POLITECNICO DI TORINO

Master's Degree in Automotive Engineering

Master's Degree Thesis

Connected Vehicle : Virtual validation of vehicle's cooperative perception

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Abstract

Autonomous and connected vehicle or also could be termed as CASE (Connected cars, Autonomous / Automated driving, Shared and Electric vehicle) is becoming quite normal in academic ecosystem. The vision behind this terminology is to make mobility safer, much more reliable, and emission-free. With the advancement in Artificial Intelligence capabilities and communications technology, the trends are moving at a higher pace. Where 5G, C-V2X are Key harnessing pillar's of AI capabilities with cloud computing in autonomous and connected driving. The V2X in it's all version (V2V, V2I, V2N..etc) could be seen as the third eye of the vehicle, which give access to the information of other vehicles and their surroundings that are not possible otherwise.

This thesis work is part of an EU project called AI@EDGE, from which one of the test cases is being considered for developing this thesis work. The report first discusses the key technological enabler's of AI@EDGE platform based on AI exploitation for various connected vehicle services and functions. The use case related to 'virtual validation of vehicle cooperative perception' would be the main focus of this project work. Given the complexity and costs to support many vehicles in the real world, the use case adopts 5G emulation and virtual traffic simulation environments. Considering different possible specific traffic scenarios, the roundabout is a particularly challenging situation where fluidity and safety are important and will be implemented under the Use case.

To test it in a virtual environment a traffic simulator (SUMO) is being used and the roundabout scenario is built. With the help of TraCI library of SUMO the simulation data are being subscribed and communicated to the edge server. For the purpose of sending and receiving CAM/DENM messages a AMQP client is also integrated with the TraCI based program. To deploy the program along with AMQP client on a TBM, on-board device, the communication specific testing is carried out on a 5G emulation bench. Various test cases such as cell handover, dual-connectivity, carrier aggregation, and MIMO etc; related to cellular network LTE/5G are being performed on a network based emulation HIL environment. In addition, the network throughput testing is also carried out for the DUT (Device Under Test), which is equipped with C-V2X wave stack. Finally, the feasibility of a virtual validation platform for vehicular perception is being assessed based on the developed capabilities and results from the HIL testing.

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Acronyms

AI

Artificial Intelligence

AMQP

Advanced Message Queuing protocol

API

Application Programming Interface

AV

Autonomous Vehicle

BSM

Basic Service Message

CAM

Cooperative Awareness Message

CA

Carrier Aggregation

DENM

Decentralized Environmental Notification Message

DSRC

Dedicated Short Range Communication

EN-DC

E-UTRAN New Radio – Dual Connectivity

GUI

Graphical user interface

GNSS

Global Navigation Satellite System

HO

Handover

ITS

Intelligent Transport Systems

MIMO

Multiple Input and Multiple Output

NR

New Radio

NSA

Non-Standalone

OSM

Open Street Map

RSU

Road Side Unit

SUMO

Simulator of Urban Mobility

SA

Standalone

TCP

Transmission Control Protocol

TraCI

Traffic Control Interface

V2I

Vehicle-to-Infrastructure

V2V

Vehicle-to-Vehicle

V2N

Vehicle-to-Network

V2X

Vehicle-to-Everything

XML

Extensible Markup Language

Chapter 1

Introduction

If the cooperative applications of vehicular perceptions within the ITS (Intelligent Transportation Systems) reach sufficient maturity and readiness, then the dream of the future connected vehicle will come true. Which would ultimately result in a decrease in fatalities and accidents on the road, an increase in traffic efficiency, a decrease in the carbon footprint of road transportation, and an overall improvement in user safety and experience. Under the ITS framework, significant efforts have been made in this direction. This paradigm provides a bundle of applications and services for all transportation system needs, and not just road safety and traffic system efficiency. The automotive industry, policymakers, and academic researchers are working together to standardize the ITS framework's various dimensions, all of which have the potential to benefit ecosystems as a whole.

The role of telecommunication technology in vehicular applications envisioned for the short, medium and long terms. Furthermore these could be categorized in the following groups [1]:

- *Safety.* The goal of these kind of applications is to cut down on accidents and protect the lives of people in cars and on foot. Collision avoidance, accident notification, and the approaching emergency vehicle are some examples.

- *Traffic efficiency.* Applications that increase the capacity of the road network and shorten travel times fall into this category. Variable speed limits, dynamic management of road intersections, and congestion detection and mitigation are just a few examples.

- *Infotainment.* Primarily focused on providing multimedia, Internet access, and value-added comfort applications. Video on demand, video conferencing, and context-aware touristic guidance are a few examples.

Many researchers say that it is not scalable to design a new protocol for each of the aforementioned application areas in order to support these multiple services and functions in the same communication system. Almost all ITS applications require a communication strategy that falls into one of the two categories outlined below, with the exception of a few services:

- Periodic status exchange. messages that applications need to know about a vehicle's or roadside terminal's status. Most of the time, these exchanges are data packets sent by a terminal on a regular basis that include information like location, speed, or the terminal's identifier.

- Asynchronous notifications.. These messages are sent to inform people about a particular event. Due to the significance of the information being transmitted, the timely delivery of these messages to a single terminal or a group of terminals is typically a crucial requirement in contrast to the previous status messages.

Due to the proliferation of numerous ITS applications requiring the usage of these two communication strategies, according to the ISO/ETSI reference ITS communication architecture (Kosch et al., 2009; European Telecommunications Standards Institute, 2010a; International Organization for Standardization, 2013, [2]), ETSI has defined two basic messaging services (also known as facilities) included in the communications stack as a common reusable middle-ware. These are the Cooperative Awareness Basic Service (European Telecommunications Standards Institute, 2011), defining the Cooperative Awareness Message (CAM), and the Decentralized Environmental Notification Basic Service (European Telecommunications Standards Institute, 2010b), which specifies the Decentralized Environmental Notification Message (DENM).

Consideration one of the test cases from the EU project AI@EDGE [3], which is the basis for this thesis work. The report begins by discussing the primary technological enablers of the AI@EDGE platform, which is based on AI exploitation for various connected vehicle services and functions. The use case titled "virtual validation of vehicle cooperative perception" would be the project's primary focus. Due to the difficulty and expense of supporting a large number of vehicles in the real world, the use case makes use of virtual traffic simulation environments and 5G emulation. The roundabout will be implemented in accordance with the Use case because it is a particularly challenging situation in which safety and fluidity are essential.

Agents and artificial intelligence form the basis of the use case logic, which employs reinforcement learning. Each Agent is a digital twin of a vehicle in the Use case context. The AI@EDGE Connect-Compute platform's network and service automation capabilities will be utilized in this strategy. In terms of the 5G stack, a 5G network emulator and the AI@EDGE platform's 5G network core will be interfaced to enable testing of a wider variety of scenarios and configurations.

When dealing with mixed real- and virtual-traffic situations and creating such a scenario, cooperative perception becomes more complicated. Traffic simulators and dynamic driving simulators will be connected to design, implement, and test the digital twinning of a mix of real and emulated vehicles. The objective of the testbed is to establish a Virtual Validation environment that is geographically dispersed in order to facilitate cooperative maneuvers between vehicles that collect and share information with one another.

Chapter 2

AI@EDGE

Autonomous and connected vehicles of the future will rely heavily on Artificial Intelligence, one of Industry 4.0's central pillars. Numerous authorities and policy-makers have acknowledged this trend, stating that intelligent, high-performance, secure, and dependable networks are necessary for the development and evolution of the multi-service Next generation Internet (NGI). In the last few years, AI-driven systems that require high performance to function accurately and safely have made significant progress. In addition, the high quality of services and the integration of such systems with numerous applications require autonomous decision-making capabilities.

The difficulties associated with utilizing the idea of "reusable, secure, and trust-worthy AI for network automation" are the focus of AI@EDGE. Academics and innovative small and medium-sized enterprises (SMEs) commit to achieving an EU-wide impact on aspects of the AI-for-networks and networks-for-AI paradigms that are relevant to the industry beyond 5G systems in AI@EDGE European industries. **Cooperative perception for vehicular networks, secure, multi-stakeholder AI for IIoT, aerial infrastructure inspections, and in-flight entertainment** are the uses cases that are shown in the Figure 2.1, targeted by AI@EDGE to maximise the commercial, societal, and environmental impact [4]

AI@EDGE aims for significant advancements in two fields to accomplish its objective:i) general-purpose frameworks for closed-loop network automation that can support flexible and programmable pipelines for the creation, use, and modification of AI/ML models that are reliable, reusable, and secure;and (ii) a converged connect-compute platform for creating and managing end-to-end slices that are resilient, elastic, and secure, and can support a wide variety of AI-enabled network

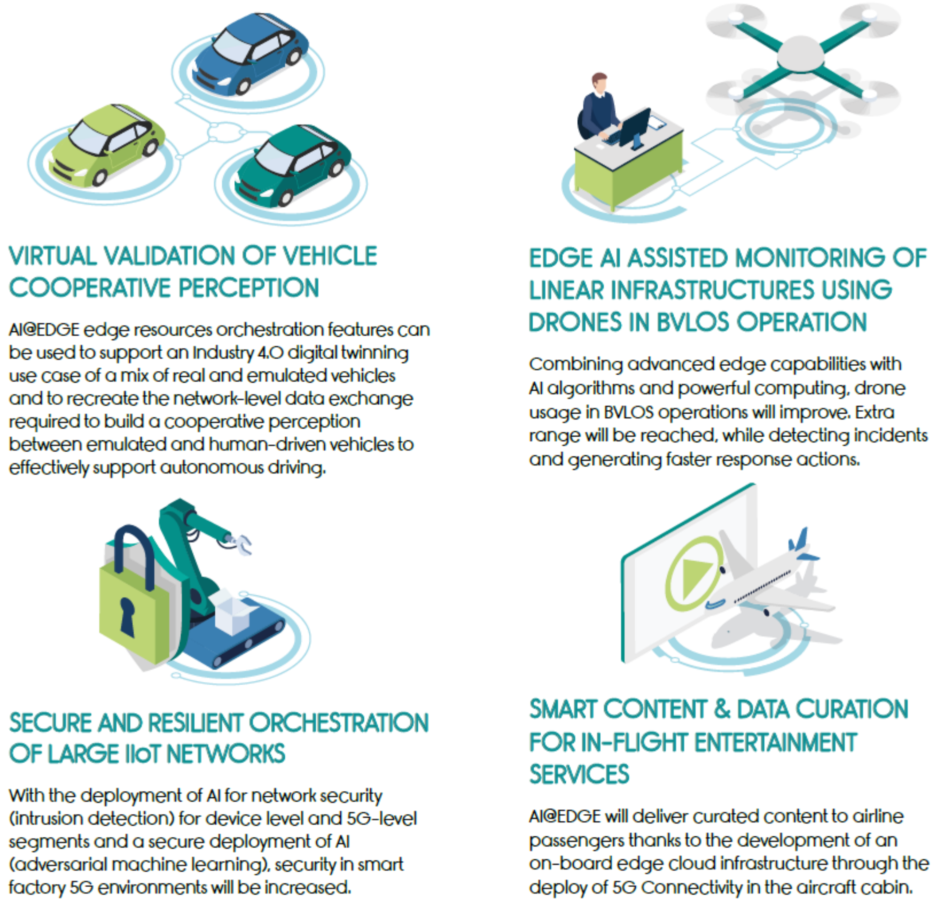


Figure 2.1: AI@EDGE:four use cases, [5]

applications.

The goal to be achieved under this flagship project is to *Leverage the concept of reusable, secure, and trustworthy AI for network automation to achieve an EU-wide impact on industry-relevant aspects of the in multi-stakeholders' environments* [5].

5G is a major technological shift in the direction of achieving this objective: Numerous Key Performance Indicators (KPIs) like latency, throughput, reliability, and node capacity all benefit from 5G's superior performance. However, this would necessitate a significant economic convergence among all stakeholders, particularly telecom and cloud computing service providers. With the use of 5G features like network virtualization, slicing, edge computing, and overall improved connectivity, there appear to be a number of applications in this project that are related to the four use cases. By providing cutting-edge services like fast connections, data processing, machine-to-machine communication, and overall Quality of Service (QoS), these features would support some of AI@EDGE's most important aspects and pillars. However, in order for this technological leap of faith to become a reality, there are obstacles to be overcome.

The most difficult problem is managing the increasing complexity of controlling and optimizing the entire 5G infrastructure, which includes issues with end-to-end security that would be exposed through the introduction of AI and ML technologies.

There are two avenues of action in the AI@EDGE strategy for addressing the aforementioned issues. A network and service automation platform that is able to support flexible and programmable pipelines for the creation, utilization, and adaptation of secure and privacy-aware AI/ML models will first be designed, prototype, and validated. Second, we will orchestrate AI-enabled end-to-end applications with this network and service automation platform. From a business and technological convergence perspective, the six technological breakthroughs would ultimately lead to a smoother convergence of the entire use case ecosystem.

The AI@EDGE project six breakthroughs and also shown in the Figure 2.2 :

1. *AI/ML for closed loop automation;*
2. *Privacy preserving, machine learning for multi-stakeholder environments;*
3. *Distributed and decentralized connect-compute platform;*
4. *Provisioning of AI-enabled applications;*
5. *Hardware-accelerated serverless platform for AI/ML;*
6. *Cross-layer, multi-connectivity and dis-aggregated radio access.*

2.1 Overview

The innovative work under this project would touch many critical areas including industrial production, e-health, smart homes and cities, self driving vehicles and drones. One of the important application of AI@EDGE is in Autonomous vehicles, where the key enablers are Virtual and Augmented reality (VR/AR), real-time computer vision with the help of cloud and edge computing in various connectivity dependent services or function especially in ADAS. However, these capabilities in the Next Generation Internet Applications will hugely rely on intensive AI, ML based compute platform, and the overall performance and reliability of connectivity

Figure 2.2: AI@EDGE:Six Technological pillars, [5]

in the mobility. Therefore, the main corner stone of AI@EDGE is the efficient and effective management of Multi-access Edge Computing (MEC) resources. Where, 4G systems are already providing the effective connectivity and capacity, and further 5G would bring edge resources and end-to-end slicing. Achieving AI/ML on a large scale would be a tough task for many reasons. First, the existing methods for intercommunication are designed for a fixed uniform cloud whereas the targeted applications and operations involves millions of IoT devices are heterogeneously distributed. Second, in a very mobile surroundings, system heterogeneity's and connectivity problems (e.g. variable channel conditions, handovers, and churn) produce uncertainty in knowing once, wherever and the way a resource can be accessed and be expected to be available for performing the tasks of a distributed method. Third, the data privacy and the learned model integrity shall not be compromised while sharing resources and their deployment, i.e. to ensuring the end-to end security in the overall resource deployment process.

2.2 Objective and concept

In order to roll out large-scale cloud and edge computing resources and accompanying infrastructures securely, reliably, and autonomously, AI@EDGE will create a platform and the necessary tools. In a serverless computing paradigm, the network, storage, and compute infrastructures—which are the heterogeneous MEC resources—are essentially touched zero times. The use of cross-layer, multi-connectivity radio access as well as native hardware acceleration (such as GPU and FPGA) will be integrated with this.

The AI@EDGE platform is focused on achieving three primary objectives:

1. *Scalability will be achieved by combining a serverless co-fabric (compute-control) with a distributed messaging architecture and dynamically deploying data-driven AI functionalities;*

2. *Adaptability will be realized through the use of adaptive management functions based on data-driven methodologies and learning models, implementing security models and intelligent countermeasures, infrastructure resilience, and efficient resource usage;*

3. *Automation will be discussed in terms of identifying efficient processes, utilizing developed systems concepts and methods, and putting into practice scalable and adaptable management functions;*

Four use cases from the following domains—Connected and Automated Mobility

(CAM), Industrial Internet of Things (IIoT), In-Flight Entertainment (IFE), and Unmanned Aerial Vehicle (UAV) for Industrial Operations—will be used to validate the outcomes of AI@EDGE. The AI@EDGE Use Cases will address a number of significant challenges, including ultra low latency, secure communication, faster connection, resilience and service continuity while mobility. At the conclusion of the project, the anticipation is such that the AI@EDGE platform and developed concepts will play a significant role in the 5G ecosystem.

2.3 AI@EDGE Concept and methodology

The AI@EDGE platform is intended for the automatic deployment of a secure and adaptive compute layer's. The platform will include the essential APIs to enable the deployment of large-scale compute virtual overlays (interconnected VMs, containers, and serverless instances) across multi-connected heterogeneous infrastructures, supporting a variety of upcoming key applications, as shown in Figure 2.3.

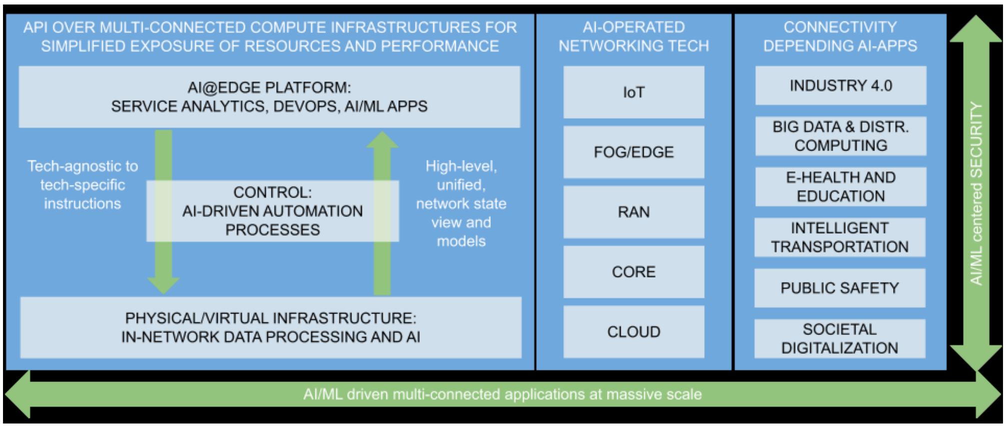


Figure 2.3: AI@EDGE:Functional overview of the platform and project scope, [4]

AI@EDGE will develop a connect-compute fabric for managing resilient, elastic, and secure end-to-end slices, specifically by exploiting the serverless paradigm. Such slices will be able to accommodate a wide variety of AI-enabled applications. To guarantee that each stakeholder can utilize the platform without releasing private information, privacy-preserving machine learning and trustworthy networking techniques will be used. The reference AI@EDGE AI-enabled connect compute platform is shown in Figure 2.4 and will be covered in more detail in the next sections [6].

As shown in Figure 2.2, the AI@EDGE framework is focused on achieving six

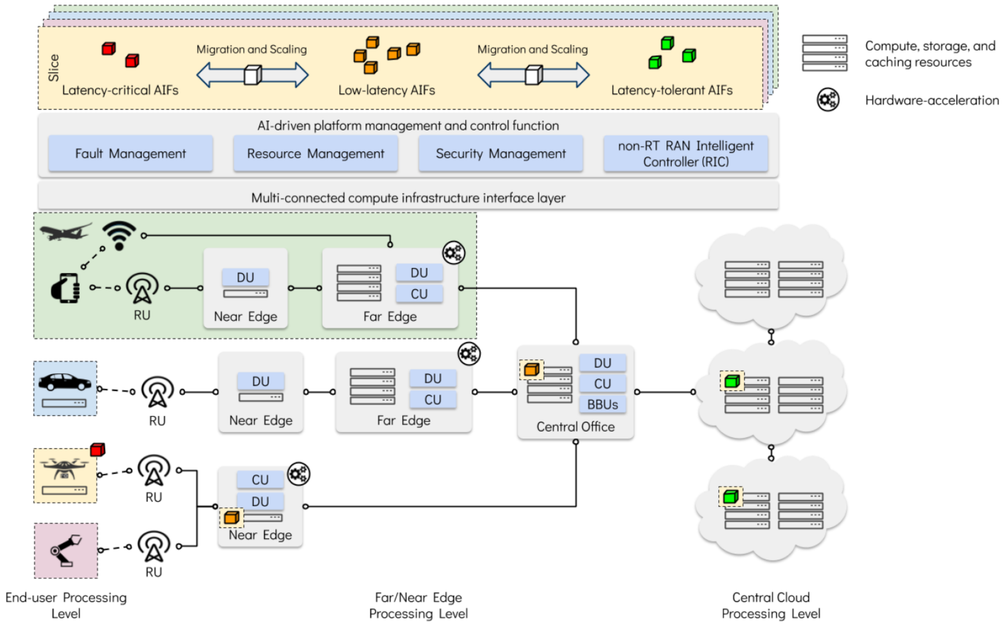


Figure 2.4: AI@EDGE: AI-enabled connect-compute platform, [6]

major achievements. The upcoming sub-sections go into much more detail about those innovations and tries to explain how they apply to the four specified use cases. These six breakthroughs can be broadly divided into two categories: the first is the integration of AI/ML solutions into 5G networks (breakthroughs 1 and 2), while the second category (breakthroughs 3 to 6) focuses on distributed, hardware-accelerated connect-compute platforms.

