VISVESWARAIAH TECHNOLOGICAL UNIVERSITY

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A TECHNICAL SEMINAR REPORT

On

“5G is Real: Evaluating the Compliance of the 3GPP 5G New Radio System With the ITU IMT-2020 Requirements”

A Dissertation Submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF ENGINEERING

In

COMPUTER SCIENCE & ENGINEERING

Submitted by

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CERTIFICATE

This is to certify that the Seminar Report titled **“5G is Real: Evaluating the Compliance of the 3GPP 5G New Radio System With the ITU IMT-2020 Requirements”** is a bona fide work carried out by **Ms. Tara Anna Mathews(1RG16CS104)** in partial fulfillment for the award of **Bachelor of Engineering** in **Computer Science and Engineering** under **Visvesvaraya Technological University, Belgavi**, during the year **2019-2020.** It is certified that all corrections/suggestions given for Internal Assessment have been incorporated in the report. This technical seminar report has been approved as it satisfies the academic requirements in respect of technical seminar (15CSS86) work prescribed for the said degree.

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DECLARATION

I hereby declare that the technical seminar report entitled **"5G is Real: Evaluating the Compliance of the 3GPP 5G New Radio System With the ITU IMT-2020 Requirements"** submitted to the **Visvesvaraya Technological University, Belagavi** during the academic year **2019-2020**, is record of an original work done by me under the guidance of **Mrs. Pragathi M,** Asst Professor, Department of Computer Science and Engineering, RGIT, Bengaluru in the partial fulfillment of requirements for the award of the degree of **Bachelor of Engineering** in **Computer Science & Engineering.** The results embodied in this technical seminar report have not been submitted to any other University or Institute for award of any degree or diploma.

Tara Anna Mathews **(1RG16CS104)**

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Tara Mathews (1RG16CS104)

ABSTRACT

The 3rd Generation Partnership Project (3GPP) submitted the 5G New Radio (NR) system specifications to International Telecommunication Union (ITU) as a candidate fifth generation (5G) mobile communication system (formally denoted as IMT-2020 systems). As part of the submission, 3GPP provided a self-evaluation for the compliance of 5G NR systems with the ITU defined IMT-2020 performance requirements. This paper considers the defined 5G use case families, Ultra Reliable Low-Latency Communication (URLLC), massive Machine Type Communication (mMTC) and enhanced Mobile Broadband (eMBB), and provides an independent evaluation of the compliance of the 3GPP 5G NR self-evaluation simulations with the IMT-2020 performance requirements for connection density, reliability, and spectral efficiency for future mobile broadband and emerging IoT applications. Independent evaluation indeed shows the compliance of the 3GPP 5G NR system with the ITU IMT- 2020 performance requirements for all parameters evaluated by simulations.

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INTRODUCTION

CHAPTER 1

INTRODUCTION

In telecommunications **5G** is the fifth generation technology standard for cellular networks, which cellular phone companies began deploying worldwide in 2019, the planned successor to the 4G networks which provide connectivity to most current cellphones .Like its predecessors, 5G networks are cellular networks, in which the service area is divided into small geographical areas called cells. All 5G wireless devices in a cell are connected to the Internet and telephone network by radio waves through a local antenna in the cell.

The main advantage of the new networks is that they will have greater bandwidth, giving faster download speeds eventually up to 10 gigabits per second(Gbps).Due to the increased bandwidth, it is expected that the new networks will not just serve cellphones like existing cellular networks, but also be used as general internet service providers for laptops and desktop computers, competing with existing ISPs such as cable internet, and also will make possible new applications in IOT and M2M areas. Current 4G cellphones will not be able to use the new networks, which will require new 5G enabled wireless devices.

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The increased speed is achieved partly by using higher frequency radio waves than current cellular networks. However higher frequency microwaves have a shorter range than the frequencies used by previous cell phone towers, requiring smaller cells. So to ensure wide service, 5G networks operate on up to three frequency bands, low, medium, and high.A 5G network will be composed of networks of up to 3 different types of cell, each requiring different antennas, each type giving a different tradeoff of download speed vs distance and service area.

5G cellphones and wireless devices will connect to the network through the highest speed antenna within range at their location:Low-band 5G uses a similar frequency range as current 4G cellphones, 600 – 700 MHz giving download speeds a little higher than 4G: 30-250 megabits per second Mbps).Low-band cell towers will have a similar range and coverage area to current 4G towers. Mid-band 5G uses microwaves of 2.5-3.7 GHz currently allowing speeds of 100-900 Mbps, with each cell tower providing service up to several miles radius.

This level of service is the most widely deployed, and should be available in most metropolitan areas in 2020. Some countries are not implementing low-band, making this the minimum service level. High-band 5G uses frequencies of 25 – 39 GHz, near the bottom of the millimeter wave band, to achieve download speeds of 1 – 3 gigabits per seconds (Gbps), comparable to cable internet. However millimeter waves(mmWave or mmW) only have a range of about 1 mile (1.6 km), requiring many small cells, and have trouble passing through some types of building walls. Due to their higher costs, current plans are to deploy these cells only in dense urban environments, and areas where crowds of people congregate such as sports stadiums and convention centers.

The above speeds are those achieved in actual tests in 2020, speeds are expected to increase during rollout. The industry consortium setting standards for 5G is the 3rd Generation Partnership Program(3GPP).It defines any system using 5G NR(5G New Radio) software as "5G", a definition that came into general use by late 2018. Minimum standards are set by the International Telecommunications Unit(ITU). Previously, some reserved the term 5G for systems that deliver download speeds of 20 Gbps as specified in the ITU's IMT 2020 document.

