Performance evaluation of a handover enabled 5G communication system

- Azeem Abrar Khan, Matriculation number: 55088

Final Presentation , Research Project

Supervisor: Shashini Wanniarachchi
Professor: Dr. Volker Turau

Overview

Hamburg University of Technology

- Project Goals
- Architecture of the 5G Cellular Network
  - ✓ Mobile Core
  - ✓ Radio Access Network
- Types of Handovers
  - ✓ Inter-5G handovers
  - ✓ Intra-system 5G handovers
- Deployment Options
  - ✓ Non-Standalone Deployments (NSA)
  - ✓ Standalone Deployments (SA)
- Simulation Model
- Use cases
- Performance Metrics
  - ✓ Latency
  - ✓ Data Delivery Ratio
  - ✓ Handover Success Ratio
- Performance Evaluation
  - ✓ Number of Packets
  - ✓ Number of Bytes
  - ✓ Packet Delivery Ratio
  - ✓ Average Latency
  - ✓ Vector plot of the number of agents
  - ✓ Vector plots of latency
- Conclusion and Future Extension

Project Goals

Hamburg University of Technology

- To model a 5G network with several base stations and air taxis as 5G user equipments.

- To model user equipments with following capabilities:
  - ✓ Handover enabled: Handing over a mobile device from one base station to another.
  - ✓ Transmit different types of data (Coordinates, images, video).

- To evaluate the performance of the network under the following criteria:
  - ✓ Amount of data being exchanged
  - ✓ Latency
  - ✓ Data delivery ratio
  - ✓ Handover success percentage

Architecture of the 5G cellular network

A 5G cellular network consists of two parts as shown in figure 1.

Mobile Core

- ✓ Provide internet and fulfills the QoS requirement.
- ✓ Tracks the real-time movement of user equipments.
- ✓ Collects network usage statistics

The function block of user plane is known as UPF. It is a collection of PGW (Packet Gateway) and SGW (Serving Gateway).

Radio Access Network

Contains several base stations (gNBs) and station provides bearer service to the user equipments.

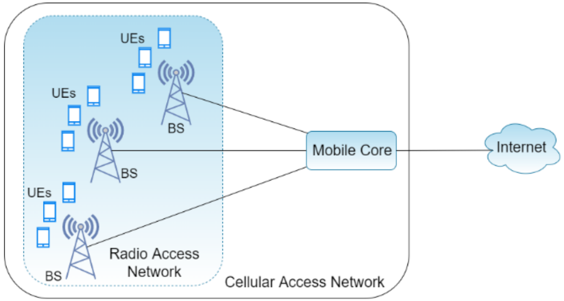


Figure 1

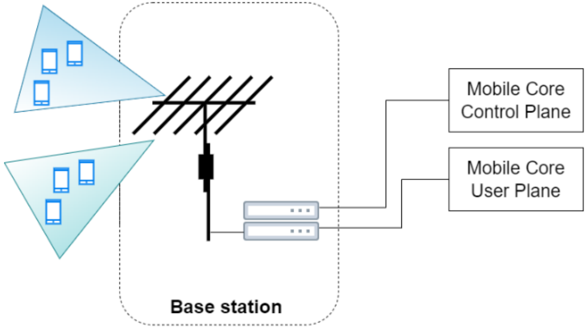


Figure 2

Types of Handover

Hamburg University of Technology

UE mobility is supported through handover.

- **Inter-5G handovers**

Device is handed over from a source to a target network where one of them implements last generation 4G LTE standard.

- **Intra-system 5G handovers**

Device is handed over from a source to a target network when they both implement the 5G standard.

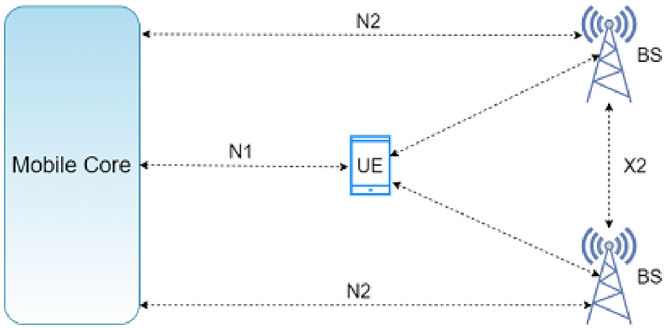


Figure 3

Types of Intra-system handovers

1. Handover of UE through mobile core (N2 handover)
2. Handover of UE directly between base stations (X2 handover)

As this project is purely based on 5G, we considered intra-system X2 based handover.

Deployment Options

Hamburg University of Technology

There are two deployment options available.

- **Non-Standalone Deployment(NSA)**

Contains both eNBs (4G base stations) and gNBs (5G base stations).

eNBs are connected with the mobile core, which is the implementation of EPC (Evolved Packet Core).

gNBs are only used to carry user data.

- **Standalone Deployment (SA)**

Purely based on 5G and only contains gNBs and 5G NG-Core.

