International Journal of Early Childhood Special Education (INT-JECSE)
DOI: 10.9756/INT-JECSE/V14I2.802 ISSN: 1308-5581 Vol 14, Issue 02 2022

Ensuring End-To-End Performance of 5G Cellular Systems using NS-3

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Abstract:
The fifth-generation (5G) and sixth-generation networks will be the bigrevolution in the area of mobile and wireless communication.This will be due to the high data rate and connecting applications in various areas ultralow, the Internetof things (IoT), and massive device-to-device communications.These applications are only possible in the changes of the core network ofthe 5G and 6G virtualizationtechniques with higher performance, low latency,and quality of service guarantee.Due to its potential for multi-gigabit and low latency wireless links, millimeter wave (mmWave) technology is expected to play a central role in 5th generation (5G) cellular systems.
The growing demand for ubiquitous mobile data servicesalong with the scarcity of spectrum in the sub-6 GHz bandshas given rise to the recent interest in developing wireless systems that can exploit a large amount of spectrum availablein the millimeter-wave (mmWave) frequency range. Overcoming the poorradio propagation and sensitivity to blockages at higher frequenciespresents major challenges, which is why much of thecurrent research is focused on the physical layer. In this paper, the mmWave module is integrated with ns–3 simulators to incorporate real measurements or raytracing of data and simulations of end-to-end connectivity and dual-connectivity. This paper also presents an open-source framework to model the mmWave cellular networks using an ns-3 simulator with a configurable physicaland MAC-layer implementation, that may be communicated with the higher-layer protocols and core network model to simulate end-to-end connectivity.Our framework may help to simulate the various situations to enhance the end-to-end performance of the 5G cellular network using the mmWavemodule.

Keywords:5G, 5G new radio 4G, end-to-end performance, mmWave, cellular, channel, handover, simulation, network simulator, ns–3

1. INTRODUCTION

In the pasttwo decades,cellular communication technologies are rapidly from the 2nd Generation global system for mobile communication to the 4thGeneration Long Term Evolution(LTE) and are also developing in the 5th Generationnetworks communication era. Various organizations from Govt. the sector, Private sector are working on the development of a 5G network for mobile communication. And all the stakeholders from different bodies like, Govt. and Private sectors must work in agreement to bring 5G to completion. The revolution in 5G and 6G networksadaptsto the current situation and fulfillsthe requirementsof users. To do so, network infrastructureis configured using techniques like software-definednetworking (SDN) and network function virtualization(NFV) that enable the dynamicity of both radio and corenetworks. Automation in radio andcore networks provides reliable resource allocation management, agile services, Realtime service, quality of service (QoS), and on-demandservices to fulfill the user's requirement.
5G and 6G evolution in a cellular system are essential to full fill the user's requirement, reduce the traffic, and provide the high data rate services. By the end of 2018, 3GPP group standardization used for the 5G mobile communication system which is discussed in [19].Paper [20] Enlighted the overview of multi-connectivity operation by using long-term evolution (LTE) and NR access technologies. Software-defined network and network function virtualization, and End-to-end 5G network architecture and protocols in[21]. 5G and 6G will replace the 4G's evolved packet core (EPC), access and mobility management function (AMF), session management function (SMF), and user plane function (UPF) [22].
MILLIMETER Wave (mmWave) are emerging technology and a requirement for future 5G cellular systemwireless systems to achieve massive throughputs[23,24]. mmWave signals have unique propagation characteristics that transmit in beams with much greater directionality than previously used in cellular systems. However, designing End-to-End (E2E) cellular systems provide high throughput with low latency at the physical layer and layers of the communication protocol stack [25-27]. These signals are hadhigh susceptibleto blockage [23], and results may affect the channel quality and avoid congestion [27,28].

