

## A Review on Massive MIMO Antennas for 5G Communication Systems on Challenges and Limitations

Mandeep Singh Jit Singh<sup>a,b\*</sup>, Wan Syahrumsaleh<sup>a\*</sup>, Amer T. Abed<sup>c</sup> & Muhammad Ashraf Fauzi<sup>d</sup>

<sup>a</sup>Department of Electrical, Electronic and Systems Engineering,

<sup>b</sup>Space Science Centre (ANGKASA), Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Malaysia

<sup>c</sup>Al-Ma'moon University College, Iraq

<sup>d</sup>Faculty of Industrial Management, Universiti Malaysia Pahang, Malaysia

\*Corresponding authors: mandeep@ukm.edu.my; wan.syahrumsaleh@gmail.com

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### ABSTRACT

High data rate transfers, high-definition streaming, high-speed internet, and the expanding of the infrastructure such as the ultra-broadband communication systems in wireless communication have become a demand to be considered in improving quality of service and increase the capacity supporting gigabytes bitrate. Massive Multiple-Input Multiple-Output (MIMO) systems technology is evolving from MIMO systems and becoming a high demand for fifth-generation (5G) communication systems and keep expanding further. In the near future, massive MIMO systems could be the main wireless systems of communications technology and can be considered as a key technology to the system in daily lives. The arrangement of the huge number of antenna elements at the base station (BS) for uplink and downlink to support the MIMO systems in increasing its capacity is called a Massive MIMO system, which refers to the vast provisioning of antenna elements at base stations over the number of the single antenna of user equipment. Massive MIMO depends on spatial multiplexing and diversity gain in serving users with simple processing signal of uplink and downlink at the BS. There are challenges in massive MIMO system even though it contains numerous number of antennas, such as channel estimation need to be accurate, precoding at the BS, and signal detection which is related to the first two items. On the other hand, in supporting wideband cellular communication systems and enabling low latency communications and multi-gigabit data rates, the Millimeter-wave (mmWave) technology has been utilized. Also, it is widely influenced the potential of the fifth-generation (5G) New Radio (NR) standard. This study was specifically review and compare on a few designs and methodologies on massive MIMO antenna communication systems. There are three limitations of those antennas were identified to be used for future improvement and to be proposed in designing the massive MIMO antenna systems. A few suggestions to improve the weaknesses and to overcome the challenges have been proposed for future considerations.

**Keywords:** Massive MIMO; Fifth Generation; 5G; Millimetre-wave; mm-wave; antenna design

### INTRODUCTION

Recently, there have been demands on the high-speed internet, video streaming in high-definition, high data transfer rate as the technology also expanding to cater to the needs. The fifth-generation (5G) communication system can handle the increase of those devices' requests, such as high data throughput. It was set by the fourth industrial revolution such as the internet of things (IoT), industrial internet, Augmented Reality (AR), Virtual Reality (VR) applications, massive machine-type communications (mMTC), enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and the next-generation communication systems (i.e., 5G) (Manabu Sakai et al. 2020; Alex et al. 2018; Petteri et al. 2016).

The MIMO technology evolved to a Massive MIMO technology. There are a few hundred antenna arrays in the massive MIMO system. The benefits from the MIMO system have been utilised in the Massive MIMO system at a larger scale. Generally, massive MIMO is evolved from the next generation networks with energy-efficient, robust, and secure spectrum efficiency (Akhil & Rakesh 2015).

In recent years, Massive MIMO system has been identified to be enhanced technologies in the wireless communication technology in the future known as 5G communication systems. It will act as an enabler to cater to the next-generation wireless system known as 5G wireless systems since it can tackle those requirements by proposing to expand the usage of a vast number of antennas at the base station known as BS. On the other hand, it can also increase the system's reliability and efficiency and gain impressive spectral density, quality of service (QoS), and objectivity

compared to the current systems (Marcus et al. 2018; Erik et al. 2017; Qurrat-Ul-Ain et al. 2018; Alex et al. 2018; De Mi et al. 2017).

