# Theoretical Study of Massive MIMO and 5G technology

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**Abstract:** 5G is a futuristic and promising cellular wireless technology which plays an important role to enhance and improve wireless network and pave the way for a new and faster network that has capability to transform internet. Rapid Growth and innovations in wireless communication have unveiled new and exciting challenges. One of the major challenges is the maximization of transmission rate due to growing demand of multimedia and safety related applications. Among several solutions proposed in the literature, one of the most exciting and promising one for future 5G technologies is massive Multiple Input Multiple Output (MIMO). Various studies have indicated the utility of massive MIMO in forthcoming networks. Therefore, this paper presents an overview of recent studies in massive MIMO along with a comprehensive overview of latest research issues. We also provide future prospect of massive MIMO by discussing how massive MIMO can be integrated with imminent technologies for better utilization of resources.

**Index Terms – Massive MIMO, long-term evolution, 5G technology .**

## 1.INTRODUCTION

Now a days the cellular, mobile users and mobile industry wants reliable, accurate and more faster data speeds and internet, the futuristic wireless network which is going to be 5G affirm to deliver that. With existence of next wireless network users would be able to utilize data and internet faster and more reliable. The rapid development of wireless mobile communication has led to the explosive growth of the number of mobile users and the scale of related industries. Therefore, the wireless communication system needs to meet the higher data, transmission rate and higher system capacity, and the communication system needs to utilize the bandwidth resource efficiently, due to the shortage of spectrum resource, it is very important to improve the spectrum utilization of the system. Traditional MIMO technology can use limited spectrum resource to meet users' demand for system performance. But there are fewer antennas in the base station of traditional MIMO system, and it has limited system performance. As one of the key technologies of future 5G, massive MIMO can meet the needs of future wireless communication business, improve the spectrum efficiency and channel capacity of communication system, and effectively improve link reliability and data transmission rate [1].Multiple-input and multiple-output (MIMO) is a wireless technology that can provide significant performance improvement over the traditional single- input and single-output system, has attracted growing interest since being introduced in the past two decades. It is a key technology that takes the advantage of multiple antennas at transmitter and/or receiver that can substantially improve the network throughput, capacity, and coverage without requiring additional bandwidth or transmit power level [1]. The idea is to utilize multiple antennas at both the transmitting ends and receiving ends to separate independent wireless channels in a rich multipath environment, and uses them to transmit multiple data streams simultaneously to increase the channel capacity by applying diversity combining approach. To date, MIMO technology has been utilized in the fourth generation (4G) wireless communication standards, such as Long Term Evolution (LTE), wireless LAN (IEEE 802.11n), and Worldwide Interoperability for Microwave Access (WiMAX) [2]. The use of MIMO antennas, coupled with modulation formats, such as Orthogonal Frequency Division Multiple Access (OFDMA) can provide both increased channel capacity and protection against multi-path fading due to their rich scattering nature that provides improved spectral efficiencies. Multiple-input and multiple-output (MIMO) has been well studied and understood in terms of point-to-point links to achieve enhance radio link reliabilities via diversity [3] and increase data rate via multiplex [4]. This has brought huge challenges for antenna designers to hosting multiple antennas in a size limited mobile terminal. However, recent advance on MIMO has led the transformation from a point-to-point single user MIMO to multiuser MIMO (MU-MIMO) to reduce the challenge to hosting multiple antennas in a size limited mobile terminal [3]. A MU-MIMO antenna system refers to a base station (BS) with multiple antennas simultaneously serves a set of single antenna users and the multiplexing gain can be shared by all users [4].Extending the benefits of MU-MIMO, Massive MIMO also known as Very Large MIMO, Full Dimensional MIMO (FD-MIMO) and Large-Scale Antenna Systems are introduced, where BS is equipped with orders of magnitude more antennas, e.g., 100 or more [5]. Massive MIMO has shown over 10 times spectral efficiency increase over a point-to-point MIMO under realistic propagation environment with simpler signal processing algorithms [3], [6]. Therefore, this paper intends to study and review Massive MIMO as one of the key technologies in fifth generation (5G) wireless communication standard, its main progress to date, and summarizes its opportunities and challenges. The paper is organized as follows. In Section 2, the literature review and discussion of recent works related to Massive MIMO with its comparison to traditional MIMO had been provided , section 3 overview regarding 5G with respect to its application is provided, summarizing its opportunities and challenges are presented in Section 4 and respectively at Section 5 conclusion of our study would be presented.