2.3.1 AI/ML for closed loop automation

Low latency is one of the key requirements for networking application development. MEC technology, which is still in its infancy, is crucial for achieving this demand. To create AI-Driven applications at an extremely large scale, it is not entirely feasible to move the majority of computing operations to the cloud. Therefore, as Internet technology, applications, and businesses improve, moving these compute jobs to the edge opens up a path to reach the domain's astonishing size. acknowledging the interdependence between AI-based apps, AI-driven network operations, and service management. As a result, the scale and speed at which computing resources must be assigned and scaled necessitates unprecedented levels of full-fledged automation, with at least 99 percent of service management and network operation being automated and only at most 1 percent requiring human interaction (in cases when, e.g., failures, cannot be automatically resolved).

Building a platform for the automated deployment of AI/ML compute infrastructure across MEC nodes is the idea behind AI@EDGE. Such a platform must have three key components: 1) information-efficient and high-fidelity local models that reflect the performance and resource availability of local nodes, including their proximity in terms of latency; 2) quick data processing pipelines and data dissemination strategies with minimal data transmission overhead; and 3) AI/ML-based functions for automated infrastructure control. It is essential to address these critical issues in order to enable distributed and federated learning at scale.

The deployment of distributed processes is challenging due to the instability of mobile edge resources, comprising both fixed edge and mobile UEs with computing resources, in terms of network performance and resource availability. The monitoring methods now in use are insufficient to forecast the performance and availability of networking and computing resources under such a wide range of circumstances. The cost of monitoring billions of devices with the level of accuracy needed for efficient resource use would be prohibitive and incredibly ineffective. Instead, AI@EDGE will create cutting-edge strategies like federated learning and local modeling for exchanging information about the network performance and resource availability. Such methods are relevant because they enable high-fidelity models that can be used for automated decision making with significantly better prediction performance, leading to improved resource usage, energy efficiency, and the ability to adhere to stricter service level objectives, in addition to reducing the volume of data needed for monitoring and information exchange (SLOs).

A well-researched area for cloud infrastructures is a quick data processing and disseminating of partial outcomes for distributed and federated learning. The dominant paradigm in use today relies on a server to coordinate the output among a group of workers. Reduced overhead from model parameter updates between the parameter server and workers has been a major focus of research. Regarding data transaction overhead, durability, and convergence rate for the relevant learning algorithm, the dissemination approach is crucial. Since the aforementioned paradigm is primarily intended for fixed cloud compute infrastructures, novel dissemination strategies tailored to MEC infrastructures—characterized by resource volatility and heterogeneity in performance and capacity—are necessary in a scenario where millions of algorithms of various dimensions would be executed at scale over volatile resources. Beyond the server-worker paradigm, current research on efficient and scalable AI/ML virtual learning infrastructures will be advanced by AI@EDGE, with a focus on efficient information exchange appropriate for MEC.

For present and new networking technologies, such as MEC, 5G, and anything beyond 5G, to reach their full potential, automated, zero-touch network operation and service management is essential. Network automation and controls have been studied for decades, but the current situation is different because significant machine learning advancements, along with increased computational power, infrastructure processing power, link bandwidth, and distributed computing innovation, open the door to practically usable AI functions. Existing machine learning techniques, however, are still essentially focused on offline, centralized processing and are not intended for particular network operating and service management needs. Based on the two aforementioned earlier research concepts, we will create ML-concepts in AI@EDGE that are appropriate for the operation of distributed systems and resilient service management (mainly fault and resource management). The development of quick, scalable, and adaptable machine learning-based methods will be our main focus. These methods will include a combination of deep learning techniques like (conditional) Generative Adversarial Networks (GAN), Long Short-Term Memory (LSTM), Gated Recurrent Units (GRU), Deep Reinforcement Learning (DRL), and Graph Neural Networks (GNN). This entails investigating representation learning, attention mechanisms, pointer networks, etc. in order to develop ML-methods that are practically appropriate for 5G MEC circumstances. Overall, the project's goal is to have gathered significant knowledge on ML design patterns that are practically useful for zero-touch management of distributed systems and networking infrastructures [4, 6, 7].

2.3.2 Secure, reusable, and resilient machine learning for multi-stakeholder environments

The AI@EDGE architecture is founded on the principle of security by design. Frameworks for intrusion detection algorithms will be created, put into use, and assessed. The ML methodology we envision follows a distributed paradigm giving special care to cooperation and privacy aspects in multi-stakeholder environments. Detection speed and intrusion resistance, model propagation and computational efficiency, and privacy of the parameters exchanged are the three main research questions that will be covered.

In the first place, the benefit of participation of an assortment of edge devices regarding the identification capacities, recognition speed (stay time) and interruption flexibility (for example if there should arise an occurrence of compromised edge devices) is inspected. In addition to being able to survive the compromise of edge devices and related attack scenarios, such as adversarial machine learning and poisoning attacks, that are a part of the detection sensor network, the proposed architecture will be able to identify attacks promptly and reliably. Adversarial machine learning is a strategy where unsafe information is made to deceive AI calculations. To make an AI model strong against Adversarial machine learning assaults, weaknesses in the model will be recognized and countermeasures will be created.

When a foe compromises a member edge hub and feeds manipulated information to a retraining AI model, harmful attacks may occur. A nearby exception recognition based sifting was put forth in writing as a moderation; further relief measures will be outlined. Ongoing examination demonstrates the way that blockchain and conveyed record advancements can be utilized to give secure review trails as an assurance system in ill-disposed AI situations. These outcomes will be utilized to expand the interruption strength of the proposed framework. Early recognition also enables the automated design of countermeasures in addition to identification. Albeit full meaning of countermeasures without any preparation is processing serious (for instance redistributing assets or rerouting traffic in light of enhancement calculations), developing an information data set including pattern situations will accelerate against the assaults.

Second, the zero-day detection capabilities, detection model propagation, and computational efficiency of the edge device network's federated learning capabilities are examined.The proposed architecture will be able to efficiently update and propagate the learning detection models within the detection sensor network and adapt to previously unknown attack types, long-term attacks, distributed attacks (security-related events are observed at various edge devices), and distributed attacks. Given the anticipated growing reliance on smartphones and IoT devices for edge applications, mobile device-level botnet detection is another particular area of attack search;We will use public traces to investigate this area.A common machine learning model can be created using federated learning by combining local models collected from edge devices without disclosing any data and maintaining privacy constraints. Using the relevant local data, an initial model is trained on the edge devices, and improved models are later combined into a global model. Although federated learning is a promising strategy, there are numerous issues that must be resolved. AI@EDGE will investigate how parameters and hyper-parameters can be changed and how heterogeneous datasets can be combined despite local biases or temporal offsets.

Third, the privacy aspects of federated learning architectures are evaluated in relation to the information gain for the local threat model versus the parameters exchanged between edge devices, which may be operated by different parties.Since no stakeholder will be able to extract information that is relevant to the business from the exchanged detection model parameters, massive parameter exchange will be possible, which will result in improved detection capabilities [4, 6, 7, 8, 9].

2.3.3 Distributed and decentralized serverless connect-compute platform

Using well-established cloud-native paradigms, AI@EDGE will combine FaaS/serverless computing, hardware acceleration (GPU, FPGA, and CPU), and a cross-layer, multi-connectivity-enabled dis-aggregated RAN into a single connect-compute platform for developers.

As a cloud computing execution model that frees developers and service providers from managing resource allocation and enables them to concentrate solely on their core activities—managing their own code and services—the serverless and FaaS computing paradigms are currently gaining traction.The infrastructure provider is in charge of managing the underlying infrastructure and dynamically allocating sufficient resources to automatically scale applications and services in response to demand in this model. Serverless computing is an appropriate technology for a number of use cases, including stream data processing, chat-bots, stateless HTTP applications, etc., because it offers a variety of advantages over traditional computing. These advantages include the ability to scale to zero without charging customers for idle time, zero server management, and auto-scaling.

AI@EDGE will provide telecom operators with the means to evolve their networks toward a hybrid multi-cloud-native paradigm by making the concepts of serverless computing and FaaS first-class citizens in the 5G ecosystem. This will support significantly increased developer productivity and provide solutions to the unsolved problem of deploying applications that can easily leverage advanced 5G capabilities.In addition, AI@EDGE will define a set of open APIs that will enable the neutral host paradigm by allowing mobile network operators (including virtual ones), vertical industries, service providers, and end users to interact with the network.

Application and application-intent models capable of capturing the heterogeneity in the application building domain will be added to the existing ETSI MEC/NFV architectures as part of AI@EDGE.We will add serverless technologies to the Cloud Native Application Bundling (CNAB) initiative in AI@EDGE. Currently, CNAB only supports VMs and containers.Finally, AI@EDGE will implement intelligent control and management of applications and services deployed over the serverless, decentralized, and distributed AI@EDGE platform by utilizing the context and metadata derived from application and application-intent modeling studies [4, 6, 7, 8, 9].

2.3.4 Provisioning of AI-enabled applications

With AI@EDGE, the entire set of computation, storage, and network capabilities required to provision AI-enabled applications over a distributed computing platform with dynamically orchestrated applications and services will be transformed. AI@EDGE will innovate in two areas to achieve this breakthrough: (i) AIFs' Reference Models and ii) AIFs' End-to-End Orchestration

Reference models for AIFs. A reference model for AIFs that is able to capture and represent the heterogeneity of AIFs at various levels of the technology stack will be developed by AI@EDGE.Following well-known, cutting-edge ontology engineering techniques, this will be constructed as a network of modular ontologies that are interconnected and will be implemented in standard knowledge representation languages (e.g. OWL). A special focus will be placed on not only describing AIFs f rom the perspective of their functionality, which can be found in other catalogs but also taking into account any additional constraints that are required to support their dynamic orchestration and any additional capabilities that complement the AIFs, such as computation, communication, storage, and hardware acceleration. In a similar vein, the reference model ought to have the capacity to describe strategies for facilitating the provisioning of AI-enabled WP5 applications. Additionally, this task will produce a catalog of AIFs, which will be populated with AIFs from AI@EDGE and other sources (such as the AI4EU platform at https://www.ai4eu.eu/).

End-to-end orchestration of AIFs. The provision of resources across multiple administrative and technological domains is required for the large-scale deployment of AI-enabled applications.As a result, it is crucial to divide applications made up of multiple AIFs into multiple domains based on the requirements of each AIF.AI@EDGE will begin with "de facto" orchestration standards for cloud and edge services like Docker and Kubernetes to achieve this objective.and from their emerging variants, such as FaaS, to accommodate increasingly extreme provisioning scenarios for software and hardware resources.AI@EDGE will investigate novel approaches to the end-to-end orchestration of AI-enabled applications in light of the heterogeneity and complexity of the edge computing platforms that are currently in use, particularly when they are as extensive as the one that is anticipated to be the focus of this project.Utilizing the AI@EDGE network automation platform, monitoring solutions that address the particular requirements of optimized hardware, edge devices, communication infrastructures, and cloud services will be designed and developed in order to accomplish this objective.The Quality of Service (QoS) indicators that provide insight into the correct behavior of multiple AIFs orchestrated and linked to create complex AI-enabled applications will be collected by the monitoring subsystem.Traditional IT system metrics, such as performance, will be included in the quality indicators, as will specific items to verify that AIFs operate in accordance with their initial design.At the same time, the quality indicators and metrics that have been collected will guarantee that orchestrated AIFs can be managed and even incorporated with AI-based features for abnormal situation detection and predictive maintenance [4, 6, 7, 8, 9, 10].

2.3.5 Hardware accelerated serverless platform for AI/ML

AI@EDGE will enable multiple stakeholders to deploy sensitive and computationally demanding workloads on the same platform by utilizing the most recent hardware acceleration solutions (FPGA, GPU, and CPU) and privacy-preserving machine learning.Advanced processing scenarios that utilize acceleration can be utilized in far more complex processing functions directly on the edge of the network by utilizing the capabilities of heterogeneous acceleration platforms.FPGA-based hardware accelerators are a promising solution for the network's edge to ensure optimal performance, energy, and cost efficiency in the execution of specialized functions (such as real-time network intensive processing), but GPUs are currently the de facto solution for AI and ML workload acceleration.To increase resource efficiency across the computing continuum, AI@EDGE will investigate resource-aware hardware acceleration techniques, as well as methods for taming accelerator heterogeneity and making it possible for accelerators to integrate with serverless computing concepts. This will result in a unified technology and tool stack that can allocate resources and migrate functionality between accelerators on various edge devices or between edge and cloud infrastructures [4, 6, 7, 8, 9, 10].

2.3.6 Cross-layer, multi-connectivity, and disaggregated radio access

From a connectivity perspective, it is common knowledge that supporting use cases beyond 5G will necessitate vastly distinct communication paradigms.Dual-connectivity methods, for instance, were first implemented in Release 15 of 3GPP radio access technologies to make Ultra-Reliable Low Latency Communications (URLLC) possible. This improved support for IIoT use cases was the result of this introduction.Data duplication at the PDCP layer is used in the current version of the dual-connectivity paradigm to improve reliability (in terms of the packet delivery ratio) without increasing latency.Its poor performance when it comes to using radio resources (data is replicated even when it is not necessary) is its primary flaw.In 3GPP Release 16, dual connectivity received significant enhancements, and in 3GPP Release 17, these enhancements will continue.

Based on heterogeneous radio access technologies, such as 3GPP (5G and beyond) and non-3GPP (e.g., Wi-Fi) technologies, we will investigate an evolutionary path from current dual-connectivity solutions to future multi-node connectivity approaches in AI@EDGE.The investigation of various user-plane data replication strategies that involve various protocol stack layers will take place.To support link bonding with non-3GPP interfaces, we will specifically consider user-plane traffic duplication at layers 3 and 4, particularly with Multi-Path TCP (MP-TCP), in order to provide mobile devices with the same information over distinct wireless links.The overarching objective is to maximize radio resource utilization while simultaneously increasing throughput and reliability without sacrificing latency. A multi-path AIF, which will serve as a multi-path Conversion Point (MCP) on the way to the application servers, will be in charge of integrating the various traffic flows received from the terminal across multiple paths.Throughout the project, we will investigate traffic load-balancing as well as the most effective MCP placement and scaling [4, 6, 7, 8, 9, 10].

2.4 Use Cases

The project addresses the following use-cases [10]:

UC1: Virtual Validation of Vehicle Cooperative Perception. Vehicles exchange in real-time their trajectories and use artificial intelligence models to understand the surrounding environment and predict possible dangers.

UC2: Secure and Resilient Orchestration of Large Industrial IoT Networks. Smart factory communication and computing infrastructures, involving a large and heterogeneous set of industrial actuators, sensors, specialized application servers and network fabric, are designed to be secure and resilient against faults, attacks, bugs and load variations.

UC3: Edge AI Assisted Monitoring of Linear Infrastructures in Beyond Visual Line of Sight Operations. Monitoring drones exchange data with ground computing facilities to detect anomalies, by using 3D environment reconstruction and data fusion to guide drone mobility and operations along large distances.

UC4: Smart Content and Data Creation for In-Flight Entertainment Services. High definition multimedia content is offered to passengers by dynamically computing the content of interest and aggregating 3GPP and non-3GPP network technologies to reach high throughput and reliability.

To evaluate the capabilities and goals associated with each use case, a distinct framework and requirements are required, as are close-to-real scenarios under production conditions. The UC1 use case is the primary focus of this thesis project,

Technological Enabler	UC1	UC2	UC3	UC4
Distributed and decentralized serverless connect-compute platform	Y	Y	Y	Y
AI-enabled application provisioning	Y	Y	Y	Y
Cross-layer, multi-connectivity radio access				Y
Hardware accelerated serverless platform for AI/ML	Y	Y	Y	Y
Network and service automation platform	Y	Y	Y	
Secure, reusable, and resilient machine learning for multi-stakeholder environments		Y		

Table 2.1: Technological enablers exploited by each use case

out of the four cases. We will talk about UC1's motivation, goals, and overall framework in subsequent sections. In particular, it will be categorized into various parts and more empathize would be given to those parts which are completed under this thesis project timeline and its possible objectives.

2.4.1 Use case 1 : Virtual Validation of Vehicle Cooperative Perception.

Cooperative perception consists of a group of vehicles in a defined region of a traffic scenario, where they cooperate with each other, in other words, they exchange data about their ongoing and futuristic intended trajectories. Shared data is gathered in a decentralized way at the edge of the network. Then the data is being processed and the map surrounding scenarios is created, which then used by Artificial Intelligence Functions (AIFs), in order to predict possible hazardous situations such as collisions, road damages, and potential accidents. The entire closed loop system development is very complex and challenging to integrate, off-course which involved huge costs at stake for the UC platform development. Therefore, UC1 adopts an environment-based emulation technique that could be scaled with such complexity and be able to perform all different kinds of exhaustive tests that can be reproduced.

In AI@EDGE, the 5G and AI-based connect-compute framework provide a traffic system with the capabilities necessary to eventually increase vehicular fluidity and make roads safer. A roundabout scenario is one of the most difficult and potentially dangerous situations, making it difficult to maintain safety and fluidity. As a result, this difficult circumstance is being thought about for UC1, which also has the option to conduct this test on mixed vehicles with automated, manual, and semi-automated vehicles in a roundabout. Validating a vehicle's cooperative perception is difficult because of the large number of vehicles involved in the roundabout scenario, which necessitates (i) near-real-time scenario detection. ii) transmit and receive the sensed data to and from the cloud and other vehicles. iii) disseminating the intended trajectories to other vehicles, which also involves protecting privacy and safety. When mixed traffic scenarios included both automated and human-driven vehicles, the complexity grows even more. Therefore, the simulation environment is not sufficient to replicate these mixed traffic scenarios. As a result, the strategy in this use case is to link a traffic simulator like SUMO with a dynamic driving simulator that is controlled by a human driver in the loop. At the information sharing level, a digital twining framework would be used here to combine the real and simulated vehicles. As depicted in Figure 2.5 , the objective is to establish a data exchange at the network level to facilitate cooperative perception between the virtual and emulated scenarios and the human in the loop.

As can be seen in Table 2.1, the AI-enabled application provisioning features and the distributed and decentralized serverless connect-compute platform are the two main technological pillars that the AI-enabled digital twining would take advantage of. In addition, the AI@EDGE network and service automation functions will also play a significant role in the digital twining procedure in a radio network environment that is extremely dynamic. The network automation platform will be able to test on a 5G emulation network, allowing for the validation of a wider range of connectivity-related testing scenarios, such as connection failure, mobility, and the handover process on LTE and 5G both RFs, which will be discussed in the following chapter regarding 5G emulation. The ability to anticipate the maneuvers chosen by a human driver in the driving simulator, which would be twinned to the virtual traffic simulator, is one of the most significant value additions that digital twining brings to this mixed environment of virtual and real. In a driving simulator, where the simulation-emulation environment plays a central role in anticipating and exchanging information regarding traffic and vehicle situations, this could be perceived as an automated car controlled remotely by a human driver. In this case, the results of the remote operation would demonstrate the logic and ramifications of investigating the viability of 5G and determining to what extent the introduction of NR would permit vehicles to be safely guided remotely. The 5G key performance indicators (KPIs) that will be measured will precisely determine the node density, communication latency, and overall quality of service (QoS) that are required to enable this use case, as well as suggest its implementation in the cooperative perception paradigm for connected vehicles.

