DEDICAT 6G: Dynamic coverage Extension and Distributed Intelligence for human Centric Applications with assured security, privacy and Trust: from 5G to 6G

Deliverable D4.1
First release of mechanisms for dynamic coverage and connectivity extension

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Table of Content

List of Acronyms and Abbreviations

Acronym/Abbreviation	Definition
µS	Micro-service
3D	3-Dimensional
3GPP	Third Generation Partnership Project
5GPPP	5G Public-Private Partnership
AGV	Autonomous Guided Vehicle
AI	Artificial Intelligence
AMAP	Aerial Mobile Access Point
AP	Access Point
API	Application Programming Interface
B5G	Beyond 5G
BS	Base Station
CA	Cooperative Awareness
CAN	Controller Area Network
CDF	Cumulative Distribution Function
CEDM	Coverage Extension Decision Making
CNN	Convolutional Neural Network
CPU	Central Processing Unit
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
C-V2X	Cellular Vehicle to everything
DB	Data Base
DEN	Decentralized Environment Notification
DL	Downlink
DM	Decision Making
DMC	Discrete Monte Carlo
DUST	Distributed Uniform Streaming
DVB-T	Digital Video Broadcasting – Terrestrial
EIRP	Equivalent Isotopically Radiated Power
ENB	eNodeB
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FC	Functional Component
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FG	Functional Group
FSLP	Free Space Path Loss
GA	Genetic Algorithm

GNSS	Global Navigation Satellite System
GPU	Graphics Processing Unit
HMI	Human-Machine Interface
IDDM	Intelligence Distribution Decision Making
ILP	Integer Linear Programming
IoT	Internet of Things
IoT PC AP	IoT People Counter Access Point
IQ	in-phase and quadrature-phase
ISG	Industry Specification Group
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
IVI	Infrastructure to Vehicle Information
KPI	Key Performance Indicator
LBT	Listen Before to Talk
LCM	Lifecycle Management
LoS	Line of Sight
LTE	Long Term Evolution
MAC	Media Access Control
MAEC	Multi-Access Edge Computing
MANO	MANagement and Orchestration
MAP	Mobile Access Point
MBS	Mobile Base Station
MCS	Mission Critical Service
MCV	Manned Connected Vehicle
MEC	Mobile Edge Computing
MINLP	Mixed Integer Non Linear Programming
MIP	Mixed Integer Programming
ML	Machine Learning
mmW	Millimeter Wave
MQTT	MQ Telemetry Transport
MTC	Machine Type Communication
NBI	North Bound Interface
NFV	Network Function Virtualization
NFVI	Network Functions Virtualization Infrastructure
NFV-O	Network Function Virtualization Orchestrator
NLoS	non-Line of Sight
NODM	Network operation Decision Making
NR	New Radio
NR-U	New Radio - Unlicensed

NSA	Non-Stand Alone
OBU	On-Board Units
OF	Objective Function
OSM	Open Source MANO
PoC	Proof of Concept
PPDR	Public protection & Disaster Relief
PPP	Point-to-Point Protocol
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RO	Resource Orchestrator
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
RSU	Roadside Unit
SBI	Southbound Interface
SDR	Software Defined Radio
SINR	Signal to Interference plus Noise Ratio
SLA	Service Level Agreement
SON	Self-Organizing Network
SOTA	State of the Art
srsRAN	Software Radio System RAN
SW	Software
TCP	Transmission Control Protocol
TDD	Time Division Duplex
UAV	Unmanned Aerial Vehicle
UBS	
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UMA	Urban Macro base station
UMI	Urban Micro base station
URLLC	Ultra Reliable and Low Latency Communication
USRP	Universal Software Radio Peripheral
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-everything
VANET	Vehicular Ad-hoc Network
VCA	VNF Configuration and Abstraction

VNF	Virtualized Network Function
VRU	Vulnerable Road User
WIM	Wide Area Infrastructure Manager
YANG	Yet Another Nest Generation

List of Figures

List of Tables

Executive Summary

This deliverable reports the activity conducted in the work package 4 on the design and development of mechanisms for the dynamic coverage and connectivity extension through the exploitation of innovative devices (e.g., drones, robots, connected cars, other mobile assets like forklifts in a warehouse, etc.). The objective is to enable the dynamic, opportunistic set up of dynamic coverage and connectivity extensions for covering areas that cannot be easily reached, where infrastructure is required only for a finite, short amount of time, or where regular network infrastructure has been damaged e.g., due to terrorist actions or natural disasters.

The document starts from an update of the state of the art for coverage extension (on *Mobile Access Point (MAP)*, decision making exploiting MAP, knowledge and context/situation awareness, *Radio Access Network (RAN)* management and network management and orchestration) and benchmarks the project's investigation against the state of the art. For example, a large volume of research has been conducted in recent years on MAP. DEDICAT 6G is focusing on four use cases: Smart Warehousing with the utilization of *Automated Guided Vehicle (AGV)* and mobile asset for improving operations, Enhanced experiences with dynamic MAPs closer to moving audiences, Public safety with the utilization of diverse assets (Drones, AGVs, etc.) and Smart highway with the use of cars and roadside infrastructures.

Second, DEDICAT 6G proposes preliminary considerations to harmonize the research and development of innovative mechanisms for coverage extension. On the one hand, D4.1 deliverable recalls DEDICAT 6G network architecture and the functional and non-functional requirements defined in WP2 and maps the mechanisms for dynamic coverage and connectivity extensions to the functional model. On the other hand, D4.1 discusses about design considerations and modelling methodologies. It describes the prototypes in terms of Software / Hardware (e.g., robots, drones, cars, IoT devices) used to validate the technology enablers in the *Proof of Concept (PoC)* and relevant models to align the simulation frameworks parameters such as deployment scenarios, traffic models and channel models.

Finally, D4.1 presents preliminary studies/implementation of strategies for dynamic coverage and connectivity extension (e.g., strategies to deploy MAPs, to manage MAPs, to associate users to MAPs, to count people with IoT devices). For example, DEDICAT 6G investigates different strategies which can be applied at RAN level to extend the coverage of the network by means of MAPs. This includes complex optimization problems aiming to decide the optimal number of MAP entities to deploy, the optimal positions of MAPs in continuous space, the configuration of the radio network of the MAP, the dynamic association of multiple users to multiple access points and the finding of the nearest docking station for charging to provide the required coverage and connectivity extension and to ensure the QoS expected by the mobile nodes.

1 Introduction

WP4 addresses the design and development of mechanisms for the dynamic coverage and connectivity extension through the exploitation of innovative devices (e.g., drones, robots, connected cars, other mobile assets like forklifts in a warehouse, etc.). The overall aim is to enable the dynamic, opportunistic set up of dynamic coverage and connectivity extensions for covering areas that cannot be easily reached, where infrastructure is required only for a finite, short amount of time, or where regular network infrastructure has been damaged e.g., due to terrorist actions or natural disasters. These will be combined with the mechanisms for dynamic, distributed intelligence, caching and storage (developed in WP3) and will consider a wide range of factors such as the location and trajectory of devices that can play the role of temporary MAPs, communication capabilities, locations of docking and charging stations of the candidate mobile access points. In this direction, the main objectives of this WP are:

- To formulate and develop algorithms for deciding on the creation and optimal configuration of the dynamic coverage and connectivity extensions in terms of the location of MAPs, the communication configuration of the MAPs and the allocation of nodes to MAPs;
- To formulate and develop mechanisms for knowledge building to support the decision-making process;
- To develop a laboratory PoC platform (including prototypes as well as simulations) to validate the technology enablers;
- To implement MAPs using connected cars, drones and robots as MAPs.

The WP will investigate various types of approaches to address the coverage and connectivity extension; in particular, machine learning and AI-based solutions for knowledge building to support the optimal configuration of the dynamic coverage and connectivity extensions will be studied.

1.1 Scope

Task T4.1 investigates the different strategies which can be applied at RAN level to extend the coverage of the network by means of MAPs. This includes how heterogeneous resources can be allocated to MAPs in order to provide the required coverage and connectivity extension and to ensure the QoS expected by the mobile nodes. It also addresses preliminary issues on the way the backhauling link is set up between MAPs and the fixed architecture. A central aspect in this task relates to the spectrum sharing options which can be used for both the air interface and the backhauling, as well as to the MAPs multi-*Radio Access Technologies (RAT)* capabilities as this would yield to different levels of achievable performance (capacity, latency, etc.) in the area of the coverage and connectivity extension. Along the considered use-cases, the different strategies will be analyzed and detailed in terms of input/output parameters as well as dependencies to feed Task T4.2 where decision making algorithms will be developed.

D4.1 document will provide a first specification of the mechanisms for dynamic coverage and connectivity extension. It will also include the preliminary implementation and release of these mechanisms.

1.2 Structure

Section 2 provides an update of the *State Of The Art (SOTA)* for coverage extension (on mobile access point, decision making exploiting MAP, knowledge and context/situation awareness, RAN management and network management and orchestration) and benchmarks the project's investigation against the state of the art. Section 3 introduces design considerations (hardware and software for robots, drones, cars, IoT devices) and modelling methodologies. In particular, we discuss about the tools and relevant models to harmonize the research and development of innovative mechanisms for coverage extension (e.g., to align the simulation frameworks parameters such as deployment scenarios, traffic models and channel models). Section 4 presents preliminary studies/implementation of strategies for dynamic coverage and connectivity extension (e.g., strategies to deploy MAPs, to manage MAPs, to associate users to MAPs). Finally, Section 5 concludes the deliverable.

2 Background and State of the Art

This section provides an update of the SOTA for coverage extension and benchmarks the project's investigation against the current SOTA).

2.1 Mobile Access Points for coverage extension

SOTA

A large volume of research has been conducted in recent years on MAPs such as cars, robots, drones or *Unmanned Aerial Vehicles (UAVs)*. The concept of moving base stations has been used, primarily in military, and also in civilian communications [1][2]. Claussen *et al.* [3] used the concept of self-deploying and moving wireless AP. Performance gains were quantified for self-deploying networks in a highly dynamic environment (airport) and it has been shown that by using self-deployment and optimization algorithms significant reduction in number of base stations can be possible with improved network performance. The OneFIT project [4] addressed operator governed opportunistic networks. These are temporary/local extensions of the infrastructure, created at places and for the time they are needed for resolving cases of no (or poor) coverage or of low capacity. The proposed work is a complementary contribution bringing cost-efficient solutions to difficult and unpredictable situations like moving hotspots, areas with no infrastructure or hard morphology (e.g., construction/manufacturing sites), etc. Such environments are especially relevant to a naval context. Such cases are especially important also in a wider emerging military context as is the one described in [5].

Claussen *et al.* [6] outline the concept of **robotic** base stations and highlight the need for such type of base stations. The topic of wireless sensor networks deployment, redeployment and post-deployment network maintenance based on mobile robotic nodes in order to achieve optimal connectivity and minimum energy consumption is addressed as well [7]. First studies on the topic of autonomous functionalities in a wireless network, using robots, were targeted to the provision of adaptive sensor functionality in a dynamic environment. In order to guarantee communication for a mobile robot involved in a dynamic coverage problem, Batalin *et al.* [8] propose a static network of markers autonomously dispersed by the robot during its motion. Tan *et al.* [9] presented a distributed model for cooperative multiple mobile robot systems in which each mobile robot has sensing, computation and communication capabilities. Choxi *et al.* [10] investigate robots acting as access points with the objective of maximizing signal strength in the changing their positions. In the scope of utilizing mobile robots for speeding up industrial processes, Haxhibeqiri *et al.* [11] propose a flexible and configurable architecture for the mobile node that is able to operate in different network topology scenarios The proposed solution is able to operate in presence of network infrastructure, in ad-hoc mode only, or to use both possibilities. In case of mixed architecture, mesh capabilities enable coverage problem detection and overcoming.

Drones (or UAVs) will also be an important component of B5G cellular architectures that can potentially facilitate wireless broadcast or point-to-multipoint transmissions. Sekander *et al.* [12] investigate the feasibility of multi-tier drone network architecture over traditional single-tier drone networks and identify scenarios in which drone networks can potentially complement traditional RF-based terrestrial networks. Mozaffari *et al.* [13] introduce a novel concept of *3-Dimensional (3D)* cellular networks, for integration of *drone Base Stations (drone-BS)* and cellular-connected drone users (drone-UEs). For this new 3D cellular architecture, a novel framework for network planning for drone-BSs and latency minimal cell association for drone-UEs is proposed. For network planning, a tractable method for drone-BSs' deployment based on the notion of truncated octahedron shapes is proposed, which ensures full coverage for a given space with a minimum number of drone-BSs. Research on drone-assisted wireless communications has looked into issues such as altitude optimization, power optimization, traffic offloading, and optimal placement [14][15][16][17].

Similar research utilizing **cars** can be found, e.g., Sargento *et al.* [18] propose an approach for connecting vehicles to the Internet through a multi-technology network device, able to form a mesh network of vehicles connected to the infrastructure.

Beyond SOTA

DEDICAT 6G will build on the existing work to develop its dynamic coverage and connectivity extension mechanisms exploiting innovative devices (e.g., drones, robots, connected cars, other mobile assets like forklifts in a warehouse, etc.) for covering areas that cannot be easily reached (e.g., hard geo-morphology: cave forest, facilities), where infrastructure, or additional capacity is required only for a finite, short amount of time (e.g., moving hotspots : festivals), or where regular network infrastructure has been damaged (e.g., after an emergency: earthquake, fire, terrorist attack). DEDICAT 6G will address mobility aspects of client nodes, application specific optimization of deployment, mobility, and operation of MAPs and integration of MAPs computation and communication resources along with other resources.
DEDICAT 6G focuses on four use cases with their respective MAPs:

- Smart Warehousing with the utilization of AGVs and *Manned Connected Vehicle (MCV)* such as forklift for improving operations;
- Enhanced experiences with dynamic MAPs (Drones)closer to moving audiences;
- Public safety with the utilization of diverse assets (AGVs and MCVs);
- Smart highway with the use of cars and roadside infrastructures.

2.2 Decision making exploiting MAP

SOTA

An important part of any communication system design is the **network planning** [19]. The overall process consists of pre-planning and post-planning phases. The pre-planning phase aims at finding optimal set of access points to cover a region of interest based on the anticipated user profiles in average. On the other hand, the post-planning phase fine-tunes the pre-planning decisions by taking into account the details affecting the network performance which are available after the network is being operated. However, the phases are coupled in a way that the pre-planning decisions may somewhat restrict the operative decisions in the post-planning phase. *Aerial MAPs (AMAP)* provide an interesting opportunity to increase the flexibility to optimize the network performance in the post-planning phase. The inherent flexibility comes with the possibility to dynamically place a given set of AMAPs in three dimensions. The MAPs moving on the ground are more limited to change their paths than AMAPs although there are several safety restrictions for the path adaptation of AMAPs as well. These include aerial regulations and aircraft limitations for operation times, speed, acceleration, and turning abilities. Good surveys that discuss AMAP placement can be found from [20][21][22][23].

The placement of AMAPs depends largely on the selected scenario defined via t**arget system parameter sets**, **deployment strategy**, and **optimization criteria**. By defining a simple scenario, the placement can be trivial but for more practical assumptions, the placement optimization can be notoriously difficult. The AMAP altitude is often a non-monotonic function of many *Key Performance Indicators (KPI)*. One main reason is that the trade-off between the increasing *Line-of-Sight (LoS)* probability and increasing path loss as altitude is increased. Another view of the underlying system scenario is how much is assumed to be known on the network topology, including heterogeneous and dynamically changing access point and user locations and loading conditions. Several other topics, such as backhaul connection support and aerial interference deserve to be mentioned regarding the air-ground and air-air links.

A number of different system parameters can be involved in the AMAP **placement problem**. These can be roughly divided into **uncontrolled** and **controlled** parameters. Here controlling means that a system designer can directly adjust the parameter value while the uncontrolled parameters can be affected only indirectly. The controlled parameters are then used in the optimization procedure. In addition to AMAP positioning parameters, these include user association and resource scheduling parameters as well as a number of transceiver parameters such as transmission power, beam direction etc. The target is typically either to maximize some network performance parameter such as coverage or throughput or then minimize some cost function including transmission power and number of AMAPs. For these purposes, a number of different optimization frameworks have been used. Various constrained linear and nonlinear programming approaches is a popular choice when applicable for the target combinatorial optimization problem. In case the optimization function is not readily resolvable, several meta-heuristic algorithms can be used including genetic algorithm and particle swarm optimization, to reduce the search space. While centralized optimization objectives lead to global optimum, the message exchange to enable optimization can become too difficult. The distributed optimization approaches utilize local search methods and seek opportunities to exchange information locally. If the objective function includes random variables, several stochastic optimization methods have been developed to deal with them. Finally, model-free iterative learning algorithms, such as Q-learning and deep neural networks, are typical approach if there is a limited amount of information on the objective function modelling, or it is too complicated to resolve.

The deployment strategy of the AMAPs can be either **static** or **dynamic**. In the former one, the objective is typically to find static places for one or more AMAPs that fulfil the desired optimization objective. In the dynamic strategy also the path between the initial and destination points is of interest and some related parameters such as AMAP speed may be of interest to optimize in order to maximize the operation lifetime. To reduce the optimization complexity typically some kind of discretization of continuous AMAP trajectory model is used. It is obvious that the optimal locations depend on the target system assumptions and selected optimization objective.

In literature, several studies investigate **static deployment strategies** for deciding the optimal number and position of the MAP. Optimizing the locations of MAPs can significantly enhance the network performance. Mozaffari *et al.* [13] propose a novel framework for network planning for UAV-BS (ensuring a full coverage with a minimum number of UAVs) and latency minimal cell association for UAV-UE (minimizing transmission computation and backhaul latency). Selim *et al.* [24] optimize the UAV's 2D locations for fixed UAV association, resource and power allocations. Peer *et al.* [25] propose a framework for joint optimization of UAV placement and the update interval according to the user and UAV mobility. They consider the time separation between two consecutive UAV placement updates as an important parameter to optimize the UAV assisted network. Wang *et al.* [26] model the deployment problem of multiple UAVs as minimizing the number of UAVs and maximizing the load balance. They propose a hybrid algorithm in two steps: a centralized greedy search algorithm to heuristically obtain the minimal number of UAVs and their suboptimal positions in discontinuous space and a distributed motion algorithm to optimally position UAVs in a continuous space. Nevertheless, they don't take into account the user needs and the association problem. Sharafeddine *et al.* [27] determine efficiently how many UAVs are needed and where they should be positioned within in a relatively large 3D search space. They propose a two phases greedy approach that mimics the optimal behavior assuming a grid composed of a finite set of possible UAV locations. (Selection phase determines the minimum number of UAVs needed, association phase finds the best locations of UAVs based on a score computed for each site and until the capacity constraint of each site is reached). Then an algorithm for multiple UAV deployment in a continuous 3D space is proposed based on an unsupervised learning technique that relies on the notion of electrostatics with repulsion and attraction forces. Sun *et al.* [28] optimize the UAV placement (i.e., the altitude) and user association in order to maximize the spectral efficiency.

However, 3D UAV placement has generally overlooked the mobility aspects of the **ground users**. Since UAVs are expected to deploy in order to offload traffic from ground BSs around hotspots or large gathering, the characteristics of UE's distribution (i.e., located in high UE density area and to be closer to each other forming clusters) is also used in literature. Turgut *et al.* [29] consider a user-association mechanism based on maximum average received power while the SINR based coverage probability is analyzed by using the stochastic geometry models for UE's distribution. Hoymann *et al.* [30] proposed the approach to grouping UEs so that UEs in proximity to each other and with a high LoS probability can be the same cluster by unsupervised Agglomerative hierarchical clustering algorithm. The location of AMAPs per each cluster is found by exploiting deep neural networks. Then, UEs in each cluster becomes to connect to one AMAP in the cluster. Peer *et al* [31] propose a ground user mobility aware multi-UAV placement taking into account the UAV flight time constraint. Ghanavi *et al.* [32] also investigate the UAV placement by taking into account the user movement. They propose a reinforcement learning method continuously adapting the solution for small change (no re-initialization in dynamic environment where network topology changes).

Moreover, in some cases it is more appropriate to provide access point service only at the destination while in some other missions, the AMAP should provide continuous service while flying. Few works in the literature discuss the **dynamic deployment strategies** (i.e., trajectory optimization of the UAVs). Optimizing the UAVs trajectories can be very important in dynamic or changing environments. Zeng *et al.* [33] define some typical trajectory constraints: minimum/maximum altitude, initial/final locations, maximum/minimum UAV speed, Maximum acceleration constraint, obstacle avoidance, collision avoidance, no fly zone. Alsharoa *et al.* [34] optimize the locations and trajectories of multiple UAVs for dynamic and practical scenario. They propose a two-steps solution: mixed integer Linear Programming problem that optimizes the user-UAV association and the transmit power level and an efficient and quick heuristic deployment algorithm to adjust the UAV trajectories. Susarla *et al.* [35] jointly optimize path planning and beam tracking for any uplink *millimeter Wave (mmW)* cellular enabled UAV. They consider a connectivity-constrained based trajectory optimization and optimal beam tracking where BS acts as a commander for all UAVs in a multi-UAV scenario.

An emerging challenge that can be tackled by MAPs such as autonomous robots with wireless capabilities is the trade-off between the high **cost** and low expected **profit** from the construction of next-generation wireless networks (i.e., 5G and 6G) at rural sparsely populated areas and the need for full network coverage of such areas. To this end, the authors at [36] present a new stochastic, geometry based model in order to show the coverage spatial variation among urban, suburban, and exurban settlements. In [37], the coverage probability for a UAV assisted cellular network is derived as a function of the battery size, the density of the UAV charging stations, and the charging time. The main conclusion drawn is the trade-off between deploying high density of low quality charging stations (high charging time) and deploying low density of high quality charging stations (low charging time).

Last but not least, some **interactions** between MAPs could be defined to manage their trajectories in a distributed manner. Brust *et al.* [38] consider the positioning problem of UAVs for efficient 3D coverage. They propose a solution based on molecular geometry where forces among electron pairs surrounding a central atom arrange their positions. Each UAV's position is determined by the distance and role of its neighboring drones (central drone influencing the entire topology and individual drones affected by their direct neighbors). This study considers how to self-organize a fleet of UAVs but not how they can use as BS to extend the network coverage.

Based on the above discussion, a taxonomy on the MAP placement is represented in Figure 1. Some examples of the different categories are then given in the right side of the figure.

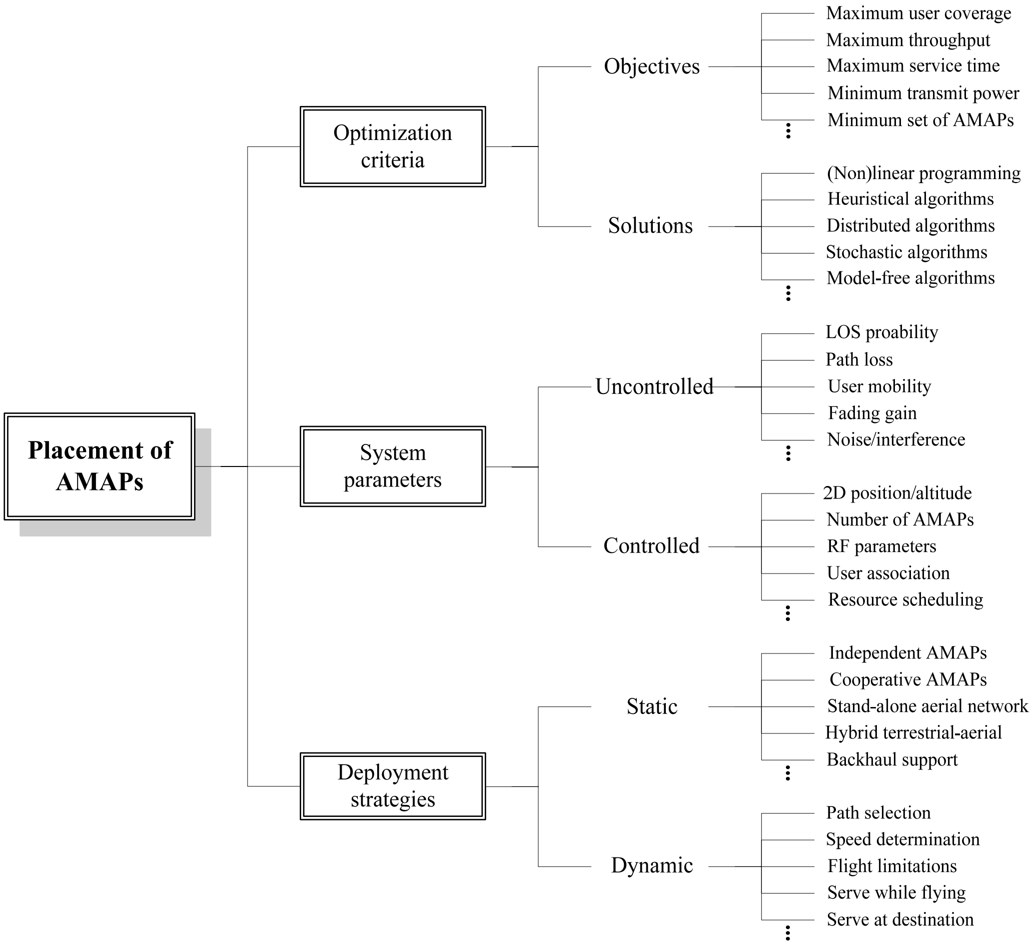


Figure 1: A taxonomy on the MAP placement procedure.

Beyond SOTA

DEDICAT 6G will build on the existing work to develop its dynamic coverage extension mechanisms that will rely on a combination of robots, drones, cars and IoT fixed devices to offer the most satisfactory QoS to users through MAPs-based opportunistic radio network.

DEDICAT 6G will investigate complex optimization problem aiming to decide on the deployment of MAPs to ensure connectivity of the appropriate QoS to mobile nodes and to find (i) the optimal positions to which each MAP entity should move, (ii) the path or trajectory that each MAP entity should follow so as to reach the target position, (iii) the selection of nearby docking/charging stations for drone MAP and (iv) the configuration of the radio network of the MAP entities.

DEDICAT 6G should first focus on how to deploy MAPs i.e., the optimal number and the optimal 3D positions of MAPs in continuous space. MAP entities should then dynamically move near the area where the users are concentrated or more service is requested. Thus, MAPs trajectories should take into account typical trajectory constraints, application specific optimization of deployment, and mobility of the ground users in dynamic and changing environments.

2.3 Knowledge and context/situation awareness

SOTA

One important feature for dynamic coverage and connectivity extension is the ability to monitor what is happening in the network and the system as a whole, to constantly deduce the current status and whether decision making is possible. The system shall be able to obtain and **monitor information** on, application, service and network goals and objectives to be achieved, as well as potential policies. The system shall be able to monitor information on capabilities of network elements, MAPs and edge devices in terms of communication networking (e.g., RAT and spectrum, capacity, and coverage), physical movement, the type of the MAP, computation capabilities, storage capabilities and available power. The system should **maintain information and knowledge** on the context that has to be addressed in terms of computation tasks, power consumption requirements, a set of mobile nodes that need coverage, mobility and traffic profiles of the different nodes, radio quality experienced by client nodes, options for connecting to wide area networks, the locations of docking and charging stations for drone and robot MAPs and the current locations of the terminals and MAPs elements.

