Science Arena Publications
Specialty Journal of Electronic and Computer Sciences
ISSN: 2412-7485
Available online at www.sciarena.com
2019, Vol, 5 (1): 1-10

Investigation the Massive Systems in the Field of Millimeter-Wave

Farahnaz Nikmaram[1], Seyed Ahmad Olamaei[2*]

[1] Student of M.Sc. Electronic and Telecommunication Engineering, Islamic Azad University- South-Tehran Branch, Tehran, Iran.
[2] Assistant Professor, Ph.D. Electronic and Telecommunication Engineering, Islamic Azad University- South-Tehran Branch, Tehran, Iran.

***Corresponding Author**

Abstract: *Several active technologies of the fifth-generation telecommunications systems (5G) were studied in this paper. The purpose of the present study is to develop a cellular network in all dimensions, so that the performance parameters of the previous (old) mobile telecommunication networks are developed. One of the most important technologies related to the 5G networks is the millimeter wave massive (MIMO) which is continuously provided in the list of 5G capabilities. This indicate that the considerable increase in the user efficiency could bring about some changes including the increase of spectrum and energy efficiency, increase of mobile networks capacity by using common capabilities of available wide bandwidth in millimeter wave frequency bands and accessibility to array antennas. In this research, several initial results were obtained from extensive investigations of millimeter wave massive MIMO which are still in the transformation phase. This paper covers the fields of wireless telecommunications technologies. Moreover, it aims to study current and future telecommunications systems (the millimeter wave massive MIMO) which has been introduced as a new technology. This system will provide the new boundaries of services and useful tools for the next-generation mobile networks.*

Keywords: *Massive MIMO Systems, the Fifth Generation Cellular Telecommunications, Millimeter Wave Massive MIMO.*

INTRODUCTION

Nowadays, many researchers have studied in the field of the fifth generation of wireless telecommunications (5G) which were due to the remarkable advances in technology and increasing users of telecommunications networks, and also, as a result of ever-increasing demands for designing and utilizing the new generation of wireless telecommunications (BoRong et al., 2016).

The technologies that can be used in the fifth generation have been investigated extensively in which three important technologies have been introduced as the overall solutions to respond to the new demands in the field of telecommunications. One of the most important growing demands in the field of wireless telecommunications is regarded to higher data transfer rate in telecommunications networks which requires higher capacity (BoRong et al., 2016).

Among these technologies, application of the millimeter-wave systems for transferring the data in telecommunications networks creates so many opportunities and challenges in various fields including

designing a useful and low-cost hardware, using the array antennas to configure the radiation pattern properly and the designing associated to the medium access control (MAC) layer with regard to the properties of these wave. Each of these challenges requires a precise study and investigation to reach the maximum profit of the networks. Therefore, wireless cellular networks have been investigated in the challenges using these waves. In this regard, researchers have studied the effects of using millimeter-wave systems in design of MAC layer. One of the significant differences of the waves related to telecommunications networks is the presence of the directed antennas which creates higher degree of freedom in all MAC layer designs. In fact, determining the angle and beam width of these antennas is the new degree of freedom which has been created in these networks (BoRong et al., 2016).

In recent years, massive MIMO systems have been equipped with plenty of users and one basic station (BS) with hundreds of antennas which would be emerged as a key aspect for the next-generation wireless systems. Massive MIMO system could prepare all capabilities of normal MIMO systems in a larger scale.

Millimeter-wave massive MIMO systems have been constituted of several parts and thus, it is anticipated the concepts and advantages of the previous technologies (MIMO, massive MIMO) are somewhat that their techniques are applied or adapted; Therefore, massive MIMO systems will be studied in the field of millimeter-waves in this paper.

Literature Review

The fifth generation of cellular telecommunications (5G)

The fourth generation of cellular networks (4G) has been emerged and developed in the current decade (2010s). The statistics obtained from the first years of the decade and the predictions for the next upcoming years indicates a doubling in the demand growth in internet data traffic in each year. Overall by 2020, the demand for data networks is expected to reach 1000 times higher than that of the 2010.