SA deployment is used in this project.

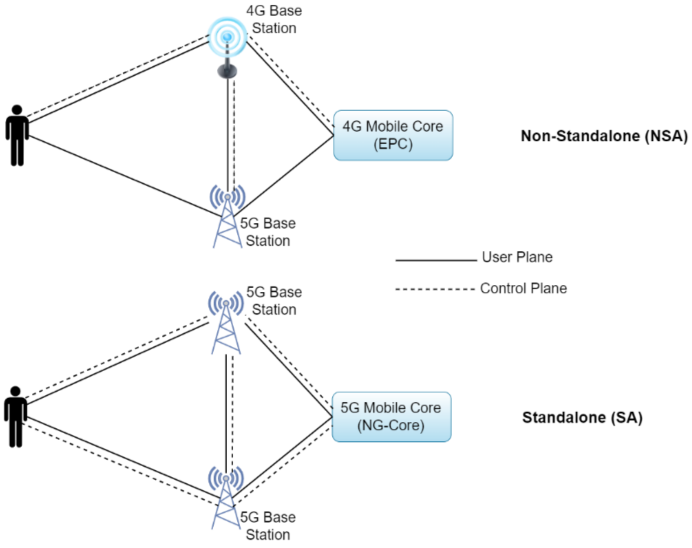


Figure 4

Simulation Model

The model contains 4 gNBs, Flight schedule manager, UPF, a router and a ground station.

gNBs are connected with each other through x2 interfaces.

gNBs are connected with the UPF through 10 Gbps bidirectional links.

Flight schedule manager spawns agents inside the network area and deletes them on completion of their path.

Agents are modified form of NrUe module of Simu5G, containing a GPS sensor and a camera module.

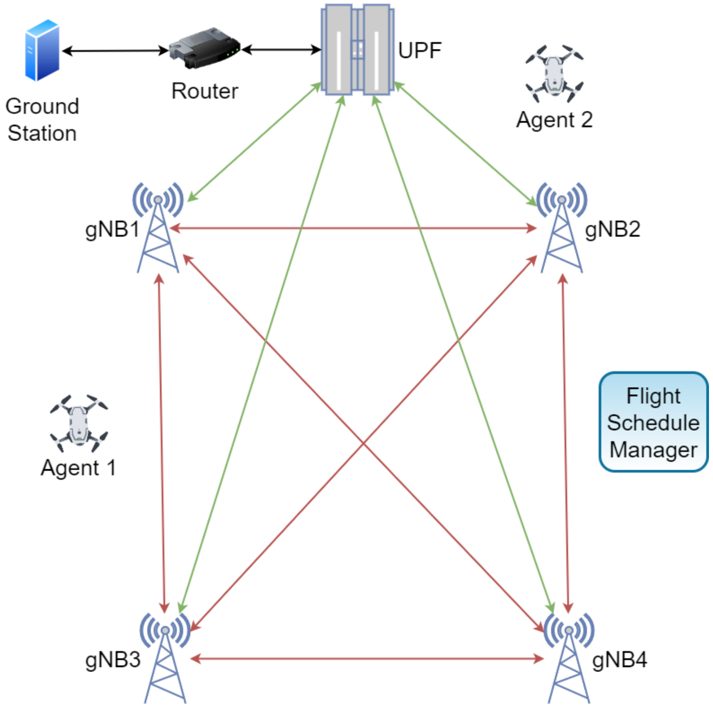


Figure 5

Use cases

Hamburg University of Technology

Coordinates, images and videos are sent at different interval, thus producing different use cases.

Images are bigger in size than coordinates data, whereas videos have a larger size as compared to images.

Frames and length of videos are also varied to produce more use cases.

S.No.	Use case name	Period	Fps	Video Length
1	Coordinates - Slow	uniform(5s,6s)	-	-
2	Coordinates - Fast	uniform(0s,0.04s)	-	-
3	Images - Slow	uniform(5s,6s)	-	-
4	Images - Fast	uniform(1s,2s)	-	-
5	15fps, 5secs Video - Slow	uniform(18s,20s)	15	5s
6	15fps, 5secs Video - Fast	uniform(7s,8s)	15	5s
7	15fps, 10secs Video - Slow	uniform(18s,20s)	15	10s
8	15fps, 10secs Video - Fast	uniform(7s,8s)	15	10s
9	30fps, 5secs Video - Slow	uniform(18s,20s)	30	5s
10	30fps, 5secs Video - Fast	uniform(7s,8s)	30	5s
11	30fps, 10secs Video - Slow	uniform(18s,20s)	30	10s
12	30fps, 10secs Video - Fast	uniform(7s,8s)	30	10s

Table 1

Use cases

A gNB requires one x2 app for every other gNB. There are 3 x2 apps for every gNB in our case.

Agent sends their current location through GPS coordinates in the first two use cases.

The packet size is only 40 B in case of GPS coordinates as payload.

