SOGNO

D3.2 v1.0

Detailed description of 5G based ICT concepts for autonomous and self-healing power systems

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Abstract

This report describes the 5G performance evaluation for Fault Location, Isolation and Service Restoration (FLISR) use case by running the system level simulation on 5G New Radio. The report describes the analysis of two different simulation scenarios and compares the result of these scenarios. It also describes further optimisation that can be done in the mobile network in order to achieve latency requirements of Ultra-Reliable Low-Latency Communication (URLLC).

Keyword list

Simulation, 5G, FLISR, URLLC

Executive Summary

Fault Location, Isolation and Service Restoration (FLISR) is the most critical service in SOGNO. The FLISR service should quickly detect a fault in the grid, isolate the faulty areas and restore the power network by sending actions to the switches. Therefore, it needs highly reliable and low latency communication and it is for this reason that the use case for doing the 5G simulation is chosen based on FLISR service.

The performance evaluation of 5G New Radio (5G NR) is done in this task by running a system level simulation. Two scenarios are considered for the simulation. In the first scenario, the mobile network is only used by the power network devices (sensors on the load-break switches), while in the second scenario, the mobile network is also used by the public mobile users that are creating background traffic. Various traffic models are considered in the simulation including Machine Type Communication (MTC) for the communication of power electronic devices.

The analysis of simulation results is done and described in this report. The report also describes the potential optimisation in the over the air transmission in order to reduce latency and increase reliability.

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1. Introduction

This project report is describing the 5G radio system simulations performed for FLISR use-case and analysis of the results achieved from the simulation.

1.1 Related Project Work

This report is based on Task 3.3 of WP3. This task focuses on running the system level simulation for FLISR use case. The FLISR use case is defined in D1.1. The simulation is conducted with two different scenarios: one with ideal condition where no mobile users are using the network and the other one with public mobile users generating mixed traffic.

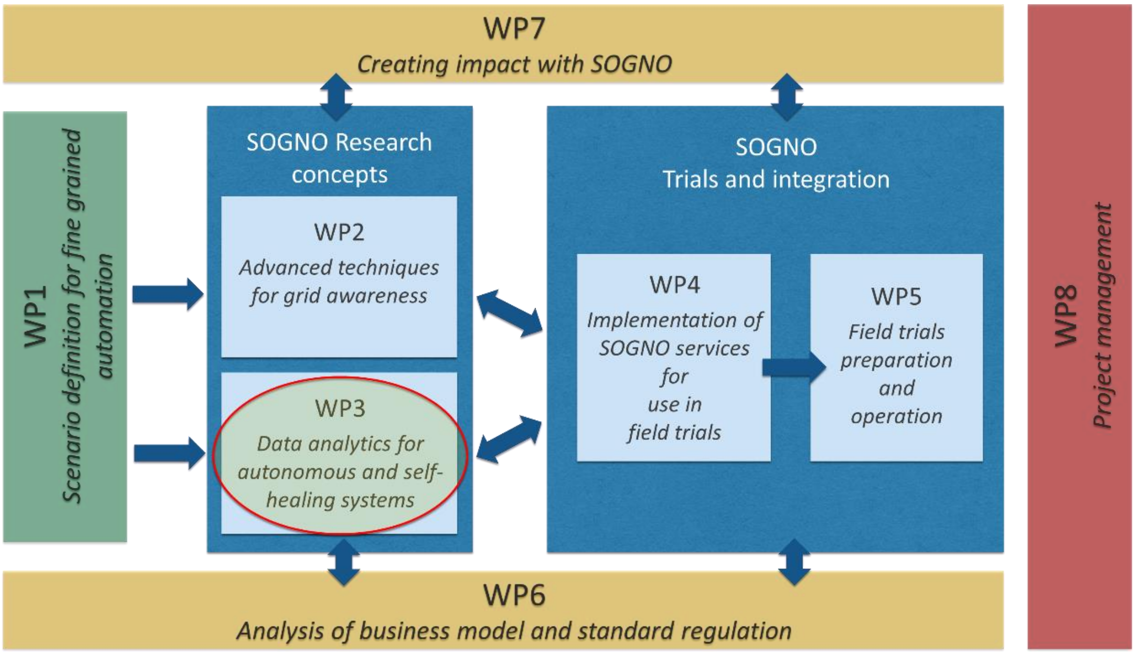

Figure 1: Overview of SOGNO activities

1.2 Objectives of the Report

The main objective of this report is to investigate the behaviour of 5G mobile network under two different radio network conditions and still to fulfil the requirements of the FLISR use case, as well as to understand and optimise transmission streams over the radio interface between Virtualised Substation Automation (ViSA) and power devices.

1.3 Outline of the Report

The Chapter 2 describes the radio network simulator and the scenario architecture in detail. Chapter 3 describes the system methodology, simulation setup, simulation parameters and traffic models. Chapter 4 describes the simulation results and analysis of the results. Chapter 5 describes the optimisation of over the air transmission. Finally, Chapter 6 concludes the report.