The second motivational factor of the researches in the fifth-generation networks will be the increase in the users connected to the wireless cellular networks in the next years. Rising the wireless cellular users on the one hand and emerging some phenomena such as internet of things and machine to machine communications on the other hand will result in a remarkable increase in the number of the tools connected to wireless telecommunication networks in the next decade.

The third factor is related to the variety of the services and the increase in the demands for new and high quality utilities. At present, the demand for optimizing different parameters of the service quality (i.e. data rate, delay and network coverage) is being rapidly increased.

In total, three factors mentioned above and some of other factors caused that the telecommunications engineers around the world would attempt to develop the fourth-generation networks towards the beyond 4G networks which is called the fifth generation networks.

- **Requirements of the fifth-generation cellular telecommunications**

The fifth-generation cellular telecommunications refers to the technologies which have the capabilities beyond the current generation technology (especially the fourth generation). Also, it could respond to the future demands of wireless communications. For this reason, these networks are called beyond fourth generation (B4G) or the networks beyond 2020 as well.

One of the significant technologies for the fifth-generation is related to utilizing millimeter waves instead of micro waves. The millimeter waves could provide wider bandwidth due to the higher frequency than micro waves. The millimeter waves have dealt with this paper which will be investigated extensively in the next sections (Michael, 2016).

Main and common objective of all researches regarding the fifth-generation technologies is related to the connection of the infinite things together with unlimited communicative capacity and high quality service. In the meantime, a set of requirements for the fifth-generation networks has been defined which include

supporting high growth rate (approximately 1000 times than the previous system) in data traffic, supporting remarkable increase (ten times than the previous system) in the tools associated with each other, the increase (at least ten times than the previous system) in data rate of users, considerable decrease in delay, increasing reliability and availability of the network, reducing energy consumption, help the environment, increase the batteries lifetime, using high frequencies, increase the spectrum efficiency of frequency, reducing the cost of network equipment and the users, more security, supporting the services based on cloud computing and, finally software processing in network's core part.

The ambitious objectives for 5G networks compared to the 4G networks have been set which include increasing the mobile data traffic in every geographic area(1000 times more), increasing the routine data of users (100 times more), (100 times more)when connecting devices, decreasing the network energy consumption (10 times less) and also terminating each delay (5 times less). Table 1 represents a quantitative comparison between 4G network performance criteria and corresponding objective of 5G network (BoRong et al., 2016).

- **The difficulties of the fifth generation of cellular telecommunications**

The major difficulty is that the 5G should support higher data rates (100-1000 times), however the current systems are not so far from the Shannon limit.

In this regard, three acceptable solutions have been recommended by research community in order to obtain the amount of the efficiency including the extreme infrastructure congestion, great amount of the new bandwidth, and plenty of the other antennas which cause increased penetration in spatial dimensions. So, in many case, these methods are complementary to each other. The extreme bandwidth requires higher frequencies, particularly millimeter wave with the frequencies of 30-300 gigahertz, which the high frequencies need to use the antennas to overcome the dangers of such environments (like small antennas), since semi-polar dipole antennas are extremely low in this frequency. In addition, high frequencies need smaller cells to overcome the blocking. That's why main subjects of the research procedure for the next-generation mobile networks have been configured by creating the Heterogeneous network (HetNet) architecture and millimeter-wave massive MIMO parameters.