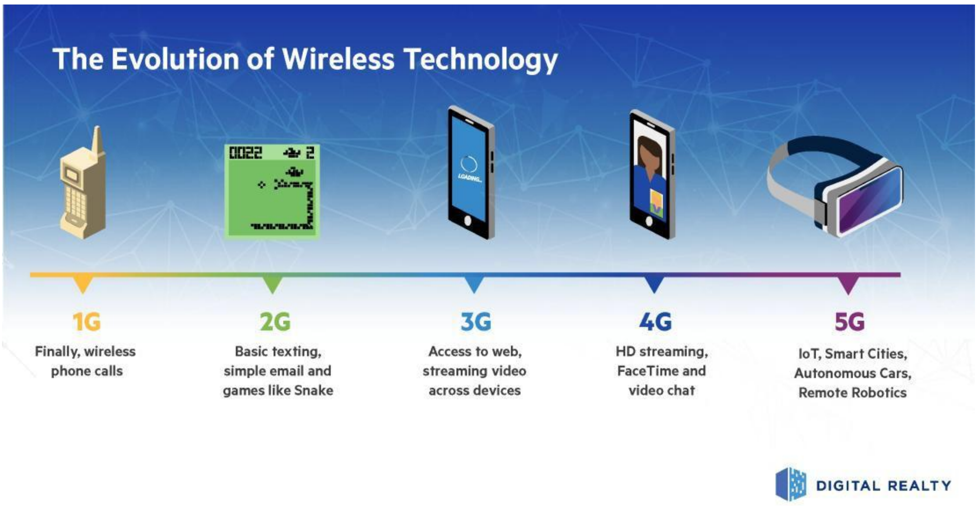

Fig 1: Evolution of Wireless Technology

The world’s connectivity needs are changing. Global mobile data traffic is expected to multiply by 5 before the end of 2024. Particularly in dense urban areas, the current 4G networks simply won’t be able to keep up.That’s where a new G comes into play. With 5G commercial networks being switched on, the first use cases are enhanced mobile broadband, which will bring better experiences for smartphone users, and fixed wireless access, providing fiber speeds without fiber to homes. 5G smartphones will be available in beginning of 2019.Being able to download a full-length HD movie in seconds . The true value of 5G is the opportunity it presents for people, business and the world at large: industries, regions, towns and cities that are more connected, smarter and more sustainable.

It’s allowing industries to reinvent themselves. It affects you. And it’s starting now.

First, let’s recap how we got here.

- 1G: Mobile voice calls
- 2G: Mobile voice calls and SMS
- 3G: Mobile web browsing
- 4G: Mobile video consumption and higher data
speed
- 5G: Technology to serve consumers and digitalization of industries.

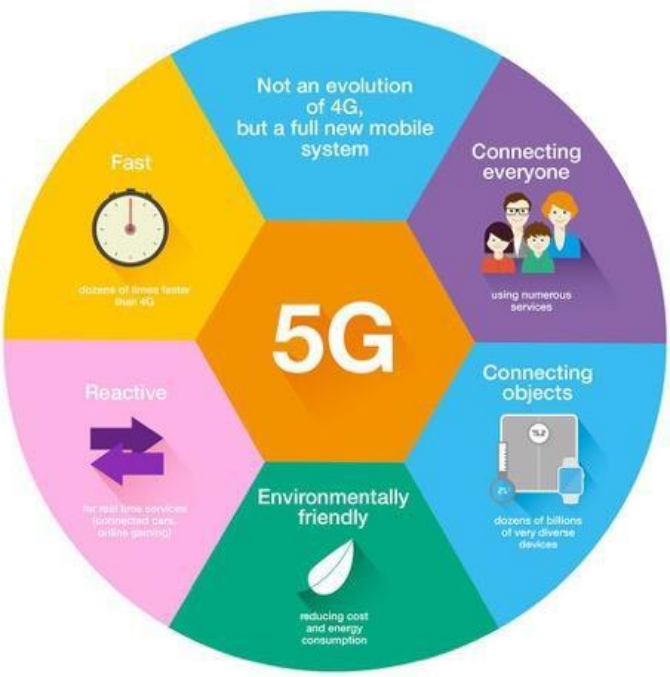

Fig 1.2 : Why 5G is advantageous

5G will improve network connections dramatically. Disruptions when sharing videos from crowded arenas, nor will high-quality videos on your news feed cause frustration from all the buffering will be a thing of the past. Instead, you'll get a faster, more stable, more secure connection – along with new services and experiences, just around the corner.More efficient capabilities and vastly increased capacity means you'll enjoy better performance than ever before.

Data rates-100 times faster, supporting instant access to services and applications.
Network latency-significantly reduced to 1-10ms.
Network slicing-technology, making it possible to dedicate a unique part of a 5G network for a service.

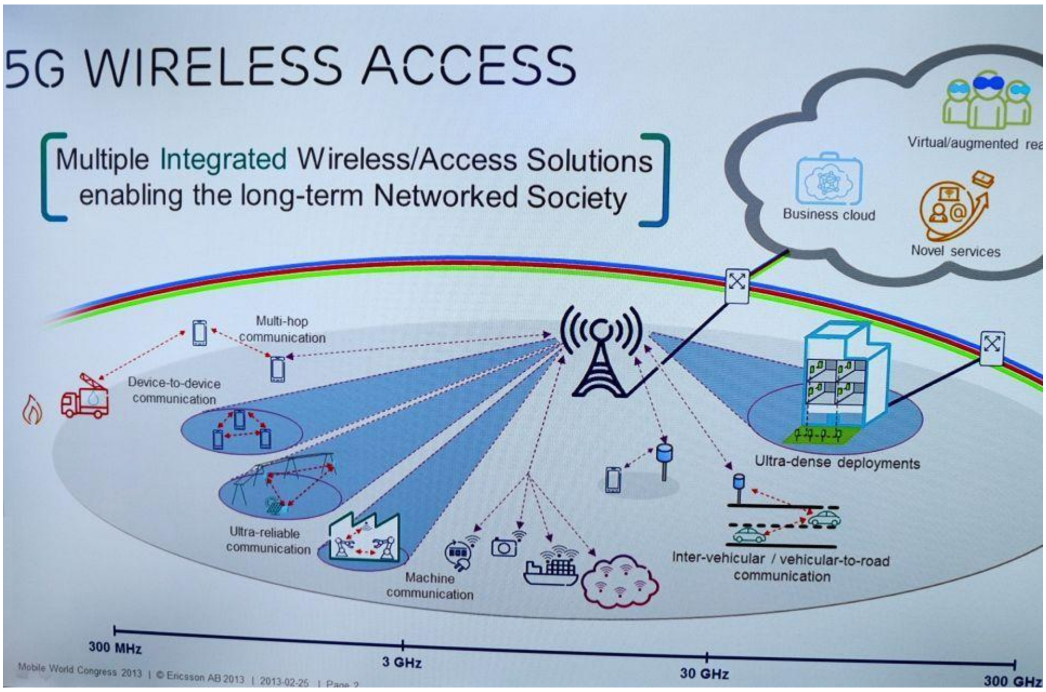

Fig 1.3: 5G Wireless access

There are several advantages of 5G technology, some of the advantages have been shown in the above image, and many others are described below −

- High resolution and bi-directional large bandwidth shaping.
- Technology to gather all networks on one platform.