Submodule “Images” contains pre-defined drone images encoded in base64 format.

Each packet contains one image of size 51,200 bytes and 56,320 bytes as the maximum payload for a UDP packet is 65,507 bytes.

Use cases

In case of video, it is assumed that every frame is equal to 51,200 bytes.

One frame can be enclosed in one packet, therefore the total number of frames for a video provides the total number of packets.

The interval between the frames (packets) is the reciprocal of frames per second.

Use case name	Fps	Video Length	Packets (Fps x Video Length)	Frame's period
15fps, 5secs Video	15	5s	75	66.6 ms
15fps, 10secs Video	15	10s	150	66.6 ms
30fps, 5secs Video	30	5s	150	33.3 ms
30fps, 10secs Video	30	10s	300	33.3 ms

Table 2

Latency

The time taken by the packet to reach its destination.

Ground station calculates the average latency by using the following formula.

$$latency = \frac{latency(numReceived-1)+currentLatency}{numReceived}$$

where
latency = average latency
currentLatency = latency of the received packet
numReceived = number of received packets

Performance Metrics

Hamburg University of Technology

Data Delivery Ratio

The ratio represents the efficiency of the network to deliver packets.

$$\mathrm{packetDeliveryRatio} = \frac{\mathrm{totalNumberOf\ PacketsReceived}}{\mathrm{totalNumberOf\ PacketsSent}}$$

Handover Success Ratio

The ratio represents the efficiency of the handover procedure.

$$handoverSuccessRatio = \frac{\mathrm{totalNumberOf}SuccessfulRequests}{\mathrm{totalNumberOf}HandoverRequests}$$

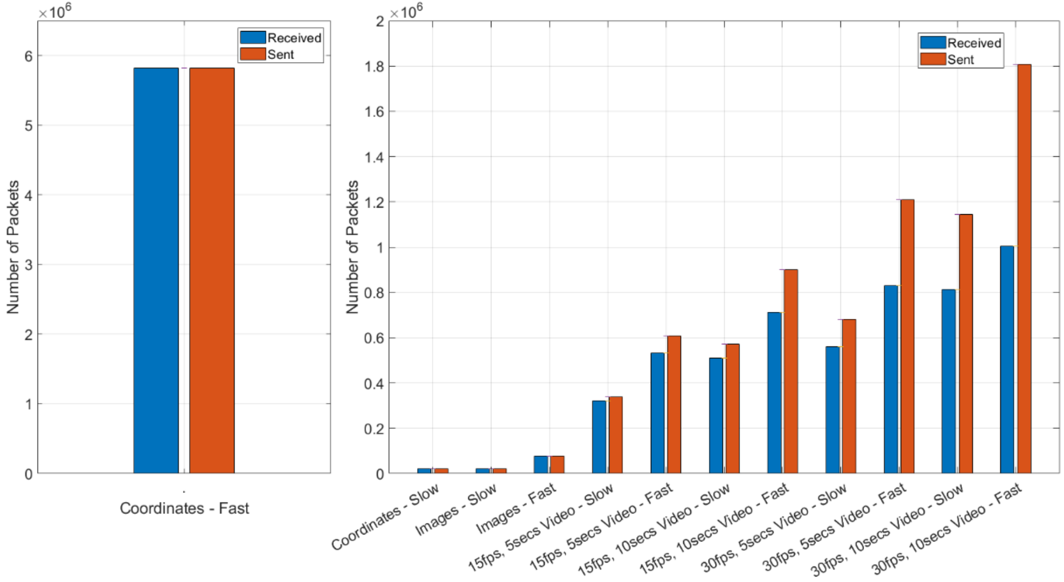
Performance Evaluation
Number of Packets

“Coordinates - Slow “ and “Images – Slow” have the same and least number of 20,000 packets sent and received.

“Coordinates – Fast” has the maximum number of sent and received packets (5.8 million)

In video use cases, the number of packets increases with the increase of frames.

The maximum number of frames sent - 1.8 million.