The people embrace the 5G communication systems with the refreshed design of antenna design for mobile stations and base stations. The operation of the 5G communication systems' frequency bands requires multiple antenna elements. As a comparison, the elements in 5G mobile communication systems with 2 x 2 MIMO or 4 x 4 MIMO schemes are only applied for 2G/3G/4G communication with frequency ranging 698-960 MHz and 1710-2690 MHz. Therefore, the system needs at least 6 or 8 antenna elements to provide a better diversity and multiplexing to be incorporated into the mobile terminal (Yixin et al. 2017).

In recent years, development in wireless communication technology to cater to the demand for high traffic capacities in electronic devices has increased rapidly. Fifth-generation (5G) technology utilizes higher-frequency bands in providing the large information capacities needed to support multi-Gbps information rates and collect infinite information broadcasts using the latest mobile technology (Yu Huang et al. 2020).

The Millimeter-wave (mmWave) technology enables low latency communications and multi-gigabit data rates. It is widely influencing the potential of the fifth-generation (5G) New Radio (NR) standard (Diego et al. 2020). The technology ranging from 30 to 300 GHz keeps on increasing the demands for a higher data rate. Nevertheless, the minimum number of radio frequency chains limiting the potential multiplexing gain. It supports wideband cellular communication systems such as hotspots and small cell, wireless backhaul, indoor and device-to-device (D2D) communications systems (Shijian et al. 2019; Jie et al. 2017). On the other hand, the mmWave band allows packing

massive multi antenna arrays onto a small base station (BS) and dozens onto the user equipment (UE) (Diego et al. 2020).

In contrast, there is a slight difference in the simulation and measured results of S-parameters due to the insertion loss and inaccuracy in fabricating the SMA connector. In addition, the efficiencies of the antenna elements dropped and became worse due to the hand and head phantom effects. Other issues in designing the antenna are costs and power consumption.

One of the architectures having high costs is Digital Beamforming (DBF) because it needs many complete transceiver chains. In addition to that, it needs high power consumption. Low power efficiency also may lead to heat dissipation to the whole radio unit of the mmWave power amplifier (PA). The main purpose is to identify the weaknesses in designing a Massive MIMO antenna for 5G in the previous related work. Furthermore, it is to determine the challenges and limitations in the design of those antennas.

MASSIVE MIMO

MIMO schemes can fulfil the objective of a new mobile radio communication standard, the 5G mobile networks. The spectral efficiency (SE) per unit area or unit volume needs to be increased. The MIMO system permits one node to transmit several streams to one or more user equipment (UE) by implementing spatial degrees of freedom.

The movement of the enormous scale number of antenna elements at the base station for both uplink and downlink supports the MIMO systems in increasing their capacity in the system. This arrangement is called a Massive MIMO system, which refers to the vast provisioning of antenna elements at base stations over the number of the single antenna of user equipment.

