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Developments of 5G Technology

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By

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ABSTRACT

This technology is the future of current LTE technology which would be a boost to the future of wireless and computer networks, as the speeds would be way higher than the current LTE networks, which will push the technology to a new level. This technology will make the radio channels to support data access speeds up to 10 Gb/s which will turn the bandwidth radio channels as WiFi. Comparing it with other LTE technology's it has high speed and capacity, support interactive multimedia, voice, internet and its data rate is 1 Gbps which makes it faster than other LTE’s . This is much more effective than other technology’s due to its advanced billing interfaces. This paper provides detail explanation of 5G technology, its architecture, challenges, advantages and disadvantages, issues and ends with future of 5G technology.

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CHAPTER I

INTRODUCTION

The world has seen a lot of changes in the realm of communication. Today we no more use landlines. Everyone possesses a mobile phone that functions nine to seven. Our handsets not only keep us connected with the world at large but also serve the purpose of entertainment gadget. From 1G to 2.5G and from 3G to 5G this world of telecommunications has seen several improvements along with improved performance with every passing day. 5G technology is on its way to change the way by which most of the users access their handsets. Users will go through a level of call volume and data transmission with 5G pushed over a VOIP enables gadget. With increasing awareness of customers with respect to upcoming technologies, affordable packages and good looks; it is very important that mobile producers must give an altogether decent package for keeping up the customer loyalty. The most important and leading motive of leading mobile phone manufacturers is the creation of best and latest technology to compete with innovative market giants. We have seen great cell phones one after another, with unbelievable traits. Apple has remained successful in shivering the electronic world by putting forth its latest iPhone 7 has taken the market by storm.

In such a small electronic piece, huge features are getting embedded. There are very few mobiles left without mp3 player or/and camera. People are focusing on getting everything without spending a penny more. Keeping in mind the user’s pocket, economic cell phones are introduced with maximum features. With 5G technology you can hook your mobile phone to your laptop for broadband internet access. The characteristics especially video player, camera, mp3 recorder, messengers, photo treatment and games have made today’s mobile phone a handheld computer. The developed world is already utilizing 4G and it is beyond imagination that what will be engulfed in 5G as everything is already embedded such as smallest mobile phones, speed dialing, largest memory, audio and video player, Microsoft office, etc. Pico net and Bluetooth technology has made data sharing a child's play. Initially infrared kept us bound for properly aliening two handset devices for data sharing. We still remember the disturbance and irritation caused in transferring data but the advent of Bluetooth changed the history. It enabled us to share data between two gadgets within a range of 50 meters. With the swiftness in data sharing the cell phone manufactures focused on mobile broadband that can open a new window of communication and navigation in the world of telecommunication.

5G technology will change the way cellular plans are offered worldwide. A new revolution is about to begin. The global cell phone is around the corner. The global mobile phone will hit the localities who can call and access from China to Germany's local phone with this new technology. The way in which people are communicating will altogether upgrade. The utilization of this gadget will surely move a step ahead with improved and accessible connectivity around the world. Your office will shrink into your handset with this cell phone that is going to resemble PDA (personal digital assistant) of twenty first century.

1.1 HISTORY

First Generation(1G):

In the early 20th century, Mobile radio communications were used in the military communications. Car based telephones was tested in 1946. This system used Single large transmitter on top of a high-rise building. A single channel was used like a half-duplex system was known as "Push-to-talk" systems in 1950. In 1960 IMPS (Improved mobile phone system) was introduced which can handle talk and listen at the same time. IMPS used two channels one for sending and one for receiving in telecommunications for a full duplex mode.

DAWN of Telecommunication: In 1970, private companies started developing their own systems to evolve existing systems further those private organizations were Analog mobile phone system(AMPS) were used in USA, Total access communication system(TACS), Nordic mobile telephone(NMT) used in parts of Europe and Japanese-Total access communication system(J-TACS) used in japan and Hong Kong. These systems were referred to First generation networks introduced in 1982 by BELL Labs popularly known as Advanced mobile phone system(AMPS).

The basic idea in AMPS was to use Geographic locations which can be treated as small cells and then can be used as frequency re-use which can support 5 to 10 times more users which was then referred to 1N IMPS (Improved Mobile Telephone System). The major concerns in 1G was weak security on Air Interface, Full analog mode of communication and no roaming.

Second Generation(2G):

Furthermore, to enable roaming formation of ETSI (European Telecommunications standards Institute) was created which was the beginning of 2nd Generation. The networks were commercially launched in 1991 at Finland based on GSM (Global System for mobile). Second Generation can deliver

Data rates of up to 9.6kb/s. Major benefits were conversations digitally encrypted, more efficient on spectrum and greater mobile phone penetration and introduce data service(SMS).

To generate higher data rates GSM carriers started developing a service called General Packet Radio Service(GPRS) referring to 2.5G. It was developed in 1995 and it mainly was packet switch network with GSM. GPRS can transmit data of up to 160 Kb/s**.** The phase after GPRS was Enhanced data rates for GSM Evolution (EDGE) referring as 2.7G in 1997. It introduced 8PSK modulation and can deliver data rates of up to 500 Kb/s using the same GPRS infra. During this time the internet was becoming popular 2.5G started growing and phones started supporting web browsing. This was an Internet boom in 1998.

Third Generation(3G):

This demand established 3GPP UMTS (Universal Mobile Telecommunications Systems) in 1999. This system uses wide band CDMA and this system was referred by W- CDMA (UMTS).

In 2000 3GPP Formation of governing bodies were developed. In interests of truly producing global standards. The collaboration for both GSM and UMTS were expanded further from ETSI to encompass its regional standards organizational developments such as ARIB and TTC from Japan, TTA from Korea, ATIS from America and CCSA from China. The successful creation for such a large and complex system specification required a well-structured organization. This gave birth to 3GGP which gave birth to the observation of ITU.

ITU-R manages the International Radio-Frequency Spectrum, Ensures the effective use of spectrum, defines technology families, allocate spectrum and proposed requirement for radio technology. Three organizations started developing to meet the requirements proposed by ITU-R is 3GPP, 3GPP2 and IEEE. The evolution of 3GPP started from GSM (Global System for Mobile communications), GPRS (General Packet Radio Service), EDGE, UMTS (Universal Mobile Telecommunications Systems), HSDPA (High-Speed Downlink Packet Access), HSUPA (High-speed Uplink Packet Access), HSPA (High Speed Packet Access), LTE (Long-Term Evolution) and LTE advanced.

The evolution of 3GPP2 started from IS-95, CDMA 2000, CDMA EVDO, CDMA EVDO REV A to CDMA EVDO REV B. The evolution of IEEE started from 802.16 FIXED WIMAX, 802.16 MOBILE WIMAX to 802.16M. Only 3GGP was dominated and widely accepted, this only incorporated Road map evolved by 3GGP Evolution.

The goal of 3GPP (UMTS) was to provide a data rate of 2 Mb/s for stationary/walking users and 384 Kb/s for moving vehicles. 3GGP designated as RELEASE 99. The upgradation was RELEASE 4 of 3GGP standard provided for the efficient use of all IP in core in the year 2001. This was the key enabler which laid foundation for HSPA.

In 2002, RELEASE 5 was introduced which was a core HSDPA. It provided the use for Downloading packet which provides a data rate up to 14 Mb/s by reducing latency (Delay). Further, RELEASE 6 was introduced which included the release of HSUPA in 2004 with a reduction in Uplink delayed enhanced link data rate of 5.74 Mb/s by reducing Latency (DELAY). This release also was the introduction of MBMS for Broadcasting services. Then further RELEASE 7 was introduced which also introduced MIMO and Higher order modulation of up to 64 QAM. Which evolved HSPA+ in 2007 providing Download link (D/L) data rates up to 28 Mb/s and Upload link (U/L) data rates of up to 11 Mb/s.

Fourth Generation(4G):

Initially the goal of telecommunication was mobility and Global connectivity. The whole new architecture was evolved in LTE SAE (System Architecture Evolution) and Radio port. Long Term Evolution(LTE) standardization began in 2004 and in June 2005 RELEASE 8 was finally crystallized after a series of refining.

Important Features of LTE Release 8.

- Reduced Delays for both connection establishment and transmission latency.
- Increased User data throughput.
- Increased Cell-EDGE bit-rate.
- Reduced cost per bit, Implying Improved spectral efficiency.
- Simplified network architecture.
- Seamless mobility, indulging between different Radio-Access technologies.
- Reasonable power consumption for the mobile devices.

These features made an advancement in radio technology.

Three fundamental technologies that have shaped the fourth-generation system in the radio technology interface were multi carrier, MIMO multiple Antenna technology and application of packet switching on radio interface. As a result of intense activity by a larger number of organizations. Specifications of Release 8 were completed by December 2007. The first commercial deployment of LTE took place in end of 2009 in northern Europe. The advanced LTE of Release 10, 11, 12, 13 in 2011, 2012, 2013 and 2016 were targeting Multicell HSDPA, HETNET, Coordinate multipoint, Carrier Aggregation and massive MIMO.

1.2 EVOLUTION OF FIFTH GENERATION

It's time to move from services to multiservice approach. The transformation will be moving from LTE to LTE Advanced and the features would be added as pervasive networks where users can be concurrently being connected to several wireless accessed technologies and seamlessly move between them.

Group Cooperative Relay: This technique is used to avail high data rates below over a wide area of a cell. Cognitive radio technology would enable the user equipment to look at the radio landscaping it is located to choose the optimum Radio Access Network, Modulation scheme and other parameters to configure to get the best connection in optimum performance. Smart Antennas will be redirected for better connection provided to the user.

Furthermore, 5G will leverage on the strengths of both optical and wireless technologies. 5G will be driven by software *Network Functions Virtualization (NFV)* and *Software-Defined Networking (SDN)*, IoT, IoE and Mobile Content Delivery Networks(CDN).

The 5G (Fifth Generation Mobile and Wireless Networks) can be a complete wireless communication without limitation, which bring us perfect real world wireless – World Wide Wireless Web (WWWW). 5G denotes the next major phase of mobile telecommunications standards beyond the 4G/IMT-Advanced standards. At present, 5G is not a term officially used for any particular specification or in any official document yet made public by telecommunication companies or standardization bodies such as 3GPP, WiMaxForum, or ITU-R. Each new release will further enhance system performance and add new capabilities with new application areas. Some of the additional applications, benefiting from mobile connectivity are home automation, smart transportation, security, and e-books [2]. IEEE 802.16 is a series of Wireless Broadband standards authorized by the Institute of Electrical and Electronics Engineers (IEEE). It has been commercialized under the name “WiMAX” (from "Worldwide Interoperability for Microwave Access") by the WiMAX Forum industry alliance. IEEE 802.16 standardizes the air interface and related functions associated with wireless local loop [12]. 5G mobile technology has changed the means to use cell phones within very high bandwidth. User never experienced ever before such a high value technology. The 5G technologies include all type of advanced features which make 5G mobile technology most powerful and in huge demand in near future. For children rocking fun Bluetooth technology and Pico nets has become available in market. Users can also hook their 5G technology cell phones with their Laptop to get broadband internet access. 5G technology includes camera, MP3 recording, video player, large phone memory, dialing speed, audio player and much more one can never imagine [13]. In fifth generation, Network Architecture consists of a user terminal (which has a crucial role in the new architecture) and a number of independent, autonomous radio access technologies (RAT) [14]. 5G mobile system is all-IP based model for wireless and mobile networks interoperability. Within each of the terminals, each of the radio access technologies is seen as the IP link to the outside Internet world.

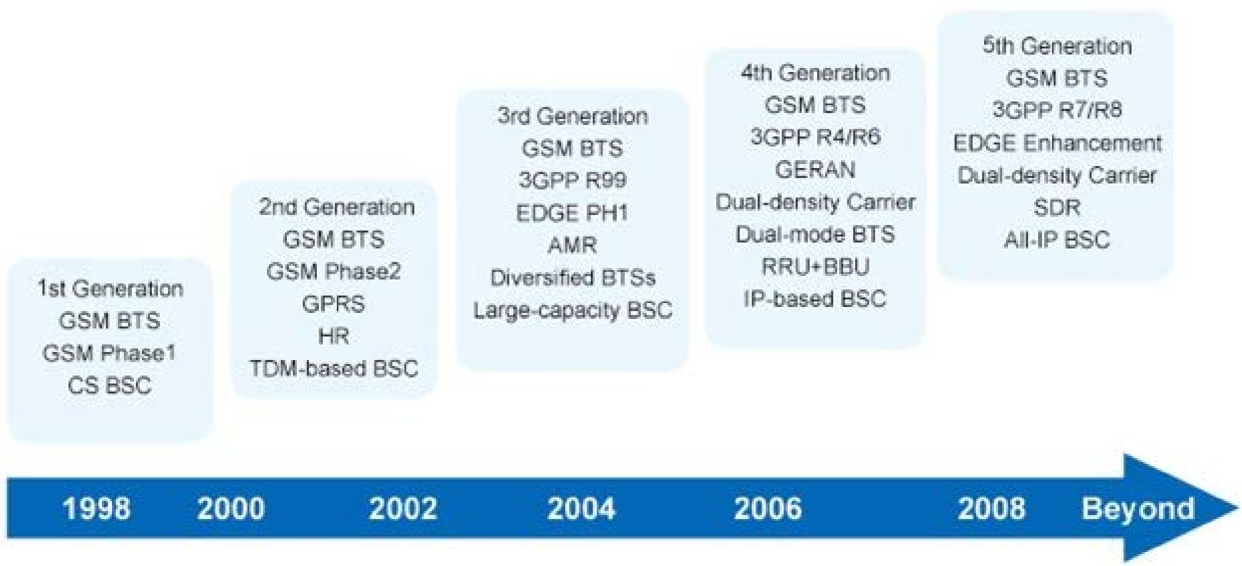


Figure 1: Technologies from first generation to fifth generation

The difference between all the 5 generations LTE's are shown in the below tabular representation:

Generation	1G	2G	3G	4G	5G
Deployment	1970/1984	1980/1989	1990/2002	2000/2010	2017/2020
Data Bandwidth	2 Kbps	14-64 Kbps	2 Kbps	200 Kbps	1 Gbps
Standards	AMPS	TDMA, CDMA, GPS, GPRS	WCDMA	Single unified standard	Single unified standard
Technology	Analog cellular	Digital Cellular	Broadband with CDMA, IP technology	Unified IP and seamless combination of broadband LAN, WAN and WLAN	Unified IP and seamless combination of broadband LAN, WAN and WLAN and WWWW
Services	Mobile Technology (voice)	Digital voice, SMS, Higher capacity packetized	Integrated high quality audio and video	Dynamic Information Access, Wearable devices	Dynamic Information Access, Wearable devices with AI capabilities
Multiplexing	FDMA	CDMA, TDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit and panel	Packet	All Packet	All Packet
Core Network	PSTN	PSTN	Packet network	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical

Figure 2: Difference between all the Generations

1.3 TECHNOLOGIES EXPECTED IN 5G

While considering the LTE scenario, the focus was on the availability of the bandwidth. But when it was beyond it, the research was aiming on providing pervasive connectivity which would provide users to access fast and pliable access to the internet, no matter wherever they are may be in between the sea, underground or at the sky. Although LTE standard is incorporating a variant called Machine Type

Communications(MTC) for the IoT. 5G technologies are designed from grounds up to support MTC like devices. As far as the new technologies are concerned, almost every technology is a prerequisite of the older versions. Similarly, 5G would comprise of 2G, 3G, LTE, LTE-A, Wi-Fi, M2M, etc. We can predict that the design of 5G would be capable of supporting a lot of applications such as IoT, augmented reality for HD streaming, connected wearable and immersive gaming.

Furthermore, 5G will avail the ability to handle the plethora of connected devices and a variety of traffic types. For example, 5G will provide much more faster speed links for High Definition streaming of videos as well as low data rate for sensor networks.

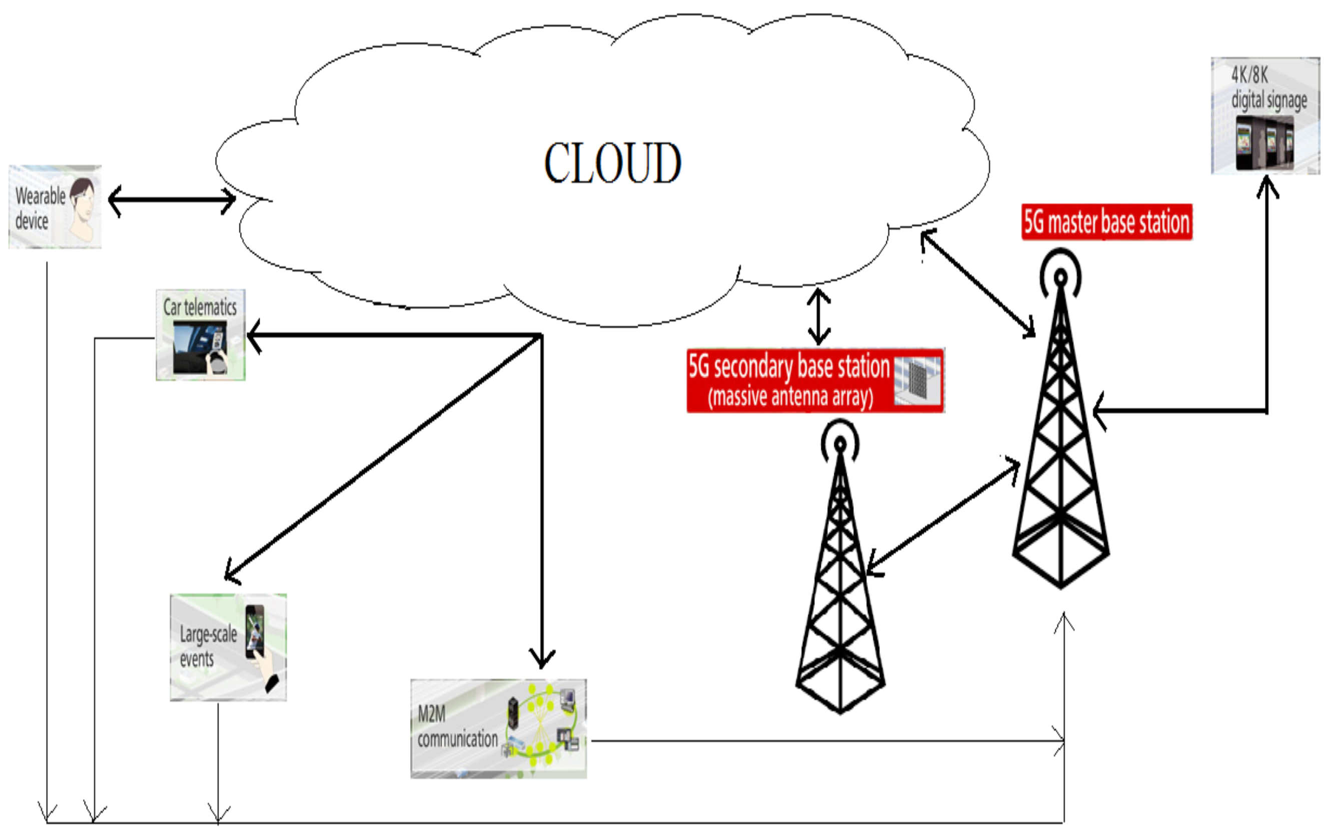


Figure 3: Cloud cycle of fifth Generation

5G networks would acquire new architectures like Radio Access Networks(RAN) categories such as cloud RAN and virtual RAN to establish a more centralized network and make the best use of server farms through localized data centers at the network edges.

Finally, 5G would use the cognitive radio techniques to allow the infrastructure to automatically decide the kind of the type of channel being offered differentiate between the movable and immovable objects and adapt to the conditions at the restricted time frame. In other words, 5G networks would be able to serve the industrial network and the social networking apps at the same time.

1.4 ORGANIZATION OF THE SURVEY

The main contributions of this Thesis are: (i) identifying what is 5G; (ii) how it works; (iii) Software used and their importance.

Additionally, Section 1 presents Overview of 5G; Section 2 covers Architecture of 5G; Section 3 discusses about Software uses and how it would be related with 5G; Section 4 Challenges in 5G technology; Section 5 Security in 5G; Section 6 concludes the Thesis.

Chapter II

Architecture of 5G Technology

This section first presents the key features of 5G architecture, later presents the basic architecture of 5G then presents the network architecture of 5G along with key requirements of the architecture and lastly ends with explaining about the mobile network architecture.

Key Features of 5G Architecture.

The main challenges to focus on is the challenges of 1000 times higher traffic volume and 100 times higher user data rate. This explosive traffic growth and the user data rate can be controlled by many technologies but we can focus on the three which can control such a high ratio. They are, the Physical layer(PHY) technologies which include the massive Multiple Input and Multiple Output(MIMO), Filter Bank Multi-Carrier(FBMC), Non-Orthogonal Multiple Access(NOMA), etc. It mainly focuses on the improvement of spectrum efficiency to enhance the network capacity. Furthermore, the exploitation of underutilized spectrum at the millimeter(mm) Wave Frequency can be very useful to improve the network capacity.