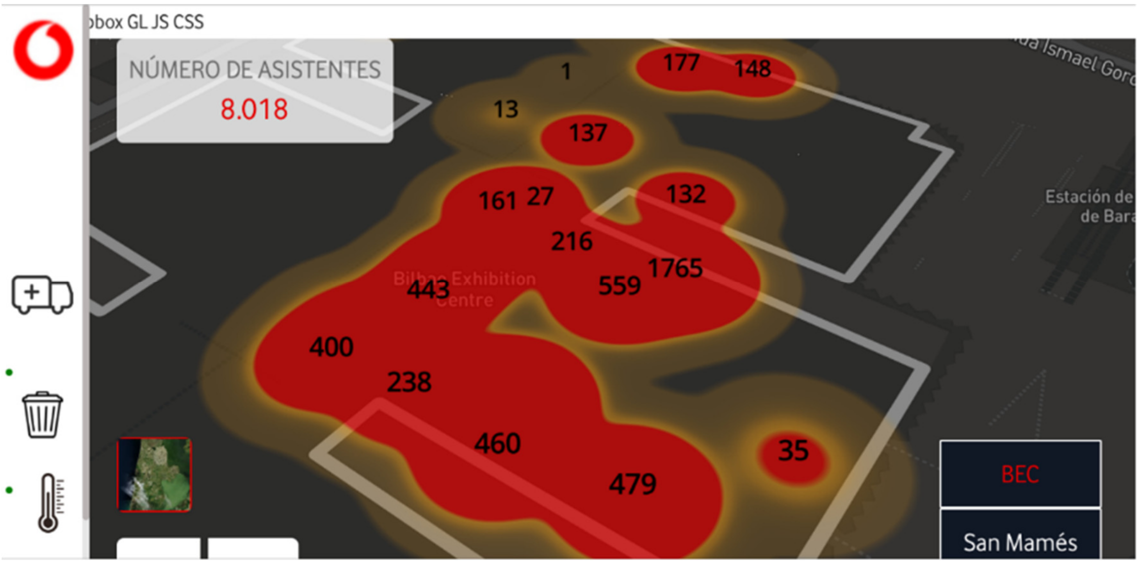


Figure 2: Heat map generated by the people counter system in MTV Vodafone event

In Smart cities, the use of IoT devices offers new services and efficiency to public administration, allowing to **know** and manage, in real time, basic services such as water, waste, lighting, etc. so that the public administration can anticipate real needs of its citizens, even before they occur, providing greater efficiency to the operation of public services. Pilots have been carried out where the intention was to provide these public spaces with crowd control through the **availability of information** about the number of people distributed in a stadium. This allowed to the user, for example, to move with the help of an application on their mobiles, through the clearest routes in the stadium [39].

The control of people in the enclosure was performed through the knowledge of Wi-Fi *Media Access Control (MAC)* addresses detected around IoT devices designed for crowd control.

Before performing any network operation, the first process that must be done in a networking environment **is being aware of itself** and how it is defined to be called as network. Such preliminary process is typically called as network discovery. A network discovery is a set of procedures and tasks aimed to recognize the set of available network entities and their interrelations, such that information will be used a to build representation of what we understand as network, which is basically a graph (or several) with a set of nodes (network entities/devices) connected by links (nodes relations) in a specific way, thus creating a network topology. Normally, in a 5G and B5G context, network discovery is handled by the network controller that commands the retrieval of basic information and **status** from network devices, by using concrete interfaces, to draw the complete network picture. In recent years, information/network models have contributed to facilitate controller's operation in the definition of technology agnostic network topologies. One of the most relevant contributors to unify network awareness is the *Yet Another Next Generation* (YANG) data modelling language [40]. YANG is a structured modelling language that provides a set of rules to define network devices and operations from a unified manner regardless the device fabric this way easing the controller to not only the network discovery procedure but also the configuration methods or the device status tracking.

The latest research in B5G/6G technologies, architectures and facilities are reducing the gap towards the deployment of operational infrastructures. Current wireless communication systems do not meet the convenience of a rapid deployment or even performance requirements of new services. Furthermore, the current conditions require rapid changes in communications and operation systems, further advancing the B5G/6G infrastructures and networks services. New services impose new requirements and the need of a reliable, high quality and highly configurable system. One of the core needs of a system that will support the aforementioned is the ability to **monitor**, **diagnose** and finally trigger decision making (Section 2.2) to handle any issues. To this end, the authors in [41] propose an unsupervised detection approach using a multivariate version of the Online Arima forecasting algorithm consuming real-time monitoring data. In [42], an anomaly detection problem is specified with scenarios involving *Service Level Agreement (SLA)* violations to satisfy the practical needs of network management. Real-time **fault detection and diagnosis** systems are often aligned with the ISO 13374 information reference architecture [43]. Anomaly detection has attracted the attention of the research community in many areas, such as intrusion detection, health monitoring, preventive maintenance, and fault detection [44]. One of the first examples of the deployment of the heterogeneous network by adopting the achievements of *Artificial Intelligence (AI)* for automatic management and optimization is presented in [45]. They show that the exploitation of AI-based *Self-Organizing Networks (SON)* have enabled the **self-configuration, self-healing, and self-optimization** features defined by 3GPP [46]. The authors of [47] studied anomaly detection in self-organizing 5G networks. The goal was to automatically detect if there were any failures or degradation of the base stations, due to which the users no longer met their requirements. However, one of the main limitations of traditional anomaly detection methods is their unsuitability for operational mobile communication networks, which are almost always normal. Indeed, since cell failures are rare, normal and anomaly data are unbalanced. In addition, most studies do not consider many KPIs in the network, such as resource utilization efficiency, latency, network availability, etc. Finally, although some studies such as [48] propose automatic network reconfiguration based on the observation of network and user changes, there is often a lack of evaluation of network management of mechanism activation/deactivation in dynamic environments.

Moreover, **harmless coexistence** of various heterogeneous wireless networks, within a single MAP or between multiple MAPs, can enhance the overall network performance by optimally using the system capacity, supporting higher data rates, and reducing latency and packet loss. To achieve efficient and harmonious coexistence between different co-located technologies, a coexistence mechanism should be able to estimate and take into account the available resources, the concurrent traffic demands and the co-located RATs.

The **identification of co-located RATs** is essential in making coexistence decisions. In [49], a *Convolutional Neural Network (CNN)* -based model is used to perform the identification of co-located Wi-Fi transmissions and *Long Term Evolution* (LTE) transmissions. A similar CNN model has been trained by capturing *In-phase and Quadrature-phase (IQ)* samples of LTE and Wi-Fi transmissions [50]. The model is validated using commercial off-the-shelf LTE and Wi-Fi hardware equipment and it can identify the duration of each transmitted frame from each technology, the duration of idle slots as well as collisions between multiple concurrent transmissions. Furthermore, a model that can classify LTE, Wi-Fi, and DVB-T technologies is proposed and validated in [51]. In [52], a Convolutional Neural Network (CNN) based model is proposed to sense the Wi-Fi saturation status. This Wi-Fi saturation status is used to estimate if the available resources in spectrum and time are sufficient for the generated Wi-Fi traffic.

In addition, **traffic prediction** is getting more attention in the last few decades [53]. In that direction, different machine learning-based traffic dynamics prediction solutions are proposed by many researchers. Forecasting the available traffic of each RAT and the available resource is important to make the coexistence decisions that lead to the best performance [54].

Beyond SOTA

In the scope of DEDICAT 6G mechanisms will be developed for system-level monitoring along with diagnostic capabilities in order to retain QoS at high standards. More specifically, an unsupervised learning algorithm will be used in real testbeds with mature virtualization technologies. Large scale metrics will be collected in order to train the algorithm appropriately in order to be able to detect any anomaly presented. The data collection will be enabled, in part, by the instantiation of small pieces of software (agents) to be deployed in the computational resources of the devices (or close) to monitor the device/network status in every required moment and sending such information to the DEDICAT 6G platform to feed the learning algorithms to perform network analytics/diagnosis.

DEDICAT 6G will propose a new type of improved fixed IoT device oriented to estimate the number of users in the coverage area through Wi-Fi scanning techniques, so that in situations where the number of people or vehicles connected in the area may imply a congestion problem, the device can allocate its connectivity resources (5G, Ethernet connection, etc.) to provide coverage extension to MAPs and end users. Extending this concept to the city as a whole, heat maps can be established to identify those points in the city suffering from congestion, both of people and connected vehicles. This, together with an evolution of the current IoT people counter devices, giving them the ability to extend coverage in their range of action, will allow the network manager to consult these anonymized public data, allocate and distribute the necessary resources to extend the connection capacities of the devices that need it dynamically and, finally, depending on the congestion expected at any given time, offering the coverage extension. Connection strategies will have to be defined to ensure the safe use of the system by both MAPS and end users.

On May 3, 2021, the *Federal Communication Commission (FCC)* issued its final rule to split the 5.9 GHz band between unlicensed use (initially indoor and potentially outdoor) and its previously specified use for intelligent transportation systems [55]. This decision has created concerns about potential interference between unlicensed technologies (e.g., Wi-Fi, LTE-U, 5G-NR-U) and ITS technologies (C-V2X PC5 and ITS-G5). In the future, it is envisioned that spectrum management and utilization will become more flexible and dynamic compared to today's static and conservative approaches. Hence, a RAT might be able to operate in any frequency band (as long as this is supported by the frontend and allowed by the regulators) offering coexistence with other technologies and protecting potential incumbents. In that direction, and specifically for MAP deployment and operation in the 5.9 GHz band, the deployed MAPs should be able to coexist with other co-located technologies (LTE, 5G-NR, Wi-Fi) operating in the same frequency and protect transmissions from incumbent technologies such as C-V2X PC5 and ITS-G5.

When a MAP is initialized, the selected RAT should try to avoid an occupied channel and operate in an empty one. If this is not possible, the less busy channel should be used, providing at the same time coexistence to other MAPs or co-located technologies and enabling incumbent protection (e.g., C-V2X PC5 and ITS-G5 operating in the 5.9 GHz band). DEDICAT 6G will propose AI/ML and/or domain expertise techniques that can be used for identification and characterization of the wireless technologies operating in the considered frequency domain. Furthermore, technology recognition techniques will be used to identify transmission patterns of incumbents so that future incumbent transmissions can be predicted, and interference can be avoided. In that direction, a Neural Network will be trained to identify C-V2X PC5, ITS-G5, LTE, 5G-NR and Wi-Fi transmissions in the 5.9 GHz band. IQ sampling through *Software Defined Radios (SDR)* will be used as input initially for training of the Neural Network and later for real-time identification and characterization of the co-located wireless technologies.

2.4 RAN Management

SOTA

With the deployment of MAPs comes the problem of **dynamic association** of multiple users to multiple access points (fixed or moving). A large volume of research has been conducted on UE-BS association for fixed BSs. For example, Sana *et al.* [56] study user association based on multi-agent reinforcement learning in which users act as independent agents based on their local observations only and learn to autonomously coordinate their actions in order to optimize the network sum-rate. Since the communication links in MAP-assisted networks are implemented by the shared use of the wireless communication resources, Mozaffari *et al.* [57] include flexible deployment of MAPs in wireless networks, bringing an emerging demand for efficient user association. When there are MAPs and ground BSs to serve multiple users, the overall network performance relies on the number of connected users and their perceived *Quality of Service (QoS)*. Thus, Zhang *et al.* [58] show that user association exploits the multi-user diversity by proper selection of users for transmission and different traffic loads in MAPs or BSs. Its goal is to achieve conflict-free feasible transmission connections for users based on the estimation of channel quality of different links with different transmission demands. Due to the complexity of the MAP-assisted network' topology, researchers have proposed novel centralized or distributed methods by using classical optimization, game theory, and machine learning. In addition, while the MAP-user's association can be affected by MAP's placement, there are studies about a practical association rule that can jointly operate with MAP placement algorithms.

Sun *et al.* [59] formulate the **joint optimization** of 3D UAV placement and user association but iteratively solve the two sub-problems and only with one UAV. Esrafilian *et al.* [60] simultaneously study UAV-UE association and 3D placement of multiple UAVs with a suitable weighted combination of UE's positions and a probabilistic and deterministic LoS classifier based on statistical model and city map based information. Kalantari *et al.* [61] propose an algorithm to find efficient UAV 3D locations in addition to UE-BS association and resource allocation for access and wireless backhaul links. El Hammouti *et al.* [62][63] propose a joint 3D placement of UAVs and users association under bandwidth limitation and quality of service constraints in an urban environment to support damaged/overloaded ground BSs. Optimization of user association is formulated with 3D deployment of aerial MAPs together to maximize the sum data rate. Then, for given fixed 3D location of AMAPs, one-to-many matching based method is proposed to find the best user association satisfying the threshold of average spectral efficiency, the required data rate and the backhaul link capacity. Zhang *et al.* [64] focus on how to determine the 3D location of UAV, the user association and the bandwidth allocation policy between *Mobile Base Station (MBS)* and UAVs in order to minimize the total average latency ratio of all the users. They decompose the problem into two sub-problems (user association and bandwidth allocation problem and 3D placement problem) that they alternatively optimized at each iteration. The 3D UAV placement is limited to one UAV and is based first on coverage maximization with the altitude determination and then with exhaustive search of candidate horizontal locations. Pan *et al.* [65] study the 3D UAV placement and user association in flexible and elastic software defines cellular networks. They propose a computationally efficient two-phase algorithm involving the optimal UAV placement altitude-to-ratio ratio and the optimal 2D UAV horizontal coverage combined with user association. This framework does not take into account the backhaul link and the users' mobility.

In a **multi-RAT** network, one of the most important mechanisms for radio resources management is the mechanism used for initial network access for a given connection. This mechanism is referred to as initial choice of the radio access network or **RAT** selection. An efficient RAT selection approach is crucial for efficient resource utilization, QoS and user satisfaction [66]. The optimal network is selected based on various network' and user's statistics, including network bandwidth, required data rate, latency sensitivity of the requested service, packet loss, priority, and signal strength. Another important factor that should be considered during the RAT selection process is the coexistence of the selected RAT and other co-located concurrent transmissions.

Besides to an effective RAT selection, the RAT **resource configuration** is essential to realize harmless coexistence between the technologies. Recently, extensive research has been conducted to assure fair coexistence between different RATs in the unlicensed spectrum. In [67], a coexistence scheme that uses blank LTE subframes to give transmission opportunities to Wi-Fi is proposed. The authors in [68] modelled allowable LTE transmission time selection which is determined by considering different targets of Wi-Fi service protection. In [69],[70], CNN based technology classification is used to implement coexistence schemes between private LTE and Wi-Fi. These coexistence schemes use channel occupancy time to estimate the Wi-Fi traffic and select optimal transmission time of LTE and Wi-Fi.

While above studies consider that UEs are associated to only one of MAPs or ground BS at a certain time (i.e., single-connectivity), Li *et al.* [71] consider **dual-connectivity**. In MAP-assisted wireless networks where AMAPs and ground BSs provide data services for users simultaneously, all users are assumed to connect to both a UAV and a ground BS by using UE's dual-connectivity capability all the time. Then, user association to a MAPs and ground BSs and power allocation are proposed by using *Genetic Algorithm (GA)* to maximize sum data rate.

Beyond SOTA

DEDICAT 6G will investigate different strategies at RAN level to extend the coverage of the network by means of MAPs for the considered use-cases: How heterogeneous resources can be allocated to MAPs in order to provide the required coverage and connectivity extension and to ensure the QoS expected by the mobile nodes; MAPs multi-RAT capabilities yielding to different levels of achievable performance (capacity, latency, etc.) in the area of the coverage and connectivity extension.

For a newly activated MAP, specific RATs can be selected based on the capabilities of the MAP, the traffic demands of the applications/services, and/or the identified characteristics of the wireless environment. DEDICAT 6G will investigate different strategies that can lead to a robust and efficient RAT selection. The activated RATs then can be used in different ways to serve the applications. For instance, a single RAT can be used for a specific MAP, a RAT can be selected per traffic flow or multiple RATs can be used for a single traffic flow for redundancy or optimization purposes. For instance, some technologies such as LTE/5G-*New Radio (NR)* can be selected when no or little other traffic is identified, while Wi-Fi could be a better choice in more busy channels because of its inherent coexistence mechanisms (CSMA/CA, LBT).

Furthermore, DEDICAT 6G will propose RAN configuration schemes that can be used for a harmonious coexistence between different technologies. Information derived by the knowledge building can be used for properly configuring the selected RATs. For instance, LTE/5G-NR based MAP can be configured to avoid the transmission of control and data signals during the identified transmission patterns of incumbents. Besides, traffic estimation and prediction models outcomes, such as the Wi-Fi saturation status proposed in our previous work [32] can be used as input for coexistence decisions.

DEDICAT 6G will investigate the multi-connectivity configuration to serve multiple UEs of different types of QoS requirements. Considering the required QoS level, the user association will be decided to maximize the user satisfaction level with fairness.

DEDICAT 6G will propose a joint optimization of 3D placement of multiple UAVs and user association. DEDICAT 6G will jointly optimize (i) the MAP mobility, (ii) the configuration of the radio network of the MAP entities, (iii) the nodes allocation to MAPs and (iv) the resource allocation for access and wireless backhaul links.

Finally, the decision and optimization process will take into account knowledge and information on the context, the capabilities of the users and the MAP entities and the potential policies and will continuously adapt the solution for small network topology changes thanks to reinforcement learning methods.

2.5 Network management and orchestration

SOTA

In recent years, the stringent requirements set by the 5G KPIs, where much more information (bandwidth) needed to be managed, at much higher speed (transfer rate), with many more devices, much higher reliability and lower latency, [72] highlighted the need for much more programmable, flexible, configurable and scalable networks. This paradigm shift in network management and orchestration came, in part, thanks to the emergence of two key and complementary technologies, *Software Defined Networking (SDN)* and *Network Function Virtualization (NFV)*.

On the one hand, SDN is a technology that encompasses a set of network management-oriented techniques that focuses mainly on one basic principle: decoupling the actions of control plane logics from the data plane [73]. This principle allows for a high degree of flexibility in the system, since the network switches and other network devices become simple dummy boxes that just send and receive traffic, while the logical control of the network can easily be centralized in an external entity, e.g., the SDN controller [74].

The concept of decoupling control logic from the data plane has been a key topic since the early stages of 5G definition and has been applied to all network domains, from Access/RAN to Core/Backbone, and has made SDN the de facto technique/technology for managing 5G/B5G networks. The *International Telecommunication Union (ITU)*, the *Third Generation Partnership Project (3GPP)*, the *5G Public-Private Partnership (5GPPP)* and the *European Telecommunications Standards Institute (ETSI)*, among other organizations or initiatives, have created roadmaps and working groups specific to the SDN objective. For example, in the framework of the 5GPPP many of the projects in all phases, such as 5G-Xhaul (phase 1), METRO-HAUL (phase 2) or TeraFlow (phase 3), took the approach of managing the configuration of network devices in a centralized and decoupled way [75].

In addition, the implementation of the SDN concept has also contributed to filling a traditional gap in intercommunication, through the definition of standardized protocols and interfaces. Actually, from a historical perspective, the original idea on which SDN is based was first expounded in the Open-Flow protocol [76]. A specific set of protocols has been designed and defined to exploit the control-data decoupling, which forms the so-called *Southbound Interface (SBI)*, dedicated to enable communication between the control and data planes. The community has put, and continues to do so, a remarkable effort in defining open protocols to be used in any network implementation regardless of the technology provider, reducing the vendor island problem. Protocols such as Open-Flow, NETCONF, RESTCONF or P4 are specially defined to maximize the benefits of the SDN approach.

NFV, on the other hand, is another pillar underpinning 5G. NFV virtualizes traditional network functions, typically deployed on physical equipment, into pieces of software that can run on servers or devices with certain computing capabilities. These *Virtualized Network Functions (VNF)* can be deployed rapidly and dynamically, allowing for great flexibility and scalability across network data centers or other compute-enabled network elements. According to ETSI's NFV definition [77], the key element of a virtualized system is the NFV Orchestrator that provides these functionalities for the correct provisioning of the VNFs in the NFV Infrastructure, which contains the set of computational resources to be consumed by the VNFs.

As a key technology in the 5G ecosystem, and in parallel to the development and deployment of SDN, standards organizations, initiatives and research projects have driven the evolution of NFV. One of the most prominent initiatives was started by ETSI in 2012 and is currently active, the ETSI *Industry Specification Group (ISG)* NFV [78]. The ETSI ISG NFV created a collaborative framework to establish the key points and features of NFV and translated them into standards. The latest ETSI NFV specification is version 4, which has identified and established key issues for the future of NFV, such as the evolution of NFVI, the improvement of NFV automation or the evolution of NFV management and orchestration tasks (MANO). Furthermore, in the context of the 5GPPP framework, NFV has been present since its inception being an essential part of the roadmaps from Phase I until now. Shining a light on 5GPPP projects with similar themes to DEDICAT 6G on NFV we can find the following example projects: 5GTANGO [79] provided a service platform and a set of tools to facilitate the implementation of NFV in 5G networks. The architecture proposed in the 5G ESSENCE project [80] allows orchestrating the placement of VNFs in the RAN and edge cloud nodes and the live migration of VNFs, both orchestrated by a centralized manager, essential operations to achieve the necessary latency reduction and efficiency for mission critical applications/services. In addition, the MATILDA project [81] provided an open development environment for NFV orchestration that enabled the instantiation of end-to-end multi-site connectivity with management of physical and virtualized cloud/edge resources. Finally, within the 5GinFIRE project [82], a flexible NFV orchestration framework was applied to achieve experimental end-to-end connectivity in several testbeds covering some of the most typical 5G scenarios, such as automotive, smart city or e-health.

On the academic side, in the literature, we can find a myriad of papers on NFV, especially in recent years, and it is unfeasible to cover all the literature in this document. In our scope, we only focus on some of them related to end-to-end connectivity that can potentially be applied to coverage/connectivity extension. **Supporting mobility** in the orchestration of virtualized and computational resources is critical to ensure connectivity when expanding coverage. In Hung *et al.* [83] an NFV-based edge platform is proposed and validated to support vehicles with lightweight computational resources for low-latency vehicle-to-everything (V2X) services. The platform can forecast the requirements of the services and auto-scale the VNFs associated to such service accordingly. The NFV MANO operations are expanded in [84] to handle UAVs in a MEC/NFV context. In this work, authors proposed an *Integer Linear Programming (ILP)*-based method to place the VNFs in nodes' facilities taking into account the mobility of the UAVs. Finally, in [85] a novel technique is proposed and tested to use aerial and vehicular devices with NFV capabilities to build virtual infrastructures (network slices) that can meet with the requirements of vertical services and provides end-to-end connectivity. In this work, authors managed two different ad-hoc network domains, one for vehicular mobility and other using flying devices (drones) both orchestrated from a unified manner by a centralized NFV Management and Orchestration core.

Combining **control-data decoupling** in network management and **virtualization-based orchestration** techniques is essential to properly achieve end-to-end connectivity in 5G/B5G networks when applying dynamic coverage extension. For example, given a remote area where extended connectivity can be provided by a MAP that can be reconfigured by a centralized controller, and, in parallel, its computational resources are managed to host the necessary VNFs to enable the establishment of a network slice to provide 5G connectivity to the extended area. Many studies can be found in the literature highlighting this joint approach, decoupled network management and virtualized resource orchestration, in 5G-based scenarios in general and related to connectivity extension in particular. Just to mention a few, the work presented in [86] shows a PoC in a dynamic SDN-NFV environment, where a planning tool (Net2plan) effectively instructs, from a combined perspective, the NFV orchestrator in the tasks of VNF instantiation and virtualized resource management, and the SDN controller to properly configure the IP network equipment in the data plane to meet the vertical demands in terms of end-to-end latency. In [87] the authors present an on-the-ground demonstration of a disaggregated network infrastructure, in packet and optical domains, in which network devices are configured remotely from a hierarchical SDN structure, a master controller managing SDN controllers, one per domain, and encompassing NFV orchestration capabilities via *Wide Area Infrastructure Manager (WIM)* to enable the establishment of a dedicated network slice for a crowdsourced live video streaming service. In the framework of the METRO-HAUL project, the work presented in [88] provided end-to-end latency-based connectivity by agile establishment of 5G network slices over a metro optical network especially dedicated to enable public safety services. In this demonstration, the joint SDN-NFV approach shows an end-to-end delay on an 80 km link of less than 1ms and a total service deployment time of less than 180 seconds.

The networks architecture including MAPs represents a fundamental evolution in 5G networks. Najla *et al.* [89] consider AMAPs as the **relay stations** working in the half-duplex decode-and-forward mode. While the type of non-transparent relay stations (known also as Type I) which create their own cell and perform almost all functions ground BSs do (e.g., radio resource management) in many studies, the transparent relay stations (Type II) which are of limited functionalities and BSs can control a majority of the communication management functions are assumed in the system. Mach *et al.* [90] consider inter-cell interference in multiple cells scenario where each cell includes one ground BS, multiple AMAPs, and multiple ground users. For the spectrum bands, the shared use of same spectrum for **backhaul and access links** are assumed. While AMAPs are able to operate the full-duplex mode, the access link capacity (i.e., connection link between user and AMAP) is assumed to be the same with the backhaul capacity (link between AMAP and ground BS with a channel allocated to specific user). For a given transmit power budget of AMAP, the proposed algorithm calculates the association gain indicating the difference of maximum capacity and the achievable rate of access links, and additionally calculate the power efficiency by using the transmit power. Thus, based on greedy method, the solution of user-association is found to maximize the sum data rate for a given transmit power constraint. Qiu *et al.* [91] study a joint placement, resource allocation and user association problem for multiple UAVs networks with constrained fronthaul and backhaul links. They first derived the optimal resource allocation schemes under different fronthaul and backhaul conditions. Then, by using the gradient ascent, dual-domain coordinated descent, and bipartite graph matching techniques, they developed an efficient iterative algorithm to optimize user association and BS placement jointly.

Beyond SOTA

DEDICAT 6G will investigate techniques to automate the correct configuration of a connection from the central platform in coverage extension operations. This research will focus on how to instruct the NFV-O to correctly instantiate the necessary VNFs associated with a specific network service/slice to enable ad-hoc connectivity when extending or moving the area of connectivity. This topic will also involve how to deploy lightweight VNFs at edge or far edge nodes, such as on drones or robots.

In order to orchestrate the computational resources potentially available in the mobile nodes to properly accommodate the given VNFs, the DEDICAT 6G project will investigate how to include such computational resources as part of the NFV infrastructure and thus be handled by the NFV Orchestrator. In this way, the DEDICAT 6G platform will be able to instruct the NVF-O to properly instantiate the network service/slices using the corresponding interface to send the instructions.

DEDICAT 6G will investigate how the platform can potentially be used to orchestrate network functions and perform integration and configuration tasks, together with the necessary testing to validate the requirements of the verticals.

DEDICAT 6G will extend the catalogue of 5G-blueprint project [111] to support the configuration of 5G/RAN components, as well as extending the current blueprint fields to support day2 configuration in VNFs, in order to allow run-time operations or reconfigurations after instantiation. Such procedures may be necessary when, for instance, migrating intelligence, derived from UE or node mobility, between different nodes without interrupting the established connectivity to a specific network slice. DEDICAT 6G will also investigate how the backhauling link is set up between MAPs and the fixed architecture.

3 Preliminary considerations

This section aims to harmonize the research and development of innovative mechanisms for coverage extension. First, WP4 is linked to WP2 with a short recall of DEDICAT 6G network architecture and the functional and non-functional requirements to be achieved by current developments. Then some design considerations are made according to the selected use cases. Finally, some modelling methodologies are discussed in order to align the simulation frameworks parameters (e.g., deployment scenarios, traffic models and channel models).

3.1 DEDICAT 6G Architecture Overview

This section enumerates the *Functional Components (FC)* that are designed and developed in the context of this WP. An introduction to the high-level functionalities has been provided in D2.2 [107], so the scope of this section is to provide further design details, implementation technologies and interface and data model definitions for each functional component.

Figure 3 recalls the Five *Functional Groups (FG)* for coverage extension.