Challenges. Latency and reliability are the two most crucial KPIs for this use

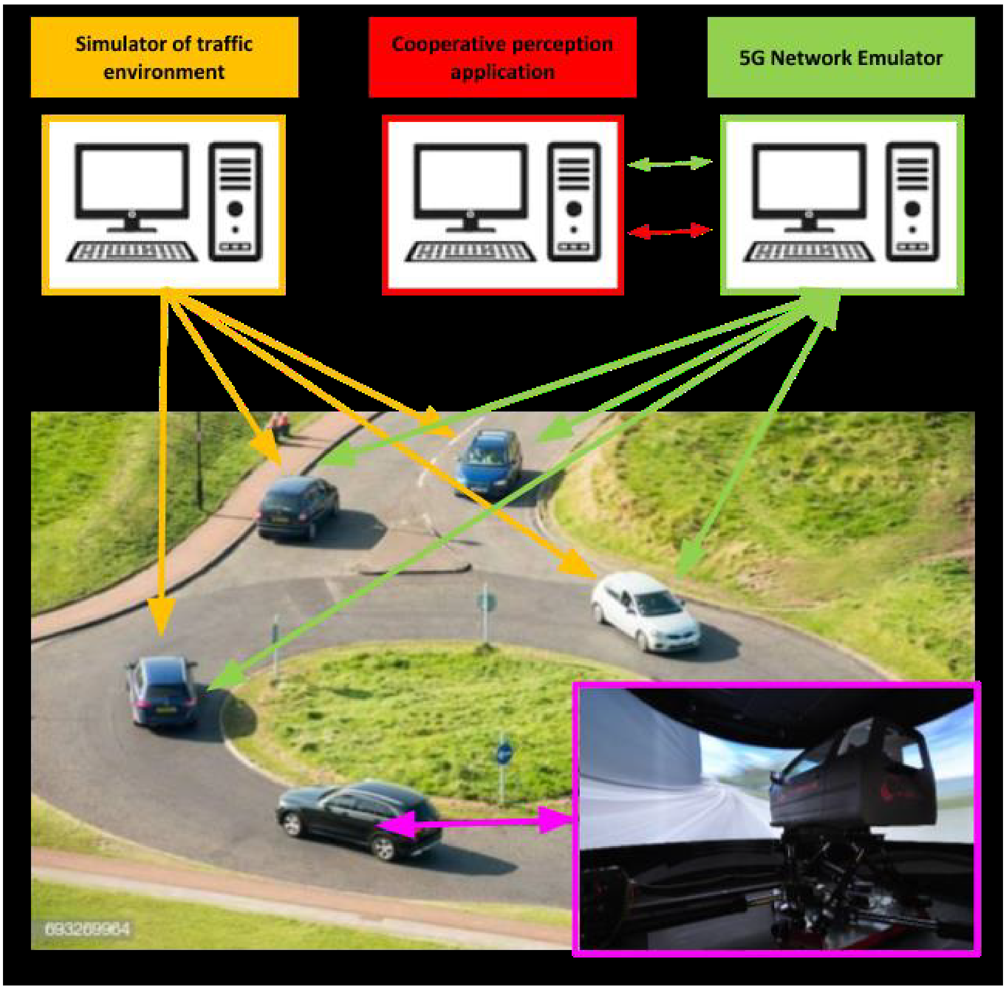


Figure 2.5: Virtual Validation of vehicles cooperative perception, [10]

case, listed in Table 2.2. The fundamental question is therefore whether the 3GPP's current mobile network meets these requirements in Release 15 and Release 16. Additionally, this use case anticipated performance levels present a fundamental challenge that goes beyond the 5G network's current design framework.

The cooperative perception requires real-time data exchange rate performance and measurement time resolutions below 10 milliseconds for practical use. In addition, the density of vehicles would have a significant impact on cooperative perception capabilities. An easy illustration of this scenario is a highway with a lot of fast traffic and a high density of vehicles. At an average speed of 25 meters per second, or 90 kilometers per hour, the average human driver's reaction and action time are less than 0.7 seconds. Communication latency is severely constrained in these kinds of situations due to the time factor that plays a role in facilitating the vehicle's efficient and effective cooperative perception and the immediate instances in which a human driver acts in response to the vehicle's initial commands. In addition, testing how quickly the surrounding vehicle's motion control systems can collect, update, process, distribute cooperative perception data to other vehicles, and perform fusion with sensed data is a significant challenge. The current mobile network architectures face significant challenges as a result of all these steps, which contribute to the overall communication latency.

KPI	**Goal**
Vehicle Density	1200 vehicles/km2 at 20km/h
Sensor fusion latency	Total from sensor detection to vehicle including sensor fusion on edge less than 10 ms
Communication reliability	from 99.9% to 99.9999%
Range	Up yo 500m

Table 2.2: Various KPI's for Cooperative Perception

Impact. Complex data-sharing experimental testing in real-world settings is challenging within the framework of cooperative perception for a number of reasons. To ensure the widespread use of cooperative perception devices, numerous tests must be conducted on a regular basis, and strict safety restrictions exist. However, by utilizing the dynamic driving simulator, such a large number of complex and repetitive tests could be completed at a relatively low cost and in a shorter amount of time.

AI@EDGE would mark a significant advance in the deployment of technological enablers for automated and connected vehicles by validating the vehicle's cooperative perception. With its dynamic resource allocation and autonomous connect-compute container deployment method, AI@EDGE will specifically make it possible for a variety of cooperative perception services to effectively manage a large number of vehicles in urban traffic situations. This will be made possible by i) utilizing knowledge of network systems to implement local learning models; (ii) adapting the network to meet the needs of the service; iii) MEC/NFV-based data-driven service management strategies for AIFs; (iv) Allocating resources and deploying distributed AI/ML services while maintaining privacy and security. Additionally, this study's overall impact would be on the success of connected and autonomous vehicles because cooperative perception is the primary enabler for a variety of safe driving services like vision transparency, a forward collision warning, collision detection at an intersection, and an automated system for avoiding hidden obstacles.

2.4.2 Use case architecture

The deployment of a geographically dispersed virtual validation testing platform that would facilitate cooperative vehicle operations is the primary use case application of AI@EDGE fabric in cooperative perception; as follow:

- Utilizing the 3GPP UU and PC5 interfaces, the development of a geographically distributed virtual validation system connected to a 5G network [3GPP].
- facilitate the following cooperative services/functions amongs the vehicles:
  - Gathering and sending the information from/to vehicles.
  - Processing and aggregation of the data through centralized digital twining systems based on AI.The vehicles and Roadside Assistance Units provide this information.Using multi-agent-based reinforcement techniques, vehicles will learn cooperative strategies in this manner.
- All vehicles whose learning departs from cooperative policies will receive information messages from AI traffic control.

There are numerous components that must be categorized and handled by various teams in order to implement this geographically distributed use case. The architecture of this use case is shown in Figure 2.6, and its primary components are as follows:

- Simulation Environments
  - The roundabout simulation environment on virtual platform.
  - The Outgoing-Incoming surrounding traffic simulation environment.
- The AI traffic controller.
- The Digital twin : It is a virtual representation of the roundabout and surroundings which is being crated by collecting information from various resources;
  - Static data: road and intersection information obtained from static digital maps.
  - Semi-static data: road signs, landmarks.
  - Semi-dynamic data: information for temporary changes, such as weather,

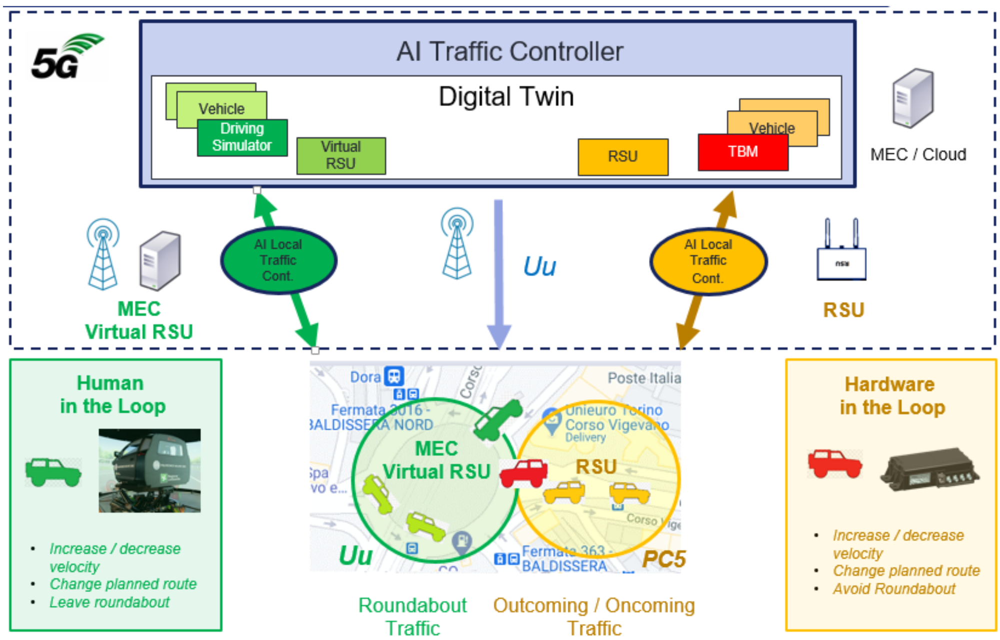


Figure 2.6: Cooperative Perception use case functional architecture, [10]

traffic jams.

  – Dynamic data: dynamic rapidly changing information, such as vehicle information (GPS position, speed, heading, etc.).

- The 5G Network Emulation infrastructure.
- The Telemetic Box (On board unit that provides the connectivity from/to the vehicles)
  – Uu and PC5 radio interfaces.
  – GPS.
  – MQTT/AMQP and C-V2X Client

Because the UC1 is a case with two different locations connected by a 5G network and is distributed geographically. The two locations are sharing the computational resources. A geographically dispersed testbed could be seen between two locations (Milan and Turin) in Figure 2.7, [11].

1. Turin site:

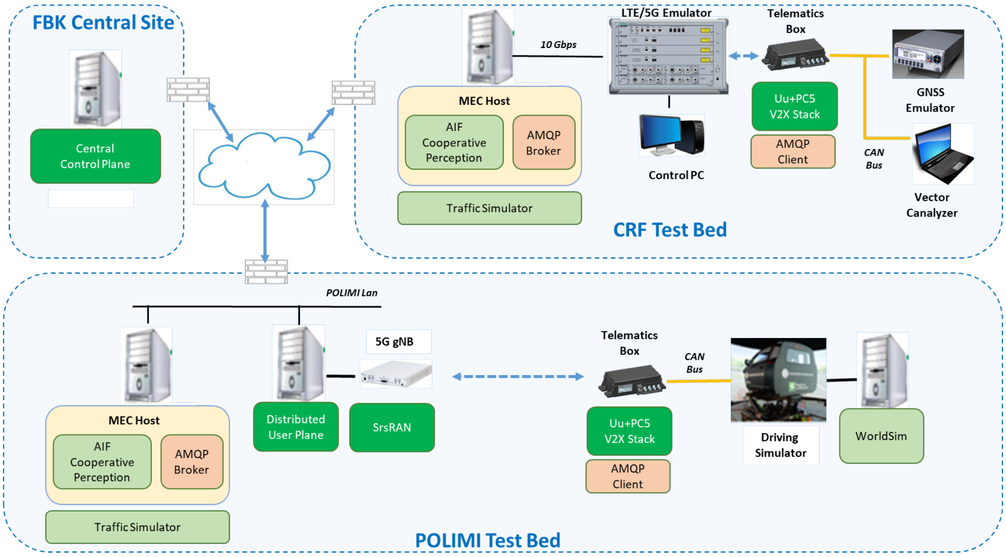


Figure 2.7: Geographically distributed testbed environment for use case 1, [10]

   (a) On board Telemetic box setup emulation (with Uu and PC5 interfaces), TBM with CAN Bus and Head unit with a HMI (Human Machine Interface).

   (b) PC5 channel emulator.

   (c) V2X simulation environment. (Vehicles and Road side units).

   (d) 5G RAN emulation.

2. Milan site:

   (a) Driving Simulator (figure if needed)

   (b) Traffic simulation environment.

   (c) Sensor for detecting drivers psychological workload.

3. 5G network

   (a) 5G core network as a MEC based network solution to allow local traffic break out.ù

   (b) MEC and Cloud server.

The Digital Twin and AI traffic controllers are managed by the AI@EDGE Platform on the 5G network.

Because of the complexity and limited time available, the implementation of all Turin site components is beyond the scope of this thesis. Therefore, the primary works under the AI@EDGE umbrella that are the subject of this thesis project are further categorized as follows:

1. On board Telemetic box setup emulation

2. LTE/5G Network Virtualization and running a number of test cases involving RF network signals in the HIL using a TBM box

3. Traffic simulation and sending/receiving the information of vehicles

The detailed discussion about above mentioned parts will be in the dedicated chapters.

Chapter 3

Network emulation and testing

This use case aims to create a testbed for virtual validation, as discussed in the AI@EDGE chapter. It should be distributed geographically and support cooperative vehicle operations. When it comes to demonstrating the capabilities of safety-critical connected services and functions, the role of a network system becomes even more crucial in this situation. As a result, the C-V2X system relies heavily on the emulation of a network for testing and validation of these cooperative applications. The 3GPP system with Uu and PC5 interfaces would be used to connect this virtual validation platform to a 5G network and carry out the operations related to the use case. Before going into the emulation and testing related part it is also important to discuss the various communication systems for the V2X application and could possibly trace the overall technological advancement it went trough over the years.

3.1 Vehicular Communication

One of the primary areas of focus in automotive industry-related research is the enhancement of safety-related systems. Everything from the hydraulic brake to the current ABS system, built-in seat belts, and airbags all aim to make the driver and passengers safer. In recent decades, there has been a significant push toward maturing Intelligent Transportation Systems (ITS), which place an emphasis not only on safety but also on traffic efficiency, user experience, and a variety of mobility options, with the same goal of improving safety systems. As a result, it is clear that the entire transportation ecosystem is working together to standardize ITS systems. Vehicle communication networks have seen the most significant advancements in the implementation of ITS systems. The most important enabler is a vehicle-specific communication and network system, which enables the faster, more direct, and more trustworthy exchange of information. Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Network (V2N), and Vehicle-to-Pedestrians (V2P) information exchanges can be accomplished with very low latency thanks to the Dedicated Short Range Communication (DSRC), Wireless Access in Vehicular Environments (WAVE), and Cellular Networks (C-V2X). A possible example of an ITS-V2X communication is shown in the Figure 3.1.

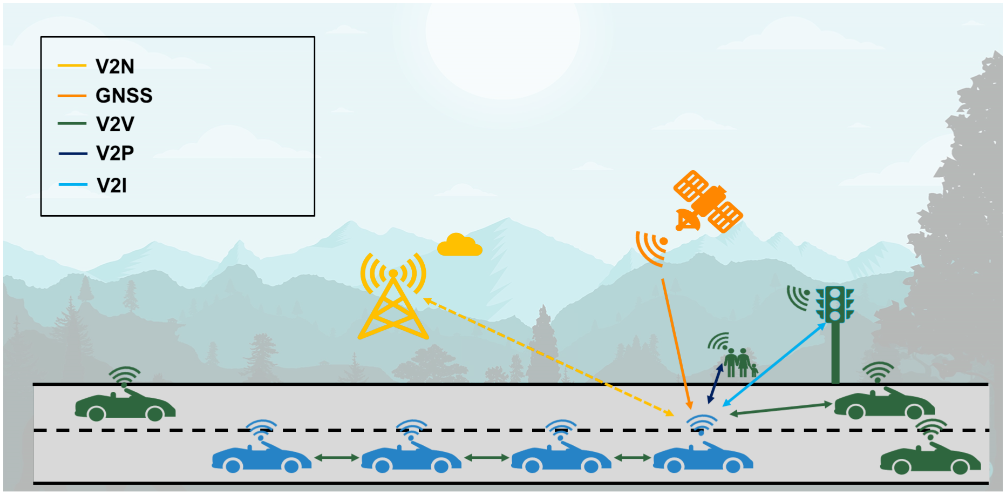


Figure 3.1: ITS V2X Communication example

3.1.1 ITS Architecture

The three main communication domains—from the vehicle to the network infrastructure—can be used to describe an ITS system, which includes almost all of the components of a traffic system. However, in order to comprehend it from a high-level architectural perspective, The infrastructure domain, the V2X domain, and the in-vehicle domain, of which are also shown in Figure 3.2 [12]

The data pertaining to the vehicle and its surroundings as perceived by the onboard sensors are collected by the in-vehicle domain, which could be interpreted as an intra-vehicle communication system. The vehicle's information and traffic-related parameters are sent and received to and from other vehicles and edge servers by the onboard device for communication with surrounding vehicles, which acts as an agent. The in-vehicle communication process, which was described in the project's introduction as being carried out using a virtual traffic simulator, will be thoroughly

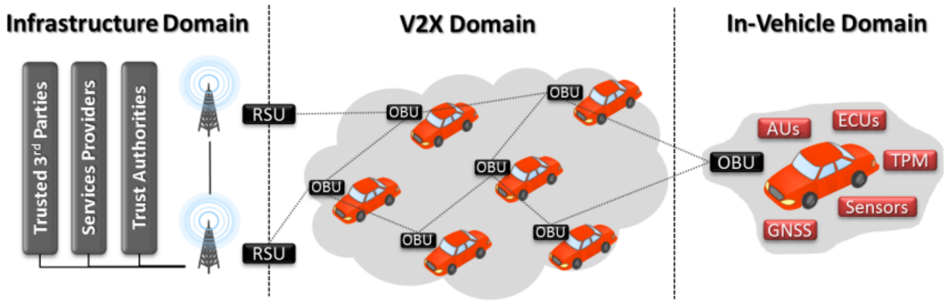


Figure 3.2: ITS high level architecture. RSU, road side unit; OBU, on-board unit; AU, application unit; ECU, electronic control unit; TPM, trusted platform module [12].

discussed in chapter 4. However, the network-related testing is carried out in a HIL environment, primarily for LTE/5G services, and the Telematic box Module (TBM) or Tele-communication Unit (TCU) is being prepared.

The V2X domain in its all modes (V2V, V2I, V2N, and V2P) and also the infrastructure domain are mainly concerned with the third party's communication and equipment, so calling it inter-vehicle/infrastructure communication is not incorrect. Because so many parties and organizations are involved in the process, standardization is of the utmost importance in this case. Although we won't go into too much detail about the infrastructure, it would be helpful to know about the various communication level standards for V2X applications. There are two types of standardized communication technologies competing to serve the ITS system's needs, as stated by the 3GPP and IEEE. One is C-V2X, which is defined by 3GPP, and the other is Dedicated Short Range Communication (DSRC), which is also known as WAVE in the United States, and ITS-G5 in the European Union. The main issue still remains regarding the distribution of the band in the ITS systems and its significance for each of these technologies. Many technological experts envision the future of V2X as coexistence between DSRC and C-V2X-based networking systems.

There are many different approaches has been taken in this direction like the one in [13], where the presenter candidate a possible solution based on three steps. In which, the the safety critical ITS services/functions in both the types of technologies should be ensured to operate free of the co-channel interference.

The revision of these various technologies based on DSRC and C-V2X for the V2X deployment is the subject of the following sections. By critically examining and highlighting their main limitations, a high level of comprehension would be developed. In the vehicle networking system, an examination of the possibility of coexistence between those various technologies and the opportunities presented by each would be carried out.

3.1.2 IEEE 802.11p/DSRC/ITS-G5

IP-based fixed networks and long-range radio communication (Cellular 2G, 3G, and 5G) network systems were available prior to the standardization of IEEE 802.11p, but Short Range Radio Communication (SRC) was clearly absent. The primary requirements of Road Transport Telematics (RTT) call for an SRC system. The major requirements of RTT or an ITS system are contravened by the possibility that cellular networks (up to 3G, and occasionally 4G) will be unavailable, overloaded, or extremely slow. These are the fundamental requirements for fast mobility scenarios to improve road safety. Therefore, for general use, a network must operate in the RTT with the functional requirements of an allocated 5 GHz band, a high data rate of 10 Mbps (for quick data transfers), and a low cost. However, given that almost all of these functional requirements could be met by IEEE 802.11a, the question that arises is, "Why not use 5 GHz WLAN technology itself?" The answer to this is no because we neglected the most crucial element, which is having a fast connection. For example, meeting the three functional requirements won't matter if there isn't a connection between vehicles and Roadside units (RSUs).

