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Efficiency of massive MIMO for future wireless communication systems

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Abstract
One of the main issues will continue to focus more and more on the "speed of communication" that researchers have been focusing on these days. As a result, mobile communication has seen a rapid change from 1G to 5G technology. Meanwhile, new techniques have been continuously developed to overcome the shortcomings of existing systems or to improve existing systems. Among these techniques, the technique has been studied for a long time MIMO (Multiple Input Multiple Output). Massive MIMO is a more advanced version of MIMO and is worthy of touching many points. Current communication standards provide limited services to users and the quality of services is inadequate, but Massive MIMO technology is expected to provide some improvements in these areas. The aim of this paper is to present efficiency of Massive MIMO technique for the next generation of wireless communication technologies, and in particular to demonstrate the role of Massive MIMO.

Keywords: 5G; multiple-ınput multiple-output Technologies; massive mımo; wireless communication.

1. Introduction

Massive multiple-input, multiple-output (MIMO) is existing the best fascinating wireless technology and a very important role of fifth-generation (5G) systems. The main reason for Massive MIMO for 5G is very significant key is that very high frequency (mm Wave) signal will used in 5G. For this reason, 5G technology will require the use of a large number of antennas. The solution to this is Massive MIMO.

Massive MIMO which is increasingly used in wireless communication technology in recent years is known a system that communication is performed via multiple antennas at the transmitter and the receiver sides. There is no limitation on the number of antennas. Moreover, this situation also allows to perform studies on comparisons of differences in the number of transmit and receive antennas. Various works about issues such as Massive MIMO's design, analysis, and functions have focused on more. In [1], theoretical studies about network design and signal processing and coding of Massive MIMO is presented. In addition, difficulties and performance limits of this system and some algorithms for these systems have been mentioned. Another study presents to eliminate some notions caused by deficiencies because of high mobility and low SNR for multi-user MIMO [2]. Furthermore, the benefits of the HetNet system which is formed by combining Massive MIMO with mmWave is mentioned in [3]. A study is available which is performed with the help of various analysis to determine how the number of antennas do need for Uplink and Downlink Massive MIMO cellular network [4]. In addition, various comparative studies about Frequency Division Duplex (FDD) and Time Division Duplex (TDD) techniques for Massive MIMO systems are also available [5]. In [6], the comparison of the general technical features of FDD and TDD techniques are available. Moreover, a study about number of antennas for Massive MIMO in uplink and downlink cellular systems is also available in [4]. In [2], it is specified that a system that have number of antenna is more efficient than without MIMO system.

2. 5G (5. Generation)

Growing demands of users constantly is the reason of rapid progress of wireless communication system, so 5G will substitute the 3G, 4G systems which are being used in these days step by step. In addition, mobile operators are in a great effort to provide better quality of services to users. Therefore, they follow advancements of the 5G process closely. Demands, improvements and benefits expected from

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5G technology should be tried to determine exactly. Hence, studies continue in order to overcome difficulties will arise in this respect. Even if the studies are inadequate for the industry, METIS [7] and 5GNOW [8] projects help to create the required standards in the academic field. Architectural and functional requirements of 5G technology have not been determined yet. Some of the projects have been launched for this purpose are as follows: METIS [7], 5GNOW [8], COMBO [9], the MOTO [10]. If we look at planning for 5G scheduled to be completed in around 2020 [11].

2.1. Data rate

The most important expectation in wireless communication is to meet users' requests about data rate sufficiently. Therefore, one of the priority issues is higher data rates that is supported by 5G technology. Hence, in [12], it is emphasized that 5G technology provide higher data rates that it can be reached high speed at gigabit levels per second. Higher data rate is among the demands of wireless system which designers are constantly faced. It is stated that studies began to carry out these demands in 5G which is planned to be completed around 2020 [13]. If we ask, why further improvement should be in data rate, we can list the following reasons: Firstly, users expect better quality of service through increased technological possibilities. Secondly, it is to be established a wide range of system that will enable a large number of devices which will be able to communicate with each other in the coming years. The importance of the data rate will be better understood when each of these requirements is assessed. By way of a simple example; high speed trains are known to be able to reach 250 km / h. Although communication is possible with 4G network in these speeds, 4G system will not be sufficient for a high-speed trains whose speeds are about 500 km / h [25-14*]. It can be considered the use of heterogeneous networks in 5G for this highly mobile users [15]. Indeed, the proposed mobile femtocell (Mfemtocell) systems contribute to signal improvement with the using of vehicles with high mobility [16]. For these reasons, 5G technology is absolutely necessary to increase the data rate. Despite connection of over 10 billion devices is predicted in the scope of the Internet of Things, it is not possible to be covered with 4G [17]. The gap which will occur at these points needs to be fulfilled with 5G technology. At this point, it is stated that 30 times more data rate than 4G was reached as a result of studies made by Samsung Electronics Company in terms of data transmission rate [18]. In this study, it is stated that 1.2Gbps was observed at 100 km / h. It is also noted that 7.5Mbps speed was reached using the 28 GHz spectrum. Hence, it has been reported that the high frequency band is suitable for 5G and this condition also allows high data rates [19]. Briefly, because the use of smart devices will continuously increase with technological developments within the next 10-15 years, significantly performance improvement is necessary. Increasing use of smart devices is not only reason for this improvement. In addition, users want to access smart devices which have better quality applications in terms of user interface, whenever and wherever they want at high speeds [20]. When all these aspects are considered together, higher data rate is emerging as an essential point for 5G. For this reason, one of the topics of future works is the higher data rate. Therefore, researchers should take into account it at the beginning of the priority areas.