## 2.literature review

The exchange of information between two or more devices without the inclusion of wires in the path for signal propagation is known as wireless communication. Considering the exponential rise of wireless communication around the globe, a great deal of research has been done to improve the reliability of data. In addition to the ease of instalment of communication systems the wireless networks can serve a large number of communicating devices at one time without need of any physical elements. The wireless communication can be of three main types which are known as simplex, half duplex and full duplex [1]. In case of simplex communication, the transfer of message takes place in one direction only. However, in case of half-duplex communication can be done in both directions but not at the same time. Similarly, when communication can be done in both directions and at the same time, then it is called full-duplex communication. In the following part we will go through some of the recent advancements in field of wireless communication. During the past few years, the data traffic (fixed and mobile) has increased exponentially because of the increasing number of devices like smart phones, laptops, tablets, and several other devices. In the future, the requirement for wireless data traffic will be much more than today [2], [3]. Mobile data traffic worldwide is anticipated to escalate to 48.3 Exabytes per month in 2021, Along with the data traffic, the number of connected devices is projected to increase to 35 billion in 2021. Implementation of new technologies is necessary to fulfil these demands. Even though there are a lot of benefits from wireless systems as compared to wired systems, however, there are a few major challenges that exist. The major constraint in wireless systems is availability of limited frequency spectrum for an ever increasing number of users and demand for data rate [4]. It is challenging to accommodate the increasing users in the limited frequency band available. To resolve these challenges researchers came up with the scheme of frequency reuse which was not a simple task to do. There are numerous problems associated with frequency reuse. For instance, there will be a lot of interference when multiple users have to share the same spectrum. Another major difficulty in wireless networks is fading such as multipath or frequency selective fading. In this regard, a Multiple Input Multiple Output (MIMO) antenna system emerged as a remedial technique to achieve better spatial diversity which makes the wireless systems more reliable. Moreover, with MIMO antenna system, multiple streams can be transmitted and thus, multiplexing gain can be achieved which significantly increases the capacity of wireless systems. MIMO systems have been given major consideration in the previous decade, and are being integrated into numerous new generation wireless standards (e.g., LTE-Advanced, 802.16m) [5]. The attempts to utilize spatial multiplexing gain have been moved from MIMO to multi-user MIMO (MU-MIMO), in which multiple-antenna Base Stations (BSs) simultaneously serve many users. With MU-MIMO systems, spatial multi-plexin gain is attained even if the users have a single antenna [6]. This is an important characteristic as the users are not capable to have a lot of antennas because of small size and cost of user terminals. MU-MIMO reaps all the benefits of MIMO, and also overcomes many limitations of MIMO for example the effects of poor/ degraded channels. Line of sight propagation, which leads to major decrease in performance of MIMO systems, is not an issue for MU-MIMO.

### 2.1.Massive MIMO for 5$^{Th}$ generation(5G)

MIMO stands for Multiple-Input Multiple-Output. While there are many layers of depth in MIMO technology, Massive MIMO, as you might guess, takes MIMO technology and scales it up to hundreds or even thousands of antennas and terminals. These antennas, attached to a base station, focus the transmission and reception of signal energy into small regions of space, providing new levels of efficiency and throughput. The more antennas that are used, the finer the spatial focusing can be. The general idea of MIMO has been around for decades, but the deployment of base stations with multiple antennas is not very widespread. To reach "massive" heights, even 4X4 MIMO (4 transmit streams, 4 receiver streams) doesn't qualify. The term massive MIMO is thought to have originated with Tom Marzetta of Bell Labs, and is often understood to denote at least 16 antennas on both the transmit and the receive end.