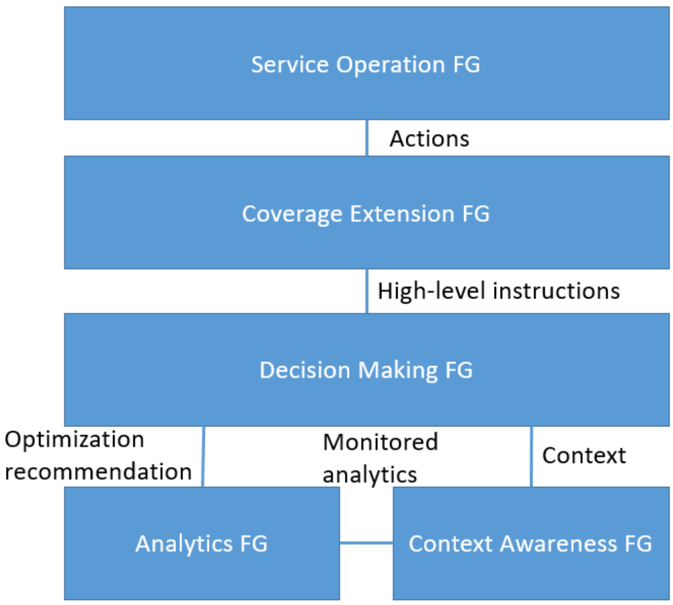


Figure 3: DEDICAT 6G functional Model

The corresponding functional requirements are:

- **Analytics**: Detect uncovered devices or low experienced QoS Users from the decision making or from the application;
- **Analytics & Context awareness:** The system must be able to monitor and analyze what is happening in the network and the system as a whole;
- **Decision making**: The system must be able to make decisions on the creation, reconfiguration and termination of an ad-hoc coverage extension network. It will also reduce network management for infrastructure deployment.
- **Coverage extension**:
  - AGVs/Robots, Drones and other devices should be able to communicate with each other and with the "central" network infrastructure;
  - Relaying shall be supported by central nodes or by edge nodes;

    - More than one coverage extension networks shall be supported at the same time.
- **Service operation:**
    - The module shall offer the resource allocation including multi-connectivity configuration to adapt to dynamic environment;
    - Device and infrastructure capable to set-up connection;
    - The system should command the NFV Orchestrator (NFV-O) in the deployment of the needed VNFs to enable connectivity when extending the connectivity.

The non-functional requirements are:

- The **user perceived** quality of service/quality of experience;
- The **network** performance such as a seamless mobility in the extended coverage, support of dynamic peak of demands, imperceptible end-to-end latency and fast response time, energy efficiency, reliability;
- To provide **equal** opportunity to citizens and applications **regardless their location.**

3.1.1 Service Operation FG

The FCs in in that FG are responsible for implementing the decisions carried out by the Decision Making FCs under the coverage extension FG supervision. This includes:

- Network Services and micro-service (µService or µS) orchestration providing the configuration needed for the correct operation phase;
- Inter- and intra-node load balancing to service and networking components;
- Resource management;

This FG will execute the Network Operation outcomes of the Decision Making and Coverage Extension FGs and will physically deploy DEDICAT 6G vertical FCs.

3.1.2 Coverage Extension FG

The FCs in in that FG are responsible of DEDICAT 6G vertical FCs at the different nodes involved in Coverage Extension and provides the dynamic coverage extension functions to DEDICAT 6G verticals such as:

- Self-organizing as an ad-hoc network;
- Optimization of MAPs placement in order to fulfill the coverage area constraints;
- Optimization of MAP operation according to the overall requirements and taking into account the diversity of MAP characteristics (e.g., supported radio carrier and interfaces, autonomy, freedom of movement, etc.);
- Self-management of resources including autonomy (e.g., how frequently and where does a MAP have to get back to its docking station);

This FG will exchange high-level instructions with the Decision Making FG (e.g., mission parameters or stop/resume/end-up the mission) and will order some actions to Service Operation FG (e.g., communication configuration of the MAPs and allocation of nodes to MAPs).

3.1.3 Decision Making FG

This FG takes decisions (applying various AI algorithms) to increase capacity of functioning base stations, to avoid poor network performance or network failure and to deploy MAPs. This includes the following FCs relevant to Coverage Extension:

- Network operation generating the decisions about the network provisioning and maintenance, keeping the optimal operation of the network based on data it receives from the Context-Awareness FG and from optimization recommendations issues by the Analytics FG. It processes the recommendations and create the concrete actions to perform in the network infrastructure to fulfill the vertical application topology, requirements and declared SLAs.
- Coverage Extension Decision Making producing the optimal configuration of the radio network of the *Mobile Access Points* (MAP) entities and the paths (trajectories) that need to be followed by the MAP entities, in order to offer adequate QoS levels, in terms of service availability, performance and reliability. This optimization also includes the most appropriate allocation of nodes to MAPs as well as selection of nearby docking/charging stations for drone and robot MAPs to ensure connectivity of the appropriate QoS to mobile nodes.

This FG exploits available information and knowledge provided by Context-Awareness layer and optimization recommended by Analytics and defines the actions that Service Operation FG should apply on the network elements in the infrastructure.

3.1.4 Context-Awareness FG

This FG builds up "contexts" on which the Decision Making FCs can base their decisions on. A context is a collection of pieces of information that gives the needed level of detail and characterization of a system state (or space). It is based on raw data, which is enriched using various methods (like correlation, analytics, machine learning) in order to reach the level of "knowledge".

In DEDICAT 6G, we consider the following contexts:

- µService status (lifecycle, resource consumption etc.) and awareness (information about a cluster or group of clusters to the µService orchestrator and Edge Load Balancing)
- Edge Node status (CPU/GPU available computation time, available memory/storage, bandwidth, etc.) and awareness (overall Edge Node context such as for the deployment of edge node whenever a new node appears).
- Network status (status of the communication network) and awareness (overall Edge Node context)
- Deployment status (which FCs have been deployed in a given domain, and which Edge Nodes are hosting them) and awareness (overall deployment status for decision making).

This FG exchanges contexts with the Decision making FG and predetermined criteria with Analytics FG.

3.1.5 Analytics FG

This FG monitors and analyzes data for various purposes e.g., for providing better QoE/QoS to user, or decreasing the UE processing by shifting the computation to edge nodes. It includes:

- Network Optimization dynamically optimizes network topology ensuring the desired network coverage for a set of users. This optimization framework should consider end-to-end performance (e.g., end-to-end delay), computation-related parameters (e.g., CPU rate of target servers), users' heterogeneity (e.g., different QoS targets and different location-dependent channel characteristic) and limitations of specific MAPs (e.g., feasible trajectories and operation times without recharging) with minimal cost (e.g., number of required MAPs and their energy consumption);

- Network Prediction analyzes and makes predictions about future conditions, using AI predictive algorithms. It could be the network traffic (using ML/statistical techniques) in order to isolate patterns;
- Platform Performance analytics assesses the DEDICAT 6G platform performance according to pre-defined KPIs;
- Analytics toolbox provides a collection of Machine Learning algorithms.

This FG is closely related to Decision Making and Context-Awareness FGs where the monitored analytics can be used for directing the system performance towards the predetermined criteria e.g., for decreasing the network load, optimizing network KPIs, or altering the device specific characteristics, such as power consumption. The functional entities can provide the results for evaluating the system performance against the baseline criteria as well selecting optimized network parameters dynamically depending on its state.

3.1.6 Mapping example to functional model

The following figure illustrates an indicative functional model of the mechanisms for dynamic coverage and connectivity extensions, which are introduced in this deliverable.

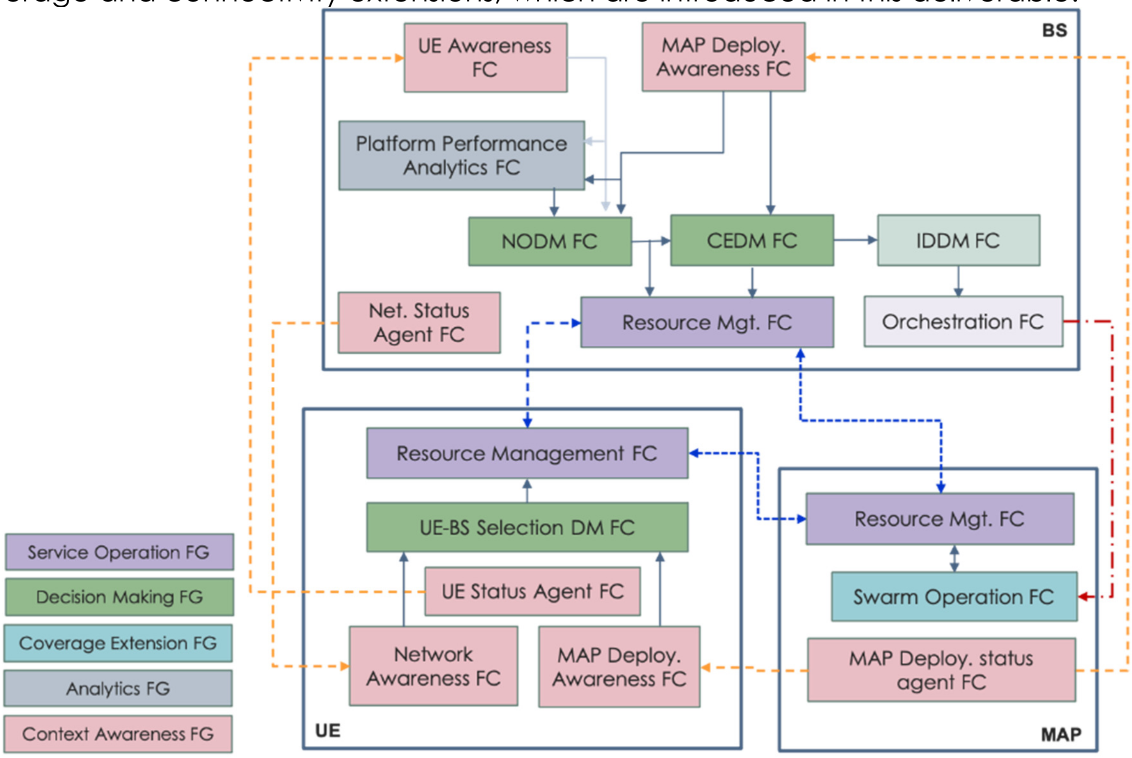


Figure 4: Mapping to functional model

Particularly, in order to describe the operation of this functional model in detail, network entities, BS, UE and MAP, are analyzed in the level of the FCs which belong to one of the previously described five FGs. (More information on FCs can be found in Deliverable D2.2 [107]). For these three network entities, different FCs are identified required for each entity first, and the link between FCs in the same entity and belonging to the different entity is represented to indicate the data flow.

UE

- **Network Awareness FC:** The network information from the BS such as the RSSI (Received Signal Strength Indicator) and channel bandwidth;

- **MAP Deployment Awareness FC:** The network information from the MAP such as the RSSI (Received Signal Strength Indicator) and channel bandwidth;
- **UE-BS Selection DM FC:** Based on collected network information by Network Awareness FC and MAP Deployment Awareness FC, UE can decide the appropriate BSs or MAPs to be connected. Depending on the UE's multi-connectivity capability, the number of BSs/MAPs can vary;
- **Resource Management FC:** For the chosen BSs/MAPs (by UE-BS Selection DM FC), UE will negotiate its association with BSs and establish the connection link. After setting up the connection link, management of the connection link is also managed in this FC;
- **UE Status Agent FC:** UE will inform the contextual information including its capability (e.g., supportable RATs, frequency bands, multi-connectivity), and the instantaneous SNR level and performance indicator (e.g., data rate) which produce from its connection to the network.

BS

- **UE Awareness FC:** Those component aggregates the different UE contextual information. From each UE's location before connected to UE's achieved performance after connected to the network, a lot of information will be gathered and utilized in Analytics FGs and Decision Making FGs;
- **MAP Deployment Awareness FC:** As the MAP's management entity, the BS will collect an overall deployment status of MAPs (e.g., location, produced performance, etc.) and utilize the gathered information in Decision Making FGs;
- **Platform Performance Analytics FC:** Based on collected information from UEs and MAPs, the BS can assess the overall network performance which can be used for further network performance optimization, prediction aligned with decision making FGs;
- **Network Operation Decision Making (NODM) FC:** For a given analyzed data coming from one of the FC in the Analytics FG, this FC can generate the network provisioning and maintenance decisions to keep the optimal network operation. For a new UE requesting the connection, the possibility of its association is decided depending on the current network performance and traffic loads. When the network performance degrades, this FC can trigger actions from the Coverage Extension DM FC to provide the expected connection capability in a certain area;
- **Coverage Extension Decision Making (CEDM) FC:** When the need of coverage extension by MAPs is identified (by NODM FC), it decides the optimal configuration of MAPs (i.e., location and/or trajectories) to provide the proper communication networks;
- **Resource Management FC:** Based on decision made in Network Operation DM and Coverage Extension DM, this FC will manage the communication link with UEs and MAPs;
- **Intelligent Distribution Decision Making (IDDM) FC**: This FC is not considered in this example;
- **Orchestration FC:** This FC is not considered in this example.
- **Network Status Agent FC:** BS's status (e.g., cell ID, supportable channel frequency, traffic load, etc.) can be broadcasted so that UE can detect BSs to prepare its connection to BSs and maintain the network connection.

MAP

- **Swarm Operation FC:** After a MAP is instruction by the BS, this FC is in charge of the MAP's deployment. When multiple MAPs are involved in a cooperative way, communication between MAPs will be also managed in this FC;

- **MAP Deployment Status FC:** After a MAP is deployed, the MAP provides its instantaneous status (location, trajectory, etc.) to the BS so that the BS can assess the network performance and make decisions required for network optimization. The MAP can also provide its information (e.g., cell ID, location, trajectory, supportable channel frequency, traffic load, etc.) to UEs so that UE can decide to initiate its network connectivity with the MAP and/or maintain its communication link;
- **Resource Management FC:** Based on decision made in Network Operation DM and Coverage Extension DM in the BS, this FC will manage the communication link with BS and UEs.

3.2 Design considerations

This section discussed about design considerations. It describes the prototypes in terms of Software / Hardware (e.g., robots, drones, cars, IoT devices) used to validate the technology enablers in the PoC for dynamic coverage and connectivity extension.

3.2.1 Robots and Drones

Hardware

AGVs such as Robots and UAVs will be used as MAPs in order to reach a specific location based on the sequence Context-Awareness FG (and Analytics FG) → Decision Making FG → Service Operation FG. After the final trigger from the Service Operation FG, MAPs will move and change their positions in order to provide Users with opportunistic wireless network.

AGVs:

1. One LoCoBot-WX200;
2. Two LoCoBots-PX100;
3. One custom-made TurtleBot.

UAVs:

1. One custom-made quadcopter with PixHawk flight controller and a Raspberry Pi as a companion board.

For the purposes of the DEDICAT 6G project various vehicles (autonomous or not) will be converted to MAPs. Thus, extra equipment will be added to them for **Wi-Fi** and **5G extensions**.

Wi-Fi equipment such as Wireless N USB Adapter (TP-LINK TL-WN722N) allows you to connect a desktop or notebook computer to a wireless network and access high-speed Internet connection. This complies with IEEE 802.11n and provides wireless speed up to 150Mbps, which is beneficial for online gaming or even video streaming.

Figure 5: Wi-Fi equipment (TL-WN722N)

5G equipment such as RMU500EK

Figure 6: Quectel's RMU500EK 5G Development Kit

3.2.2 Cars

3.2.2.1 Vehicular MAPs for German Smart Highway

Concerning the design restrictions and limitations for the vehicular/connected autonomous mobility scenarios, we assume various modes of connectivity whereby the assumption is that the networks are transient and therefore of an ad-hoc nature. Such *Vehicular Ad-hoc Networks (VANET)* mainly use two types of communication: *Vehicle-to-Vehicle (V2V)* communication and *Vehicle-to-Infrastructure (V2I)* communication. The requirements of low latency and high reliability need to be met.

Given the transience of the situations in which vehicles, RSUs (*Roadside Units*), and VRUs (Vulnerable Road Users) need to communicate with each other, and the fact that the mobility of the vehicles and VRUs changes very quickly (depending on their respective degree of mobility), there is a continuously changing need for capacity. In times when many (road) users share an area, more capacity is needed, when the numbers drop, the required communication resources will also be less. In the German smart Highway scenario, the fluctuation of users is analysed and based on the observations from the sensors etc, predicted and recommendations about when additional communication resources are allocated to an RSU are made depending on the expected/predicted user (Vehicles/VRUs) density in the local area.

To be able to gain this situation awareness that drives the coverage extension decisions, there must be sufficient capability within the network to process the available information and derive the situation knowledge as well as a recommendation for coverage planning/extension.

The architecture to facilitate these application cases includes *Mobile Edge Computing (MEC)* features that allow autonomous vehicles to offload resource-intensive tasks and run applications on multiple platforms and enhances connectivity between the actors (vehicles, RSU, VRU).

A typical scenario is shown in Figure 7.

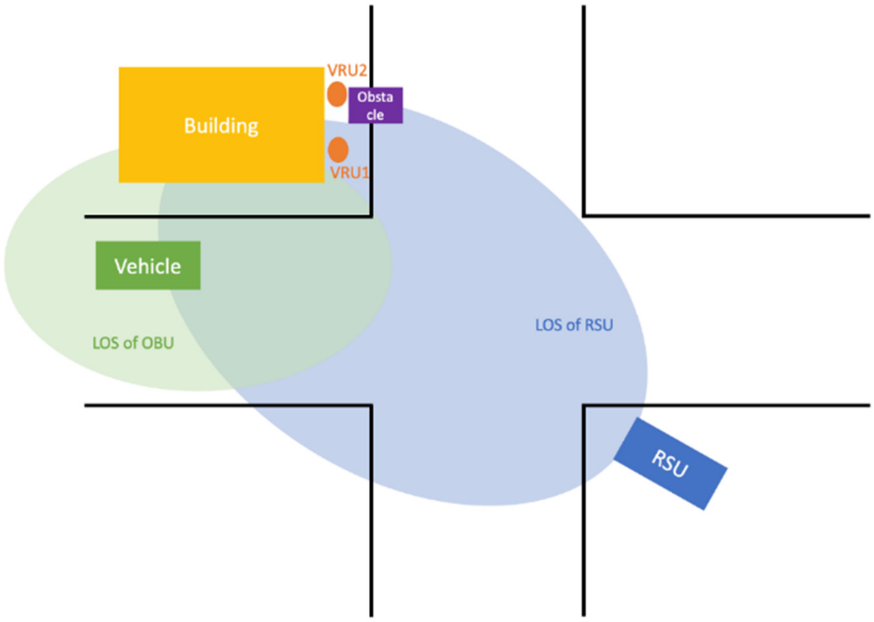


Figure 7: Example of VRU, RUS, and vehicle on the road

Software

The RSU will detect VRUs on the pavements or road-side, track their trajectory, and transmit (VRU) information and movement characteristics to the vehicle. The vehicle will receive this information and integrate it with environment information detected by the available sensors (e.g., LiDAR/Camera) attached to the vehicle, and information about the area (i.e. the relevant area around the RSU) information detected by the RSU, ultimately expanding the space in which VRUs can be detected/recognised by the vehicle. So, it will be possible to extend the spatial area in which VRUs can be detected on the road-side through the co-operation between the RSU and the vehicle. This means that the vehicle will be able to decide the likelihood of collision or the actual situational risk by extending the overall detection space for each vehicle.

For expanding the relevant observed area that feeds into collision risk determination, message exchanges will be implemented using the JSON data format to transmit messages between RSU, VRU, and Vehicle as shown in Figure 8. It will be implemented as part of RSU using Python, see also Figure 8.

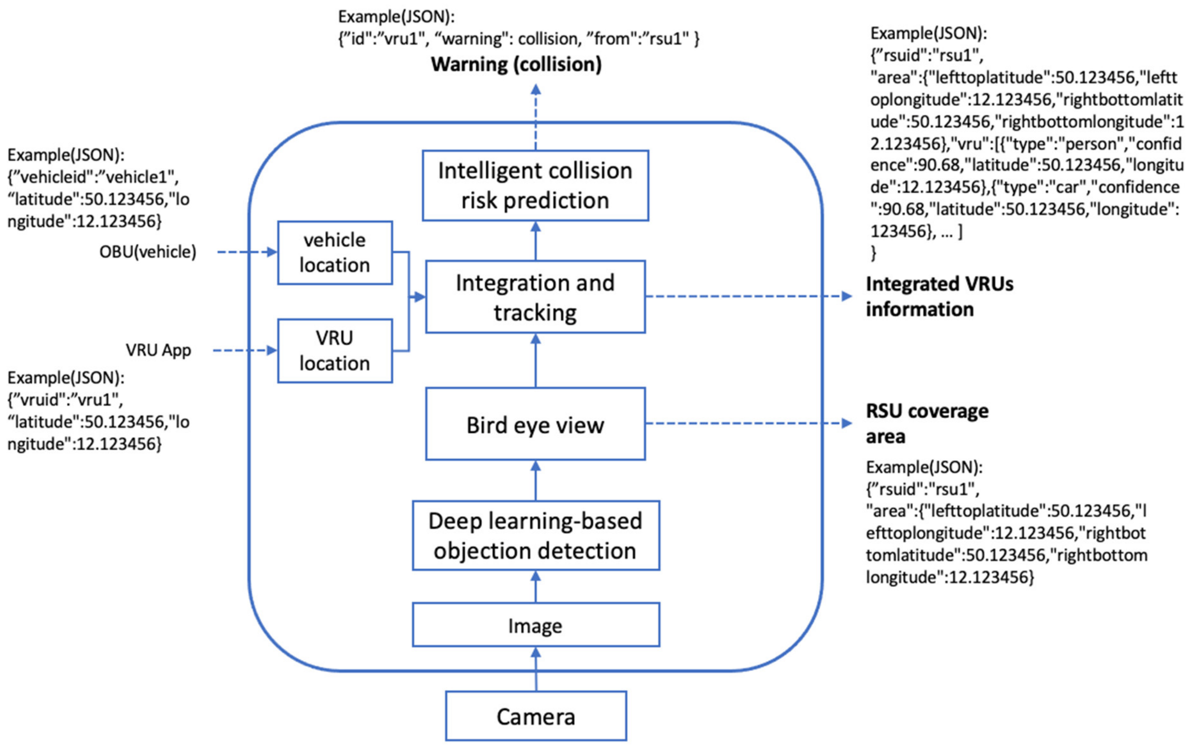


Figure 8: Example of data flow

<u>Hardware</u>

Primarily, and for the smart highway scenarios, the RSU acts as an edge node where AI algorithms can be processed locally, making independent decisions in milliseconds without the need for Internet or cloud connectivity. NVIDIA Jetson AGX Xavier, an embedded device equipped with a *Graphics Processing Unit (GPU)* core to process AI algorithms, and Mako G-223C, an AVT camera, are configured in the RSU to recognize and detect VRUs on the pavements/roadside. Beyond providing functionality and enhanced situation awareness for the various road users, the RSU is also perfectly suited to provide a site and the means to act as a hob for coverage extension in mobile networks. The RSU prototype hardware includes a (small cell) gNB that can be used to either provide (V2X) connectivity to the vehicles within the vicinity and also to act as a temporary coverage extension for a mobile network within the local area.

In the demo and trial set up a USRP N321, a software-defined radio for communication between the cloud server, VRU, vehicle is used, Connected to the USRP is an Intel NUC which implements the protocols and stack features that used by and instantiated on the USRP N321. The AI part and the communication part are processed in parallel by Jetson AGX Xavier and Intel NUC, respectively. See Figure 9.

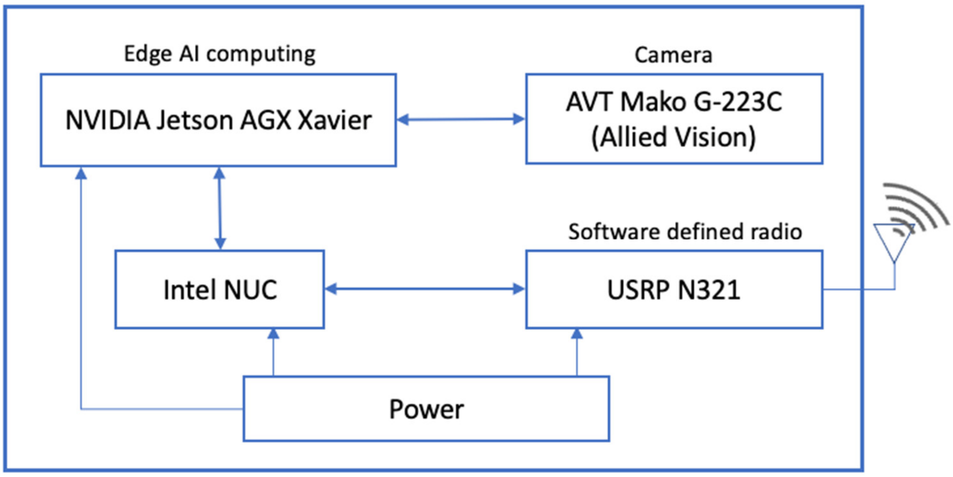


Figure 9: The RSU prototype hardware configuration

3.2.2.2 Vehicular MAPs for Belgian Smart Highway

Hardware

The Belgian Smart Highway is a cutting-edge C-ITS testbed deployed at main highway locations in Flanders (across the E313 highway near Antwerp) and shall be extended to the (urban) road network. The Belgian Smart Highway testbed consists of eight RSUs with *Multi-Access Edge Computing (MAEC)* capabilities and two *On-Board Units (OBU)* that can be integrated into vehicles. Seven of the RSUs are deployed along the E313 highway at the locations shown in Figure 10.

Figure 10: RSU locations of the Smart Highway testbed along the E313 highway

In addition to the setup of the highway, one setup has been created in a lab environment, consisting of one RSU and one OBU, which are identical to the ones deployed along the highway and in the vehicles respectively. This setup can be used for development and debugging purposes, so that the implemented services and tools can be safely tested before they are deployed at the highway. Figure 11 shows the RSU and OBU of the permanent setup.

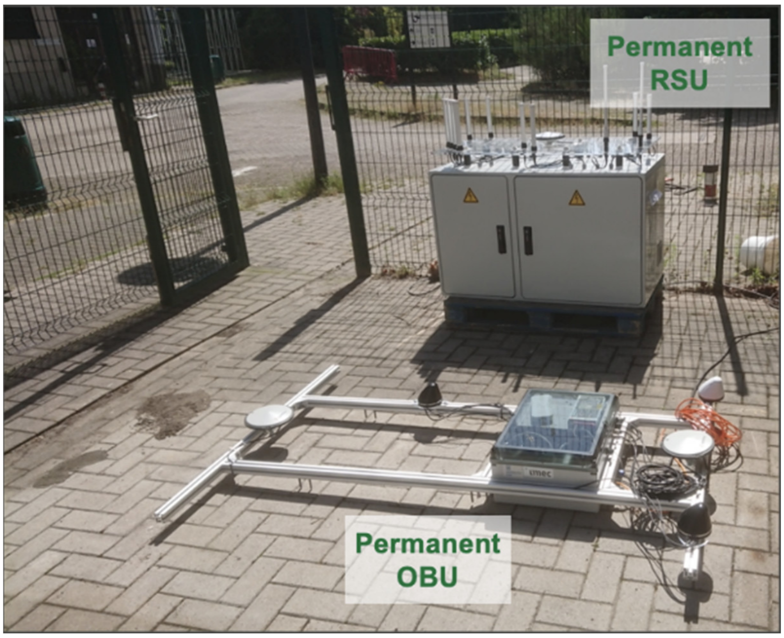


Figure 11: Permanent setup of the Smart Highway testbed

The Smart Highway testbed will be used in the context of WP4 for the development and evaluation of the envisioned dynamic coverage and connectivity extension mechanisms on top of vehicular MAPs.