- **Remarkable technologies of the fifth generation of cellular telecommunications**

The remarkable technologies in the 5G networks are either the developed form of the previous generations or the new technologies which have not been used in the previous generations. Some of the remarkable technologies in the 5G networks are as follows:

- Heterogeneous network (Het Net) include different cells varies from microcell to femto-cell and the networks comprising the technologies with different accessibility
- Small cell networks to increase the network capacity and more use of the frequency
- Machine to machine communications
- Using wider bandwidth towards the higher frequencies and the carriers aggregation
- Using large scale multi antenna systems (massive MIMO systems)
- Cognitive Radio and advantageous use of radio spectrum
- Configure three dimensional beam and utilizing sectoralization method of 2D cells
- Non-orthogonal multiple access methods
- Using the waves of millimeter band and especially the frequencies higher than 50 GHz
- Wi-Fi offloading in indoor environments
- Using Full duplex sending systems

Regarding the use of the fifth-generation cellular telecommunications, so far several projects have been carried out which are focused on the 5G functionality. One of the first coherent activities accomplished in 5G networks has been launching an independent research center called 5G innovation center (5GIC) in university of Surrey in late 2012. The budget of this center is 35 million pounds which is provided by a number of organizations including government of the United Kingdom, consortium of telecommunications

operators, the owners of telecommunications infrastructure and great manufacturing companies such Huawei, Samsung and Iricom. At present, the activities of this center are focused on proper development of the technology for the fifth generation, particularly in air interface. Another remarkable project of the fifth generation cellular telecommunications is mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) project which is a massive project in European Union that has been formed particularly in the field of the next-generation wireless networks in late 2012. This project is carried out by the Ericsson management and a consortium including 29 international telecommunications companies. Budget of this project is about 15 million Euros. Activities of this project was so extended that consist of all parts of the fifth generation (i.e. network architecture, radio availability, services and usages). Since 2013, China and Huawei Company (in particular) has initiated vast activities for the researches in the field of the fifth generation systems. The NTT DoCoMo operator in Japan has started to examine the fifth generation networks in association with companies such as Alcatel lucent, Ericsson, Fujitsu, Nokia and Samsung.

MIMO telecommunications systems

MIMO systems originated from array antennas which has been introduced by George (1970) and Etten (1975-1976). Besides, Winter and Salz (1984, 1986) presented some researches about the configuration of antenna beams by publishing some scientific articles in Bell laboratories. The historical trend of MIMO systems could be investigated by two different perspectives. The first is related to the historical trend from the viewpoint of diversity in transmitter and the second, from the viewpoint of spatial multiplexing. The diversity idea in transmitter was introduced by Wittneben in 1993, which the technique utilized in this idea, is the using delay diversity in the transmitter. Wittneben idea was expanded using time-space codes developed by Vahid Tarokh and Seshadri in 1998.

From the viewpoint of business, the first MIMO system based on Orthogonal Frequency Division Multiple Access (OFDMA) was developed in which the diversity and spatial multiplexing were used in 2001. In 2006, OFDMA-MIMO technology was developed in order to standardize wideband telecommunication systems (e.g. e.802 IEEE16 or WIMAX) by various companies (Sherif Adeshina Busari, 2017).

MIMO stands for Multiple Input-Multiple Output that is an arbitrary wireless communication system in which both points of send and receive are equipped by array antennas (R. W. Heath et al., 2016). In MIMO systems, the signals of transmitter antennas on one side of the connection line and the receiver antennas on the other side are combined in a way that would improve the quality of bit error rate (BER) or data rate for every MIMO user. MIMO wireless technology could increase spectrum efficiency, data rate, energy and the capacity of cellular mobile networks using common capabilities of the available wide bandwidth in millimeter wave frequency bands which leads to the access to array antennas. Furthermore, the capacity of wireless channels considerably rises by using the array antennas in transmitter and receiver. Thus, the MIMO has been an important section of wireless telecommunications standards (R. W. Heath et al., 2016).