1.4 How to Read this Document

It is recommended to read D1.1, D2.2 and D3.1 before reading this document as D1.1 describes the FLISR use case and ICT requirements related to the FLISR, D2.2 describes ViSA platform and D3.1 describes the main concepts of autonomous and self-healing power systems.

- D1.1 – Scenario & architectures for stable & secure grid (M12): it includes a description of power system scenarios investigated in the project, with motivations for the services presented in this deliverable for current and future distribution grids.

- D2.2 - Description of initial interfaces & services for grid awareness (M12): it includes the detailed description of ViSA platform.
- D3.1 - Description of new SOGNO techniques for autonomous and self-healing power systems (M10): it includes the main concepts of autonomous and self-healing power system as well as the main services implemented in WP3 such as FLISR.

2. Simulated scenario

FLISR is the most critical service in SOGNO. It needs highly reliable and low latency communication. Therefore, the use case is chosen as FLISR service.

2.1 Mobile Network Simulator

Simulations are done on Ericsson proprietary LTE and 5G NR simulator. It is a system simulator platform with focus on radio network simulation and has detailed models for all layers of communication networks. The simulator is capable of simulating WCDMA, Wi-Fi, LTE, and 5G radio networks. The 5G core network, which consists of network components serving the purpose of mobility management, user and control plane management and subscriber management, is assumed in the simulation and the processing latency which is generated by the 5G core network nodes is also assumed.

The simulator has frameworks for modelling protocols, traffic and propagation. It also has frameworks for logging the simulation, generating users in the simulation and designing the network structure.

2.2 Use case: FLISR

The FLISR service is capable of detecting faults in the power network. Upon detection, the fault location is isolated, and the service makes sure to restore the power network by connecting the resulting isolated loads back to the power source. For complete details on FLISR, please see D1.1 Section 3.3 and D3.1 Section 3.

The sensors connected to the power network generate the analogue current and voltage signals, which are scaled to acceptable levels for the measurement devices. The measurement devices digitalise the signals and calculate the measurements.

Measurement devices are connected to the FLISR service via 5G mobile network, which consists of 5G User Equipment (5G UE) and 5G base station. 5G UE is a communication device used as a gateway, which enables measurement devices and load-break switches to communicate with 5G mobile network. The measurement data are transmitted by 5G UE over 5G network to the edge cloud deployed close to the radio network, where they are received and forwarded to the FLISR service by the message broker. Upon detection of any fault, the FLISR service updates the information in the topology database and trigger the action on the load-break switches to turn them on or off. These relationships are illustrated in Figure 2.

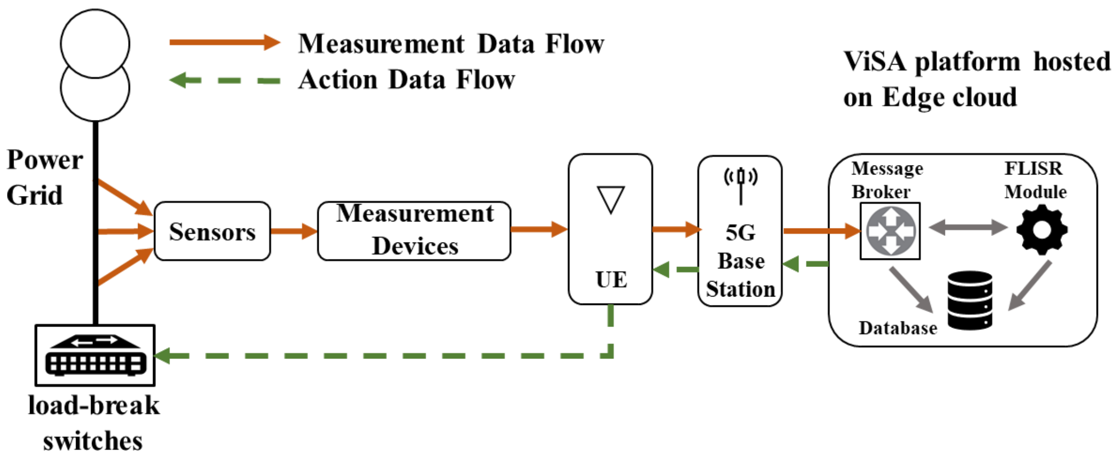

Figure 2: Flow diagram of messages between FLISR service and load-break switches

2.2.1 FLISR requirements on ICT

<u>Latency:</u> For FLISR, time is an important aspect, as the power network should be realigned swiftly after a disturbance in the LV or MV feeder. In many markets the operator of a distribution grid has

to pay penalties even for disturbances as short as three minutes. Therefore, the total round-trip time of the FLISR service, including sensors, switches, data transmission and processing should be well below this limit.