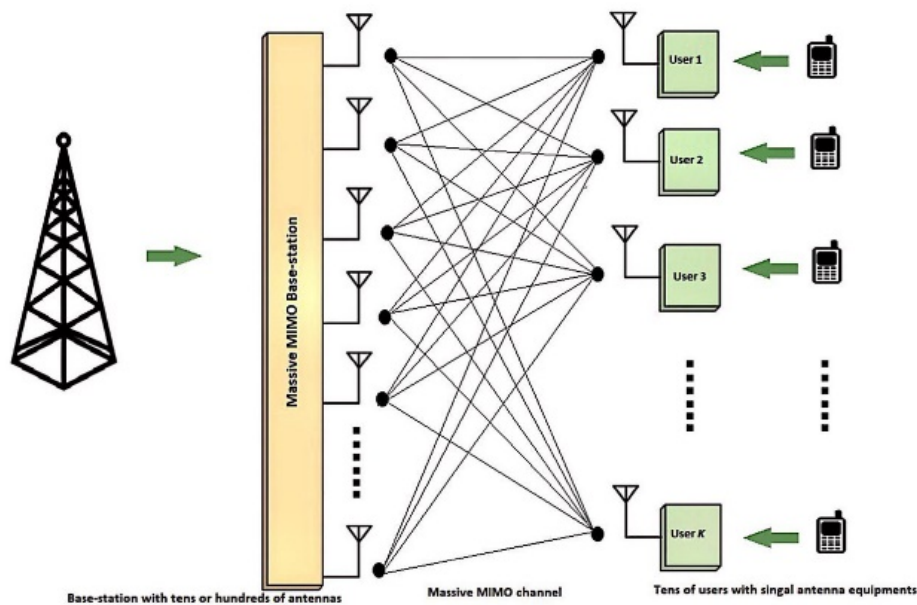


FIGURE 1. Massive MIMO architecture

Massive MIMO technology depends on spatial multiplexing to increase gain and diversity gain by adding the number of antenna elements in the BS (Mahmoud et al. 2019). It is a scaled up version of MIMO systems, the conventional small scale system. The architecture of massive MIMO system can be seen in Figure 1. It is a multiuser communication solution employing a large number of antenna elements to serve multiple users simultaneously at any given time. Commonly, the concept of massive MIMO assumed that the user terminals have a single antenna and the number of antennas at BS is larger (Mahmoud et al. 2019).

There is a need to add many channel estimations for each terminal since the number of antenna elements of the base station increased due to uplink slots. Generally, to solve this issue, it needs to work in Time Division Duplexing (TDD) mode and reciprocity amid the uplink and downlink channels (Akhil & Rakesh, 2015).

On the other hand, the system is also known as “Very Large MIMO,” “Hyper MIMO,” “Full Dimension MIMO,” “Large-Scale Antenna Systems,” or “ARGOS.” Massive MIMO also denotes any MIMO configuration beyond the most significant MIMO mode in the current LTE standard, currently  $8 \times 8$  with 100 or more antennas at BS (Stefan et al. 2020). Nowadays, mobile devices with sub-6GHz 5G communication systems started to have promoted and sold in Malaysia. The system supported 3.4-3.8 GHz and 3.8-4.2 GHz. In achieving a higher transmission rate in 5G communication systems, increasing the gain to cater to the new and cost-effective systems conducted by Naser et al. (2020).

Fabricating and integrating the unipolar radiator designs with the 5G smartphone circuit design are challenging. The MIMO antenna scheme of designs underwent a narrow frequency bandwidth in residing the space on a smartphone circuit system. However, spatial diversity and multiplexing can achieve a higher channel capacity with better reliability (Yixin et al. 2017; Naser et al. 2020). Several kinds of 5G MIMO smartphone antennas are compared in Table 1 conducted by Naser et al. (2020).

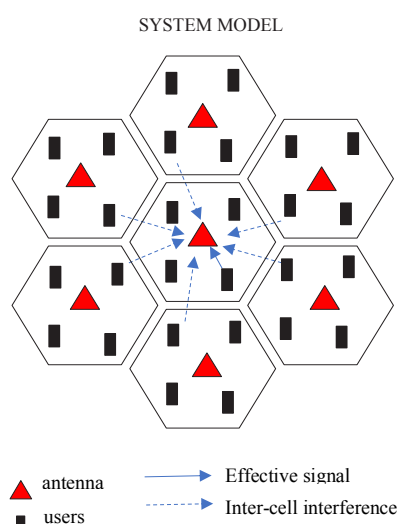


FIGURE 2. Massive MIMO system model

The system model of massive MIMO as illustrated in Figure 2. The maximum number of users within a cell can simultaneously receive data from the base station which is the same as the number of total users by each cell. (Kwihoon et al. 2018). As in the figure, there are effective signal between the user in the same cell and inter-cell interference occurred to those in neighbouring cells.