However, network densification is the most dominant ingredient contributing to the capacity of wireless communication system. It is believed that the capacity of the network using Universal Domain Network(UDN) can increase in the linear ratio of the number of cells. Considering the network densification, Heterogeneous Network(HetNet) including macro ENodeB(eNB) and low-power eNB(micro eNb, pico, eNB, etc.). Furthermore, Device-to-Device(D2D) Communication, a substitute to HetNet is capable to improve the peak data rate and spectrum efficiency. The load balancing among multi-Radio Access Technology(RAT) systems is still able to enhance the network capacity through improving the efficiency of the network resource.

Although the network densification can enhance the network capacity by reducing the path loss between the user and base station it increases both the interfering and the desired signals and effectively dwarfing the impact of the thermal noise. It would be considered equivalent to say that the system becomes interference limited, and the interference migration would be an improvement for link efficiency. Additionally, the interference becomes more complex as the density of the complex cells increases. At the receiver side, the advanced interference cancellation is required, the network architecture should also support the efficiency and the coordination among the different cells. Since the amount of control signaling in distributed coordination mechanism will increase quadratically with the increase of small cell intensity. The centralized coordination would be the first important priority feature for 5G architecture. Based on the centralized processing, the network performance can be further improved through joint resource coordination and management across multiple cells and multiple RAT systems. Besides, due to the limited coverage area of small cell and user mobility, fast moving user will undergo frequent handover. To provide the efficiency of seamless mobility, multiple small cells must be managed in the centralized way. It is clearly seen that the centralized coordination and management is necessary for Radio Access Network (RAN) of 5G mobile network. Meanwhile, the cellular Core Network (CN) should also be considered to manage the explosive growth of traffic volume.

The traditional way which centralizes the data-plane function at the boundary with the Internet and forces all traffic to flow through the P-GW in LTE network complicates the realization of P-GW, and yields the bottleneck at P-GW. Besides the function of data-plane, P-GW also performs a wide variety of functions like traffic monitoring, billing, access control, etc. With so much functionality in P-GW, results in lower flexibility and scalability. Then the operator can not enhance the data and control function individually. Additionally, the traditional network does not support to flexibly direct a chosen subset of traffic through the necessary middle boxes(e.g. firewall, DPI, etc.) according to the network state and user’s individual requirements. Therefore, it is necessary to separate the control plane from data plane and logically centralize the control plane. Obviously, it can be concluded that separating the control plane from data plane and centralizing processing (e.g. joint scheduling, centralized interference mitigation, etc) are important features of 5G mobile network for further improving the network capacity.

Lower Latency: Some services and applications related to healthcare, security, vehicle-to-vehicle and mission-critical control may have strict requirements on latency, in which the most challenging demand is on the order of 1ms [4]. Fortunately, one PHY scheme named Generalized Frequency-Division Multiplexing (GFDM) is designed to overcome the real-time challenge for 5G network [7]. Besides, technologies including content local caching [8] and D2D also have the potential to dramatically decrease the end-to-end latency. For example, caching the popular content within EPC is able to reduce the duplicate content transmission and the response latency. In addition, caching at eNB can further eliminate the latency and traffic growth in EPC. Considering the limited caching space of eNB and small number of users served by individual eNB of small cell, the hit ratio becomes smaller, thereby resulting in longer latency. Therefore, the 5G network architecture should support cooperative caching policy among different eNBs, and optimize the caching resource utilization globally in a centralized manner. Furthermore, the caching policy among multi-RAT systems also needs to be considered. Additionally, although the D2D can directly reduce the end-to-end latency, the interference problem in D2D scenario is also necessary to be handled in centralized way. Briefly speaking, the end-to-end latency can be directly reduced by proper caching and D2D, which need a logically centralized controller to coordinate and manage the corresponding resources.

Huge Number of Connected Devices: Different from human-to-human communication, MTC has a wide range of characteristics and requirements. The huge number of connected MTC devices further broaden the diversity of MTC. On the one hand, the number of served users per eNB can be decreased through network densification, thereby alleviating the pressure of eNB. On the other hand, the network needs deeper programmability and flexible adaption to different applications and guarantees the corresponding

QoS. Therefore, it is recommended that the network should decouple the software from hardware and build software over general-purpose processors (GPPs) via programming interface and virtualization technology. For example, in order to satisfy some special MTC services, the protocol stack should be simplified or tailored for reduction of the power consumption and latency. This implies the network architecture should have the ability to provide two different protocols based on the same infrastructure through network virtualization. Clearly, decoupling the software from hardware is necessary for 5G network to support the programmability and virtualization, which makes the network more programmable and flexible to adapt to various services and applications.

Decrease of Cost: Since the network functions always come with separate proprietary hardware entities, the deployment of new network services means a high cost for energy, capital investment challenges and rarity of skills necessary to design, integration and operation of complex hardware-based appliances. Moreover, hardware-based appliances rapidly reach end of life, requiring much of the procure-design-integrate-deploy cycle to be repeated with little or no revenue benefit. Worse, hardware lifecycles are becoming shorter as technology and services innovation accelerates, inhibiting the roll out of new revenue earning network services and constraining innovation in an increasingly network-centric connected world [9]. Therefore, it is necessary to decouple the software from hardware to architect operator's network towards deploying network services onto virtualized industry server, switch and storage. Besides, in order to cut down the investment of Mobile Virtual Network Operator (MVNO), future network should support network virtualization, which reduces the deployment of base station equipment and energy to run wireless network through sharing the network infrastructure of network operator. It is equivalent to say that the network resources can be utilized efficiently through network virtualization. Therefore, both decoupling the software from hardware and network virtualization are necessary for 5G network to reduce the CAPEX and OPEX, through reducing the equipment cost and improving the utilization of network resources.

Improvement of Energy Efficiency: Energy efficiency can be understood from two viewpoints, which are the energy efficiency of network infrastructure and terminal. Higher energy efficiency of network and terminal implies lower operational cost and longer battery lifetime, respectively. The above technologies (massive MIMO, UDN, etc.) are able to improve the link quality, which reduce the energy consumption on radio link. Both the network and terminal can save energy consumption simultaneously. In order to prolong the battery lifetime of terminal, its design should select the optimal components (such as CPU, screen, RF, audio devices, etc.) in terms of energy efficiency. Meanwhile, the protocol stack can also be simplified or tailored in terms of energy efficiency. As mentioned above, these specific requirements can be fulfilled through virtualization. That implies the network architecture should provide different protocols based on the same infrastructure through network virtualization. Regarding to the network energy efficiency, besides the benefit from massive MIMO and UDN, the network architecture should be able to switch on/off the base station of small cell depending on the traffic load while maintaining the coverage by macro cell. Note worthily, this dynamic switching on/off also needs the cooperation and coordination among multiple cells in a centralized manner. It can be seen that, besides the improvement of energy efficiency of equipment, the 5G network architecture can also increase the total energy efficiency through network virtualization and centralized network resources coordination and management.

2.1 Basic Architecture of 5G

Architecture of 5G is highly advanced, its network elements and various terminals are characteristically upgraded to afford a new situation. Likewise, service providers can implement the advance technology to adopt the value-added services easily. However, upgradeability is based upon cognitive radio technology that includes various significant features such as ability of devices to identify their geographical location as well as weather, temperature, etc.

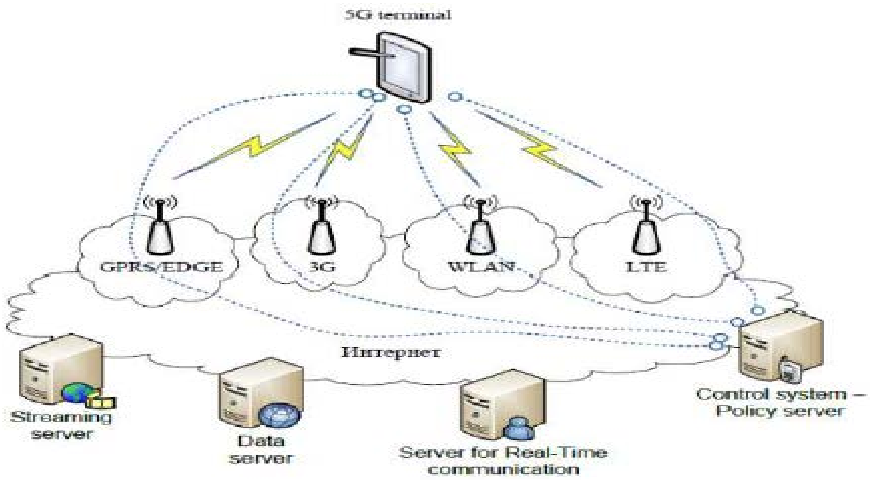


Figure 4: 5G Basic Architecture

The following image, the system model of 5G is entirely IP based model designed for the wireless and mobile networks. The system comprising of a main user terminal and then a number of independent and autonomous radio access technologies. Each of the radio technologies is considered as the IP link for the outside internet world. The IP technology is designed exclusively to ensure sufficient control data for appropriate routing of IP packets related to a certain application connections i.e. sessions between client applications and servers somewhere on the Internet. Moreover, to make accessible routing of packets should be fixed in accordance with the given policies of the user.

There are different sections in 5G architecture: core, cellular, wireless and mobile. The most widely used section is network architecture, which is discussed in the below subsection

2.2 Network Architecture of 5G

Agyapong, Iwamura, Staehle, Kiess, and Benjebbour [4] proposed an architecture for 5G. Before presenting the architecture, we would discuss the key elements of the network architecture, they are:

- Two logical network layers, a radio network (RN) that provides only a minimum set of L1/L2 functionalities and a network cloud that provides all higher layer functionalities

- Dynamic deployment and scaling of functions in the network cloud through SDN and NFV
- A lean protocol stack achieved through elimination of redundant functionalities and integration of AS and NAS
- Separate provisioning of coverage and capacity in the RN by use of C/U-plane split architecture and different frequency bands for coverage and capacity
- Relaying and nesting (connecting devices with limited resources non-transparently to the network through one or more devices that have more resources) to support multiple devices, group mobility, and nomadic hotspots
- Connectionless and contention-based access with new waveforms for asynchronous access of massive numbers of MTC devices
- Data-driven network intelligence to optimize network resource usage and planning

Network Architecture

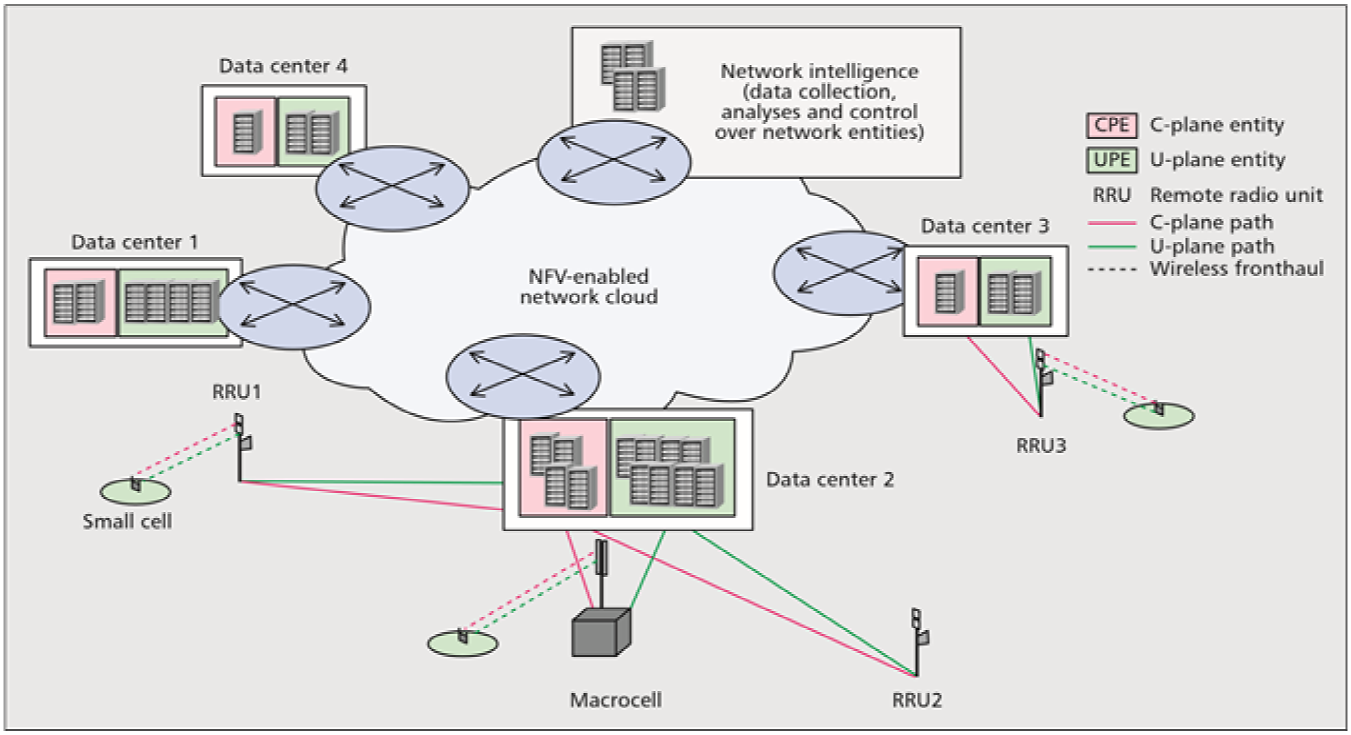


Figure 5: Network Architecture of 5G

The network architecture consists of only two logical layers: a radio network and a network cloud. Different types of base stations and RRUs performing a minimum set of L1/L2 functions constitute the radio network. The network cloud consists of a U-plane entity (UPE) and a C- plane entity (CPE) that perform higher-layer functionalities related to the U- and C-plane, respectively.

The physical realization of the network cloud could be tailored to meet various performance targets. For example, instances of UPEs and CPEs could be located close to base stations and RRUs to meet the needs of latency- critical services. To support latency-critical services, for example, it may be better to connect RRU3 to a small nearby data center (data center 3) rather than a large data center farther away (data center 2). On the other hand, RRU1 may be connected to a large data center located farther away (data center 2) rather than a nearby small data center (data center 1) if support for latency- critical services is not required. Such flexibility allows the operator to deploy both large and small data centers to support specific service needs.

Such architecture simplifies the network and facilitates quick, flexible deployment and management. Base stations would become simpler and consume less energy due to the reduced functionalities, thereby making dense deployments affordable to deploy and operate [15, 16]. Additionally, the network cloud allows for resource pooling, reducing overprovisioning and underutilization of network resources.

Dynamic Deployment and Scaling of Network Functions with SDN and NFV -

By employing SDN and NFV, CPE and UPE functions in the network cloud can be deployed quickly, orchestrated and scaled on demand. For instance, when a local data center is unable to cope with a flash crowd (e.g., due to a local disaster), additional capacity can be borrowed quickly from other data centers. In addition, resources within a data center can be quickly shifted to support popular applications simply by adding additional instances of the required software.

Besides this application-level flexibility, the use of a cloud infrastructure also provides flexibility with respect to the available raw processing capacity. Spare cloud resources can be lent out when demand is low, whereas additional resources can be rented through infrastructure as a service (IaaS) business models during peak hours. Furthermore, a broad range of “as a service” business models based on providing specific network functionalities as a service (i.e., XaaS) could also be envisioned. The complete or specific parts of the network could be provided to customers (e.g., network operators, OTT players, enterprises) that have specific requirements, for example in a “mobile network as a service” or “radio network as a service” model. “UPE/CPE/NI as a service” models, where specific core network functionalities (Fig. 2) of the mobile network are provided a la carte as a service, could also be envisioned. Last but not least, parts of the platform could be rented out to third parties like OTT players to enable the pro- vision of services and applications that require extremely low latency to end users. Besides the XaaS business models that could be facilitated, the flexibility of a cloud, coupled with SDN and NFV technologies, also makes the network easier, faster, and cheaper to deploy and manage.

2.3 Mobile Network Architecture:

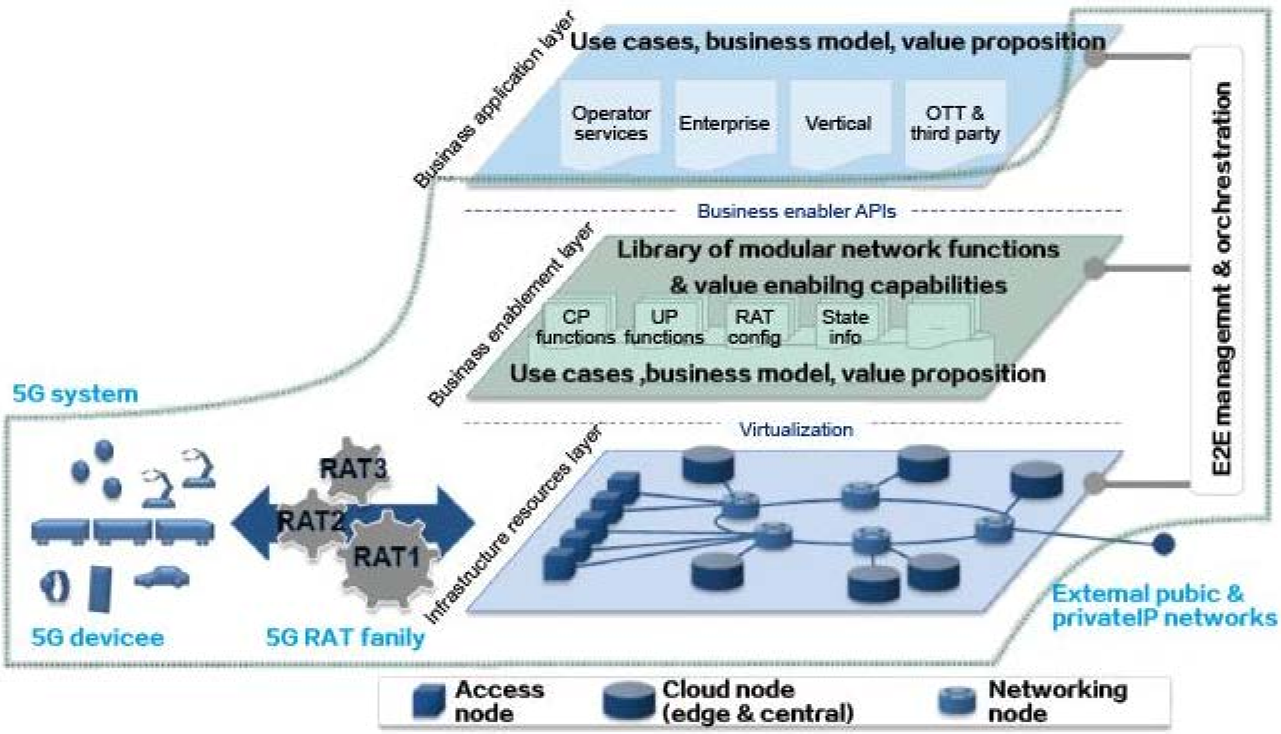


Figure 6: 5G Mobile network architecture

The 5G system comprises three layers:

Infrastructure resource layer: The physical resources of a fixed-mobile converged network, comprising access nodes, cloud nodes (which can be processing or storage resources), 5G devices, networking nodes and associated links. The resources are exposed to the higher layers and to the orchestration entity through virtualization principles.

Business enablement layer: Library of all functions required within a converged network in the form of modular architecture building blocks, including functions realized by software modules that can be retrieved from the repository to the desired location, and a set of configuration parameters for certain parts of the network, e.g., radio access. Those functions and capabilities are called upon request by the orchestration entity, through relevant APIs.

Business application layer: Specific applications and services of the operator, enterprise, verticals, or third parties that utilize the 5G network.

These three layers are articulated by an orchestration entity, which plays a central role in this architecture. It has the capability to manage such a virtualized network end-to-end, in addition to the traditional OSS and SON automation capabilities. The entity serves as the contact point to translate the use cases and business models into actual services and slices. It defines the network slices for a given application scenario, chains the relevant modular network functions, assigns the relevant performance configurations, and finally maps all of this onto the infrastructure resources. It also manages scaling of the capacity of those functions as well as their geographic distribution. In certain business models, it could also possess capabilities for third parties (e.g., MVNOs and verticals) to create and manage their own network slices, through APIs and XaaS principles. Data-aided intelligence will be utilized to optimize all aspects of service composition and delivery.

Network Slicing: A network slice, namely “5G slice”, supports the communication service of a connection type with a specific way of handling the C- and U-plane for this service. To this end, a 5G slice is composed of a collection of 5G network functions and specific RAT settings that are combined for the specific use case or business model. Thus, a 5G slice can span all domains of the network: software modules running on cloud nodes, specific configurations of the transport network supporting flexible location of functions, a dedicated radio configuration or even a specific RAT, as well as configuration of the 5G device. Not all slices contain the same functions, and some functions that today seem essential for a mobile network might even be missing in some of the slices.

The intention of a 5G slice is to provide only the traffic treatment that is necessary for the use case, and avoid all other unnecessary functionality. The flexibility behind the slice concept is a key enabler to both expand existing businesses and create new businesses. Third-party entities can be given permission to control certain aspects of slicing via a suitable API, in order to provide tailored services. Figure 3 illustrates an example of multiple 5G slices concurrently being operated on the same infrastructure.