Data volume: It is less critical, as the number of switches in a LV grid is limited.

Protocols: The measurement devices send their real-time measurements using IEC 61850 protocol or Message Queuing Telemetry Transport (MQTT).

Reliability: FLISR is the most critical service in SOGNO. Therefore, maximum reliability of the communications system through network slicing is recommended, where the data traffic is separated from other users of the 5G system. Likewise, it is essential that the data is transmitted in a secure way ensuring full data integrity because of automatic modification of grid edge settings; and in this context, higher security than for monitoring services expected.

2.3 Scenario Architecture

Figure 3 shows how the measurement devices are connected to the FLISR service via 5G mobile network. The background traffic users are also shown in Figure 3. The public mobile users are uniformly distributed in each cell also covering cell borders. The measurement devices are connected to the 5G mobile network and they share the radio resources with public mobile users. The channel model is considered as rural, since the measurement devices will be deployed on the load-break switches and these switches are installed in rural areas on electric poles.

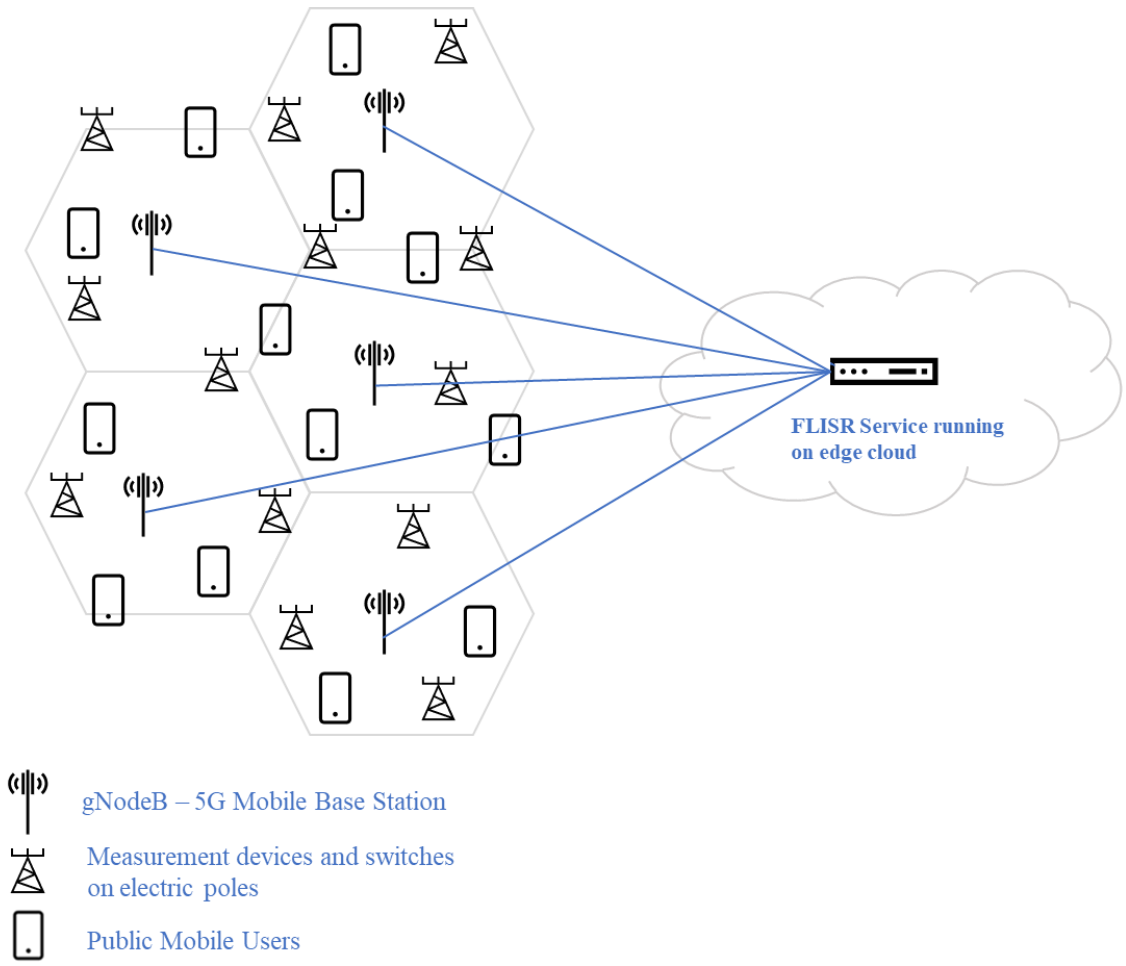

Figure 3: Scenario Architecture

3. Simulation methodology

3.1 Simulation test setup

The 5G simulation is done for two scenarios.