### Why Do We Need Massive MIMO for 5G?

Estimated by several researches, about 5% of service providers would start offering 5G wireless service, representing big progress from 5G proofs of concepts (POCs) in 2018. 5G, as the next-generation cellular standard after 4G (LTE), has been defined across several global standard bodies: ITU (International Telecommunication Union), 3GPP (Third Generation Partnership Project), ETSI (European Telecommunications Standards Institute). The official ITU specification, International Mobile Telecommunications-2020 (IMT-2020), targets maximum downlink and uplink throughputs of 20 Gbps and 10 Gbps, respectively, and latency below 5 ms (milliseconds) and massive scalability.5G will not be able to achieve IMT-2020 requirements, such as 20 Gbps, without some major breakthroughs. At this moment, it's not yet clear which technologies will do the most for 5G in the long run, but a few early favourites have emerged. The front runners include millimetre waves, small cells, full duplex, beamforming…and of course, massive MIMO. Telecoms have already been adopting massive MIMO on existing 4G LTE networks, especially TD-LTE (Time-Division LTE) networks (for example, SoftBank in 2016 and China Mobile in 2017). However, FDD-LTE (Frequency-Division-Duplex LTE) massive MIMO comes later because TD-LTE has the advantage of using the same frequency for both downlink and uplink, and the uplink channel quality information could be used for the downlink as well. FDD-LTE, on the other hand, requires another radio's resources to obtain the feedback information that is necessary to implement beamforming for the downlink communication. This indicates that FDD massive MIMO requires bigger overhead and is not as efficient as TD-LTE massive MIMO. It wasn't until 2018 that Verizon started massive MIMO trials of 96 antenna elements. With 5G up and coming, commercial networks almost certainly have to adopt massive MIMO, and a typical 5G massive MIMO plans are 64 or 128 arrays at 3.5GHz and more than 128 arrays at 28GHz or above. Massive MIMO offers two major innovations: 3D beamforming and MU-MIMO (multi-user MIMO). Beamforming is a traffic-signalling system for cellular base stations that identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process. At massive MIMO base stations, signal-processing algorithms plot the best transmission route through the air to each user. Then they can send individual data packets in many different directions, bouncing them off buildings and other objects in a precisely coordinated pattern. In brief, think massive MIMO as a massive 3D beamforming that increases horizontal and vertical coverage capabilities. Standard MIMO networks tend to use two or four antennas to transmit data and the same number to receive it. Massive MIMO, on the other hand, is a MIMO system with an especially high number of antennas. Massive MIMO increases the number of transmitting antennas (dozens or more than 100 elements) at a base station.

MU-MIMO further expands the total capacity per base station by enabling communication with multiple devices using the same resources, creating a virtually unified device side. The simultaneous use of the antennas of multiple devices help achieve the formation of virtual large-scale MIMO channels. The combination of these two innovations makes it possible to raise wireless transmission speed by increasing the number of antennas at the base station without consuming more frequency bandwidth or increasing modulation multiple values.

### 3.2 Performance comparison between massive MIMO and traditional MIMO

In 3GPP, MIMO technology generally evolves along the development of single-user MIMO, multi- user MIMO and network MIMO. Compared with traditional MIMO technology, the performance of massive MIMO technology is reflected in many aspects. The performance comparison between traditional MIMO and massive MIMO is presented in table 1.

**Table 1.Performance comparison between traditional MIMO and massive MIMO**

| Technology content | Traditional MIMO | Massive MIMO |
|---|---|---|
| The antenna number | ≤8 | ≥100 |
| Channel angular domain value | Uncertain | Certain |
| Channel matrix | Low requirement | High requirement |
| Channel capacity | Low | High |
| Diversity gain | Low | High |
| Link stability | Low | High |
| Resistance to noise | Low | High |
| Array resolution | Low | High |
| Antenna correlation | Low | High |
| Coupling | Low | Low |
| SER | High | Low |
| Pilot pollution | No | Yes |

### 2.2. Benefits Of MASSIVE MIMO

Theoretically, massive MIMO technology can offer some specific advantages towards the wireless communication system. Two significant advantages of massive MIMO are:

A. Increase in system capacity, spectral efficiency and energy efficiency : Massive MIMO wireless system refers to a very large number of antennas with orders of magnitude, e.g., 100 or more [7] are equipped at the cellular BSs to enhance the system capacity, spectral and energy efficiency in both the downlink and uplink communications [8]. In essence, massive MIMO BSs exploit a very high degree of spatial multiplexing to improve the system capacity. As the BSs are deployed with a large number of antenna arrays, simple linear beamforming/precoding is possible to increase the spectral and energy efficiency [3], [5], [6]. Several simulation works have been reported to analyse the effect of large number of antenna arrays on spectral efficiency. A uniform linear array (ULA) with 400 antenna elements serving 10 user terminals was simulated at 2.6GHz by using two different precoding schemes, eigen beamforming (BF) and zero forcing (ZF) [11]. Spectral efficiency of 58b/s/Hz and 48b/s/Hz has been achieved for ZF and BF respectively.