- **MIMO functions**
    1. **Pre-coding:** it can be introduced as a multi stream beam forming in a subtle definition, however generally pre-coding can be known as the interval processing which occurs in the transmitter. Advantages of beam forming are the increase of efficiency of the received signal according to the signals of multiple antennas and the decrease of multipath fading effect. While the receiver has multiple antennas, the transmitter beam forming could not simultaneously maximize the signal level in all receiver antennas and for this reason, pre-coding is used with multi stream (X. G. Peter Legg, 2017).
    2. **Spatial multiplexing:** it requires MIMO configuration. In spatial multiplexing, one signal with high rate is divided to wave streams with lower rates and each of the streams is transferred from different antennas to common frequency channel. If the sufficiently effected signals would reach the receiver, it can consider the wave streams as the separated (almost)

parallelized channels. The spatial multiplexing is a useful technology in increasing the capacity of channel for high signal-to-noise ratio (SNR) (X. G. Peter Legg, 2017).

3. **Diversity coding:** In this method, although a unit-wave stream (unlike multiple streams in spatial multiplexing) is transferred, the signal is coded by using the methods called space-time coding. So, the signal of every transmitter antenna is transferred due to the complete coding or almost orthogonal. Thus, in order to increase the signal diversity, this coding utilizes independent fading which are available in multiple antennas links (X. G. Peter Legg, 2017).

- **Millimeter wave massive MIMO**

The advancement of millimeter wave massive MIMO have brought about a remarkable combination of wide bandwidth of the millimeter waves and also several huge achievements of MIMO array antenna, as the technology of millimeter wave massive MIMO is used in HetNet topology. The next-generation mobile networks could use the advantages of the three factors in a very large scale. Thus, it can support high speed service frequency and the bandwidth programs which have not been possible so far. The logic of using this method is in a way that is physically placed the users adjacent to the basic station .The small cells covering the old macro-cells which cause multi-surface HetNet in which mobile units control the host macro-cells significantly (i.e. allocation of resources, synchronization, mobility management and so forth.), while the small cells of mobile unit provide high quality services and useful spectral information for users. HetNet topology has potential to be presented in all movements: this topology causes to increase the capacity of the network which is based on increasing the cell density and reusing spatial and high frequency and also increasing spectrum efficiency due to signal to noise ratio (SNIR) improvement by controlling close interference; and improvement of energy efficiency based on the decrease of transmission power and bandwidth resulting from smaller radius or short gap between the small cells and user equipment. Millimeter wave massive MIMO is an advanced technology which was utilized in 5G networks for the first time in order to discover the new boundaries of the next- generation mobile systems. This technology is gained from the available wide bandwidth (in the millimeter wave frequency bands) and high antenna achievements (accessible to massive MIMO array antennas). Figure 1 indicates the massive MIMO network in which it has been constituted from a transmitter, a wireless channel and the receivers (user equipment).

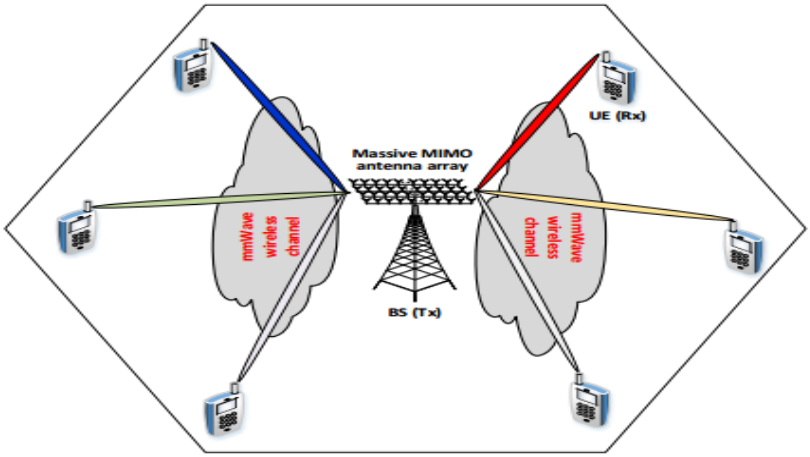

Figure 1. Millimeter-wave massive MIMO

The major advantage related to millimeter massive MIMO systems can be achieved when various antenna pairs of transmitter and receiver have restricted channel coefficient independently. This would be practical when the spacing of antenna elements is 0.5 at least which is called signal wavelength. The carrier frequency is increased, although the number of array antennas elements is physically decreased, which have been

observed in the wave frequencies such as the millimeter wave. The maximum number of antennas by the 3rd Generation Partnership Project group (3GPP) for Basic Stations (BS) and User Equipment (UE) are 1024 and 64 GHz, respectively. Regarding Radio frequency (RF) chains, this numbers would be 32 and 8 for BS and UE, respectively (Sherif Adeshina Busari, 2017).