1. Power electronic devices communicating over 5G network with ViSA in ideal conditions (no other mobile users' traffic over the network)
2. Power electronic devices communicating over 5G network with ViSA in the presence of public mobile users

3.1.1 Scenario 1 with ideal condition

In the first scenario, measurement data packets are sent from the 5G UEs to the ViSA platform where the FLISR service is running with a periodicity of 100 milliseconds. No background users either static or mobile are assumed in the simulation. Only the power electronic devices are communicating over 5G network. The number of 5G UEs will be static and will not increase with time. In this scenario, the number of 5G UEs, which are generating measurement data packets, is set to 50.

3.1.2 Scenario 2 with public mobile users generating mixed traffic

In the second scenario, background user traffic is added on top of scenario 1. The mobile users are being generated continuously in the simulated area where power electronic devices are also located. The public mobile users are running various types of background traffic such as File Transfer Protocol (FTP), Voice over IP (VoIP) and Web surfing, see Section 3.3 for details. The mobile users running background traffic are added in the simulation and the initial number of users are fixed as 20 users for each traffic type and arrival intensity of background users is 15 per second in order to achieve 1000 users at the end of the simulation. Maximum number of public mobile users are limited to 1000 for the whole simulation, since the considered use case is for rural area in which load-break switches are located.

3.2 Simulation Parameters

This section provides the basic mobile network parameters that are configured for the implementation of the two simulation scenarios described earlier.

3.2.1 General Parameters

In the simulation procedure, a channel bandwidth of 40 MHz is used. The sectorial antennas are established on the base station site, each having a different direction. The propagation environment considered is a rural area because of the scenarios. The 5G UEs and background traffic users are deployed uniformly within the cell area. The 5G UEs generate Machine Type Communication (MTC) traffic while the background users generate mixed traffic.

The transmission power of the gNodeB has a value of 43 dBm, whereas the user transmission power is 23 dBm. The number of antenna elements for gNodeB is 32, whereas the number of antenna elements for user is 4.

The table summarises the basic deployment configuration parameters used in the simulation.

Parameter	Value
System bandwidth	40 MHz
Carrier Frequency	4 GHz

Transmission Time Interval	1 ms	
Transmission mode	**gNodeB**: MIMO 32x32	**user:** MIMO 4x4
gNodeB transmission power	43 dBm	
UE transmission power	23 dBm	
gNodeB noise figure	5 dB	
User noise figure	7 dB	
Channel Model	Rural	
Cell Radius	577 m^2	

3.2.2 Scenario Specific Parameters

3.3 Traffic Models

In the simulation scenarios, several public mobile users are assumed to use the mobile network along with FLISR devices. These mobile users are running typical applications on their smartphones such as web browsing (HTTP), making calls with VoIP and video streaming (RTP) and transferring files via the same network (FTP).

For our simulation the traffic generated by the mobile users is called Background traffic. The following section describes about the background traffic model used for the simulation.

3.3.1 Background Traffic Models

3.3.1.1 Web - Hyper Text Transfer Protocol (HTTP)

The HTTP is an application protocol typically used for web-browsing sessions. HTTP functions as a request-response traffic model based on client-server computing model. In a HTTP request, client initiates a request message sent to the server, server which has resources response to the client with desired request information [1]. HTTP works on top of underlying reliable Transmission Control Protocol (TCP). TCP provides reliable, ordered and error-checked delivery of messages.

3.3.1.2 Real-Time Transfer Protocol (RTP)

The RTP is an internet protocol standard that is used to transmit real-time transmission of multimedia data [2]. RTP does not in itself guarantee real-time delivery of multimedia data, however, it provides means to manage the data as it arrives to best effect. RTP runs on top of underlying User Datagram Protocol (UDP). UDP does not offer any mechanism to provide error-free and reliable communication. It is considered best-effort mode of communication.

3.3.1.3 File Transfer Protocol (FTP)

FTP is a standard network protocol used to transfer computer files from an FTP Source to an FTP Client over a TCP-based network, such as the Internet [3]. FTP is an asymmetric and bi-directional traffic model. Large and fixed-size block data frames are transmitted from an FTP Source to an FTP Client, whereas short-size TCP ACK is sent from an FTP Client to an FTP Source. FTP traffic is modelled as a sequence of file transfers separated by reading time, where reading time is defined as the time between the end of file transmission and the start of the subsequent file transmission. The packet call size is equivalent to the file size (S) and the packet call inter-arrival time is the reading time (D).

3.3.2 Traffic model used for FLISR devices

3.3.2.1 Machine Type Communication (MTC) Traffic model

MTC traffic model is a lightweight periodic traffic model. MTC uses UDP or TCP underlying protocol on transport layer. In our simulations, we have used UDP on transport layer, but application layer is responsible for receiving Acknowledgement (ACK) packets from receiver. This traffic model is used in the simulation to simulate the traffic generated by the sensors in the field. The MTC traffic model is used as an alternative to MQTT for the simulation purposes.