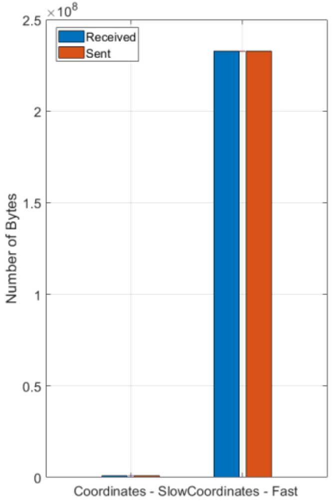


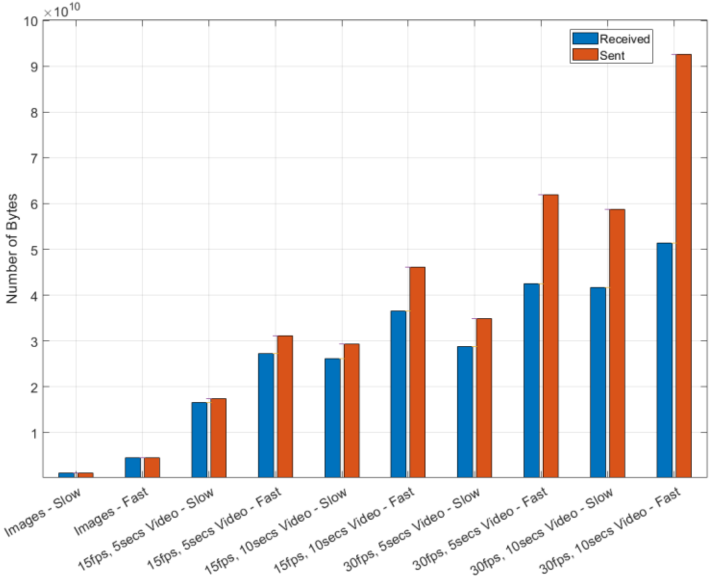
Performance Evaluation
Number of Bytes

Coordinates use cases provides least number of bytes as compared to images and videos because of small packet size of only 40 bytes.

The number of bytes increases with the increase of frames in case of videos.

The difference between sent and received increases with the increase of number of bytes.





Coordinates - Slow: 1 million bytes (976 KB)
Coordinates - Fast: 233 million bytes (222 MB)
30fps, 10secs Video - Fast: 9.26x10^10 bytes (92.6 GB) sent
30fps, 10secs Video - Fast: 5.14x10^10 bytes (51.4 GB) received

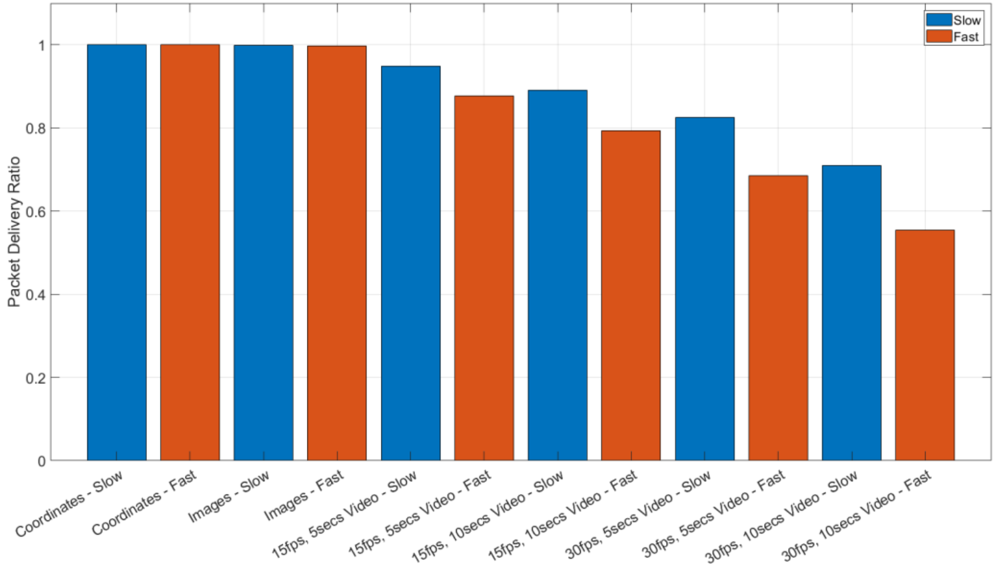
Performance Evaluation
Packet Delivery Ratio

Ratio is almost 1 in the first four use cases.

Ratio decreases with the increae of number of bytes sent as we move from left to right in the graph.

“Slow” use cases have better delivery ratio than their “fast” counterparts in case of videos.

The last use case shows the worst delivery ratio of 0.55.