To handle various challenges in cellular systems, in this work, we used the mmWave simulation tool for Long Term Evolution (LTE) in a 5Gnetwork that canevaluatecross-layer and end-to-end performance using ns–3 network simulator [29]. ns–3 is an open-sourceplatform and implemented various protocols using C++ to analyze the cross-layer design. In our paper, we have used the mmWave module, which is based LTELENA module covered in [30, 31], which implements necessaryService Access Points (SAPs). The ns–3 withmmWave module was discussed by [32,33] and the 3GPP channel model in [34]. In this paper, we extended the work using the ns–3 mmWavemodulesthat may help the researcherwhois planning to do a simulation of cellular networks and systems.
The rest of the paper is organized as follows; In the first section, we have discussed the background related to cellular generation till 4G and some related to 5G. Section 2 covered the background related to mmWave and NS-3. The section highlighted some research challenges. In section V we proposed our approach, and finally, section VI concludes our paper.

2. 5G BACKGROUND

5G is not just another mobile generation, it is the global platform for the automation and digitization of almost everything we can think of. It is a group of technologies and concepts, particularly fiber, very high speed, MIMO-based new radio, ultra-low latency, reliability, edge computing, network slicing, virtualization, and much more.
5G is a whole new approach aimed at putting telcos back in the market for services and network applications. 5G will eventually enable telcos to sell assured business services that can be tailored to suit different 'vertical' industry segments.
In our research, we have selected the 5G network that opens several problems for the research associated with communication and various applications of the 5G network for the improvement and development of the new world. Many advancements are already done from 1G to 4G telecommunications network systems and 5G networks shown in Figure 1[1,2] with growing data rate, but still, some issues need to be focusedon and highlighted [3-5]. Some key difference from 1G to 5G is depicted in Table 1[1]

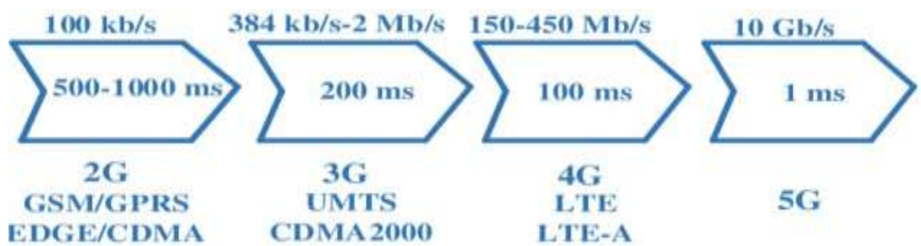

Figure 1 Network growths from 2G to 5G

5G uses is the frequency 24-86 GHz range [6], which may waste the frequency due to obstacles, so need to find a solution to this problem. Nowadays 5G is the major phase of mobile telecommunication over the 4G standard. This technology will change the way of wireless communication that will provide very high bandwidth with various advantages over 4G technology.

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Table 1: Comparison of 1G to 5G Network technologies

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 with LAN, WAN and WLAN	Unified IP with 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
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

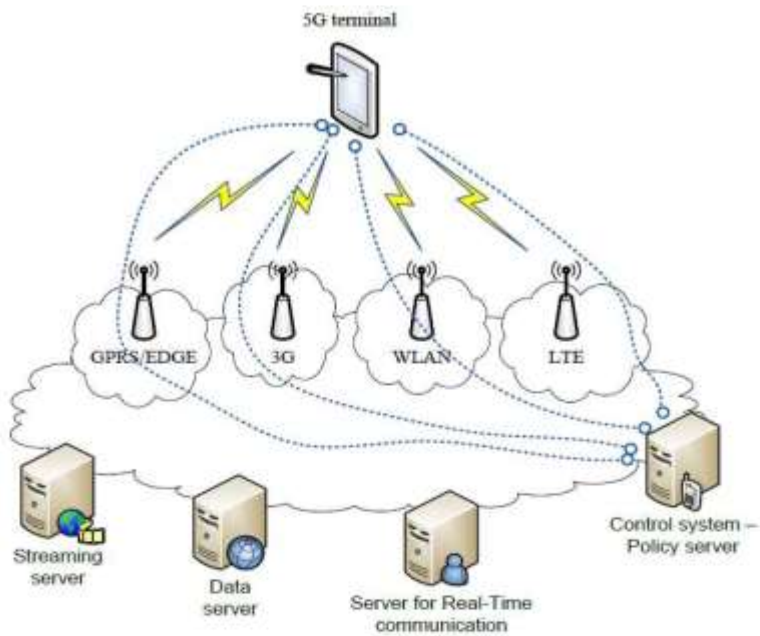

Figure 2 Functional Architecture of 5G Network

The functional architecture of the 5G network is shown in Figure 2 and is based on an IP model designed for wireless and mobile networks. This system consists ofa 5G terminal (The main role in 5G architecture) and autonomous radio access technologies (RAT) connected with the outside internet world using a radio interface in the mobile terminal. IP technology can work as efficiently control using routing of IP packets over the internet. For example, if we want to have access to four different RATs, we need to have four different access-specific interfaces in the mobile terminal, and have all of them active at the same time, intending to have this architecture be functional [7].