Figure 2 illustrates 5G network architecture based on millimeter wave massive MIMO. The HetNet architecture is multi-cellular which has been constituted from several small cell keys. All of the small cells have communicative capability with the massive MIMO, Microwave and millimeter-wave

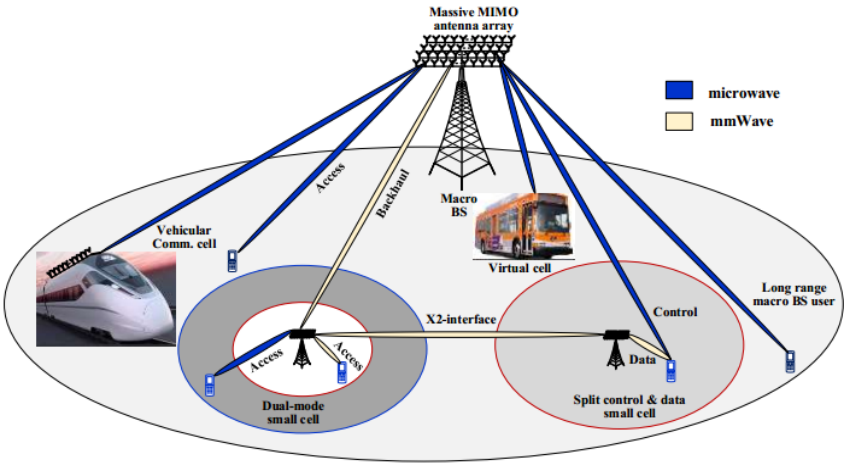

Figure 2. 5G network architecture based on Millimeter-wave massive MIMO

The millimeter wave bands have larger bandwidth due to the capacity, the high data rate and shorter wavelength. It can cause using the massive MIMO and the strengthening techniques of adaptive beams directly (Xie, Gao, & Jin, 2016).

On the other hand, signal weakening of the millimeter wave in terms of the precipitation, intense atmosphere absorption and losing high path could be more than the microwave signals. Therefore, the directed communications in the millimeter wave systems is widely used to deal with the interferences and the losses (better energy efficiency and more products).

Additionally, an enormous range is presented by the millimeter wave, and also both (BS-UE) access and front or back link are used to support the higher capacity than the 4G networks. In fact, poor short time connection was assumed, or short time connection of millimeter wave in UDN trend would be proportionate and the new ways are opened for useful short time programs (like potential use in databases)

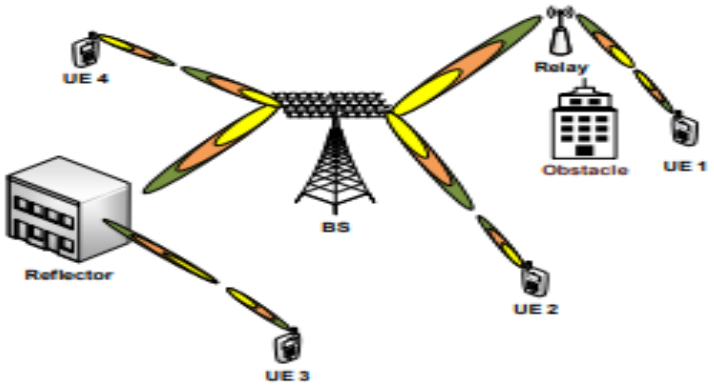

Figure 3. Directed communications in 5G Het Nets

- **Evolution of massive MIMO**

The MIMO systems use various antenna in both transmitters (BS) and receivers (UE), while the single-input and single-output (SISO) system utilize single antenna in the both. The MIMO has higher capacity and reliability than the SISO systems, because its channels are considerably benefited by the variety and the arrays with regard to SISO channels. The different achievements of MIMO scale which the maximum advantage is the number of the independent channels between transmitter and receiver, whereas the number of the antennas in transmitter and receiver were less; However, the maximum multiple benefit and various advantages could not use the MIMO systems simultaneously as a basic exchange between the two. Moreover, the MIMO uses more antennas with respect to the general MIMO systems.