3.4 Performance Metrics

For the scenarios defined above, independent simulations are conducted. The main objective of the simulations is to verify whether the performance requirements of FLISR use-case is satisfied or any optimisation in the network parameters, configuration is needed.

Since the communication between FLISR devices and ViSA service is considered to be reliable and much lower latency is required, therefore the following performance metrics are used for the simulation results evaluation.

- **Reliability:** Communication where messages are guaranteed to reach their destination complete and uncorrupted and in the order they were sent.
- **Network Latency:** Transmission time for a measurement or control signal to be sent from point A to point B over the communications network. These times include the end-to-end transport of data over radio interface, processing in base station, transport over backhaul network, and processing in core network.

4. Results analysis

4.1 Results of Scenario 1 with ideal condition

For the Scenario 1, the number of 5G UEs is fixed to 50 and there are three base stations, all covering three sectors individually. Client (5G UE) initiates the data transmission to the server with a periodicity of 100 milliseconds and server (ViSA) receives this data and sends back an acknowledgement (ACK) packet to the client, see Figure 2. Figure 4 shows the Cumulative Distribution Function (CDF) of the delay, which is the time it takes for a data packet to be sent from client's application layer to the server's application layer including processing and retransmission delay. This figure shows the reception delay of MTC traffic without background users.

The first scenario is simulated, where only 5G UEs and ViSA are communicating with each other and generating MTC traffic. The observed latency is between 10.15-11.41 milliseconds as seen in Figure 4.

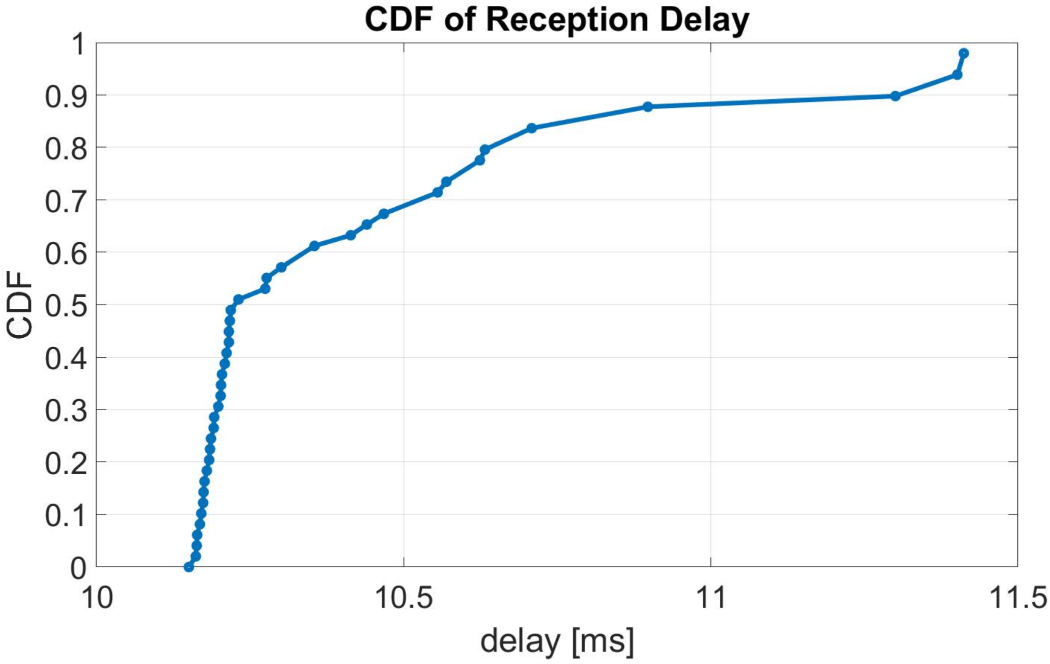

Figure 4: Reception delays of server for the Scenario 1

Both simulations are run multiple times for different simulation times from 10 seconds to 60 seconds. The one with 20 seconds is illustrated here. It is observed that on average, 1.25 radio resources (resource blocks) out of 25 and maximum 20% of the radio resources were being used during the 20 seconds simulation. That means most of the resource blocks were empty during the simulation and more than 50 5G UEs could be served.

Figure 5 show the error rate of Hybrid Automatic Repeat Request (HARQ) transmissions in the first simulation. HARQ is a Medium Access Control (MAC) layer protocol and it is used to reduce the transmission errors and create a more robust system. It performs both forward error-correcting coding and very fast retransmission of erroneous data [4]. During the simulation, around 70,000 transmissions were performed and nearly in 3,000 of them, the packets were not successfully transmitted in the first attempt, but they were retransmitted and successfully received in their second or third attempt out of maximum 5 HARQ attempts per transmission. As seen in Figure 5, the HARQ transmission error rates are changing from 3.9% to 5.2%, with an average error rate of 4.28% for the Scenario 1.

