, various other approaches have been proposed by different countries, such as the USA, Japan, Korea, Russia, Australia, and the UK. The important part is to calculate the actual demands of spectrum based on exponential growth of mobile networks and data. The answer is described by OFFCOM [8].

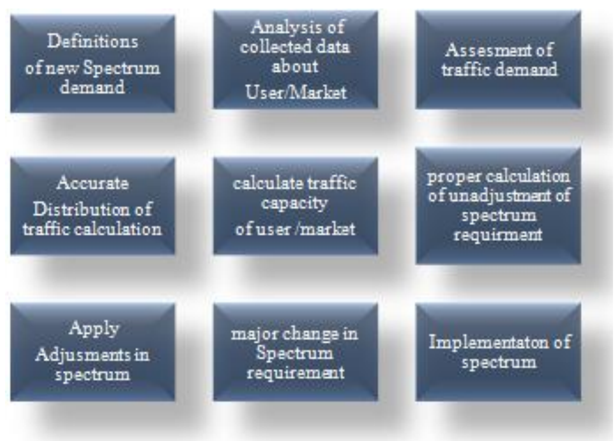

Fig. 2. Steps of spectrum calculation [8].

High spectrum ranges will require a new spectrum for 5G because the existing spectrum is insufficient for the deployment of the technology. Hence, IMT recommended a methodology for future spectrum requirement, which is divided into two radio access techniques groups (RATGs) [9]. The first group is RATG1, which includes Pre- IMT systems, IMT-2000, and its first enhancements; the second group is RATG 2, which describes IMT advancements [10]. A spectrum has specific frequency ranges with specific names or bands, such as high, mid, and low frequency. Higher frequency bands have faster speed and shorter distance, whereas lower frequency bands have slower speed and longer distance.

TABLE II. MULTI-LAYER SPECTRUM [11]

Spectrum Layer	Frequencies	Spectrum	Contiguous Bandwidth
Super data layer (eMbb)	High Frequencies	Above 6 GHz	<800 MHZ
Coverage and capacity layer (eMBB, URLLC, Mmtc)	Medium frequencies	2 -6 GHz	<100 MHz
Coverage layer (mMTC, eMBB, URLLC)	Low frequencies	Below 2GHz	<20Mhz

A multi-layer spectrum (ref. Table II) is proposed for the deployment of 5G. The spectrum consists of three layers. The first layer is coverage and capacity layer, which deals with frequencies from 2 to 6 GHz to deliver the best performance. The second layer consists of the super data layer, which delivers the best performance for extremely high data rates. The third layer is the coverage layer that deals with low range frequencies within the spectrum that provides access to the IoT network, wide area coverage, and indoor communication [11].

Spectrum frequencies of different countries were studied and compared to determine the effective range for better results. The data were collected from 5G New Radio (NR), which is the new standard for 5G wireless technology (Ref. Figs. 3(a–c). NR is capable of connecting the things with low latency and better speed. Figs. 3(a–c) plot and present the results.

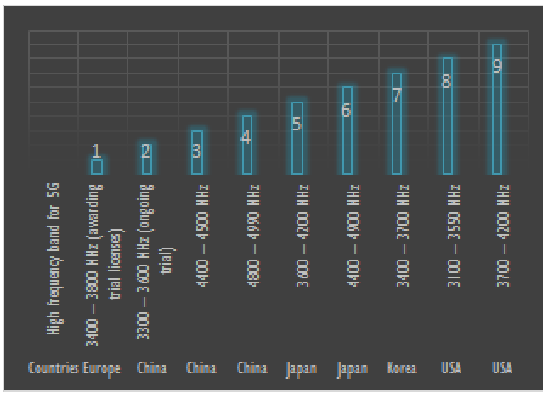

Fig. 3(a) On going traila of High frequency bands

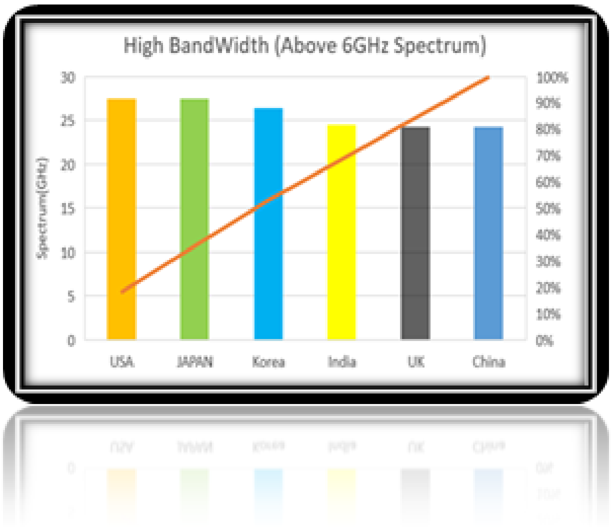

Fig. 3(b). Deployments above 6GHZ[12]

Fig. 3(c). Deployments below 6GHZ[12]