- More effective and efficient.
- Technology to facilitate subscriber supervision tools for the quick action.
- Most likely, will provide a huge broadcasting data (in Gigabit), which will support more than 60,000 connections.
- Easily manageable with the previous generations.
- Technological sound to support heterogeneous services (including private network).
- Possible to provide uniform, uninterrupted, and consistent connectivity across the world.

Mobile communication applications have shifted from basic voice telephony to empowering a wide range of verticals across various industries, most notably via the rapidly expanding Internet of Things (IoT) applications,and are expected to continue to grow, occupy an integral part of our lives and ultimately transform societies as a whole.

While the fourth generation of mobile communication systems, formally referred to as International Mobile Telecommunications-Advance (IMT-Advanced) systems, provided a versatile platform for enabling a wide range of Mobile Broadband applications (and, to a certain extent, Low Power Wireless Internet of Things (IoT)applications), the increasing potential for disruptive IoT applications with very high deployment densities (millions of devices in a relatively small areas) was one of the main motivators for the development of the next generation of mobile communication systems, the International Mobile Telecommunications-2020 (IMT-2020) commonly referred to as 5G – the fifth generation of mobile communication systems.

The other motivators were increasing demand for enhanced mobile broadband services and the vast potential for mobile communications providing ultra-low latency and ultra-high reliability for higher frequencies .Candidate IMT-2020 systems are undergoing a rigorous evaluation process to ensure they fulfill the requirements set out by the International Telecommunication Union (ITU) for IMT-2020 systems, illustrated in Fig.1, to meet the performance requirements of emerging 5G applications, commonly grouped into enhanced Mobile Broadband (eMBB), Ultra Reliable Low-Latency Communications

(URLLC) and massive Machine Type Communications (mMTC) .The prime IMT-2020 candidate system, the 5G New Radio (NR) system developed by the 3 rd Generation Partnership Project (3GPP), promises to fulfill the IMT-2020 system requirements set out by the ITU as detailed in the 3GPP self-evaluation submission .

Nevertheless, it is of utmost importance to independently verify the validity of the 3GPP submission prior to officially declaring the 5G NR system as an IMT-2020 compliant system.This paper focuses on assessing the performance of the 3GPP 5G NR system for applications in the areas of massive Machine Type Communications (mMTC), Ultra-Reliable Low-Latency Communications (URLLC) and enhanced Mobile Broadband (eMBB), which are expected to play an integral role in future Internet of Things (IoT) applications, with focus on key parameters evaluated by system simulations to providing an independent evaluation to the compliance of the 3GPP submitted 5G NR self evaluation simulations via a custom simulator, which considered numerous academic and industrial simulations and compares the results of 3GPP developed simulations by companies such as Huawei, Ericsson, Intel and NTT Docomo among others. Some of these applications include, but are not limited to: smart wearables, health monitors, autonomous driving, and remote computing .

The contributions of this work are as follows:

(i) a detailed system-level simulator for evaluating 5G candidate systems and

(ii) an evaluation of the simulator performance in achieving 5G requirements for IMT-2020 in comparison with other industrial simulators for multiple test environments. The rest of this paper is as follows. Overviews of IMT-2020 system requirements, evaluation processes and scenarios are in Chapter 2. The system structure for performance evaluation and additional features are detailed in Chapter 3. Chapter 4 discusses the system setup and methodology for simulation and the simulation results are detailed in Chapter 5. Chapter 6 concludes the paper and the appendix details tables providing requirements and results for each assessment as well as the results.

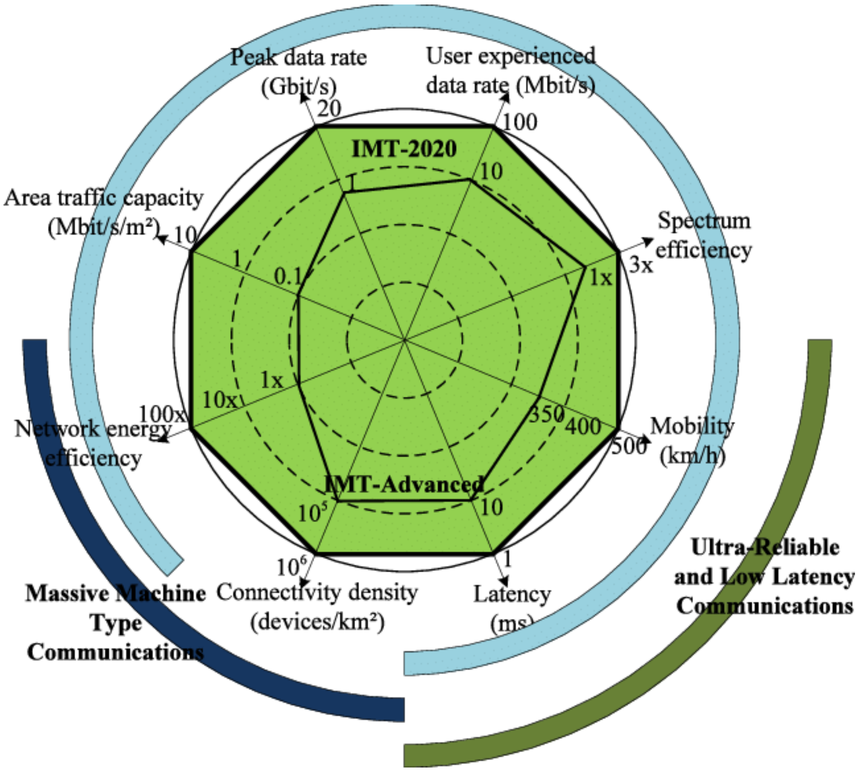

Fig 1.3: IMT 2020 Performance Requirements

SYSTEM REQUIREMENTS

CHAPTER 2

SYSTEM REQUIREMENTS

A. EVALUATION GUIDELINES

The simulator acts as an evaluation tool for the submitted 3GPP proposal as per the specified evaluation methodology and configurations in the 3GPP report. System-level and link-level simulations are performed using our simulation tool to provide an independent evaluation of the 3GPP self-evaluation, which provides a complete compliance documentation for several technologies with the minimum IMT-2020 performance requirements.