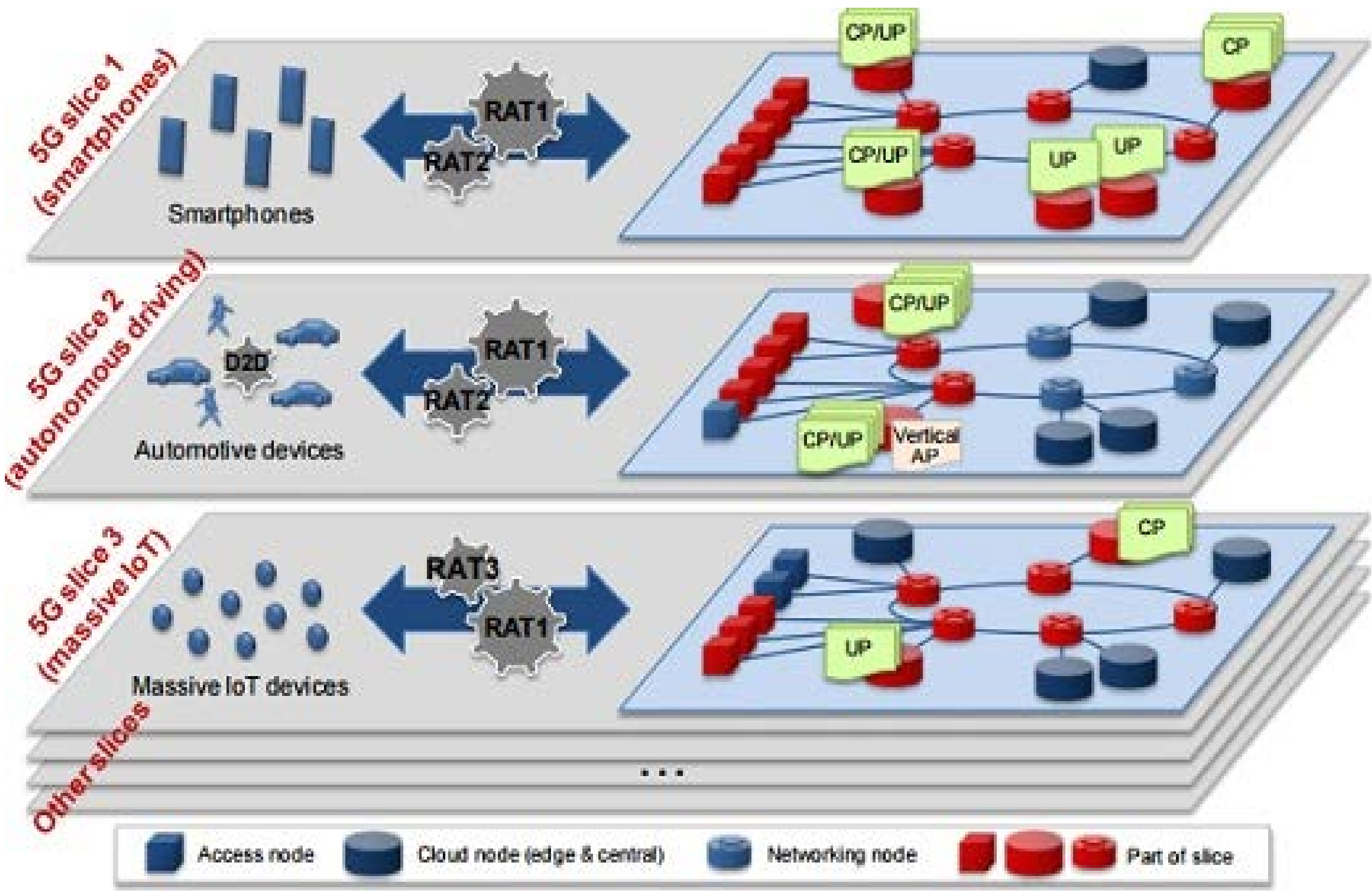


Figure 7: 5G network slices implemented on the same infrastructure

For example, a 5G slice for typical smartphone use can be realized by setting fully-fledged functions distributed across the network. For a 5G slice supporting automotive use case, security, reliability and latency could be critical. For such a slice, all the necessary functions can be instantiated at the cloud edge node, including the necessary vertical application due to latency constraints. To allow on-boarding of such vertical application on a cloud node, sufficient open interfaces should be defined. For a 5G slice supporting massive machine type devices (e.g., sensors), some basic C-plane functions can be configured, omitting any mobility functions, with contention-based resources for the access.

Irrespective of the slices to be supported by the network, the 5G network should contain functionality that ensures controlled and secure operation of the network end-to-end and at any circumstance. Scenario-Dependent Function Distribution: As outlined above, a 5G system will move away from the “one size fits all” approach towards a network that can be tailored to specific use cases by appropriately combining 5G network functions with a suitable 5G RAT. Figure 4 shows different physical realization examples that are possible with such a system.

The use of generic programmable hardware using NFV principles is expected for all network processing functions. Nevertheless, the architecture should allow U-plane functions to use dedicated hardware, where required to achieve a certain cost or performance target. Due to the recent advances in virtualization technologies, however, it is not expected that dedicated hardware will be needed for C-plane functionality.

A distinctive characteristic of 5G will be its ability to tailor network functions and their implemented location in the network. The C- and U-planes are envisioned to be logically separated from each other so that a physical separation is possible as appropriate. This has several advantages like independent scalability and location flexibility. It facilitates a device-centric approach where the C-plane is handled by a macro cell and the U-plane is handled by a small cell. The flexibility may also be used to achieve low latency by placing functions very close to the radio interface, or to implement local breakout to offload traffic from the network by placing all necessary functionality directly in a small base station.

Thus, the concept of a dedicated core network will become obsolete, as 5G network functions are not bound to a dedicated piece of hardware any more, but can be flexibly instantiated at the most appropriate location.

To optimize the network usage under such heterogeneity of use cases and traffic, it is evident that context awareness plays a vital role. The network needs to detect the traffic behavior, e.g., whether the device is nomadic or moving at a high speed, thereby allowing the network to utilize the most appropriate functions and location for the function, per traffic flow. For instance, a user can be sitting on a high-speed train, whereas another user can be sitting in a couch at home, while consuming the same video streaming service. Context awareness should be an integral part of the end-to-end management and orchestration entity, supported by the necessary measurements spread across the network and data collection functions. Statistical analysis of big data will be essential to improve the accuracy of control based on context awareness.

5G System Components: The architecture and principles described above lead to emergence of a set of key components and terminology of a 5G system, as described below.

5G RAT family (5GRF): As a part of the entire 5G system, 5G RAT family is the set of one or more standardized 5G RATs that together support NGMN 5G requirements. 5G RAT family should provide wide coverage, as this is a critical factor for marketing new technology.

5G RAT (5GR): A 5G RAT is a component radio interface of the 5G RAT family.

5G Network Function (5GF): A 5G network function provides a capability to support communication through a 5G network. 5G network functions are typically virtualized, but some functions may be provided by the 5G infrastructure using more specialized hardware. The 5GFs comprise RAT-specific functions and access agnostic functions, including functions to support fixed access and can be classified into mandatory and optional functions. Mandatory functions are common functions necessary for all use cases, e.g., authentication and identity management. Optional functions are the functions that are not always applicable for all the use cases, e.g., mobility, and may also have different variants tailored to the traffic type and use case.

5G Infrastructure (5GI): The 5G infrastructure is the hardware and software basis for the 5G network, including transport networks, computing resources, storage, RF units and cables supporting the network functions providing the 5G network capabilities. 5GRs and 5GFs are implemented or realized using the 5GI.

5G End-to-end Management and Orchestration Entity (5GMOE): The 5G end-to-end management and orchestration entity creates and manages the 5G slices. It translates use cases and business models into concrete services and 5G slices, determines the relevant 5GFs, 5GRs and performance configurations, and maps them onto the 5GI. It also manages scaling of the capacity of individual 5GFs and their geographic distribution, as well as OSS and SON.

5G Network (5GN): A 5G network is the 5GFs, 5GRs, the associated 5GI (including any relaying devices) and the 5GMOE supporting communication to and from 5G devices. In other words, a 5G network is realized when a 5G RAT utilizes any subset of functions from the 5GFs implemented on the 5GI to support communications with a 5G device. On the contrary, the network created when the 5GFs are used to support communications with a 5G device through a non-5G RAT is not considered as a 5G network.

5G Device (5GD): A 5G device is the equipment used to connect to a 5G network to obtain a communication service. 5G devices can support machines as well as human users.

5G System (5GSYS): A 5G system is a communications system comprising a 5G network and 5G devices.

5G Slice (5GSL): A 5G slice is a set of 5GFs and associated device functions set up within the 5G system. that is tailored to support the communication service to a user or service.

CHAPTER III

SOFTWARE PLATFORMS OF 5G

The Open-Air Interface(OAI) platform includes a full software implementation of fourth generation mobile cellular systems which complies with 3GPP LTE standards which is coded in C language under real-time Linux which dedicated for x86. At the physical layer, it provides the following features:

- LTE release 8.6, with a subset of Release 10;
- FDD and TDD configurations in 5, 10 and 20 MHz bandwidth;
- Transmission mode: 1 (SISO), and 2, 4, 5, and 6 (MIMO 2x2);
- CQI/PMI reporting;
- HARQ support (UL and DL);
- Highly optimized baseband processing (including turbo decoder).

This are the operations made and practically defined when the LTE was new. Currently, MATLAB has performed some operations to generate the type of signals which would be expected during 5G.

We have picked MATLAB simulations to define the different results being obtained between WLAN (Wireless Local Area Network), LTE (Long Term Evolution) and LTE A (LTE Advanced) and 5G.

3.1 Wireless Local Area Network(WLAN):

As a necessity, wireless connectivity for computers has been well established and basically all new laptops have a Wi-Fi capability. The WLAN solutions that are available the IEEE 802.11 standard, often termed as Wi-Fi has become the de-facto standard. With operating speeds of systems using the IEEE 802.11 standards of around 54 Mbps being commonplace, Wi-Fi can compete well with wired systems. To increase the flexibility and performance of the system, Wi-Fi "hotspots" are widespread and in common use. These enable people to use their laptop computers as they wait in hotels, airport lounges, cafes and many other places using a wire-less link rather than needing to use a cable.

In addition to the 802.11 standards being used for temporary connections, and for temporary Wireless Local Area Network, WLAN applications, they may also be used for more permanent installations. In offices WLAN equipment may be used to provide semi-permanent WLAN solutions. Here the use of WLAN equipment enables offices to be set up without the need for permanent wiring, and this can provide a considerable cost saving. The use of WLAN equipment allows changes to be made around the office without the need to re-wiring.

As a result, the Wi-Fi, IEEE 802.11 standard is widely used to provide WLAN solutions both for temporary connections in hotspots in cafes, airports, hotels and similar places as well as within office scenarios.

IEEE 802.11 standards: There is a plethora of standards under the IEEE 802 LMSC (LAN/MAN Standards Committee). Of these even 802.11 has a variety of standards, each with letter suffix. These covers everything from the wireless standard themselves, so standards for security aspects, quality of service and the like:

- 802.11a - Wireless network bearer operating in the 5 GHz ISM band with data rate up to 54 Mbps.
- 802.11b - Wireless network bearer operating in the 2.4 GHz ISM band with data rates up to 11 Mbps.
- 802.11e – Quality of service and prioritization.
- 802.11f – Handover.
- 802.11g – Wireless network bearer operating in 2.4 GHz ISM with data rates up to 54 Mbps.
- 802.11h – Power control.
- 802.11i – Authentication and encryption.

- 802.11j – Interworking.
- 802.11k – Measurement reporting.
- 802.11n – Wireless network bearer operating in the 2.4 and 5 GHz ISM bands with data rates up to 600 Mbps.
- 802.11s – Mesh networking.
- 802.11ac – Wireless network bearer operating below 6GHz to provide data rates of at least 1Gbps per second for multistation operation and 500 Mbps on a single link.
- 802.11ad – Wireless network bearer providing very high throughput at frequencies up to 60GHz.
- 802.11af – Wi-Fi in TV spectrum white spaces (often called White-Fi).
- 802.11ah – Wi-Fi using unlicensed spectrum below 1 GHz to provide long range communications and support for the Internet of Everything.

The most widely used standards known are the network bearer standards, 802.11a, 802.11b, 802.11g and the latest well known is 802.11n.

Network bearer standards 802.11: All the types of 802.11 bearer Wi-Fi standards operates within the ISM (Industrial, Scientific and Medical) frequency bands. These standards are shared by a variety of other users, but no license is required for the operation within these frequencies. This provides access to the general systems for the widespread use.

There are several bearer standards which are commonly used. These are the 802.11a, 802.11b, and 802.11g standards. The latest WLAN standard used is 802.11n which provides raw data rates of up to 600 Mbps.

All types of bearer standards are different and with respect to they have different specifications, features and were launched at different times. The first accepted WLAN standard was 802.11b. This standard used the frequencies in the 2.4 GHz Industrial Scientific and Medical (ISM) frequency band, which offered raw and over the air data rates of 11 Mbps using a modulation scheme known as Complementary Code Keying (CCK) as well as supporting Direct-Sequence Spread Spectrum (DSSS) which comes from the first introduced 802.11 specification. Similarly, the second standard 802.11a was defined which can use a different modulation technique, Orthogonal Frequency Division Multiplexing (OFDM) used the 5GHz ISM band. Of these two standards, it was the 802.11b which became popular because the chips for the lower 2.4 GHz band were easier and cheaper to manufacture. Hence this popular 802.11b standard became the main Wi-Fi standard. Hence to obtain higher speeds, the new version was introduced which was 802.11g and was launched in June 2003. It used the same 2.4 GHz band with OFDM and offered data rates of up to 54 Mbps, same as 802.11b. It offered the backward compatibility to the 802.11b. So, in the latest the WLAN bearer standard 802.11g were used.

Moving forward, In January 2004, the IEEE announced that it had a new team which is developing an even higher speed standard. 802.11n was being established at that time similarly to the 802.11g. It was getting accepted by the industry in early 2006. Hence with the complete understanding for the hardware requirements it was introduced in 2007.

802.11 Networks: There are two types of networks they are Infrastructure networks and Ad-hoc networks. The infrastructure networks are aimed at the office areas or to provide ‘hotspot’. The WLAN equipment is flexible and can be installed where intended instead of a wired system providing restrictions and can provide considerable cost savings. The wired network would be required to get connected to the server. The wireless network is then split up into several cells each serviced by a base station or Access point (AP) which would act as a controller for the cell. Each Access point may have a range of between 30 and 300 meters depending on the environment and the location of Access point.

The other type of networks are Ad-hoc networks. These networks come in to existence when computer and peripherals are brought together. They may be needed when several people come together and would require sharing the data or if they need to access the printer without the need of using the wire connections. With such circumstance the user can only communicate with each other but not with the larger wired network. As a result, there is no Access point and special algorithms within the protocols are used to enable one of the peripherals to take over the role to control.

	802.11A	**802.11B**	**802.11G**	**802.11N**
Date of standard approval	July 1999	July 1999	June 2003	Oct. 2009
Maximum data rate (Mbps)	54	11	54	~600
Modulation	OFDM	CCK or DSSS	CCK, DSSS, or OFDM	CCK, DSSS, or OFDM
RF Band(GHz)	5	2.4	2.4	2.4 or 5
Number of spatial streams	1	1	1	1,2,3, or 4
Channel width (Mhz) nominal	20	20	20	20 or 40

Figure 8: Summary of major 802.11 Wi-Fi Standards

WLAN SIMULATIONS RESULTS FROM MATLAB:

WLAN transceiver:

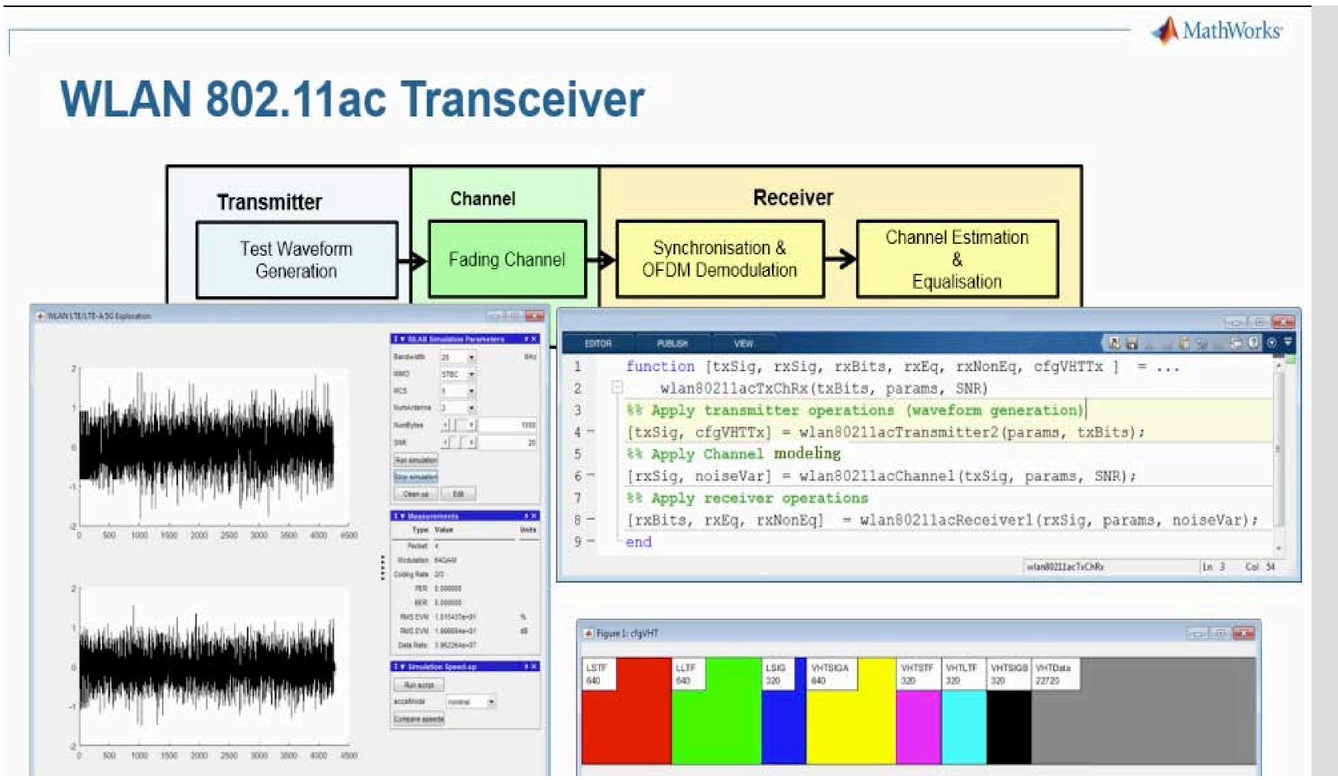


Figure 9: Block Diagram and Code functionalities of WLAN

Transmitter: A transmitter side is an equipment or tool used to generate and transmit electromagnetic waves carrying messages or signals especially those of like radio signals. Here we would be using transmitter as an input function used to generate a test waveform.

Channel: A channel can be defined as the bandwidth used to allocate the frequencies used for radio and television transmission. A fading channel can be referred to a communication channel that experiences fading. In wireless systems, fading can be due to a multipath propagation and due to shadowing from obstacles affecting the wave propagation, referred to as shadow fading.

Receiver: Similarly, to the transmitter side which is used to transmit the signals, there is a receiver side which is there to receive those signals. We have two operations at the receiver side they are synchronization and OFDM demodulation and channel estimation and equalization.

Synchronization: In wireless communication, the receiver side should determine the time instants for the incoming signal which needs to be sampled (timing synchronization). For bandpass communications, the receiver needs to take the frequency and the phase of its local carrier oscillator with those of the received signal which will be termed as carrier synchronization.

Orthogonal Frequency-division Multiplexing(OFDM) demodulation: The term is used as a digital multi-carrier modulation method. It can be defined as a large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. OFDM can be demodulated using FFTs (Fast Fourier Transform). But if in case you have a very few number of carriers, you might be able to use a small number of orthogonal quadrature demodulators.

Channel estimation: It can be defined as the User Defined pilot-averaging method performs two-dimensional interpolation to estimate the channel response between the available pilot symbols. An interpolation window is used to specify which data is used to perform the interpolation.

Equalization: It is a process of adjusting the balance between the frequency components within an electronic signal. The most common equalization can be seen in the sound recordings and reproduction where there are many applications in signal processing tools and telecommunications.