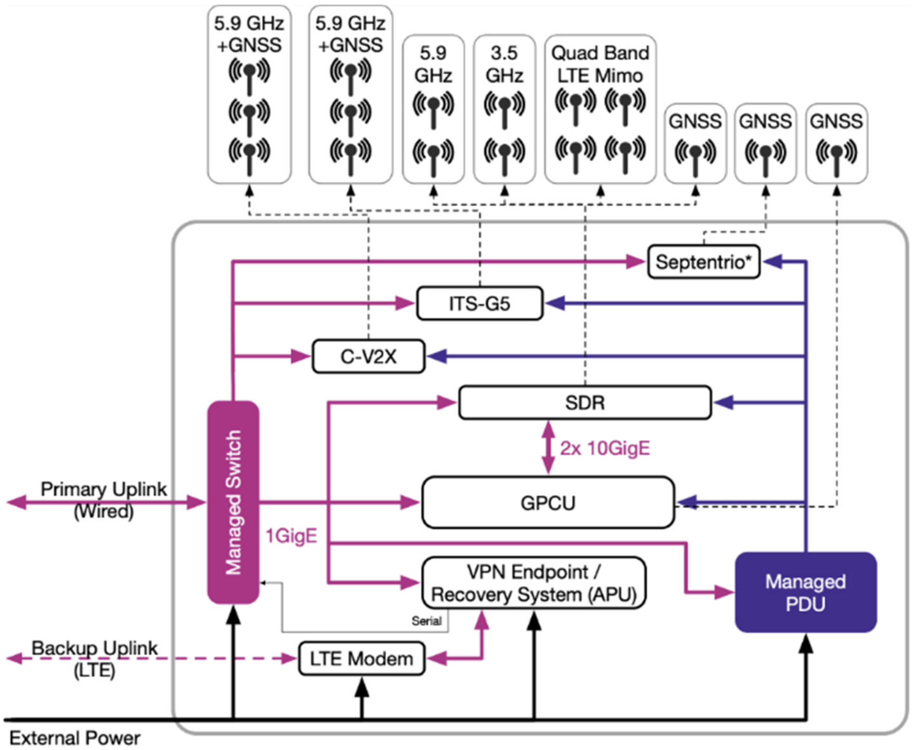


Figure 12: RSU architecture

The equipment that is deployed along the roadside to support C-ITS services and to enable connected, cooperative and autonomous features is called the roadside ITS subsystem or more commonly referred to as RSU. The RSUs allow data message exchange between the vehicles and the infrastructure (V2I/I2V) via short- and long-range communication technologies. The RSU can also act as a router to forward data from vehicles to other vehicles (V2I2V), RSUs or the central ITS subsystem (V2N/N2V) using different types of backhauling technologies, such as optical fiber, wireless backhauling, etc. Different types of sensors may also be attached to the RSU such as cameras, Lidar, traffic lights, environmental sensors (e.g., fog sensor). This way, these sensors can be integrated into the C-ITS system. Each RSU of the Smart Highway testbed contains V2X wireless communication modules including 5G-NR, LTE, C-V2X PC5 and ITS-G5. In addition, each RSU offers processing hardware for performing computations on the RSU itself, a *Global Navigation Satellite System (GNSS)* device and SDR equipment (USRP N310). In addition, it also contains a number of modules that are needed both to support performing experiments on the RSU and to allow the RSU to be managed and recovered remotely. The summary of the RSU architecture is presented in Figure 12.

The Smart Highway OBUs can be mounted on vehicles in order to enable them to communicate with other vehicles, roadside infrastructure and cloud services. The OBU architecture is split into two separate units. The first one is installed inside the vehicle and contains the processing component for the Lidar (Nvidia Jetson computer board), the power system and the in-vehicle sensor processing modules (e.g., *Controller Area Network (CAN)* processing). The second unit is installed on the roof of the vehicle and is only connected to the in-vehicle OBU with an Ethernet and power connections. The roof unit contains all the V2X communication hardware (similar to the ones of the RSUs), the V2X processing hardware, the SDR (USRP B210) equipment and the GNSS device. The antennas of the communication modules are also attached on the roof of the vehicle. Figure 13 illustrates the overview of the OBU architecture.

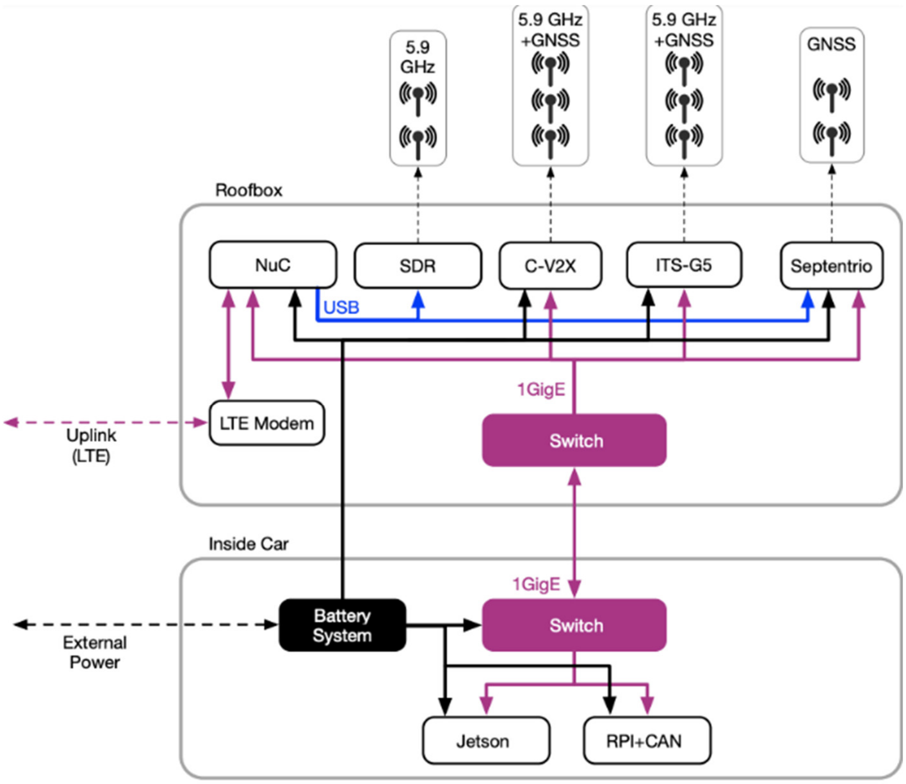


Figure 13: OBU architecture

As it has been mentioned in the respective sections, both the RSUs and the OBUs offer *Software Defined Radio (SDR)* capabilities. More specifically, each RSU includes a Universal Software Radio Peripheral (USRP) N310 device, while each OBU a USRP B210. The SDRs will allow the development of the mechanisms of dynamic coverage and connectivity extension, building on top of open-source 5G software suite (e.g., srsRAN [92]). The USRP N310 offers frequency range from 10 MHz to 6 GHz, while the USRP B210 offers frequency range between 70 MHz and 6 GHz. Such frequency ranges are ideal for the development of the envisioned MAP solutions as sub-6 GHz frequencies offer enhanced coverage and signal propagation.

Software

Technology recognition solution

In our previous LTE/Wi-Fi network coexistence studies we have developed a CNN based technology recognition model that can classify LTE and Wi-Fi frames. The CNN model has been trained by capturing IQ samples of LTE and Wi-Fi transmissions and it is validated using commercial off-the-shelf LTE and Wi-Fi hardware equipment. In DEDICAT 6G, the technology recognition model will be extended to include other RATs including ITS-G5, C-V2X PC5, and 5G NR. The neural network algorithm framework is developed based on Python with Keras. Keras is a high-level application programming interface for neural networks written in Python and it is designed to run seamlessly on top of both *Central Processing Unit (CPU)* and GPU. The neural network algorithm framework will be trained and validated by collecting examples from all the considered RATs. The statistics obtained from the technology recognition model will be used as an input for the development of the RAT selection and RAT configuration.

CAMINO framework [93] is the core framework for managing the V2X communication technologies of the Smart Highway testbed and the services running on top of them. The framework enables integration with existing and future short- and long-range V2X technologies such as ITS-G5, C-V2X PC5 and C-V2X Uu (5G/4G). Moreover, it allows integration with vehicle or roadside infrastructure sensors, vehicle actuators, Human-Machine Interfaces (HMIs) and third-party service providers. CAMINO supports several standardized C-ITS services, such as *Cooperative Awareness (CA)*, Decentralized Environment Notification (DEN) and Infrastructure to Vehicle Information (IVI) that can be triggered dynamically. The generated messages can be transmitted in a flexible way by one or multiple V2X technologies (hybrid-V2X communication) increasing the transmission capacity or enhancing the transmission reliability. Furthermore, the CAMINO framework can run on top of any type of ITS device such as OBU, RSU, UE, servers, etc. It offers rich logging capabilities that allow the collection of valuable information for evaluating the performance of the V2X technologies and the services running on top of them. Figure 14 presents the overall architecture of the CAMINO framework.

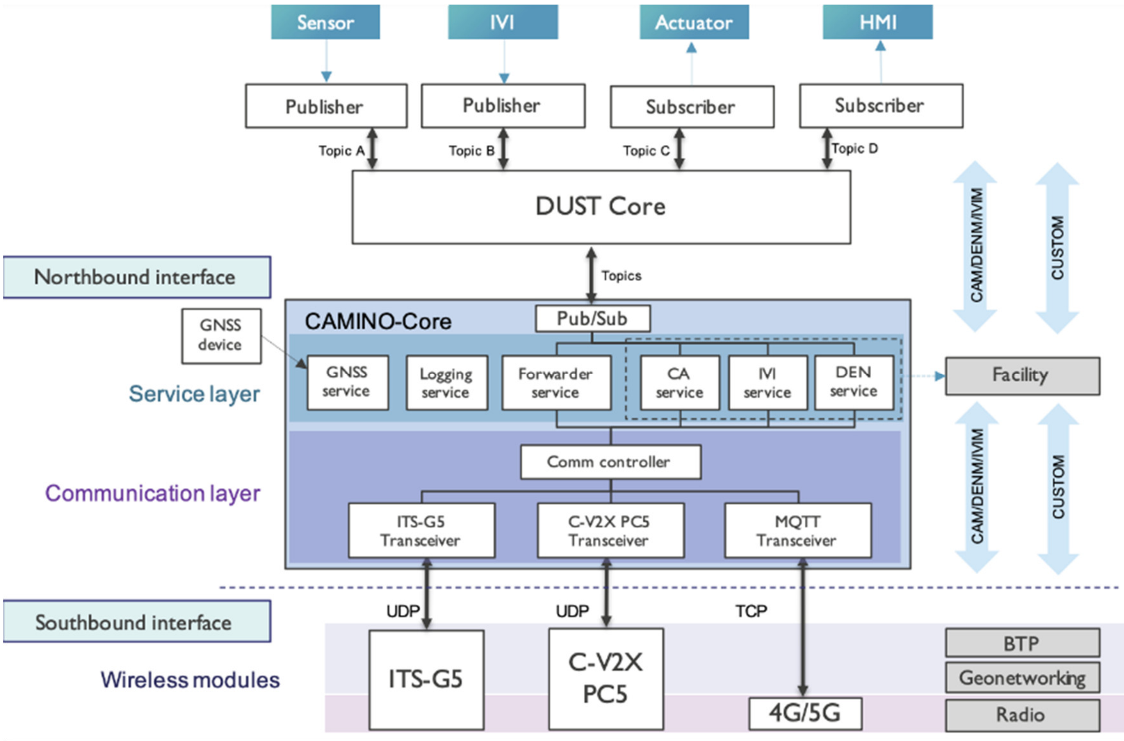


Figure 14: CAMINO framework architecture

The CAMINO-Core is the heart of the framework, implementing the main functionality that is required to control the incoming and outgoing data flows between the northbound and southbound interfaces. At the southbound interface, CAMINO-Core interconnects with the different V2X wireless technologies, using the several transceiver classes. For example, it can communicate with commercial C-V2X PC5 and ITS-G5 modules via UDP sockets and with an MQTT broker through TCP over wired or cellular networks. The transceiver classes can interact with the CAMINO-Core services via the Communication (Comm) Controller. At the northbound interface, CAMINO-Core is integrated with the Distributed Uniform Streaming (DUST) open-source framework [94] that provides interconnection to sensors, actuators, third-party services and HMIs by using a publisher/subscriber architecture. The CAMINO framework provides a series of publishers that can be used to trigger specific services at the CAMINO-Core based on information that may derive from the CAN BUS or the sensors of the vehicle and a series of subscribers that bring the information from the different ITS services in the vehicle. This information then may be used to trigger an actuator or to be visualized using an HMI. The facility layer of the ITS stack, as specified in ETSI, can be managed by the CAMINO-Core. Several C-ITS standardized (e.g., CA, DEN, IVI) or custom services are supported that can run independently or simultaneously.

In the context of the DEDICAT 6G project, CAMINO can be used in multiple ways. Initially, it will be used to generate traffic from multiple wireless communication technologies that will be used for training and validating the technology recognition mechanism. Next, CAMINO can be used as part of the Resource Management Functional Component for the MAP entity, allowing the management of the communication link with the BS and the UEs in order to load balance the data traffic over the selected RATs.

srsRAN

The RAT selection and RAT configuration mechanisms of the vehicular MAPs will be designed and developed on top of srsRAN SDR solution. Specifically, the srsRAN SDR solution will be used to implement LTE and 5G networks. srsRAN is an open source SDR solution which has modular implementation. The srsRAN has 4G LTE SDR solution which is LTE Release 10 compliant. LTE FDD mode is implemented in both eNB and UE side, while TDD Mode option is also included in the UE side. In the latest release of srsRAN (release 21.04), Non-stand Alone (NSA) UE modem that supports 4G LTE and 5G NR is implemented. The NSA gNB is expected to be included in the next release, at the end of October 2021.

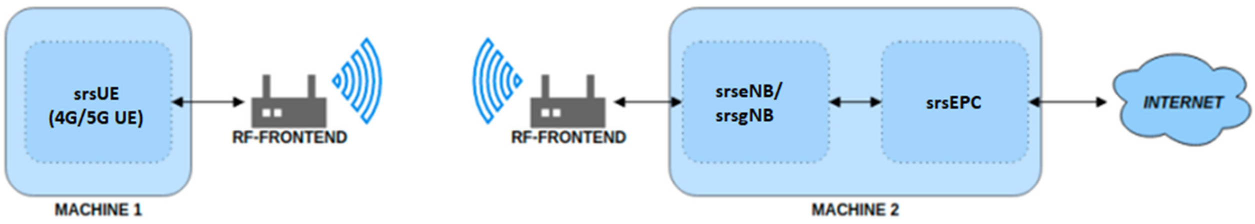


Figure 15: Architecture of srsRAN SDR solution

Figure 15 shows the overall architecture of srsRAN SDR solution for a single UE and single eNB/gNB. The overall system requires at least Linux host PCs, one UE (4G/5G) host PC and one eNB host PC, with 1 RF-frontend in each host PC. The UE runs on machine 1 while the eNB/gNB runs on machine 2. Similarly, the EPC will run on the same machine as the eNB/gNB.

srsUE is a software-only NSA UE modem that supports 4G LTE and 5G NR. srsUE connects to any LTE network and provides a standard network interface with high-speed mobile access. It runs as an application on a conventional Linux-based operating system. SDR hardware, such as the Ettus Research USRP, is required for srsUE to transmit and receive radio signals over the air.

srsENB is a fully software-based LTE eNodeB base station. srsENB connects to any LTE core network (EPC) and builds a local LTE cell while running as an application on a typical Linux-based operating system To transmit and receive radio signals over the air, srsENB requires SDR hardware such as the Ettus Research USRP.

3.2.3 IoT Devices

The *IoT People Counter Access Point (IoT PC AP)* devices are going to collaborate in the DEDICAT 6G project coverage extension tasks from two approaches. On the one hand, they will be part of the DEDICAT 6G platform, implementing the functional components of Logging FC, Dashboard FC, Management FC, Edge Node Registry FC and Network Awareness FC. On the other hand, IoT nodes will be deployed, which will have extended connectivity capabilities, so that they will be able to participate in coverage extension functions, allowing to user devices temporarily use their communication interfaces for data download.

In addition, through the information available at the back end of the platform and accessible through the dashboard, it will allow to have a context awareness through estimates of device occupancy, in their range area, so that this information can be used by the different DEDICAT 6G agents to prevent situations of blockage or network saturation.

Hardware:

As of today, the current design of the people counter has the appearance depicted in Figure 16, including a slot for plugging in the battery charger. However, the ultimate goal involves preparing a wired version, which allows the DEDICAT 6G consortium to treat it as a public fixed access point, with high connectivity and data routing capabilities, allowing, not only to generate heat maps of devices present in the vicinity for crowd control or traffic management (the information can be easily exploited by traffic management systems in smart cities), but to enable dynamic paths to ensure that data are sent even in the most difficult conditions (e.g., in the most remote locations.

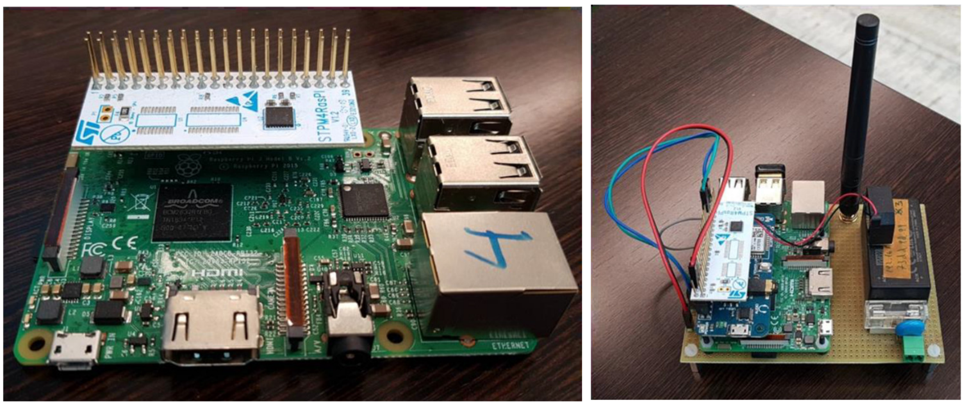


Figure 16: People counter devices circuitry

The extended version of the people counter will also be integrated into the final solution with network hardware that will allow, through the development of open operating systems, to control connections and routing of information dynamically.

Software:

To provide the data generated by these IoT devices, about the presence of devices in the coverage area, the MQTT protocol is used in them, something that simplifies the collection of data from the sensors, the publication of the different values obtained and the remote configuration of the nodes.

The current people counter IoT device, is a prototype that works with a Raspberry Pi, relying on buildroot operating system based on Debian OS.

Referring to data, the information sent by this IoT device follows the structure depicted in Table 1, where it is easy to appreciate the different parts of every frame, and a real-life example is also offered.

Table 1: People counter data frame

SN@WIFI@$DATE@$TEMPERATURE@$NUM_WIFI_PKTS@$NUM_WIFI_DEVICE	MAC@RSSI
000000006956C35F@WIFI@20192208-22:41:55@65.53@12076@5	8C:F7:10:07:AE:C2@-71
	B8:27:EB:71:FF:F5@-57
	00:16:9D:F5:0B:80@-85
	CC:4B:73:64:59:66@-41
	44:07:0B:E9:4D:30@-35

The device sends the information to a server in the cloud that has a *Data Base (DB)* of devices that is accessible through a web application and the information can be dynamically visualized as shown in the following figures:

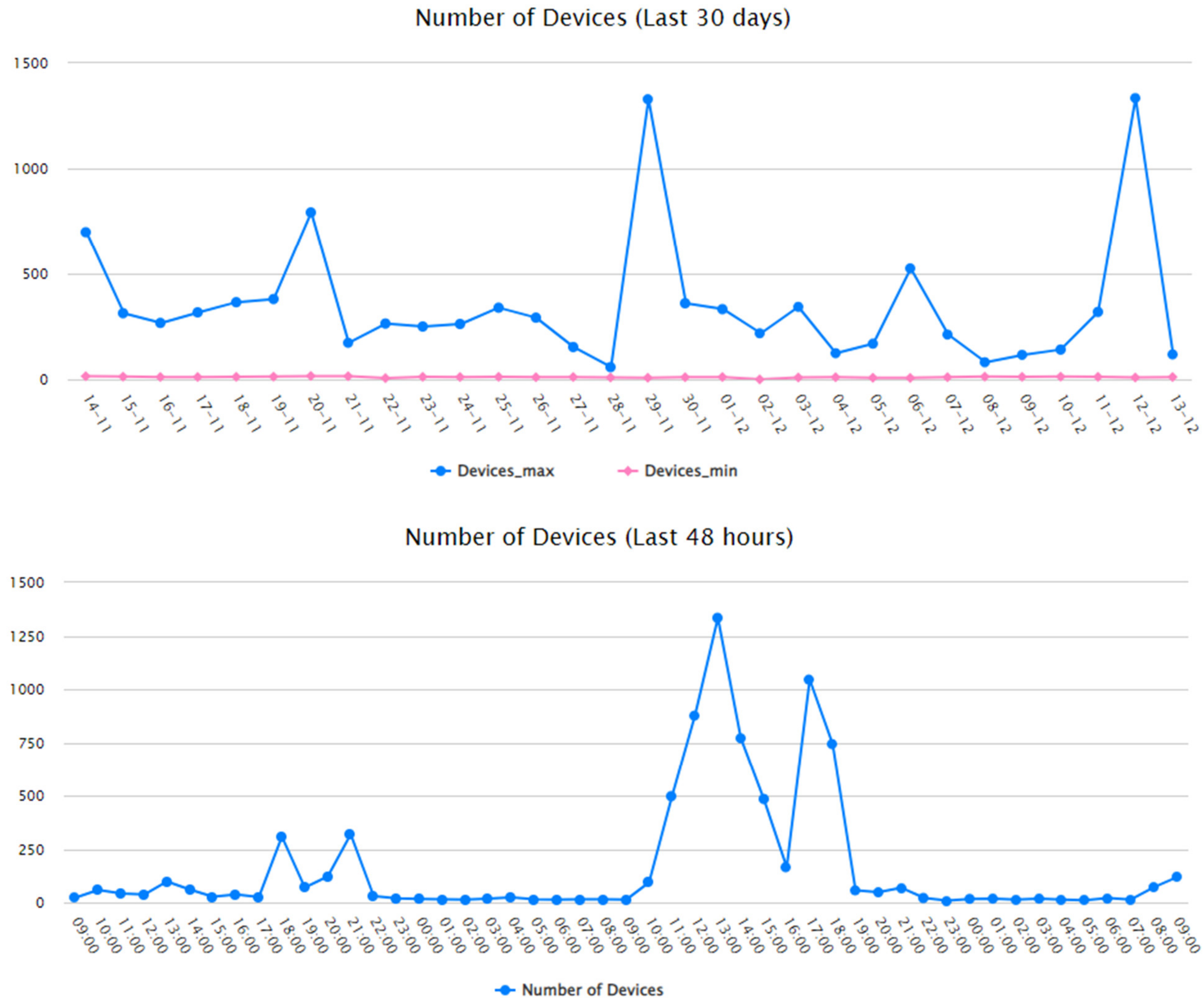


Figure 17: Device discovery reports

The extended version of the people counter will also allow, through its SW platform, to visualize the connections of DEDICAT 6G network devices using the coverage extension service, where it will be possible to extract workload reports, actualize the control information of allowed devices from the DEDICAT 6G Central Manager, manage the network dynamically and allow and deny connections depending on the congestion of the network.

3.2.4 NFV Orchestrator

Network Functions Virtualization (NFV) is a key element of 5G/B5G strongly related to the dynamic and flexible SDN network management paradigm and Multi Access Edge Computing (MEC) technology. In a 5G-based ecosystem, NFV technology is responsible for the *Management and Orchestration (MANO)* of physical and virtual resources and procedures that enable the deployment of *Virtual Network Functions (VNF)* attached to specific network services/slices that enable vertical applications' connectivity in a 5G system. Regarding to the ETSI and 3GPP 5G standards the central element in NFV is the *NVF Orchestrator (NFV-O)* that oversees the management and orchestration tasks.

Preliminary design considerations:

Thus, NFV orchestration needs to be considered as part of the dynamic coverage and connectivity extension provided by the DEDICAT 6G solution. In this sense, we must consider two main minimum requirements to support NFV capabilities in the system when applying coverage and connectivity extension.

- The computational (virtual or physical) resources of the MAPs can be externally reachable and available to be included as part of the NFV Infrastructure (NFV-I). This way, the NFV Orchestrator will be able to orchestrate the deployment of lightweight VNFs in their computational resources to enable the establishment of network slices that provides the 5G connectivity. This point is not only relevant in general deployments but also especially essential in 5G ultra reliable and low latency communications (URLLC) or mission critical services, where the providing minimum network access by the proximity of the MAPs is key;
- The DEDICAT 6G platform will be able to communicate with the NFV-O by using the NFV-O API to remotely send a set of recommendations to the NFV-O in order to assist it in the establishment of network slices and VNFs instantiations when expanding the coverage to provide the 5G connectivity. Such set of recommendations will be based on the output of the mechanisms exposed in this document (later implemented in the Decision-Making FG) and translate them to the NFV-O in a standardized format given by a 5G blueprint.

Software:

Open Source MANO (OSM) is an Open Source initiative lead by ETSI to release a NFV-O tool following the ETSI NFV standards [101]. This initiative is underpinned by a world-wide open community that contributes to its development, testing, documentation, and exploitation under the umbrella of the ETSI. OSM have been chosen to perform the role of the NFV-O in multiple 5G-PPP projects and telco operators given its multiple features, its information models based on ETSI recommendations (SOL006 standard) and its zero-touch-oriented cloud-native architecture.

One of the major benefits of OSM is that it has fully integration with the majority of the most relevant cloud-edge frameworks or infrastructures where VNFs can be deployed and monitored, such as OpenStack, Kubernetes, Microsoft Azure or Amazon Web Services, as well as direct interrelation to some relevant SDN controllers, like ONOS.

The overall functional architecture of OSM is illustrated in Figure 18 where we can see the three main functional components, among others, related to MANO operations: the *LifeCycle Management (LCM)*, the *VNF Configuration and Abstraction (VCA)* and the *Resource Orchestrator (RO)*. It is also worth to mention that OSM exports its main functionalities via NBI, by a specific API based on the SOL005 standard to be remotely accessed by a OSM client. Potentially, this OSM client can be integrated in the DEDICAT 6G platform to command OSM according to the recommendations on how to consume the resources obtained by the dynamic coverage extension algorithmic.