TABLE III: COMPARISON AMONG THREE MAIN TYPES IN 5G SPECTRUM LSA, LICENSED AND UN LICENSED

LSA	Licensed	Unlicensed
Secondary access to Primary user	Dedicated for Primary user only	Spectrum share with unlicensed System
Homogenous Horizontal Scheme	Homogenous horizontal Scheme	I)Heterogeneous Horizontal Sharing ii)Homogenous horizontal sharing in some scenarios
Sharing of frequency /location at same place but does not Overlap [17]	-------------------	Whole Spectrum based upon Sharing
Below 6GHz [18]-[20]	Above 6Ghz	Primary Access 1900 MHZ Horizontal Access 790 MHz [21]
Sharing between Mobile network	Dedicated for Mobile operators	Used for 700MHZ Broadcasting, WLAN, WIFI, Bluetooth (2.4 and 5.8) [21]
Equal rights distribution for Sharing	Authorized licensed holder is always on highest priority in case of sharing	I)Priority Base Sharing II) Equal Rights sharing in some scenarios

Predicting which technology has an early impact on 5G is difficult, but certain technologies have emerged, such as the massive MIMO, full duplex, millimeter waves, beamforming, and small cells [13]-[16]. Previous, current, and next generation networks, namely, 2G, 3G, 4G, and LTE, only use dedicated licensed spectrum provided by their home government. Hence, this situation adds difficulty to finding sufficient bands to meet 5G requirements within the existing spectrum. Table III presents the three main types in a 5G spectrum, namely, licensed, Licensed Shared Access (LSA), and unlicensed.

III. SPECTRUM SHARING TECHNIQUES

Spectrum sharing will play vital role to shape 5G model. The important advantages are described in spectrum sharing, first is to unlock the spectrum which is lightly used by the primary user, secondly to increase the spectrum utilization and third most important advantage is to attract the new service providers for enabling the new service models [22] and so on. Major types of sharing in spectrum; vertical sharing, horizontal and dynamic sharing; are given below [23].

Vertical sharing:

Vertical sharing describes priority-based spectrum sharing among different users, such as between primary and secondary users. Unequal distribution of sharing rights between users, such as primary users, has the highest priority in the spectrum; whereas secondary users have lower priority. Static and dynamic models are included in vertical sharing. This scheme is typically used in LSA.

Horizontal sharing:

Horizontal sharing describes the same priority or priority-based sharing in the spectrum among different users. Every user has equal access to the spectrum or different priorities. In horizontal sharing, the sharing among different users can occur with different sharing scenarios with different or the same technology [24]. The horizontal sharing scheme is divided into two parts, namely, homogeneous and heterogeneous. If the spectrum adopts the same scheme between the users, the horizontal sharing is homogeneous; otherwise, the sharing is heterogeneous. Licensed band of 2.4, 5, and E uses the horizontal sharing scheme. In this sharing method, multiple licenses are allocated on the same frequency and location, with no overlapping.

Dynamic sharing:

In dynamic sharing, vertical and horizontal sharing are combined to achieve efficiency gain and greater utilization and are commonly used in 3.5 GHz CBR band [25]. Table IV presents the comparison of the three schemes commonly used in the 5G spectrum.. (see Table IV.)

TABLE IV: COMPARISON OF THREE SCHEMES WHICH ARE COMMONLY USED IN 5G SPECTRUM

Vertical Sharing	Horizontal sharing	Dynamic Sharing
Priority Based Sharing	Same Priority in Homogenous Different priority in heterogeneous	Both exists Equal priority and Priority based sharing
Static and Dynamic models	Static and dynamic models	Static and dynamic models
Used In LSA	Used in Licensed	Used in unlicensed and CBRS

CR-Based Sharing:

CR-based sharing technique used in the existing WSN in an unlicensed spectrum transmission enhances spectrum efficiency. This technique is based on a cognitive period that has two phases. The first phase called spectrum sensing, is where the cognitive user senses the environment and collects the information. The second phase is where the cognitive user selects the best spectrum band according to the collected information and adapts the transmission [26].

D2D-Based Spectrum Sharing:

D2D-based spectrum sharing in IoT spectrum D2D communication will be the best. The technology reduces the distance to achieving the required throughput and minimizes energy consumption with decreased latency [27].

IV. INTERNET OF THINGS

The IoT industry is estimated to be worth in trillions of dollars by the 2020s. The introduction of IoT shall change daily lives with the connectivity of 5.7 million devices. The exponential growth of IoT is unpredictable, with great attention given to its market [28]. The connected objects in everyday activities will be in billions in the web. Hence, IoT will create a new revolution in this era. After 2020, the deployment of 5G and IoT will result in the frequent use of these technologies, which will drastically change the industry. Moreover, smart homes, cities, industries, grids, and so on, will become common.

There are several emerging IoT standards and frameworks, including: 6LoWPAN, ZigBee, LiteOS, OneM2M, DDS (Data Distribution Service), AMQP (Advanced Message Queuing Protocol), CoAP (Constrained Apsplication Protocol), AWS IoT, ARM Mbed IoT, Microsoft's Azure IoT Suite, Google's Brillo/Weave Calvin, and so on.