Figure 4 represents four different scenarios of downlink wireless communication model including SISO, single user MIMO, multi user MIMO and massive MIMO which are used to evaluate the performance of the cellular systems with different adjustments (e.g. SISO to massive MIMO). The adjustments include a transmitter (TX) to transmit N antennas and K users equipped a receiver (RX) to receive M antenna (Mumtaz, Rodriquez & Dai, 2016).

The MIMO systems have two types of configurations: Single User (SU)-MIMO and Multi User (MU)-MIMO. The latter system brings about more advantages which are listed as follows:

1. SU-MIMO transmitters assign all time-frequency resources to one terminal with the help of various transmission approaches, spatial distribution and beam forming techniques. However, the MU-MIMO system applied different multi users in the spatial field through a time-frequency resource which has been assigned to several users, especially when the channels are spatially connected.
2. MU-MIMO basic stations of antennas provides services to so many users, while the inexpensive single antenna devices are used in user's terminals and otherwise, the expensive equipment is only required in the basic stations to decrease the costs
3. MU-MIMO system is less sensitive to environmental propagation than SU-MIMO and thus, there is no need to rich scattering.

Considering the remarkable advantages of the Massive MIMO systems with respect to the SISO, SU-MIMO and MU-MIMO, it has been presented as an incomparable technology. As a whole, massive MIMO is being progressed to increase the advantages of the MIMO considerably.

Massive MIMO has been known as a large scale antennas systems (LSAS), full dimensional-MIMO (FD-MIMO) and very-large MIMO. In addition, it is an array antenna system with hundreds of basic stations which simultaneously provides tens of user terminals in the time-frequency resource. In order to use the spatial area of depth of field (DOF) in high resolution beams and representing the variety and compensation as a result of improving energy efficiency, this can lead to increase the spectrum efficiency by use of transmitting a lot of basic stations antennas.