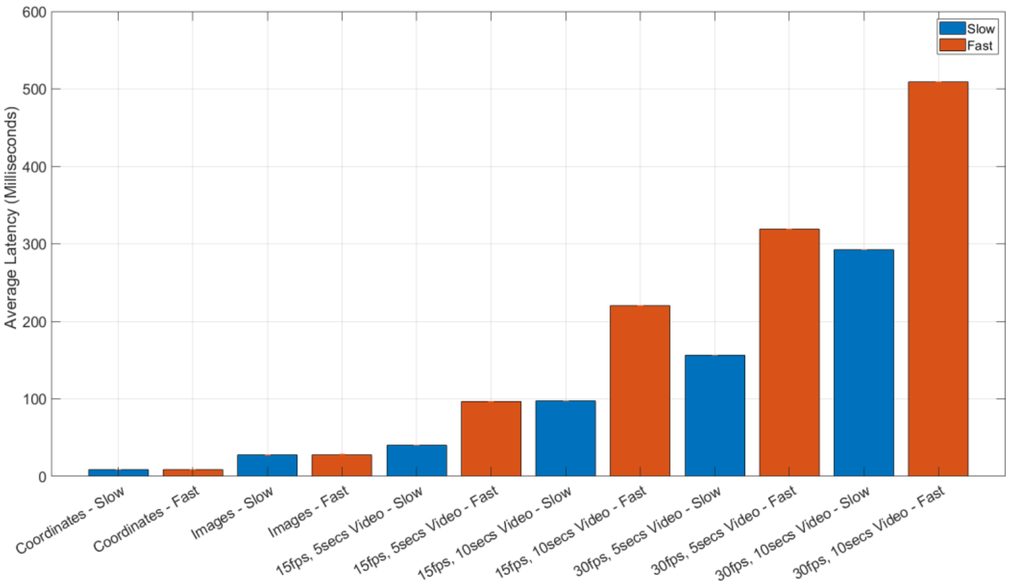
Performance Evaluation
Average Latency

Average latency increase with the number of bytes sent.

Coordinates - Slow: 9 ms
Coordinates - Fast: 9 ms

Images - Slow: 28 ms
Images - Fast: 28 ms

30fps, 10secs Video - Slow: 292 ms
30fps, 10secs Video - Fast: 509 ms

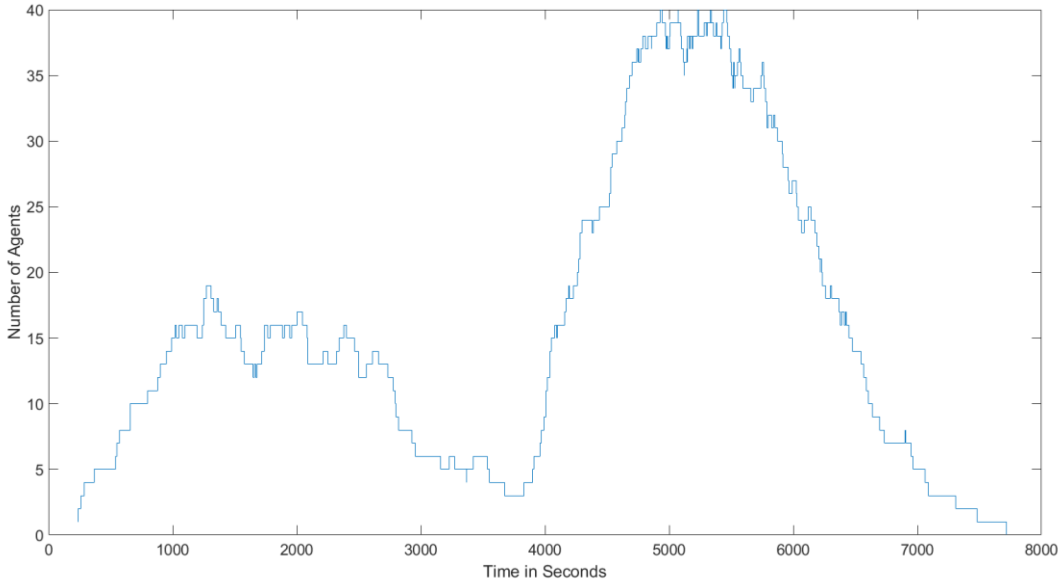


Performance Evaluation
Vector plot of the number of agents

Flight schedule manager is used to record the active number of agents.

19 agents at 1270 secs.