Therefore, IEEE 802.11p, which repurposes most of the technology from IEEE 802.11a and adapts the MAC protocol to V2V and V2I communication, is the solution developed for RTT applications. In addition, improvements were made to the earlier version to address the issue of slow association. As an additional protocol in the IEEE 802.11 family, IEEE 802.11p is compatible with all 802.11 protocols' common features. The primary objective of this standard is to provide the minimum set of specifications necessary to guarantee interoperability between infrastructure or ad-hoc IEEE 802.11 networks and wireless devices attempting to communicate in potentially rapidly changing communication environments or in situations where transactions must be completed in a much shorter time frames than the minimum possible (10ms - 100ms). In general, the following is accomplished by the IEEE 802.11p standard:

- The description of the services and functions that stations need to exchange messages without joining the Basic Service Sets (BSS) and operate in an environment that is constantly changing.

- Defines the IEEE 802.11 MAC-controlled signaling methods and interface functions utilized by stations communicating outside of a BSS.

However, despite the accomplishments previously mentioned, the IEEE 802.11p standard is insufficient to implement the V2V and V2R systems. This is due to two primary factors: the first is that the standard only covers the two lowest layers of the network architecture, and the second is that V2V and V2R communication applications heavily rely on these layers. As a result, additional network layers are absolutely necessary. As a result, two additional protocol stacks that are nearly identical are defined: ITS-G5 (EU) and WAVE (USA).

WAVE

The IEEE WAVE (Wireless Access in Vehicular Environments) protocols are made up of the family of standards [14], where the IEEE 802.2 standard is used at the logical link control layer (LLC) and the IEEE 802.11p standard is used at the MAC and physical layers. The WAVE system is a radio communication system designed to offer interoperable, seamless transportation services. The U.S. National Intelligent Transportation Systems (ITS) Architecture recognizes a number of these services, as do numerous others that are being considered by the automotive and transportation infrastructure industries. Vehicle-to-roadside (V2R) and vehicle-to-vehicle (V2V) communications between OBUs (On-Board Units) and RSUs are examples of these services. The specification of the MAC sub-layer functions and services that enable multi-channel wireless connectivity between IEEE 802.11 WAVE devices is the goal of this standard. The IEEE 802.11p defines how WAVE-based applications will operate in this environment based on the management activities described in IEEE P1609.1, the security protocols declared in IEEE P1609.2, and the Network-layer protocol defined in IEEE P1609.3.The IEEE 1609.4 protocol, which is located above 802.11p, enables multi-channel operation and channel coordination between WAVE devices without requiring the use of physical channel access parameters [15]. The WAVE protocol stack is shown in the Figure 3.3, where a data plane for higher level information and a management plane is defined for information transfers between the layers.

ITS-G5

ETSI defined the ITS-G5 standard for vehicular communication by developing the ITS-G5 protocol stack and drawing inspiration from the WAVE architecture. It encompasses a wider range of specifications, from MAC to applications, and its capabilities are more extensive and complex than those of WAVE. This protocol stack's ability to support a wide range of Access Methods is its most impressive feature [16]. In Chapter 4, the implications of this standard's other facilities, such as Cooperative Awareness (CA) and Decentralized Environmental Notification (DEN), on a traffic simulator are discussed.

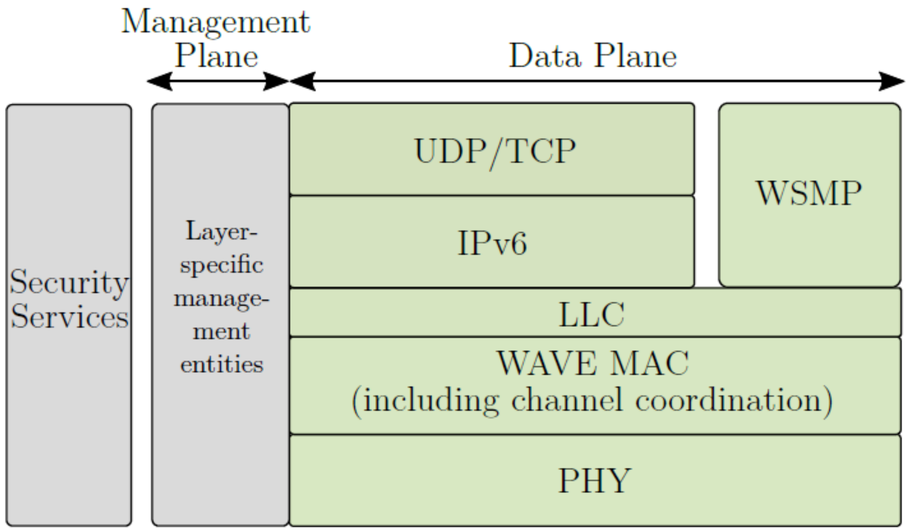


Figure 3.3: WAVE protocol stack

The following capabilities and their limitations in V2X applications can be used to summarize these two standard WAVE and ITS-G5 components of the DSRC system.

- Amendment to IEEE 802.11 (derived from 11a) - Ratified in 2010.
- Investigated for two decades as enabling radio excess tech. For V2V and V2I communication based applications.
- EU: Car-to-Everything (C2X), ITS-G5
- U.S: Dedicated Short Range Communication (DSRC), WAVE
- Distributed localized interactions among vehicles based on Peer-to-peer ad-hoc communication
- Backend connectivity through Road Side Units
- Fits the requirements of applications in low congested scenarios, it suffers from dramatic throughput degradation and poor performance at high density conditions
- For futuristic V2X applications limited performance's due to the very low latency and high-bandwidth requirements.

- 5.9 GHz ITS frequency band.

.

3.1.3 C-V2X defined by 3GPP

When 3GPP was able to standardize the C-V2X technology in Release 14 [17], the interest in cellular-based technologies for vehicular communication skyrocketed. In light of the preceding discussion, it is evident that IEEE 802.11p did not meet the stringent requirements for V2X applications in many ways. Even though there has been almost a decade between the introduction of these two technologies, the 3GPP's solutions include cutting-edge features like increased radio coverage, minimal need for parallel infrastructure, and a higher penetration rate due to smartphone's already biased deployment.

LTE-V2X

The introduction of C-V2X as LTE-V2X and the floating definition of V2V communications based on D2D (Device-to-Device) communications began with 3GPP Release 14. With 3GPP's Rel12 and Rel13, the D2D communications were already defined as a component of ProSe (Proximity Service) services. By creating a brand-new physical layer channel called sidelink, V2V communication became possible. The sidelink was designed with vehicular use cases in mind, allowing for a high node density at high speeds.

There are two mode's of operation defined by the 3GPP in [17], for enabling the V2X communications.

1. Using the PC5 interface for communication:The over-the-air message is directly received by the UEs around the transmitter thanks to the PC5 interface's ability to establish a direct connection between them. Sidelink is used to support V2X communication in Mode 3 (when the UE is covered by the LTE network) and Mode 4 (when the UE is not covered by the LTE network).

2. Over the LTE-Uu interface, communication: The LTE-Uu interface is connecting the UEs to eNB (E-UTRAN NodeB). In LTE networks, the eNB node serves as the base station.V2X messages can be received via unicast or broadcast over a downlink, while V2X messages can be sent over an uplink. Only when the UE is a part of the network does the LTE-Uu support communications.

Rel-14 also aims to deliver data transport services to facilities using basic service messaging like CAM and DENM, just as IEEE 802.11p did. The flaw in the previous release is fixed in Release 15, and new requirements for vehicle platooning, advanced automated driving, and remote sensing are being supported to improve support for V2X application scenarios. Additionally, key new features like 64-QAM support and support for Carrier Aggregation (CA) for transmission mode 4 are included in Release 15 [18].

5G V2X

The LTE-V2X was not suitable for some use cases in terms of the requirements for latency, reliability, throughput, and node density; therefore, 5G V2X is a supplement to those requirements and will not replace the previous one. While a small number of NR V2X use cases require the timely delivery of non-periodic messages, most do not necessitate the transmission of traffic data on a regular basis. In addition, not all use cases function while broadcasting messages; however, there are some, such as vehicle platooning, in which the messages are only sent to a predetermined number of vehicles or UEs. Regarding enhancements to the PC5 interface made by 5G-V2X, these include a 64-QAM modulation and coding method, frequencies above 6 GHz, the use of MIMO antennas, and other features. The results of testing some of these features on the 5G-capable modem will be discussed in the following sections.

In general, the C-V2X be it LTE or 5G based capabilities and offering to the V2X applications are summarized in the following points:

- From 3GPP Release 12 (D2D) to LTE-V2X Release 14, and to Release 16 (5G NR V2X)
- V2V published in 2016, V2X in 2017, industry term: Cellular V2X (C-V2X)
- V2V, V2I : Direct communications over the side-link (PC5) interface to ensure ultra-high availability under all geographies conditions.
- Peer-to-peer ad-hoc communication:service continuity, to operate independent of any centralized system
- Backend connectivity through mobile network
- Superior performance of C-V2X Mode 4 w.r.t. IEEE 802.11p under many circumstances V2N communications occur over the cellular C-V2X –Uu
- New Radio (NR) : further enhancing the PC5 and LTE-Uu interfaces, NR encompass high frequencies, MAC techniques that well answer the quest for

high capacity, massive connectivity, ultra-low latency and high reliability.

- V2V targets 5.9 GHz ITS frequency band

3.2 Telemetic Box

The Device-Under-Test (DUT) modem, which is equipped with the ITS network system and has C-V2X capabilities, is now the subject of a brief discussion on the various communication technologies for V2X applications. The Quectecl AG55xQ series (5G NR + C-V2X/DSDA Module) serves as the foundation for this DUT, which can operate in either the NSA or SA modes of 5G NR. This telematic box has the bare-bones version of the aforementioned features, making it possible to perform fundamental networking-related tests like device registration, mobility from LTE to NR and back again in both NSA and SA modes, carrier aggregation, and MIMO antenna based connection. This DUT offers additional options, such as C-V2X PC5 direct communications, but the modem that is currently in use (Sample-1) lacks the aforementioned capability so thats work will need to be done in the future for this project. From a compatibility standpoint, the module can be found in traffic systems' On-Board Units (OBU) as well as in telematics boxes (TBM), telematic control units (TCU), ADS systems, and C-V2X systems. [19].

3.3 5G Emulation platform

The integration of the network automation platform with the 5G network emulator is one of AI@EDGE's technological pillars. That will make it possible to test network configuration testing in addition to complex scenario testing. In the past, the automotive industry had a tendency to test the modules directly on the vehicle in a real network environment. Virtual environment-based testing is becoming more favorable as a result of the development of hardware-in-the-loop (HIL) testing equipment for network testing and the rise in requirements brought about by V2X. Testing on a virtual validation platform not only speeds up the overall development cycle but also reduces associated costs. In the context of cooperative perception as a whole, the emulation aims to measure and evaluate a variety of key performance indicators (KPIs), including node density, end-to-end latency, and overall quality of service. Additionally, radio communication tests are a part of the overall emulation process, with LTE and 5G-based communication registration testing, CA, EN-DC mode, and MIMO, among other things, serving as the primary test cases.

The Anritsu MT8000A single box platform is the test solution for RF and application testing of 5G SA/NSA devices. Users can quickly and easily set up the 5G connection test environment with the help of the MT8000A base station simulating function. It supports RF tests for 3GPP compliance in addition to a number of other application tests, such as the IP layer data transfer and throughput test, among others. It addresses issues related to the verification of 5G devices, ensuring dependable connectivity and smooth communication [20]. The basic layout of this 5G emulator bench is shown in the Figure 3.4. More information regarding the platform and its slots that are used here are given the **Appendix B**

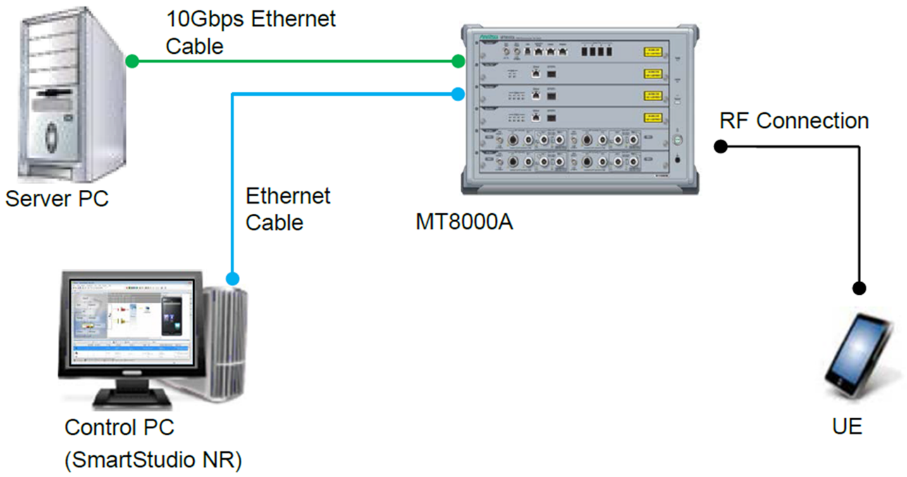


Figure 3.4: Virtual validation : 5G Emulation bench layout [20]

As can be seen in Figure 3.4, the platform comes with a control software called SmartStudio NR (SSNR) for the test station MT8000A. SSNR mimics the conditions of the network as well as communication between the mobile terminal and the 5G network in order to conduct effective functional tests, application tests, and software regression tests without requiring users to have special knowledge of the complex scripting and communication protocols that exist between the base station and mobile terminal. For functional and application testing, it has a Graphical User Interface (GUI) based on state machines. NSA/SA environment simulation with a lot of interaction for scenarios like measurements, dual connectivity, handovers, and carrier aggregation-based connectivity. During device registration or communication, it also provides the ability to reject or ignore signaling messages. IMS, SMS/PWS service, EPS Fallback, VoLTE, VoNR, DSS, network slicing, and other features and functions are among the others that SSNR supports; however, it is beyond the scope of this work to cover them all.

3.4 Network testing

The network testing portion, including a discussion of the outcomes, would be the subject of this section. The V2X requirements have been used to select and execute the various test cases for the 5G network's various features and functions on this virtual validation bench. A list of test cases and a brief procedure for each one are provided in Table 3.1.

3.4.1 Handover scenario

The procedure known as handover is used to provide mobile users with uninterrupted calls while they are conversing and mobile user localization while they are idle, both of which were designed into the cellular networks to provide an interrupted telephone service to mobile users. When the MT is moving (up to 300 km/h), handover makes it possible to transfer an active call from the current cell to a cell that is nearby. It could be the transfer of an LTE cell to a 5G cell or the other way around in the NSA mode of 5G with dual connectivity. It is a complicated operation that involves a lot of network entities, necessitates fast, dependable communication protocols, and requires a high level of security. Due to the extremely short time allowed to transfer a call from one cell to another, handover is only possible within a network.

SA mode

The handover test case is carried out after the mobile device registers with an LTE cell in this mode. The power rampage is also operating as the mobility occurs from LTE to NR cell. LTE cell power decreases while NR cell power rises during the power rampage, reaching a threshold before connecting to the mobile device. In every test case, the cell that initiates paging and sends the Radio Resource Control (RRC) connection request must first have certain cell parameters. These parameters must match the capabilities of the User Equipment (UE), such as the supported channel, cell type, and band combination, among other things. Figure 3.5 below provides an illustration of a possible configuration for the cell parameters.

The target network simulation configuration can be set up to begin the network emulation once the target cell parameters have been selected. The physical connection with the device under test must be established in accordance with the target network emulation. The possible connection diagram for this handover scenario, in which SA mod, LTE, and NR cells are imitated, can be found in Figure 3.6. The RF modules depicted in connection with the MT8000A are as follows: MT8000A-030/031 RF Sub-module, 0.4GHz-6 GHz:2TX/2RX per SLOT, up to a maximum of 2 SLOTS.

Test cases	**Description**
LTE to NR HO SA (In opposite direction also)	LTE1 and NR1 (SA) cell is available. Network performs cell handover to NR1 cell.
LN1 to LN2 HO NSA	LTE1, NR1 (NSA) and NR2 (NSA) cells are available. Network adds NR1 cell in EN-DC. Network triggers NR cell change procedure where NR1 cell is removed and NR2 cell is added in EN-DC.
LTE to LTE HO + NR add - NSA	LTE1, LTE2 and NR1 (NSA) cells are available. Network triggers handover from LTE1 to LTE2 cell and adds NR1 cell to END-DC.
LTE to LTE HO + NR Release - NSA	LTE1, LTE2 and NR1 (NSA) cells are available. Network triggers Handover from LTE1 to LTE2 and releases NR1 cell from EN-DC.
LTE to LTE HO + NR change - NSA	LTE1, LTE2, NR1 (NSA) and NR2 (NSA) cells are available. Network triggers handover from LTE1 to LTE2 and changes EN-DC cells from NR1 to NR2.
LTE to LTE HO + NR no change - NSA	LTE1, LTE2 and NR1 (NSA) cells are available. Network triggers Handover from LTE1 to LTE2 and keeps NR1 cell in EN-DC.
Carrier Aggregation - SA/NSA	LTE1, LTE2 cells are available. DUT registers to LTE.
2x2 and 4x4 MIMO - SA/NSA	LTE1 and NR1 (SA/NSA) cell is available. This connection is done according to MIMO type, if 2x2 then 2DL antennas and 4DL antennas if 4x4 MIMO simulated.

Table 3.1: Test cases based on the network emulation platform

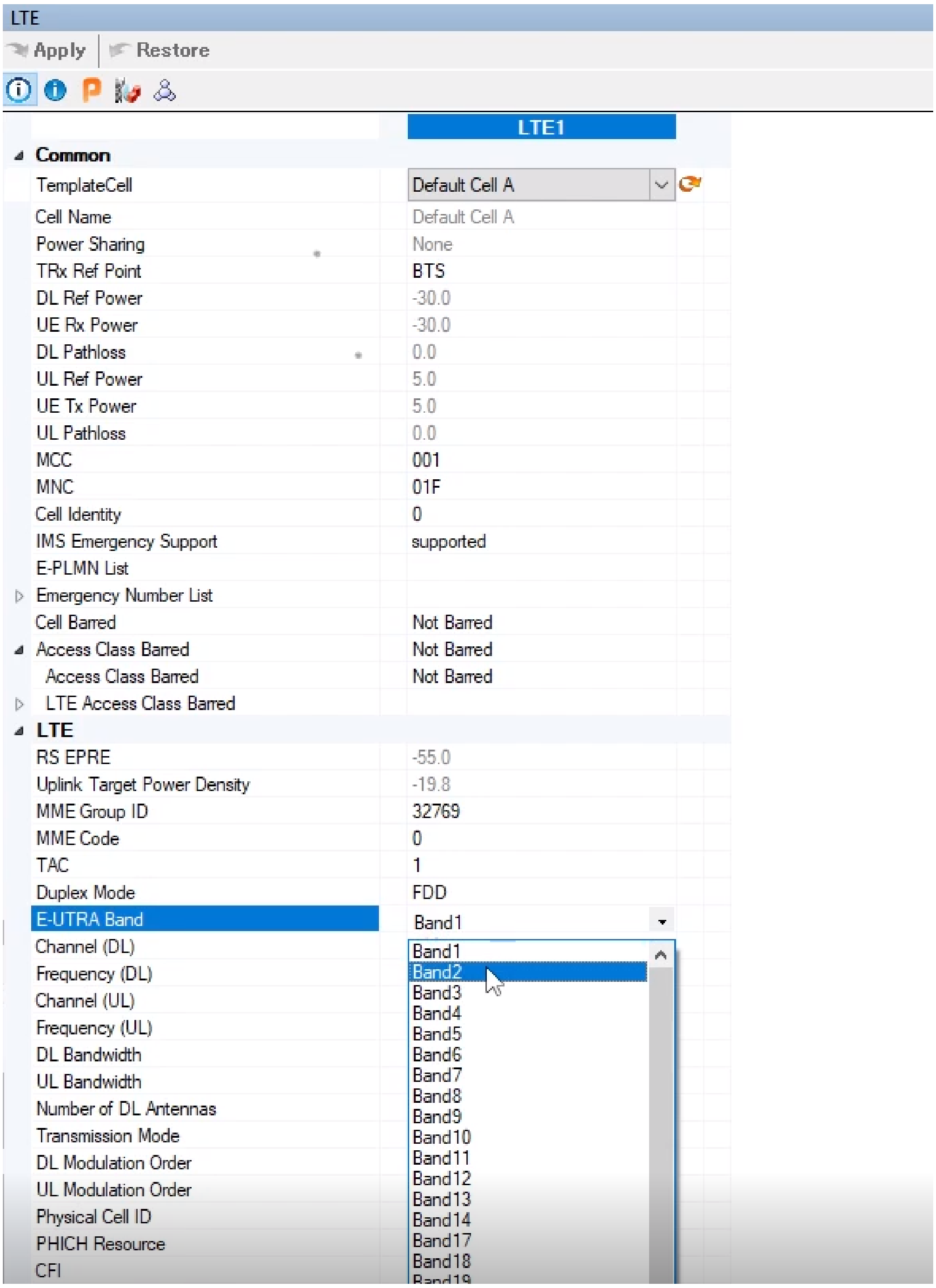


Figure 3.5: A LTE Target cell parameters

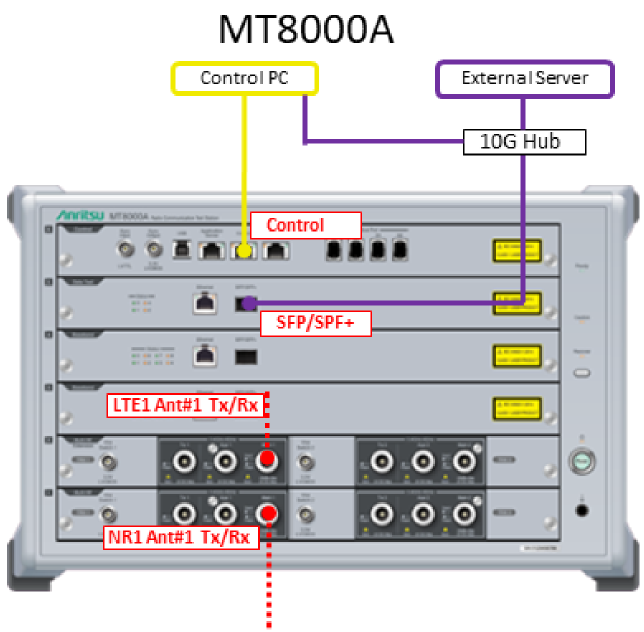


Figure 3.6: MT8000A connection diagram for LTE+NR SA mode

The connection diagram reveals that there are two RF antennas, one for NR cell and one for LTE. The external server hub for data connection and the control PC with SSNR is the other connections.