B. Cost effective and energy efficient (low power consumption) components : Massive MIMO system is predicted to be built by using cost effective and energy efficient (low power consumption) components [6]. Very large MIMO systems are made up of antenna arrays consist of individual antenna element that uses extremely low power, in the order of milliwatts [3]. The reduction in transmit power is required to achieve better system performance with a prescribed quality of service (QoS ) [12] because the energy consumption of cellular base stations is a growing concern. Unlike conventional MIMO system, massive MIMO reduces the complexity of the hardware (accuracy and linearity of each individual amplifier and RF chain) and energy consumption of the signal processing at both ends. Moreover, massive MIMO relies on the large numbers of antenna to make it resilient against fading and failures of individual antenna elements [6]. Several hybrid analog/digital precoding architectures have been proposed to reduce power consumption in massive MIMO. Hybrid precoding involves a combination of analog and digital processing which uses a small number of RF chains and divides the precoding process between RF and baseband domains. The work in [16] used networks of variable phase shifters to be implemented in the RF precoding solution as depicted in Fig. 4. Further reduction in power consumption can be achieved by using switches instead of phase shifters in the hybrid architecture as shown in Fig. 5 [17]. However, this architecture only assumes that each RF chain connects only to one antenna and this can reduce the array gain since fewer antennas are active [18]. Therefore, a combination of switches and constant phase shifters is proposed in [18] to perform the precoding/combining solution as illustrated in Fig. 6. Finally, to ensure the low cost and power consumption in massive MIMO, researchers in [19] has exploited the array architecture to implement massive MIMO BSs in a scalable manner. In contrast to previous testbeds [14] and [15], designed in a fully centralized processing, they have proposed a scalable array architecture where each antenna element is connected to common modules (RF chains). A distributed beamforming is used rather than centralized processing to reduce the bottleneck of backhaul network.

## 2.3.CHALLENGES OF MASSIVE MIMO

While massive MIMO renders some potential benefits to make the system a reality, there are still few issues and challenges that need to be addressed.

A. Antenna mutual coupling and spatial correlation Theoretically, massive MIMO systems are considered to achieve high system capacity, spectral and energy efficiency with the increase in number of BS antennas. This assumption might be misleading when antenna coupling along with circuit power consumptions is considered. A usual practice when deploying antenna elements in the antenna arrays is to space them by a distance equal to wavelength of the transmitted frequency or more [12]. One of the challenges towards this end is the constraint physical area for deployment of large number of antennas at the base station. The proximity of the antenna elements as signal sources and electrical components causes spatial correlation and antenna mutual coupling respectively [20]. In order to deploy large number of antenna elements efficiently in a limited space as well as maintain the required performance, research on such antenna arrays have been investigated [21-25] via simulations and testbed. Authors in [21] have analytically proposed an electromagnetic (EM) lens integrated with ULA (50 antenna elements) to reduce the spatial correlation as well as increasing the energy focusing. Average achievable rate for antenna array with EM-lens is 50b/s/Hz and without EM-lens is 45b/s/Hz. However, due to the space limitation of BS tower a linear array structure is practically difficult to install with large number of antenna elements. New antenna array arrangement called parallelogram is proposed by [22] also aimed to reduce the spatial correlation often encountered with square and circular array. The optimum inter element spacing of the parallelogram is 4□ in the horizontal and 11□ in the vertical direction. 2-Dimensional patch antenna array that utilized both the horizontal (H) and vertical (V) space is proposed by [23] with dual linear polarization at ±45$^{o}$. With this configuration, a large number of antenna elements can be deployed and at the same time can increase the cell throughput tremendously. The work in [24] presented a compact 36 sub-sectors antenna array utilizing mm-wave to the fact that it is possible to install large number of antennas into a small area due to the short wavelength. Antenna array with low mutual coupling that consists of a compact dual-polarized antenna with four radiating square patches is presented in [25]. LuMaMi testbed demonstrated in [22] used a planar antenna array in their experiment to test the uplink massive MIMO transmission. However, the antenna elements deployed in the antenna arrays is assumed to be spaced by a distance equal to wavelength of the transmitted frequency.