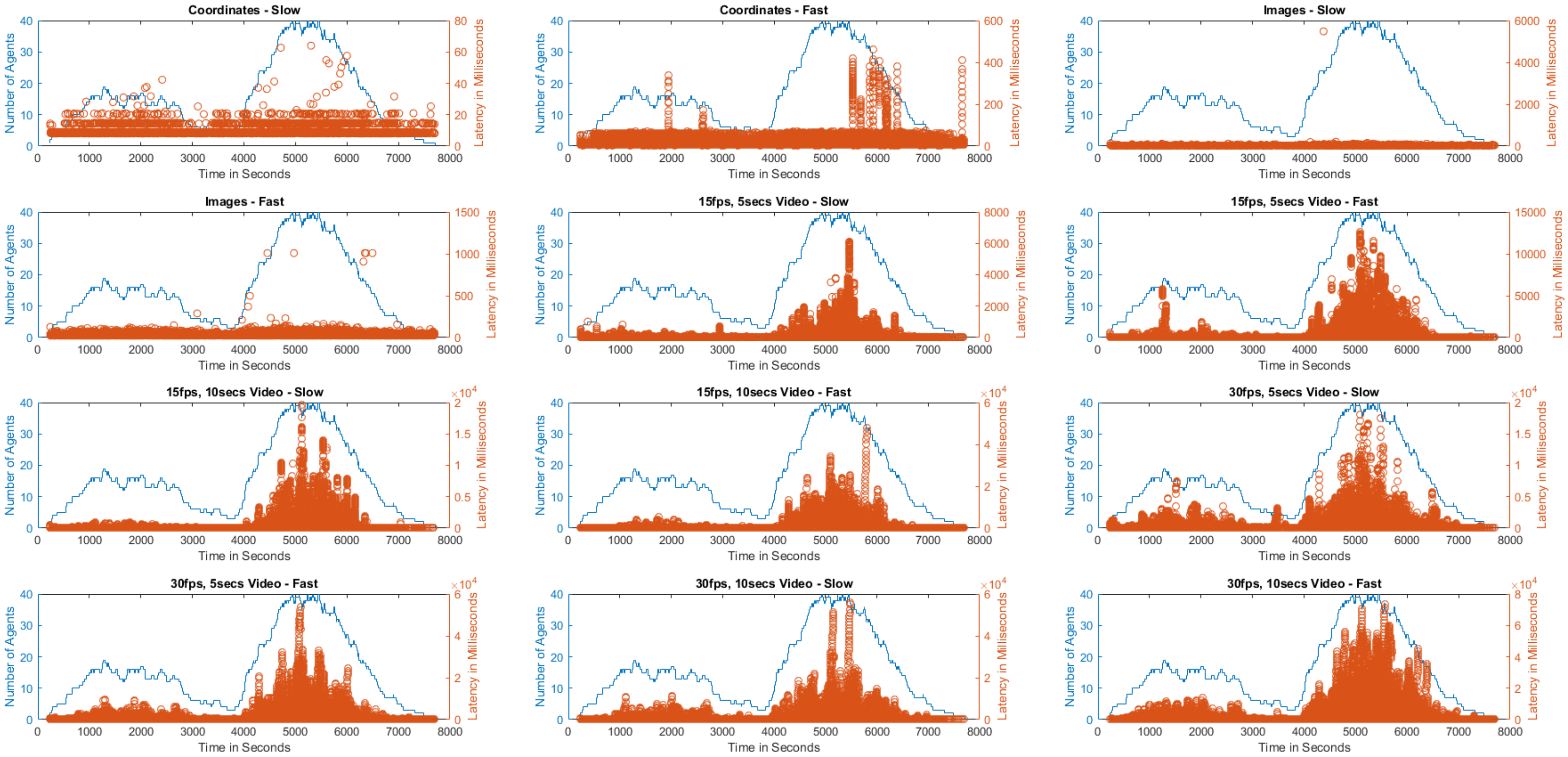
Reaches a maximum value of 40 in between 4,930 seconds and 5,440 seconds.



Performance Evaluation

Vector plots of latency

Hamburg University of Technology

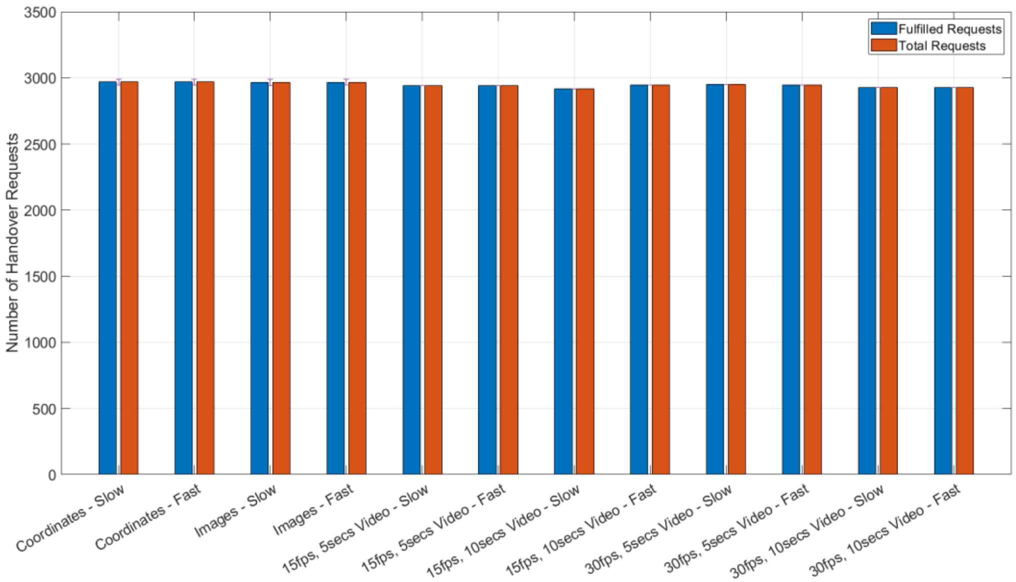


Performance Evaluation
Handover Success Ratio

The graphs shows the combined number of requests for all the base stations.

A little less than 3,000 requests are made in each of the use case.

All the requests are fulfilled, thus producing handover success ratio of 1 for every use case.



Conclusion and Future Extension

The network was modelled on OMNeT++ and supported libraries.

An application for the 5G agent was developed to support different data types.

5G provides low latency even for high number of packets and can be used for latency critical applications.

Packet delivery ratio was also found to be 0.95 in case of short length videos.