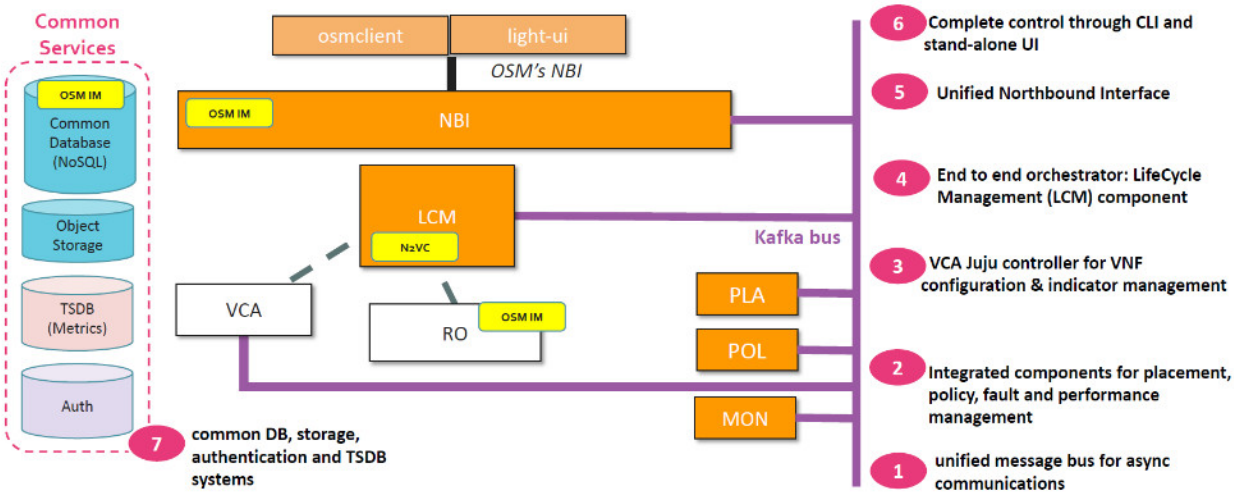


Figure 18: OSM Architecture Basic Overview. Source [101]

Exemplary Orchestration Use Case:

Figure 19 shows an exemplary scenario where NFV orchestration is involved in a coverage extension process. For this example, we assume an area with three fixed RAN access points connected to a central office with a RAN hub with external connectivity to the Internet. In this case, we present a high-level description of the scenario in four different stages:

1. Initial phase, the system is stable, and all the users are covered by the existing coverage ranges and the user's services are guaranteed (Figure 19 a));
2. Getting crowded, during a specific period the situation is getting crowded where more people are requesting new connection and not only some access points are about to cover their capacity limits but also some users are out of the current coverage area. In this case, the DEDICAT 6G platform, thanks to the Context-Awareness FG, is able to monitor this change in the scenario and triggers an action to solve it (see Figure 19 b));
3. DEDICAT 6G reaction, the Decision-Making FG, with the assistance of the Coverage Extension FG and Analytics FG, if proceed, executes a concrete algorithm to handle the new context situation and as it results new Mobile Access Points (in this case drones with RAN capabilities) are planned to be deployed and placed in the concrete areas specified by the algorithm. To manage the drones is necessary to deploy a drone control agent in nodes close to the new areas (e.g., central office or fixed access points), as depicted in Figure 19 c) and then expand the overall coverage area. Thus, establishing connectivity links with the closest RAN hub or fixed RAN access point;
4. NFV Orchestration, finally, the Orchestration FG of the platform, in line with the algorithm outcomes, commands the NFV-O (OSM in this case) to deploy a specific set of lightweight VNFs in the MAPs to provide 5G connectivity and this way, first enable the connectivity in the new coverage areas given by the MAPs that can serve connectivity to the user outside the original coverage but also have an additional effect in the alleviation in the capacity of the fixed access points (Figure 19 d)).

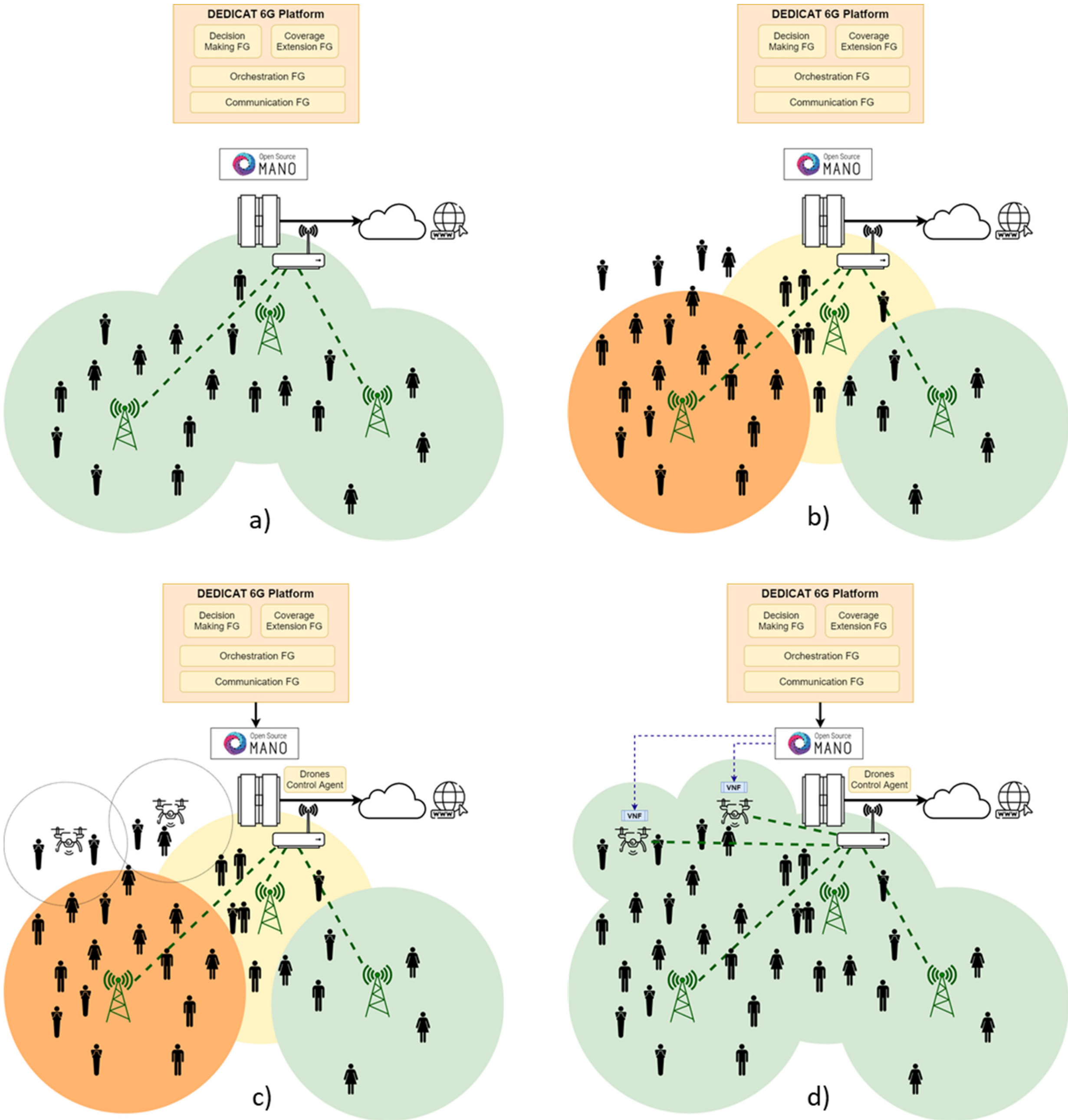


Figure 19: Exemplary use case of NFV Orchestration in VNF deployment with DEDICAT 6G support

3.3 Assumptions and models

This section describes modelling methodologies used to define and validate the different strategies for dynamic coverage and connectivity extension. In particular, we discuss about relevant models used in system level simulations for performance evaluation of coverage and connectivity extension mechanisms and to harmonize the research and development (e.g., to align the simulation frameworks parameters such as deployment scenarios, traffic models and channel models).

3.3.1 Scenarios of interest

In DEDICAT 6G, we consider three classes of MAPs:

- Unmanned Aerial Vehicles (UAV) such as drones and possibly airships;
- Autonomous Guided Vehicles (AGV) such as Robots;
- Manned Connected Vehicles (MCV) such as connected cars/vans.

Several scenarios can be considered according to three network management approaches: **self-configuration, self-healing and self-optimization.**

- **Initial deployment at T_0**: This self-configuration approach determines the configurations and the positions of MAPs in order to have an optimal solution for users. It covers the discovery of the network topology and the decisions taken by the DEDICAT 6G platform to undergo the MAPs deployment. The objective is to start building up the deployment where different MAPs can improve the network performance according to the certain level (i.e., energy, latency, throughput, load distribution) with the help of triggered analytics, context-awareness and decision making policies;
- **Reacting to a radio network failure**: This self-healing approach is the ability of the network to manage its stability, especially in case of failure. Awareness agents are deployed in order to collect raw information from the 5G legacy network concerning various performance indicators. The objective is to plan and initiate the deployment of MAPs with 5G capability, based on the pool of available MAPs and their characteristics, when the existing MAPs cannot fulfill the constraints of that particular case (e.g., no drone has been already physically deployed in the targeted area);
- **Reacting to an optimization recommendation**: This self-optimization approach is all the techniques used by the network to achieve an optimal configuration without having an enormous process and computation times. It does not rely on direct notification from the 5G legacy network as for the failure, but on the result of the optimization task performed by the Network Optimization / Network Prediction FC and related agents.

DEDICAT 6G focuses on four use cases, thus four scenarios can be defined

- Smart Warehousing use case with the utilization of automated guided vehicle (AGV) and mobile asset (i.e., forklift) for improving warehousing operations:
  - Size of the area: total storage area of 18.270 m^2;
  - Height 11m;
  - Type of environment: Indoor (Warehouse);
  - Number of UEs: 20~30 ;
  - UE mobility: AGV will be mobile (up to 5 km/h), and warehouse workers walk at about 5 km/h;
  - User traffic: network traffics and device data transmission.

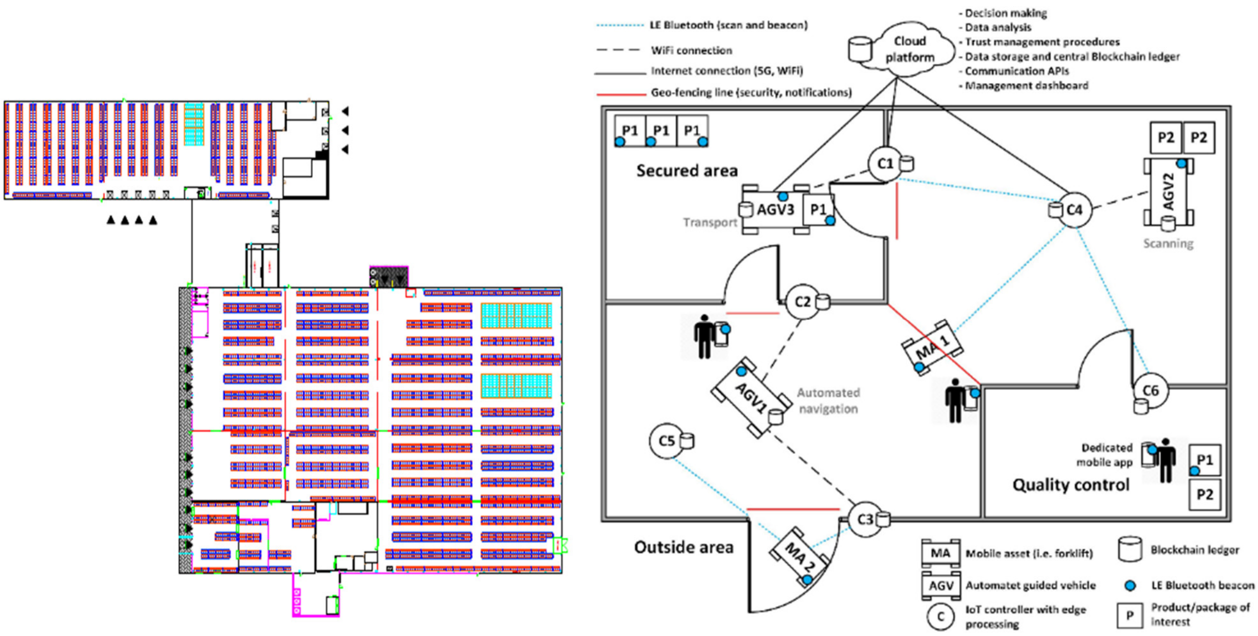


Figure 20: Smart Warehousing with MAPs scenario.

- Enhanced experiences use case with dynamic MAPs closer to moving audiences. The main objective of enhanced experience is to utilize MAPs to assist organizing social events as the existing terrestrial network is built on some average user traffic demands when the events do not take place. The scenario is illustrated in Figure 21. The main actors involve on-site users and devices physically located at the event and using an event-related wireless service and off-site users participating remotely. More information about the use scenario is given in D2.1. There can be different types of social events that can benefit from MAPs. The following ranges of system parameters are of interest:
  - Size of the area: 0.01 - 10 km^2;
  - Type of environment: Urban/suburban, outdoor;
  - Number of UEs: 1000 - 100 000;
  - UE mobility: 0 km/h - 3 km/h;
  - User traffic: Poisson process.

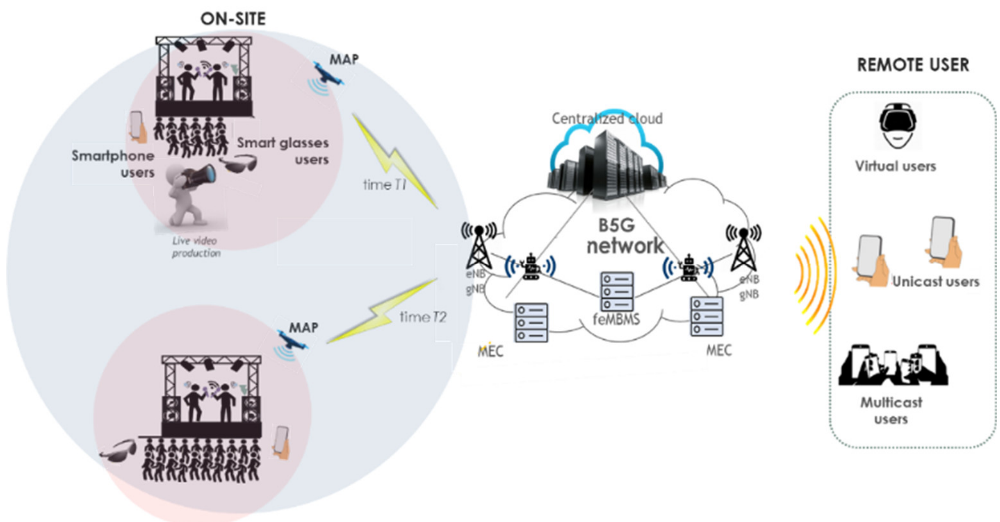
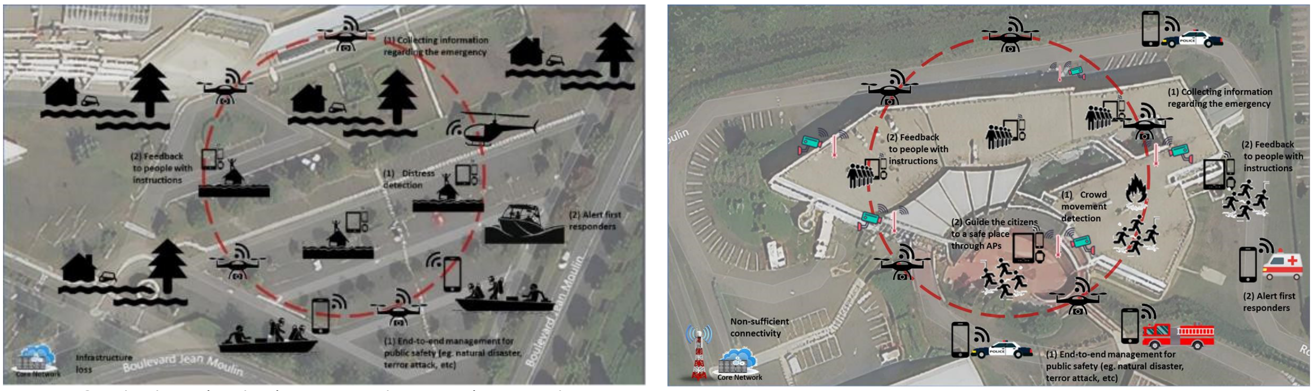


Figure 21: Enhanced experience with MAPs scenario.

- Public safety use case with the utilization of diverse assets (Drones, AGVs, etc.) Two examples are provided in D2.1[112] : Disaster in a non-urban environment and Public infrastructure overloaded. The characteristics for both types of context are:
    - Size of the area: in the first context of UC3, the area which is considered is about 7500 squares meters, a second area could be considered to simulate a large disaster event and add 2000 squares meters of area; in the second context the global area considered is about 6000 squares meters;
    - Type of environment: the first context on AIRBUS premises in Paris area is an outdoor area without obstructions for wireless connectivity; the second area is composed of an outdoor area and an indoor area with obstructions by building structure which will be used as a concert place;
    - Number of UEs: an average of 10 UEs and simulation of 100 UEs; 2 MCVs and 1 AGV;
    - UE mobility: Ues will be able to move inside the areas; MCVs will be able to move on specific way of the areas at a maximum speed of 20km/h; Specific authorization will be requested to allow the flight of AGV in the defined area;
    - User traffic: network traffic, Voice, video and data transmissions.



Context 1: Disaster in a non-urban environment

Context 2: Public infrastructure overloaded

Figure 22: Public safety with MAPs scenario.

- Smart highway use with the use of cars and roadside infrastructures. Smart highway use case will consist of two sites. The first one in Germany, and the second one in Belgium.
    - German site: Reichenhainer Campus of the Technical University Chemnitz (half a square kilometer, Figure 7)
    - Belgian site: The intersection is a junction between a national road and E313 highway (Wommelgem, near the city of Antwerp, Figure 10)
        - Size of area:
            - The area of the scenario which covers the wireless communications between different nodes is centered around the roundabout, which is about 4000 square meters.
        - Type of environment:
            - The type of the environment used in the Belgian site would be outdoor. This consist of a mix between highway and a semi-urban area (less obstructions by buildings).
        - Existing infrastructure:

- In the Belgian site, we have deployed 7 roadside infrastructures, or Road Side Units (RSUs), on the highway. In addition, a smart car is available, having vehicle-to-everything (V2X) communications module, able to handle Intelligent Transport Systems (ITS) scenarios. The smart car has also a LiDAR sensor and a camera that can capture the environment condition.

- Number of UEs:
  - 7 RSUs, 1 of which is located on the roundabout near where the scenario takes place;
  - 1 Car with wireless connectivity module;
  - 1 Smart car with wireless connectivity modules and edge computing capabilities;
  - At least 3 handheld devices of the Vulnerable Road Users (VRUs). These VRUs consist of both types, pedestrian and cyclist.
- UE Density:
  - The 5 UEs will be moving around the roundabout at the exit of the highway. The area covered for the roundabout scenario will be 4000 square meters.
- UE mobility:
  - Only the RSUs will be static. Both cars and handheld devices of the VRUs will be mobile circling around the roundabout;
  - The cars will move at the maximum of 50 km/h;
  - The pedestrians walk at about 5 km/h, whereas the cyclist will move at a maximum of 30 km/h.
- Type of users traffics:
  - The scenario will consist of network traffics that make up video transmission, lidar data transmission (that requires larger bandwidth) and device data transmission (time sensitive).

Figure 23 shows an overview of the Smart Highway use case and the interaction between the UEs and the network infrastructure.

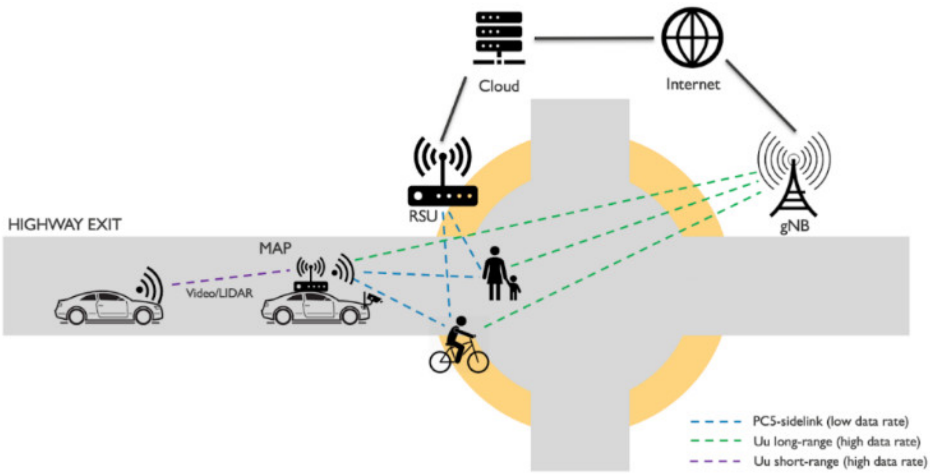


Figure 23: Interaction between UEs and the networking infrastructure

3.3.2 Channel Models

In order to evaluate and optimize the performance of 6G Networking including MAPs, we can define the propagation models according to several criteria:

- The type of **environment** (sub-urban, Urban, Dense urban, High-rise building);
- The **band** (sub-6GHz and mm-wave);
- The **type** of communication (ground-to-ground, air-to-ground and air-to-air);
- The **direction** of the communication (UL and DL).

The average path loss can be defined depending on the *Line of Sight (LoS)* and *non-Line of Sight (NLoS)* conditions as follows:

$$\overline{PL} = PL_{LoS}p_{LoS} + PL_{NLoS}(1 - p_{LoS})$$

where p_{LoS} is the probability of LoS condition.

Table 2 summarized the selected ITU-R parameters for urban environments

Table 2: Selected urban environment

Env.	α_0	β_0	γ_0
Suburban	0.1	750	8
Urban	0.3	500	15
Dense Urban	0.5	300	20
High-rise	0.5	300	50

Parameter α_0 represents the ratio of built-up land area to the total land area, parameter β_0 represents the mean number of buildings per unit area and parameter γ_0 describes the buildings' heights distribution according to Rayleigh probability density function.

The state of the art gives the following parameter sets:

Air-to-ground sub-6GHz

The path loss model can be defined as follows [95]:

$$PL_{LoS} = FSPL + \eta_{LoS}$$
$$PL_{NLoS} = FSPL + \eta_{NLoS}$$

Where

$$FSPL = 20\log_{10}(d) + 20\log_{10}(\mathrm{f}_{MHz}) - 27.55$$

with d the distance between the user and the access point and f_{MHz} the carrier frequency in MHz.

η_{LoS} And η_{NLoS} follow a normal distribution of a mean μ_{LoS} and μ_{NLoS} with a standard deviation σ_{LoS} and σ_{NLoS} where $\sigma_{LoS,NLos} = a_{LoS,NLos}e^{-b_{LoS,NLos}\theta}$

The LOS probability is defined as

$p_{LoS}(\theta) = c(\theta - \theta_0)^d$ with $\theta_d = 15°$ the lower possible angle.

Table 3: Coefficient of sub-6GHz air ground model

	700 MHz			
	Suburban	Urban	Dense Urban	Highrise Urban
μ_{los}	0	0.6	1	1.5
μ_{nlos}	18	17	20	29
(a_{los}, b_{los})	(11.53,0.06)	(10.98,0.05)	(9.64,0.04)	(9.16,0.03)
(a_{nlos}, b_{nlos})	(26.53,0.03)	(23.31,0.03)	(30.83,0.04)	(32.13,0.03)
(c, d)	(0.77,0.05)	(0.63,0.09)	(0.37,0.21)	(0.06,0.58)

	2000 MHz			
	Suburban	Urban	Dense Urban	Highrise Urban
μ_{los}	0.1	1	1.6	2.3
μ_{nlos}	21	20	23	34
(a_{los}, b_{los})	(11.25,0.06)	(10.39,0.05)	(8.96,0.04)	(7.37,0.03)
(a_{nlos}, b_{nlos})	(32.17,0.03)	(29.6,0.03)	(35.97,0.04)	(37.08,0.03)
(c, d)	(0.76,0.06)	(0.6,0.11)	(0.36,0.21)	(0.05,0.61)

	5800 MHz			
	Suburban	Urban	Dense Urban	Highrise Urban
μ_{los}	0.2	1.2	1.8	2.5
μ_{nlos}	24	23	26	41
(a_{los}, b_{los})	(11.04,0.06)	(10.67,0.05)	(9.21,0.04)	(7.15,0.03)
(a_{nlos}, b_{nlos})	(39.59,0.04)	(35.85,0.04)	(40.86,0.04)	(40.96,0.03)
(c, d)	(0.75,0.06)	(0.56,0.13)	(0.33,0.23)	(0.05,0.64)

The LOS probability could also be defined with [96] as

$p_{Los}(\theta) = \frac{1}{1+a \exp(-b[\theta-a])}$ Where $a = \sum_{j=0}^{3}\sum_{i=0}^{3-j} C_{i,j}(\alpha\beta)^i\gamma^j$ and $b = \sum_{j=0}^{3}\sum_{i=0}^{3-j} C_{i,j}(\alpha\beta)^i\gamma^j$

Table 4: Coefficient $C_{i,j}$ for a

$C_{i,j}$	i	0	1	2	3
j					
0		9.34E-01	2.30E-01	-2.25E-03	1.86E-05
1		1.97E-02	2.44E-03	6.58E-06	
2		-1.24E.04	-3.34E-06		
3		2.73E-07			

Table 5: Coefficient $C_{i,j}$ for b

$C_{i,j}$	i	0	1	2	3
j					
0		1.17E00	-7.56E-02	1.98E-03	-1.78E-05
1		-5.79E-03	1.81E-04	-1.65E-06	
2		1.73E-05	-2.02E-07		
3		-2.00E-08			

Air-to-ground mmW

The path loss model can be defined in [97] as follows:

$PL(d) = \alpha + 10\beta \log_{10}(d) + \gamma$

And γ follows a normal distribution of mean 0 and a standard deviation σ

Table 6: Parameters of mmW air ground model at 28 GHz

Sce	Env.	α	β	σ
Suburban	LOS	84.64	1.55	0.12
	NLOS	113.63	1.16	2.58
Urban	LOS	82.54	1.68	0.79
	NLOS	97.81	1.87	1.69
Dense Urban	LOS	78.58	1.85	0.49
	NLOS	98.05	1.86	0.59
High-rise	LOS	88.76	1.68	2.47
	NLOS	66.25	3.30	4.48

The LoS probability is defined in [100]as

$$p_{LoS}(\gamma) = \prod_{n=0}^{\max(0,\gamma(r))} 1 - \exp\left(-\frac{\left(\gamma(r)\max(h_t,h_r) - \left(n+\frac{1}{2}\right)|h_t - h_r|\right)^2}{2\varepsilon^2\gamma(r)^2}\right)$$

Where $\gamma(r) = \lfloor r\sqrt{\alpha_0\beta_0} \rfloor$ represent the mean number of buildings crossed for a distance r in m with α_0 and β_0 given in Table 2.
ε represent height of each obstacle following a Rayleigh distribution (equal to 20m in [100]).
h_t is the height of the transmitter and h_r the height of the receiver.

Ground-to-ground mmW/sub 6Ghz

The path loss model can be defined as follows:

$PL(d) = 10\alpha\log_{10}(d) + \beta + 10\gamma\log_{10}(f) + \chi$

Where d is the distance between the transmitter and the receiver, f the carrier frequency, χ_σ describing the shadowing effect.

The pathloss parameters are given in [98] for urban micro base station (UMi) and urban macro base station(UMa) for frequencies from 2 GHz to 73.5 GHz ,distance from 19m to 121m for UMi and from 58m to 930m for Uma

Table 7: Parameters of mmW ground model in urban

Scenario	Env.	α		β		γ		σ	
Urban		UMi	UMa	UMi	UMa	UMi	UMa	UMi	UMa
	LoS	2	2.8	31.4	11.4	2.1	2.3	2.9	4.1
	NLoS	3.5	3.3	24.4	17.6	1.9	2	8	9.9

For a dense urban scenario and mmW, [99] gives this pathloss model :

$PL = \alpha + 10\beta\log_{10} d + \xi$ with $\xi \sim \mathcal{N}(0,\sigma^2)$ representing the shadowing effect

The LOS probability is defined in [99] as

$p_{Los}(d) = e^{-a_{Los}d}$ With $a_{Los} = 0.0149m^{-1}$

Table 8: Parameters of mmW ground model in dense urban

Dense Urban	α		β		σ	
28 GHz	LoS	NLoS	LoS	NLoS	LoS	NLoS
	61.4	72	2	2.92	5.8	8.7
75 GHz	LoS	NLoS	LoS	NLoS	LoS	NLoS
	69.8	86.6	2	2.45	5.8	8

3.4 Performance indicators

The main requirements of DEDICAT use scenarios have been analyzed in D2.1 and D2.2 (D2.1 2021, D2.2 2021). A number of different key performance indicators (KPIs) can be used to evaluate and optimize these use scenarios enabled via wireless networks. Some KPIs focus on measuring single user satisfactory while other KPIs are meant for designing networks from overall network optimization point of view. The KPIs may be defined qualitatively or quantitatively. Given a number of possible KPIs to be taken simultaneously into account, the optimization problem typically involves multiple objectives which may be conflicting, i.e., improving one objective impairs another objective. Then different objectives may have different prioritizations or weights, depending on the optimization target at hand.