Device registration is started and a connection is made with an LTE cell after the simulation configuration and target cell parameters have been set up, as shown in Figure 3.7.

The setup is now ready to run the test cases for this particular scenario once the simulation is started and the connection is established. Obtaining the UE capability once the connection is established is also crucial in this case. The simulation's sequence log could be used to locate this UE capability file. The various bandwidths that UE supports for a single connection, multi-cell connection, EN-DC mode, and carrier aggregation are depicted in Figure 3.8 for the DUT's capability. When setting the target cell parameter values, additional test cases would require this information.

The Handover scenario can be planned and carried out once the connection has

Figure 3.7: UE status and its connection with LTE cell with an estimated throughput

UE Capability Information
NR
Supported Band = n2, n5, n25, n41, n48, n66, n71, n77, n78
CA Band Combinations:
n48A, n41A, n71A, n66A, n78A, n25A, n2A, n77A, n5A
LTE
Supported Band = 2, 4, 5, 7, 12, 13, 14, 17, 25, 26, 28, 29, 30, 41, 48, 66, 71
CA Band Combinations:
2A-66B, 2A-5A-66A, 2C-5A, 4A-13A, 5A-25A, 5A-66A, 4A-7A, 2A-30A, 4A, 12A, 66B, 29A, 2A-7A-66A, 2A-13A-66A, 4A-17A, 13A-66A
14A-66A, 12A-66A, 2A-17A, 41A, 14A-30A, 4A-71A, 66A-66A, 4A-12A, 12A-30A, 5A-7A, 5A-7A, 2A-13A, 2A-17A, 2A-66A-66A, 2A-66A-66A
2A-4A-71A, 25A-25A, 25A-26A, 25A-26A, 5B, 5A-5A, 7B, 2A-12A, 2A-29A, 25A, 2A, 4A-4A, 4A-13A, 66C, 29A-66A, 4A-5A, 7C, 2A-4A, 13A
4A-71A, 66A-71A, 12B, 7A-66A, 2A-71A, 14A, 13A-66A, 14A-66A, 4A-12A, 12A-12A, 12A-66A, 7A-12A, 26A, 2A-2A-66A, 2A-5A-66A
2A-7A-66A, 2A-5B, 4A-17A, 5A-30A, 7A-12A, 2A-7A, 2A-66B, 2A-66C, 2A-13A-66A, 4A-30A, 30A-66A, 66A-71A, 2A-12A, 2A-66A, 2A-66A
48A, 71A, 2A-2A-71A, 2A-4A-71A, 28A, 2C-29A, 2A-7C, 2A-7A-7A, 2A-7A-7A, 4A-7A, 2A-5A, 2A-7A, 66A, 5A, 2A-2A-29A, 12A-25A, 5A-25
2A-5A, 2A-66C, 2A-2A-66A, ...
EN-DC Band Combinations:
2A-n41A, 2A-n48A, 7A-n71A, 7A-n77A, 7A-n78A, 12A-n2A, 13A-n2A, 71A-n2A, 12A-n25A, 5A-n66A, 12A-n66A, 66A-n41A, 66A-n77A
12A-n78A, 5A-n2A, 13A-n66A, 66A-n71A, 2A-n5A, 25A-n41A, 66A-n48A, 12A-n77A, 66A-n25A, 66A-n2A, 66A-n5A, 5A-n41A, 5A-n48A
2A-n71A, 2A-n77A, 2A-n78A, 71A-n66A, 5A-n77A, 5A-n78A, 66A-n78A, 2A-n66A

Figure 3.8: UE capability

been established and the fundamental UE information has been traced. Again, there are options for setting up this test case, such as the power rampage and its values and the direction of handover (LTE to NR here). The handover direction diagram can be seen in Figure once the setup is ready 3.9.

Upon execution of this mobility scenario the UE status change to handover mode and the cell is changed from LTE to NR as shown in the Figure 3.10. One can observe from the Figure 3.7 and 3.10 that the downlink (DL) throughput has increased from 17.64 Mbps to 333.3 Mbps after the handover.

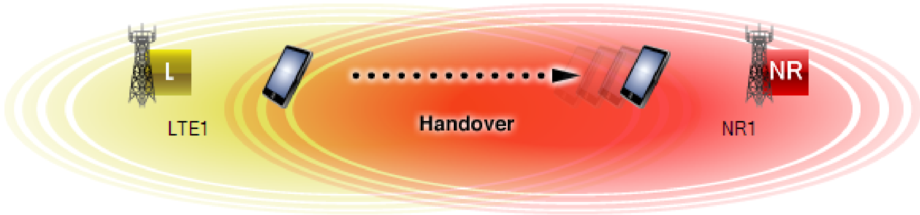


Figure 3.9: Handover scenario in SA mode from LTE to NR

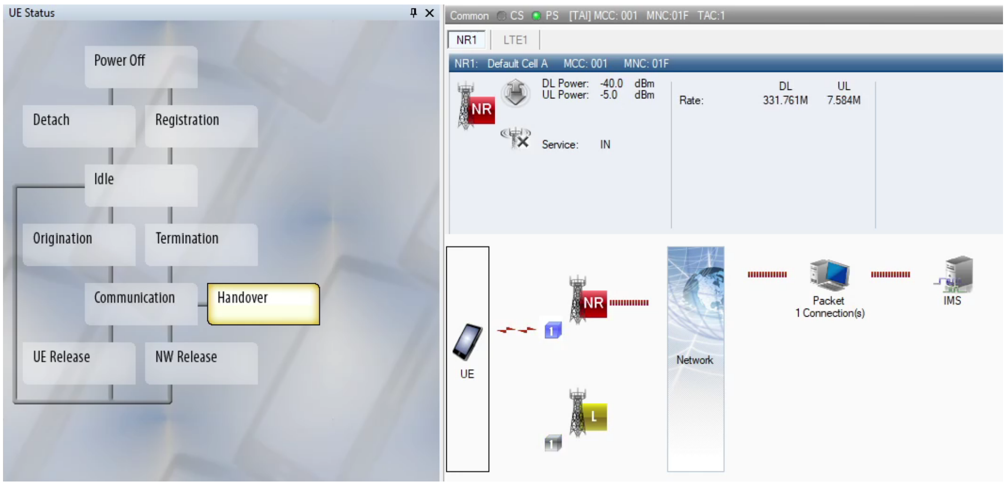


Figure 3.10: Handover Completion and connection NR cell done

3.4.2 Dual Connectivity Handover

The technology that makes it possible to connect simultaneously with both 4G and 5G cells is called dual connectivity, which is also known as EN-DC (E-UTRAN New Radio – Dual Connectivity). With ENDC, LTE and 5G data connections can flow simultaneously, increasing bandwidth and decreasing service interruptions overall. The LTE-based network serves as an anchor band that is supplemented by NR through multi-cell dual connectivity. ENDC allows traffic requirements to determine whether an LTE connection is sufficient for data transmission or whether the traffic should be routed to a 5G stream that is available when connected to a 5G modem.

The procedure for first establishing a connection with LTE is the same as before, with the only difference being that there are now four cells, two of which are LTE cells and two of which are NR cells. For LTE, the cell parameters are the same as before, but for NR, the band must be chosen based on the combination of supported bands that is depicted in the UE capability in Figure 3.8. Any one of the supported LTE band 2 NR bands—n41, n71, n77, or n78—can be selected. The supported band list also allows for the choice of either 5A-77A or 5A-78A for any other LTE-NR cell combination. The connection diagram for the MT8000A is the same, but this time there are two more antennas.

Once the cell and simulation parameters are chosen then the network emulation can be started. The network connection before enabling the EN-DC mode is shown in the Figure 3.11.

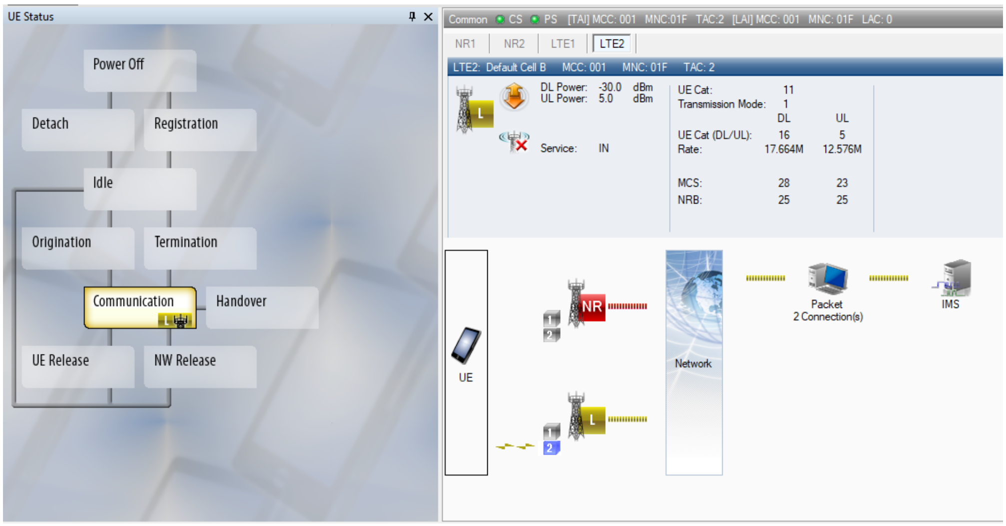


Figure 3.11: Multi cell simulation connection with LTE before ENDC

The parameters for the multi-cell connection can be set up once the connection is established. In this case, NR acts as a secondary node while LTE mode always acts as the master node. Again, this dual connectivity could only be made possible by matching the UE capabilities with the band combination of the emulated network. The network connection is depicted in Figure 3.12 following the execution of the multi-cell connection for ENDC.

Similar to the SA handover case, the handover test setup parameters can be configured here as well. LTE1 to LTE2 or the other way around could be the direction of handover. In this particular instance, the transfer of one LTE cell to another has four possible outcomes: NR-added, NR-change, NR no-change, and NR-Release. All of them were carried out, but only one of them is shown here to avoid overcrowding the report with figures. Figure 3.13 depicts the handover direction, and Figure reffig3.14 depicts the connection in EN-DC multi-cell mode following the handover.

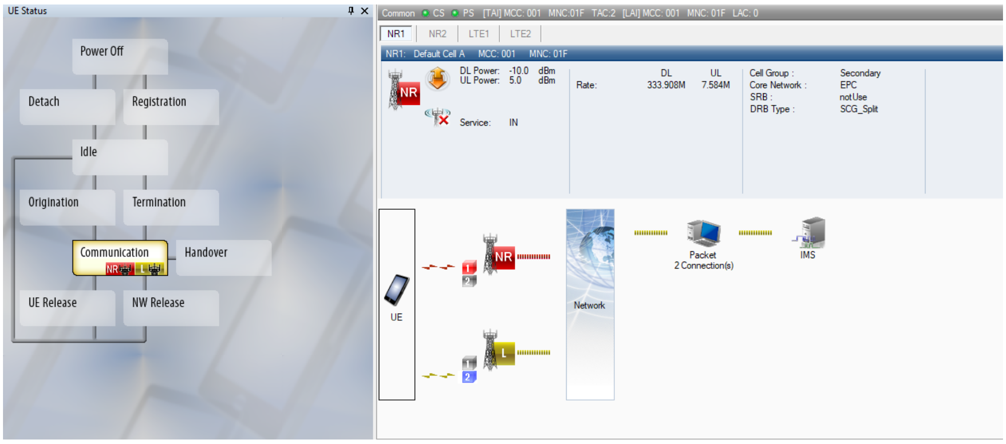


Figure 3.12: Multi cell simulation connection with LTE & NR after ENDC

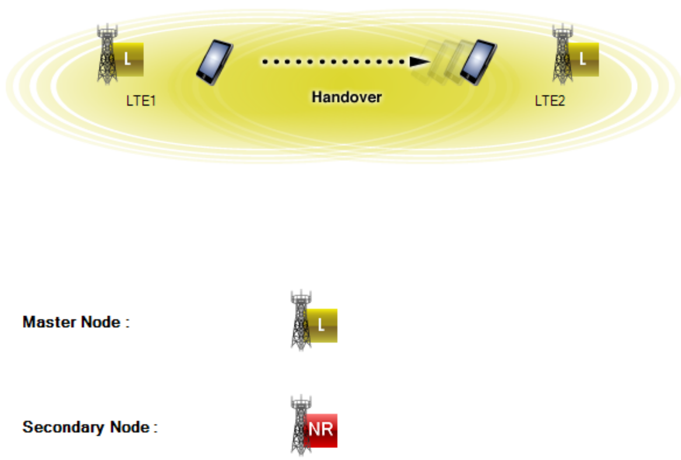


Figure 3.13: Handover of LTE2 to LTE1 in Multi cell ENDC mode

3.4.3 Carrier Aggregation

In LTE-Advanced, a technique called carrier aggregation (CA) is used to boost the bit-rate and overall bandwidth. CA can function in either the FDD or TDD modes. Currently, 5G CA is also a possibility, but the MT8000A system does not offer this option, so it is limited to LTE only. The same user is given multiple frequency blocks (component carriers) in the CA. With LTE Advanced, up to five component carriers can be combined with up to 20 MHz of bandwidth for a maximum of 100 MHz transmissions. One important factor that helps LTE-Advanced meet the IMT-Advanced requirements for peak data rates is carrier aggregation. Therefore, the test, in this case, would be to add up the bandwidth and check the total bit

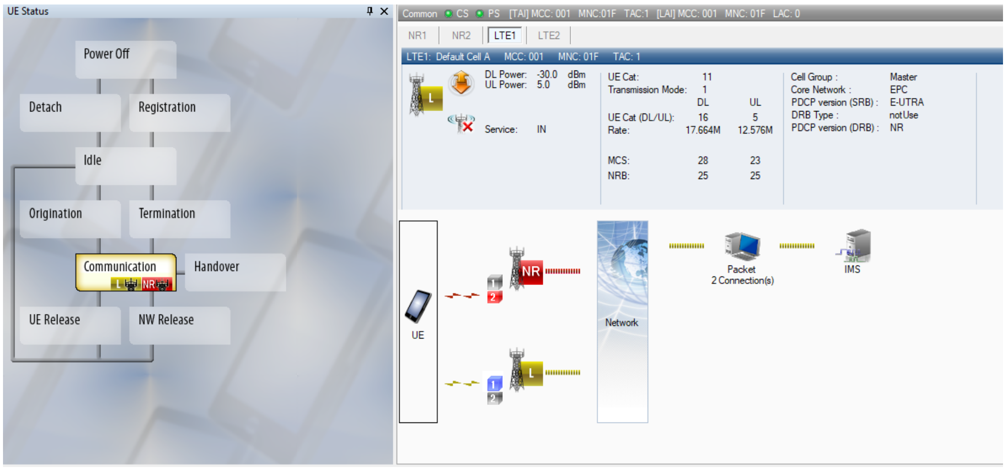


Figure 3.14: Connection after Handover in Multi cell ENDC mode

rate. With the allowed bandwidth of 5 MHz, it is possible to aggregate only the DL component with the current setup.

The procedure remains unchanged in the simulation setup, requiring only two LTE cells and one additional NR cell to test additional capabilities. With each 5 MHz DL frequency, band 2 and band 5 are selected for the CA when the cell parameters are set. The Figure 3.15 depicts the CA band setup for this test case with aggregated bands.

An LTE cell is first added to the simulation after the parameters for the CA test cases have been set. Then, another cell, this time an LTE one, is added, just like in the multi-cell case. The fact that the aggregation only occurs downlink; consequently, additional LTE cells with UL will share the same band, but the DL band will be aggregated. Eventually results in two aggregated bands and a nearly two-fold increase in throughput. Figure 3.16 depicts the final connection between two LTE cells and demonstrates the increased bit rate.

The throughput graph with time is shown in the Figure 3.17, where it is being highlighted that after carrier aggregation the throughput increases for downlink whereas the uplink remains same.

3.4.4 MIMO

In wireless communications, a technology known as multiple-input/multiple-output makes it possible to send and receive data signals simultaneously over the same radio channels. Wi-Fi communications, as well as 3G and 4G LTE networks, make

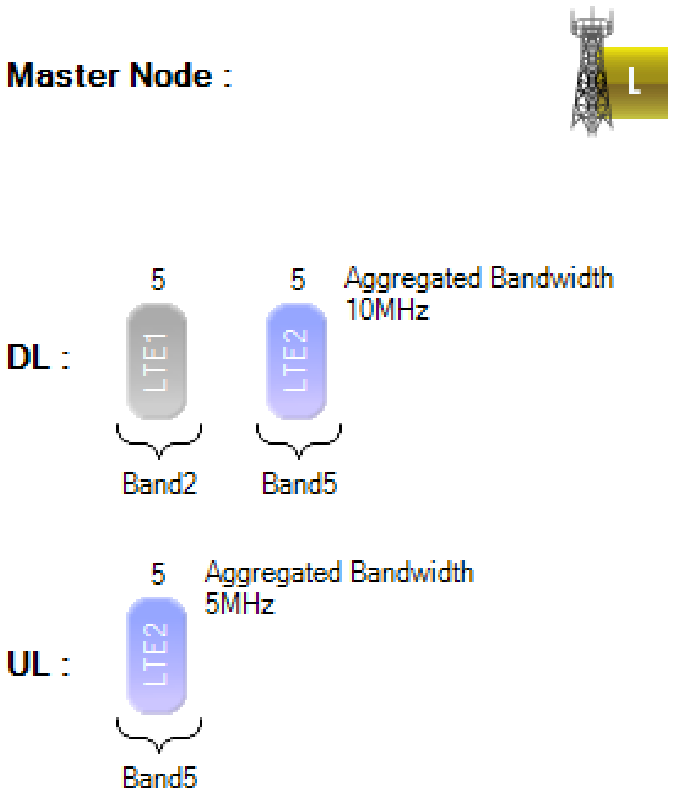


Figure 3.15: Aggregated bandwidth of 5 MHz each

use of these methods.MIMO systems necessitate the expansion of antennas and the support of intricate algorithms. Multiple antennas are common on mobile devices as well as networks to improve connectivity, speed, and user experiences."Massive MIMO" is the name of addition to MIMO. It has a lot of antennas that it can use on the base station, which dramatically improves the network and overall efficiency.