5G network architecture consists of the following components 1) General Packet Radio Service (GPRS) is used to transmit the data with less battery consumption when the internet will be surfed for different purposes, 2) Exchanged Data Rate for GSM Evolution (EDGE)- advanced GPRS with very good speed around 470 kb/sec. 3) 3G is used for purpose of a video calls on mobile networks with efficient internet browsing on the mobile network, 4) Wireless LAN (WLAN) provides ahigh-speed wireless connection within a short range between mobile devices and radio signals, and 5) Long Term Evolution (LTE) is then used for high-speed data transmission for a mobile network in mobile communication up to 100mbps speed [7].

5G networkshave some key features like Lower Latency, many device connection capabilities, less cost with improved energy efficiency, and application in various areas like Real-time wireless world, smart wearable devices, IPv6, at the global level for mobile communication [8].Many developments are going on in 5G network and various researchers are working in this area, some researcher work is explained below related to the 5G Network and End to end performance enhancementQualcomm, 2014[20] expected that the fifth-generation (5G) mobile network will increase the limits of mobile communication that can also address the latest shortcoming of 5G network. For the research, there are many challenges to the development of 5G network communication due to some reasons like heterogeneity of devices, increased number of devices daily basis, higher bandwidth requirement with constant speed, reduction in the latency and maybe more reasons[3-5].

Millimeter waves are extremely high frequency (EHF), andthe right option for 5G networks. It transmitted data in frequency between 30 GHz and 300 GHz as compared to 5 GHz which was previously used. These frequencies (30 GHz and 300 GHz) are millimeter waves as they have wavelengths between 1 mm and 10 mm. Nonetheless, the use of millimeter (mmWave) wave frequencies to connect mobile users to nearby base stations is an entirely new approachfor better end-to-end performance in 5G and 6G networks. mmWave has various advantages due to its frequency range that increases the data transmission rate, as we know the higher the carrier frequency, the greater the signal bandwidth. That’s why, mmWaveis the most promising approach for 5G, by using mmWave frequency can increase the bandwidth of the spectrum by a factor of 10, which increase the transmission speed.

3. END-TO-END SIMULATION OF 5G MMWAVE NETWORKS AND NS-3

Current cellular systems (4G) operate below 6 GHz, so due to low frequencies, signals propagation will be low and penetration loss is also high (i.e., attenuation by walls and other obstacles), but in mmWave frequency spectrum is between 30 GHz and 300 GHz, whichis well suited for high data rate communication in 5G networks. The mmWave is already used in many applications like point-to-point backhaul communication, satellite communications, etc. mmWave used the high-gain directional antennas to overcome the limitation of mmWave with existing network and provide a better magnitude and throughput for mobile devices [35, 36]. Nowadays directional smart antennas are the major technology with mmWave used in cellular systems to overcome the poor propagation effect of mmWave devices [35,37]. So mmWave is highly required in 5G networks due to massive bandwidthand high-gain antennas. In this paper we have considered the following challenges in the 5G network at the physical layer 1) Adaptive beamforming and beam tracking, 2) Directional synchronization and broadcast channels, and 3) Issues for the MAC, Network, and Transport Layers. To work on these challenges and model of mmWave channel with cellular network protocol and TCP/IP protocol we have considered the ns–3simulator, which is the best option as compared to MATLAB [38-41].This is what motivated us to develop an open-source cellularmmWave module for the ns–3 simulator, which we willdescribe in the following sections.We have discussed several aspects of millimeter waves, and how these waves offer a practical approach to solving the mobile bandwidth crunch. The technology is likely to gain widespread adoption soon. The NS–3network simulator [29,42] is avery powerful tool available to communication and networkingresearchers for developing new protocols and analyzingcomplex systems. It is the best-tested tool for simulation of networking validation. It is an open-source tool, which is available online for all researchers free of cost with various features and is easily downloadable from the NS-3 community website. NS-3 helps both academicians and industry researchers. NS-3 hasmany algorithms to simulate wired and wireless networking protocols. Besides the core module, which provides the basic structure of the simulator, there are modules for networkingprotocols (e.g., the TCP/IP stack protocols [43]), wirelessprotocols (LTE [30], Wi-Fi [44], WiMAX [45]), routing algorithms[46], mobility, embedding obstacles and buildings inthe simulation scenarios, and data collection.

