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| Chalmers University of Technology |
| Research Logbook |
| 5G New Radio Research Topic |

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| **Olalekan Peter Adare, Haitham Babbili**  . |

**Supervisor**

Professor Tommy Svensson

**Broad Research Paper Topic**

5G New Radio

**Preliminary Title**

5G New Radio (NR): Next Generation Radio Access Technology

**Final Research Paper Title:**

5G New Radio: Next Generation Radio Access Network

**Background**

This is a research work in partial fulfillment of the requirements for completing the Wireless Network Course, SSY145. The project is built on 5G New Radio (NR) solution, as an innovation in Wireless Access Networks. This is to acquire the needed knowledge of the 5G network, and other related specifications around it.

**Main Objective**

This research will investigate the uniqueness of the 5G network as regards the New Radio (NR) solution. It will be compared with the older and existing mobile access technologies, to further buttress on the dividends of this technology. It will also point out its various unique features, key performance indices, and applications, as a huge improvement to the telecommunication work space.

**Task Description (Team)**

* Management of project page on overleaf: Haitham
* Initial reference List: Peter
* Updated reference list: Peter and Haitham
* Communication with the supervisor: Peter
* Initial draft: Peter and Haitham
* Proof reading: Haitham and Peter
* Submissions: Haitham & Peter
* Final write-up: Peter and Haitham
* Defense slides preparation: Haitham (presentation design and sections) and Peter (5G NR diagram and edit)
* Mini-conference trial presentations on zoom: Haitham and Peter
* Logbook management: Peter

**Meetings**

The meeting sessions were either on Facebook call, WhatsApp call or zoom video.

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| **Date** | **Progress since last meeting** | **Materials/sub-sections updated** | **Agreed Tasks for next meeting** | **Comments/Feedbacks** | **Duration of meeting** |
| 29th March 2020 | - | Reference materials and discussion on fore-knowledge of mobile communications | References, extensive self-study on 5G NR, Planning report | The planning report should contain a detailed time chart. What is the approach? | 1 hour |
| 30th March 2020 | Introduction to the planning report, sub-sections and time chart approach | Initial Introduction for planning report | Finish the planning report  (Peter) | Deadline for the planning report must not be missed. | 30 minutes |
| 1st April 2020 | Review of the planning report on overleaf | Final Planning report | Finish the planning report (Haitham & Peter) | Submission of the planning report | 1 hour |
| 2nd April 2020 | Review of the scope | Initial draft | Start writing the draft (Haitham & Peter) | Start writing the draft | 30 minutes |
| 8th April 2020 | 5G Architecture, Review of the Radio Access Network of 1G, 2G,3G and 4G | Initial draft/Sketch, just for the group’s review | More references and findings (Peter) | Initial draft was inadequate as a couple of sub-sections were incomplete. | 1 hour |
| 15th April 2020 | NR Standardization and frequency spectrum | Sub-section: NR design, standardization | Self-study based on reference materials | Further discussion on NR frame structure, design and NSA/SA deployment | 1 hour |
| 22nd April 2020 | Discussion on SDN/NFV | Outline of the final report in the progress report | Write another introduction to 5G NR (Haitham) | Deadline for the progress report must not be missed. | 2 hours |
| 24th April 2020 | Building up on the progress report on overleaf | Outline of the final report in the progress report | Build on the findings and feedback from the progress report | Submission of progress report | 2 hours |
| 29th April 2020 | 5G NR: eMMB, mMTC and URLLC aspects | Outline of the final draft | Keep working on the draft | More information is needed for URLLC part | 1 hour |
| 3rd May 2020 | 5G Network Deployment and Roll-out  5G NR Service Interfaces  5G Forward/Backward Compatibility | Addition of Abstract and conclusion. Overall proof reading | Keep working on the draft (Peter) | Include abstract and conclusion in the draft and submit so there can be an overall review | 2 hours |
| 4th May 2020 | Draft is ready for submission | Addition of Abstract and conclusion. Overall proof reading | Build-up towards final report based on the feedbacks (Haitham & Peter) | Submission of full first draft to Prof. Kathryn Strong Hansen for review. Also share with the other selected group | 1 hour |
| 6th May 2020 | Prepared Q&A with Prof. Kathryn Strong Hansen | Build on suggestions from Prof. Kathryn Strong Hansen | Review and effect corrections | Effect all necessary corrections | 1 hour |
| 13th May 2020 | Prepared Q&A with Prof. Tommy Svensson | Details to discuss with Prof. Tommy Svensson | Identify the missing details from the progress report | Effect all necessary corrections | 45 minutes |
| 14th May 2020 | Prepared Q&A with Prof. Tommy Svensson | Details to discuss with Prof. Tommy Svensson | Re-write some aspects of the report | Updated scope and outline | 1-hour meeting with Tommy.  1hour group meeting |
| 16th May 2020 | Some corrections have been made on the earlier full draft | Discussion more on eMBB, mMTC and URLLC | Re-write some aspects of the report, and make corrections to a few parts. | The final report is almost ready. Proof-reading, corrections and proper referencing is still needed | 3 hours |
| 18th May 2020 | Final report is ready for peer review | Overall review of the report | Build-up of the presentation slides and final details in the logbook | Submission of Final report | 4 hours |
| 20th May 2020 | Key points for mini-conference/presentation | Read-up the final report again and prepare presentations without prior references | Build-up of the presentation slides and final details in the logbook | Output of presentation slides and logbook | 2 hours |
| 23rd May 2020 | Self-designed inputs for the slide | 5G NR diagram, frequency allocation | Build-up of the presentation slides and final details in the logbook | Output of presentation slides and logbook | 2 hours |
| 25th May 2020 | Preparations for mini-conference presentation | - | - | Submission of presentation slides and logbook | 1 hour |