The model of the uplink multi-user of Millimetre-Wave (mm-wave) massive MIMO system at the base station contains the array antenna elements of  $M$  and  $K$ , the array antennas, and single antennas, respectively, at the simultaneous user terminal. Based on Figure 3, the phase shifter network will play a prominent role in processing the received signal for the angular domain. It is also to reduce its dimension from  $M$  to  $M'$ .

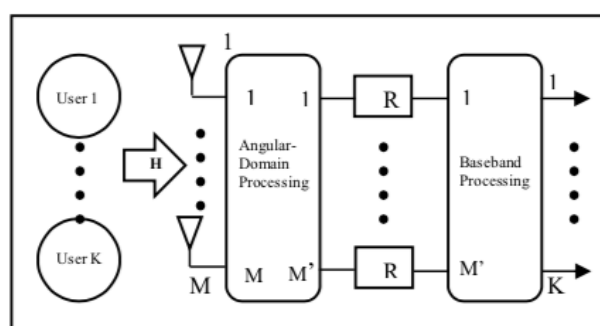


FIGURE 3. Angular-domain detection architecture for Millimeter-Wave massive MIMO systems

There is a process in the angular domain called space compression in recovering the transmitted signal. On the other hand, one needs to execute a baseband processing to help recover the signal being transmitted. The multipath channel model system is being deliberate to prototypical the mmWave propagation environment. The propagation path in the base station and the user equipment is related to the scattering pattern in the environment (Xiaoxuan et al. 2020).

Table 1 shown the data of comparison of various design of smartphone array massive MIMO antenna used in mobile (Naser et al. 2020). Among all antennas in the table, CPW-Fed Diversity type has better performance in terms of impedance match and bandwidth (BW) including its clearance size at satisfactory level.

Apparently, all other antennas listed in the table have double-sides or unipolar configuration while this type of antenna was implemented in one side of the smartphone board which makes it easier in fabricating and integrating with the circuit. Its design achieves around 1GHz impedance BW and better mutual coupling as compared to the other antennas. However, there are still limitations in its design which also known as hand-phantom due to its absorption (Naser et al. 2020).

Table 2 is showing the comparisons of various design of massive MIMO antennas and their limitations. One of the antenna, CPW-Fed Diversity is the best as compared to the other, previously but it still has limitations and could be improve further. There are different types of antenna with various sizes with their own limitations.

One of the limitations to consider in designing antenna is the cost. Obviously the costs will increase further to consume the suitable materials. However, massive MIMO can reduce the costing by eliminating the needs of bulky

items such as coaxial cables. Potentially, it also can reduce the the radiated power by using cheap milliwatts amplifier (Mahmoud et al. 2019).

TABLE 1. Comparison on 5G Smartphone Antennas

Design Type	BW (GHz)	Eff (%)	Size (mm <sup>2</sup> )	Isolation (dB)
Gap-Coupled	3.4-3.6	-	150 x 75	15
Inverted-F	3.4-3.6	55-60	100 x 50	10
Patch-Slot	3.55-3.65	52-76	150 x 75	11
Monopole	3.4-3.6	35-50	150 x 75	11
Spatial-Reuse Antenna	3.4-3.6	40-70	150 x 75	12
Inverted-L Monopole	3.4-3.6	40-60	136 x 68	14
Inverted F	3.4-3.6	-	120 x 70	20
Ring-Slot	3.4-3.8	60-75	150 x 75	15
Monopole	4.55-4.75	50-70	136 x 68	10
Tightly Arranged Pairs	3.4-3.6	50-70	150 x 73	17
Wave-Guide	3.4-3.6	50-80	150 x 75	15
Monopole	3.4-3.6	60-70	150 x 75	18
Diamond-shaped Slot	3.3-3.9	60-80	150 x 75	17
Open-end slot	3.4-3.6	50-60	136 x 68	11
Loop element	3.3-3.6	40	120 x 70	15
CPW-Fed Diversity	3.4-4.4	65-80	150 x 75	16

Other than costing, there are other factors to be considered in designing antenna in massive MIMO systems. Capacity and link reliability increase diversity gain providing the robust link. Massive MIMO also improves spectral efficiency (SE) by spatial multiplexing in cellular networks.