B. TEST ENVIRONMENTS

Five specific test environments are defined for evaluating compliance with the performance requirements of IMT-2020 systems: Indoor hotspot-eMBB, Dense Urban-eMBB, Rural-eMBB, Urban Macro-mMTC, and Urban Macro-URLLC. Simulation of all test environments (with the exception of Indoor Hotspot-eMBB) uses a wrap-around configuration of 19 sites as shown in figures 2 – 4, each of 3TRxPs (cells) creating a hexagonal layout. Antenna element distribution, cell range, and inter-site distance (ISD) is considered for geometry. The indoor hotspot scenario models a 120m x 50 m building floor with 12 Base stations placed 20 meters apart as per Figure 3. The Dense urban area consists of a macro layer following a 3-TRxP hexagonal layout, and a micro layer with 3 micro-sites randomly dropped in each TRxP area a number of user equipment (UE) distributed in the area. The rural eMBB test environment follows the macro layer of the dense urban area. A high-speed test environment is shown in figure 4 for mobility scenarios of UEs moving at 30 km/h, 120 km/h, and 500 km/h.

C. EVALUATION CRITERIA

For evaluating system performance using simulations, the following key parameters are taken into consideration:

1) SPECTRAL EFFICIENCY

The average spectral efficiency is obtained by running system-level simulations over a number of drops for each of the following three test environments: Indoor Hotspot-eMBB, Dense Urban-eMBB, and Rural-eMBB. Each drop is a sum of correctly received bits by all users over time as per the following equation.

2) CONNECTION DENSITY

The connection density is the total number of devices fulfilling a specific quality of service (QoS) per unit area (per km 2)where N mux is the average number of multiplexed users for a given SINR i , ISD is the Inter-site distance, and B i is as The requirement is fulfilled if the 99 th percentile of delay per user is less than or equal to 10 seconds and the system achieves a connection density of at least one million devices per square kilometer, evaluated for the Urban Macro scenario.

3) RELIABILITY

Reliability is defined as the success probability (1- P e) in which P e is the residual packet error ratio within maximum delay time as a function of SINR taking retransmission into account. The minimum requirement for the reliability is 1-10 −5 success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (such as 20 bytes application data + protocol overhead). The requirement is fulfilled via downlink/uplink and LOS/NLOS as per Tables 3 and 4.

4) MOBILITY

Mobility is the maximum mobile station speed at which a defined QoS can be achieved (in km/h). The successful evaluation of mobility is to fulfill the threshold values for the packet error ratio and spectral efficiency for a mobility of 120km/h and 500 km/h. Table 5 defines the mobility classes that are to be supported in the respective test environments. A mobility class is supported if the traffic channel link data rate on the uplink, normalized by bandwidth, meets the criteria specified in Tables 5 and 6.

5) USER-EXPERIENCED DATA RATE

User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. The target values for the UE data rate are 100MBits/s for downlink and 50MBits/s for the uplink user experienced data rate.

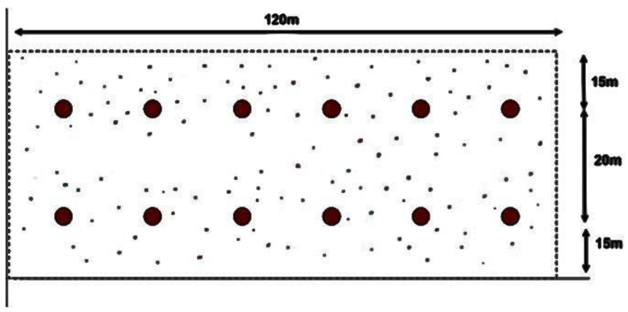

Fig 2.1: Indoor scenario with 12 access points and distributed

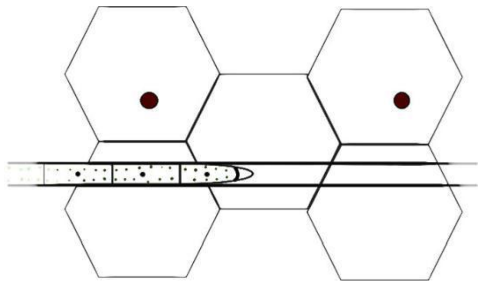

Fig2.2:High speed mobility scenario (large circles are base)