B. Challenge of hardware impairments :The realization of massive MIMO BS equipped with low cost hardware can be a challenge since it requires economy of scale in manufacturing as compared to mobile terminals [6]. Besides that, the impact of hardware impairments on massive MIMO systems becomes larger with low cost components since they yield higher levels of quantization noise. Study in [22] has shown that hardware impairments can lead to channel estimation error and a capacity ceiling even though a high array gain is achieved with a large number of antennas deployed at the BS. Moreover, the user side will experience severe hardware impairments compared to the BS side. Therefore, the transceiver algorithm has to be designed thoroughly to avoid the phase noise problem. Some other works has also studied the impact of per-antenna power constraints [21], and hybrid analogue/digital beamforming architectures [23], but they are only limited to signal processing models rather than actual transceiver implementations. The potential of reduction in power offers by massive MIMO only considers the radiated power rather than the total power consumed by the system [6]. Practically, the internal power consumption including the cost of hardware for baseband processing has to be investigated in order to realize the massive MIMO system.

**The key technological characteristics of Massive MIMO are:**

1. **Fully digital processing**; each antenna has its own RF and digital baseband chain. Signals from all antennas at each base station are processed coherently together. Core advantages of fully digital processing include the avoidance of specific assumptions on propagation channel, the possibility to measure the complete channel response on the uplink and respond fast to changes in the channel. Interestingly, recent assessments show that the full digital processing may not only offer superior performance but also better energy efficiency [2], a trend which may be reinforced by the ongoing development of tailored low-power circuits.
2. The reliance on **reciprocity of propagation and TDD operation**, enabling downlink channels to be estimated from uplink pilots, and obviating the need for prior or structural knowledge of the propagation channel.
3. **Computationally inexpensive precoding/decoding** algorithms, taking the form of maximum-ratio (known also as conjugate beamforming) or zero-forcing processing. Massive MIMO functions equally well with single-carrier transmission and OFDM.
   Notably, conjugate beamforming with OFDM is equivalent to time-reversal in a single-carrier system.
4. **Array gain**, resulting, in principle, in a closed-loop link budget enhancement proportional to the number of base station antennas.
5. **Channel hardening**, that effectively removes the effects of fast fading. Operationally, each terminal-base station link becomes a scalar channel whose gain stabilizes to a deterministic and frequency-independent constant. This greatly simplifies resource allocation problems.
6. The provision of **uniformly good quality of service to all terminals in a cell** -- facilitated by the link budget improvement offered by the array gain, and the interference suppression capability offered by the spatial resolution of the array. Typical baseline power control algorithms achieve max-min fairness among the terminals.
7. **Autonomous operation of the base stations**, with no sharing of payload data or channel state information with other cells, and no requirements of accurate time synchronization.
8. The possibility to **reduce accuracy and resolution** of transceiver frontends, and the digital processing and number representations in computations.

The attractive properties of propagation -- penetration of solid objects and diffractive behaviour -- and the maturity of hardware renders Massive MIMO primarily a below-6 GHz technology for radio access. This is also the region where spectrum is most valuable. Arrays have attractive form factors even for large numbers of antennas: in the 3.5 GHz TDD band, a half-wavelength-spaced rectangular array with 200 dual-polarized elements is about 0.6 x 0.3 meters large; in practice, larger antenna spacing may be desired and is easily afforded. However, systems operating at higher frequencies up to millimetre-waves may also benefit from the application of Massive MIMO, especially when these systems would need to support multi-user access in potentially non-Line-of-Sight scenarios.

### 2.4. What is Massive MIMO not?

Various large antenna systems are investigated and deployed in the quest for higher capacity and robust wireless access solutions. "Full dimension", "3D beamforming", and "grid-of beams" concepts, that rely on FDD operation or even hybrid beamforming, are sometimes marketed as Massive MIMO. Such solutions are less scalable with respect to the number of antennas, and importantly, they rely on specific properties of propagation or user location that limit their application to a substantial extent.