In this case, the test case concentrated on basic testing with multiple antennas and observed an increase in overall throughput. First, a 2x2 MIMO test case is used, followed by a 4x4 MIMO test case. In order not to overwhelm the report with yet more figures, the setup of the simulation and cell parameters is very similar to the cases that came before it. This time, there are two simulated cells, one for LTE and one for NR. The MIMO option must be set to the intended type when setting up the simulation (two-by-two or four-by-four, and which cell). Figure 3.18 depicts the physical connection diagram following the simulation configuration. It is essential to emphasize here that the number of antennas used for Tx and Rx is different; in 2x2 MIMO, the total number of antennas used for Tx is two, whereas the number

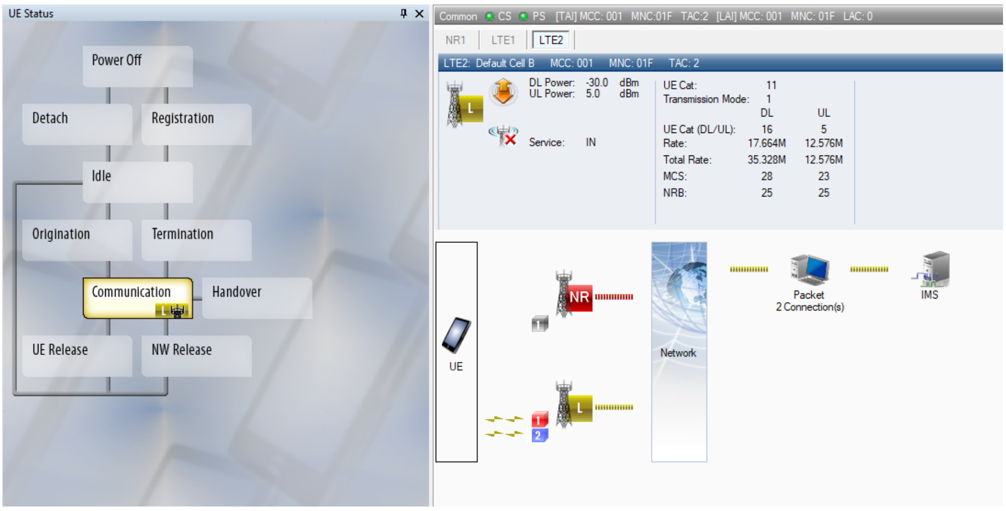
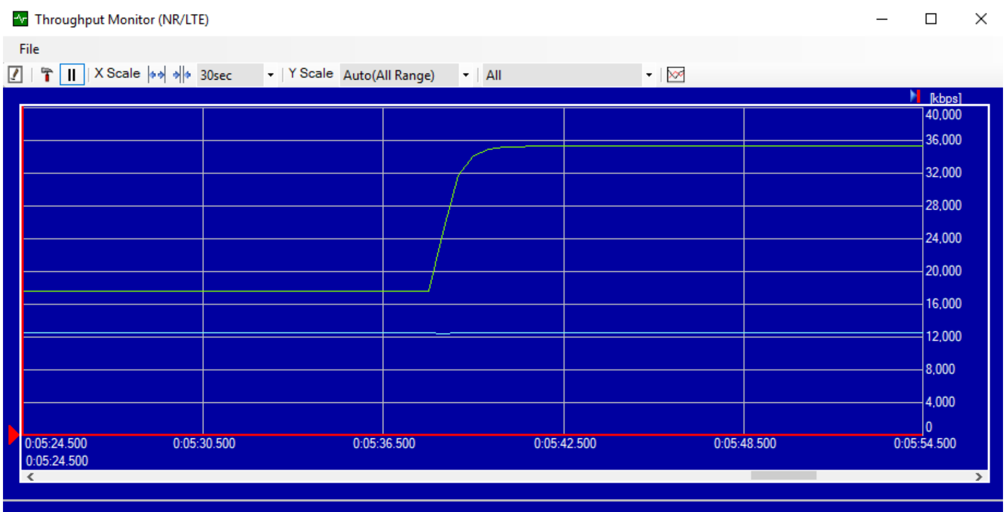


Figure 3.16: Connection with carrier aggregation



Color	Item	Marker [kbps]	Accumulate [bytes]	Average [kbps]	Max Rate [kbps]	Min Rate [kbps]
	QFI/EBI/NSAPI - ALL DL	0.0	0	0.0	0.0	0.0
	QFI/EBI/NSAPI - ALL UL	0.1	2,508	0.1	1.2	0.0
	QFI/EBI/NSAPI - 5 DL	0.0	0	0.0	0.0	0.0
	QFI/EBI/NSAPI - 5 UL	0.0	0	0.0	0.0	0.0
	QFI/EBI/NSAPI - 6 DL	0.0	0	0.0	0.0	0.0
	QFI/EBI/NSAPI - 6 UL	0.1	2,508	0.1	1.2	0.0
	NR MAC PDU DL	0.0	0	0.0	0.0	0.0
	NR MAC PDU UL	0.0	0	0.0	0.0	0.0
	LTE MAC PDU DL	17,664.0	644,444,393	24,803.5	35,324.0	5.8
	LTE MAC PDU UL	12,576.0	324,181,735	12,483.4	12,576.0	7.1

Figure 3.17: Throughput measurement graph in carrier aggregation

used for Rx is one. Therefore, as depicted in the diagram, LTE antenna 2 serves only as Tx, whereas LTE antenna 1, which occupies the primary sub-slot, serves as both Tx and Rx. When NR 2x2 MIMO is also being simulated on the NR slots, the situation is the same.

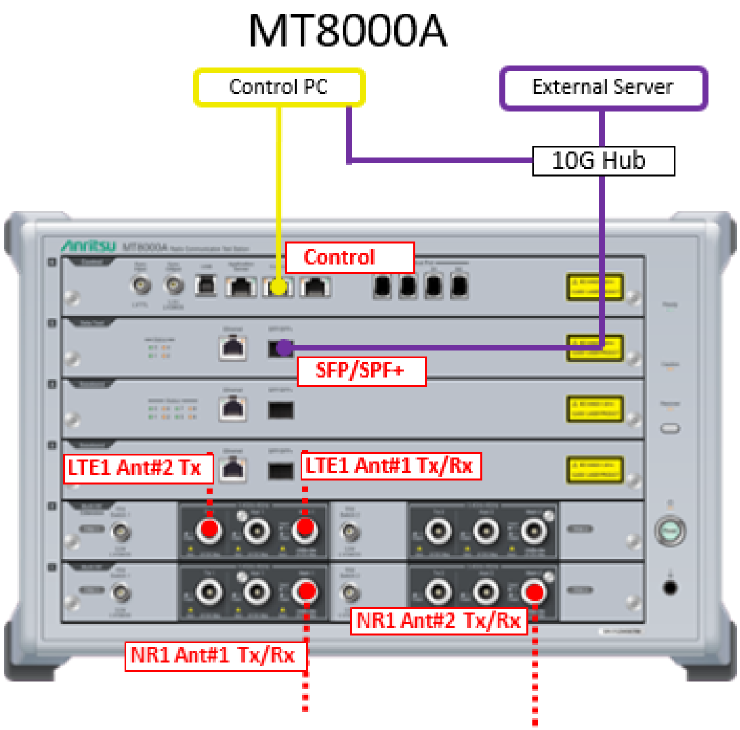


Figure 3.18: Connection diagram of MIMO 2x2 combination with one LTE cell

For the emulation of a MIMO based network the number of antenna's needs to selected as per the MIMO mode. In the 2x2 MIMO case the number of antenna's for a LTE cell needs to be 2 for DL, whereas MIMO in UL for LTE is not available with the current setup.

The number of antennas needed to simulate a MIMO-based network must be chosen in accordance with the MIMO mode. For DL, an LTE cell must have two antennas for 2x2 MIMO, whereas MIMO in UL for LTE is not possible with the current setup.

Figure 3.18 depicts the connection diagram for MIMO with NR in a 2x2 configuration on NR-based RF slots. After the simulation and cell parameter setup (mainly the number of antennas in DL and UL for NR cell needs to be changed, all other parameters remain the same), the simulation started and the device is registered. Figures 3.19 and **??** depict the device connection with one DL antenna and then with two DL antennas, respectively. Both figures show that the first case has a throughput of 333.9 Mbps, whereas the second case has a throughput of 727.34 Mbps with 2x2 MIMO.

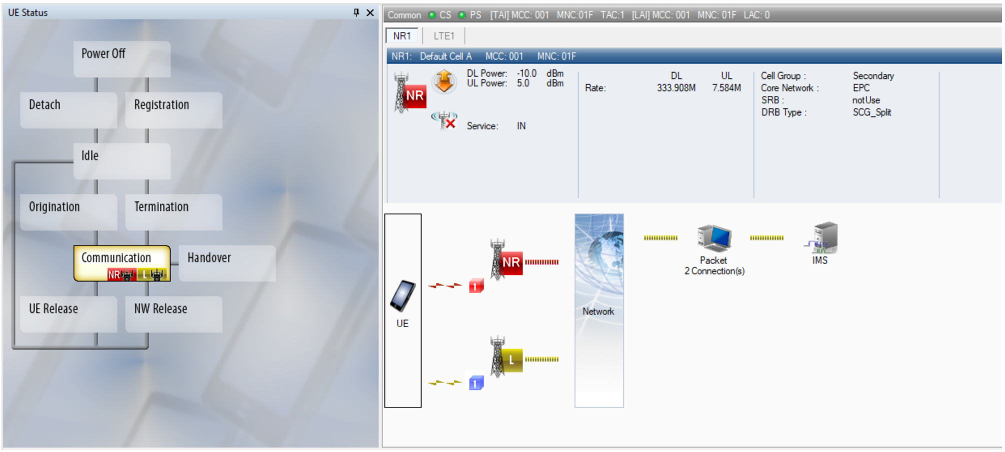


Figure 3.19: Connection and throughput without MIMO

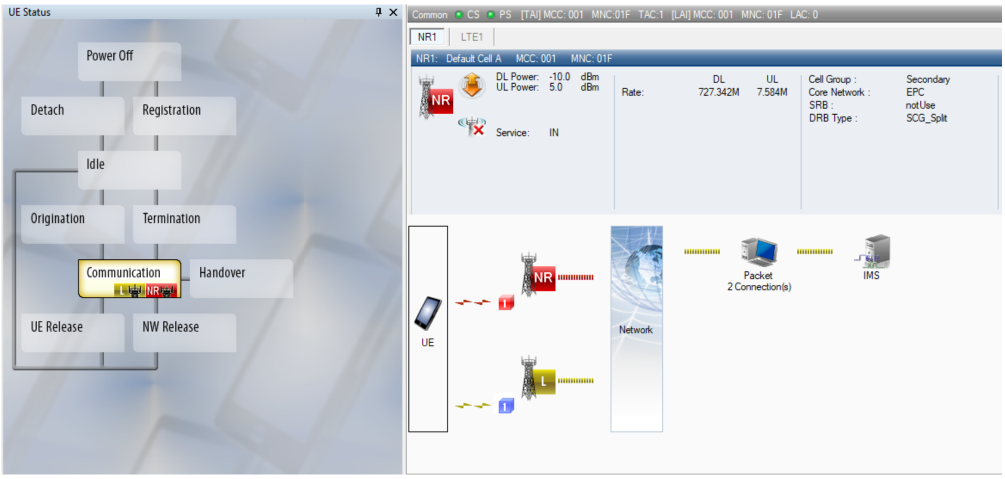


Figure 3.20: Connection and throughput with 2x2 MIMO

4x4 MIMO with NR

The final test case in which NR cells are used to perform a 4x4 MIMO.For the DL, four antennas are assigned, while for the UL, only one is retained. As anticipated, this configuration significantly increases throughput to 1335.45 Mbps. Figure 3.21 depicts a complex 4x4 MIMO connection diagram, and Figure 3.22 depicts the device connection and throughput status. Since the device only has two ports, one for LTE and one for NR, the multiplexer, also known as a combiner, is used to connect to the device in all of the scenarios above that require more than two antennas, such as MIMO, multi-cell, and CA.

Figure 3.21: MT8000A connection with the device in 4x4 MIMO mode (real picture of the platform

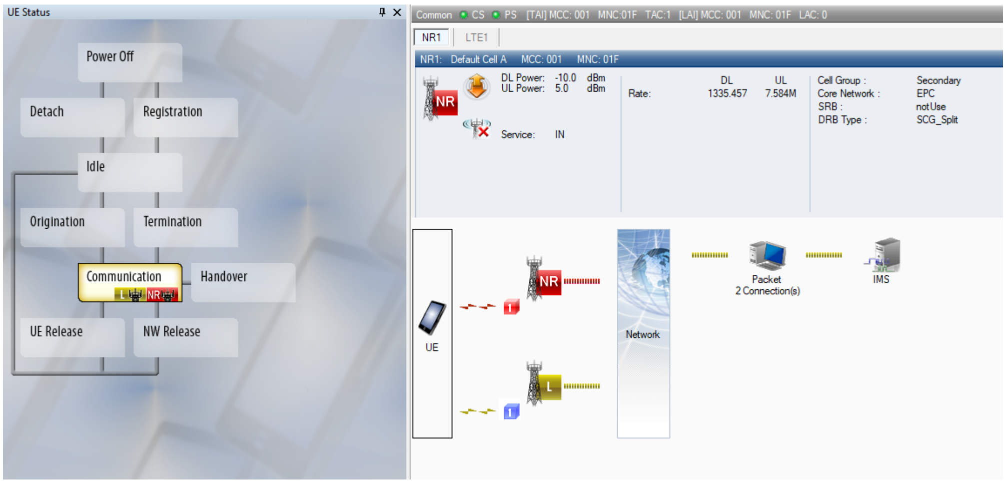


Figure 3.22: Connection and throughput with 4x4 MIMO

Chapter 4

Traffic simulation and vehicle's messaging

A traffic simulation environment becomes an essential tool for developing and evaluating V2X technologies in the current development scenarios, in which front loading is the new normal. The overall development cycle time and associated costs are reduced as a result. Simulators are in great demand in the transportation industry because of the high volume of traffic, increased demand, and rising safety-related requirements [21].

Traffic scenarios like junctions, traffic lights, turnarounds, and parking lots can be generated by traffic simulation platforms. It should also be able to handle the rarest of situations that can draw a large crowd, such as the ICC Cricket World Cup Final Match in Mumbai, and it should have features like traffic control, optimization, and the ability to predict the behavior of the network. A virtual scenario has the advantages of being easily configurable and adaptable to a variety of traffic system topologies, thereby reducing the timing of the result feedback loop and enabling the validation of new models at low cost and without the need for a physical structure.

It is now possible to measure a large number of data, such as emission, intended route, and battery charge, with high precision using big data and AI-based traffic simulators. This makes it easier to perform vehicle platooning. Co-simulation and inter-vehicle communications are also now possible thanks to this simulator.

The traffic models topology could be classify with different criteria [22]:

1. The independent variables scale: Since the described system is typically dynamic, the time scale must be taken into consideration. A discrete model depicts changes in a discontinuous manner, either after specific events or at regular intervals. A continuous model, on the other hand, describes how traffic changes over time continuously. The only dimension that can be discrete or continuous is time: Examples are provided by position or speed.

2. The processes are represented: In this type of classification, the determining factor is whether these processes are stochastic or deterministic. In the first scenario, the simulation is completely predictable if two simulations with identical input parameters are run simultaneously. However, due to the presence of some random factors, simulations based on stochastic models are unpredictable.

3. Application scope:the manner in which the dynamics of isolated entities like networks, links, and intersections are depicted.

4. Detailing level:whether the simulation is macroscopically, mesoscopically, nanographically, or microscopically.

It's important to focus on the same thing because the level of detail in the current traffic simulation varies a lot and, depending on that, the current transportation systems are also classified as urban, rural, and motorway.

4.1 SUMO

SUMO, or "Simulation of Urban Mobility," is a platform for multi-model, microscopic traffic simulations that is open source. It makes it possible to simulate the movement of multiple vehicle types through a given road network as part of a traffic system. As a result, it is possible to virtualize any traffic scenario with a variety of mobility options. It allows for the explicit modeling of each vehicle because it is completely microscopic, has its own route, and moves independently through the network.

DLR, which stands for the Deutsches Zentrum für Luft- und Raumfahrt e.V. in the year 2000 to take advantage of the modeling opportunity in the traffic research field. It provides an open-ended platform for traffic modeling and algorithm evaluation. Even though the majority of the development was done by DLR itself, it has been kept open and accessible to allow researchers to collaborate on transportation and traffic system research. Additionally, SUMO supplies a unified model and architecture, making it possible to implement more comparable algorithms [23]. This simulator platform has reached its 33rd release, and the community has grown to include numerous significant university contributors from around the world, including Politecnico di Torino, UCLA, and IIT Bombay. Consequently, it can be considered a commercial platform for traffic simulations as a result of these ongoing improvements.

4.1.1 Application of SUMO in Connected vehicles

The major achievements of this simulator correspond to the requirements for performance in real-world traffic scenarios under the model of connected vehicle services and functions. The command-line execution of these programs furthers the goals of speed and portability for the initial programs. Later, these programs could be interfaced with using a graphical user interface (GUI), but running them without one is still possible. As a result, these strategic programs have resulted in a platform that can perform space-continuous, discrete-time-based simulations, allowing for the management of networks with thousands of edges, a variety of vehicle types, and, most importantly, the execution speed of up to 100,000 vehicles on a machine running at 1GHz. The simulator outputs could be vehicle-based, network-based, or edge-based [24].

Since the deployment of shared services and functions in the real world would necessitate information sharing in almost real-time, this simulator's data subscription feature is crucial during the simulation run time. As a result, SUMO can be used for a variety of projects in the connected vehicle research field. V2X (V2V and V2I) communications, AV simulations, and traffic testing techniques like vehicle platooning made up the majority of SUMO projects. The involvement of SUMO in a variety of studies from 2002 to 2012 is depicted in Figure 4.1. As can be seen from the image, V2X communication systems simulation accounts for 70% of all SUMO-based research, according to [24].

The very first European project TransAID that has been developing new hierarchical traffic management system which would allow the smooth transition of automated vehicles into the traffic systems. There the use of SUMO is to simulate the automated vehicles behaviour's which are at the systems limits i.e. a situation which can not be handled automatically and driver needs to be engaged again [26].

The first ever European project, TransAID, was working on a new hierarchical traffic management system that would make it easy for automated vehicles to integrate into traffic systems. There, SUMO is used to simulate behaviors of automated vehicles that are beyond the system's capabilities, such as a situation that cannot be handled automatically and necessitates driver involvement once more [26].

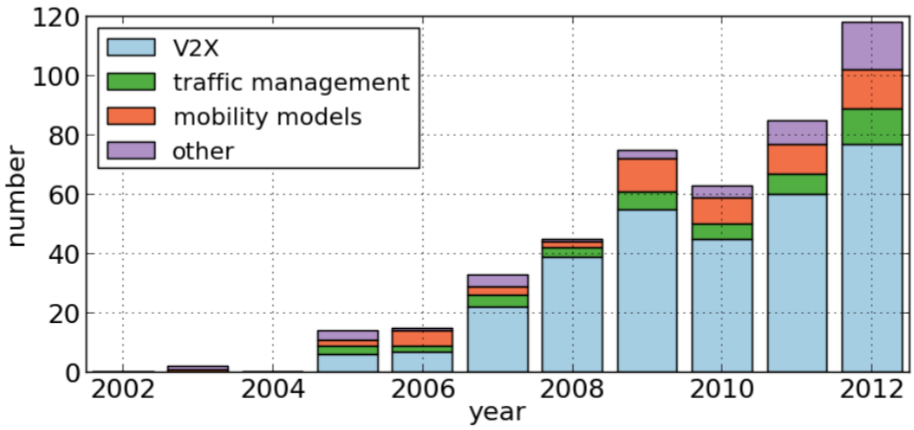


Figure 4.1: Development of research publications 'major topics' [25]

The SUMO was also used as a traffic simulator in a separate project that was connected to the monitoring system. The project intends to construct a "Traffic Tower": a virtual traffic management center that uses virtual traffic mapping to monitor traffic at major events and evaluate traffic control algorithms in the SUMO simulation environment [27].

There are numerous ongoing projects that are connected to connected vehicles, such as MAVEN (Managing Automated Vehicles Enhances Network), Vital, a novel traffic light control system that uses V2X communication, and so on. Utilizing virtual simulators [28], it is also possible to investigate the emission scenarios (CO2 and PM2.5).