The relevant KPIs introduced by ITU-R for **5G systems** [104] and their minimum requirements for the relevant scenarios (i.e., eMBB, URLLC, mMTC) are shortly summarized as follows:

- Rate related KPIs:
  - Peak data rate in bit/s: 20 Gbit/s (DL); 10 Gbit/s (UL);
  - Minimum user data rate (5th percentile) in bit/s: 100 Mbit/s (DL); 50 Mbit/s (UL);
  - Peak spectral efficiency in bit/s/Hz: 30 bit/s/Hz (DL); 15 bit/s/Hz (UL);
  - Minimum user spectral efficiency (5th percentile) in bit/s/Hz: 0.12-0.3 bit/s/Hz (DL); 0.045-0.21 bit/s/Hz (UL);
  - Average spectral efficiency in bit/s/Hz: 3.3-9 bit/s/Hz (DL); 1.6-6.75 bit/s/Hz (UL);
  - Area traffic capacity in Mbit/s/m^2: 10 Mbit/s/m^2 (DL);
  - Bandwidth in MHz: 100 MHz.
- Latency related KPIs
  - User plane latency in ms: 1-4 ms;
  - Control plane latency in ms: 10-20 ms.
- Mobility related KPIs
  - Maximum speed in km/h: 500 km/h
  - Mobility interruption time in ms: 0 ms
- Connection density in #devices/km^2: 1M devices/km^2;
- Energy efficiency (metric not explicitly defined by ITU-R; typically bit/J is used);
- Reliability in packet success probability: $1\text{-}10^{-5}$.

It is emphasized that only a target subset of KPIs should be attained simultaneously depending on the selected scenario. The above KPIs are still valid for 6G but with significantly (typically 1-2 orders of magnitude) higher expectations on the quantitative minimum targets. Moreover, there are several additional KPIs that have been proposed for **6G systems** on top of that of 5G. Some examples include [105][106]:

- Positioning accuracy: Allow positioning in cm level;

- 3D coverage: Transform from 2D terrestrial coverage notations into 3D non-terrestrial coverage;
- Timeliness: Transform from memoryless latency metrics into freshness of latest data regarding its birth-time;
- Security: Include and quantify security and privacy performance more explicitly. E.g. percentage of security threats that are identified by the system;
- Expenditure: Include minimization of capital and operational expenditures more deeply into network design;
- Flexibility: Flexible use of all network resources (physical/virtual);
- Programmability: Customization of air interfaces on the fly;
- Versatility: Allow a number of different kind of tasks to be performed simultaneously (e.g. joint sensing and communications);
- Sustainability: In addition to minimization of energy and resource consumption, reduce emissions and enhance social aspects holistically (Cf. sustainable development goals of UN);
- Scalability: The network performance ultimately becomes independent on number of users requesting service;
- Mission completion time: In some emerging technologies, such as AMAP, the remaining operation time becomes an important performance metric.

Since the main focus of this deliverable is on network coverage extension, in the following, we elaborate a bit more on different coverage viewpoints as a performance measure in practice [102][103].
In general, there are a multitude of definitions used for the **network coverage**. The coverage can be divided into i) signal detectability and ii) ensuring sufficient SINR for the target service quality. One of the most common usages is the coverage area of a single base station. Instead of directly measuring an area metric, deterministic limiting value of an allowable coupling path loss or minimum SINR operating point between a transmitter and received for which a service is still in coverage are typically used. The SINR operating point is associated with an error rate target that satisfies the reliability needs of a service. In addition to these link-level deterministic measures, the coverage can be evaluated by estimating cumulative distribution functions over the network with given percentile. While the mean throughput can give the expected throughput in average, the percentiles of the *Cumulated Distribution Function (CDF)* provide information about expected minimum throughput with certain probability. Other probabilistic metrics include outage and coverage probabilities where random phenomena are averaged out to obtain inference how the system is able to provide coverage over time and spatial domains. A summary of different performance metrics related to coverage is provided in Table 9.

Table 9: Overview of different performance metrics related to coverage

Coverage metric	Definition	Comments
Maximum coupling loss	Difference between TX power and RX sensitivity	Coverage at link level; typical target is 140-160 dB
Maximum path loss	Difference between EIRP and RX power	Coverage at link level; includes antenna gains
Minimum SINR operating point	Ratio of signal power and noise+interference power	Coverage at link level; includes error rate target
Pilot signal coverage	Pilot signal strength is above a given threshold for signal detectability	Coverage at link level; besides SINR, also signal strength must be sufficient for signal detectability
5^{th}-percentile of SINR cdf	The *p*th percentile is the point where the cdf reaches p/100	Coverage at network level; SINR can be replaced e.g., by spectral efficiency.

Outage/coverage probability	Probability that SINR is below/above a threshold	Coverage at either at link level or network level; a probabilistic measure averaging temporally and/or spatially
Voice service coverage	Complete a voice call during x s without interruptions	User experience oriented metric; typically, x = 90 s; operation point can be different in indoor/outdoor
Data service coverage	User has coverage if wireless device enables at least x Mbit/s rate	User experience oriented metric; typically, x = 2 Mbit/s; operation point can be different in indoor/outdoor
Radio access bearer retainability	Ratio of normally terminated connections over the total number of connections	Indirect measure of coverage
Handover success rate	Relative number of successfully executed handovers	Indirect measure of dynamic coverage
k-coverage	A location is reached by at least *k* network nodes	Coverage measure that is important for multi-connectivity or multi-sensoring network

More specifically, DEDICAT 6G will evaluate the performance in terms of metrics defined in Table 10

Table 10: Overview of the selected performance metrics for coverage extension evaluation

metric	Definition	Comments
Number of Users	Number of detected user equipment inside the network	Real-Time centralized performance.
Ratio of well-deserved user	Number of users with their traffic demand satisfied	Real-time centralized performance
Coverage	Total covered space by the network	Real-time centralized performance for simulations
Number of MAPs supported	Number of well managed MAPs inside the network	Experimental performance
Fast response time	Time for MAPs to make its action depending on the decision	Experimental distributed performance
Time of infrastructure deployment	Total time to deploy and configure x MAPs	Centralized performance
End-to-end latency	Time for a MAP to receive a response from the service	Centralized performance
Reliability	Proportion of successfully distributed data	Experimental performance
Availability	Proportion of time the network can ensure the service	Experimental performance
Throughput	Amount of successfully distributed data in Mbit/s	Real time performance
QoS satisfaction level	Proportion of supported data rate compared to required rate	Centralized performance
Fairness	For multiple UEs, Indication to what extent each user gets a share of the available resources in proportion to its traffic requirements	Centralized performance or Experimental distributed performance
Power consumption	Energy used to maintain the network	Real-time centralized performance
Power efficiency	The ratio of consumed	Real-time centralized per-

	transmit power over attainable data rate	formance
Spectrum occupancy	Percentage of the considered spectrum occupied during a specific time unit	Experimental distributed performance
Resource allocation efficiency	The ratio between the allocated resources and the total available resources	Experimental distributed performance
Cost	Quantity of resource used to process a MAP action	Decentralized performance
Complexity	Number of operations to manage x MAP	Offline performance for simulations

4 Strategies for dynamic coverage and connectivity extension and preliminary implementation

This section presents the different strategies for dynamic coverage and connectivity extension investigated in DEDICAT 6G and their preliminary implementation:

- Strategies to deploy and manage UAVs, cars and robots;
- Strategy to associate users to MAPs;
- Strategy for counting people with IoT devices;
- Strategy for edge Mission Critical Services;
- Strategy for enhanced experience of temporary events;
- Strategy for smart Highway to track vulnerable road users with RSUs.

4.1 Strategy to deploy UAVs

In this section, we investigate complex optimization problem aiming to decide on the deployment of MAPs to ensure connectivity of the appropriate QoS to mobile nodes. Our objective is to find (i) the optimal number of MAP entities to deploy, (ii) the optimal positions of MAPs in continuous space, (iii) the configuration of the radio network of the MAP entities and (iv) the dynamic association of multiple users to multiple access points (fixed or moving).

4.1.1 Problem formulation

We consider a communication network where $\mathcal{M}$ mobile access points (MAP), e.g. unnamed aerial vehicles (UAVs), are jointly deployed with $\mathcal{G}$ grounded access points (GAP) to provide ubiquitous coverage to $\mathcal{U}$ user equipments (UEs). Let $\mathcal{A} = \mathcal{G} \cup \mathcal{M}$ the set of all *Access Points (AP)* (including the MAPs and GAPs) in the network.

In this network, we are interested in the optimization of the localization and the number of MAPs to deploy. In this context, let $\mathcal{L} = \{0, \dots, L\}$ denote the set of all possible location of MAPs, and $\mathcal{L}_i(t) \subset \mathcal{L}$ the set of all possible location of MAP i at time t. This set may vary depending on the mobility constraint in the network. Let $l_{i,k}(t)$ be the binary location variable, which equal to 1 when the MAP i is at the location k.

In the presented model, every UE has a multi-radio access technology and can receive signals from multiple APs. Let $x_{i,j}(t)$ be the binary association variable, which equals 1 if the UE j is associated to an AP $i \in \mathcal{A}$ at time t. To evaluate UE performances, Let $\kappa_{i,j}(t) = \min(1, \frac{R_{i,j}(t)}{D_j(t)})$ the ratio, as the QoS satisfaction of UE j where $R_{i,j}(t)$ is the achievable communication rate between the UE j and the AP i and $D_j(t)$ the traffic request of the UE j. We can also define the sum rate of the network as : $S(t) = \sum_{i \in \mathcal{G}} \sum_{j \in \mathcal{U}} \min(R_{i,j}(t), D_j(t))$

Accordingly, the MAP placement optimization problem can be formulated as follows:

$$minimize \sum_{k \in \mathcal{L}} l_{i,k}\,, \ \forall i \in \mathcal{A} \qquad (1)$$

$$subject\ to\ x_{i,j}, l_{i,k} \in \{0,1\} \qquad (1.1)$$

$$\sum_{j \in \mathcal{U}} x_{i,j} \leq N_i\,, \forall i \in \mathcal{A} \qquad (1.2)$$

$$\sum_{i \in \mathcal{A}} x_{i,j} \leq 1\,, \forall j \in \mathcal{U} \qquad (1.3)$$

$$\sum_{k \in \mathcal{L}_i(t)} l_{i,k}(t) \leq 1\,, \ \forall i \in \mathcal{M} \qquad (1.4)$$

$$\mathcal{L}_i(t) \subset \mathcal{L} \quad (1.5)$$

$$\frac{1}{U}\sum_{i \in \mathcal{U}} \kappa_{i,j} \geq Q \quad (1.6)$$

The constraint (1.1) defines $x_{i,j}$ and $l_{i,k}$as binary variables. The constraint (1.2) ensures that a given access point i can connect at most N_i UE at the same time. The constraint (1.3) indicates that each UE is associated with exactly one BS. Concerning the MAP positioning, the constraint (1.4) indicates that every MAP can only take one location at the same time and the constraint (1.5) define the set of possible location for the MAP i. The constraint (1.6) ensures a satisfying ratio in term of quality of service with a minimum of well-deserved UE.

The objective function (1) represents the number of deployed MAP inside the network and gives their current location. The set of position $\mathcal{L}$ is an assumption of the space discretization. We can assume that these positions are defined as "safe" location for MAP where their contribution can be the higher, e.g., in the middle of a crossroad or above a stadium.

4.1.2 Problem Approach

With the space divided to predefined positions, the proposed mechanism will have to test and find the best deployment, meaning the set of position that ensure a given quality of service level with a minimum amount of MAP. However, as MAP have a limited coverage range, e.g., due to millimeter-wave communication constraints, the number of predefined combinations is growing quickly.

Exhaustive approach

A first approach could be to test every combination over possible one, but it leads to unrealistic time of computing with gigantic amount of try ($2^{Number\ of\ position)}$). Our proposed methods tries to reduce the set of tested combination and then reduce complexity.

Discrete Monte Carlo Method (DMC)

In that approach, we give each position k a probability p_k to be selected by a MAP and then considered as deployed on the cell. Each iteration, each position does a Bernoulli trial and in case of success, a MAP takes the position. Moreover, p_k is sweeping from 0 to 1 with a step of $\frac{1}{number\_of\_position}$. Then each iteration, the network tries a deployment with one more MAP, on average. This procedure is repeated over E episodes. The algorithm is testing a subset of positions among all the possibilities then reducing the number of deployments to $C = E \times L$.

Scored Iterative Monte Carlo based algorithm (SIMBA)

This method is an extension of the DMC approach. The cell is still divided on a given number of positions. Each position has a probability p_k to be selected by one MAP and has a score. Each time a MAP takes the position, it updates the associated score for the position k defined as:

$S_k(t) = \frac{1}{UT}\sum_{t=0}^{T}\sum_{j \subset \mathcal{U}_k,} sgn(R_{i,j} - D_j) \times \log_{10}(|R_{i,j} - D_j|)$ where $U = card(\mathcal{U}_k)$ is the number of users covered by a MAP at the position k.

The score represents the gain to deploy a MAP at the corresponding position. The more the MAP contributes to the network, the higher the score. If UEs are not well deserved with a MAP deployed, the score will be negative.

For a given number of iterations, given by the p_k array, every position updates its score. With the episode ending, it chooses the position with the highest score and fixes a MAP at this position, resetting all the scores. The deployed MAP is fixed meaning that on every following deployment, this MAP will be active and placed at this position. This approach is finding sub-optimal deployment of $N + 1$ MAP knowing N MAP creating the iterative behavior.

4.1.3 Preliminary results

To achieve a better overview and clear vision of methods and approaches, we computed a strict comparison between methods developed above, on a small-scale dimension first:

Table 11: Simulation parameters for small scale scenario

Cell Dimension	100m x 100m
UE deployment	Uniform
Number of UEs	25
UE mobility	Random
UAV Positions	[0,16]
Number of GAPs	1 macro base station
AP Capabilities	UAV: 10 connections max
UE association	Max SNR Heuristic
Iterations	20
QoS Threshold	Ratio ≥ 1

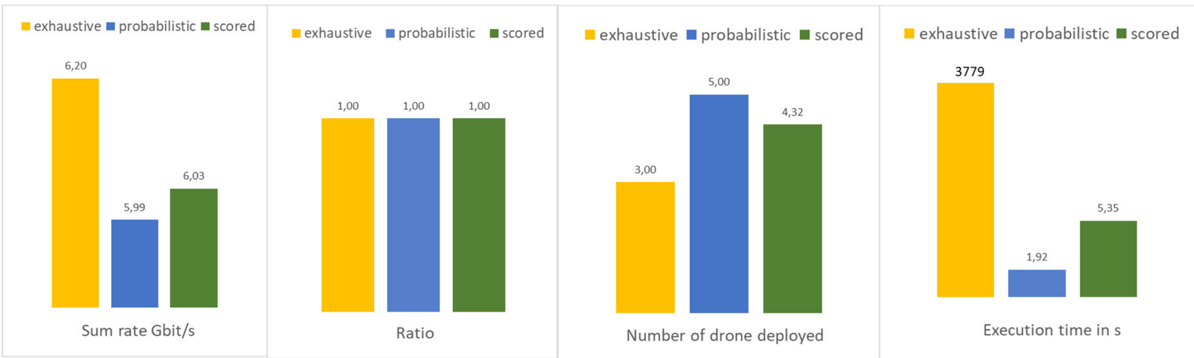


Figure 24: Comparison between methods in terms of sum rate, ratio, number of drones to deploy and time to deploy

To begin, in terms of sum rate, three methods are on the same scale, really close to each other (5% variation) and allow all methods to have a close optimal deployment in terms of quality of service. The exhaustive will give the upper bound with high execution time cost. This data can be coupled with the ratio's deployment which leads to performant results with always a ratio equal to one. Nevertheless, it's important to remind that the simulation takes place on a small scale area and small variation in terms of data requirement, positions, etc. can lead to big differences as seen in the number of drones. A single MAP can be deployed to cover only all UEs and then achieving a ratio of 1.

In this case, the number of MAPs to deploy is smaller for the score than the probabilistic. This behavior traduces the necessity to make a choice depending on the cell's configuration. In fact, in terms of time to deploy, the probabilistic approach leads the comparison. The main objective by introducing a score is to easily focus on more promising position in terms of sum rate and reduce the possibilities of deployed MAP on a bad position. This add gives a more efficient deployment in term of deployed MAPs.

The next step is to compare methods for larger simulation in terms of UE and positions. For these approaches, the exhaustive cannot be computed anymore due to the number of combinations.

Table 12: Simulation parameters for large scale scenario

Cell Dimension	100m x 100m
UE deployment	Uniform
Number of UEs	100
UE mobility	Random
UAV Positions	[0,100]
Number of GAPs	1 macro base station
AP Capabilities	UAV: 10 connections max
UE association	Max SNR Heuristic
Iterations	20
QoS Threshold	Ratio ≥ 0.95

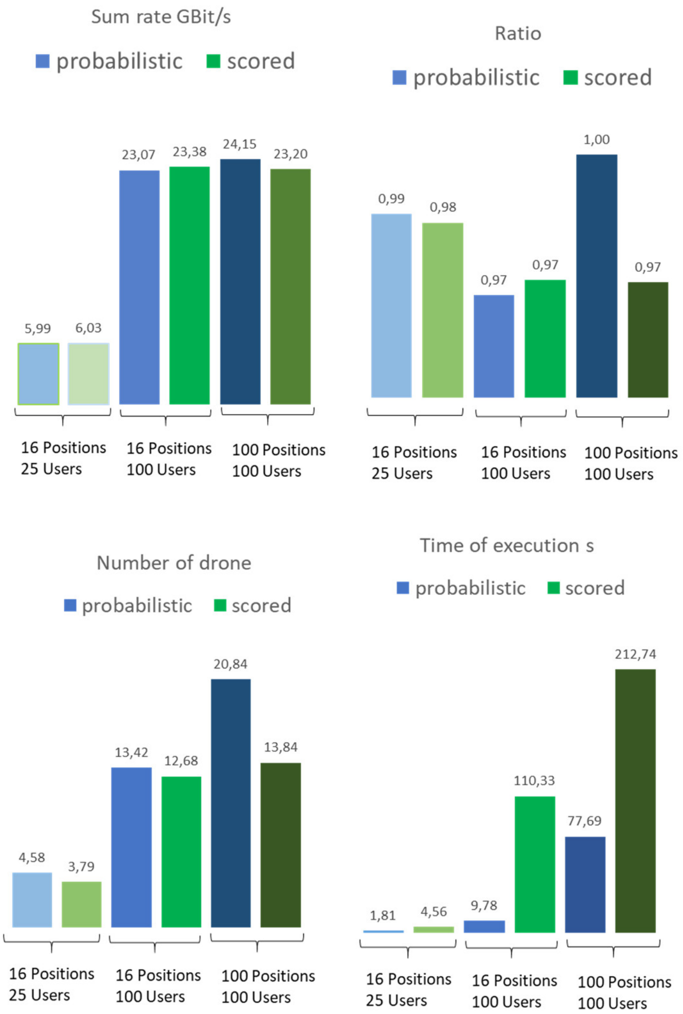


Figure 25: Comparison between DMC and SIMBA

In this comparison, we're studying three types of scenarios during 20 deployments. The first case is the small scale studied previously (case 1), then we increase the number of UE (case 2) and finally the number of positions (case 3). It allows us to see the impact of the number of UE on the methods and the number of points on the grid for the drone deployment.

In terms of coverage extension performance, with a mean on the sum rate and the ratio, the scored method and the probabilistic methods are similar. Besides, by multiplying the number of UE by 2.5, the sum rates have been multiplied by 3.8 demonstrating the sum rate optimization of the association. With more UE, it has more handover and association to optimize.

The main difference is on the number of deployed MAP and the time to deploy them. By multiplying the number of positions by 4, the probabilistic takes 8 times more to compute, with 2 times more for the scored. Moreover, the number of MAP deployed is conserved with the scored approach with nearly 13 deployed.

4.1.4 Future Work

For the future steps, we will continue to work on the computational complexity with AI mechanism for the user association. In fact, these mechanisms have a key role due to the inter-dependency of the MAP position and the association. A MAP needs to predict how users will be associate to know its efficiency and the user association algorithm needs to know the location of MAPs to compute the best candidate. That's why cross-optimization solutions will be studied.

The considered optimizations will be extended to a multi-connectivity context where AP can provide sub-6GHz or millimeter wave connection and MAP are connected with wireless backhaul links with associated models.

Another key aspect is the introduction of the move cost. Different cost depending on the KPIs and way to optimize it, will be defined depending on the scenario. In fact, we need to take into account the MAPs energy consumption, the non-coverage time while the MAP is moving and the predefined trajectories of map. On a connected car context, if the map leaves its predefined path, it implies higher cost than locations on its planned trajectory.

4.2 Strategy to manage MAPs

4.2.1 Problem Statement

A remote area where deployed, wireless infrastructure is not widely available will be considered. The area shall comprise network entities, i.e., the moving access points (MAPs) and the APs that offer access to remote users. In addition, it will be assumed that users require services at specific QoS levels (e.g., in terms of bitrate, latency, etc.), while a capacity (e.g., in terms of bitrate, number of users that can be served) and a transmission range based on standardized propagation models will be assigned to the MAPs and the fixed access points.

4.2.2 Problem formulation

Let M be the set of the MAP entities, A will be the set of the APs, while U will denote the set of users (with mobile clients) and D will be the set of docking stations e.g., for charging drones. In addition, L will denote the set of the locations at which the network elements (MAPs, APs) can be placed, while $e(i)$ will depict the element that is located at $i \in L$. Also, each MAP $m \in M$ has a capacity cap_m. Capacity can reflect for instance the number of users that are served by a specific MAP. In order to avoid congestion issues (e.g., a lot of users are served at the same time by one only MAP), we can set low values of capacity to MAPs.

Moreover, the following decision variables are considered :

$$X_{m,i} = \begin{cases} 1, if\ MAP\ m \in M\ is\ located\ in\ i \in L \\ 0, otherwise \end{cases}$$

$$Y_{m,n} = \begin{cases} 1, if\ MAP\ m \in M\ is\ connected\ with\ MAP\ n \in M \\ 0, otherwise \end{cases}$$

$$Z_{u,m} = \begin{cases} 1, if\ user\ u \in U\ is\ connected\ with\ MAP\ m \in M \\ 0, otherwise \end{cases}$$

$$Q_{m,a} = \begin{cases} 1, if\ MAP\ m \in M\ is\ connected\ with\ AP\ a \in A \\ 0, otherwise \end{cases}$$

$$D_{m,d} = \begin{cases} 1, if\ drone\ or\ MAP\ m \in M\ is\ connected\ with\ docking\ station\ d \in D \\ 0, otherwise \end{cases}$$

Furthermore, the connection of two entities (e.g., when two MAPs are connected, when a MAP is connected to an AP, or when a MAP serves a user) results in a communication cost ct. In general, this cost depends on the frequency used for the communication and the distance of the entities. As a result, ct values can be high for entities that are far away between each other, in order to let the algorithm determine closer entities (if available). Also, the movement of drone/MAP to a docking station for charging results in a moving cost mc. In general, this cost depends on the distance of the drone/MAP from the current position to the docking station.

Accordingly, the overall optimization problem can be formulated as follows:

$$minimize\ OF = \sum_{m\in M}\sum_{i\in L}\left(X_{m,i} * ct(m,i)\right) + \sum_{m\in M}\sum_{n\in M} Y_{m,n} * ct(m,n)) + \sum_{m\in M}\sum_{u\in U}(Z_{u,m} * ct(m,u)) + \sum_{m\in M}\sum_{a\in A}(Q_{m,a} * ct(m,a)) + \sum_{m\in M}\sum_{d\in D}(D_{m,d} * mc(m,d))$$

Constraints:

$$\sum_{i\in L} X_{m,i} = 1, \forall\ m \in M$$

$$\sum_{m\in M} X_{m,i} \leq 1, \forall\ i \in L$$

$$\sum_{n\in M} Y_{m,n} \geq 1, \forall\ m \in M$$

$$\sum_{m\in M} Q_{m,a} \geq 1, \forall\ a \in A$$

$$\sum_{m\in M} Z_{u,m} = 1\ , \forall\ u \in D$$

$$\sum_{m\in M} D_{m,d} = 1, \forall\ d \in D$$

$$\Phi_m \leq cap_m, \forall m \in M$$

Where

$$\Phi_m = \sum_{u\in U} Z_{u,m} + \sum_{n\in M}\left(Y_{m,n} * \Phi_n\right), \forall m \in M$$

The *Objective Function (OF)* in (6) monitors the location of all MAPs and calculates the total communication costs that are related from these locations, as well as the finding of the nearest docking station for charging (of drone MAPs). The first term of the function illustrates the communication cost related to the MAPs location. The second term depicts the communication cost due to the connections among MAPs. The third term denotes the communication cost because of the connections among users and MAPs. The fourth term depicts the communication cost of the connections of the MAPs with the APs. The fifth term depicts the cost related to the docking station where the drones should go for charging.

Regarding the constraints, the first constraint denotes that every MAP can be placed at one only location. The second constraint denotes that at each location one MAP at most can be placed. The third constraint depicts that every MAP should be connected with at least another MAP (in order to realize the opportunistic network). The fourth constraint denotes that all APs should be connected with at least one MAP and the fifth constraint denotes the fact that each user can be served by one only MAP at a time. The sixth constraint denotes that each docking station can serve one drone/MAP at a time. Also, φ_m represents the MAP's load which cannot exceed its capacity cap_m.

4.2.3 Execution environment/Deployment options

Architecture Perspective

Based on the Architecture which was defined in D2.2, an optimization algorithm will be implemented. More specifically, the algorithm will be the core logic of the *Coverage Extension DM (CEDM)* FC, one of the three FCs of the Decision Making FG. As it has already been mentioned, CEDM will receive information from the Context-Awareness FG and based on the system-context of that particular time, it will try to produce the most optimal configuration of the radio network of the MAP entities. The aforementioned will take place, always, with respect to the QoS levels. After the optimal solution has been found, the CEDM will construct an appropriate CEDM-based message for the Service Operation FG, which will trigger the actual systems entities to do a specific task.

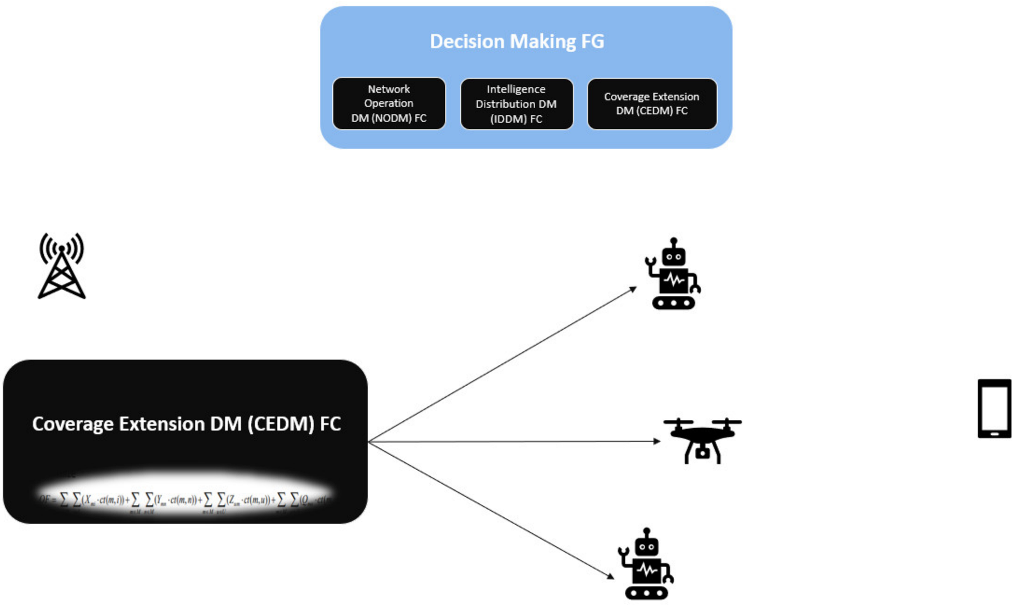


Figure 26: Drones/Robots scenario

Software

Python-MIP package (https://www.python-mip.com/) will be used in order to solve the Coverage Extension optimization problem. Python-MIP is a collection of Python tools for the modeling and solution of Mixed-Integer Linear Programs. Its syntax was inspired by Pulp (linear programming modeler written in Python), but the package also provides access to advanced solver features like cut generation, lazy constraints, MILP starts and solution pools.