Retransmissions were not enabled neither from application layer protocol (MTC) nor transport layer protocol (UDP), but they were only available on Packet Data Convergence Protocol (PDCP) layer, Radio Link Control (RLC) layer and MAC layer (HARQ). Nevertheless, no packet losses on application layer were observed for Scenario 1 simulation.

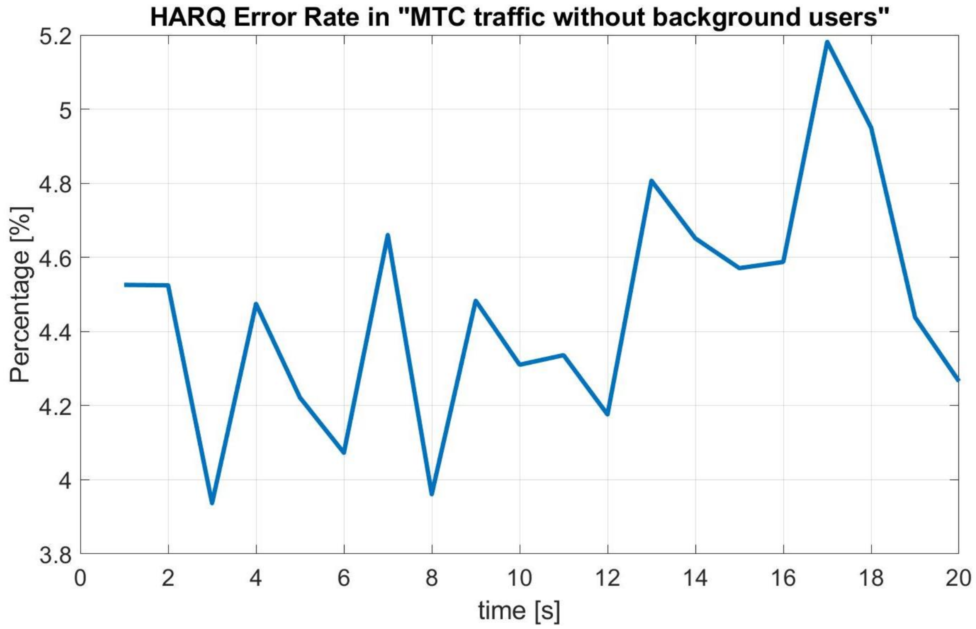

Figure 5: Error rate of HARQ transmissions for the Scenario 1

4.2 Results of Scenario 2 with public mobile users generating mixed traffic

For the Scenario 2, number of 5G UEs is again fixed to 50, but there are also background traffic users, which generate FTP, HTTP and RTP data traffic during their communication. The number of mobile users initially starts from 20, then increases by 15 users every second for each traffic model. Figure 6 shows the CDF of the delay, which is the time it takes for a data packet to be sent from client's application layer to the server's application layer including processing and retransmission delay. This figure shows the reception delay of MTC traffic with background users.

Figure 6 shows that the observed reception delay is between 11.61-25.91 milliseconds.

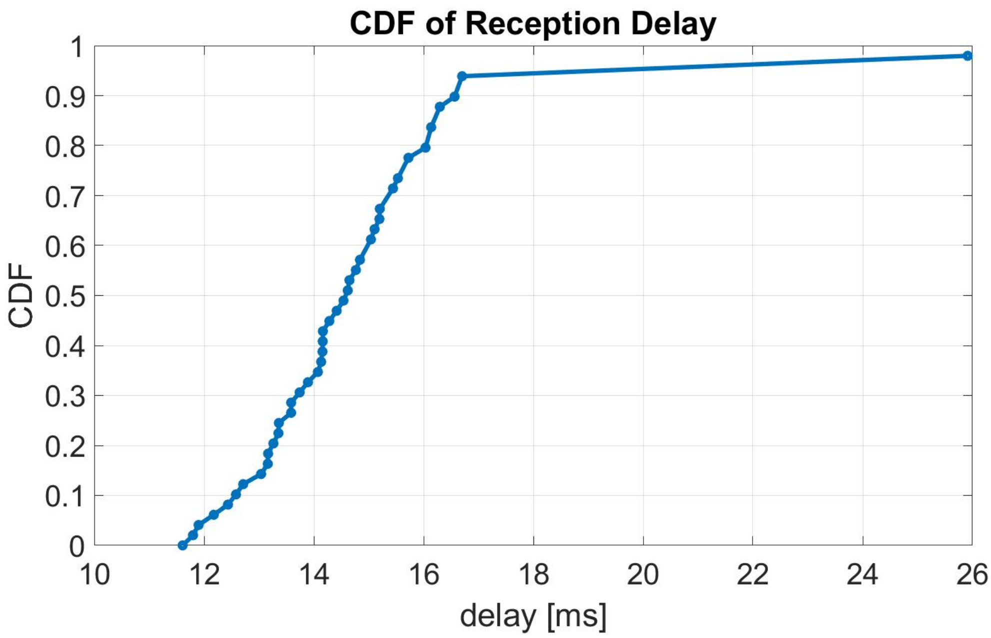

Figure 6: Reception delays of server for the Scenario 2

Both simulations are run multiple times for different simulation times from 10 seconds to 60 seconds. The one with 20 seconds is illustrated here. It is observed that on average, 2.81 radio resources (resource blocks) out of 25 were being used during the 20 seconds simulation. However, compared to the Scenario 1, all of 25 resource blocks were being used only during 4% of the simulation time.