DLR holds annual conferences at which participants present their SUMO-related work in order to support the community and provide opportunities for collaborative research in the areas of connected vehicles, traffic simulations, and other safety-related projects.

4.1.2 SUMO Package's and scenario generation

As was mentioned earlier, SUMO the traffic simulator is made up of many different packages, most of which are designed to cover all possible scenarios. Since utilizing all of the available packages is outside of the scope of this work, we will not discuss them here [29].

4.1.3 TraCI

The exchange of data between vehicles and to and from a cloud server is one of the most crucial tasks in the virtual validation of vehicle cooperative perception. As a result, it needs an interface that makes it easier to access the running traffic simulation. An interface known as TraCI, which stands for "Traffic Control Interface," gives users access to running SUMO instances by means of a series of commands. Additionally, TraCIAPI c/c++, libtraci java, TraCI4Matlab, and TraCI python can be used as TraCI's interface. The TraCI Python libs are used for this project's task because other tasks in the same process will also use the same platform.

This interface connects to SUMO which is currently running and operates as a client/server architecture based on TCP. In this manner, SUMO functions as a server and is initialized with additional command lines such as "sumo-GUI."According to the respective modules, TraCI divides this series of commands into fourteen distinct domains: GUI, poi, simulation, lane, edge, route, traffic light, junction, induction loop, multi-entry exit, polygon, people, vehicles, and vehicle types [30]. Python is the most widely used library in TraCI, and that's also the one used here.

Three main commands types offered by TraCI:

- Control related commands : execute a simulation step, start/end the connection, reload the simulation.
- Value retrieval: allow the retrieval of simulation data such as vehicle value retrieval, route value retrieval, Charging Station Value Retrieval, and edge value retrieval etc.
- State changing: allow to change the state of the various objects, in particular Change Vehicle State change a vehicle's state,Change Person State Change Vehicle Type State, Change Route State change a route's state

When developing any TraCI-related application, there are a few drawbacks that must be taken into account. The simulation's slowdown, was caused by a variety of factors:

- in a simulation step the number of TraCI function calls.
- the type of the TraCI function being called (few of them are very expensive)
- computation within the TraCI script

- extra communication channel within the TraCI function call (AMQP broker based)
- client language

One of the example of such a slowdown in simulation is being recorded by the studies of Bologna scenario [31].

4.2 Scenario generation : Roundabout

In traffic simulation, scenario generation or map availability is the most delicate task. In general, SUMO is used to simulate a particular scenario or situation, such as a roundabout that only requires a few blocks or junctions. As far as fixing the map is concerned, it is no problem to generate such small scenarios because it is simple to generate synthetic traffic within the scope of the required study. When a large scenario is required for the study, the situation becomes more complicated. A large number of studies and research projects involving complex scenarios demonstrate the significance of criticality in the generation of such scenarios. In order to construct a realistic simulation, the majority of works devoted to the generation of large scenarios focused on the collection of input data, particularly for traffic and map generation. The scenario that is being considered here is a bizarre one, as previously stated. It is one of the most difficult situations, especially when it occurs in traffic between and within cities.

A roundabout is a type of intersection in which traffic moves in one direction around an island in the middle. According to FHWA (2010), roundabout traffic management would improve traffic safety, operational efficiency, and other aspects. The geometry of a roundabout needs to be such that it forces vehicles to enter and circulate at a slow speed without long stops in order to maintain its operational safety. As a result, the roundabout design needs to achieve goals like a low entry speed, a sufficient number of lanes, smooth channelization, dedicated lanes for pedestrians and cyclists, etc [32].

Since scenario design is beyond the scope of this work, the factors that would affect roundabout operations' performance will not be taken into account. The primary objective is to examine the various types of vehicles—manually driven, semi-automated, and autonomous—in a roundabout setting to determine how vehicle communications with infrastructure and between them could enhance operational awareness.in addition to creating a virtual testing environment in which the Edge could digitally link data from vehicles and a driving simulator equipped with the Telecommunication Box unit. As a consequence of this, a cooperative perception mechanism that, with the assistance of AIFs located at the traffic stations, could be developed could direct traffic around roundabouts in a safe manner, alert drivers or autonomous systems to potential dangers, and so on.

Although the traffic simulator that is being used for this project's work has already been mentioned, additional attempts at traffic simulation on the roundabout using various tools merit discussion. For instance, Trueblood Dale (2003) [21] used VISSIM to simulate a roundabout. The analysis of their work's results revealed that VISSIM's realistic roundabout simulation relies on four key components: the links and connectors for the geometric coding of roundabouts, routing decisions, the precision of reflecting on gap acceptance at roundabouts, and a feature in VISSIM simulation control for the vehicle's final speed. In addition, TRACSIM by Krogscheepers Roebuck, 1999, a program related to driver behavior and gap acceptance at roundabouts, is being used for the roundabout simulation [33]

The LuST (Luxembourg SUMO Traffic) project is one research project that uses SUMO for major scenario generation: a 24-hour scenario for the SUMO traffic simulation [34] in Luxembourg City. Given the advantages of using SUMO, the traffic simulator used in this work, the scenario generation for Roundabout is less complicated than in the previous work. Now that we've talked about simulators and the work they do, it's important to know how to make the scenario on SUMO and any additional steps that need to be done.

4.2.1 Building the network

The SUMO user documentation says that there are three main ways to make a network: *netonvert, netgenerate, and netedit*, all of which use the same process. In general, four steps are required to construct the network and carry out the simulation. The traffic-related portion of a map is defined by a SUMO network, which contains the following data:

- Every street as a collection of lanes
- Traffic light logistics
- junctions
- Connections between lanes at junctions

These can be improved with district and roundabout descriptions and set processing options for user input. In our case, it's not just about simulating traffic; it's also about developing a communication platform and evaluating various capabilities related to six AI@EDGE technological enablers. As a result, it's critical to avoid creating an overly large and complicated network with too many traffic entities.

Other digital networks that are compatible with SUMO can be used to build a sumo network. For instance, OpenStreetMap (OSM) can be used to import a network by setting the network-related parameters. Neconvert or Netgenerate, which can assist in building a network as a converter/importer, must be used to construct a roundabout traffic scenario-like network using the tailored description. A network can be imported by an importer from a variety of sources, including OSM, VISUM, VISSIM, SUMO native XML descriptions, and so on. Figure 4.2 depicts the most typical and general method for importing a network from various resources.

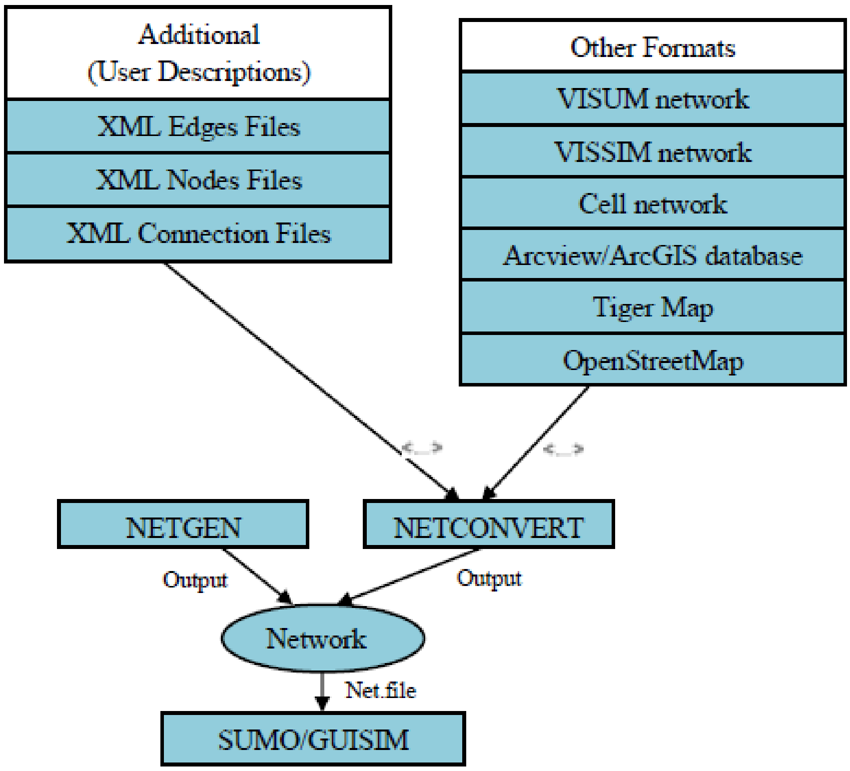


Figure 4.2: Network Building procedure (Krajzewicz & Behrisch (n.d.))

The method that was used to create the roundabout in this instance is shown on the left side of Figure 4.2. The network was created using a NETCONVERT command-line application and the defined user descriptions of nodes, edges, and connection files. The next step is to add the SUMO's traffic to the network after it has been created. Editing the routes file with traffic-related parameters like the number of vehicles, vehicle types, the route taken by each vehicle, the vehicle's physical properties, the timing of the traffic simulation, the introduction of a specific vehicle at a specific time during the simulation, the projection and UTC of the traffic scenario, etc. is the simplest way to accomplish this. When there are fewer route and traffic entities, this method of editing the route files is simple. The acceleration, deceleration, length, color, and the maximum speed for each vehicle type are all contained in the description file, which also contains all information assigned as a vehicle identity. In addition to these parameters, there are constraints on how the routes can be designed. For instance, they must be connected and have at least two edges. Another thing to keep in mind about vehicles is that they can start at a specific position until they start at the specified edges at a specific time, which is how that particular route is sorted.

As depicted in Figure 4.3, there is a variety of ways to generate random networks using OSM. OSM is a free, editable map of the entire world that lets anyone create and provide data for any area. Street maps are included in the data, which can eventually be transformed into a SUMO network file using NETCONVERT. A script called *osmWebWizard.py* is used in this method, making it simple to construct a complete scenario. The network can be imported using a variety of maps, giving you control over the creation of various traffic modes using a variety of traffic entities. The fact that this method is free but subject to technical and legal restrictions prevents users from making more creative and productive use of the data.

The roundabout scenario has been generated by following the procedure in Figure 4.2, which makes use of the description files (Nodes, Edges, and Connections) and the necessary traffic parameters. The number of vehicles in the network, which is 10, is the same for simplicity's sake. The simulation setup's instance of the SUMO GUI, Figure 4.4, depicts the generated roundabout network. The generated network could be simulated with the assistance of the SUMO GUI once the network has been constructed and the traffic has been defined as discussed. TraCI API applications or command-line applications can also be used to run it without a GUI. TraCI Python library applications are the method used here, and you can run them with or without GUI options. The simulation is now ready to run in order to obtain the base model of the targeted network and can be applied to other vehicle dynamics model-equipped simulation scenarios after the start and end times have been defined.

The simulation and vehicle data subscription from running sumo instances will be discussed in the following section. The architecture for closed communication with the server will then be developed further.

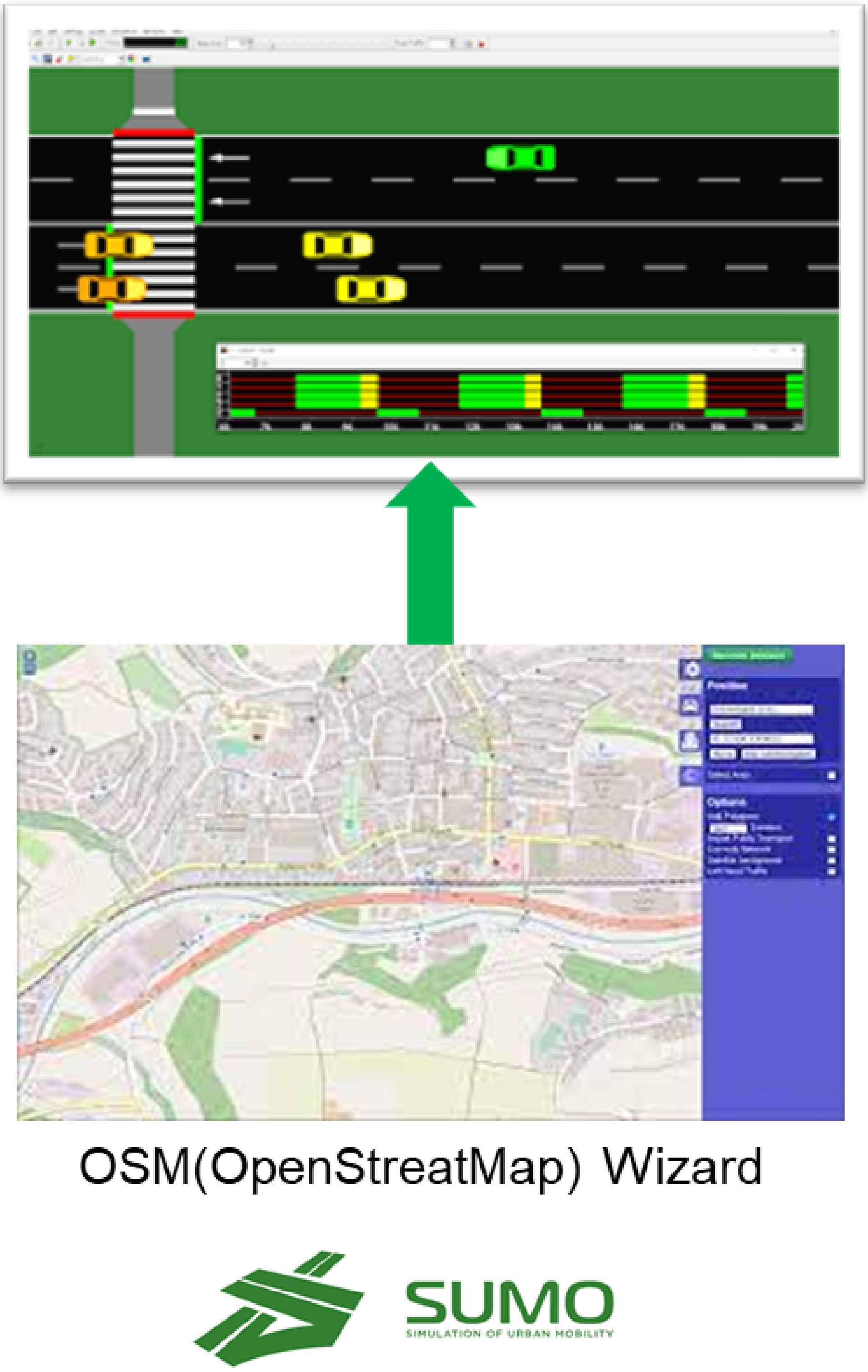


Figure 4.3: Network generator with OpenStreetMap

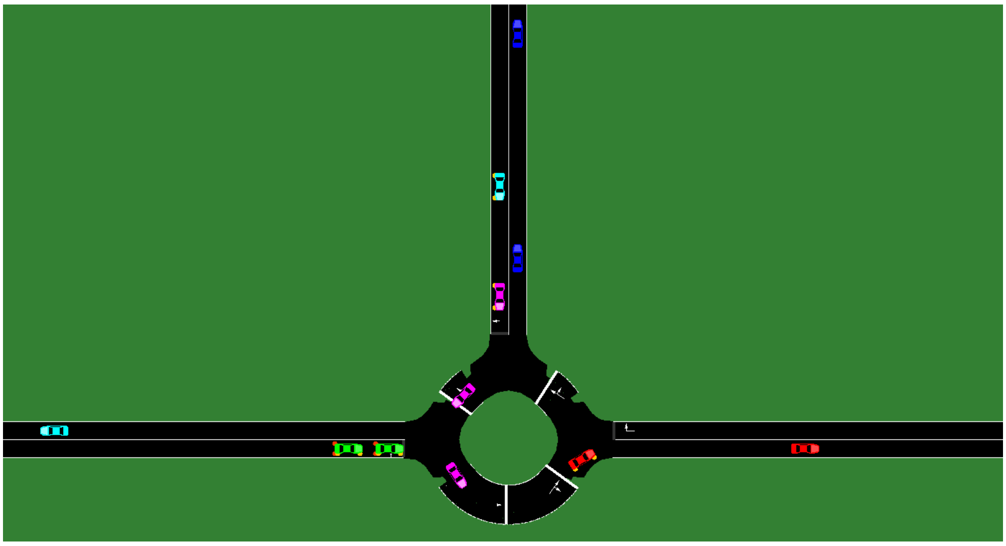


Figure 4.4: Roundabout Scenario GUI on SUMO with vehicles

4.3 Simulation and Vehicle's data generation

The TraCI functions must be utilized in order to gain access to the simulation variables and exert control over them. The SUMO client application is the name of the program or application that will be used for everything from simulation to sending messages and creating vehicle data. Submodules like Subscriber, message binder, AMQP client, and others are also included. which will be discussed in greater detail in the following section of this chapter. It will be possible to invoke the SUMO client based on the TraCI API as soon as the simulation runs without any network-related errors, such as roads that are not connected or a vehicle in the wrong position, among other things. We could summarize the entire SUMO client process in the following steps, and a high-level architecture is also depicted in Figure 4.5.

- STEP 1: Insertion of various traffic entities through TraCI, such as vehicles, traffic light signals, and simulation timing step etc. The enumerable entities are assigned by specific ID numbers.

- STEP 2: With assigned ID's of vehicle, getting other traffic related parameters which are specific to a particular vehicle; vehicle position (then converting into longitude and latitude), date and timing, speed of the vehicle, road edge, lane, turning angle of vehicle, and next traffic light signal vehicle is heading to etc.

- STEP 3: Then lane specific traffic lights related information; current traffic light signal state, traffic light phase duration, traffic next switch, etc.

- STEP 4: Inserting the functions for controlling and updating vehicle and traffic related variables which are received from edge/server in the previous simulation step and have decoded with the help of V2X coder application.

- STEP 5: Then packing all the data so could be used in CAM/DENM formation and possibility to export them in csv/xls files.

- STEP 6:Then binding all the required info into CAM/DENM format as per the ETSI standards.

- STEP 7: In the end encoding the messages with the help of V2X coder application and sending the messages to the edge server via AMQP client.

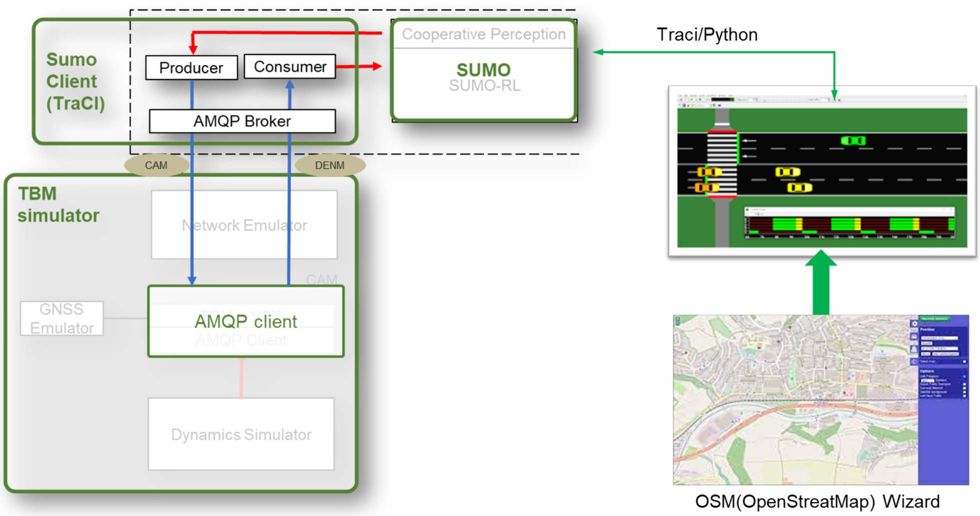


Figure 4.5: SUMO client architecture

A more detailed discussion on some of the above mentioned steps in the dedicated sections.

4.4 V2X Coder

Having a standard format for messages that are exchanged between vehicles and edge servers or between vehicles is crucial in the context of vehicle messaging. As a result, a common framework is used to define a few fundamental applications in the "Intelligent Transport System" (ITS). *Cooperative Awareness* (CA) and *Road*

Hazard Warnings (RHW) are the most crucial services. CA itself refers to itself as a cooperative, which means that it participates in cooperative perception among a group of vehicles with the assistance of edge services by exchanging messages in the ITS network to raise awareness of other vehicles and road users [35].