In addition to that, a large number of antennas will eliminate the interference effects and simplifying the signal processing. As the number of transmit antenna increased, the transmit power will be reduced. This is due to the coherent combining which the transmitted power is inversely proportionate to the number of transmit antenna (Mahmoud et al. 2019).

#### ANTENNA DESIGN

A tuneable antenna designed using a hybrid of copper and graphene to achieve reasonable efficiency, gain and tuneable frequency range conducted by Hamzah & Nidal (2020) and Nidal & Hamzah (2020). The following equations are to be considered in designing the antenna.

$$W = \frac{c}{2f_r \sqrt{\frac{\epsilon_r + 1}{2}}}$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-2}$$

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left[ \frac{W}{h} + 0.264 \right]}{(\epsilon_{reff} - 0.258) \left[ \frac{W}{h} + 0.8 \right]}$$

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{reff}}}$$

$$L = L_{eff} - 2\Delta L$$

$$f_i = \frac{\cos^{-1} \left( \sqrt{\frac{Z_o}{R_{in}}} \right)}{\frac{n}{L}}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

$$G_{pf} = \frac{c \times 4.65 \times 10^{-9}}{f_r \sqrt{2\epsilon_{reff}}}$$

$$W_f = \frac{2h}{\pi} \left\{ B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left[ \ln(B - 1) + 0.39 - \left( \frac{0.61}{\epsilon_r} \right) \right] \right\}$$

$$L_f = 3.96 \times W_f$$

$$W_s = 2 \times W$$

$$L_s = 2 \times L$$

TABLE 2. Comparison between various types of Massive MIMO antennas

Ant. Ref.	Types of Antennas	BW (GHz)	Gain (dB)	Efficiency (%)	Size	Limitations
Yixin Li et al. 2017	12-element antenna array	(3.4-3.6) (3.6-3.8) (5.15-5.925)	-	Low band: 41-82 High band: 47-79	150 mm x 80 mm	Insertion loss due to the SMA connector and fabrication inaccuracy.
Binqi Yang et al. 2018	mmWave MIMO DBF	0.5	7	7.6	16 x 4 array	High cost to consume high power
Alex et al. 2018	64 BS elements 128 BS elements	0.1	5.8	-	250 x 280 array	Additional antennas contribute to the channel hardening.
Jie Huang et al. 2017	mmWave massive MIMO channel	2, 2, 4, 4.	-	-	60 cm x 60 cm, 60 cm x 60 cm, 36 cm x 36 cm, 36 cm x 36 cm	Antenna aperture increase with the increasing of antenna and violate wavefront.
Guangyi Liu et al. 2017	3D MIMO	0.02	-	10-40	128 antennas	High cost to increase RF transceivers. Power efficiencies degraded with the decreasing of the output power of power amplifier (PA).
Kazuki Maruta 2020	CB-SDMA	0.02	20	-	100 antennas	Increasing of packet loss rate due to retransmission at the upper layer (TCP) due to time domain back off.
Xu Du et al. 2020	LYRRC	0.02	>15	10	64 antennas	Spatial multiplexing correlated user leads to smaller SINR, and non-correlated user leads to longer queueing latency
Naser et al. 2020	CPW-Fed	3.4-4.4	4	65-80	150 x 75 array	The gain and efficiencies reduced due to user's hand and/or head.
Le Kuai et al. 2020	N260 Band 64 Channel mmWave	0.4	13	-	16 x 4 array	The array gain varies over different scanning angles. Small amplitude of phase error results in the imbalance of different beam peaks.
Dierks et al. 2020	Indoor scenario	0.02	-	-	1200 antennas	Difficult in acquiring CSI due to many antennas in massive MIMO
Dey et al. 2021	SWB antenna	1.74-100	9.24	67.6-93	60 mm x 40 mm x 0.1 mm	Complex surface current distribution on antenna structure. The current propagates across a range of scattered area on the edge.
He Huang et al. 2020	FSS	22.4 27.2	8.6 8.9		1 x 4 array	High band element of the main beam split due to interference resulting nonideal XPD.