**First Written Introduction**

The mobile communication network has grown over the years and these growths has been represented as generational technological innovations. This encompasses 1G, 2G,3G,4G and 5G. The G standards for generation. Each generation has its own unique architecture, advantages, as well as its challenges. Mobile services have been broadly classified into voice, video and data, with other sub-sets breaking out of these three. 5G NR (New Radio) is an air interface developed for 5G. An air interface is the radio frequency part of the radio access network, between the mobile device and its base station. It is using the wireless channel to connect mobile devices, mobile stations and, generally, user equipment to the base station. There a couple of base stations that make up the network and are geographically spread out. This helps to achieve expected service coverage and hand off of service from one base station to another, thus enabling service accessibility even with mobility.

Furthermore, 5G NR, as a new radio access technology (RAT), was developed by 3GPP (3rd Generation Partnership Project) for the 5G (fifth generation) mobile networks. It was designed to be the global standard for the air interface of 5G networks. A Radio Access Technology or (RAT) is the underlying physical connection method for a radio-based communication network. 5G also uses OFDM (orthogonal frequency-division multiplexing), a spectral efficient technique already being used by WiMAX, LTE and IEEE 802.11 (Wi-Fi).

The 5G System architecture is defined to support data connectivity and services enabling deployments to use techniques such as e.g. Network Function Virtualization (NFV) and Software Defined Networking (SDN). 5G performance requirement is higher than 4G, including the capability to support between 100Mbps to 1Gbps user experience speed, 1 million connections density per kilometer square, millisecond level of end-to-end latency of less than 10ms, Tbps level of traffic flow density per kilometer square, mobility of up to 500km/h. All of these make up to the top three (3) key performance indicators of 5G network (user experience, connection density and latency). Meanwhile, 5G is required to improve the efficiency of network deployment and operation & maintenance. To compare with 4G, the spectrum efficiency improved between 5 to 15 times, and the cost efficiency improved more than hundred times.

**Initial Scope**

This research will cover the following specific topics, but not limited to them

* Architecture of the 5G network
* Review of the Radio Access Network of 1G, 2G,3G and 4G
* 5G Radio Access and NR
* 5G NR Key Features
* Frequency Spectrum and Licensing for 5G NR
* 5G NR Standards and Specifications
* 5G Network Deployment and Roll-out
* 5G NR Service Interfaces
* 5G Backward Compatibility

**Limitation on the research work**

This is a research project based on theoretical findings on 5G NR. There was no specific simulation or bench test. Also, there were no real-life data gathered from the network service operators that are already using 5G.