Utilizing the V2V and V2I networks, on the other hand, the RHW aims to increase traffic efficiency and improve road safety. Cooperative Awareness Messaging is used by the CA, and the Decentralized Environmental Notification application service is used by the RHW, which is a type of emergency service [35].

The SUMO client application's V2X coder module contains the aforementioned services.where the ETSI-defined format is used to encode or decode the vehicle-specific information in the simulated traffic.

4.4.1 Cooperative Awareness Messaging

The ETSI-defined standard structures known as CAM and DENM are used to put the aforementioned services into action. Cooperative awareness services provide the sending and receiving of CAMs.ITS stations may differ in the frequency with which the CAMs are sent. In order to collect the data obtained from CAMs, the facility layer's CA services interface with the application layer. Figure 4.6depicts the CA basic service architecture.

The encoding and decoding functions are necessary for sending and receiving CAMs.Transmission and reception management sub-functions are also required, but this work only requires the encoding and decoding ports because these tasks are always carried out while the V2X coder is operating.

The dissemination of CAM is not a significant issue because the work here is more program-level with virtual traffic simulation. However, a successful dissemination strategy is essential for successfully covering a region with CA messages. In most cases, CAMs are sent in a single hop to all receiving ITS stations within range. Due to the simultaneous operation of ITS-S within the range, a vehicle's data stream is activated and deactivated. The degree of channel congestion affects the frequency with which messages are massaging. Nevertheless, the message generation process accepts a time between 100 and 1000 milliseconds [35]. This may be different for different network systems, like LTE-V2X, where the access layer manages channel congestion and, as a result, generation timing.

The ITS PDU header, which contains information about the protocol version, message type, and ITS-S ID from which the message originated, is one of CAM's most important components. The ITS-S could be a vehicle, RSU, or pedestrian in

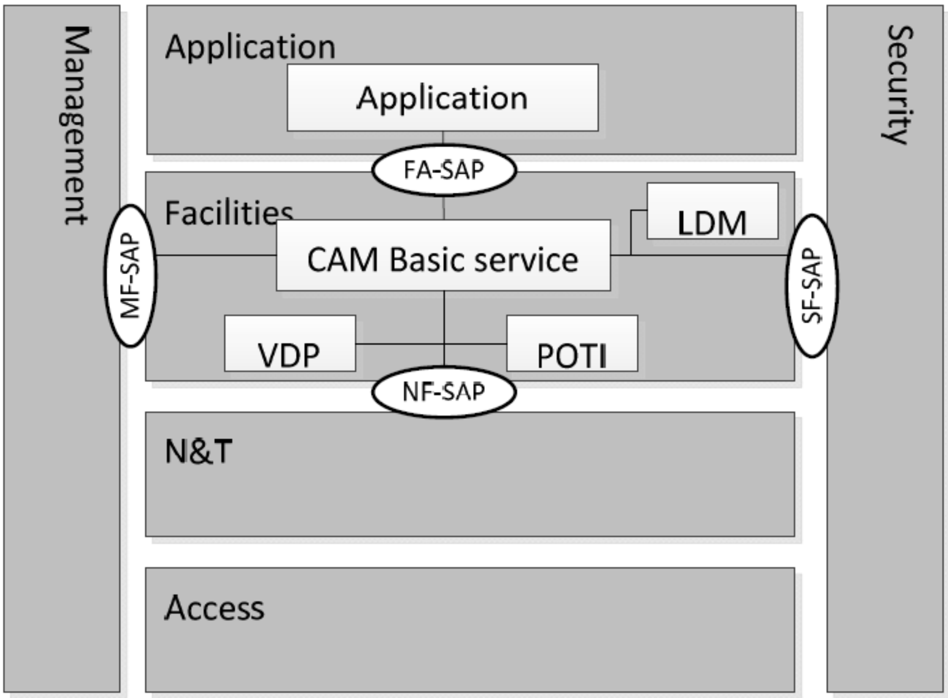


Figure 4.6: CA basic service architecture, [35]

general in this instance. There are primarily three types of containers that a CAM can be made up of:

- **Basic container** this consists of the information about the originating ITS-Station.
- **High frequency container** this consists of highly dynamic information about the ITS-Station (in our case vehicles).
- **Low frequency container** this consists of static or slowly changing information.
- **Special vehicle container** this consists info specific to a particular type of vehicle (i.e. Public transport, Special transport etc.)

4.4.2 Decentralized Environmental Notification Messaging

As the name suggested DEN services are different in their application as compare to CA services, DEN services application are more in a specific event detection and alert users in a decentralized manner [36]. There is specific process in which ITS

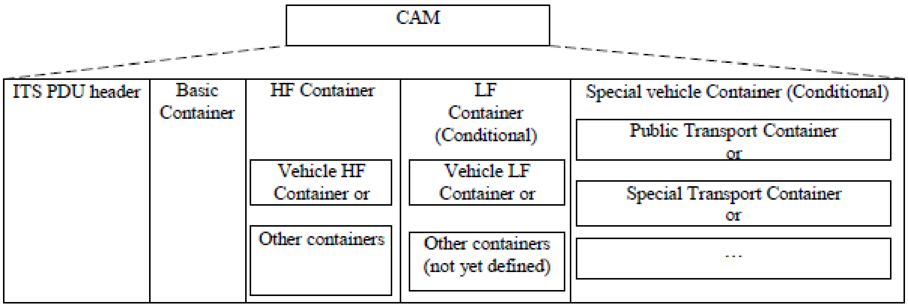


Figure 4.7: CAM structure (ETSI), [35]

uses the DEN service's :

- DENM disseminates itself across the ITS-stations in a area called 'Zone of Relevance', when an alert is raised.
- The transmission continuous till the detected hazards event has not been ceased.
- Exchange of messages could forwarded between ITS-S itself.
- HMI could be used to alert users also with the information in DENM but it's not compulsory.

The CA service architecture, which interfaces with the application layer to send and receive DENMs, is also similar to the DENM architecture. As soon as messages are received, the facility layer's Local Dynamic Map (LDP) is updated. Even though the CA service architecture and the DEN service architecture are similar, the message-generating station identification is different. An unused actionID is created when the DEN services are triggered by an alert event at the application layer, allowing the generating station to be distinguished from other stations [36].

One of the distinguishing features of the DENMs is their relevance area, which identifies an exposed area where vehicles may be in danger. The generating station always includes this zone as well as two additional parameters: the *relevanceDistance* parameter, which specifies the distance at which other vehicles will be receiving messages, and the *relevanceTrafficDirection* parameter, which specifies the vehicles' directions in which they should encounter the alert.

DENM Container: The DENMs also have an ITS-PDU header with the same functionality as the CAMs. Figure 4.9 depicts the DENM container structure,

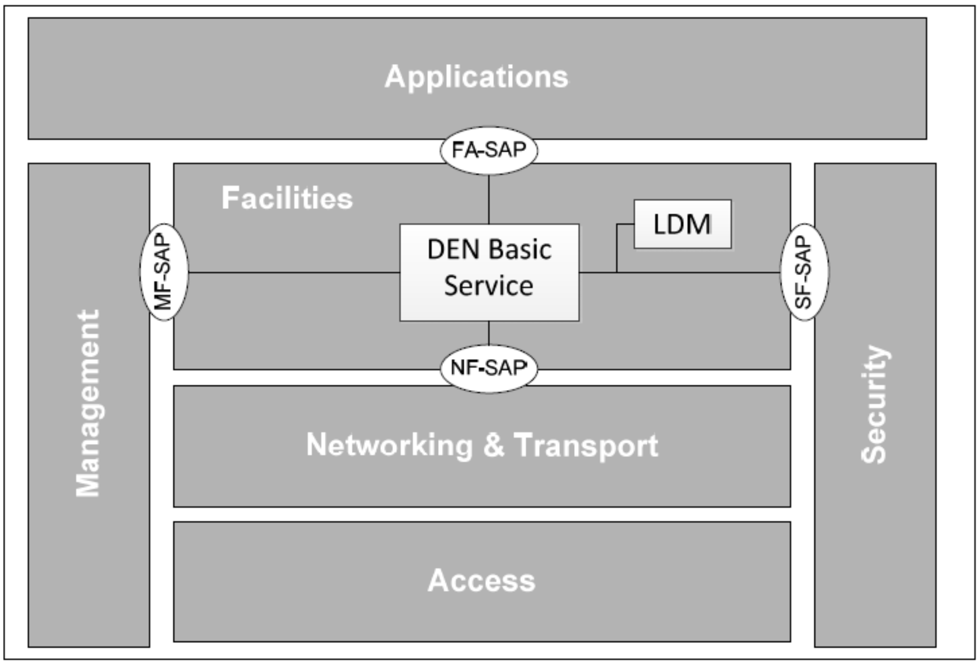


Figure 4.8: DENM architecture (ETSI), [36]

which includes five containers. The situation container contains the main information about the event that needs to be communicated to other ITS Stations. The management container contains information about *actionID*, *detectionTime*, *referenceTime*, etc. The event speed, position heading, traces, and type of road information are all stored in the location container. The final container, **à la carte** is optional; however, in abnormal conditions, it may contain additional information that cannot be included by other containers like *externalTemperature*.

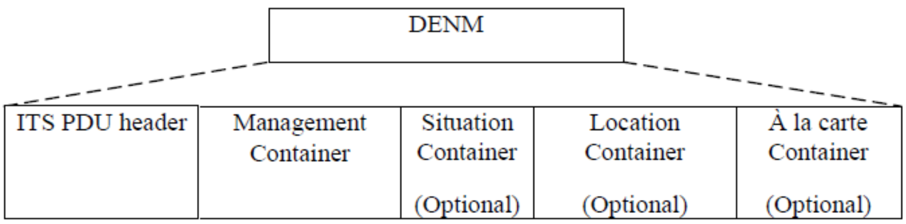


Figure 4.9: DENM Structure (ETSI), [36]

4.4.3 Encoding-Decoding

Let's return to the SUMO client, which would implement the CA and DEN services and send and receive CAM and DENM messages to and from the server, after a brief discussion of their architecture and CAM and DENM structures. According to the CAM's structure in Figure 4.7, vehicle and traffic-related data must be bound into the specified format. Sub-functions in the SUMO client bind these data to a JSON format and then encode them into binary forms before sending them to the server. Decoding is also required when messages are received from the server. A SUMO client handles the encoding and decoding locally, while an AMQP client handles the message sending and receiving. Other team members at Stellantis developed the applications for encoding and decoding tasks. These applications can perform CAM to BIN, CAM to HEX, DENM to HEX, and other encoding and decoding operations. Also in a different way. As a result, these applications are utilized by the SUMO client. The Encoder/Decoder application could be invoked and the necessary operations could be performed in SUMO simulation steps after the CAM binding has been completed.

In order to send a CAM message there are few conditions that are defined by ETSI, as given in **Appendix A**, needs to be satisfied. So, these conditions are nested before the message generation process could start.

4.5 AMQP Client

The AMQP corporate messaging protocol is primarily utilized in the business setting. It depends on infrastructure that is safe, dependable, and interoperable. It works with the public/subscribe and request/response architectures. It also has reliable queueing, topic-based publishing, subscribes messaging, flexible routing, and transaction [37], among other things.

Nodes are important entities in AMQP. *links* connect them, and their primary function is to store and deliver messages. The fact that the link is a one-way connection between the nodes and the particular terminus point is an important point to emphasize here. The nodes are in the container; One or more nodes, such as a broker or a client, make up a container. There are two nodes in this AMQP client, one of which is the sender and the other of which is the receiver. A producer, a consumer, or a queue could be the node beneath a container.

A message emulation step, which is nothing more than a CAM/DENM generation process, is required in order to organize end-to-end communication between the traffic simulator and the cloud server. Encoding methods are used to generate these messages, as previously mentioned. The first step in emulating CAM/DENM is to transform the information into an ETSI text file that contains the message structures. The information contained in the DENM message is related to the situation container's cause code and sub-cause code. The crucial information, on the other hand, is being loaded into the text file for the CAM message. These CAM data will be discussed at a later point in the message generation algorithm. The textual messages are in the form of strings, making it possible for encoding programs to convert them into the required BIN format. The encoding applications make use of the Python library **ans1tools** and the other Python packages [38] that are related to app development. It's also important to note that Geo-networking and Basic Transport Protocols are added during the encoding process.

Many of the available sources can be used to build an AMQP client with a sender and a receiver, but the Qpid Proton [39] library was used here. It is a lightweight, high-performance messaging library that can be used to build clients, brokers, routers, and more. The AMQP message transfer takes place when links are established between peers, as it does in the messaging process.

The link for the sending peer is *Receiver*, while the name for the receiving peer is *Receiver*. These links must include the address of the Source or Target, and they cannot begin until both the sessions and the connections have been established. As a result, the primary points of entry are the connections, which are established with containers that must be uniquely defined.

A link is said to be in delivery once a message is sent. Either the Sender or the Receiver can settle a delivery to confirm it. The successful delivery must be promptly communicated to the opposing side following this action. At that point, all further communications are stopped.

4.5.1 Sender

The forwarding of information for During a simulation step, the Sender establishes a connection to send these CAMs to the server. The creation of application logic in a class that handles various events [39] serves as the foundation for the sending procedure. The following classes are used in the application container to define these kinds of events, which are taken care of by the Proton event handler:

- *on_start* When an event loop is initialized
- *on_sendable* When the link has sufficient credit, thus permitting message flow
- *on_accepted* When the remote peer acknowledges the message coming from

the sending peer

- *on_disconnected* Called only when the connection socket has been closed

All of the aforementioned events are contained in the imported from Reactor class **container**. This makes it possible to easily program an event loop that responds to events as they occur. The broker's address location is required every time the container is initialized. The location of the used broker's address is as follows.

"admin:admin_c3f@13.38.15.28:5672/amqpclient://"

where the broker's address and port were the first elements passed. For all AMQP transmissions, there is a default port 5672 that is defined. The subject is then defined. The encoded CAM/DENM messages are now included in the container's initialization of the event loop alongside the message destination address. The *event.sender.message* command is then used to label the message with a unique identification code before sending it.

4.5.2 Receiver

The Receiver is also created within a container that takes care of the events, following the same procedure as the Sender. The following are the events that the Receiver takes care of:

- *on_start* where variables are initialized.

- *on_message* where processes such as decoding, Geo-networking extrapolation takes place.

Similarly, with the help of the topic defined, the receiver will listen on:

"admin:admin_c3f@13.38.15.28:5672/amqpclient://"

The messages that are associated with the flow and belong to the specified address location and topic are subsequently consumed by the Receiver.

With the assistance of the appropriate TraCI functions, the information is retrieved and sent to the simulator after the message has been consumed.

Chapter 5

Conclusion and future work

A virtual validation based approached for the vehicle's cooperative perception has been explored which is a part of a big project called AI@EDGE. The six primary technological enablers of the AI@EDGE platform, which is based on AI exploitation for various connected vehicle services and functions, are first discussed in the report in the Chapter 2. Cooperative perception for vehicular networks, secure, multi-stakeholder AI for the Internet of Things (IoT), aerial infrastructure inspections, and in-flight entertainment were among the primary topics of discussion. As the work of thesis project aimed at one of the use case (UC1), AI@EDGE architecture's response to the use case challenges and solutions has been highlighted in subsequent sections of the discussion chapter. The use case made use of virtual traffic simulation environments and 5G emulation due to the complexity and cost of supporting a large number of vehicles in the real world.

In accordance with the Use case, the roundabout, which presents a particularly challenging situation in which safety and fluidity are essential, has been implemented on a traffic simulator called SUMO. Utilizing the Python-based library TraCI has made it easier to subscribe to online data from the traffic simulator. Using Qpid Proton's standard Python API, an AMQP client has been developed that interfaces with the subscription process and is referred to as the SUMO client in order to exchange this data with the edge server and other vehicles. Under the ITS standards, the traffic and vehicle-related information is sent to the server in the standard format defined by ETSI as CAM and DENM message services.

The communication-specific testing is carried out on a 5G emulation bench because the ultimate objective is to implement the previously developed capabilities on an on-board Telemetic Box Module device. Numerous test scenarios, including cell handover, dual-connectivity, carrier aggregation, MIMO, and others; on a network-based emulation HIL environment has been carried out in relation to the LTE/5G cellular network. By altering various network-related parameters like frequency, modulation technique, and band parameters, the C-V2X wave stack-equipped DUT (Device Under Test) has also been examined for network throughput testing. It has been possible to demonstrate that carrier aggregation and methods like MIMO can improve throughput in the DL mode and that smooth handover can be achieved with power rampage. A virtual validation platform for vehicular perception is being evaluated based on the developed capabilities and HIL testing results.

5.1 Future steps

As discussed in the Chapter 2, the deployment of a geographically dispersed virtual validation testing platform that would facilitate cooperative vehicle operations is the primary use case application of AI@EDGE fabric in cooperative perception. Therefore, the next step is to interface and synchronize the traffic scenario, which was developed using a simulator, with a real driving simulator. The AIFs can now be trained to aim for digitally twinning at the network edge level thanks to improved capabilities for retrieving simulation data into CAM formats. In the end, the tried-and-true TBM device could be used on a real driving simulator to use the developed client-based program. This allowed for further investigation and the possibility of improvement to be taken advantage of.

Appendix A

CAM Generator Algorithm

The values of D-THRESHOLD, H-THRESHOLD, S-THRESHOLD and T-THRESHOLD are the ones reported by ETSI:

- D-THRESHOLD = 5 m
- H-THRESHOLD +/- 4 degree
- S-THRESHOLD = 1 m/s
- T-THRESHOLD = 1 s

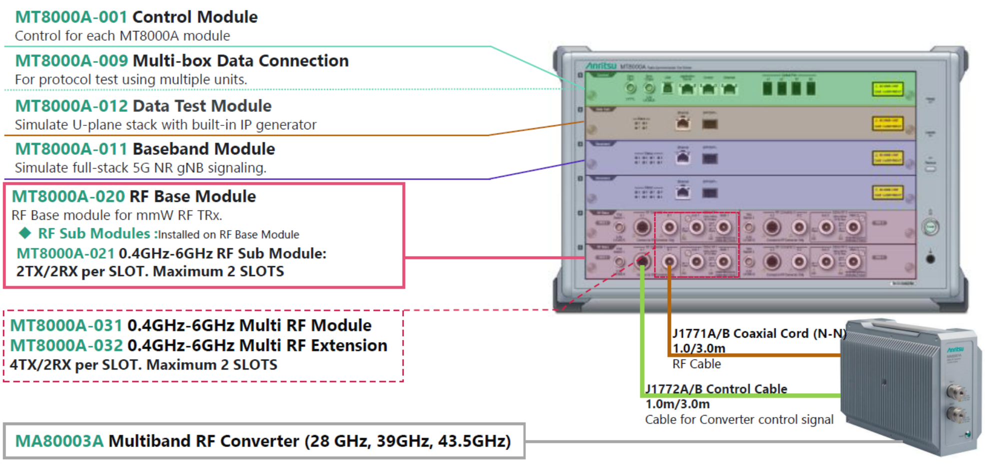
Algorithm 1 CAM generation algorithm as described by ETSI

Input: Position p; position history pHist; last CAM message sent lastCam
Output: New Cam message, lastCam updated; pHist updated with p

```
procedure CAM GENERATION(p,pHist,lastCam)
    ▷ p is the new position, pHist is the position History
    while true do
        time ←System.getTime()
        heading ← calcHeading(pHist,p)
        lastPos ←lastPosition(pHist)
        lastHist ←pHist/ lastPos
        lastHead ←calcHeading(lastHist,lastPos)
        speed ← calcSpeex(pHist,p)
        if  p ≠ null then
            lastSpeed ← calcSpeed(lsatHist,lastPos)
            if  distance(p, lastCam.pos) ≥ D-THRESHOLD or
                |heading − lastCam.heading| ≥ H-THRESHOLD or
                |speed − lastCam.speed| ≥ S-THRESHOLD  then
                cam ← newCam(time, p, heading, speed)
                sendCam(cam)
                lastCam ←
            pHist ← pHist ∪ p
        else
            p ← lastPos
            heading ← lastHead
        if time - lastCam.time ≥ T-THRESHOLD then
            cam ← newCam(time, p, heading, speed)
            sendCam(cam)
            lastCam ←
        System.wait(CHECK-PERIOD)
        ▷ The system check guarantees the CAM generation frequency of 10 Hz
```

Appendix B

MT8000A



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