Where  $\epsilon_{r_{eff}}$  is the effective dielectric constant,  $\epsilon_r$  is the dielectric constant of the substrate,  $h$  is the height of the dielectric substrate,  $W$  is the width of the patch,  $L_{eff}$  is the effective length,  $L$  is the actual patch length,  $\Delta L$  is the length extension,  $Z_o$  is equivalent to the feed line impedance,  $R_{in}$  is the resonant input resistance when the patch is fed at the radiating edge,  $W_f$  is the feed line width,  $L_f$  is the feed line length,  $W_s$  is the width of the substrate, and  $L_s$  is the length of the substrate.

#### MAIN CHALLENGES AND LIMITATION

The main challenges and limitations on designing massive MIMO antennas are varied with the different types of antennas. Results are the main factor that can affect the design of some antennas. Inaccuracy in fabrication may lead to varying results in measured and simulation trials. For the mobile antenna, the efficiencies of the antenna elements worsen due to phantom effects. It is due to hand phantom or head phantom, or both may lead to radiation patterns distorted and become weaker.

In addition, the data that is transmitted by other cells results in interference in multi-cell. The hardening effect will increase when the antenna array of similar power rises. The uplink signal goes through scattering, reflection, refraction, and diffraction. At a low Signal to Noise Ratio (SNR), it is found that the gap is high between analytical and simulation results. At the same time, the approximation of Signal to Interference Noise Ratio (SINR) becomes less accurate due to the low SINR of small K. A very narrow beamwidth, a half-power beamwidth (HPBW), is required in avoiding undesired crosstalk. Therefore, a directive antenna does not exist.

There are numerous data amounts for each user terminal (UT) to be transmitted fluctuating in time, increasing overhead and transmission delay. Therefore, the efficiency is degraded when the output power amplifier (PA) and the whole radio unit decrease. On the other hand, when there are many users at the base station, which have a slightly low number of antennas compared to the number of users, the detector's performance is unsatisfactory, and the matrix approximation inversion methods are not numerically robust. The degradation of BER in all sensors is increased with the increase of transmitting antennas. Therefore, the increasing antenna elements at the base station should enhance spectral and energy efficiency.

However, the base station acquires a large amount of power due to some enormous antenna elements. The hardware overhead cost may decrease if the hybrid combining can reduce RF chains. However, if the RF chains are maintained, the price may rise as the propagation paths channel is larger than the mobile station (MS) antennas. In addition, the constraint condition plays a vital role in determining whether the macro base station (MBS) serves the user or not.

If it is not satisfied, then the MBS might not serve the user, and due to that, the power of the small base station (SBS) does not meet the requirement in servicing the users. The MBS may not serve the user in an edge area and only serve by a single SBS. The network-wide interference raises that dominates the secrecy performance at a high-density node. The trade-offs between the coverage and the secrecy existed as higher gains at the mmWave cells led to a drop in secrecy performance.

#### DISCUSSION

Wireless communication technology keeps on growing and expanding, demanding the higher data rate transfer in a short time. Millimetre-wave (mm-wave) corresponds to a frequency band of 30-300GHz. Sometimes, it also includes the frequency bands of 10-30GHz as it shares the propagation characteristics, which, the signals experiencing intense path loss due to their sensitivity to blockage.