2.2. Latency

As soon as a wireless signal is begun to transmit, it has travelled in various ways that can be encountered obstacles such as scattering, reflection, refraction. Depending on the fading caused by these obstacles, signal reaches the receiver with delayed or within a certain time loss. Although this delay is not at the levels that users may notice when compared with the first generation system, it remains a problem that must be overcome in order to meet the requirements of a new generation wireless communication systems. It is emphasized that a more solid delay which is essential area for various applications such as logistics, automotive, health and safety is need to be supported by 5G [12]. Therefore, the realization of a lower latency is not an improvement that current's network systems has not tackled yet it. It is thought that 5G become a part of an activity at this point and it is planned that reducing latency as much as possible with 5G studies. Reducing the latency means realization of the internet-based access and applications in such a manner that incessant, interrupted as if in real time [11]. To give an example the fact that the latency is a crucial issue, it is clear that especially vehicular technology will have great developent in the future. Improving the latency for wireless and mobile communications requirements of the driverless car which is included in this improvements is indispensable for 5G. To support this indispensable condition, one of six challenges that 4G technology currently used doesn't appeal enough is low latency. For this reason, it is stated that the lower latency is an issue to be definitely solved by 5G [20]. Latency in 4G systems is 15 ms and this latency is required to be approximately 1ms for 5G [21]. Because, response time in applications such as

communication between people, communication between machines as well as communication between objects (Internet of Things) should be as fast as possible. Whereby, the remote control of heavy industrial machineries will have been occurred more quickly and also it is able to help investigation of unexplored areas such as parts of the Polar Regions or the ocean floor [18]. The realization of applications called tactile internet will be possible with a system which its Round-trip delay is 1 ms [22]. Thanks to the development of these applications, it will be carried out that processing of tactile internet in addition aural of the internet. In the best examples, it may be possible that a doctor can remote operate with the definition of the required threshold through using the tactile internet system which has very low latency by 5G. It is emphasized that the importance of lower latency to achieve higher data rates and energy efficiency [23]. Short TDD (Time Division Duplex) latency was reached thanks to the proposed 5G in this study. In addition, it is said that lower latency is a critical point for real-time applications such as transmission message by patient monitoring robots, life safety systems, nuclear reactors and drones [24]. In another study, although it should be emphasized latency in 5G is almost 1ms [25], very few studies on how this situation has been occurred. When analyzed all this situation in latency, it will be seen that the majority of currently used technology's structure is necessary to redesign. Although 4G system capacity is at the peak level, it hasn't brought enough solution in the above-mentioned topics. Studies of 5G planning for new systems to be linked millions of devices continue. Latency in this planning will be able to meet the required and also must be. 5G should have transmission mode with low air interference latency. Thus, 5G waveform should allow low latency used with very short TTI (Transmission Time Interval) [26]. In relation to this, a study on a new radio frame format is provided for 5G [39]. In this study, shorter TTI was carried out, which meets requirements of the latency. Therefore, it appears that TTI duration for low latency is an important point for latency. Therefore, it is expected to realize of a shorter TTI by 5G.