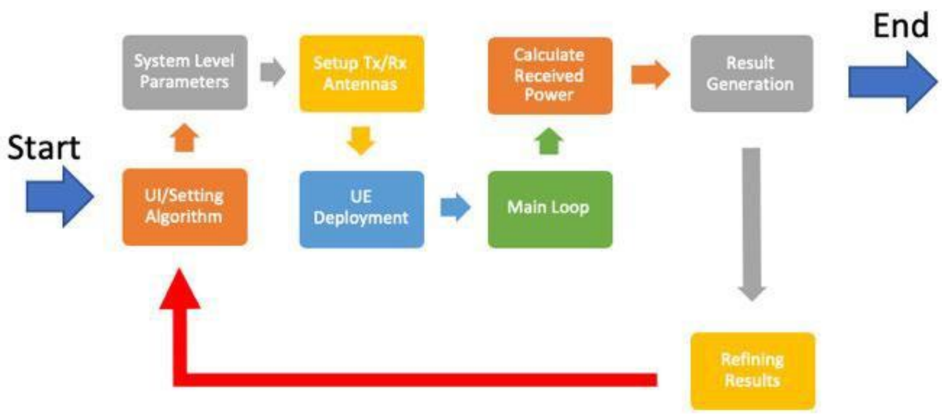

Fig2.3:Modular Structure of the simulator

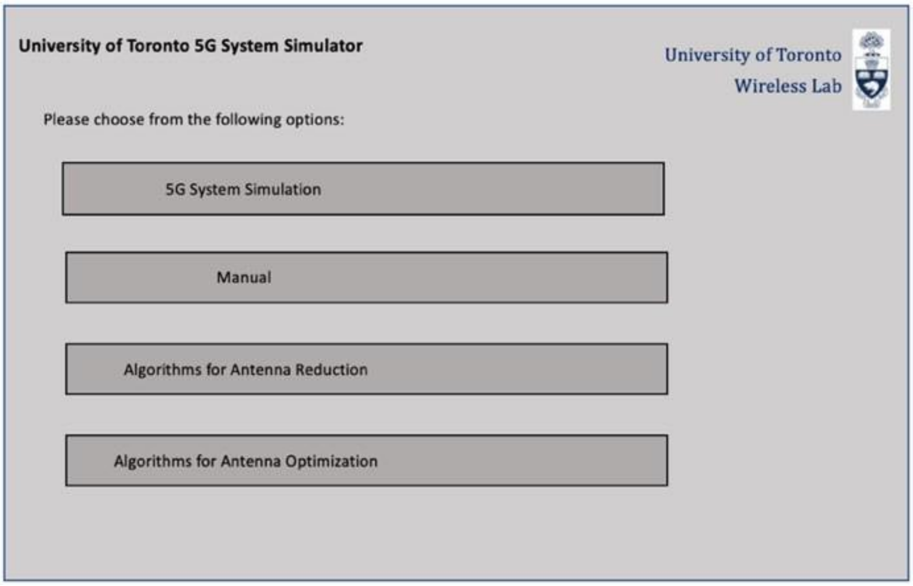

Fig 2.4 : Simulator User Interface with Mode Options

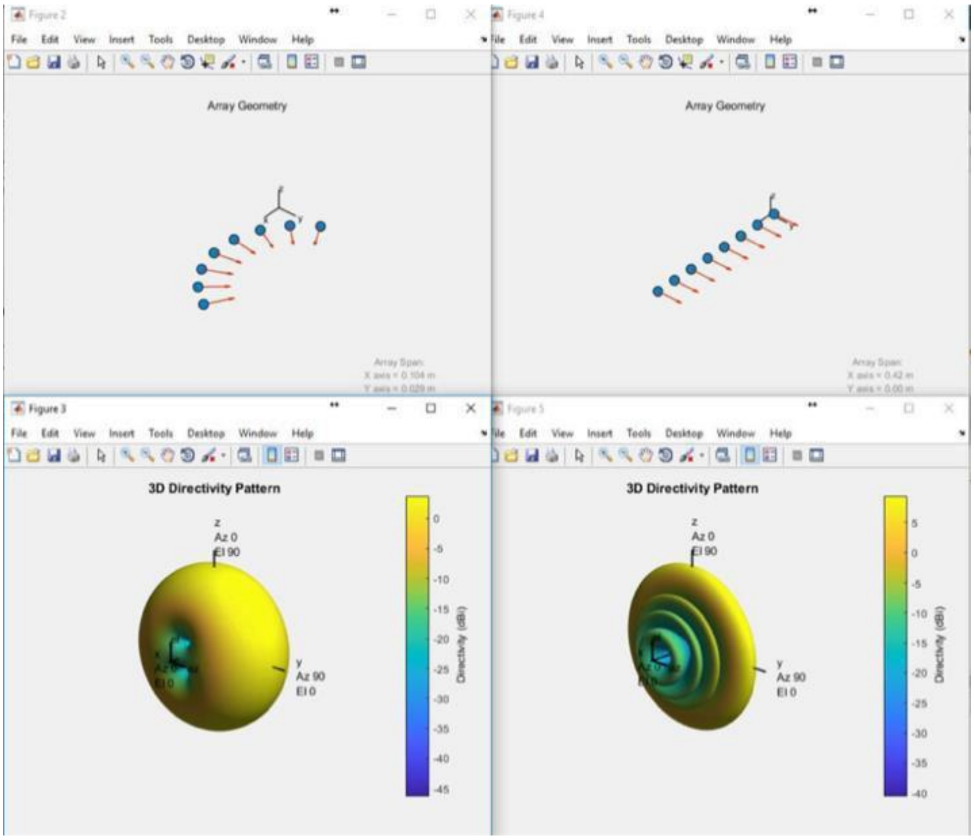

Fig 2.5: Antenna Gain and Directivity Calculation via Simulation

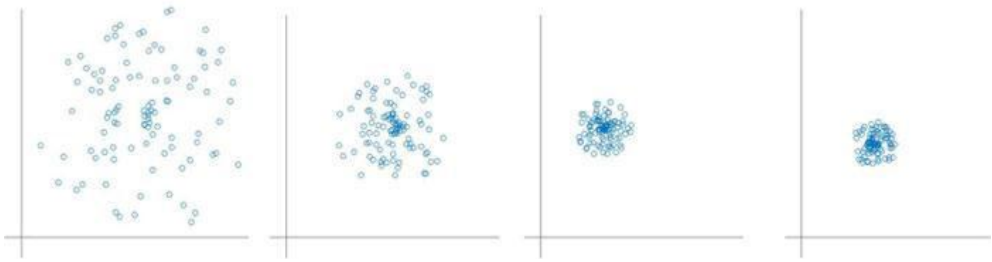

Fig 2.6: Convergence of SINR Averages for URLLC Calculation for, 100 drops, 5000 drops, and 10,000 drops(left to right)

SIMULATION FEATURES

CHAPTER 3

SIMULATION FEATURES

In this section, a description of our system level simulator structure and methodology are introduced for evaluating the requirements. Simulations are performed to evaluate each requirement independently with the exception of the joint evaluation of 5 th percentile user spectral efficiency and the average spectral efficiency as simulations are performed to simultaneously evaluate them. The simulator structure is entirely modular as shown in Figure 5 and supports multi-link transmissions. A spatial geometry application is integrated for single and multiple antenna configurations to obtain results. A Graphical User Interface (GUI) allows users to choose whether to set variables manually, choose from a predetermined test scenario,or optimize the placement of antenna elements by choosing an algorithm as per figure 6.Using the GUI, values are assigned to parameters as per the user choice in the previous stage. Once again, value assignment can be predetermined or set manually.

The number of drops and time durations set the complexity level for the loop in the next stage. Each time iteration, and once all parameters are defined, transmitters and receivers are deployed in two-dimensional or three-dimensional modes depending on the desired degree of complexity. Finally, the transmit/receive antenna configurations and antenna element patterns are defined. Figure 7 shows an example of choice of parameters. Simulations are then performed for all drops in which the SINR and performance is computed. Once the parameters are initialized, the system then loops the desired configuration scenarios.

The inner loop calculates the performance for each transmit/receive antenna element pair, adding the following into consideration: interference, path loss, antenna gain (shown in figure 8), and antenna beam steering properties. This is enclosed within another loop that combines the received signals between antennas for the time duration indicated during the input stage as maximum ratio combining or proportional fair scheduling. The third outer loop is to repeat the inner two loops for each user normally distributed around the environment space (either two or three-dimensional).