4. CHALLENGES IN DESIGNING THE NEXT GENERATION NETWORK:

Based on the background covered in sections 2 and 3 various researchers are working on related or research. In this paper, we have studied various papers on 5G networks and millimeters (mmWaves), we have concluded from the researcher’s work that, As the traffic on the Internet is increasing day by day on 3G and 4G wireless technologies.

So, there is a requirement of 5th generation wireless communication networks expected to be in 2020. There is no unique definition (yet) for 5G [3], [4].As technical requirements over currently existing technologies (4G) [5] lists the following:

• 1000 times higher mobile data volume per area,
• 10 to 100 times higher typical user data rate,
• 10 to 100 times higher number of connected devices,
• 10 times longer battery life for low power devices,
• 5 times reduced end-to-end latency.

As the number of mobile users and their expectations rise, 5G must be capable of transmitting more data quicker than existing mobile network base stations.

To achieve this, wireless communication engineers must design a set of entirely new technologies. These technologies will allow the latency of 5G data transmission to be less than one millisecond (compared to the about 70-millisecond latency of existing 4G networks) and achieve a peak data download speed of 20 Gbit/s (compared to 1 Gbit/s for 4G).

Some challenges related to the 5G network are covered by [13-18]are given below

1) **Multiple-input, multiple-output (MIMO).** 5G research in MIMO has found that the technology enables base stations to support many more antennas than 4G base stations. With MIMO, both the source (transmitter) and the destination (receiver) have multiple antennas, thus maximizing efficiency and speed. MIMO also introduces interference potential, leading to the necessity of beamforming.
2) **Centimeter and millimeter-wave.** This should come as no surprise to anyone who's been paying attention to 5G chatter. There is a substantial amount of spectrum at very high frequencies, which makes it very attractive, but the engineering challenges are intense. This spectrum offers "huge opportunities and huge challenges," with the latter including the spectrum's vulnerability to shadowing.
3) **Multi-Radio Access technologies**. 5G is likely to involve Wi-Fi, traditional cellular frequencies, and high-frequency spectrum. The ability of devices to talk to different types of access points at the same time is already present in networks to some extent, he pointed out, with LTE and Wi-Fi.
   "This is the way we think we'll be able to support centimeter and millimeter wave," It is a highly reliable connection that will be maintained on a traditional cellular frequency, with surges of extra speed on millimeter-wave.
4) **Small cells.** Small cells are low-powered portable base stations that can be placed throughout cities. Carriers can install many small cells to form a dense, multifaceted infrastructure. Small cells' low-profile antennas make them unobtrusive, but their sheer numbers make them difficult to set up in rural areas. According to 5G research, consumers should expect to see ubiquitous 5G antennas, even in their own homes.
5) **Software-Defined Networking (SDN).** Whereas today's network hardware integrates both the control and data planes, 5G research incorporates the notion of separating these planes. This separation allows network equipment to be externally configured through independent management software, thereby improving flexibility, facilitating centralized control, and ensuring easy network slicing.
6) **Spectrum sharing.** Shared and unlicensed spectrum will permit 5G networks to offer greater capacity, better spectrum utilization, and unique deployment scenarios. A key takeaway from 5G research is that spectrum sharing will allow mobile operators with licensed spectrum as well as those without licensed spectrum to take advantage of 5G New Radio (5G NR) technologies.
7) **Battery life.** This one may not be as obvious, but there may be new ways to extend battery life that will be extremely important – particularly for the "Internet of Things" ecosystem, where sensors may need batteries that can last a decade or more and be produced economically.
   `Mike Wright, director of Telstra's networks, has said that more efficient networking in 5G could be a component of improving battery life, which has been hit by the popularity of devices with large screens.
8) **Research into a new waveform or air interface.** Although some have posited that 5G may not involve a new air interface, the fundamental component of a new generation of technology is the point at which it is no longer backward-compatible with the old. The messaging between the network and the device in LTE eats up a huge amount of battery life and network resources even when the related information is minimal, and for applications such as car-to-car communications, tactile Internet, and other potential use cases that require sub-10-millisecond latency, a baseline change in the technology will be needed.
9) **Intelligent data mining on the fly.** Big data analytics is already an area of interest for telecom and expects data-based intelligence to become more prevalent as part of contextual awareness. However, he acknowledged