2.3. Energy and cost efficiency

5G technology has to produce solutions about reduction of energy consumption and cost, as well as improving the care of the increase of data rate and decreased latency mentioned above. Because, it is reported that approximately 60% of the power consumption can be consumed by base stations [27], [28]. Therefore, if wireless energy consumption is reduced, the operating costs can also be reduced by a similar proportion. In addition, reduction of the carbon dioxide emission will also be provided indirectly with improvements to be made. Thus, more environment friendly communication technology will become in use. But the event is not limited the reduction of energy consumption by base station and cost reduction. In that, energy consumed by hardware components of new smart devices which use wireless communication systems is also concerned at this point. If energy consumption of the hardware component is taken into account, this is an issue that will contribute development of improving energy efficiency. An operation can be performed better performance with under the same power restrictions. When energy consumption is considered to be a growing concern for base stations, transmission power plays an important role at this point [1]. Energy efficiency can be defined as reducing the transmission power without increasing BER (Bit Error Rate). Furthermore, cost reduction can be accomplished by reducing complexity. In general, using most cost-effective components as possible should be encouraged with to be held in conjunction improvements. If these components are used, communication between machines, spreading use of Internet of Things and reaching a large target audience will be easy. If it will be summarized briefly, low power and less expensive base stations are necessary. Furthermore, it is predicted that the number of base stations will increase because of HetNets [29]. PAPR (Peak to Average Ratio Power) is an important issue in terms of energy efficiency. PAPR problem is a condition that reduces power efficiency [30]. Thus, the reduction of power efficiency will also directly affect the energy efficiency. PAPR is an issue of multi-carrier waveforms. Therefore, it is to focus on a waveform that will contribute to reducing the PAPR when determining a waveform for 5G technology. In [31], in terms of MIMO systems, performances of PAPR were analyzed for waveforms that have the potential for use in 5G. In general, studying about cost efficiency is expected by 5G technology as well as studies of energy efficiency and lower energy consumption.

2.4. Spectrum efficiency

Although the wireless communication data volume increase day by day, the electromagnetic spectrum will never increase [32]. It also becomes more important to improve use of the spectrum with increasing number of devices connected [11]. All frequency bands which mobile systems have opportunity to access is under 6 GHz and all progress

has been made in this band. But, because these frequency bands that have been used in other wireless technology are extremely full, they will not be enough to 5G communication [17]. For this reason it is necessary to develop new spectrum efficient techniques. Even the realization of spectrum sharing has been an important issue for 5G [21]. At this point, millimeter wave is a promising issue in 5G communications in terms of allocation bandwidth for high-quality multimedia [33]. A new design presented for this purpose, is stated to be expected that this new design significantly improve spectral efficiency of 5G [34]. Due to rapid spread of very high resolution mobile applications, it is also indicated that more spectral source for 5G communication is need [35]. A system which is created with a combination of some of the techniques is presented in order to increase the spectral efficiency of 5G [36]. It has been emphasized that increasing efficiency of spectrum is a necessary condition for 5G. Studies continue to create a standard for the spectrum in 5G and it is important that researchers have to work on this issue for future studies.

3. Massive MIMO

3.1. Theoretical approach of massive MIMO

In this section, most of the following theoretical approaches are based on studies in [1], [37], and [38].

The channel coefficient for an MU-MIMO system is shown in Equation-1. Here, the system is a BS, L-cell and K antenna.

$$h_{i,k,l,n} = g_{i,k,l,n} * \sqrt{d_{i,k,l,n}} \quad (3.1)$$

Channel matrix of all K users from l-th cell to i-th BS;

$$\mathrm{H}_{i,l} = \begin{bmatrix} h_{i,1,l,1} & \cdots & h_{i,K,l,1} \\ \vdots & \ddots & \vdots \\ h_{i,1,l,N} & \cdots & h_{i,K,l,N} \end{bmatrix} = \mathrm{G}_{i,l}\sqrt{\mathrm{D}_{i,l}} \quad (3.2)$$

$$\mathrm{G}_{i,l} = \begin{bmatrix} g_{i,1,l,1} & \cdots & g_{i,K,l,1} \\ \vdots & \ddots & \vdots \\ g_{i,1,l,N} & \cdots & g_{i,K,l,N} \end{bmatrix} \quad (3.3)$$

$$\mathrm{D}_{i,l} = \begin{bmatrix} d_{i,1,l} & & \\ & \ddots & \\ & & d_{i,K,l} \end{bmatrix} \quad (3.4)$$

The received signal vector in a single BS for UPLINK signal transmission is given in Equation-5.

$$\mathrm{y}_y = \sqrt{p_u}\mathrm{H}\mathrm{x}_u + \mathrm{n}_u \quad (3.5)$$

The total channel capacity is shown in Equation-6.