The fourth outer loop repeats the simulation for the indicated number of drops for the results in section V, with an average of 10,000 drops are used. The Result Generation stage provides performance assessments, tables, and cumulative distribution functions of the SINR for considered test environments. The process is repeated until the iteration results converge as shown in figure 9.

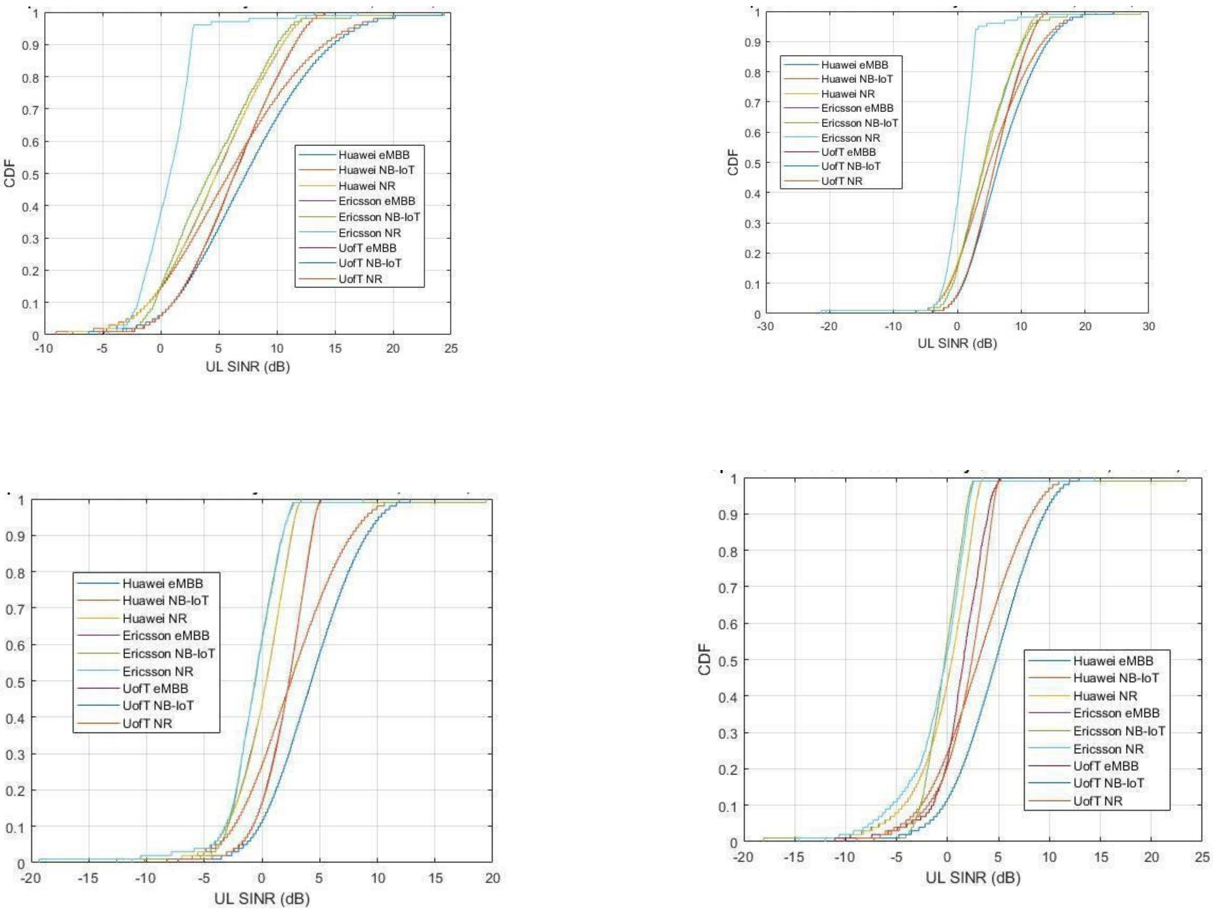

Fig 3.1: CDF of Uplink SINR, Connection Density, Dense Urban Test Scenario for Model A 500 m- Model B 1732 m- Model A 500 m – Model B 1732 m (top to bottom)

SYSTEM SETUP AND SIMULATION METHODOLOGY

CHAPTER 4

SYSTEM SETUP AND SIMULATION METHODOLOGY

For the system-level simulation, user equipment (UE) are dropped independently over a predefined area of the network layout throughout the system and are modeled according to their respective traffic model. Each UE is randomly assigned LOS/NLOS channel conditions according to the channel model.

Cell assignment to a UE is based on the cell selection scheme with applicable distances between UE and a base station depend on the proposed scenario. Signal fading and interference from each transmitter to each receiver is aggregated; interference over thermal parameter is taken into account as an uplink design constraint with an average interference of less than 10 dB. For full buffers, infinite queue depths are assumed.

Channel quality, feedback delay,feedback errors, protocol data unit error which are inclusive of channel estimation error are modeled and packets are retransmitted according to the packet scheduler. For every drop, the simulation is run and repeated with UEs dropped at new random locations.

10,000 drops are performed for each simulation to ensure convergence in the system performance metrics of corresponding mean values. Finally, error modeling for channel estimation, phase noise, and control channels to decode the traffic channel is included.