WLAN Transceiver:

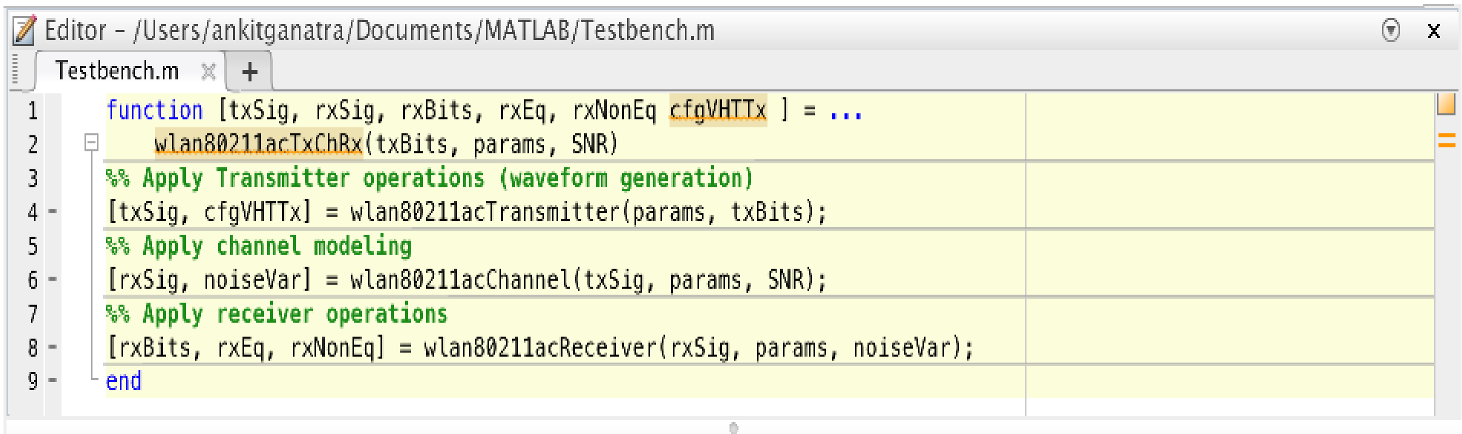


Figure 10: Test bench code for WLAN Transceiver

From figure 10, txSig is the waveform, rxSig is the received waveform, rxBits is the received Bits, rxEq is the received parametric equalizer, rxNonEq is the received parametric Non-equalizer, cfgVHTTx is the configuration parameters, txBits is the input layers which will be the transmitter bits, params is the parameters and SNR is Signal to Noise ratio.

The transceiver is represented as a single function denoted as “wlan80211axTxChRx”. The input bits(txBits) from the higher layers and the parameters of the system are being subjected as the inputs to the transmitter function. It generates the waveform(txSig) and the configuration parameters(cfgVHTTx). The received waveform, parameters and the SNR are subject to the channel modelling(cfgVHTTx) gives you the received waveform or the channel modelling waveform. The received waveform(rxSig) from the parameters are subject to the receiver operations to give received bits(rxBits).

By comparing the received bits(rxBits) with the input bits(txBits) we can compare measures such as BRPR and to qualify the system at different SNR values and different data rates.

Function for Transmitter operation:

Editor – /Users/ankitganatra/Documents/MATLAB/wlan80211acTransmitter.m

wlan80211acTransmitter.m

```
function [txSig, cfgVHTTx] = wlan80211acTransmitter(params, bits)
%% Transmitter
% VHT format object at transmitter
cfgVHTTx = wlanVHTConfig( ...
    'ChannelBandwidth',     params.cganBW,  ...
    'NumTransmitAntennas', params.numTx,  ...
    'NumSpaceTimeStreams', params.numTx,  ...
    'STBC',                params.STBC,  ...
    'MCS',                 params.MCS,  ...
    'GuardInterval',       'Long',  ...
    'APEPLength',          params.APEPLan);

% Waveform generator object
cfgWaveGen = wlanGeneratorConfig( ...
    'NumPackets', 1, ...
    'IdleTime',    2e-6); % Trailing zeros for each packet

% Generate single-packet waveform
txSig = wlanWaveformGenerator(bits, cfgVHTTx, cfgWaveGen);
```

Figure 11: Function code for WLAN Transmitter

Here at the transmitter side, we can give the input values for Channel Bandwidth, Number of transmitter antennas, number of spaces in time streams, STBC, MCS, Guard Interval and APEPLEngth. We are giving these terms so that we can obtain the values once the input parameters have been applied. Furthermore, For the Waveform generator object we can select the number of values which can be given as the number of packets and the Idle time would be obtain in the form of data rates. We can generate these parameters by generating a single packet waveform.

Function for Channel modelling:

```
Editor - /Users/ankitganatra/Documents/MATLAB/wlan80211acChannel.m
Testbench.m   wlan80211acChannel.m

function [rxSig, noiseVar] = wlan80211acChannel(txSig, params, SNR)

%% propogation Channel and Noise
%TGac channel object
TGacChan = wlanTGacChannel( ...
    'SampleRate',              params.Rs, ...
    'DelayProfile',            params.chMd1, ...
    'ChannelBandwidth',        params.chanBW, ...
    'NumTransmitAntennas',     params.numTx,  ...
    'NumReceiveAntennas',      params.numRx,  ...
    'NormalizeChannelOutputs', false, ... % SNR is per recieve antenna
    'LargeScaleFadingEffect',  'None');   % No path loss or shadowing
% pass through TGac fading channel
chanOut = step(TGacChan, txSig);
% reser(TGacChan); % Independent channels from one packet to next

% AWGN channel object
AWGN = comm.AWGNChannel( ...
    'noiseMethod', 'Signal to noise ratio (SNR)');
AWGN.SNR = SNR;
noiseVar = 10^(-SNR/10);

% Add AWGN
rxSig = step(AWGN, chanOut);
```

Figure 12: Function code for WLAN Channel modelling

The function is for the channel side, in this function we can obtain that the receiver and the noise can be defined as giving the transmitter signal values, parameters and the Signal to Noise ratio. While considering the propagation channel and noise, we must consider the parameters such as sample rate, Delay profile, channel bandwidth, Number of transmitter antennas, number of receiving antennas, normalize channel outputs which would be the SNR is per receive antenna and the large-scale fading effect. Further, we need to pass this through the very high throughput fading channel which would give us the step function of TGac channel and transmit signal. The below Figure shows how the test bench look like.

Test bench function not based on apps or any graphical interface:

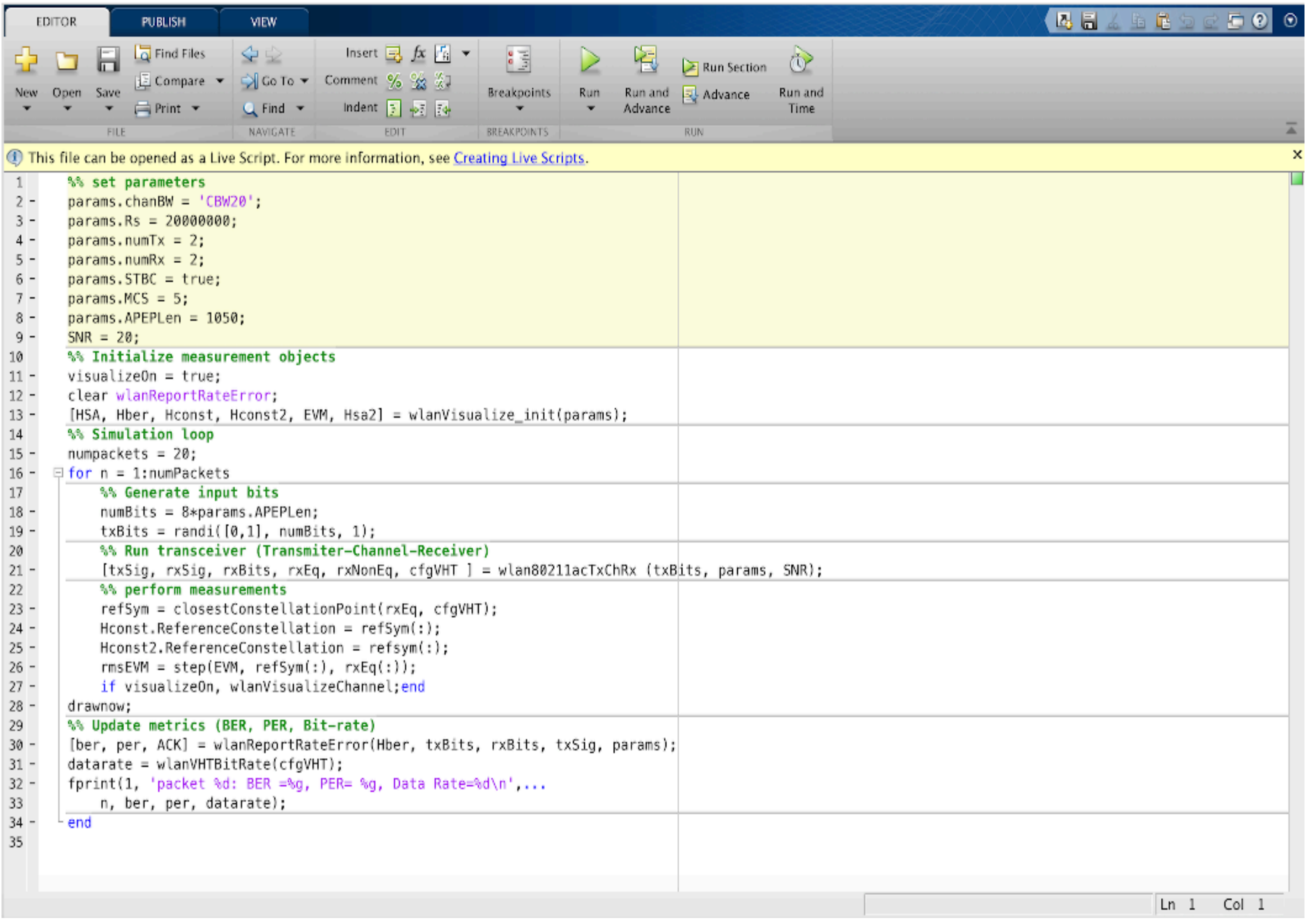


Figure 13: Independent Test bench function code for WLAN

Once we run this code we would be seeing the constellation diagram and the spectrum analyzer for WLAN system.

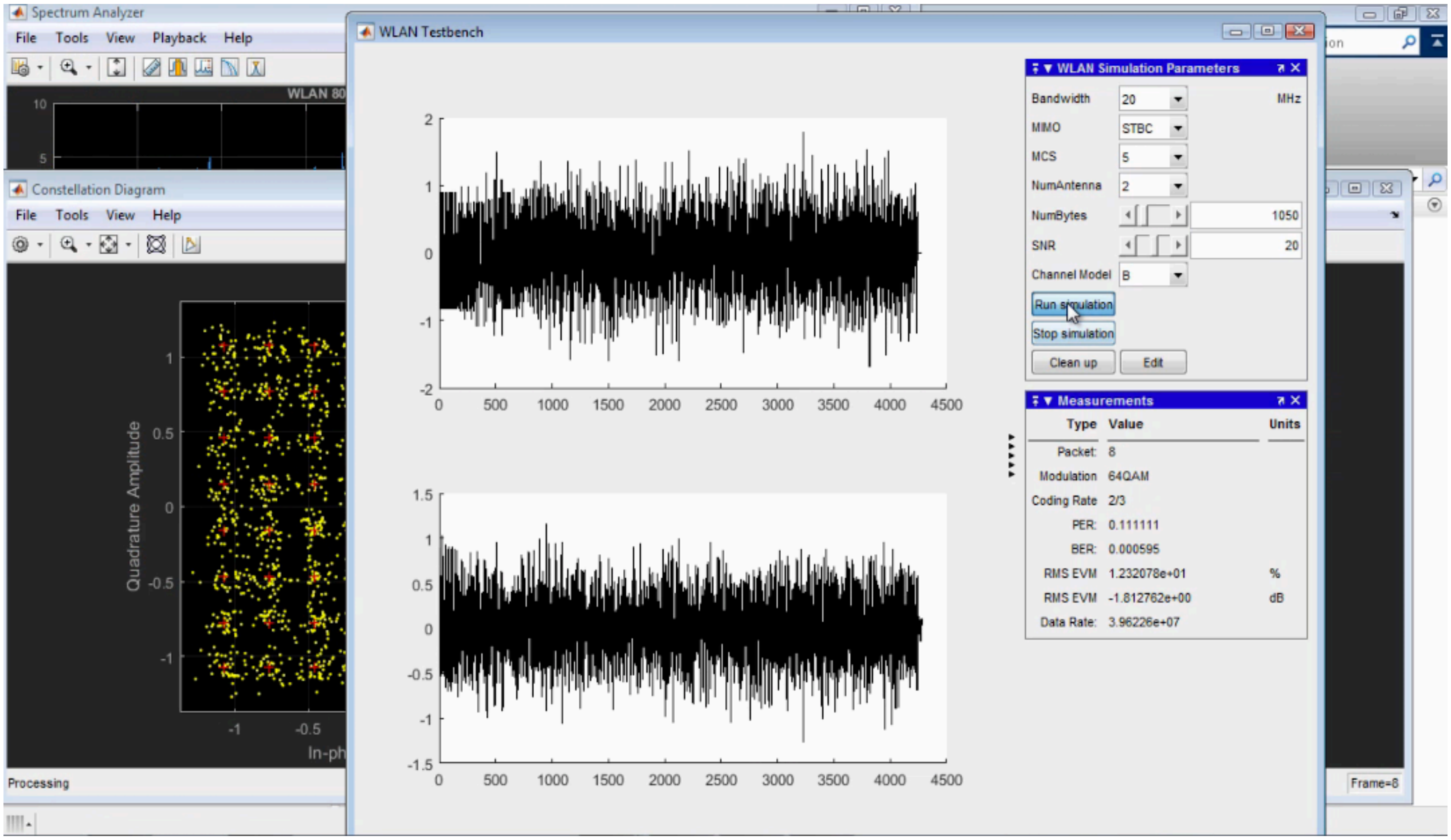


Figure 14: Simulation of WLAN

Once the run simulation has been initiated we can see that for the convenience we have set the bandwidth to 20 MHz and by default the MIMO has been set to Space time block code (STBC), the multilevel coordinate search (MCS) has been set to 5, Number of antennas has been set to 2, Number of bytes has been set to 1050, Signal to Noise ratio (SNR) has been set to 20 and channel model has been set to B. In the graph the x axis has been set to Megahertz (MHz) and y axis has been set to decibels (dB). The top shading graph is the output of the signal before channel modeling and the bottom shade presentation is the output after channel modeling. The test bench also performs the measurements which also reports you the modulation and coding rate and it also continuously reports you the packet errors rate (PER) and the Bit Error Rate (BER) and packet by packet it computes the Root Mean Square (RMS) Error Vector Magnitude (EVM) values in percentage and Decibels (DB) and give the data rates.

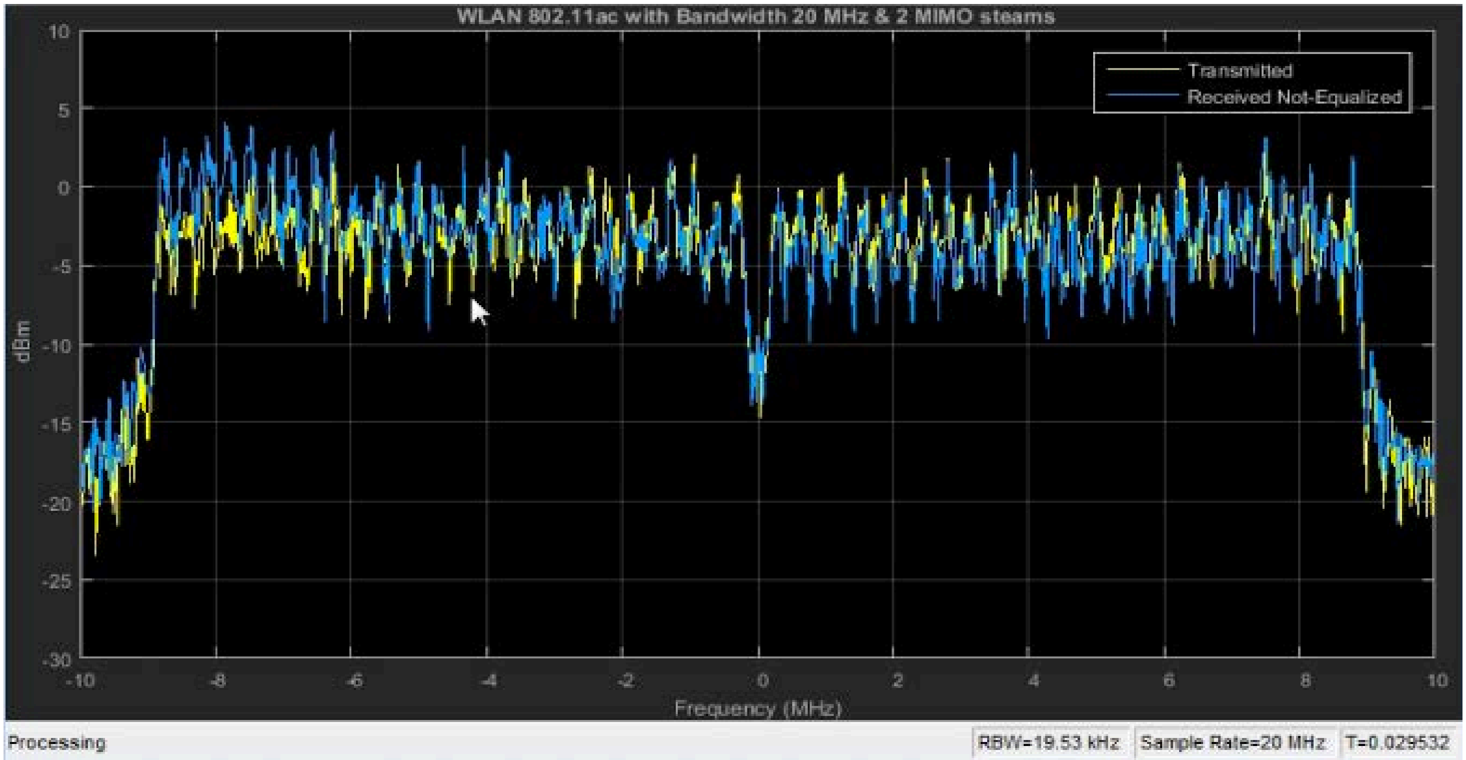
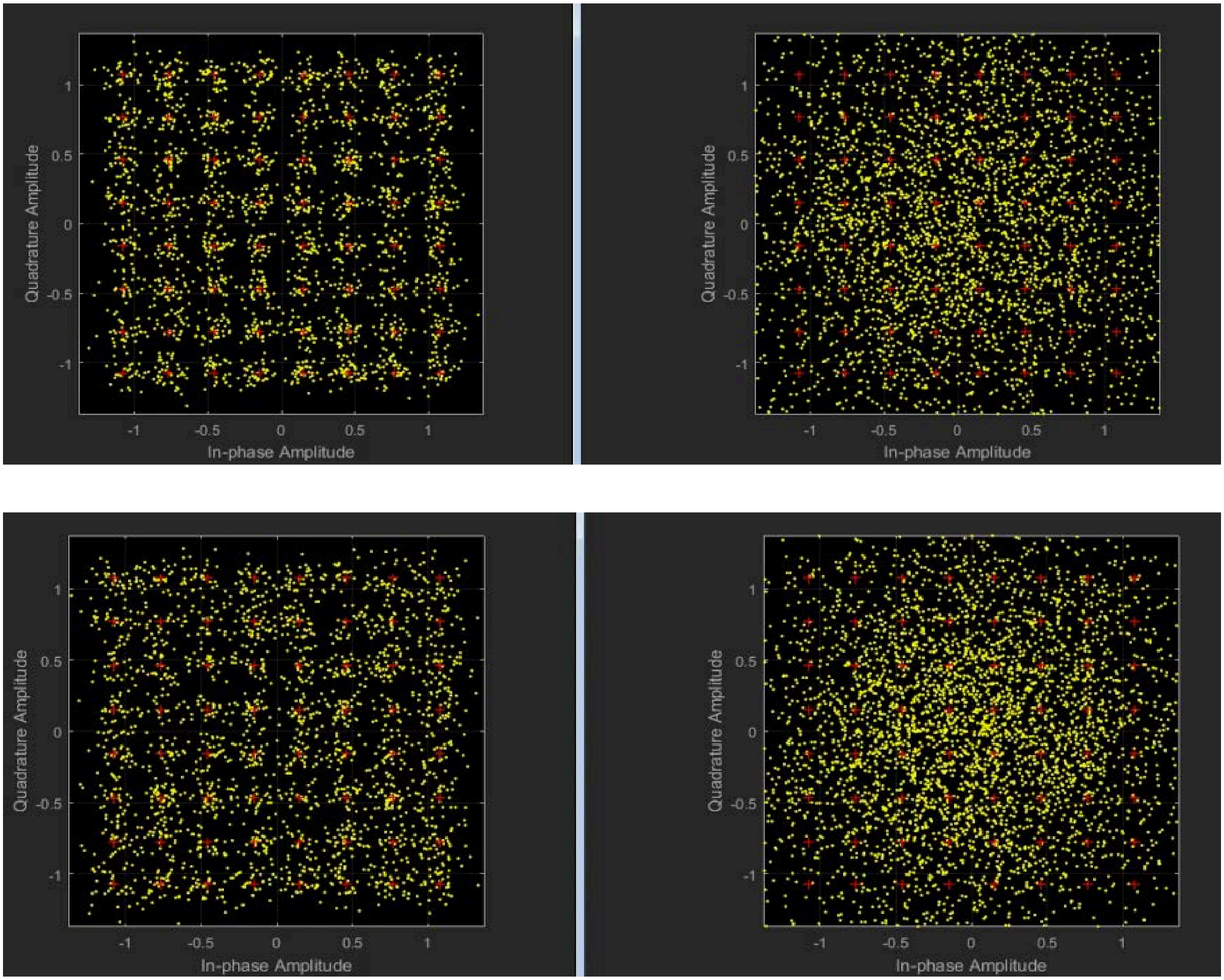


Figure 15: Spectrum Analyzer of WLAN

The frequency spectrum of WLAN. Here we can see the visualization the channel response of 802.11ac before and after channel modeling. Here the trace in yellow is 20 MHz 802.11ac signal with respect to the Orthogonal Frequency-Division multiplexing (OFDM) multi carrier channel with Dc node and we can see that the transmitter signal seems to be flat but the received signal (the trace in blue) that is after channel modelling exhibits sequential activity that is due to the multipath TGac) Very high throughput task group) fading channel applied to it.