Figure 7 show the error rate of HARQ transmissions in the second simulation. During the simulation, around 80,000 MTC transmissions were performed and nearly in 15,000 of them, the MTC packets were not successfully transmitted in the first attempt, but they were retransmitted and successfully received within maximum 5 HARQ attempts per transmission. The error rates are changing from 9.84% to 25.59% as seen in Figure 7, with an average error rate of 19.05% for the scenario that has MTC traffic with mixed background user traffic.

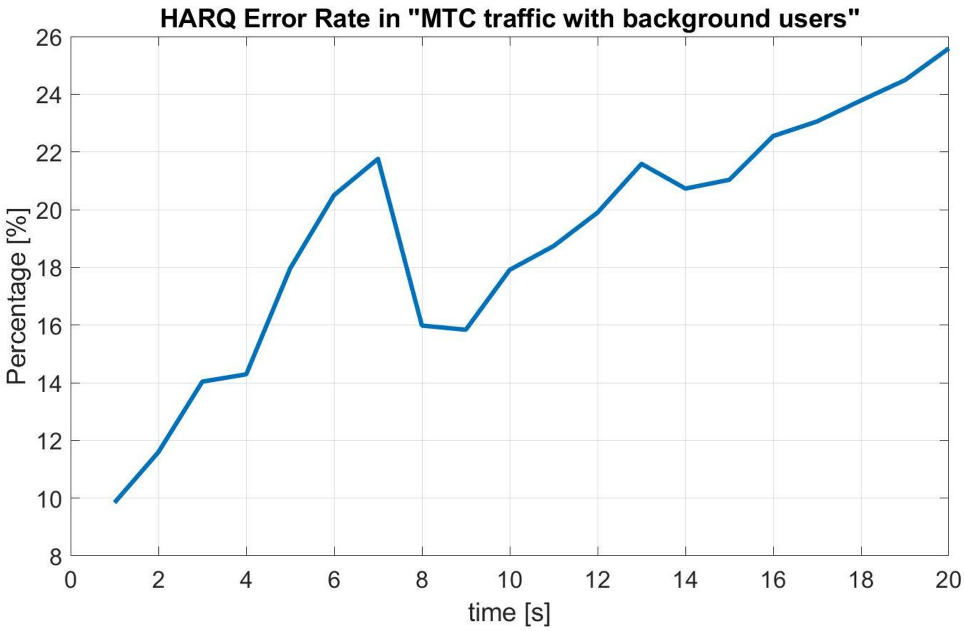

Figure 7: Error rate of HARQ transmissions for the Scenario 2

Figure 8 shows the total number of active users and number of active users per traffic type. The number of MTC users stays the same during the whole simulation, while the number of FTP, VoIP and Web users are continuosly increasing without expiring. At the end of the simulation, there are more than 1000 users in the system. Maximum number of background mobile users are limited with 1000, because the considered use case is for rural area in which load-break switches are located.