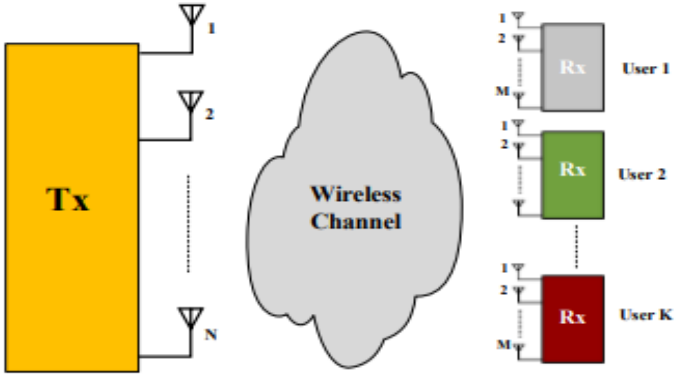

Figure 4. Wireless communication system model

- **Comparison of MIMO and massive MIMO**

Mobile users always require higher data rate and safer services which the fifth-generation wireless networks (5G) can supply these demands and even beyond that. Albeit 5G network is being designed at present so that the companies and industrial groups are attempting to determine its essence. However they were unanimous in one issue at least "as the number of mobile users and their data request increases, the 5G network should organize much more traffic from the base transceiver stations (BTS) which configure today cellular networks.
The base transceiver stations of the current 4G network have 12 ports per each antenna in which all traffic of cellular network are organized by the 12 ports. 8 ports are assigned to the transmitters and 4 ports to the receivers. However, base transceiver stations of 5G networks support one hundred port, which means more antennas can be placed on each array. So, the base transceiver station can simultaneously receive and transfer much more signals, and this increases the capacity of responding mobile networks by more than 22 times.
The mentioned technology is called massive MIMO. The story begins here. MIMO stands for Multiple-Input and Multiple-Output which is referred to the organizations which use two or more transmitter and receiver in order to simultaneously increase the capacity of transmission and receive. The idea behind the MIMO is that it can embed tens of antennas in each array. The MIMO is currently utilized in the base transceiver stations of 4G networks. But Massive MIMO was only tested in the laboratories and has been used in the field of examinations in few cases. The Massive MIMO in terms of spectrum efficiency could break the record in initial tests. The spectrum efficiency is one of the measuring parameters which indicate how many bits of data transmit in every second for certain users

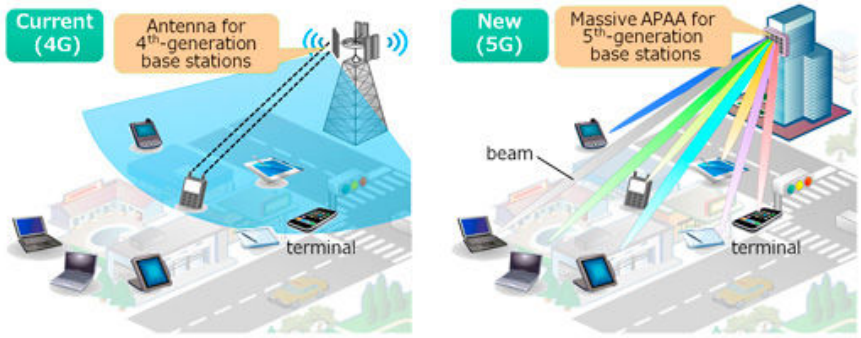

Figure 5. The comparison of the capacity of multi antennas 4G MIMO and 5G massive MIMO by simultaneous network coverage

Massive MIMO has predicted a promising future which should be noted that the installation of the excessive number of antenna in order to organize the cellular network traffic might be resulted in colliding the signals and more interference. For this reason, base transceiver stations of 5G network should use other technologies to overcome these difficulties. These supplementary technologies are millimeter waves, small cells, full duplex and beam forming.

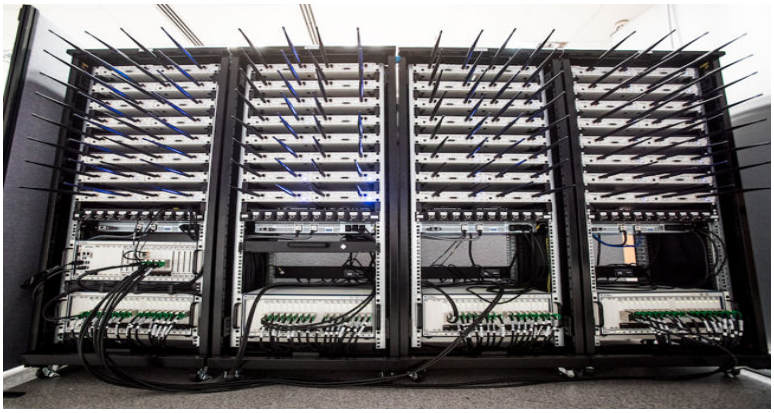

Figure 6. A base transceiver station with 128 antennas, manufactured by National Instruments Co. (NI)

Engineers hope to build a wireless network with the 5G technologies in which the future users of smart cellphones, virtual reality gamers rely one them in the daily affairs. At present, researchers and companies have high expectations from 5G networks as they believe that 5G network has a very few delay so that the data transfer rate would be record-breaking. If the remaining challenges are solved and realized how to work with the systems, super-fast 5G services could be achieved by the next 5 years (Peter Legg, 2017).