Quadrature Amplitude
In-phase Amplitude
Quadrature Amplitude
In-phase Amplitude
Quadrature Amplitude
In-phase Amplitude
Quadrature Amplitude
In-phase Amplitude

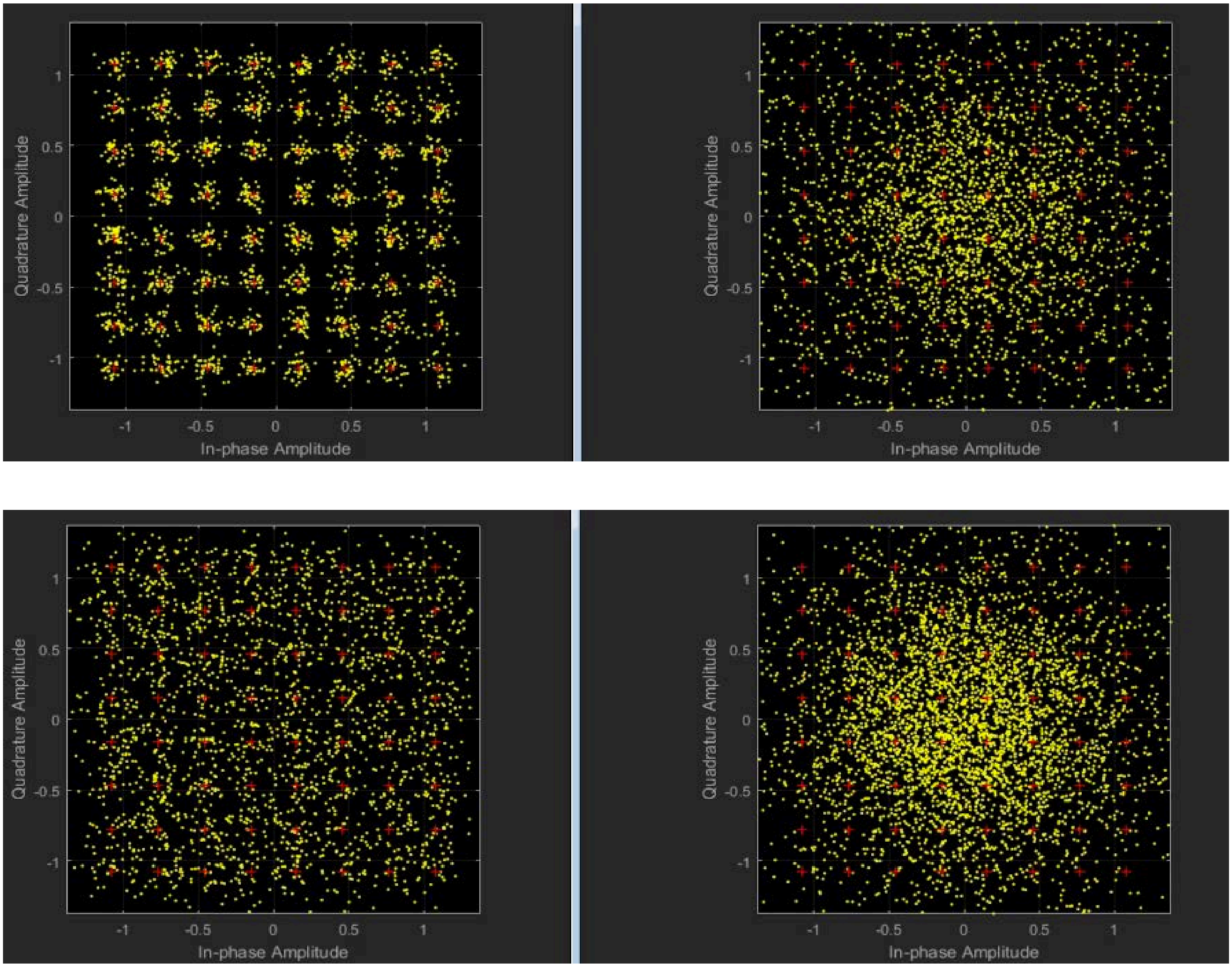


Figure 16: Constellation Diagram for WLAN

Here are the outputs for constellation diagrams where we can see the quality of the signal. The graph obtained on the right is referred to the graph obtained before channel modeling and the graph on the left is obtained after the channel modeling. It is a 64 Quadrature Amplitude Modulation (QAM) scheme before equalization (on the right) and after equalization (on the left), as the signal is receiver at the receiver end under the multi path feature reflex and all types of distortion can be seen before the channel modeling.

After channel modeling we can obtain a much organized 64 QAM modulation. We can change the bandwidth and calculate what other parameters or values can be observed.

3.2 LTE/LTE Advanced-

LTE/LTE A Transceiver:

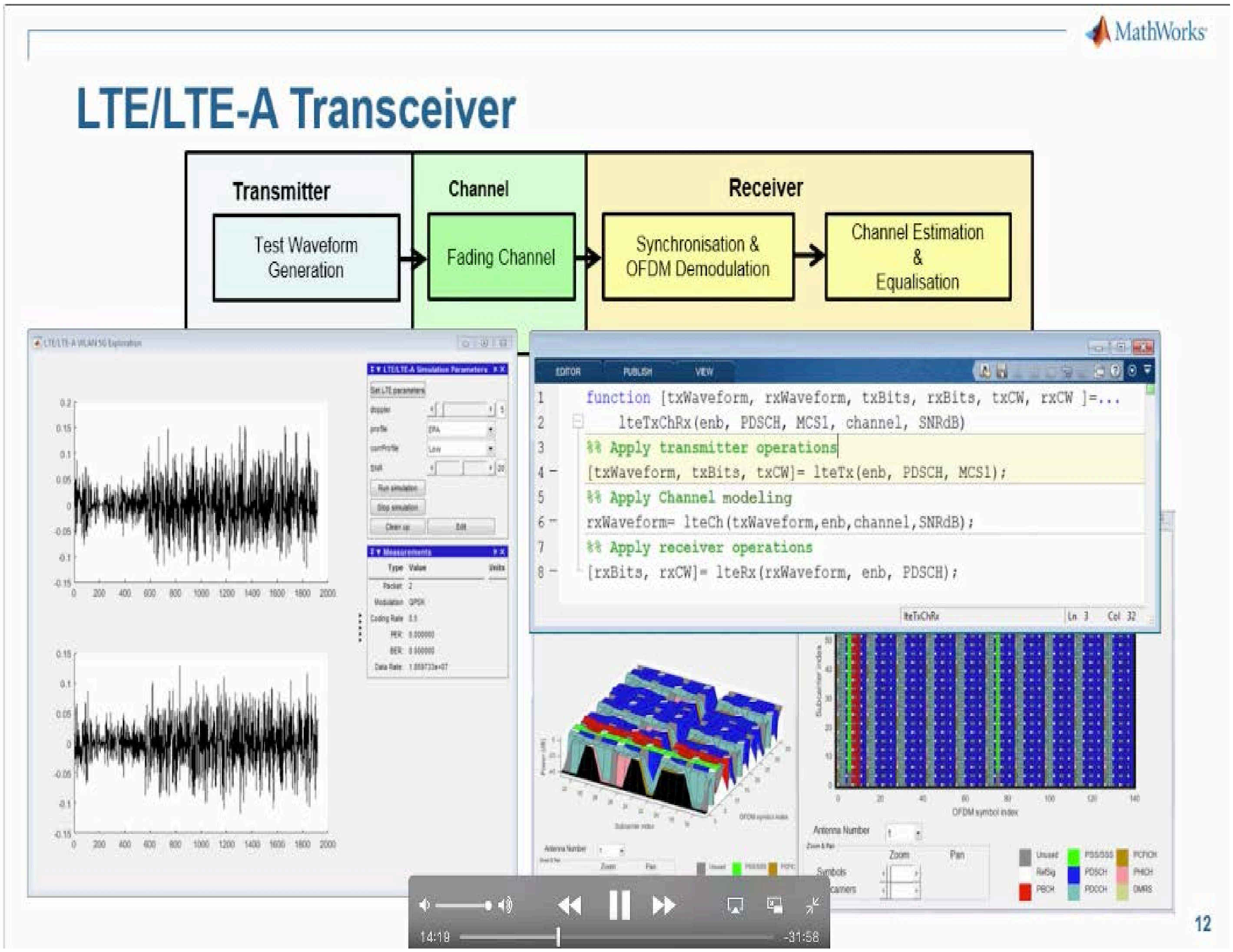


Figure 17: Block Diagram and Code functionalities of LTE/LTE A

LTE/LTE A Transceiver:

```
Editor – /Users/ankitganatra/Documents/MATLAB/lteTxChRx.m
lteTxChRx.m

funtion [txWaveform, rxWaveform, rxBits, txCM, rxCW ]=...
    lteTXChRx(txBits, enb, PDSCH, MCS1, channel, SNRdb)
%% Apply transmitter operations
[txWaveform, txCW] = lteTx(enb, PDSCH, MCSI, txBits);
%% Apply Channel modeling
rxWaveform = lteCh(txWaveform, enb, channel, SNRdB);
%% Apply receiver operations
[rxBits, rxCW] = lteRx(rxWaveforms, enb, PDSCH);
```

Figure 18: Function code for LTE/LTE A

The above code is the code functionality of the LTE transceiver.

From Figure 18 txBits are the input bits of the transmit block, Txwaveform is the generated transmit waveform, rxWaveform is the received waveform and rxBits is the received Bits.

The Input bits(txBits) is subjected to the transmitter operations to generate the transmit waveform(txWaveform). This waveform undergoes the channel modelling to give the receive waveform(rxWaveform). The received waveform then undergoes the receiver operations to give the received bits(rxBits). By comparing the received bits and input bits, we can get the system level and end-to-end matrix.

Transmitter function for LTE:

```
function [txWaveform, txBits, txCW] = lteTx(enb, FDSCH, MCSI, txBits)

%%Generate OFDM grid
subframe = lteDLResourceGrid(enb);

%% Add FDCCH
% DCI format
% can be 'format0' ,'Format1', 'Format1A', 'Format1B', 'Format1C',
% 'Format1D', 'Format2', 'Format2A', 'Format2B', 'Format2C',
% 'Format3', 'Format3A', or 'Format4'
dciConfig.DCIFormat = 'Format2';

%Build the DCI structure with relevant information
%Bitmap for resource allocation as per TS36.213 section 7.1.6.1
% for resouce allocation type 0
dciConfig.Allocation.Bitmap = '1111111111111111';
% Modulation and coding scheme $ redundancy version
dciConfig.ModCoding = MCSI;
dcuConfig.RV = PDSCH.RV;

% DCI message
[dciMessage, dciMessageBits] = lteDCI(enb, dciConfig);
% 16-bit value number
pdcchConfig.RNTI = RNTI;
% PDCCH format: 0,1,2 or 3
% define the aggregation level in CCEs (Control Channel Elements)
% The level is 2^FDCCHFormat, respectively 1,2,4 and 6
pdcchConfig.FDCCHFormat = 0;

% performing DCI message bits coding to form coded DCI bits
codedDciBits = lteDCIEncode(pdcchConfig, dciMessageBits);
% Get the total resources for FDCCH
```

```
pdcchInfo = ltePDCCHInfo(enb);
% Initialized with -1
pdcchBits = -1*ones(pdcchInfo.MTot, 1);
% Compute all candidates for placement
candidates = lteFDCCHSpace(enb, pdcchConfig, {'bits','1based'});
% Pick the first candidate in the list
pdcchBits( candidates(1, 1) : candidates(1,2) ) = codedDciBits;
% Modulate the PDCCH and compute the indices for it
pdcchSymbols = ltePDCCH(enb, pdcchBits);
pdcchIndices = ltePDCCHIndices(enb, ('1based'));
% Map PDCCH to the grid
subframe(pdcchIndices) = pdcchSymbols;

%% Add cell-Specific Reference Signals
cellRSIndices = lteCellRSIndices(enb);
cellRSSymbols = lteCellRS(enb);
subframe(cellRSIndices) = cellRSSymbols;

%% Add BCH
if mod(enb.Nsubframe,10) == 0
    mib = lteMIB(enb);
    pbchIndices = lteFBCHIndices(enb);
    QuarterLength = numel(pbchIndices)/enb.CellRefP; % 240 for Normal
    bchcoded = lteBCH(enb,mib);
    pbchSymbols = ltePBCH(enb,bchcoded);
    startBCH = mod(enb.Nframe,4)*QuarterLength;
    pbchSymbolsThisFrame = pbchSymbols(startBCH+(1:QuarterLength),:);
    subframe(pbchIndices) = pbchSymbolsThisFrame;
end

%% Add the synchronization signals
% Generate synchronization signals
```

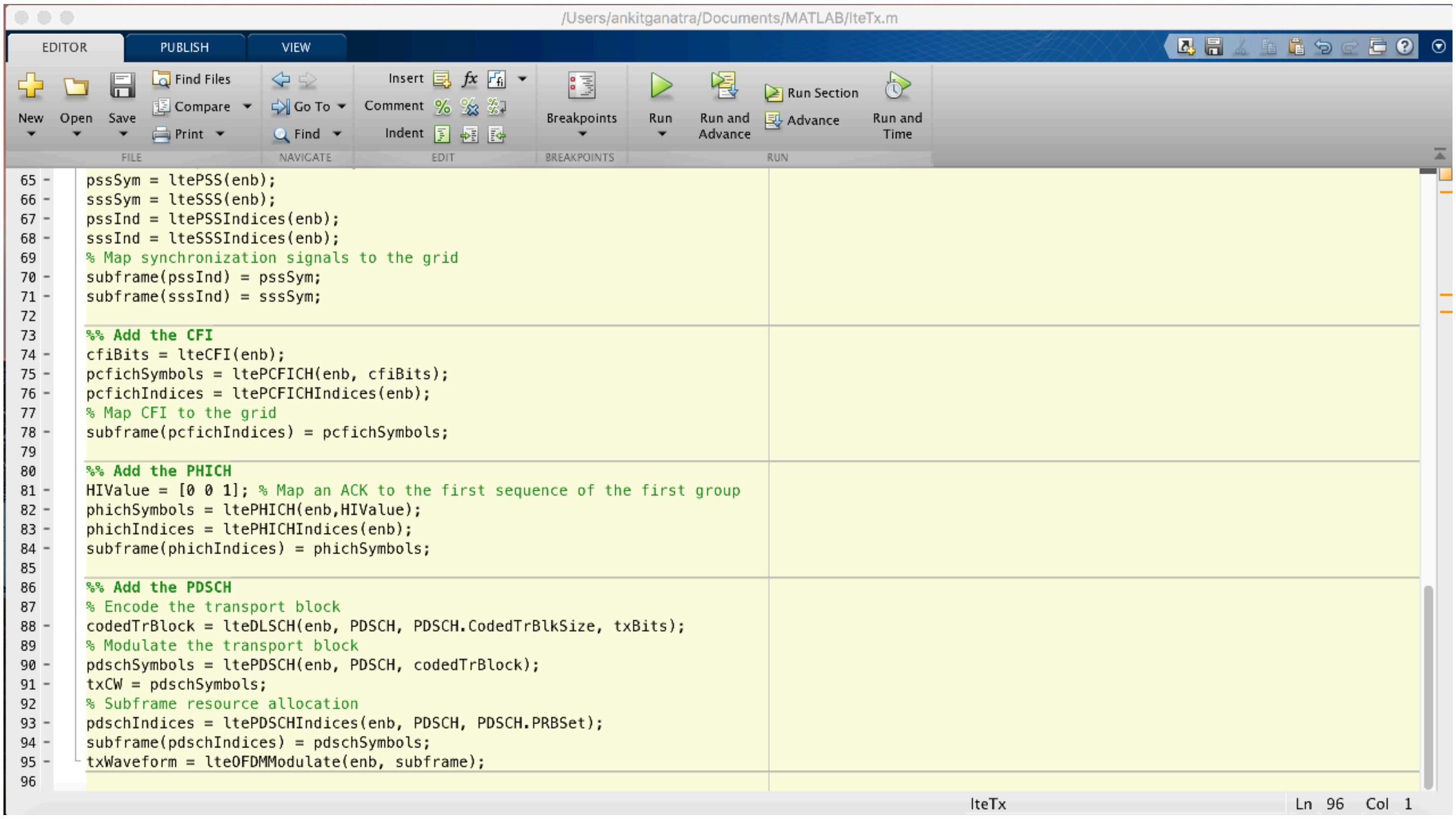
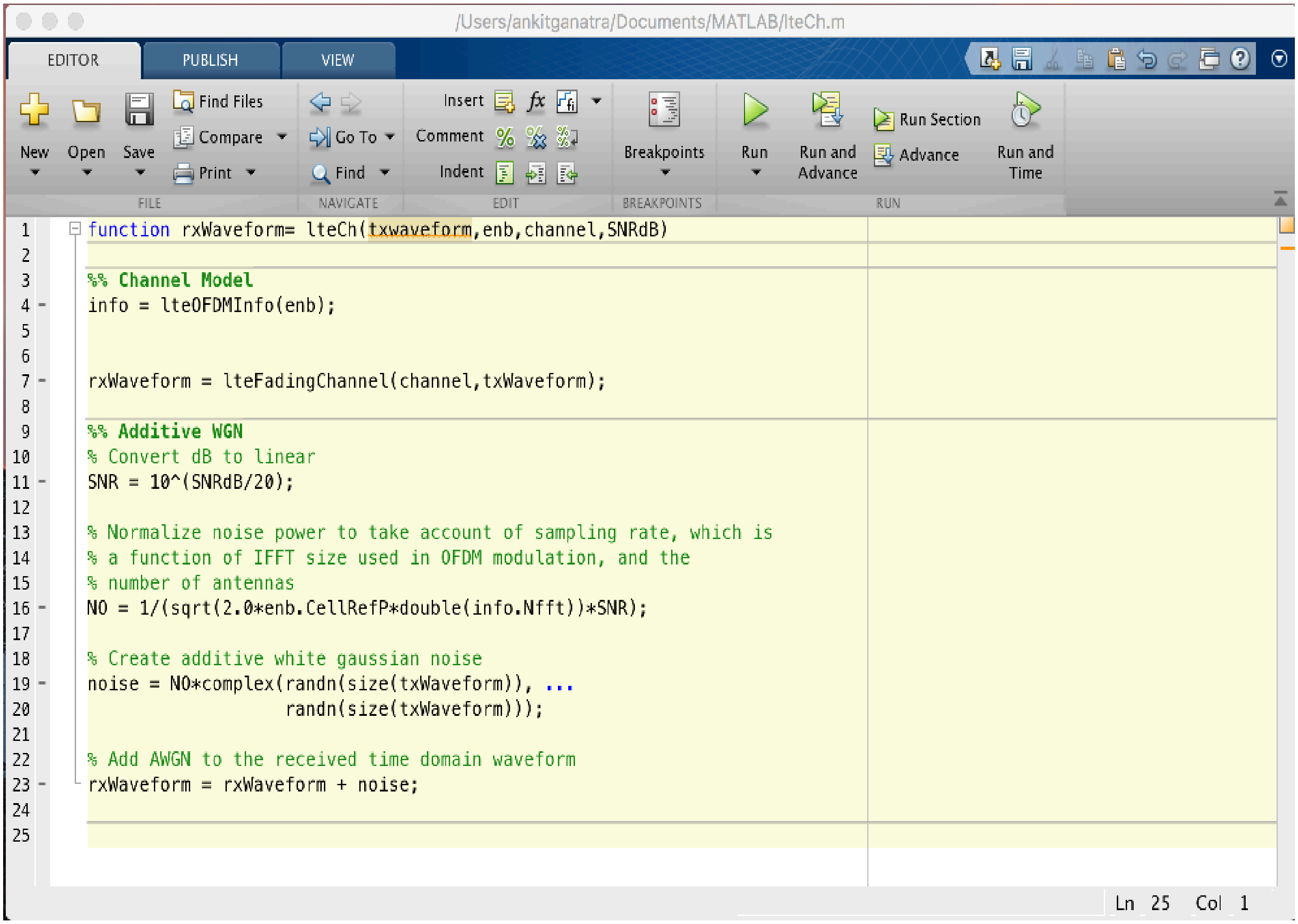


Figure 19: Transmitter function code for LTE/LTE A

Firstly, we create an empty downlink resource grid(enb) to put our estimated data symbols in there and then we create indices in that sub frame(ltecellRSIndices(enb)), where the cell specific reference belongs. Then we compute the symbol values and in the sub frame we can insert the indices at the symbol values.

