Chalmers University of Technology

Research Logbook

5G New Radio Research Topic (SSY145-Wireless Networks)

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.

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 &Peter
- 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.

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	Submission of full first draft to Prof. Kathryn Strong Hansen for review. Also share	1 hour

			(Haitham & Peter)	with the other selected group	
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

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[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

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**