that as more and more content providers move to encrypted content, network providers have less visibility into those data streams. This is a very active area of research, he said, and much can be inferred about the content of a data stream based on its behavior. It is also expecting to see content providers and network operators come around to share more information, becaue both sides ultimately want an excellent end-user experience.

10) **The cloud – particularly, the distributed cloud – software-defined networking and network function virtualization.** As the industry explores more flexible, automated network solutions, this part of the evolution toward 5G capabilities is already underway and expects to be fundamental to 5G. However, he pointed out that research questions remain on the best network architectures for different applications. Ultra-low-latency applications such as autonomous driving may require highly distributed networks simply due to the laws of physics, while applications that can tolerate higher latency could be served from fewer central locations.
11) **New applications and requirements** that can leverage and take advantage of an "always connected, always untethered, infinite capacity and response world". If there is no business case for 5G, it won't come to fruition.
12) **Ensuring end-to-end performance:** The common denominator of future networks, will be that they will all be "untethered," or wireless for at least the last few feet. Meanwhile, users "will have expectations of unlimited capacity and they will have expectations of infinite response" – essentially, the feeling that the network was built for and serves them alone.
13) **Contextual awareness:**This goes along with end-to-end performance and is the ability of a network to understand what device a user is on, what application is being used, the physical location and speed, and adapt the network performance to best serve those parameters. Work in that area is already ongoing.
14) **Potentials and Challenges of System-Level Simulations of mmWave Networks:**An End-to-End network simulator for mmWave cellularnetworks is an invaluable tool that can help address these challengesby allowing the evaluation of the impact of the channeland the PHY layer technology on the whole protocol stack.However, given the characteristics of mmWave communications described in the previous paragraphs, to haveaccurate results, it is of paramount importance to model indetail the behavior of the different elements that interact in acellular system. In the following paragraphs we will introduceand discuss some of the most important elements that needto be considered when designing a mmWave cellular systemsimulation, and show how they depend on one another:

5. PROPOSED MMWAVE FRAME STRUCTURE FOR END-TO-END PERFORMANCE EVALUATION OF 5G CELLULAR SYSTEMS

As 5G is the future communication technology in the era of the cellular network community. We are already using LTE, but still, there are lots of improvements required in terms of bandwidth, higher data rate, high speed, and end-to-end performance of the networking devices. In our paper, we have considered mmWave to overcome the 4G network communication changes. The mmWave module is shown in Figure 3 with various components of layers MmWaveEnbNetDevice represents the mmWaveeNodeB (eNB) base stationand MmWaveUeNetDevice represents User Equipment (UE) radio stacks [47]. These two-layer components classes are implementingthe LTE module Service Access Point (SAP) providerand user interfaces, which allow them to interoperate withthe LTE Radio Link Control (RLC) layer. Support for RLCSaturation Mode (SM), Unacknowledged Mode (UM), and AcknowledgedMode (AM) is built into the MAC and schedulerclasses (i.e., MmWaveMacScheduler and derived classes). TheMAC scheduler also implements an SAP for configuration bythe LTE RRC layer (LteEnbRrc). Therefore, all the componentsrequired for Evolved Packet Core (EPC) connectivityare available.