At the user data, first(PDSCH) we do the channel coding or the triple coding at the rate of two third and then we perform the PDSCH operations for the symbols and we place the symbols at the place of PDSCH indices, the values that we just created. Finally, at the lteOFDModulate we generate a transmit waveform.

Channel function code for LTE/LTE A:

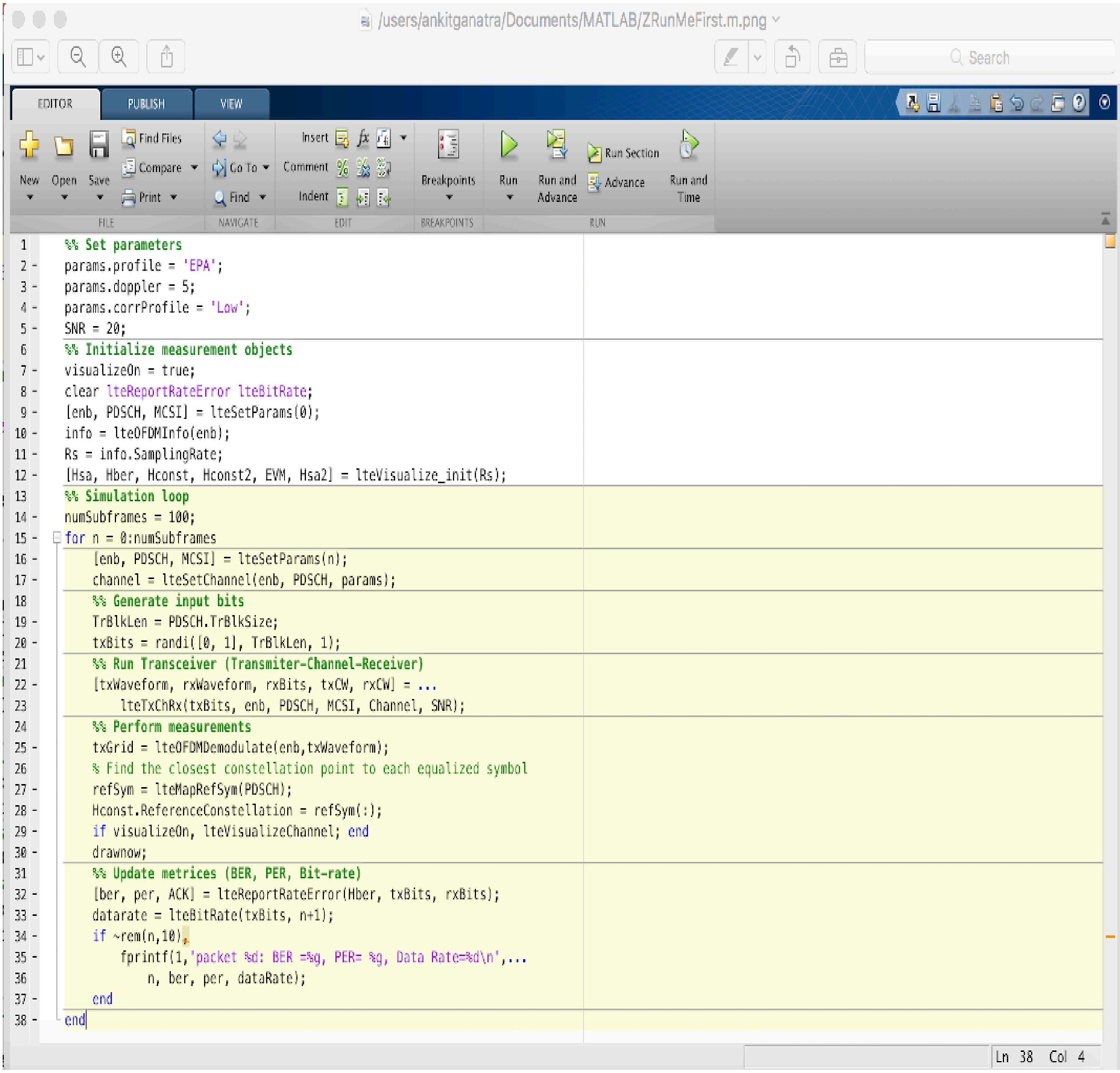


```
function rxWaveform= lteCh(txwaveform,enb,channel,SNRdB)

%% Channel Model
info = lteOFDMInfo(enb);


rxWaveform = lteFadingChannel(channel,txWaveform);

%% Additive WGN
% Convert dB to linear
SNR = 10^(SNRdB/20);

% Normalize noise power to take account of sampling rate, which is
% a function of IFFT size used in OFDM modulation, and the
% number of antennas
N0 = 1/(sqrt(2.0*enb.CellRefP*double(info.Nfft))*SNR);

% Create additive white gaussian noise
noise = N0*complex(randn(size(txWaveform)), ...
                   randn(size(txWaveform)));

% Add AWGN to the received time domain waveform
rxWaveform = rxWaveform + noise;

```

Figure 20: Channel function code for LTE/LTE A

First, we undergo a fading channel functionality and then we compute to the additive white Gaussian noise and then we add that noise to the receiver.

Test bench function for LTE/LTE A:



```
%% Set parameters
params.profile = 'EPA';
params.doppler = 5;
params.corrProfile = 'Low';
SNR = 20;
%% Initialize measurement objects
visualizeOn = true;
clear lteReportRateError lteBitRate;
[enb, PDSCH, MCSI] = lteSetParams(0);
info = lteOFDMInfo(enb);
Rs = info.SamplingRate;
[Hsa, Hber, Hconst, Hconst2, EVM, Hsa2] = lteVisualize_init(Rs);
%% Simulation loop
numSubframes = 100;
for n = 0:numSubframes
    [enb, PDSCH, MCSI] = lteSetParams(n);
    channel = lteSetChannel(enb, PDSCH, params);
    %% Generate input bits
    TrBlkLen = PDSCH.TrBlkSize;
    txBits = randi([0, 1], TrBlkLen, 1);
    %% Run Transceiver (Transmiter-Channel-Receiver)
    [txWaveform, rxWaveform, rxBits, txCW, rxCW] = ...
        lteTxChRx(txBits, enb, PDSCH, MCSI, Channel, SNR);
    %% Perform measurements
    txGrid = lteOFDMDemodulate(enb,txWaveform);
    % Find the closest constellation point to each equalized symbol
    refSym = lteMapRefSym(PDSCH);
    Hconst.ReferenceConstellation = refSym(:);
    if visualizeOn, lteVisualizeChannel; end
    drawnow;
    %% Update metrices (BER, PER, Bit-rate)
    [ber, per, ACK] = lteReportRateError(Hber, txBits, rxBits);
    datarate = lteBitRate(txBits, n+1);
    if ~rem(n,10),
        fprintf(1,'packet %d: BER =%g, PER= %g, Data Rate=%d\n',...
            n, ber, per, dataRate);
    end
end
```

Figure 21: Test bench function code for LTE/LTE A

LTE/LTE A Simulation:

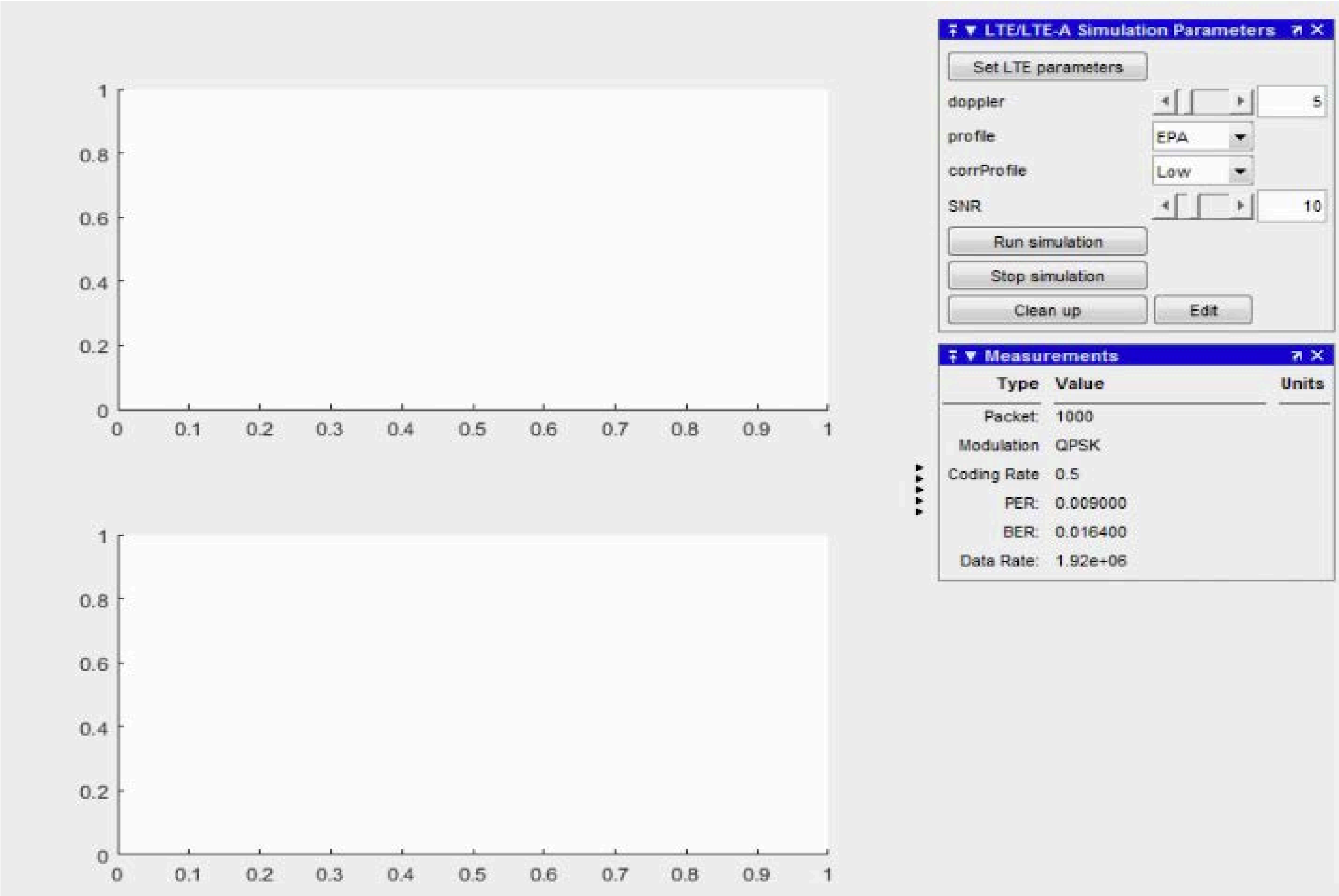


Figure 22: LTE/LTE A Simulator

Since LTE have numerous parameters We would be designing an example generator which will give us some clear idea of what is going on.

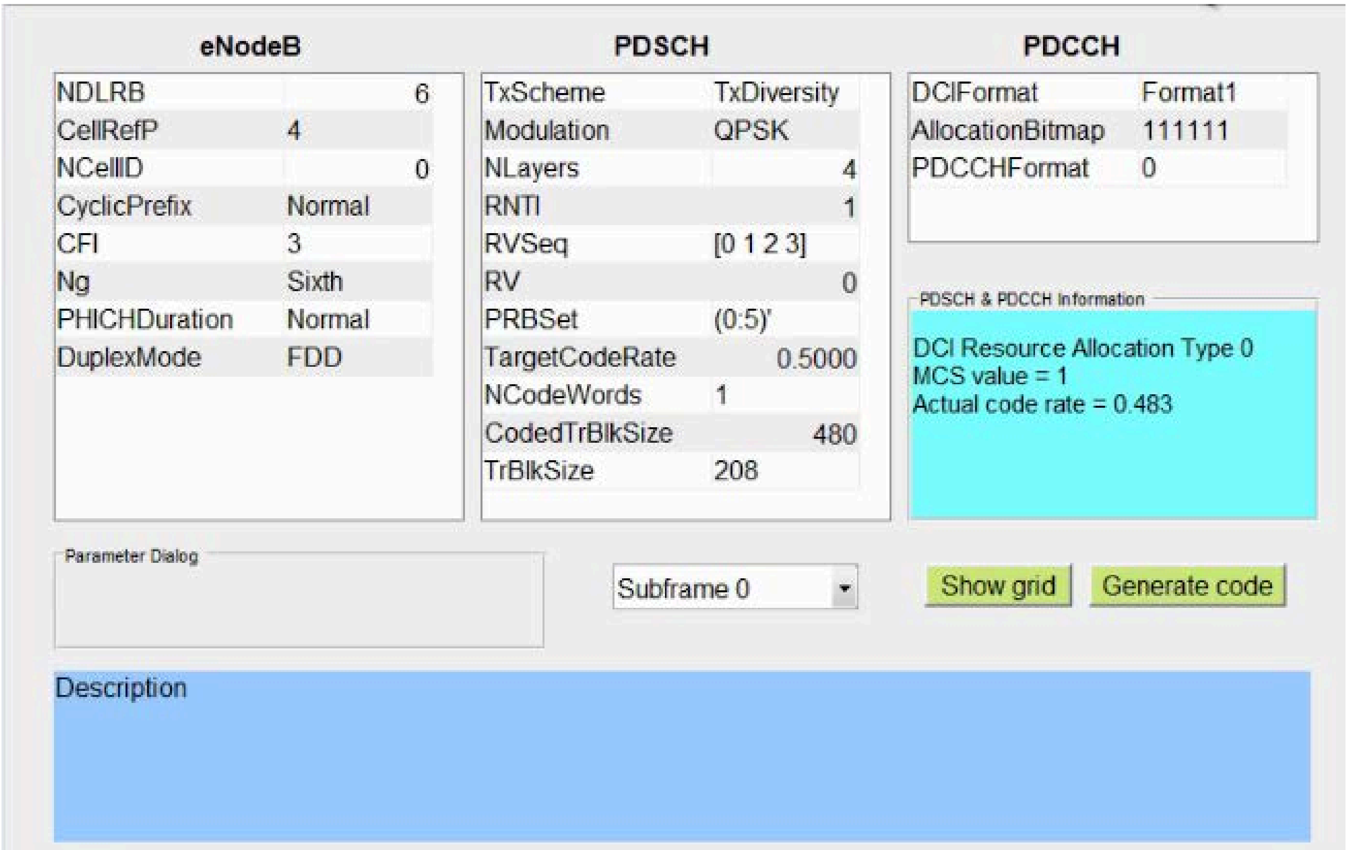


Figure 23: LTE/LTE A Example Generator

We can observe that we have set some different and unique parameters which are capable of giving us some good waveforms defining the LTE parameters and specifications. Here we are setting a eNodeB (Enhanced node B) Parameters or Physical Downlink Shared Channel (PDSCH) the parameters that reflect the MIMO mode which goes through the PDSCH which contains the used data. The first function at eNodeB relates with the transmission bandwidth.

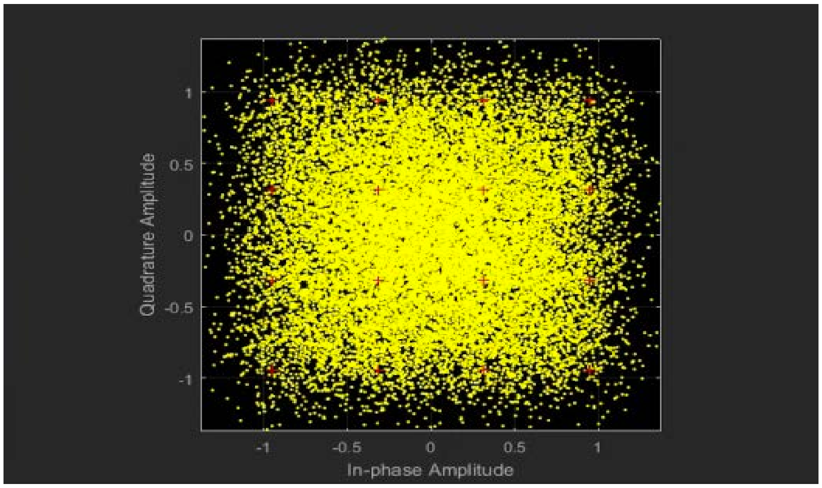


Figure 24: Constellation Diagram for LTE/LTE A

Here we are using LTE/ LTE A Mode Spatial Multiplexing Bandwidth 10 MHz with 4 layers of antennas. We are using a 16 QAM technique with a coding rate of 0.667 with an SNR of 10db we get a very distorted Constellation diagram from a receiver signal. By changing the SNR value between 23 and 27 we get better results in terms of PER and BER. We also get a good data rate of about 60 Mega bits per second.

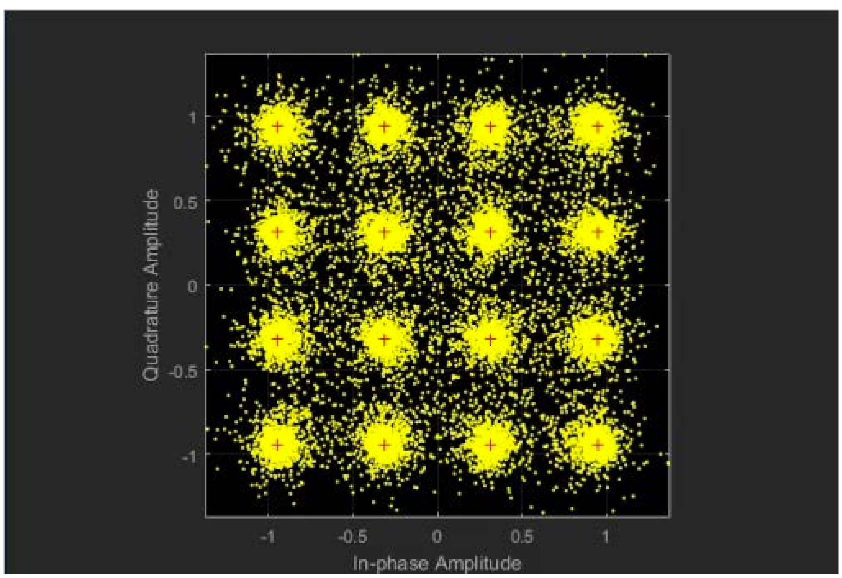


Figure 25: Constellation diagram with better SNR value

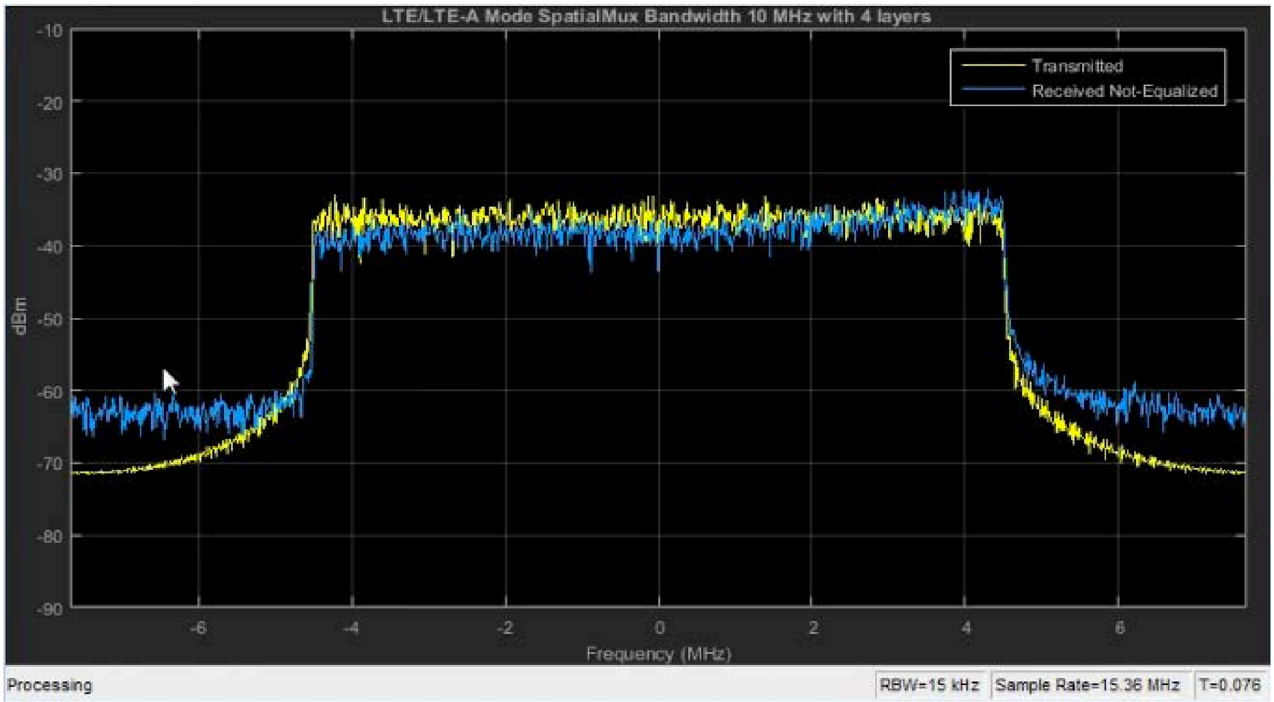


Figure 26: Spectrum Analyzer of LTE/LTE A

The shade in yellow represents the transmitted signal and the shade in blue represents the fading channel of the correspondent transmitted signal.