**Project Risk**

5G NR is new technology and yet to be deployed across all the mobile service operators. Hence, every day there will be a new idea and a lot of published research works. Therefore, to avoid miss-match, the work load will divided between group members depending on sub-section of research.

This also means the group members will have to do a lot of personal reading and cross-referencing to acquire the needed theoretical background to support this project. This also means critical feedback will be needed from the examiner in-charge and the teaching assistant progressively. This will require proactive knowledge gathering and continuous involvement of the supervisors.

**Second Introduction Written (Progress Report)**

5G new radio (NR) is the access air interface into the 5G network. 5G NR offers a unified, and more capable air interface. It has been designed with an extended capacity to enable next-generation user experiences, empower new deployment models and deliver new services. This is to be achieved with very high data rates in the wireless space, with superior reliability and very low latency. 5G NR covers higher data modulation, channel coding, waveform generation, network slicing, MIMO, frame structures, numerology, hybrid automatic repeat request (HARQ) and duplexing. 5G will expand the mobile ecosystem into new realms. It will improve every industry, from safer transportation, remote healthcare, precision agriculture, to digitized logistics, and much more. Incisively, 1G, 2G, 3G, and 4G all led to 5G, which is designed to provide more connectivity than was ever available before.

Going forward, 5G will serve as the foundation for other newer technologies. It will focus on the the expansion and enhancement of mobile internet and Internet of Things (IoT). The future 5G mobile applications defined by the International Telecommunication Union (ITU) in June 2015 are categorized into three types. They are Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC) and Ultra-Reliable and Low-Latency Communication (URLLC).

The Enhanced Mobile Broadband (eMBB) is to facilitate people-to-people exchange as a fundamental requirement set out for mobile communications. eMBB focuses on increased data rates leading to a tremendous improvement of a user's perceived experience. Massive Machine Type Communication (mMTC) promotes the increasingly interconnection, or Internet of Things (IoT) and other vertical industries, that will bring about a large number of wireless sensor networks, putting a new demand network access quantities and power consumption efficiency. Then, Ultra-Reliable and Low-Latency Communication (uRLLC) revolves around Industry automation, telemedicine, smart grids, and other vertical industries that require high reliability and low latency. Consequently, the key features of the 5G NR encompasses ultra-lean carrier design, Scalable OFDM based air-interface, UE Massive MIMO and beamforming, Usage of sub 6GHz and mmWave spectrum, and scalable numerology. A couple of technological solutions released and standardized over the years have actually made this a reality.

In order to meet the requirements of massive connections and ultra-high data rates, 5G networks are designed to be deployed in high frequency bands, such as 28 GHz and 39 GHz, (attracting industrywide attention) in addition to sub-6 GHz bands. There is also room to use other higher frequencies, licensed or unlicensed. Compared with the radio propagation features of low frequency bands, the signals in high frequency bands are more susceptible to issues such as architecture materials, vegetation, rain attenuation, atmospheric absorption and oxygen attenuation. Empirically, to increase data rate, is to increase the bandwidth used for the communication and use a better modulation technique. The wireless channel is unique as it is unguided and hence, other concerns have to be catered for the efficient use of the wireless space. 5G NR is designed to scale up to 1000MHz of bandwidth and 20Gbps data rate over the air interface.

Furthermore, 5G NR offers both forward and backward compatibility. It can co-exist with a 4G LTE network, using the same frequency band, and sharing physical infrastructure. This led to 5G networking modes denoted as standalone (SA) and non-standalone (NSA).