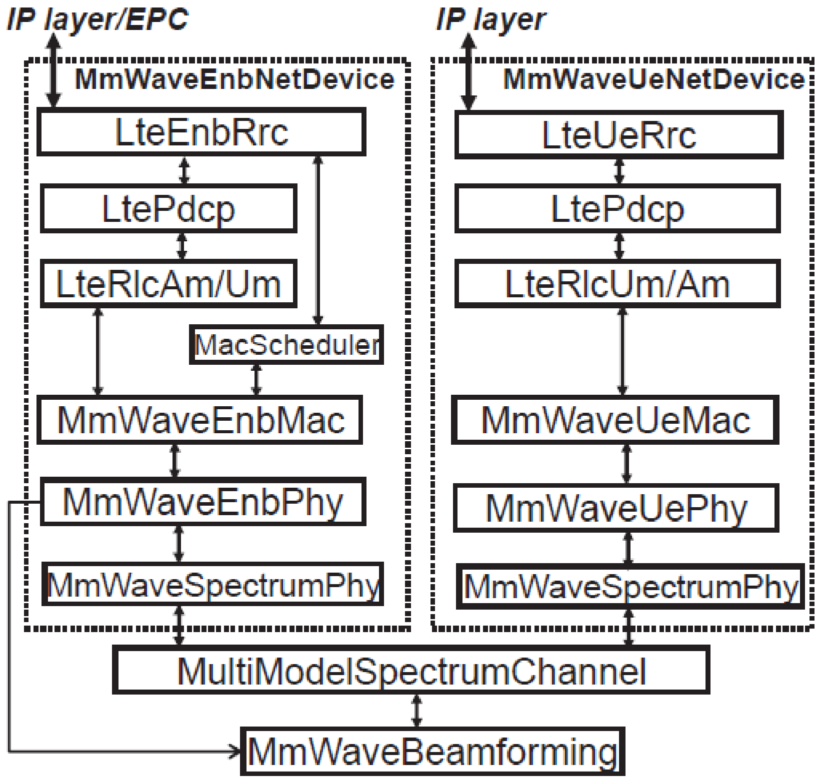

Figure 3 Simplified class diagram for the mmWave module

In our paper, we have discussed the main features of the mmWavePHY layer. The proposed mmWave frame structure is depicted in Figure 4. As the 5G mmWave systems will targetTime Division Duplex (TDD) operationbecause it offersimproved utilization of wider bandwidths and the opportunityto take advantage of channel reciprocity for channelestimation [35] and to reduce the radio link latency [49]. By using the ns-3 mmWave modulewe have implemented a TDD frame structure to support the short slots.