Below, we discuss the IoT structure, followed by the spectrum, and finally, deployment challenges. The structure and classifications of IoT are different according to researchers. Layers 3, 4, 5, and 6 of IoT architecture are considered [40] for test bed development and deployments in IoT. Usually, four layers of IoT architecture are considered according to the defining layers with different names, which have the same functions. These layers are (i) service application, (ii) platform/transport, (iii) network (divided into upper and lower), and (iv) device/sensing. The most prominent and important layer of the IoT model is the service layer, which provides surface to interface and communicates with the user. Moreover, this layer provides encryption and decryption. The second layer is the platform layer, which deals with IoT applications and supports its services. The third layer is the network layer, which transmits data, content, and services between the user and devices. This layer must be competent to process manage and control the heavy amount of data traffic between the user and device. The last layer is the device/sensing layer, which must enable sink nodes or gateways to respond [29]. Apart from the four layers in the architecture, the other important layers are security [30]-[32] and privacy [32]-[33]. Instead of defining the two layers, each of the four layers should manage its security and privacy problems and must be capable of incorporating solutions to threats by itself [33]. A standard architecture is essentially required for IoT [36], [39].

A strong, dense type of mobile connectivity is needed to support this revolution. This new technology will play an important leading role in supporting the next generation of connected technologies, such as driverless cars and smart sensors. The design is a combination of pre-existing technologies, including GSM, Wi-Fi, LTE, and other radio access technologies. IoT architecture will definitely manage a minimum density of 100 or more devices in any given 10*12 size location. In addition, IoT will have enabling features, such as critical rapid response, real-time mission, and connectivity to self-driving cars, IoT sensors, and mobile devices. IoT technology requires fast real time communication with low-latency data transmission. Such architecture will have adequate capacity to connect thousands of buildings, save energy, power smart city grids, and build entire networks of billions of connected devices in the near future with new advanced skills, approaches, models, and services. In the near future, IoT will have remarkable effects on Internet-connected objects, and mobile connectivity standard and protocols [37], [38]. Internet services will realize potential enhancements and achievements. Other protocols must be defined for low-power massive communication for machine-to-machine communication as well as man-to-machine communication. Indoor communication, which will be most common in the 2020s, will allow interaction among different devices and communication scenarios described by IoT. The IoT spectrum will range from below 1 GHz up to 6 GHz and deal will millimeter wave in licensed, unlicensed, and LSA schemes. The technology is likely to adopt advanced wireless technologies, such as massive MIMO, robust -mm-wave, advanced OFDM, full duplex, millimeter waves, beamforming, and small cells [40]. Several countries are remarkably attempting to achieve harmonized spectrum to enable applications of IoT with supporting frequencies, such as 780 MHz in China, 868 MHz in Europe, 920 MHz in Japan, and 915 MHz in the USA. (Please see Ref. Fig. 4).

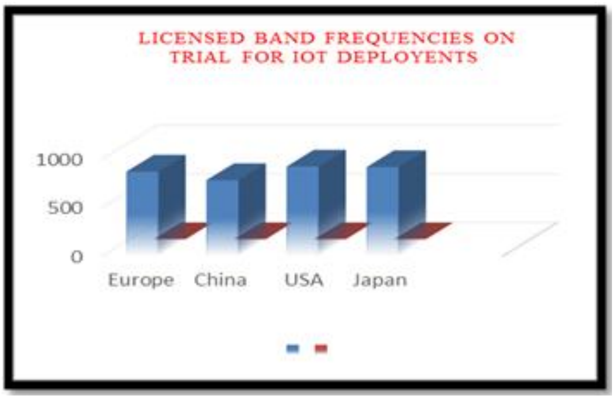

Fig. 4. Trial phase frequencies for Internet of things spectrum deployment [12].

In the release of 3GPP, 14 or 15 more frequency bands are added but have low power, and massive MIMO communication would be defined with low-power consumption, small data packets, low cost, and massive connections. Approximately, 1 M connections for a small town require support, deployment, and delivery by IoT [34]. Frequency ranges between IoT communication must be wide rather than different [35]. The biggest challenges in the deployment of IoT are market, price, product, spectrum standardization, frequency band, and certification.

V. Conclusion and Future Discussion

This study has analyzed the existing knowledge regarding 5G and IoT spectrum. Clearly, 5G requires additional bandwidth, long range, flexible usage, and managing patterns, while IoT must meet low bandwidth, short range, flexible usage, and define patterns. Spectrum characterization, sharing, analysis, and deployments are important in the current times for the deployment scenarios of 5G and IoT. For this analysis, the following are in the trial phases: higher frequencies from 3300 to 4900 MHz and IoT frequencies below 1000 MHz. The existing spectrum range for 5G is from 24.25 to 27.25 GHz for high bandwidth. Better results can be achieved if the range can be enhanced from 27.25 to 40 GHz. Spectrum harmonization remains important for the deployment and even more important for higher frequencies to support IoT and advanced antenna systems. China is targeting to deploy 5G network for extremely high peak rates in the range of 26 to 42 GHz. Various spectrum techniques are existing in the wireless system, but additional work is required for the efficient quality of service deployment for the next generation.

Conflict of Interest

The authors declare that they have no conflict of interest of interest regarding this paper

Author Contributions

All the authors contributed equally

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