The main issue in mm-wave communication systems is designing a small antenna with a wide band feature that includes the entire band (Hamzah & Nidal 2020). There is a huge quantity of unlicensed spectral space, approximately 7 GHz, utilised by the Industrial Scientific and Medical (ISM) application ranging from 57 to 64 GHz (Hamzah & Nidal 2020; Nidal & Hamzah 2020).

Another challenge in the mm-wave system is increasing the path loss. The signal will easily attenuate and may fade during rainfall (Nidal & Hamzah 2020). It allows the antenna elements to be packed within the same physical area of the system. In a few kilometres distance, multi-gigabit data rates can be achieved at a line-of-sight whenever there is a large antenna array of point-to-point mmWave communication system (Binqi et al. 2018; Jie et al. 2017; Abdul Haq et al. 2020).

Organisations of standardisation develop mm-wave channels to utilise the frequency range from 6 GHz to 100 GHz. The said organisations are METIS, MiWEBA, mmMAGIC, 5GCM, 3GPP 38.900, IEEE 802.11 NG60, and NYU Wireless (Jie et al. 2017).

There are many complete transceivers needed to run DBF architecture for the 5G mmWave system. On the other hand, the power consumption also very high in verifying the hardware design and system. Heat dissipation occurred because efficiency is low at the mmWave power amplifier (PA). The aperture of the antenna array increases when the antenna increases, especially when it reaches hundreds and above. Each antenna element has its cluster as long as it is on a large array.

Since the size of the antenna is vast, there are some constellations, and some are not. Because of the observability over the whole array axis and the vast number of antennas, some constellations perform very well, and the rest are not.

Some variants at some different scanning angles can be verified in the feasibility of 5G Radio Frequency (RF) and the array axis in the Q-band. A slight phase error or amplitude change resulting in the imbalance of different

beam peaks. The received signal of the uplink multi-user mmWave Massive MIMO system for low complexity angular-domain based detection (ACD) is converted into the angular domain. The channel model has been reformulating so that the dominant angles can be selected. It contains the signal power for angular-domain processing.

#### CONCLUSION

In this review paper, several challenges and limitations have been addressed on massive MIMO system technology for 5G communication systems. A few designs of antennas being compared in terms of BW, Gain, Efficiency, and size. Each of them has its own limitations such as costings, loss due to fabrication, degradation of efficiencies, packet loss, and beam split due to interference.

Those compared designs have issues and limitations yet to solve. There are opportunities in improving the systems' design with stressing on the accuracy in fabricating and research on new techniques and method to reduce loss and interference with the minimum cost.

Although the numerous numbers of antennas benefiting the communication systems in massive MIMO, there are challenges for signal processing that need to be resolved. Channel estimation which is the major role of the overall performances which BS requires accuracy in estimating the CSI practically. Another important category is precoding uses the CSI to maximize the link performance. Precoding occurred at downlink BS focusing on the spatial data streaming (Mahmoud et al. 2019).

Furthermore, signal detection needs to consider the accuracy and instantaneous action of CSI to perform precoding in downlink and uplink related to the accurateness and instantaneous (Mahmoud et al. 2019).

All in all, in improving and reducing the limitations in designing for massive MIMO systems, need to be considered those factors, channel estimation, precoding and signal detection. It is impossible to obtain a perfect CSI, as it is assumed perfect CSI as perfect CSI is usually not available and also it is difficult to acquire CSI in massive MIMO due to the many antennas (Dierks et al. 2020). However, the technique which sensitive to the accuracy of the sample correlation matrix and the size of antenna array is proposed by Mahmoud et al. 2019. To acquire the CSI due to the large number of antenna, there is a need to improve or to have more robust precoding techniques. Nowadays, the massive MIMO system being used widely and it will still relevant in the near future and will expanding further yet it will be the main player in the communication systems

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#### DECLARATION OF COMPETING INTEREST

None

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