The handover procedure in 5G is also reliable and the success ratio was found to be 100%.

A large network with more gNBs and agents can be developed to observe the changes in results.

The simulation results can also be compared with those obtained from a network operating on 4G.

References

[1] 5G Mobile Networks: A Systems Approach. URL: https://5g.systemsapproach.org/.

[2] Meriem Mhedhbi et al. “Performance evaluation of 5G radio configurations for industry 4.0”. In: 2019 International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob) (2019). DOI: 10.1109/wimob.2019.8923609.

[3] Giovanni Nardini et al. “Simu5G-An OMNeT++ Library for End-to-End Performance Evaluation of 5G Networks”. In: IEEE Access 8 (2020), pp. 181176–181191. DOI: 10.1109/access.2020.3028550.

[4] Giovanni Nardini et al. “SIMU5G: A system-level simulator for 5G networks”. In: Proceedings of the 10th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (2020). DOI: 10.5220/0009826400680080.

[5] Aleksi Peltonen, Ralf Sasse, and David Basin. “A comprehensive formal analysis of 5G handover”. In: Proceedings of the 14th ACM Conference on Security and Privacy in Wireless and Mobile Networks (2021). DOI: 10.1145/3448300.3467823.

[6] Andras Varga. URL: https://doc.omnetpp.org/omnetpp/manual/.

TUHH
Hamburg University of Technology

Thank you

Latency Outliers Percentage

Use case	Percentage
2	0.1682%
12	17%

4G vs 5G (Latency and Handover execution time)

TUHH
Hamburg University of Technology

Parameter	4G	5G
Latency	20 ms	1 ms
Handover execution time	49.5 ms	0 ms

Radio Access Network

Contains several base stations (gNBs)

Base station provides bearer service to the user equipments

After authentication, the base station creates one or more tunnels between the core and the user equipments.

GTP (General Packet Radio Service Tunneling Protocol) is used to transmit user packets.

SCTP (Stream Control Transport Protocol) is used to transmit control packets.

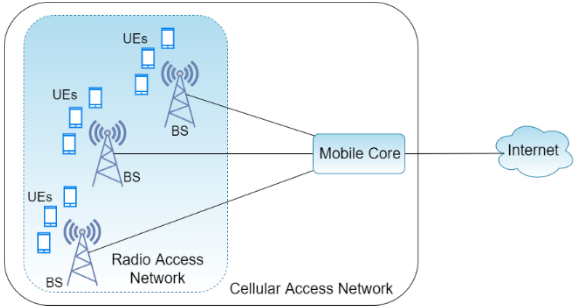


Figure 1

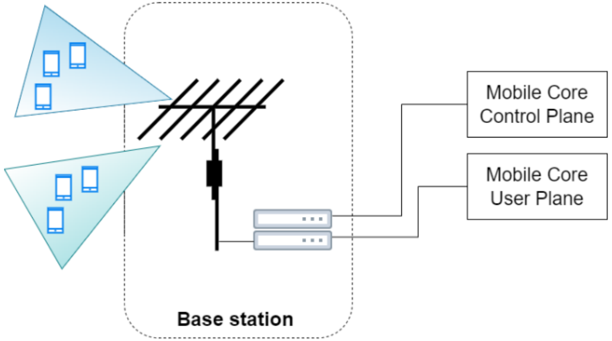
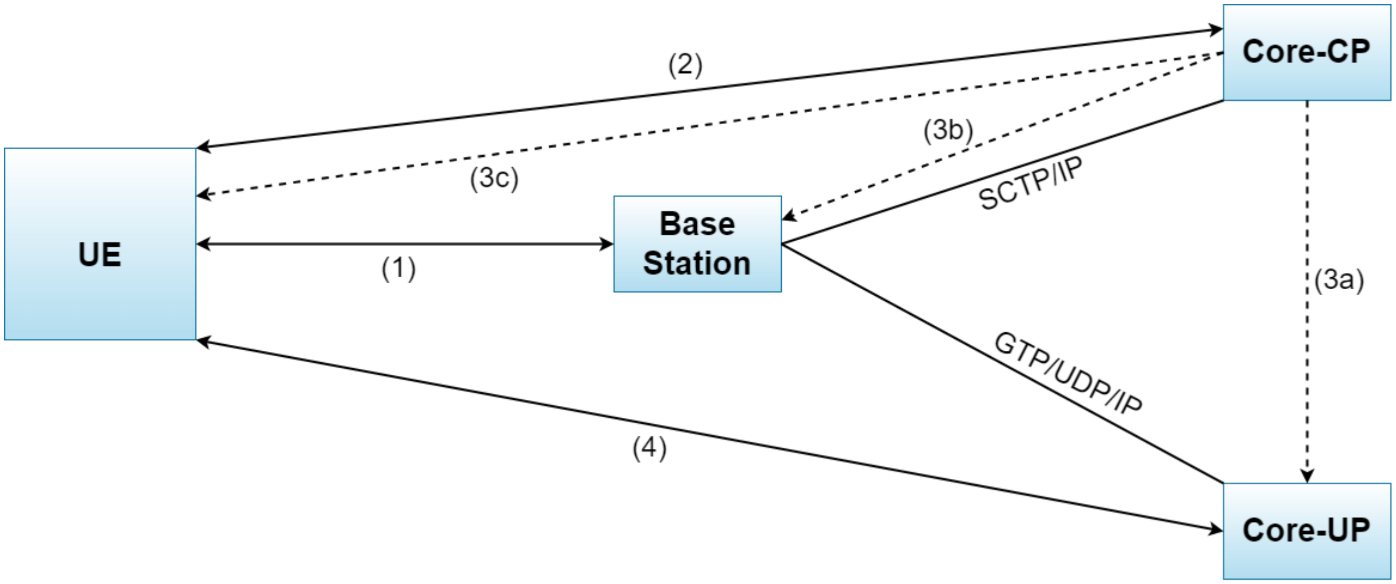