3.3 5G

5G Systems requires both spectral efficiency and robust synchronization. Majority of candidates are multicarrier and Non-orthogonal waveforms.

The members of “filtered” OFDM designs are

- FBMC: Filter Bank Multi Carrier and
- UFMC: Universal Filtered Multi Carrier.

FBMC: Filter Bank Multi Carrier –

It introduces per- Sub carrier filtering to reduce the side lobes. It has couple of implementation techniques they are frequency spreading (extended IFFT/FFT) and poly-phase network (more efficient, commonly employed)

Code for FBMC:

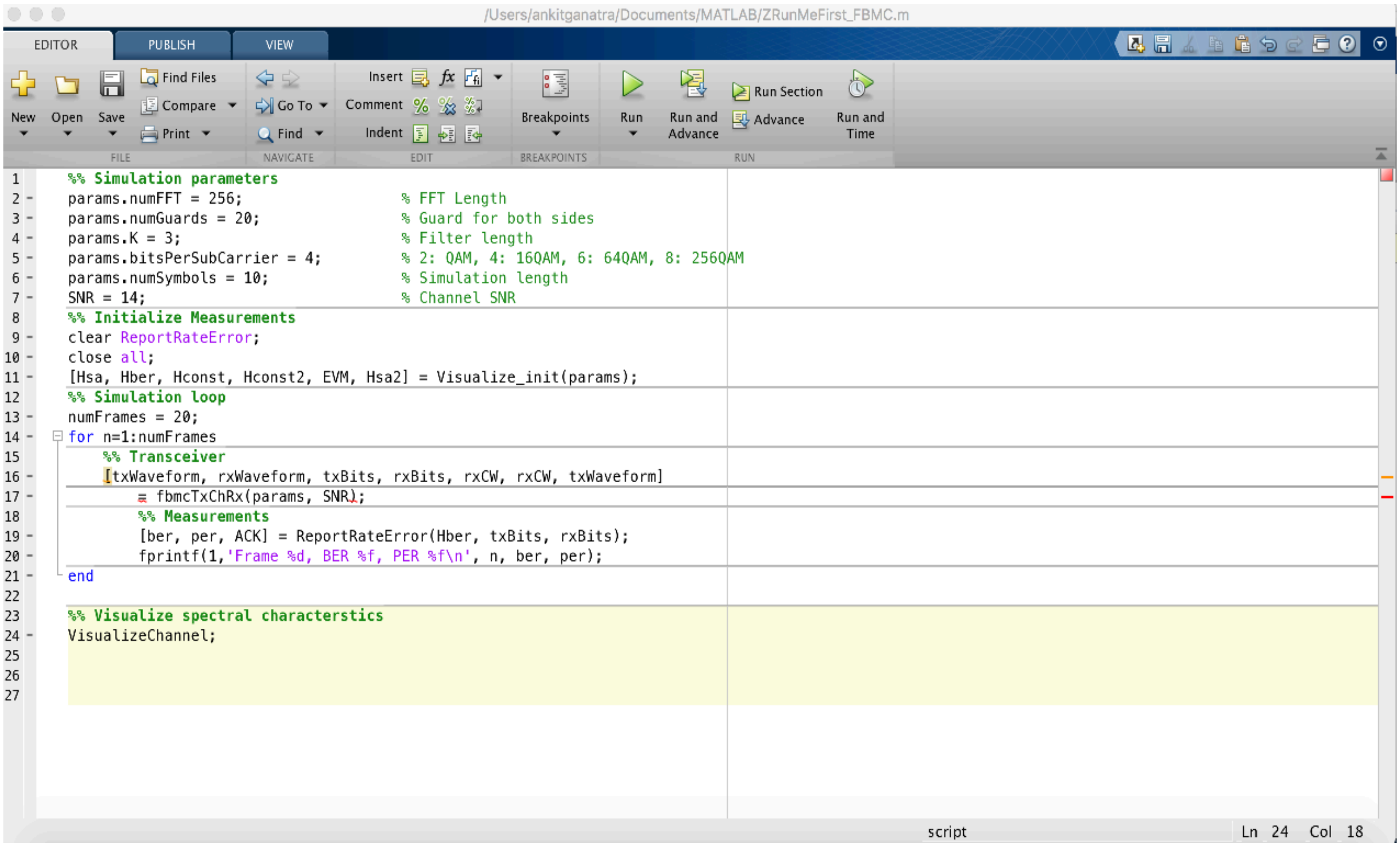


Figure 27: Code function code for FBMC

The most important characteristic of FBMC is that at a given FFT length it can perform much better than the corresponding OFDM. OFDM composes a rectangular window, the sub carrier is based on the sinc function, side lobe attenuation has a very gradual drop about 20db. We can use FBMC by managing the filter length of 3 which will be the same as but FBMC will have a very sharp drop until -100db as you can see in figure 28. Without too much use of the guard length we can pack the same frequency adjacent together. This implies the main benefit of FBMC module being proposed.

Waveforms Generated:

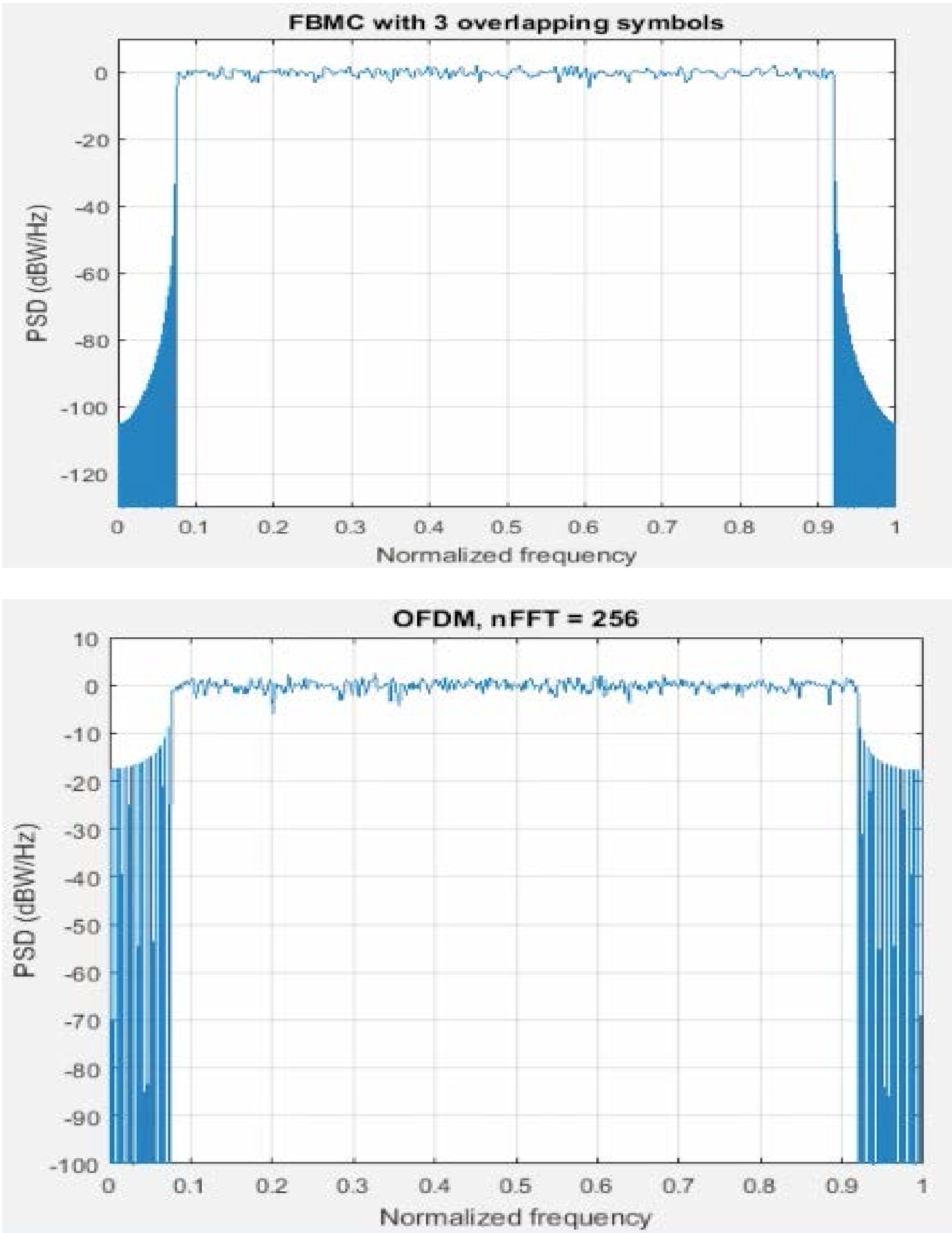


Figure 28: Waveform Generation for FBMC

UFMC: Universal Filtered Multi Carrier –

In this process, the filtering is applied per sub-bands (not per sub-carrier as in FBMC), filtering is parameterized by side-lobe attenuation, reduced filter length (compared to FBMC), good for short bursts, suited for uplink with multiple users, orthogonal in the complex plane, use QAM symbols, reapply MIMO schemes, Receiver complexity and like OFDM, uses per sub carrier equalization.

Code function for UFMC:

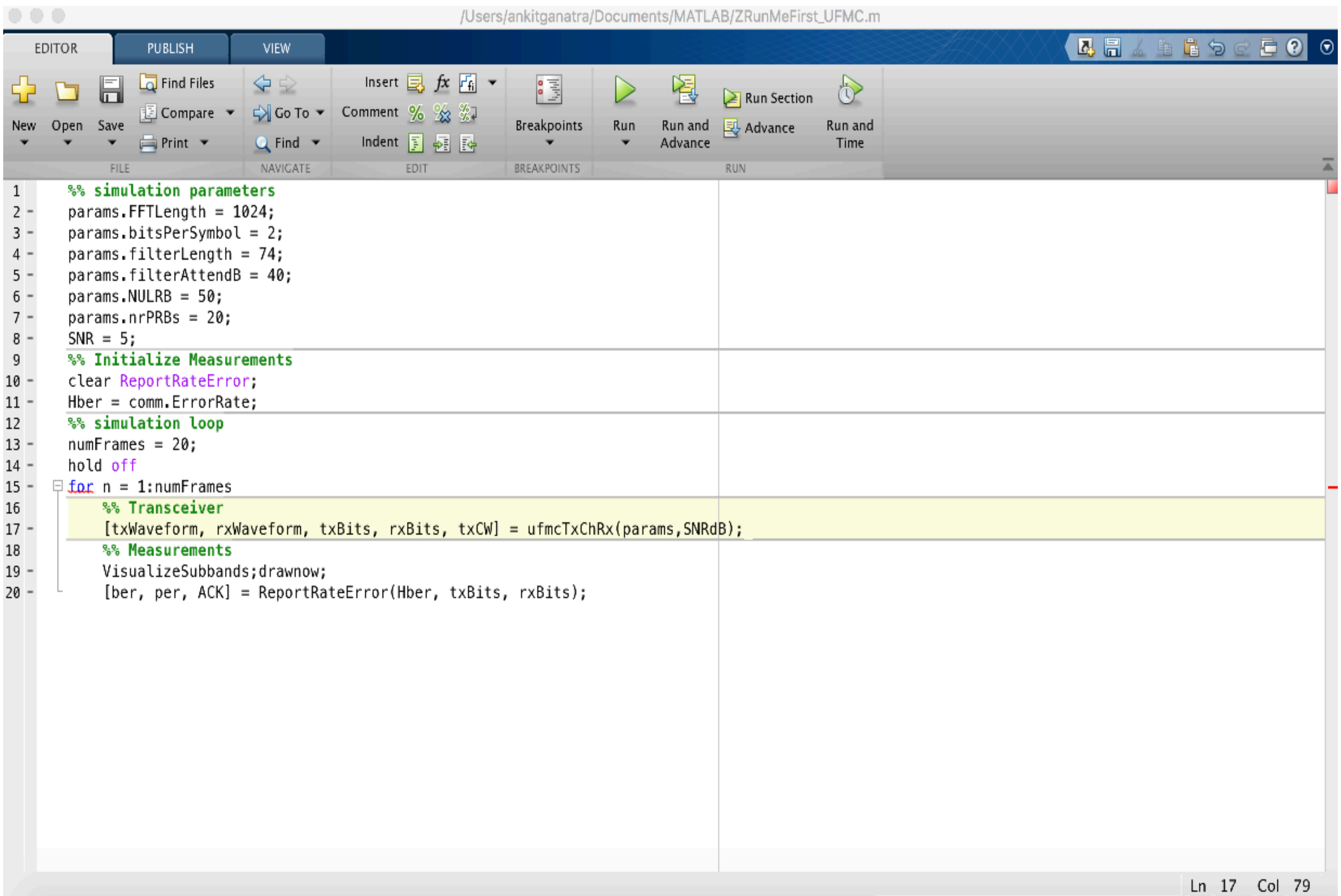


Figure 29: Code function for UFMC

Waveform obtained from UFMC:

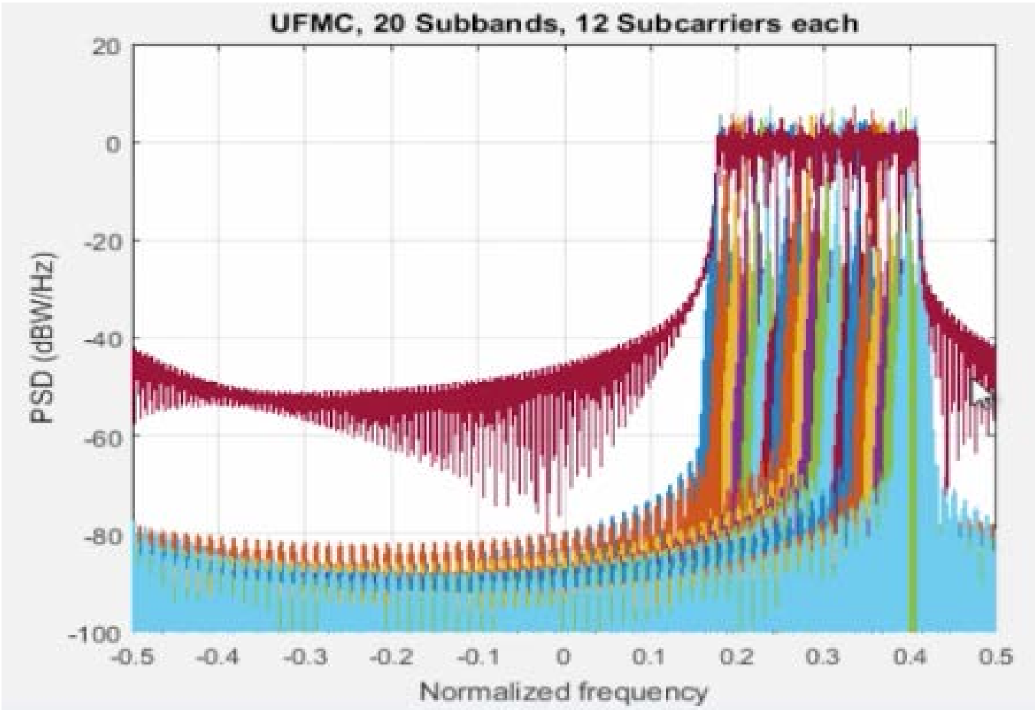


Figure 30: Waveform generated for UFMC

CHAPTER IV

CHALLENGES IN 5G TECHNOLOGY

The aforementioned vision 5G reveals a plethora of challenges that we can outline: 5G strives to provide a universal ICT infrastructure that addresses wider societal challenges through a flexible alignment of stakeholder incentives by virtue of being truly programmable, secure, dependable, privacy preserving, and flexible, while minimizing the costs per bit by efficiently harnessing all communication capabilities and reducing the system power consumption by harvesting any kind of accessible energy from the environment. First, this vision points towards a significantly increased (in comparison to earlier generations) set of stakeholders that 5G needs to accommodate when providing communication solutions. Examples of stakeholders are:

- Individual and communities of people.
- SMEs, corporations, not-for-profit and social organizations.
- Digital asset owners, such as public transport and utilities authorities and organizations.
- Vertical sectors like energy, health, manufacturing, robotics, environment, broadcast, content and creative industries, transport, smart cities.
- Municipalities and public administrations.
- Public safety organizations and defense bodies.

Providing communication solutions for this large set of stakeholders with current communication solutions is intrinsically difficult due to the large set of requirements that needs addressing at any point in time of deployment. Following our vision, it seems clear that 5G will be able to provide broadband location independent access to places like planes, high-speed trains and ships. 5G networks will optimally explore the underlying L2, and will use the existing context to provide energy efficient communications. This means that 5G will be multi-technology – not in the sense that resorts to different physical layers, but that they can resort to different networks as well, either from the point of view of technology or of administrative ownership. In this, we consider the future 5G network a “not always all-IP network”, bringing the advantages of other network architectures to the forefront where they may provide value over IP-only systems (e.g. ICN, ZigBee, etc.…). The network will also be inherently multi-tenant, in order to be able to explore the technology diversity that will exist. Driven by Moore’s Law, the networks (or some network nodes) will need to be seen as intelligent “computing & storage” entities, bringing different features into the network realm, where some concepts that resided until now at the service layer are integrated, enabling the synergetic development of network functions based on software engineering principles (thus lowering the product development costs). The 5G network thus brings to users not only better performance, but also new functionality. Its scope is not limited to the radio access, but encompasses the whole network, including aspects as subscriber management, core network and transport features.

This view on 5G leads to many key performance challenges that 5G technologies will need to address for meeting expected key performance indicators (KPIs):

Throughput: provide 1000x more available throughput in aggregate, as well as 10x more speed to individual end users, in order to enable fully immersive experiences. This may require the integration of new forms of broadcast services.

1) **Latency**: provide service-level latency down to about 1ms (when needed) for tactile Internet, interactive and immersive experiences as well as standard Internet services.
2) **Energy efficiency**: Wireless/mobile broadband infrastructures account for more than 50% of the energy consumption of telecommunication operator networks, while the amount of global energy consumption of ICT approaches 4.5% with a rising trend. It is important that future 5G networks meet requirements and challenges in an energy efficient manner

3) **Service creation time**: enable the creation of user experiences from the application over the individual service components down to the individually participating network(s) in a matter of seconds or less.
4) **Battery lifetime**: provide 10x better battery lifetime for low throughput solutions such as sensors.
5) **Coverage**: with many more people expecting to have the same coverage when travelling (on cruise liners, passenger aircraft, high-speed trains and in holiday villas), it is key to provide seamless extension of 5G services anywhere anytime. IoT coverage to wide areas involving sensors and M2M connections are ideal services to make use of satellite wide area coverage.

In addition to the key performance challenges, we also outline system-level challenges that arise from the changing ecosystem in which 5G is expected to operate:

Privacy by design challenge: provide accountability within the communication substrate and enable truly private communication when needed, aligned with policy constraints in terms of data management and ownership, ensured by the infrastructure operators that realize the overall service.

Quality of Service challenge: in order to allow for optimizing the Quality of Experience5 (QoE) for the end user, 5G should provide differentiated services across various dimensions such as throughput, latency, resilience and costs per bit as much as possible independent of users' location with respect to the antennas deployment geography. This includes increased security, availability, resilience and delivery assurance for mission critical applications such as health-related or emergency applications, but also ultra-low cost solutions for emerging countries with less stringent QoE requirements.

Simplicity challenge: provide to 5G users the best network services seamlessly without complex customer journeys (e.g. for inter RAT switching).

Density challenge: increased number of diverse devices connected in proximity, e.g., challenging the current architecture for mobility management.

Multi-tenancy challenge: provide service solutions across different infrastructure ownerships, with the different networks (not necessarily IP-based) co-existing and providing and providing an integrated as well as efficient interaction between the wireless domain and the backhaul.

Diversity challenge: Beyond the diversity of stakeholders, 5G must support the increasing diversity of optimized wireless solutions (to different application domains, e.g., M2M) and the increasing diversity and number of connected devices, and associated diversity of traffic types.

Harnessing challenge: exploit any communication capability, including device-to-device (D2D), for providing the most appropriate communication means at the appropriate time.

Harvesting challenge: devise radically new approaches to provide devices with power, which not only has to come from batteries, but also harvests existing environmental energy.

Mobility challenge: support for unlimited seamless mobility across all networks/technologies

Location and context information challenge: provide positioning and context capabilities in the sub meter range in order to enable the Internet of everything, e.g., through the integration of cellular and satellite positioning systems.

Open environment challenge: enable horizontal business models by opening the right business interfaces within the system in order to enable flexible operator models in a multi-tenancy fashion.