$$C = \log_2 \det(\mathrm{I} + p_u \mathrm{H}^{\mathrm{H}}\mathrm{H}) \approx \log_2 \det(\mathrm{I} + \mathrm{N}p_u \mathrm{D}) = \sum_{k=1}^{K} \log_2 \det(\mathrm{I} + \mathrm{N}p_u d_k) \; {}^{\frac{bits}{s}}\!/_{Hz} \quad (3.6)$$

The signal vector for all K users for DOWNLINK transmission is given in Equation-7.

$$\mathrm{y}_d = \sqrt{p_d}\mathrm{H}^{\mathrm{T}}\mathrm{x}_d + \mathrm{n}_d \quad (3.7)$$

Since BS generally has CSI based on uplink pilot transmission for all users, the total capacity is as in Equation 8 as indicated in [38].

$$C = \max_{\mathrm{P}} \log_2 \det(\mathrm{I}_N + p_d \mathrm{HPH}^{\mathrm{H}}) \approx \max_{\mathrm{P}} \log_2 \det(\mathrm{I}_K + p_d \mathrm{NPD}) \; {}^{\frac{bits}{s}}\!/_{Hz} \quad (3.8)$$

The meanings of the symbols given in the above equations are shown in Table-1 and some specific advantages that Massive MIMO technology can provide for the wireless communication system are examined below.

In addition, the graph showing the increase in the efficiency of the spectrum with Massive MIMO is available in Figure 1.

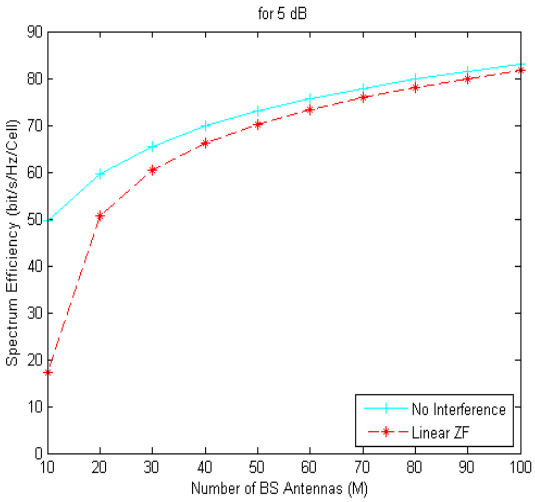


Figure 1. Gain for spectrum efficiency with massive MIMO systems.

3.1.1. Develop efficiecny of spectrum and energy

The Massive MIMO improves system capacity, spectrum and energy efficiency with more than 100 antennas equipped with cellular BSs [39]. Base stations in Massive MIMO systems use very high spatial muxing to increase system capacity. Numerous simulations have been reported to analyze the effect of multiple antenna arrays on spectral efficiency [4]. In another study [40], in simulation where they analyze the spectral efficiency of a very large MU-MIMO, consisting of 500 BS antennas serving 10 users at the same time based on the LTE standard, they implemented simple linear precodings such as maximum rate combiner (MRC), minimum mean square error (MMSE), and ZF that provide 42 b / s / Hz (excellent channel status information, CSI) and spectral efficiency of 28 b / s / Hz [41]. 130 b / s / Hz (LTE) and 110 b / s / Hz (Wi-Fi) values were measured with ZF pre-coding while with MRB pre-coded, 22 b / s / Hz (LTE) and 19 b / s / Hz (Wi-Fi). In addition, some new practical work has been studied in Massive MIMO to realize theoretical knowledge. The Argos Project [42] demonstrates experimentally the BS prototype with antennas 2 and 4 and in the 2.4 GHz band. The RUSK Lund testbeds includes a cylindrical array and a linear array [43]. CSIRO has implemented a range of applications up to 32 elements, which can serve at least 12 concurrent users [44].

3.1.2. Cost effective and energy efficient (low power consumption) components

In the study in [45], networks of variable phase shifters to be applied in the RF pre-coding solution was used, as shown in Figure 2.

Table 1. Symbols and Notations [1,37,38].

Representation of Symbol	Meaning of Symbol
$g_{i,k,l,n}$	Complex Small-Scale Fading Coefficient
$d_{i,k,l,n}$	Large-Scale Fading Coefficient
K	User Number
L	Cell Number
N	Antenna Number
$\mathbf{x}_u$	Signal vector of all users
H	Uplink channel matrix
$\mathbf{n}_u$	A zero-mean noise vector
p_u	Uplink transmission power
$\mathbf{x}_d$	The signal vector transmitted by the BS
$\mathbf{n}_d$	Additional noise

As shown in Figure 3 [46], it is possible to achieve a further reduction in power consumption. However, this architecture only assumes that each RF chain is tied to a single antenna, and it is emphasized that sequence gain can be reduced because fewer antennas are active [47]. Various studies are

performed to realize 5G's these improvements. At this point, it is mentioned briefly about pilot contamination. Because reducing the problem of pilot contamination is an important point for next wireless technology. It is stated that pilot contamination is one of the reasons for the decrease of Massive MIMO system efficiency [48]. Various techniques have been demonstrated to avoid limit the performance of the system by pilot contamination. One of these techniques is presented [49], and the comparison system's performance. Pilot contamination is a special study subjects. So, it is an important area to focus on for next generation wireless technology, especially 5G.