Figure 2

Sequence of steps taken by a user equipment to form channels



NR Resource Management

The length of an NR radio frame is 10ms and it consists of 10 sub-frames.

These sub-frames can be divided into many time slots, known as Transmission
Time Intervals (TTI).

gNB allocates resource blocks to connected UEs per TTI.

The number of resource blocks per transport block depends on the modulation and coding scheme used for transmission.

More than one carrier component (CCs) can be used at the same time for NR communication.

Only one CC, operating on FDD, is used in this project having default values of 2GHz and
0 for carrier frequency and numerology index, respectively.

NR Protocol Stack

NR protocol stack has three sub-protocol layers:

- ✓ Packet Data Convergence Protocol (PDCP)
- ✓ Radio Link Control (RLC)
- ✓ Medium Access Control (MAC)

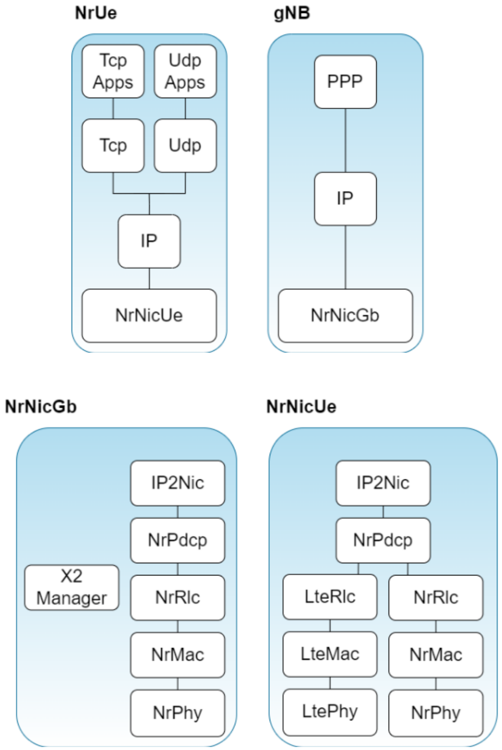
Ip2Nic acting as a bridge between the NR protocol stack and the IP layer.

PDCP protocol layer provides encryption to the IP datagrams.

The RLC layer can be configured in three modes:

- ✓ Acknowledged Mode (AM)
- ✓ Unacknowledged Mode (UM)
- ✓ Transparent Mode (TM)

On every TTI, the MAC layer assigns different numerology indexes to CCs, resulting in different TTI duration.



Base64 encoding

Word: Hey

ASCII: 72 101 121

Bits: 01001000   01100101   01111001

24 bits are divided into four equal parts

Bits: 010010   000110   010101   111001

Base64: SGV5

Index	Binary	Char	Index	Binary	Char	Index	Binary	Char	Index	Binary	Char
0	000000	A	16	010000	Q	32	100000	g	48	110000	w
1	000001	B	17	010001	R	33	100001	h	49	110001	x
2	000010	C	18	010010	S	34	100010	i	50	110010	y
3	000011	D	19	010011	T	35	100011	j	51	110011	z
4	000100	E	20	010100	U	36	100100	k	52	110100	0
5	000101	F	21	010101	V	37	100101	l	53	110101	1
6	000110	G	22	010110	W	38	100110	m	54	110110	2
7	000111	H	23	010111	X	39	100111	n	55	110111	3
8	001000	I	24	011000	Y	40	101000	o	56	111000	4
9	001001	J	25	011001	Z	41	101001	p	57	111001	5
10	001010	K	26	011010	a	42	101010	q	58	111010	6
11	001011	L	27	011011	b	43	101011	r	59	111011	7
12	001100	M	28	011100	c	44	101100	s	60	111100	8
13	001101	N	29	011101	d	45	101101	t	61	111101	9
14	001110	O	30	011110	e	46	101110	u	62	111110	+
15	001111	P	31	011111	f	47	101111	v	63	111111	/