Point-to-point MIMO solutions with large arrays at the transmitter and/or receiver also are not Massive MIMO: Massive MIMO truly entails multiuser MIMO, relying on channel state information obtained through measurements on uplink pilots. Versions that operate in FDD and rely on the transmission of downlink pilots followed by subsequent fast CSI reporting by the terminals are also possible, but only in scenarios with relatively low mobility and small numbers of base station antennas.

### 2.5 Why is Massive MIMO Becoming a Reality Right Now?

Since its inception about a decade ago, the Massive MIMO concept has evolved from a wild "academic" idea to one of the hottest research topics in the wireless communications community, as well as a main work item in 5G standardization.

The time for Massive MIMO has come at this moment for two reasons: First, conventional technology has proven unable to deliver the spectral efficiencies that 5G applications are calling for. Second, the confidence in the exceptional value of the technology has spread rapidly since impressive real-life prototypes showed record spectral efficiencies, and the robust operation with low-complexity RF and baseband circuits has been substantiated [3].

### 4. What are the Operational Limits of Massive MIMO?

Massive MIMO is scalable with respect to antennas; additional antennas always help. The ultimate limit is dictated by mobility: every coherence interval (coherence time multiplied by coherence bandwidth) needs to accommodate uplink pilots, and payload in the uplink and downlink directions. The higher mobility, the less channel coherence and the fewer pilots can be afforded. In high-mobility macro-cellular environments (highway), this limits the multiplexing gain to some dozen of terminals but in environments with less or no mobility, hundreds or even thousands of terminals could in principle be multiplexed. The number of antennas that ultimately prove useful scales similarly, and are likely to be limited to one or a few hundred in macro-cellular, but potentially thousands in low-mobility applications [4].

### 4.1. Will Massive MIMO Work in Practice?

Massive MIMO does work in practice! It has been demonstrated to achieve a record spectral efficiency of 145 bps/Hz in a real-life testbed experiment with 100 antennas at the base station. This demonstration does show an improvement of more than 20 times over 4G systems, yet was achieved in a controlled lab environment. Adding more antennas to the base station and deploying more dedicated hardware could support more simultaneous users. Efficient operation has been validated in a wide range of propagation conditions including indoor and outdoor situations. The solutions to compensate for non-reciprocity of front-ends in TDD-based channel estimation have been confirmed to be robust. Recently the proof was extended to true mobile access: communication with pedestrians and cars can be maintained. These experiments show that channels can be tracked sufficiently fast to spatially multiplex moving users [4].

In parallel, hardware implementations have been progressed very favourably. Fore mostly, it has been technically proven that Massive MIMO systems can be built with very low complexity hardware, both for the digital baseband and the analog RF chains. Moreover, innovative architectures and circuits that exploit the specific nature of Massive MIMO systems are being designed. These will further reduce power and cost and promote an attractive deployment of Massive MIMO systems [8].

### 5. What Could Massive MIMO Offer More in the Future?

Massive MIMO can offer enhanced broadband services in the future, and more. 5G networks are expected to support a great variety of wireless services in areas ranging from infotainment to healthcare, smart homes and cities, manufacturing, and many others. Massive MIMO technology can be tailored to support a massive number of Massive Machine Type Communication (MTC) devices. Also, it is an excellent candidate to realize Ultra Reliable Communication as it can establish very robust physical links.

## 5. CONCLUSION

The massive growth in traffic demands for mobile data services has made Massive MIMO is seen as one of the key technologies in fifth generation (5G) replacing the conventional MIMO system. Massive MIMO relies on the law of large number of antennas that can tremendously improve the signal strength, increase data rates and improve signal reliability. The number of antennas with orders of magnitude, e.g., 100 or more are able to increase the system capacity, spectral and energy efficiency by just performing simple linear beamforming/precoding techniques such as MRT/ ZF. Massive MIMO can reduce transmitted power, the complexity of the hardware and energy consumption of the signal processing with more efficient use of the radio spectrum. However, in order to achieve the potential benefits of massive MIMO challenges such as spatial correlation and antenna mutual coupling as well as hardware impairments have to be addressed in further research works. This paper presented an overview on 5G technology requirements that are expected to be facilitated by Massive MIMO technology. An overview of this promising systems has been presented, with a major focus on its performance part, and its challenging part, along with major design challenges and its future scope.

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