**List of References**

[1] Ericsson AB., J. PEISA, P. PERSSON, S. PARKVALL, E. DAHLMAN, A. GRØVLEN, C. HOYMANN, D. GERSTENBERGER, February 2020, 5G New Radio Evolution, IEEE Communications Standards Magazine. pp 2-14, December 2017

[2] S. Parkvall, E. Dahlman, A. Furusk¨ar, and M. Frenne. “NR: The New 5G Radio Access Technology”, IEEE Communications Standards Magazine, pp. 24-30, December 2017

[3] Qualcomm Technologies, Inc. Making 5G NR a reality Leading the technology innovations for a unified, more capable 5G air interface. pp 2-63,September, 2016

[4] Ericsson AB., A. A. Zaidi, R. Baldemair, M. Andersson, S. Fax´er, V. Mol´es-Cases, Z. Wang,”2017-07 [online] Available at ericsson.com/en/reports-and-papers/ericsson-technologyreview/articles/designing-for-the-future-the-5g-nr-physical-layer

[5] Qualcomm Technologies Inc. Expanding the 5G NR ecosystem.[online] https://www.qualcomm.com/media/documents/files/expanding-the-5g-nr-ecosystem-and-roadmap-in-3gpp-rel-16-beyond.pdf ,pp 3-25, September 2018

[6] Amitabha Ghosh, Nokia, “5G New Radio (NR): Physical Layer Overview and Performance”, IEEE Communication Theory Workshop 2018. pp 2-37, May 2018

[7] Huawei Technologies., Alexander Serbin, “On the roads to 5G: theory and practice”. ITU Seminar. pp 2-18, May 2018

[8] Ericsson AB., Shiv K. Bakhshi, Ph.D. “5G and standards: managing complexity, ensuring interoperability”. Ericsson presentation. pp 2-18, February 2018

[9] 3GPP publication. The 5G Evolution: 3GPP Releases 16-17.[online], https://www.5gamericas.org/wp-content/uploads/2020/01/5G-Evolution-3GPP-R16-R17-FINAL.pdf pp 22-27, Jan 2020.

[10] ZYXEL [online] https://www.zyxel.com/solutions/5g-nr-serviceprovider-20200115-082732.shtmlsn-nsa

[11] H. Ji, S. Park, J. Yeo, Y. Kim, J. Lee and B. Shim, ”Ultra-Reliable and Low-Latency Communications in 5G Downlink: Physical Layer Aspects,” in IEEE Wireless Communications, vol. 25, no. 3, pp. 124-130, JUNE 2018, doi: 10.1109/MWC.2018.1700294.

[12] Qualcomm Technologies Inc., “What can we do with 5G NR Spectrum Sharing that isn’t possible today?” Available at https://www.qualcomm.com/media/documents/files/new-3gpp-efforton-nr-in-unlicensed-spectrum-expands-5g-to-new-areas.pdf, pp. 4-32, December 2017

[13] GSMA publication, Road to 5G: Introduction and Migration. pp 6-27, April 2018

**IMPORTANT POINTS FOR THE REPORT**

* Abstract
* Define the aim
* Introduction
* Use of diagrams
* Pre-5G Communication
* Description of 5G NR
* 5G NR standardization
* Deployment modes of 5G NR
* Frequency spectrum for 5G NR
* 4G LTE and 5G Co-existence
* Conclusion
* Standard referencing approach

**FINDINGS**

To achieve high data rate is based on two key parameters. They are the bandwidth and the modulation schemes. The higher the bandwidth, the higher the possibility of having high data rates. Also, the modulation orders. The higher the modulation order, for a given bandwidth, the higher the possibility of having high data rates.

mMTC is optimized for IoT. This means there will be dependency on IP communication. Since there are millions of devices being looked into, then IPv6 is a fit for this. mMTC is another reducing dependency on wired connections, and still have the needed reliability, latency and security.

The reference signals are like pilot signals used for channels estimation and tracking of UE. Since 5G NR is to promote hyper-densification, then there is a need to reduce these reference signals and reduce interference.

eMMB is more like an improvement on the data rate that the 4G LTE network can offer. Increase, in bandwidth (with possibility of carrier aggregation), will surely increase data rates. For now, 5G NR and 4G LTE both use the same modulation orders: QPSK, 16QAM,64-QAM and 256QAM.

5G NR for now has three (3) defined use cases categorized as: eMMB, mMTC and URLLC.

URLLC has some strict requirements and a couple of solutions has to be used together to achieve 1ms, or less, latency. This is the encompasses advanced coding for error correction and detection, efficient modulation and use of diversity, here massive MIMO is already available.