4.3 Strategy to manage vehicular based MAPs

Within DEDICAT 6G, vehicles acting as MAPs that offer multi-RAT capabilities are investigated. Efficient RAT selection and configuration schemes are needed to satisfy the application requirements, achieving the targeted coverage and QoS, as well as enabling harmless coexistence and protecting incumbent technologies.

Multiple RAT technologies can be used for the deployment of vehicular based MAPs including LTE, 5G-NR, and Wi-Fi. Towards 6G, it is envisioned that spectrum management and utilization will become more flexible and dynamic compared to today's static and conservative approaches. Hence, a RAT might be able to operate in any frequency band (as long as this is supported by the frontend and allowed by the regulators) offering coexistence with other technologies and protecting potential incumbents. For our proof of concept and without loss of generality, we assume that the MAPs operate in any channel of the 5.9 GHz ITS band, in which short-range V2X communications take place today. As such, the deployed MAPs should be able to coexist with other MAPs operating in those channels based on LTE, 5G-NR, Wi-Fi technologies, and protect transmissions from incumbents such as C-V2X PC5, and ITS-G5.

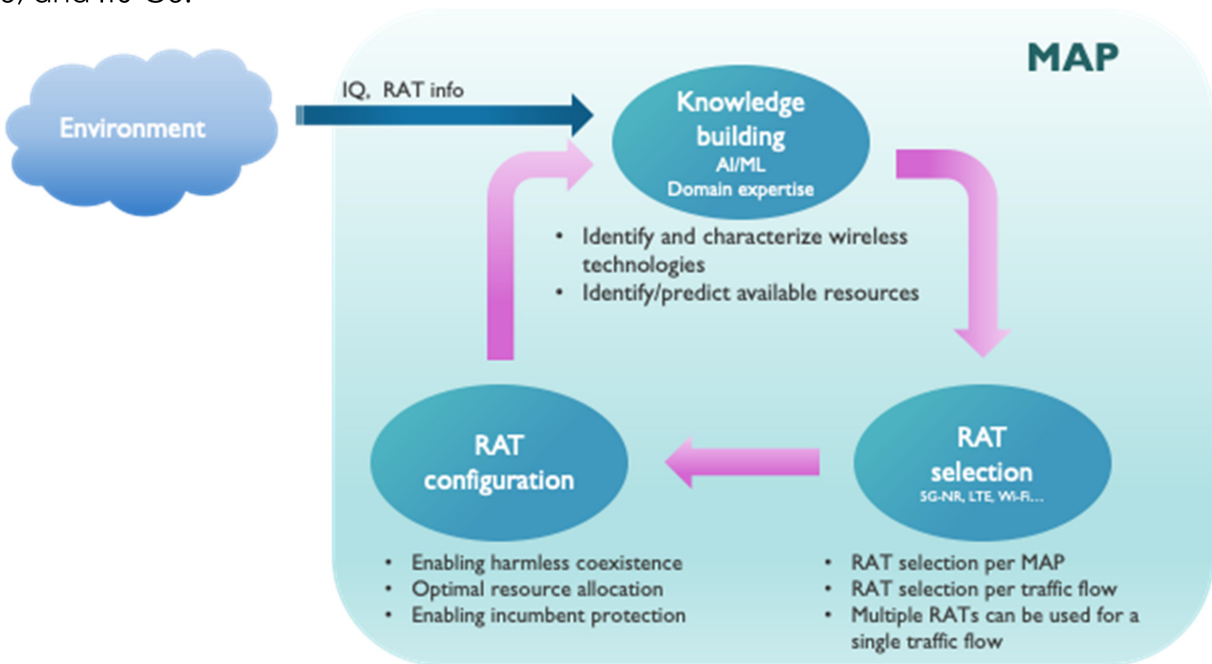


Figure 27: Vehicular MAP management procedures

Figure 27 shows the main procedures for the management and configuration of vehicular based MAPs. Initially, the *Knowledge Building* process takes place aiming to estimate the characteristics of the wireless environment. In this phase, active wireless technologies are identified and characterized. The traffic demands of the technologies and the available resources may also be predicted in this phase. The techniques used in the knowledge building phase will be implemented using machine learning and domain expertise-based solutions. After the identification of the wireless environment, the *RAT Selection* process follows. In this phase, a newly activated MAP will select a specific RAT based on several factors such as the capabilities of the MAP, the traffic demands of the applications/services and the identified characteristics of the wireless environment. Once a newly activated MAP selects the proper RAT(s), the *RAT Configuration* phase proceeds. In this phase, the main aim is to optimize the selection and management of the available wireless resources in order to provide harmless coexistence, incumbent protection and increase the overall performance of the MAP. As both the application requirements and the wireless environment change dynamically in time, the described process will be repeated periodically.

4.3.1 Knowledge Building

Knowledge building is important for the deployment and operation of the MAPs as it derives information about the wireless environment that can be used for the RAT selection and configuration, as well as for enabling coexistence and incumbent protection. Initially, AI/ML and/or domain expertise techniques can be used for the identification and characterization of the wireless technologies operating in the considered frequency domain.

For the technology recognition process, CNNs will be used to develop a machine learning based solution used to facilitate the detection and identification of frequency and time domain signatures for the considered technologies. In DEDICAT 6G, we assume that the MAPs can be deployed and operate in any channel of the 5.9 GHz ITS band. As such, the deployed MAPs should be able to identify other RATs operating in those channels and protect transmissions from incumbent technologies such as C-V2X PC5 and ITS-G5. Therefore, the technology recognition model implemented on the MAPs should be able to identify all possible co-located technologies such as LTE, 5G-NR, Wi-Fi, C-V2X PC5 and ITS-G5.

For training and validating the technology recognition model, the permanent setup of the Smart Highway testbed will be used. IQ samples of each technology and all possible overlapping transmissions will be collected over the air and labelled properly with the corresponding wireless technologies. Consecutively, these labelled IQ samples will be fed into the CNN model.

After the CNN is trained and validated, it will be capable to characterize in real-time the co-located technologies across all the channels of the entire ITS 5.9 GHz band. The results obtained from the technology recognition process will be used to determine several characteristics of the wireless environment such as the type of technology (e.g. C-V2X PC5, ITS-G5, 5G-NR, LTE, Wi-Fi, overlapping transmissions), channel occupancy, transmission pattern (e.g. for C-V2X PC5), interframe interval (e.g. for ITS-G5), frame duration of the technologies, saturation status (e.g. for Wi-Fi). Based on the collected information, the traffic demand of the active technologies and available resources may be estimated. The vehicular MAP will exploit the derived information from the wireless environment in the RAT selection and RAT configuration phase.

4.3.2 RAT Selection

When a MAP is initialized, it should try to avoid an occupied channel and operate in an empty one. If this is not possible, then it should use the less busy channel, providing coexistence to other MAPs and, if required, incumbent protection to C-V2X PC5 and ITS-G5. As shown in Figure 27, the RAT selection process is made based on the *Knowledge Building* phase In the RAT selection process, the traffic demands of the applications/services, and the identified characteristics of the wireless environment are considered as main decision-making factors. As the RAT selection is executed by the MAP, the traffic demands of applications/services associated with the MAP can be used in the decision-making scheme directly. However, the RAT selection process must consider other RATs within the MAP's coverage, potentially used by other co-located vehicles, roadside infrastructure, wireless local area networks, private networks, etc. For this reason, a MAP should be capable to select a RAT based on the information obtained in the knowledge building phase. In this direction, DEDICAT 6G aims to implement efficient RAT selection schemes using the information collected in the knowledge building phase.

A newly activated MAP selects the most suitable RAT(s) based on the RAT selection scheme, which considers the characteristics of the wireless environment obtained in the knowledge building. From the information collected in the technology recognition and characterization process, a newly activated MAP will be able to determine the type of active co-located wireless technology and estimate their corresponding traffic load and transmission pattern. The RAT selection process will also consider the traffic load of the newly activated MAP itself and the available resource based on the information derived from the knowledge-building process. Generally, the main goal of the RAT selection scheme used by a newly activated MAP is to select a RAT that leads to harmonious coexistence with the other active transmissions while guaranteeing the required quality of service.

It is known that the traffic load and the characteristics of wireless networks change dynamically. A group of MAPs can activate their RATs based on the statistics obtained during the RAT activation. However, the traffic load of each MAP can arbitrarily change after some time leading to inefficient resource utilization and higher interference. In such scenarios, load-balancing through multiple RATs can be used to improve the quality of service. Therefore, the RAT selection process is performed continuously to adapt to the traffic load of the host MAP and the available wireless resources.

On the other hand, a MAP can have traffic contents that require higher reliability. Hence, multiple RATs can be used by a MAP for redundant transmissions on a traffic flow basis. Such redundant transmissions can be triggered based on signal quality indicators used in different RATs of a MAP. Once the need for redundant transmission is determined for a traffic flow, the MAP can activate a new RAT enhancing the redundancy of that traffic flow.

In general, the activated RATs then can be used in different ways to serve the applications. For instance, a single RAT can be used for a specific MAP, a RAT can be selected per traffic flow or multiple RATs can be used for a single traffic flow for redundancy or optimization purposes. For instance, some technologies such as LTE/5G-NR can be selected when no or little other traffic is identified, while Wi-Fi could be a better choice in more busy channels because of its inherent coexistence mechanisms (CSMA/CA, LBT).

4.3.3 RAT Configuration

Once a MAP selects the proper RATs it will operate, the RAT Configuration phase proceeds. In this phase, the main aim is to optimize resource selection targeting harmless coexistence, incumbent protection, and increased overall performance of the MAP. Similar to the RAT selection process, the RAT configuration process is also based on the statistics collected in the knowledge building phase. The RAT configuration scheme will be implemented in such a way that the MAP uses transmission patterns that lead to optimal resources utilization while maintaining harmonious coexistence with other wireless technologies.

In the RAT selection process, the best RATs will be selected based on the traffic load of the MAP and the information collected from the environment. However, the selected RATs must be configured properly to achieve optimal resource utilization, while maintaining harmonious coexistence with other co-located transmissions. The RAT configuration scheme considers the wireless environment characteristics gathered during knowledge building and the traffic characteristics of the active RATs in the host MAP.

When a new MAP is activated, it selects appropriate RATs, and the selected RATs are configured optimally. Once the RATs are optimally configured, they will be activated. However, the traffic load of each MAP will change over time. Hence, the RAT configuration scheme is executed continuously so that the MAP constantly reconfigures the resources and transmission patterns of the active RATs.

4.3.4 Preliminary implementation

In our previous work [49], a CNN-based model is used to perform the identification of co-located Wi-Fi and LTE transmissions. The model is validated using commercial off-the-shelf LTE and Wi-Fi hardware equipment and it can identify the duration of each transmitted frame from each technology, the duration of idle slots as well as collisions between multiple concurrent transmissions. Furthermore, we have extended this CNN based technology classification model to develop coexistence schemes between private LTE and Wi-Fi [70]. This coexistence schemes use channel occupancy time to estimate the Wi-Fi traffic and select optimal transmission time of LTE and Wi-Fi.

In DEDICAT 6G we aim to develop a technology recognition system that can identify all possible technologies at 5.9 GHz ITS band. Hence, our CNN model used to classify LTE and Wi-Fi transmissions will be extended to include the technologies in 5.9 GHz ITS band. In this direction, a Neural Network will be trained to identify C-V2X PC5, ITS-G5, LTE, 5G-NR and Wi-Fi transmissions. IQ sampling through SDR will be used as input initially for training of the Neural Network and later for real-time identification and characterization of the co-located wireless technologies. As an initial step, we have started the IQ sample collection by generating ITS-G5 and C-V2X PC5 transmissions. The ITS-G5 and C-V2X PC5 transmissions are generated using the MK5 and MK6C commercial devices and CAMINO framework in our Smart Highway testbed.

4.4 Strategy to associate users to MAPs

4.4.1 Problem Statement

We consider a MAP-assisted wireless network to serve multiple users distributed in highly crowded areas with heavy traffic loads (e.g., outdoor social event). Users might watch videos that require high data rates throughout this event. Then, some of users in the network cannot be served by the ground conventional BS due to the wireless congestion or low channel quality. In this case, MAPs can be used as a temporary service provider for users. When multiple MAPs and BSs can provide the overlapped coverage, efficient user association, which is the mapping of UEs, and the most appropriate BSs becomes one of the key factors to impact the system performance. Particularly, when UEs are capable of multi-connectivity, a user association algorithm becomes more challenging. In this section, we study the user association algorithm to maximize the QoS satisfaction level required for UEs and the power efficiency of the network including MAPs operated with the limited battery power.

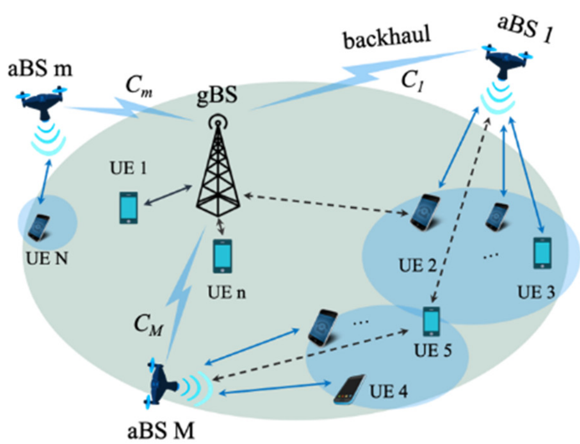


Figure 28: An example of a UAV-assisted wireless network

4.4.2 Problem Context Statement

As illustrated in Figure 28, a UAV-assisted wireless network is considered which one ground conventional BS (gBS) and multiple MAPs are included. Since UAVs are assumed to be capable of serving UEs as a temporary BSs in the air, UAVs functioning MAPs are represented as aerial BSs (aBSs) operated by limited battery power. Then the set of BSs is denoted as $\mathcal{M} = \{0,1,\dots,\mathrm{M}\}$ where the first element (BS 0) indicates the gBS and the rest M elements are aBSs. There is a set of users $N = \{0,1,\dots,\mathrm{N}\}$ in highly crowded areas and users are assumed stationary during short observation periods. When gBS cannot serve some of users due to traffic congestion or poor channel quality, aBSs can be temporary operated to serve users. For example, in Figure 28, UE 3 and 4 located at the cell-edge region of gBS would suffer from the low received signal quality. Then, deploying aBS 1 and M can serve UE 3 and 4 for high data rate communication. As the central authority, the gBS is assumed to regulate the positioning of the aBS m (x_m, y_m, h_m) for $1 \le \mathrm{m} \le \mathrm{M}$ so as to increase the data rate as well as the coverage extension. While each aBS has a dedicated backhaul link with the gBS, the backhaul capacity of aBS m, C_m is limited. For gBS, it is considered to have sufficient connection capacity with the communications infrastructure via fiber links which will not be congested [108].

For a given transmit power from BS m to user n p_{mn}, the pathloss ϕ_{mn} can be derived as explained in section 3.3.2, then the received signal strength at user n which is associated with BS m, γ_{mn} and the upper bound of achievable data rate for user n from BS m, R_{mn} can be calculated as follows.

$$\gamma_{mn} = \frac{\mathrm{p}_{mn}10^{-\phi_{mn}/10}}{\sigma_N^2}\ , \quad R_{mn} = W_m \log_2(1+\gamma_{mn}), \quad \text{for } \mathrm{m} \le \mathrm{M}, \mathrm{n} \le \mathrm{N}\ , \tag{1}$$

where σ_N^2 is the additional gaussian noise power and W_m denotes the channel bandwidth in MHz.

The total achievable rate of all users and the total transmit power of all BSs can be written as

$$R_\Sigma = \sum_{m=0}^{M}\sum_{n=1}^{N} \alpha_{mn} R_{mn}\ , \quad P_\Sigma = \sum_{m=0}^{M}\sum_{n=1}^{N} \alpha_{mn} p_{mn}, \tag{2}$$

respectively. The overall power efficiency of the network is defined by $\eta_{pe} = R_\Sigma / P_\Sigma$.

Application Utility Function

We consider utility functions incorporating required data rate to express the QoS satisfaction level. The application utility function of UE n wanting to receive the data rate R_n^{req} is represented by normalised sigmoidal-like function as follows [109].

$$\Phi_n(R_n) = \log\left(\frac{q_n}{1+e^{-c_n(R_n-e_n)}} - q_n k_n\right)\ , \quad \text{for } \mathrm{n} \le \mathrm{N} \tag{3}$$

where $c_n > 0$, $e_n = R_n^{req}$, $q_n = (1 + e^{c_n e_n})/e^{c_n e_n}$ and $k_n = 1/e^{c_n e_n}$. Let us form two vectors as follows.

$$\boldsymbol{\alpha_n} = [\alpha_{0n}, \alpha_{1n}, \cdots, \alpha_{mn}, \cdots, \alpha_{Mn}]^T, \quad \boldsymbol{R_n} = [\mathrm{R}_{0n}, \mathrm{R}_{1n}, \cdots, \mathrm{R}_{mn}, \cdots, \mathrm{R}_{Mn}]^T, \ \text{for n} \le \mathrm{N}, \tag{4}$$

where $\boldsymbol{\alpha_n}$ is the vector form of the binary user association variables and $\boldsymbol{R_n}$ represents the vectorized physical data rate. Then, the application utility function of UE n can be expressed as

$$\mathrm{U}_n(\boldsymbol{\alpha_n}) \triangleq \Phi_n(\mathbf{R_n}^T \cdot \boldsymbol{\alpha_n}), \ \text{for n} \le \mathrm{N}, \tag{5}$$

where $\mathbf{R_n}^T \cdot \boldsymbol{\alpha_n}$ stands for UE n's aggregated data rate over its connected BSs [110]. We can calculate the utility proportional fairness (UPF) value $\varphi_{ut} = \Sigma_n \log(\mathrm{U}_n(\boldsymbol{\alpha_n}))$.

4.4.3 Problem formulation

Since the goal of the resource allocation is to maximize the QoS satisfaction level and the energy efficiency by jointly optimizing user association and power allocation, the problem P is formulated along with the wireless backhaul link capacity constraint. Then, the problem P can be formulated as follows.

$$P: \max_{\alpha_{mn}, \mathrm{p}_{mn}} \{\varphi_{ut}, -\eta_{pe}\} \tag{6}$$

$$\text{s.t.} \sum_{n \le N} \alpha_{mn} p_{mn} \le P_m^{max}, \quad \forall\, m \le M, \tag{7}$$

$$\sum_{n \le N} \alpha_{mn} R_{mn} \le C_m, \quad \forall\, m \le M, \tag{8}$$

$$\sum_{m \le M} \alpha_{mn} \le q_n, \quad \forall\, n \le N, \tag{9}$$

$$\sum_{n \le N} \alpha_{mn} \le q_m, \quad \forall\, m \le M, \tag{10}$$

$$\alpha_{mn} = \{0,1\}, \quad \forall\, m \le M, \forall\, n \le N, \tag{11}$$

$$\mathrm{p}_{mn} \ge 0, \quad \forall\, m \le M, \forall\, n \le N. \tag{12}$$

As mentioned earlier, α_{mn} is the binary user association variable to indicate whether UE n is associated with BS m and p_{mn} denotes the transmit power from BS m to UE n. The constraints (7) and (8) indicate the transmit power limit and the backhaul capacity limit, respectively. UE n can be associated with multiple BSs (at most q_n BSs) simultaneously depending on its multi-connectivity capability in (9) while BS can associate multiple UEs according to (10).

4.4.4 Methodology

The optimization problem P formulated in (6)-(12) is a highly complicated mixed integer nonlinear programming problem (MINLP), non-convex and NP-hard. Depending on the number of BSs and UEs and the supportable range of the transmit power, the complexity can increase exponentially, thus the optimization problem becomes intractable. Therefore, in this study, we propose a sub-optimal algorithm adopting the matching game theory that can provide low complexity distributed solutions.

Two sets of BSs M and UEs N are considered as two team players. Since UEs are capable of being associated with multiple BSs and BSs can accept multiple UEs at the same time, the considered matching becomes a type of many-to-many matching game. While each player in M and N behaves independently, it tends to seek the most preferred matching partners in the opposite team. Thus, this matching game can be implemented in a distributed way. Each player specifies its preference over candidate matching players. Whilst the preference relation is denoted as $\succ$, the expression $m \succ_n m'$ states the UE n prefers BS m over BS m' (where $m \neq m'$). A same notation is applicable for BSs to express their preference. While the preference level over candidate players is managed with preference list.

To decide the preference list of UE n, the following increasing level of utility is considered as,

$$\Delta \mathrm{U}_{mn} \triangleq \Phi_n\left(\mathbf{R}_{\boldsymbol{n}}{}^{T} \cdot \boldsymbol{\alpha}_{\boldsymbol{n}} + \mathrm{R}_{mn}\right) - \Phi_n\left(\mathbf{R}_{\boldsymbol{n}}{}^{T} \cdot \boldsymbol{\alpha}_{\boldsymbol{n}}\right). \quad (13)$$

$\Delta \mathrm{U}_{mn}$ indicates the contribution portion to the overall utility in when the mapping (m, n) is newly arranged. In the preference list l_n, the preference relation can be expressed as,

$$m \succ_n m' \iff \Delta \mathrm{U}_{mn} \succ_n \Delta \mathrm{U}_{m'n} \quad (14)$$

Because of the higher contribution level to UE n's QoS satisfaction, UE n will prefer BS m which can more increase the UE's utility.

Similarly, BSs determine their preference on UEs. While BSs are assumed to be interested in power efficiency maximization, the level based on measurement report feedback by UEs can be considered to list UEs in the order of preference. In the preference list of BS m, the preference relation is given as,

$$n \succ_m n' \iff \mathrm{RSRP}_n \succ_m \mathrm{RSRP}_{n'} \quad (15)$$

(15) indicates that BS m prefers UE n to n' while the RSRP at UE n is higher than the RSTP at n'.

For the proposed algorithm's performance, simulation results including comparison with reference schemes will be provided in the following Deliverable, D4.2.

4.5 Strategy for counting people with IoT devices

In the first approach for the development of innovative IoT devices that could participate in coverage extension, in the terms proposed in the DEDICAT 6G project, it was proposed to make use of IoT networks in use in cities to provide coverage extension services (Figure 4).

In the first approach for the development of innovative IoT devices that could participate in coverage extension, in the terms proposed in the DEDICAT 6G project, it was proposed to make use of IoT networks in use in cities to provide coverage extension services (Figure 29).

In the case of the use of people counting devices, as the IoT device, it would also provide a context situation to the DEDICAT 6G platform by providing estimates of the number of devices present in an area so that congestion situations can be prevented. With these devices, therefore, both services, coverage extension and context awareness, can be provided.

4.5.1 Problem Statement

The main problem that arises with this approach is that IoT communications, by their nature, are low-capacity communications links, with very long transmission times, not very useful in the event that a MAP or a user requires, for example due to an overload in the 5G network, to download a large amount of information.

In case of people counter devices, since these devices require higher capacity connections, both for processing and communications, they are usually connected to the IoT network through 4G/5G or Ethernet links. In this case, these devices are the most suitable for investigating coverage extension capabilities in times of communications network overload.

These IoT devices are able to detect the BT/Wi-Fi signal of mobile devices that are in the coverage area and draw a map related to the number of users present at a given time at a designated point. Therefore, the people counter is considered an IoT device whose application is to act as a crowd counter in a given location. These features can be used to detect a possible overload in communication networks due to the presence of a high number of communication devices.

The necessary modifications to develop a functional pilot of a new version of people counter that can offer coverage extension services should be possible on the basis of the current devices.

At this time, ethernet connection is only used during device start up. Then, when the device is running, it uses the Point-to-Point Protocol (PPP) and a wireless communication module. However, if the firmware of this communication module is modified to make it dedicated to sensing the environment, for the users discovering task, the Ethernet connection could be used to send data.

The final prototypes are also implementing advanced security mechanisms to prevent unwanted external access that could affect the operation of the device, the data it delivers and the routing mechanism.

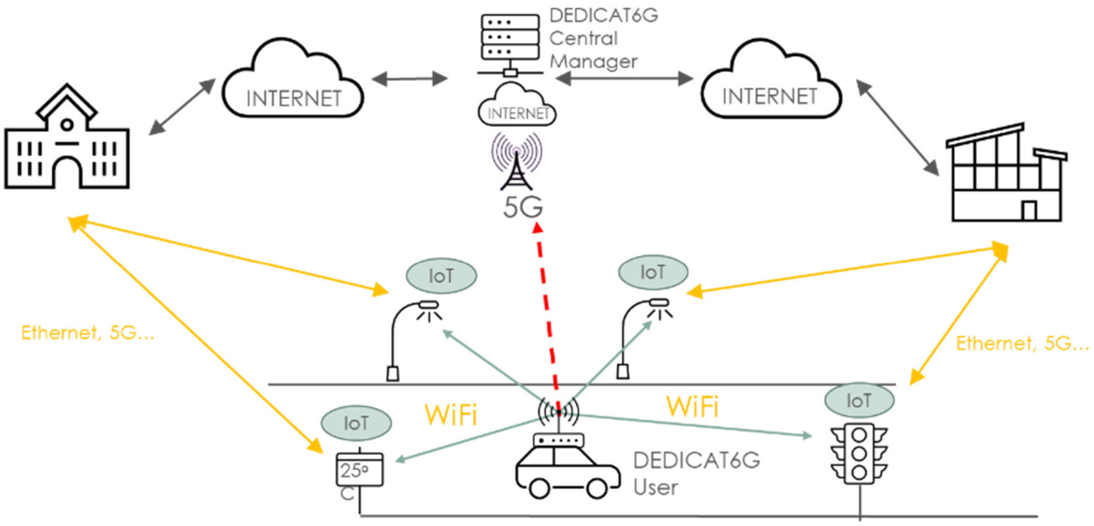


Figure 29: IoT Extended Coverage concept

4.5.2 Proposed Architecture

The proposed architecture provides context awareness in support of coverage extension i.e. occupancy of a location using people counter IoT devices on the device side. This architecture has two distinct functional blocks. On the one hand, the people counter functions of the final solution will provide knowledge of the environment, so that the device is able to discover the devices that are within its coverage radius, creating heat maps with real-time information about the occupation of a given space, which can be used to prevent congestion problems in communications networks. On the other hand, people counter IoT devices will have increased communication capabilities to provide communication services.