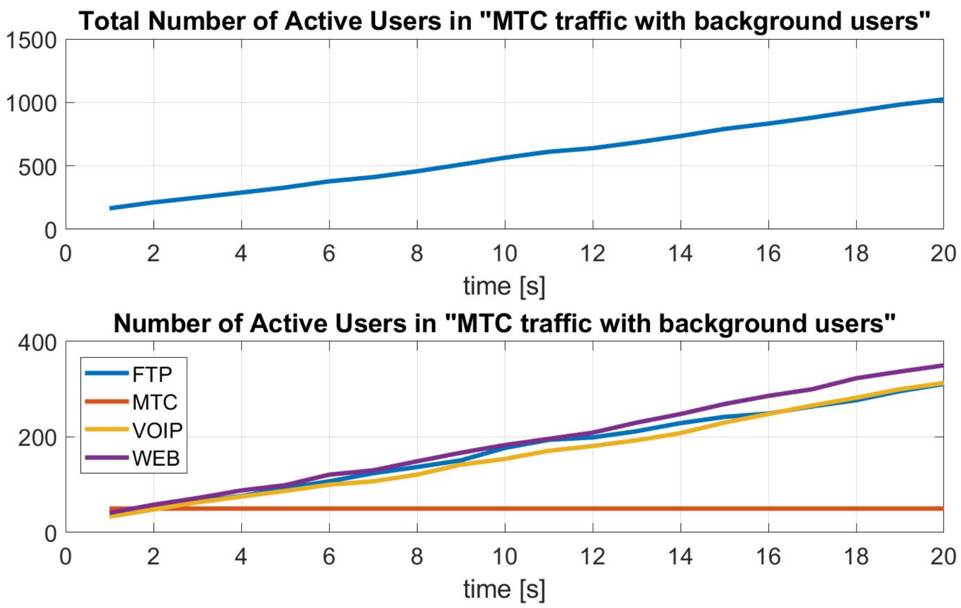

Figure 8: Number of Active Users for the Scenario 2

Retransmissions were not enabled neither from application layer protocol nor transport layer protocol for the MTC traffic users, but they were only available on PDCP layer, RLC layer and

MAC layer (HARQ). Nevertheless, almost no packet losses on application layer were observed for Scenario 2 simulation.

5. Optimisation to reduce latency and increase reliability

5.1 Enabling URLLC feature

The simulation results described above are baseline. The latency can be further decreased by enabling URLLC features [5] up to 1 ms. NR has a large set of functionalities in order to enable URLLC. The features which can be enabled include instant transmission mechanisms to minimise delays for data awaiting transmission, instant pre-emption, prioritisation mechanisms and rapid transmission protocols that minimise feedback delays from a receiver to the transmitter. The vendor specific scheduling algorithms for NR ensures an optimised utilisation of available resources.

5.2 Edge Cloud Computing concept

Edge computing places high-performance compute, storage and network resources as close as possible to end users and devices [6]. Doing so lowers the cost of data transport, decreases latency, and increases locality. Edge computing will take a big portion of today's centralised data centres and cloud and put it in everybody's backyard.

5.3 Enabling Network Slicing

Network slicing is a concept that implies the partitioning of the same physical infrastructure into multiple virtual networks or slices that can be customised to support one or several services. A network slice is built to address a desired behaviour from the network such as security, quality of service, reliability, data-flow isolation etc.

Network slicing is based on Software Defined Networking and Virtualisation. Virtualisation eliminates the dependency on hardware and replaces it with software updates, therefore network slices can be created efficiently and adapted flexibly according to the changing consumer demands and service requirements [7].

In our case, if a network slice is created with the purpose of serving communication between power network and ViSA platform, this communication will be separated from the data traffic of background users. The shared resources will be allocated to this network slice to provide transmission of measurement data from power network to the FLISR service and the actions generated from FLISR service to the load-break switches. Thus, latency that is caused by background traffic users can be eliminated and lower latency values will be achieved for Scenario 2 and reliability of the communication for power electronic devices will be increased.

6. Conclusions

The FLISR use case has put stringent requirements of latency and high reliability on 5G network because of its criticality in the power network. Therefore, in the scope of this Task 3.3, the simulations are conducted for the FLISR use case which is most relevant in terms of latency and reliability requirements. To investigate the behaviour of 5G NR mobile network, two scenarios were considered to run the simulations.

We have observed that the Scenario 2 has shown much higher latency variance as compared to Scenario 1, which is caused by the increase of HARQ retransmissions in Scenario 2. HARQ transmission errors are increased by 5 times in Scenario 2.

In Scenario 1, the number of available radio resources are more than Scenario 2, since number of users, which are using the same number of radio resources (25 resource blocks) with the second scenario, is less than second scenario. It is seen that, the latency in Scenario 2 is 16.57 ms, while the latency in Scenario 1 is only 11.31 ms for 90% of the simulation time. The worst-case scenario has shown maximum latency of up to 12 ms for the Scenario 1 and 26 ms for the Scenario 2.

The analysis of the simulations results has shown that 5G is a promising mobile technology that could be potentially used for such a use case. With the features of 5G such as URLLC, Edge Cloud and Network Slicing, it is possible to decrease the latency up to 1 ms and increase the reliability and availability of the communication network up to 99.999%.

7. List of Figures

8. Bibliography

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9. List of Abbreviations

ACK	Acknowledgement
DRX	Discontinuous Reception
FLISR	Fault Location, Isolation and Service Restoration
FTP	File Transfer Protocol
HARQ	Hybrid Automatic Repeat Request
HTTP	Hyper Text Transfer Protocol
ICT	Information and Communication Technology
IP	Internet Protocol
LTE	Long-Term Evolution
LV	Low Voltage
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MQTT	Message Queuing Telemetry Transport
MTC	Machine Type Communication
MV	Medium Voltage
NR	New Radio
PDCP	Packet Data Convergence Protocol
RLC	Radio Link Control
RTP	Real-Time Transfer Protocol
SDU	Service Data Unit
SOGNO	Service Oriented Grid for the Network of the Future
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UE	User Equipment
URLLC	Ultra-Reliable Low-Latency Communication
ViSA	Virtualised Substation Automation
VoIP	Voice over IP
WP	Work Package