The 5G network is quite simple in structure. The base station is the gNodeB (gNB), which can be centralized or distributed. The core network is just one node called 5GC. This simplicity will reduce latency has there not many nodes involved in the 5G internal network communications.

The 5G system architecture is created to support data connectivity and services enabling deployments to use techniques such as network function virtualization (NFV) and software-defined networking (SDN). The 5G performance requirement is higher than that of 4G, including the capability to support between 100Mbps to 1Gbps user experience speed, 1 million connections density per square kilometer, millisecond level of end-to-end latency of less than 10ms, Tbps level of traffic flow density per square kilometer and mobility of up to 500km/h. All of these make up the top three (3) key performance indicators of the 5G network (user experience, connection density, and latency). Meanwhile, 5G is required to improve the efficiency of network deployment, operation and maintenance. To compare with 4G, the spectrum efficiency improved between 5 to 15 times, and the cost efficiency improved more than a hundred times

As part of the ultra-lean design concept, NR offers four (4) main reference signals. They are demodulation reference signals, phase tracking reference signals, sounding reference signals, and channel state information reference signals. These signals are only transmitted when necessary, making NR design ultra-lean. NR has no cell-specific reference signals; synchronization and broadcast signal are sent every 20 ms.

NR supports scalable numerologies to address different spectrum, bandwidth, deployment, and services. Sub-carrier spacing (SCS) of 15, 30, 60, 120 kHz is supported for data channel. The concept of numerology simply means sub-carrier spacing. This is part of the flexibility of 5G NR. 4G LTE has 15KHz fixed sub-carrier spacing.

DSS makes it possible for NR signals to be transmitted over unused LTE resources. With LTE, all the channels are statically assigned in the time-frequency domain, whereas the NR physical layer is extremely flexible for reference signals, data, and control channels. This allows for dynamic configurations that will minimize a chance of

collision between the two technologies. One main concept of DSS is that only 5G users know of it, while the functionalities of the existing 4G LTE devices remain unaffected i.e. LTE protocols in connected or idle modes.

GSMA write-up gave like 5 possibilities of Non-standalone (NSA) and standalone (SA) deployments.

**Updated Time chart**

Below is the time sheet updated from the initial planning report

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| --- | --- | --- | --- | --- |
| **Group’s Deadline** | **Tasks** | **Outcome** | **Examiner’s Deadline** | **Status** |
| 4th April 2020 | Based on group research studies, a draft will be created for professional review | Initial Draft | **-** | **Completed. It was considered inadequate by the team** |
| 11th April 2020 | Review of the Radio Access Network of 1G, 2G,3G and 4G | Conclude sub-section | **-** | **Completed** |
| 18th April 2020 | Architecture of the 5G network | Conclude sub-section | **-** | **Completed** |
| 24th April 2020 | Progress Report | Itemize findings so far, list references and give a better introduction. |  | **Completed and submitted** |
| 25th April 2020 | Frequency Spectrum and Licensing for 5G NR  5G NR Standards and Specifications | Conclude sub-section and new decisions to change the format | **-** | **Completed** |
| 1st May 2020 | 5G Network Deployment and Roll-out  5G NR Service Interfaces  5G Backward Compatibility | Conclude sub-section and new decisions to change the format | **-** | **Completed** |
| 4th May 2020 | Towards pre-liminary review of the research paper | First full draft | **-** | **Completed and submitted for review** |
| 6th May 2020 | Pre-liminary review of the research paper with Kathryn Strong (Prof) | First full draft | **-** | **Review completed** |
| 14th May 2020 | Pre-liminary review of the research paper with Tommy Svensson (Prof) | Structure and Contents of the research paper |  | **Review completed** |
| 16th May 2020 | Completion of the final report | Final report | **Monday 18th May 2020** | **Submitted on 18th May 2020** |
| 23rd May 2020 | Finalize the preparations for the Oral defense | Oral Presentation | **Monday 25th May 2020** | **Completed** |
| 23rd May 2020 | Finalize the development of the presentation slides and materials | Presentation slides | **Monday 25th May 2020** | **Completed** |
| 23rd May 2020 | Finalize the details of the logbook | Logbook | **Monday 25th May 2020** | **Finalized and reviewed** |