Manageability: Improve manageability of networks in order to reduce the need for manual management and reduce the human involvement. QoE is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and / or enjoyment of the application or service in the light of the user's personality and current state. Whitepaper for public consultation, August 2014 13

Hardening challenge: deploy a communication system through a combination of bearer techniques such as cellular and satellite that is intrinsically robust to attacks from malicious entities as well as to natural disasters; a resilience without which the smart-grid/smart-city paradigm will never be achieved.

Resource management challenge: provide access agnostic control, policy and charging mechanisms and protocols for dynamic establishment, configuration, reconfiguration and release of any type of resource (Bandwidth, Computation, Memory, Storage), for any type of devices (e.g. terminal, car, robot, drone, etc.) and services (e.g. Network, Security, Data, Knowledge, Machine, and Thing as a Service), including in E2E fashion when necessary.

Flexibility challenge: devise truly flexible control mechanisms and protocols for relocating functions, protocol entities and corresponding states in a truly end-to-end manner, leveraging programmable network technologies such as SDN and NFV.

Identity challenge: provide identity management solutions for any type of device (terminal, car, robot, drone, etc.) with access agnostic authentication mechanisms that are available on any type of device, device to device and network to device, independent from specific technologies of communication entities and of their current location.

Flexible pricing challenge: provide methods for flexible pricing mechanisms across and between different parts of the future 5G value chain in order to enable pricing regimes that are common across the industries that will utilize the future 5G infrastructure. Furthermore, new business models could consider the underlying technology (e.g., wireless or mobile, legacy or later one) as well as other aspects like the contribution of a privately owned small cell to the operator's infrastructure through its open access.

Evolution challenge: provide the ability for evolution and adaptation, allowing a transparent migration from current networks and permitting future development.

From a system level perspective, our vision outlines one challenge that overarches all technology focused research priorities; this challenge is that of flexibility. Given the wide range of stakeholder incentives and requirements, future 5G system must provide an enormous degree of flexibility. This challenge drives 5G away from the rather rigid pre-5G designs with limited service classes available to its users and few assumed deployment models at the communication substrate level. Specialized network components provided as specialized hardware boxes, based on commonly agreed standards, reflect this rigidity in design. In order to achieve the necessary flexibility of 5G systems, we foresee a high degree of programmability of otherwise standard network-enabled hardware components, such as reflected in the current network function virtualization (NFV) efforts. This programmability pushes the resolution of incentive conflicts from the early standards phase to the later deployment phase where network emulation as well as validation of software components paves the way to significantly reducing the service deployment time from several days to minutes or even seconds. The programmability also provides the ability to account for the usage of resources across the network, enabling the envisioned flexible incentive alignment across several stakeholders. Furthermore, with resources interpreted as that of computing, storage, volatile memory and bandwidth, the envisioned programmability of the network will also facilitate solutions for the guarantee challenge at the system level by allowing for optimizing across all these resource dimensions towards a single deployed solution. Combining flexibility and programmability in future 5G systems should also allow to build complex, mission-critical services with specific requirements in terms of service quality, where a dedicated physical infrastructure would be normally required. Harnessing the true benefits of programmability is only achieved by openness of key APIs to network services across different domains.

Furthermore, the future 5G system needs to perform in an energy-efficient manner, by meeting at the same time all the necessary 5G KPIs in line with the 5G vision. This trend will result in the design of energy-efficient hardware that ultimately reduces the energy consumed per bit. Beyond these identified technology challenges, we also identify research priorities needed in economic and policy research that investigate the impact of this new flexibility on business and standards processes as well as on policy-making processes. We believe that this research will be transformative to today's processes. For Whitepaper for public consultation, August 2014 14 instance, we need to investigate the role of standards to agree on technological and business interfaces within the system in the light of upcoming virtualization solutions. We will also need to investigate the impact of new spectrum management approaches on spectrum policy, possibly integrating the technological solution (e.g., the exchanged information for spectrum sensing) into the policy approach itself.

Finally, the flexible alignment of incentives, as envisioned by our 5G vision, will truly enable fluid information-driven markets through our 5G platform. We will need to study the potentially transformative changes within the many industries that 5G intends to provide solutions for in the light of this new economic market fluidity. For instance, we can already see today that the 'app economy' of smartphone-based applications has had an impact on areas such as public transport as well as health. Quantifying this impact, identifying new business models as well as fostering emerging stakeholders in these future markets are the priorities of this economic research in the 5G context.

CHAPTER V

SECURITY IN 5G

Traditional Security Practice

Mobile communications systems have evolved through wireless technology innovation into 2G, 3G, and then 4G to keep pace with ever increasing voice and data traffic. Tougher security mechanisms are in place to safeguard today's mobile communication systems. For instance, one-way authentication in 2G has been elevated to mutual authentication in 3G & 4G; key length and algorithms are becoming more robust; as mobility management is improving, a forward key separation in handovers has been added in 4G; also, more effective privacy protection is considered.

Traditional security architectures focus on protection of voice and data, and they all have the following security features in common:

- User identity management based on (U)SIM
- Mutual authentication between networks and users
- Securing the path between communicating parties hop-by-hop

Security Challenges Ahead of 5G

New Business Models, in traditional mobile communications networks, the primary goal is to enrich people's life through communication. Users may communicate by text messages, voice calls, and video calls, or surf Internet or access app services using smart phones. However, 5G is no longer confined to individual customers. It's not simply about having a faster mobile network or richer functions in smart phones. 5G will also serve vertical industries, from which a diversity of new services are going to stem. In the context of vertical industry, security demands could vary significantly among services. For instance, mobile Internet of Things (IoT) devices require lightweight security while high-speed mobile services demand high efficient mobile security. The network based hop-by-hop security approach may not be efficient enough to build differentiated end-to-end (E2E) security for different services. As IoT is gaining momentum, more people will be able to remotely operate or "talk" to networked devices, for instance, instructing facilities at a smart home to get up. Therefore, there is a need of a more stringent authentication method to prevent unauthorized access to IoT devices. For example, biometric identification could be part of the authentication in smart homes.

IT-Driven Network Architecture, New IT technologies, like virtualization and Software Defined Network (SDN)/Network Functions Virtualization (NFV), are seen as a way to make 5G networks more nimble and efficient, yet less costly. While CT are happy to see, IT is injecting new vigor into their networks, new security concerns are emerging. Security cannot be built for 5G services unless the network infrastructure is robust. In legacy networks, security of function network elements (NEs) relies largely on how well their physical entities could be isolated from each other. However, in 5G, the isolation will work differently as virtual NEs on cloud-based infrastructure. It’s likely that time is right to take 5G infrastructure security into consideration. SDN is proved to be of help in improving transmission efficiency and resource configuration. On the other hand, it is important to consider in the 5G security design that it could be managed in terms of the isolation for network nodes such as control nodes and forwarding nodes, and the secure and correct enforcement of the SDN flow table. Based on network virtualization technology, a network could build different virtual network slices. Each virtual network slice could accommodate a particular service requirement and thereby may require differentiated security capabilities. 5G security design may need to consider issues of how to isolate, deploy, and manage virtual network slices securely.

Heterogeneous access will be one of the network features of next-generation access networks. The heterogeneous nature comes not only from the use of different access technologies (WiFi and LTE), but also from multi-network environment, which might imply that the access network architecture from different networks are different. So, a consideration for security designers is building security architecture suitable for different access technologies. IoT devices have many choices in the way they access networks. For instance, they may connect to networks directly, or via a gateway, or in the D2D or Relay fashion. Comparing to mobile handset, security management of IOT device in 5G may be efficient and lightweight in order to establish trust relationships between devices and networks.

Privacy Protection, With the advances of mobile Internet, more and more vertical industries, including health care, smart home, and smart transport, will resort to 5G networks. As open network platforms, 5G networks raise serious concerns on privacy leakage. In many cases, privacy leakage can cause serious consequences. As primary method for network accessing, mobile networks carries data and signaling that contains many personal privacy information (for instance, identity, position, and private content). In order to offer differentiated quality of service, networks may need to sense what type of service a user is using. The service type sensing may involve user privacy. Add all this together, privacy protection in 5G is more challenging.

5G Security Goals

As the 5G era is drawing near, the volume of data traffic and variety of services will increase to unseen-before levels. IoT service is just one of the many. When it comes to 5G, it is not simply about being a medium for communication. It can be seen as a catalyst for minimizing the boundary between the digital world and physical world. 5G security design is an all-encompassing one that provides security protection for the everything-connected world.

E2E Security for Vertical Industries

Differentiated security protection: E2E security design caters to different vertical industries. In that case, the design of security protection needs to consider how to fulfils various security requirements.

Flexibility: To provide better support and rapid response to the vertical industry requirement, it is nice that E2E security capabilities could be rapidly aligned with business changes. In that case. it would request flexible and high efficient E2E security deployment and adaptation.

Privacy protection: 5G will see APP services thriving vigorously. Along with this thriving, personal privacy data is growing massively also, including device identifiers, user IDs, and user preference. Considering that, privacy protection could be built end to end, leaving no part of the security chain vulnerable to privacy leaks.

Security as service: In face of convergence of IT and CT, telecom industry is seeking to boost their strength and better serve vertical industries. Tele communications systems have done well in protecting user privacy, and users have built relatively good level of trust with security strength of the communication systems. 5G could continue to extend the user trust by opening up security capabilities as a service to individual users and vertical industries.

Secure Infrastructure: Diversified system level protection of IT-aware infrastructure after IT technologies (e.g. NFV and SDN) are put into use, a vast array of system-level protections is in place to defend against distributed denial of service (DDoS) and other active attacks that may increase.

Identity management Both software and hardware infrastructures run in multi-vendor environment. To mitigate unauthorized access to network resources, stringent identity management is a possible need.

Data protection Integrity and confidentiality protection are provided throughout data transmission to prevent data from being intercepted or re-routed to unauthorized destinations.

5G Security Perspectives

New Trust Model and Identity Management, in legacy mobile communications networks, Telecom networks are responsible for authenticating user for network access only. A trust model with two elements, between users and networks, is formed. The authentication between user and services are not covered by the networks. However, in 5G networks, a trust model with an additional element, the vertical service provider, is favored possible design. Networks may cooperate with service providers to carry out an even secure and more efficient identity management.

Hybrid Authentication Management: 5G networks are open platforms with a plethora of services. Smart transport, smart grid, industrial IoT are some of them. Both networks and service providers face challenges in making access & service authentication simpler and less costly. Three authentication models would possibly co-exist in 5G to address needs of different businesses.

Authentication by networks only Service authentication incurs significant amount of costs to service providers. Service providers can pay networks for service authentication so users will be able to access multiple services once they complete a single authentication. This frees users from the cumbersome task of getting service grant repeatedly when accessing different services.

Authentication by service providers only on the other hand, networks may rely on the proven authentication capabilities from vertical industries and exempt devices from radio network access authentication, which can help the networks lower down operating cost.

Authentication by both networks and service providers for some of the services, a legacy model might be adopted. Networks take care of network access, and service providers deal with service access.

Diversified Identity Management: Legacy cellular networks rely on (U)SIM cards to manage user identities and keys. In 5G, equipment's such as sensors, wearable devices, and smart home devices are possibly either too small or too cheap to accommodate (U)SIM. Now the time has come to find a new way of managing device identities, for instance, produce, assign, and apply lifecycle management on device identities.

Combination of device identity and service identity In the new identity management framework, an identity consists of a device identity and a service identity. Each device identity (also called physical identity) is globally unique and may be assigned to a device at the manufacturing phase. Service identities are assigned by service providers or networks. A physical identity may correspond to one or more service identities.

From device-based management to user-based management It leaves to users to decide which of their devices can access the network and which service can use. As an example, devices of a same user may share bandwidth quotas with each other in either online or offline manner.

Service-oriented Security

Build E2E Security: Differentiated security for different services 5G systems are going to be service-oriented. This implies that there will be a special emphasis on security requirements that stem from the angle of services. For instance, remote health care requires resilient security while IoT requires lightweight security. It is quite reasonable to offer differentiated security to different services.

Flexible security architecture to support security attributes for different network slices If differentiated security is offered, then flexible security architecture is needed to support E2E protection for different service, based on network slicing architecture. Network manages different E2E security capabilities, including strength of security algorithms, ways to derive and negotiate secret keys, and mechanisms for protecting confidentiality and integrity. Within a virtual network slice, security capabilities could further be distributed.

A Uniformed security management framework for multi-vendor environment. In cloud environment, software and equipment of network infrastructure come from more than one equipment vendors, which relatively complicate the security issues. For the services and users, building an E2E data security chain could be a way to reduce the reliance on individual link security and simplifies security management.

Figure 31: Security Applications and service

Open Security Capabilities, and provide security as a Service

Security management, for instance, managing identities, performing authentication, defending against denial of service (DoS) attacks, and protecting confidentiality and integrity of service traffic, is a general request to vertical industries. However, perhaps not all industry players have the capabilities to build security management on their own, either due to economic burdens or technical challenges, etc. Utilizing security service could be a good choice to these players. On the other hand, Telecom networks have relatively nice work in the security capabilities (i.e. authentication, identity & key management) and are trusted by users after years of commitment in services. It is a good opportunity for networks to provide their security capabilities as a service to vertical industries. For instance, networks could authenticate service access and return the authentication result to vertical industries. It is the network's choice either to deploy the security service on a cloud platform or simply built it into a virtual network slice of the vertical industry who has bought the security service from networks. Security capabilities can be seamlessly built into business flows of vertical industries.

Isolate Virtual Network Slices: For virtual network slices, each of which handles a different type of application service to facilitate flexible resource orchestration and scheduling, there is a need to isolate slices from each other to prevent their resources from being accessed by network nodes in other slices. For instance, patients in a health care slice desire to allow only doctors access their health data, and they are reluctant to see their data accessed by someone in other slices. The isolation statement is also applicable to virtual network slices with the same type of application service. For instance, enterprise A may hope to block other enterprises from using its resources, although these enterprises are served by a same type of virtual network slices. The isolation effect for service and data in the virtual network slices could approach to the user experience in traditional private network, only in this way the users are willing to store the private data on cloud, and then they could freely access their private data without concern about the security risk on the data.

Security Assessment: 5G needs an open platform to support a vast array of services from vertical industries, for instance, remote health care, Internet of Vehicle (IoV), and IoT. The platform can be further divided into units based on the functions. Different software or hardware vendors can contribute their own strength in the development of the units. In this way, the service deployment can be more rapid and the operating cost can be reduced. To build an open software & hardware ecosystem, it is essential that network function units from different vendors are interoperable via standard interfaces. All network function units may need to attest to each other that they are secure, so that when they are integrated into a platform, a high level of platform security could be achieved. A traditional way to assess their security strength is that vendors sign a trust agreement and then test security performance of each other. However, the testing model is expensive and impedes the growth of the open software & hardware ecosystem. Therefore, a well-received assessment procedure and tools are seemed to be possible approaching, by which all vendors could follow a standard procedure to test their network function units. Security assessment is feasible only if specific and measurable security metrics are figured out for each network function unit. For instance, the metrics could be the password length and its complexity. An important point to note is that the way for defining and measuring these security metrics. Security metrics that are standardized and well received could help in the case that even third-party test bodies can effectively assess network function units. To support dynamic service deployment as well as automatic service rollout, deployment, and management, network units that pass the security assessment can be granted a certificate and an electric signature for automatic verification upon integration. To keep track of security risks, it is nice that security management maintenance be performed on a regular basis during business operations that security measures can be taken on a timely manner in the event of an incident.

Low-Delay Mobility Security: Emerging of delay-sensitive applications such as vehicles network and remote surgery have communication scenarios characterized by low-delay and high-security. In these scenarios, the 5G network may need to support high reliability while providing QoS guarantee with a delay not more than 1 millisecond, to prevent accidents such as vehicle collision and surgical operation errors. Further, with the deployment of ultra-dense deployment technologies in the 5G network, when a vehicle is on the move, mobility management procedure can occur frequently. Considering the delay requirement, the mobility management-specific functional entities and processes need to be optimized. To address these new challenges, mobility security may be redesigned and optimized for the 5G network to build an efficient, lightweight, and compatible mobility management mechanism to meet the more stringent delay requirements.

User Privacy Protection: As 5G networks will serve a large number of vertical industries. This indicates that a great amount of user privacy information will be carried over the 5G network also. Any information leak may lead to severe consequences. With advancements in data mining technologies, retrieval of user privacy information has been made easier. Therefore, user privacy information must be securely protected in the 5G network so that users and vertical industries can use the network without worrying about information leakage.

Usage management of privacy information in 5G network: The 5G network provides customized network services (including slice customization or selection) for users by sensing their service features. However, privacy information, such as user health information and location, may be utilized in the service type sensing process. To protect user privacy, a service sensing rule must be clearly defined for the 5G network to address users' concerns about privacy. The method must stipulate how the privacy information is used and how it is handled after being used.

More rigorous privacy protection scheme in 5G network: In a heterogeneous network where multiple access technologies are used, the protection for user privacy information varies depending on the access technology. In addition, the 5G network is one that runs over multiple types of network. User data may traverse various access networks and network functional entities supplied by different vendors. As a result, it’s possible that user privacy information could exist in any corner of the networks. With data mining technologies, a 3rd-party may be able to derive detailed user privacy information through analysis on the disperse user privacy data. Therefore, it’s time to have privacy information exposure risks thoroughly considered in the 5G network.

CHAPTER VI

FUTURE AND CONCLUSIONS

The many initiatives and discussions on 5G going on around the world by governments, vendors, operators and academia demonstrate the continuing ethos of collaboration and innovation across the industry. In these debates, we must ensure that we continue to co- ordinate with aligned goals to maintain momentum in completing the definition of 5G. The key 5G considerations at this stage are: When 5G arrives will be determined by what 5G turns out to be as discussed earlier, there are currently two differing views of what 5G is. The first view makes its implementation somewhat intangible – 5G will become a commercial reality when sufficient industry voices say so, but this will be difficult to measure by any recognizable metric. The second approach is more concrete in that it has a distinct set of technical objectives, meaning that when a service is launched that meets those objectives it will count as the advent of 5G.

As the requirements identified for 5G are a combination of both visions, in some cases the requirement set is self-contradictory – for example, it would not be possible to have a new RAN with beam forming and meet a requirement for power reduction, because beam forming uses a lot more power than today's RAN. As a result, there must be an established answer to the question of what 5G is before there can be an answer to the question of when it will arrive. The case for a new RAN should be based on its potential to improve mobile networks. The principal challenge in the 5G specification is the sub-1ms latency requirement, which is governed by fundamental laws of physics. If, as discussed above, this challenge proves too much and the requirements for sub-1ms delay are removed from 5G, the need for a new RAN would be questioned. Whether a new air interface is necessary is arguably more of a question of whether one can be invented that significantly improves mobile networks, rather than on a race to the arbitrary deadline of 2020.

This raises the question of where the industry should go next. Without a new air interface, the ‘5G’ label makes less sense, as the industry would need to shift to the evolutionary view of 5G - with the new networks building on LTE and Wi-fi by adding new functionalities and architecture. 5G should not distract from more immediate technological developments. Technologies such as multiple-carrier LTE-A, NFV/SDN, HetNets and LPLT networks will form an important part of the evolution of mobile networks. Each has the potential to offer tangible benefits to operators within the next few years, and so the industry should not risk losing focus on the potential benefits of these technologies in the short and

LTE remains very important and will continue to evolve, there remains considerable potential for future LTE growth, which still only accounts for 5% of the world’s mobile connections. LTE penetration as a percentage of connections is already as high as 69% in South Korea, 46% in Japan and 40% in the US, but LTE penetration in the developing world stands at just 2%. Hence there is still a substantial opportunity for operators to generate returns on their investment in LTE networks. LTE technology will also continue to develop, with operators already making a considerable amount of progress in increasing the data speeds of their existing networks by adopting multiple-carrier LTE-A technologies. Therefore, while there remain monetization and interconnect issues around LTE, these advancements will enable operators to offer many of the services that have been put forward in the context of 5G long before 5G becomes a commercial reality.

The industry should make full use of governmental interest and resources, there is a considerable level of governmental interest worldwide in the subject of 5G, not to mention a substantial amount of funding available for research and development in the field. It is important that the industry leverages this and effectively channels the focus and resource into something meaningful for both operators and their customers. This should be implemented in a coordinated framework to avoid a fragmented vision of 5G for different parts of the world.

5G is an opportunity to develop a more sustainable operator investment model. If previous generations of mobile technology have taught us anything, it is it that, as with each preceding generation, 5G will unlock value in ways we cannot and will not anticipate. Services that were initially expected to have a negligible impact became hugely popular (e.g. SMS), while those expected to be the ‘next big thing’ have been slow to gain traction (e.g. video calling). Through the development of 5G, we as an industry can expect a paradigm shift in the way that all the stakeholders in the mobile ecosystem play their role. Regulators especially can use this as an opportunity to create healthier environments that stimulate continuing investment in next generation technology. Some of the business cases that have worked well for 3G and 4G technologies may not be the right ones for 5G. By actively conceiving and exploring 5G business cases at an earlier stage, operators will have greater potential to shape the new paradigm. The GSMA will continue to work with its members to shape the future of 5G. Whichever form 5G eventually takes, the GSMA, as the association representing the mobile industry, looks forward to contributing to the development of a 5G ecosystem through collaboration and thought leadership.

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