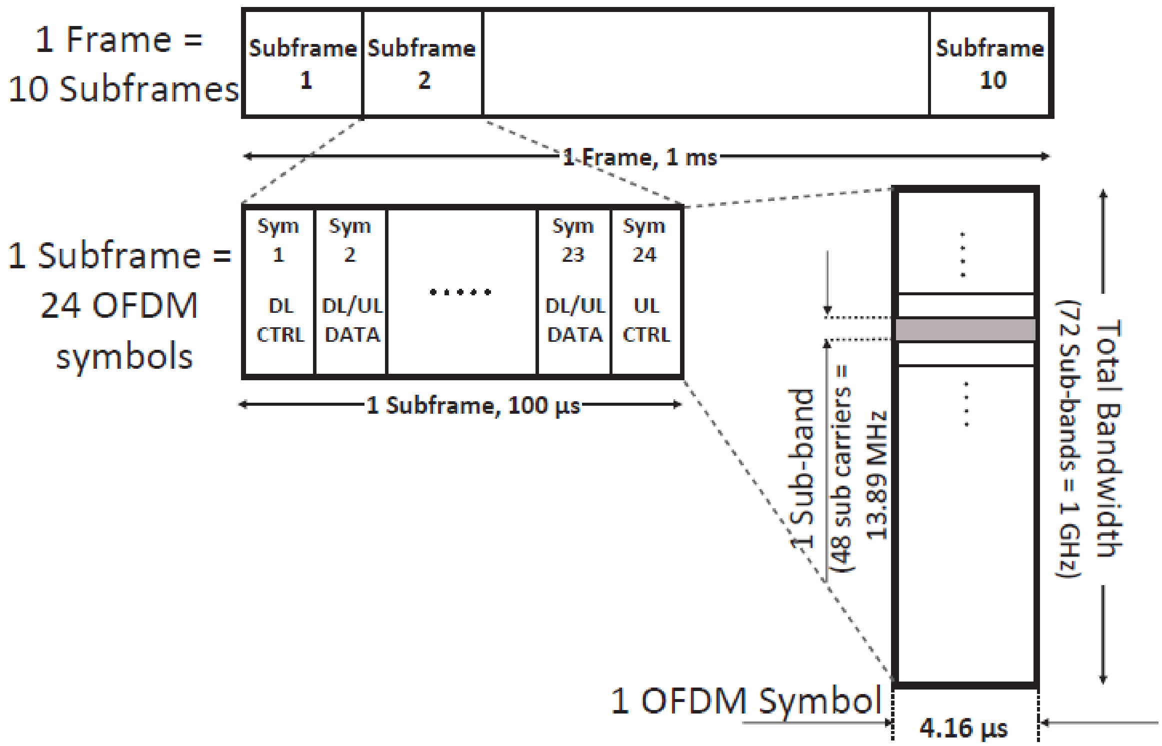

Figure 4 Proposed mmWave frame structure

Our proposed approach is depicted in Figure 4, Eachframe of length of 1 ms is split in time into 10 subframes,each of a duration 100 µs, representing 24 symbols of approximately4.16 µs in length. We have fixed DLand UL control channels in the first andlast symbol of the subframe. To change the direction from UL to DL, a switching guardperiod of one symbol is presented every time the directionchanges from UL to DL, the bandwidth of 1 GHz is separated into 72 sub-bands of width13.89 MHz, each of which is composed of 48 sub-carriers.It is possible to assign UE data to each of these sub-bands,as is done with Orthogonal Frequency-Division Multiple Access(OFDMA) in LTE, however, only TDMA operation iscurrently supported for reasons we shall explain shortly. Here mmWave module allows the user to choose betweentwo-channel models (MmWave-PropagationLossModel and MmWaveBeamforming classes). Table 2 shows the various parameters that may be used to configure the mmWave at the physical layer in the 5G cellular networks to analyze and test the higher layer protocols like TCP in 5G mmWave networks.

Table 2: Simulation Parameters required to configure the mmWave PHY

Parameter Name	Default Value	Description
SubframePerFrame	10	Number of subframes in one frame
SubframeLength	100	Length of one subframe in µs
SymbolsPerSubframe	24	Number of OFDM symbols per slot
SymbolLength	4.16	Length of one OFDM symbol in µs
NumSubbands	72	Number of sub-bands
SubbandWidth	13.89×10^6	Width of one sub-band in Hz
SubcarriersPerSubband	48	Number of subcarriers in each sub-band
CenterFreq	28×10^9	Carrier frequency in Hz
NumRefScPerSymbol	864 (25% of total)	Reference subcarriers per symbol
NumDlCtrlSymbols	1	Downlink control symbols per subframe
NumUlCtrlSymbols	1	Uplink control symbols per subframe
GuardPeriod	4.16 µs	Guard period for UL-to-DL mode switching
MacPhyDataLatency	2	Subframes between MAC scheduling request and scheduled subframe
PhyMacDataLatency	2	Subframes between TB reception at PHY and delivery to MAC
NumHarqProcesses	20	Number of HARQ processes for both DL and UL

6. FINDINGS AND CONCLUSION

As the technologies are changing and network communication and data transmission at higher speed is the main issue nowadays. In 5th Generation,wireless and mobile communication more enhancements may be possible in the area of radio interaction, radio spectrum with faster than previous versions with easily accessible and more reliable. In our research paper, we have covered the background related to the 5G cellular system. In the current cellular system, 4G LTE frequency band is below 6 GHz. In our research paper, we have suggested a mmWave module that may provide the data with high speed which is the main feature of the mmWave frequency band and spectrum (30 GHz and 300 GHz). We have also discussed a few research challenges, in which new researchers may work. In our paper, we proposed a mmWave structure to improve the End-to-End performance of the 5G cellular system at the physical layer and other higher layers, which may be relying on Ensuring the end-to-end performance of data in the 5G network.

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