Channel measurement techniques

While most millimeter wave channels are utilized for stationary radio channels, the frequencies of millimeter wave for cellular networks, particularly pico-cells and femto-cells are not usually included high speed users. However, the users or the receivers of some channels are dynamics which is necessary to consist the correlation between the mobility and dynamics of the channel.

The technical capabilities of audio equipment (software and hardware) related to millimeter wave massive MIMO should surpass previous channels in order to measure more accurately. Therefore, the effective audio channels should able to measure a few tenths of gigahertz to multi-gigahertz of bandwidth (millimeter wave) and also, hundreds of antennas in both basic stations and massive MIMO user equipment with the specifications related to high performance of radio frequency (RF) chain (audio power amplifiers, low-power audio amplifiers, up and down switches and RF switches and so on.)

Similarly, audio equipment should able to measure in static and dynamic condition, indoor and outdoor environment. Moreover, it should have the ability to generate an efficient signal, and receive and save the data. This equipment should assure precise synchronization, calibration, sensitivity, resolution and flexibility for format in maintenance of the cost of a proper system. The audio equipment with high performance is essential to model, simulate and validate of millimeter wave massive MIMO channel (Michael, 2016).

Conclusion

By considering wide bandwidth in millimeter wave frequency and achieving high capacity of array antennas systems, the technology of millimeter waves massive MIMO is a practical perspective. In this paper, an overall review of the concepts and the techniques for millimeter wave massive MIMO has been presented in which the emerging network technologies are compared to the previous systems. Also, the main challenges of the research and future paths have been determined.

It should be noted that the 5G systems are not only used by the technological advancements but also the technical capabilities for high data rates. Furthermore, it is expected to use in the next-generation cellular networks. Moreover, it was anticipated that experience in 2020 would be a balanced ecosystem in which the technical abilities are synchronized with the socio-economic and environmental issues.

Several factors (including the increase of efficiency and safety level, health improvement, low and limited energy and CO2 cost for beyond 5G (B5G)) caused a remarkable increase of network capacity, energy and spectrum efficiency.

By 2020, the researches related to millimeter MIMO massive MIMO will be continued and a new trend will be emerged. Although many challenges are recommended to solve this problem, millimeter wave massive MIMO has a remarkable perspective which has been attempted to have a 5G cellular networks 1000 times than the current network. Undoubtedly, this technology will be accompanied with the next-generation mobile network and new boundaries in the services and mobile applications.

References

1. H. Xie, F. Gao, and S. Jin, "An overview of low-rank channel estimation for massive MIMO systems," IEEE Access, vol. 4, pp. 7313–7321, Nov.2016.
2. Michael A. Jensen Electrical and Computer Engineering, Brigham Young University, Provo, UT, USA, "A History of MIMO Wireless Communications" IEEE, October 2016.
3. R. W. Heath, N. Gonzlez-Prelcic, S. Rangan, W. Roh, and A. M. Sayeed, "An overview of signal processing techniques for millimeter wave MIMO systems," IEEE J. Sel. Topics Signal Process., vol. 10, no. 3, pp. 436-453, Apr. 2016.
4. S. Mumtaz, J. Rodriquez, and L. Dai, MmWave Massive MIMO: A Paradigm for 5G, Academic Press, Elsevier, 2016.
5. Sherif Adeshina Busari, Student Member, IEEE, Kazi Mohammed Saidul Huq, Senior Member, IEEE, Shahid Mumtaz, Senior Member, IEEE, Linglong Dai, Senior Member, IEEE, and Jonathan Rodriguez, Senior Member," Millimeter-Wave Massive MIMO Communication for Future Wireless Systems", A Survey " 2017.2787460, IEEE Communications Surveys & Tutorials.
6. X. G. Peter Legg, Mobility management in small cell heterogeneous networks, Cambridge University Press: Design and Deployment of Small Cell Networks, April 2017.
7. X. Q., k.,. L. BoRong, BoRong, Xaesong Qiu ,Michel -5G Heterogeneous Network selforganizing and optimization, 2016.