Massive MIMO is not only a method of remaining in theory as can be seen when examining studies of the literature. It is also used in applications in various fields of wireless communication. Although Massive MIMO is a system which is currently being used, there are many issues that have to be addressed on.

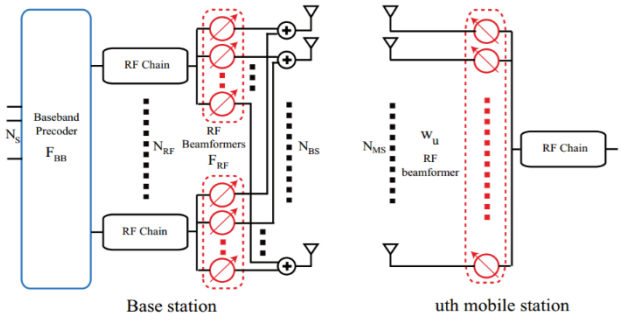


Figure 2. A BS with hybrid analog/digital architecture [45].

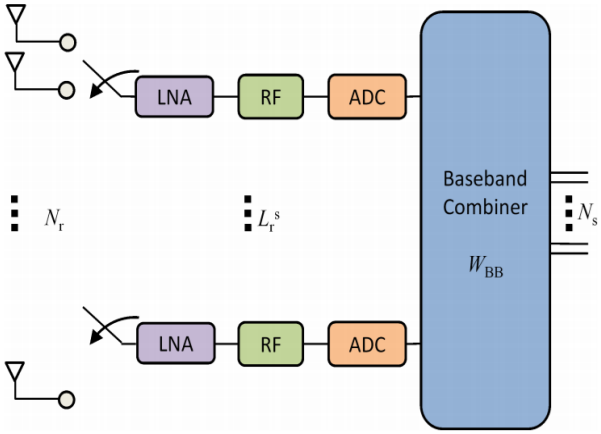


Figure 3. Hybrid architecture receiver which is used switches [46].

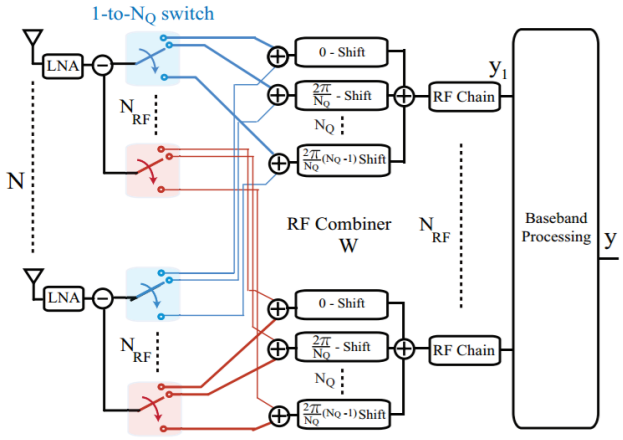


Figure 4. Hybrid architecture which is used combination of switches and phase shift [47].

4. Conclusion and future studies on massive MIMO for 5G

Generally in this paper, it has been mentioned about studies of Massive MIMO and 5G. Reasons of 5G's necessities to make improvements on these issues were indicated. Massive MIMO's contribution to these improvements is another topic that will be revealed in this study. In addition, there are also studies on potential of Massive MIMO's contributing to the improvement of these areas. This realization of the potential in a real-time application is open issues. Although there are studies which are conducted by Massive MIMO about these topics, it is necessary to extend these studies. Besides, topics which will be studied for 5G briefly stated as follows:

- Waveforms for 5G
- mmWaves
- Heterogeneous Networks/HetNets
- Beamforming
- Pilot contamination
- Standardization of 5G
- Improving performance for real-time applications in 5G

Overall, this study offers an idea to researchers especially in certain areas for 5G which is one the next generation wireless communication technology. In addition, we believe that this study will encourage researchers who will work on Massive MIMO for 5G.

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