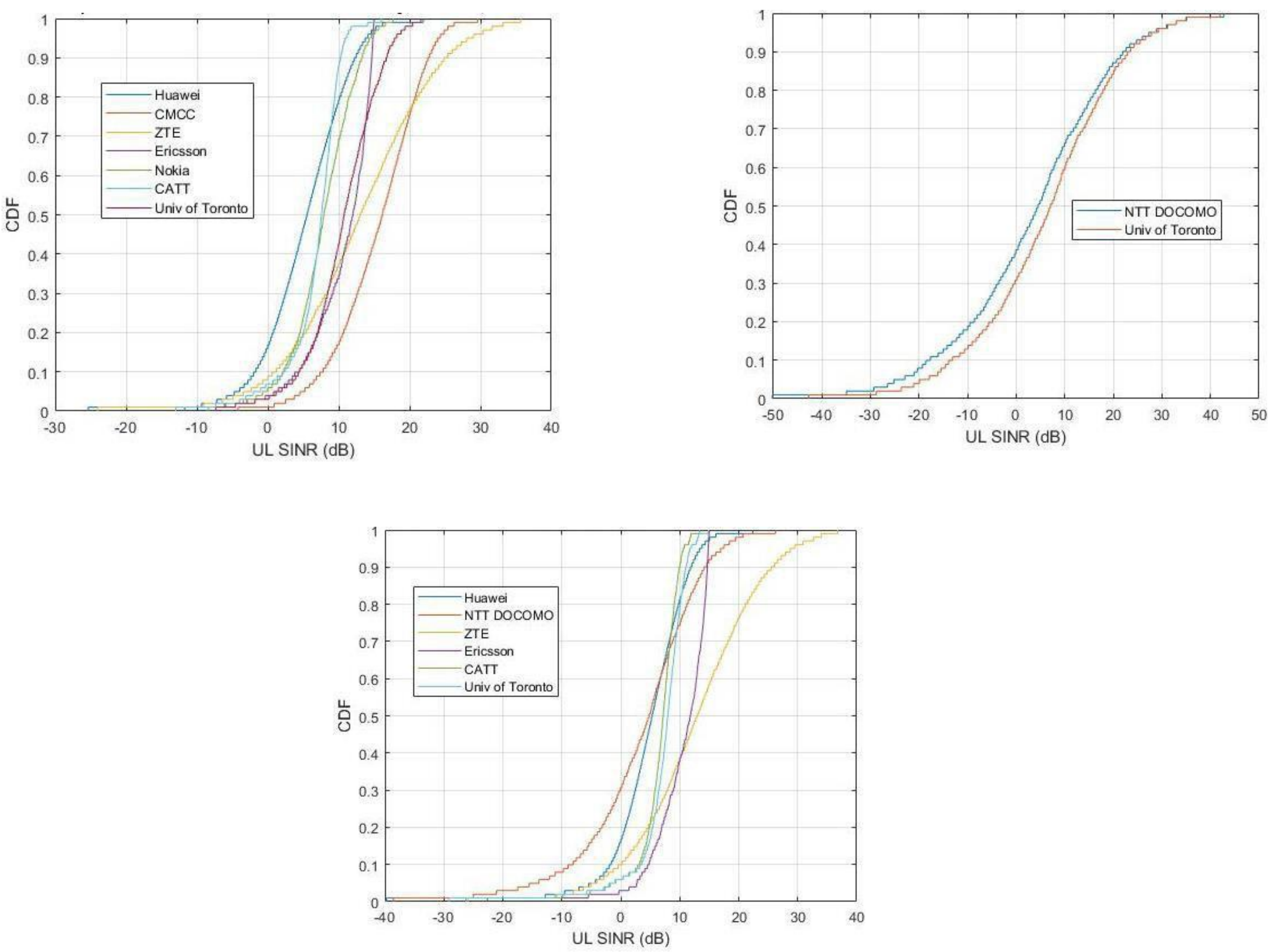

Fig 4.1 : CDF of Uplink SINR, Mobility, Dense Urban Test Scenario at 4 GHz for a 4 GHz Model A- 4 GHz Model B- 30 GHz Model A/B (top to bottom)

SIMULATION RESULTS

CHAPTER 5

SIMULATIONS RESULTS

Based on the test environments and performance requirements outlined in Chapter II, simulations are performed using t he simulator and methodology described in Chapters III and IV. The tables and figures provided in this section detail the simulation results for the 3GPP 5G NR system and compare them to the ITU IMT -2020 requirements. The results indeed show the compliance of the 3GPP 5G NR system with the ITU IMT-2020 performance requirements for a ll parameters evaluated by simulations

A. CONNECTION DENSITY SIMULATION RESULTS

Taking into account layers 1 and 2 overhead information provided by the proponents, the connection density requirement is fullfilled if it is greater than t he ITU report in . These four tables compare full - buffer and non full- buffer modes, scenarios A and B, and base-station inter- sit e distances of 1732 m and 500 m for system- level simulations between the University of Toronto, Huawei, and Ericsson simulators. The tables show that full- buffer outperforms non full- buffer for NB-Io T, mMTC, and NR technologies, and are compliant with ITU requirements

B. CONNECTION DENSITY CDF

In addition to the connection density values, figure 10 displays the cumulative distribution function of the aforementioned technologies in t he previous section and the higher -then- average uplink SINR of the University of Toronto simulator compared to other industry s imulators.

C. RELIABILITY SIMULATION RESULTS

Ultra- high reliability and good resilience capability are needed to achieve the reliability requirement for ensuring the 5 th percentile downlink or uplink value within t he required delay obtains a success probability equal to or higher than the required s uccess probabilit y. both display the Uplink SINR for a 4 GHz spectrum and reliability results for 700MHz/4GHz respectively for 5 -7 evaluators, and our simulator hence achieves the reliability requirements(>99. 999%) as well as exceeding all testing scenario s and antenna configurations.

. D. SPECTRAL EFFICIENCY

Enhanced spectral efficiency results are included for Indoor hotspot, dense urban, and rural evaluation scenarios for different TRxP and simulation bandwidths. Using the evaluation configuration para meters, the results show the data conforms with reference values and industry evaluators

E. MOBILITY

5G systems support low to high mobility applications and much enhanced data rates in accordance with user and service demands in multiple user environments. Ehibit the uplink SINR and the normalized channel link data rate for NLOS/ LOS conditions under various spectrum bandwidths.

F. UE DATA RATE

Coupled with NR usage scenario, illustrates the data rate for different antenna configurations for uplink and downlink, showing multi- band macro layer data rates are greater than that of the single - band macro layer, hence fulfilling the Data Rate requirement of 100 Mbit/ s (downlink)and 50 Mbits/ s (uplink).

URLLC Simulator Algorithm

```
Loop over number of drops:
   Distribute users over environment
   Loop over users:
         1-Set environment, network layout, and
         antenna array parameters
         2-Assign propagation condition (LOS/NLOS)
         3-Calculate pathloss
         4-Generate large scale parameters
         5-Generate delays
         6-Generate cluster powers
         7-Generate arrival angles and departure
         angles for both azimuth and elevation
         8-Couple of rays within a cluster for both
         azimuth and elevation
         9-Generate the cross polarization power
         ratios
         10-Draw initial random phases
         11-Generate channel coefficients
         12-Apply pathloss and shadowing
Calculate Reliability and SINR
```

Fig 5.1: Procedure algorithm for evaluating reliability for URLLC scenarios.

mMTC Simulation Algorithm:

```
Loop over number of drops:
   Distribute users over environment
   Loop over users:
         1-Set environment, network layout, and
         antenna array parameters
         2-Assign propagation condition (LOS/NLOS)
         3-Calculate pathloss
         4-Generate large scale parameters
         5-Generate delays
         6-Generate cluster powers
         7-Generate arrival angles and departure
         angles for both azimuth and elevation
         8-Couple of rays within a cluster for both
         azimuth and elevation
         9-Generate the cross polarization power
         ratios
         10-Draw initial random phases
         11-Generate channel coefficients
         12-Apply pathloss and shadowing
Calculate Connection Density and SINR
```

Fig 5.2:Procedure algorithm for evaluating Connection Density for mMTC scenarios.

CONCLUSION

CONCLUSION

This paper utilized an independent simulator to assess the compliance of the 3GPP submitted 5G NR self-evaluation simulations with the ITU IMT-2020 performance requirements. The results indeed confirm the compliance of the 3GPP 5G system with the ITU connection density, reliability, and mobility requirements to support the anticipated 5G applications and use cases. Building on this work,additional simulations can be performed for a wide range of frequency ranges and system configurations (rural, highway,etc.) to determine performance gaps and potential areas for improvement for the 3GPP 5G NR system.

REFERENCES

REFERENCES

[1] Next Generation Mobile Networks, Alliance, NGMN 5G White Paper, Frankfurt, Germany, 2015.

[2] IMT for 2020 and Beyond, document IMT-2020/1-E, ITU-R, Jun. 2016.

[3] Guidelines for Evaluation of Radio Interface Technologies for IMT-2020,document IMT-2020/2, ITU-R, Feb. 2017.

[4] Workshop on IMT-2020 Terrestrial Radio Interfaces, document 5/40-E,ITU-R, Oct. 2017.

[5] Requirements, Evaluation Criteria and Submission Templates for the Development of IMT-2020, document 5/57-E, ITU-R, Oct. 2017.

[6] (Sep. 2018). NR: UE Radio Transmission and Reception (Rel-15).[Online]. Available: http://www.3gpp.org/ftp/Specs/archive/38_series/38.101-1/

[7] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network NR Base Station (BS) Radio Transmission and Reception,document 3GPP TS 38.104, 2018.

[8] 5G; NR; Multiplexing and Channel Coding, document ETSI TS 138 212 V15.2.0, Sep. 2018.

[9] NR—Physical Layer Measurements—Release 15, document TS 38.215,2018.

[10] Study on NR vehicle-to-everything (V2X), document TR 38.885, 3GPP,2018.

[11] Guidelines for Evaluation of Radio Interface Technologies for IMT-2020,document ITU-R M.2412-0, Oct. 2017.

[12] S. Mumtaz, A. Alsohaily, Z. Pang, A. Rayes, K. F. Tsang, and J. Rodriguez, ‘‘Massive Internet of Things for industrial applications:Addressing wireless IIoT connectivity challenges and ecosystem fragmentation,’’ IEEE Ind. Electron. Mag., vol. 11, no. 1, pp. 28–33,Mar. 2017.

[13] A. Alsohaily, E. Sousa, A. J. Tenenbaum, and I. Maljevic, ‘‘LoRaWAN radio interface analysis for north american frequency band operation,’’ in Proc. IEEE 28th

Annu. Int. Symp. Pers., Indoor, Mobile Radio Commun. (PIMRC), Oct. 2017, pp. 1–6.

[14] C.-K. Jao, C.-Y. Wang, T.-Y. Yeh, C.-C. Tsai, L.-C. Lo, J.-H. Chen,W.-C. Pao, and W.-H. Sheen, ‘‘WiSE: A system-level simulator for 5G mobile networks,’’ IEEE Wireless Commun., vol. 25, no. 2, pp. 4–7,Apr. 2018.

[15] X. Meng, J. Li, D. Zhou, and D. Yang, ‘‘5G technology requirements and related test environments for evaluation,’’ China Commun., vol. 13, no. 2,pp. 42–51, 2016.

[16] Y. Wang, J. Xu, and L. Jiang, ‘‘Challenges of system-level simulations and performance evaluation for 5G wireless networks,’’ IEEE Access, vol. 2,pp. 1553–1561, 2014.

[17] C.-P. Li, J. Jiang, W. Chen, T. Ji, and J. Smee, ‘‘5G ultra-reliable and low-latency systems design,’’ in Proc. Eur. Conf. Netw. Commun. (EuCNC),Jun. 2017, pp. 1–5.

[18] Y. Kim, J. Bae, J. Lim, E. Park, J. Baek, S. I. Han, C. Chu, and Y. Han,‘‘5G K-simulator: 5G system simulator for performance evaluation,’’ in Proc. IEEE Int. Symp. Dyn. Spectr. Access Netw. (DySPAN), Oct. 2018,pp. 1–2.

[19] S. Pratschner, B. Tahir, L. Marijanovic, M. Mussbah, K. Kirev, R. Nissel,S. Schwarz, and M. Rupp, ‘‘Versatile mobile communications simulation:The Vienna 5G link level simulator,’’ EURASIP J. Wireless Commun.Netw., vol. 2018, no. 1, p. 226, Sep. 2018.

[20] A. Karimi, K. I. Pedersen, N. H. Mahmood, J. Steiner, and P. Mogensen,‘‘5G centralized multi-cell scheduling for URLLC: Algorithms and system-level performance,’’ IEEE Access, vol. 6, pp. 72253–72262, 2018.

[21] M. Mezzavilla, M. Zhang, M. Polese, R. Ford, S. Dutta, S. Rangan, and M. Zorzi, ‘‘End-to-end simulation of 5G mmWave networks,’’ IEEE Commun. Surveys Tuts., vol. 20, no. 3, pp. 2237–2263, 3rd Quart., 2018.

[22] Requirements, Evaluation Criteria and Submission Templates for the Development of IMT-2020, document ITU-R M.2411-0, Nov. 2017.

[23] Minimum Requirements Related to Technical Performance for IMT-2020 Radio Interface(s), document ITU-R M.2410-0, Nov. 2017.

[24] Technical feasibility of IMT in bands above 6 GHz, document ITU-RM.2376-0,

jul. 2015.

[25] The Use of the Terrestrial Component of International Mobile Telecommunications for Narrowband and Broadband Machinetype Communications,document ITU-R M.2440-0, Oct. 2018.