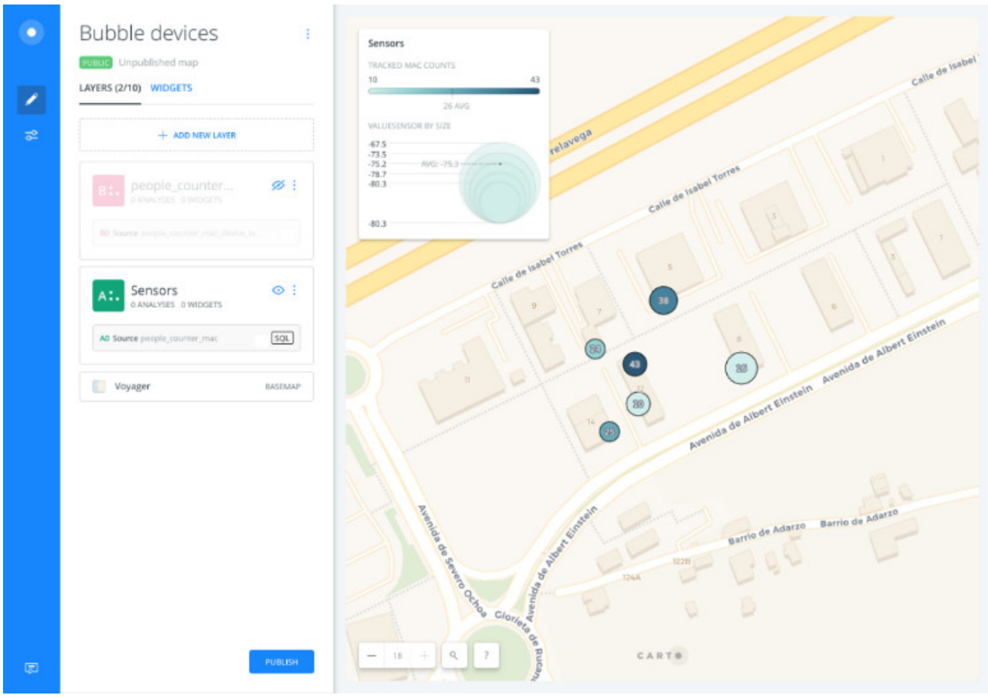


Figure 30: Devices data visualization

In case a user, authorized by the DEDICAT 6G Platform, needs to download their information through the IoT People Counter device, the device will check the permissions and location, published at each moment by the user to the back-end's databases, to allow the use of its resources for a necessary time through a high-speed Wi-Fi connection, routing the data through the communications links that the device has available, i.e., either 5G or an ethernet connection, in the case of the People Counter device.

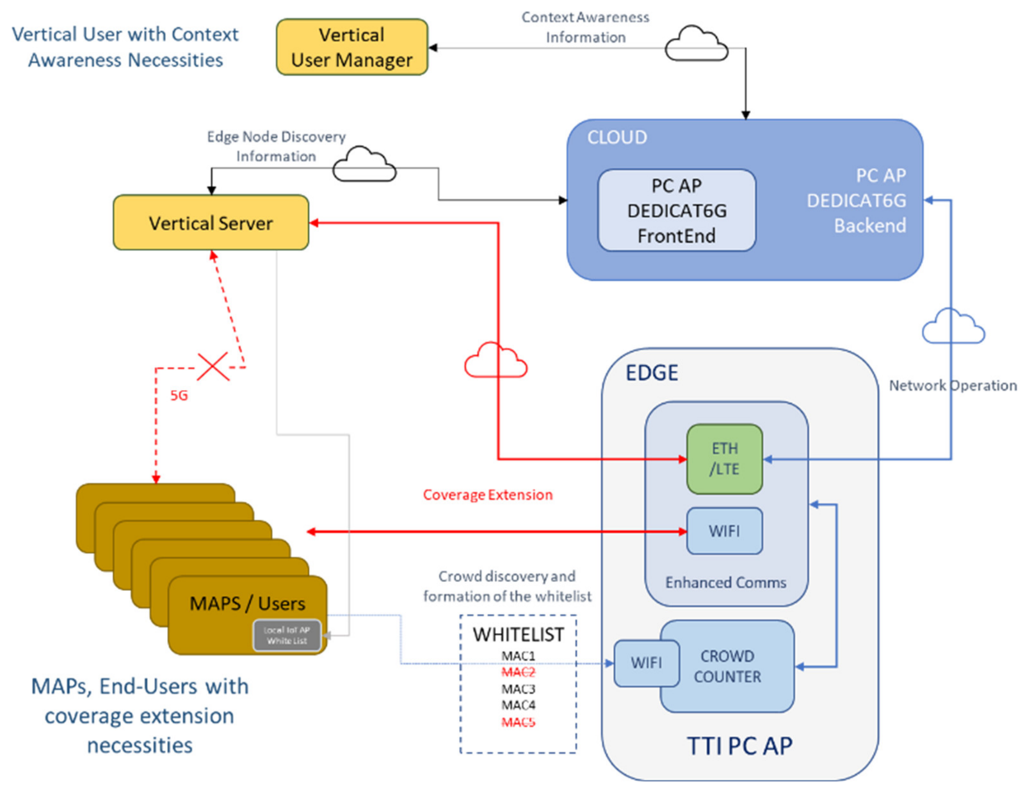


Figure 31: IoT Dynamic Extension of Coverage and Context Awareness

In addition, the DEDICAT 6G Platform, accessible in the cloud for vertical users, will be able to deliver context information to the vertical manager users regarding the estimated device occupancy of a concrete location and the resources available on the PC APs in their coverage area, to decide to make a network connection request.

The most appropriate strategies will be defined so that the information of the users and IoT nodes that allow providing the coverage extension service will be accessible to vertical users through DEDICAT 6G dashboard (or backend), so that, the IoT PC AP system can help the network orchestration tasks by location, making available to the actors, heat maps by location, lists of devices with operating permissions and network usage information in real time.

4.6 Multitier AMAPs for enhanced experience of temporary events

4.6.1 Objectives

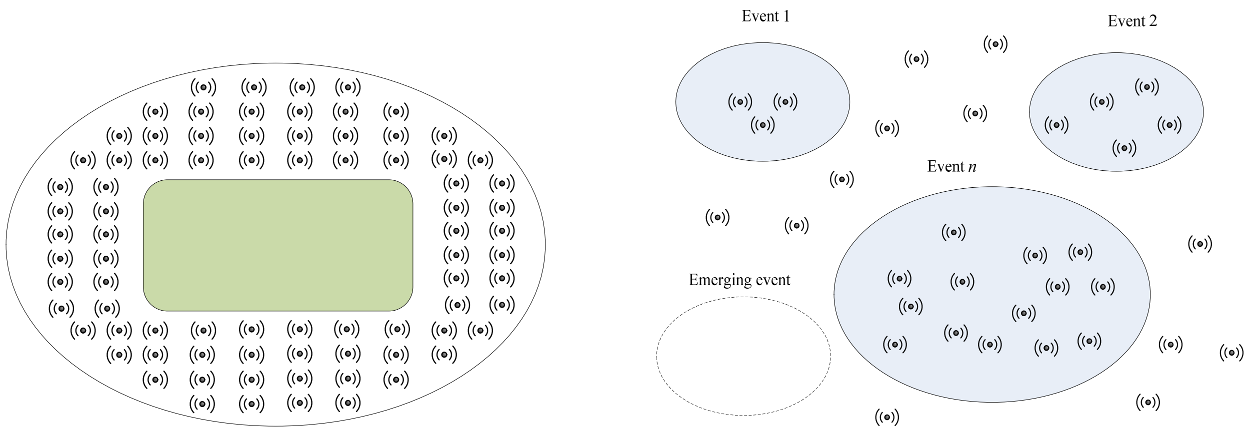
In this subsection, some preliminary contributions for performance improvement evaluation via AMAPs for temporary social events are outlined. The more in-depth results will then be reported in upcoming deliverables of WP4. As overviewed in Section 2, a number of different placement problems has been considered for AMAP scenarios. The complexity of the selected placement problem depends essentially on the target system model assumptions, network size, and the assumptions what information is known about network topology and utilized by the decision making unit.

With a focus on coverage extension and capacity improvement with AMAPs, a critical decision is the optimal 3D position of an AMAP which leads to smallest path loss towards the target radio device on the ground. In essence, the increasing altitude leads to increased LoS probability in typical urban environments. However, the increasing altitude increases the distance and the free-space path loss. The problem becomes more complicated when there are multiple users and multiple AMAPs partially operating on the same frequency creating multiuser interference. The AMAPs may further operate at different altitudes and with different transmission parameters, forming heterogeneous tiers. A tightly related issue is the user association which can be used to improve the coverage with target quality of service.

The main objective of the work is to identify and compare different AMAP placement and user association strategies for different characteristics of temporary events, multiuser interference scenarios, and different levels of network topology information what is known by the decision making entities.

4.6.2 Temporary event characteristics

There are several distinctive features on temporary events, i.e. an event which has a starting and ending point, which affect the network coverage to enable enhanced user experience. A rather straightforward scenario is a restricted small-scale event e.g. in a stadium where the number of participants and their locations are typically known, regularly spaced, and static. Another more complicated scenario is a public large-scale event where the region of interest is larger, and the number and location of participants are irregularly spaced and may not be known, as users may change position frequently or the users are not willing to share their location. The two different event types are illustrated in Figure 32 from a user location point of view.



a) Regular restricted-area event b) Irregular large-scale event

Figure 32: Examples of different models for temporary events.

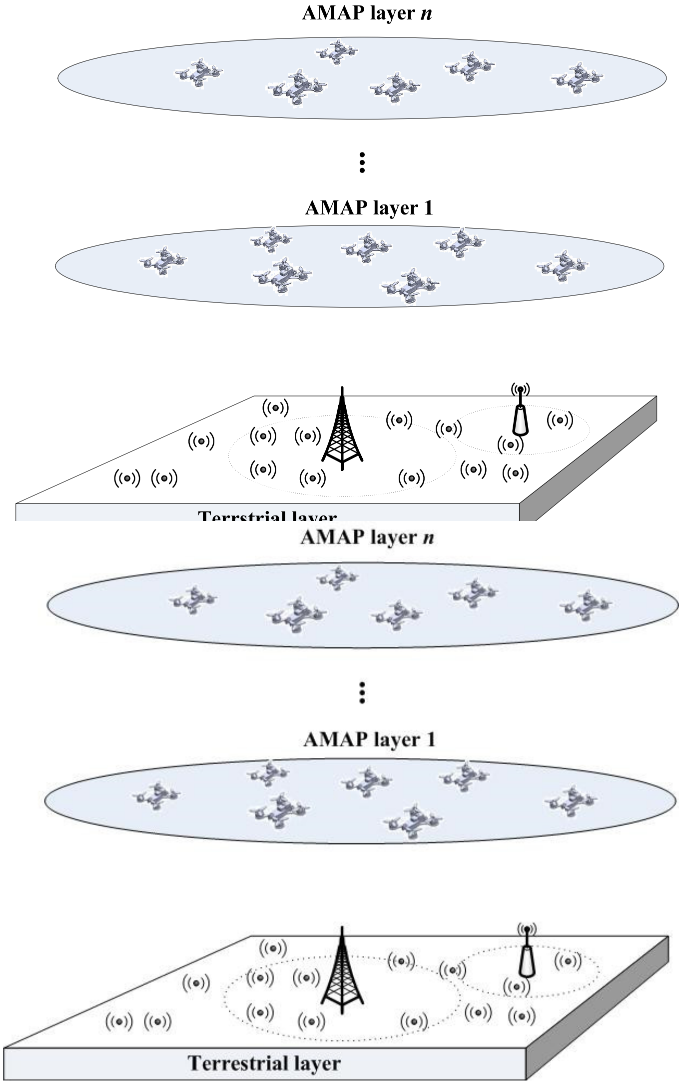


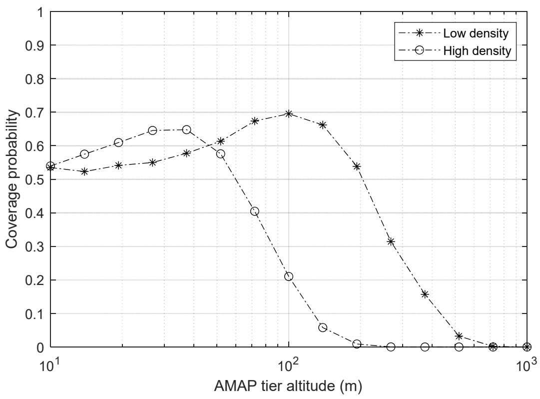
Figure 33: Illustration of a multitier heterogeneous network architecture with different type of terrestrial and aerial access points.

4.6.3 Initial performance evaluation

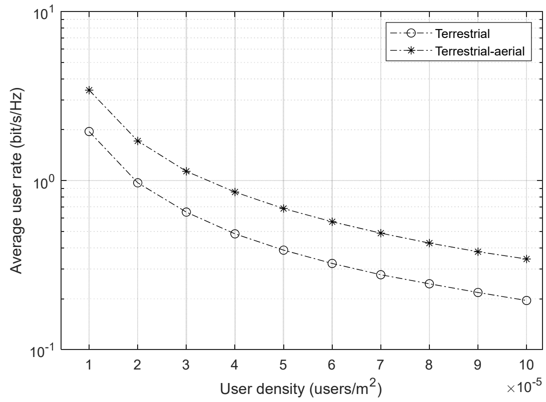
The main objective of the Matlab simulation platform under development is to allow the comparison of different AMAP placement and user association strategies for the selected temporary event scenarios. Here we present only some preliminary examples on the effect of AMAP altitude and density with random placement strategy, assuming no information about user locations. These preliminary results are important in order to understand how different system parameters affect the overall performance and will be utilized in the later work of this WP.

We assume a heterogeneous multitier downlink network where tiers consist of terrestrial static access points and AMAPs, see Figure 33. In this preliminary example, we adopt one terrestrial tier and one aerial tier. The channel model with Rayleigh fading and random LoS probability is assumed. The users are associated to the access point from which they receive the maximum power. In this preliminary example we assume the large-scale scenario where the user locations on the ground level are random and not known a priori, so that also all the access points are randomly placed into the network with a fixed altitude for each tier. Full frequency reuse between different APs in the interference-limited region is assumed to encounter the worst case effect of the multi-access interference.

The effect of AMAP tier altitude on SINR coverage probability and the effect of number of users on average user rate are shown in Figure 34. It is seen on the left side how the altitude varies the coverage probability that influences on the trade-off between the LoS probability and path loss for the case when only one AMAP tier is providing access. Clearly, the optimal tier altitude is also affected by the applied AMAP densities (5 AMAPs/km^2 and 50 AMAPs/km^2) and associated multi-access interference. The right-hand side figure then illustrates how the AMAP tier is able to assist the terrestrial tier to improve the average user rate.



a) Coverage probability



b) Average user rate in bits/s/Hz

Figure 34: Illustration of AMAP-assisted system parameter assumptions on the performance.

In the future work, selected AMAP placement and user association strategies for multitier heterogeneous networks are investigated in more detail for different temporary event characteristics. The emphasis will be on evaluation of inclusion of different amount of information on the users requesting service for the decision-making unit.

4.7 Strategy to Edge Mission Critical Services

4.7.1 Preliminary Implementation

The solution developed by AIRBUS for Mission Critical Communications is based on a Mobile Clients – Cloud Based architecture: available anywhere, anytime. For specific needs, AIRBUS can deploy on premises infrastructure. The AIRBUS solution is able to use Public or Private network.

AIRBUS aims to deploy MCS capabilities on the DEDICAT 6G Edge in order to bring Critical Communications close to the PPDR users and First Responders.

AIRBUS has started to implement Edge capabilities of its MCS solution based in order to offer Voice, Video or Data transmission as Functional Components of the DEDICAT 6G platform. Based on the Intelligent Distribution and Automatic Orchestration, each Functional Components could be deployed on demand whereas the network capacity start to fall in failure for any of those FCs. Based on Self-optimization mechanisms, DEDICAT 6G will be able to deploy the most loaded FC to support response to crisis.

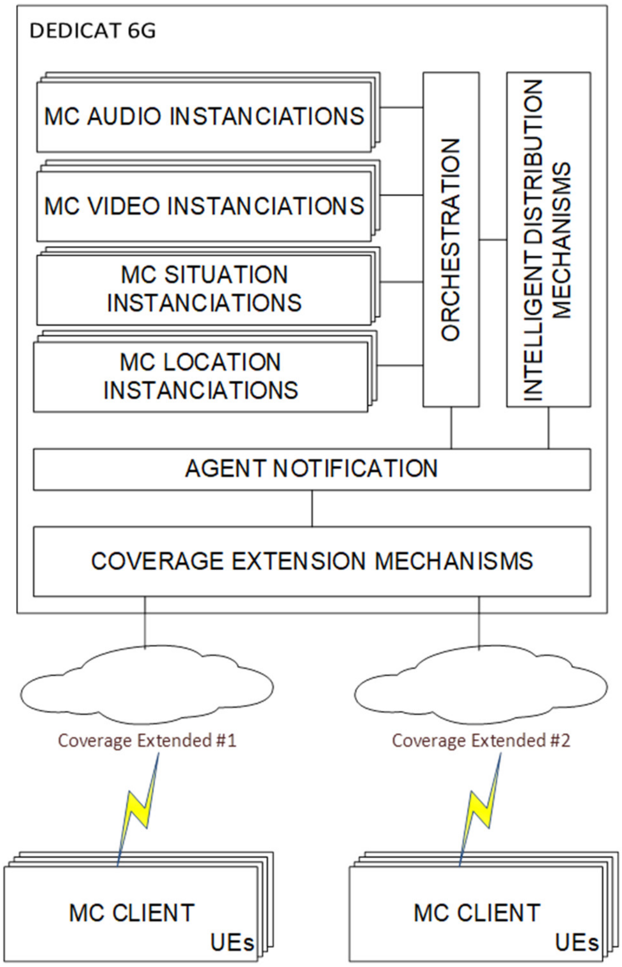


Figure 35: Mission Critical Services Architecture

4.7.2 Definition of relation between MCS and DEDICAT 6G

The MCS will not take part in the Decision Value chain of Intelligent Distribution of DEDICAT 6G platform. The DEDICAT 6G platform will be autonomous in the Self- configuration, self-healing and self-optimization network management approaches.

The Mission Critical Components will be deployed based on the needs measured by the DEDICAT 6G Agent Notification. Depending on the load of a coverage the Agent Notification will exchange information with Dynamic Coverage Mechanisms in order to adapt the coverage and with the Intelligent Distribution Mechanisms in order to adapt the services by sending to the orchestrator the need to deploy new instances of MCS Components (Audio, Video, Situation or couple of them depending on the services needed on the field).

The mechanism definition will need to request information need from MCS Functional Components in order to use such data for optimization and healing.

The hardware component of the platform (onboard on MCVs or AGVs) shall take into consideration autonomy, energy and dimensioning of the hardware in order to run Mission Critical Services with adequation to the capacity expected on the field by the users.

During the pilot, network failure or infrastructure overloaded or pick on numbers of UEs will be simulated in order to evaluate the DEDICAT 6G services and analyze system behaviours for optimization and healing which will prioritize Public Safety indicators.

The measures will be compared to the results of MCS in 5G environment based on 3GPP MCS standards.

4.8 Strategy for tracking VRUs with RSUs

4.8.1 Problem formulation

In shared traffic spaces like the smart highway scenarios pose to a system, the location and trajectory of each user of the shared traffic space needs to be detected and known. While cars and other vehicles can be expected to be equipped with localization features and can communicate their location as well as trajectory accordingly, the tracking of VRUs that may not carry any devices is an issue that needs to be solved.

Automatically analysing and predicting collision risk between VRUs perceived by the RSU may begin with accurately estimating a moving VRU's trajectory. However, accurately estimating the location and velocity of VRU on the roadside is a complex task because the boundary area of the VRU detected by the RSU-mounted camera changes slightly in real time. So, it should have the promise of accurately and seamlessly calculating the location and velocity of a VRU as it appears on the road. In other words, it is necessary to be able to calculate an accurate and smooth trajectory of the location and velocity of a VRU appearing on the roadside.

First, the VRU location at the current time t in the camera 2D area can be defined as $l_i^t = (x_i^t, y_i^t)$ and the previous location at time $t-1$ becomes $l_i^{t-1} = (x_i^{t-1}, y_i^{t-1})$, where the x_i and y_i are the center point of the x and y axes in the VRU boundary area in the video scene. Thus, the velocity of VRUs can be calculated as follows:

$$v_i = \frac{(l_i^t - l_i^{t-1})}{\Delta t} \times r = \frac{\sqrt{(x_i^t - x_i^{t-1})^2 + (y_i^t - y_i^{t-1})^2}}{\Delta t} \times r$$

where i is the index number of detected VRUs, Δt is the time difference in seconds, and r it the pixel-to-meter ratio.

To calculate the pixel-to-meter ratio r, we consider standard objects, signs, or road markings of known real-distance in a road scene. Dividing the real distance by the number of pixels in the occupied area in the image gives the pixel-to-meter ratio.

Since the variability of the detected VRU boundary area and the frames per second, fps, which is one of the camera performance features, affects the VRU location calculation, an optimization algorithm called Kalman Filter is added to compensate for the VRU location and velocity estimation errors. To track moving VRUs, the Kalman filter takes the current state of the system, makes predictions based on current measurements, and predicts the next state of the system. It then compares the received data with the predictions and corrects itself if errors occur.

The state matrix $\mathbf{x}_k$ and the observation matrix $\mathbf{z}_k$ of Kalman filter are defined as:

$$\mathbf{x}_k = [x_k \quad y_k \quad \dot{x}_k \quad \dot{y}_k]^T$$

$$\mathbf{z}_k = [x_k \quad y_k]^T$$

where k is the frame index in fps, x and y are the position, $\dot{x}$ and $\dot{y}$ are the coordinate velocity in x and y directions, respectively.

The 2D moving object is represented as follows:

$$\mathbf{x}_{k+1} = \mathbf{A}\mathbf{x}_k + \mathbf{B}\mathbf{u}_k + \boldsymbol{n}_k$$

$$\mathbf{z}_k = \mathbf{H}\mathbf{x}_k + \boldsymbol{w}_k$$

where $\boldsymbol{n}_k$and $\boldsymbol{w}_k$ are the noise which are summed to be drawn from a zero-mean multivariate normal distribution with variances $\boldsymbol{Q}$ and $\boldsymbol{R}$, $\boldsymbol{n}_k \sim N(\mathbf{0}, \boldsymbol{Q})$, $\boldsymbol{w}_k \sim N(\mathbf{0}, \boldsymbol{R})$, $\mathbf{u}_k$ is the control variable,$\mathbf{z}_k$ is the observation matrix, $\mathbf{A}$ is the state transition matrix, $\mathbf{B}$ is the input matrix, $\mathbf{H}$ is the measurement matrix, given by:

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & t_f & 0 \\ 0 & 1 & 0 & t_f \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \mathbf{B} = \begin{bmatrix} \frac{{t_f}^2}{2} & 0 \\ 0 & \frac{{t_f}^2}{2} \\ t_f & 0 \\ 0 & t_f \end{bmatrix}, \mathbf{H} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

where $t_f = \frac{1}{fps}$ is the actual time between the former and the current frame according to the camera frame rate (frames per second, fps).

Therefore, the VRU location and frame-by-frame velocities based on the Kalman filter can be calculated from $\mathbf{z}_k$.

4.8.2 Initial performance evaluation

Figure 36 shows the VRU trajectory simulation results. This simulation implements a Kalman filter algorithm based on python 3 (version 3.8.5)[1]. Assume that the VRU moves diagonally in a straight line. The red line is the movement trajectory of the VRU detected by the camera mounted on the RSU, and the green line is the movement trajectory of the detected VRU with the Kalman filter applied. That is, the green line shows a smoother movement trajectory than the red line.

[1] A simulation video can be viewed here: https://www.dropbox.com/s/we3f6yok7sxv7ny/VRU_Trajectory_KalmanFilter_Simulation.mov?dl=0

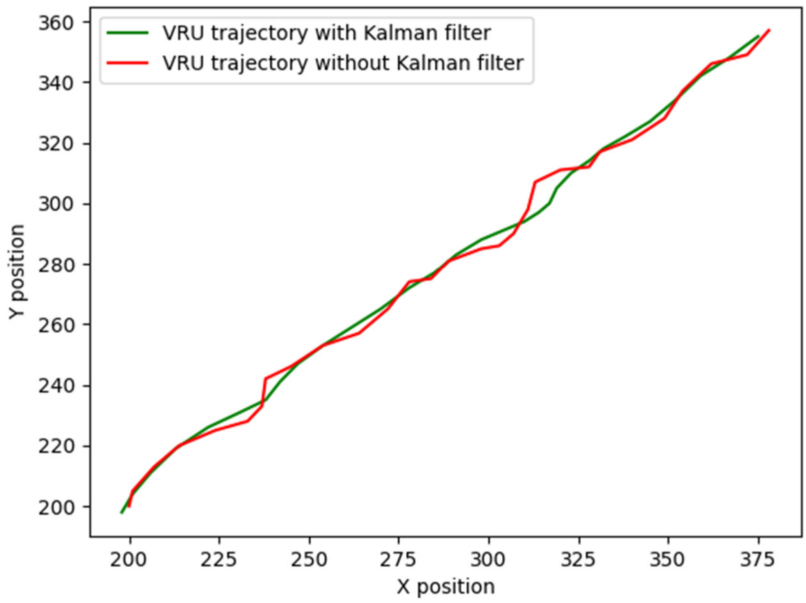


Figure 36: VRU Trajectory simulation

5 Conclusions

This deliverable reports the activity conducted in the work package 4 on the design and development of mechanisms for the dynamic coverage and connectivity extension through the exploitation of innovative devices (e.g., drones, robots, connected cars, other mobile assets like forklifts in a warehouse, etc.).

First, the document provides an update of the state of the art for coverage extension (on mobile access point, decision making exploiting MAP, knowledge and context/situation awareness, RAN management and network management and orchestration) and benchmarks the project's investigation against the state of the art. For example, a large volume of research has been conducted in recent years on Mobile Access Points. DEDICAT 6G is focusing on four use cases: Smart Warehousing with the utilization of automated guided vehicle and mobile asset for improving operations, Enhanced experiences with dynamic MAPs closer to moving audiences, Public safety with the utilization of diverse assets (Drones, AGVs, etc.) and Smart highway with the use of cars and roadside infrastructures. The decision making exploiting MAP includes network planning, (un)controlled placement problem, static or dynamic deployment strategies, the interactions between MAPs and the trade-off between the cost and the expected profit. DEDICAT 6G will build on existing work to develop dynamic coverage extension mechanisms and will investigate complex optimization problem aiming to decide on the deployment of MAPs to ensure connectivity of the appropriate QoS to mobile nodes. For the knowledge or context awareness, it is important to know and manage the network in real time to be more efficient. The network needs to monitor, detect fault, diagnose and trigger the decision making in order to enable self-configuration, self-healing, and self-optimization features. This depends on the availability of information, the awareness of itself, the harmless coexistence of various heterogeneous wireless networks and the prediction capabilities of the network. DEDICAT 6G will develop system-level monitoring mechanisms with diagnostic capabilities and provide coexistence between MAPs or co-located technologies with real-time identification and characterization of the co-located wireless technologies. Moreover, for RAN management, DEDICAT 6G will investigate different strategies at RAN level to extend the coverage of the network by means of MAPs with robust and efficient RAT selection, multi-connectivity, heterogeneous resources allocation, harmonious coexistence between different technologies and joint optimization of 3D placement of multiple UAVs and user association. For network management and orchestration, DEDICAT 6G will combine control-data decoupling in network management and virtualization-based orchestration techniques to automate the correct configuration of a connection from the central platform, orchestrate network functions and perform integration and configuration tasks. DEDICAT 6G will also investigate how the backhauling link is set up between MAPs and the fixed architecture.

Second, the document proposes preliminary considerations to harmonize the research and development of innovative mechanisms for coverage extension. On the one hand, D4.1 deliverable recalls DEDICAT 6G network architecture and the functional and non-functional requirements defined in WP2 and maps an example of a mechanism for dynamic coverage and connectivity extensions to the functional model. On the other hand, D4.1 discusses about design considerations and modelling methodologies. It describes the prototypes in terms of Software / Hardware (e.g., robots, drones, cars, IoT devices) used to validate the technology enablers in the PoC and relevant models to align the simulation frameworks parameters such as deployment scenarios, traffic models and channel models.

Finally, D4.1 presents some strategies for dynamic coverage and connectivity extension (e.g., strategies to deploy and manage MAPs, to associate users to MAPs, to count people with IoT devices) and their preliminary implementation. DEDICAT 6G investigates complex optimization problems aiming to decide the optimal number of MAP entities to deploy, the optimal positions of MAPs in continuous space, the configuration of the radio network of the MAP, the dynamic association of multiple users to multiple access points and the finding of the nearest docking station for charging to provide the required coverage and connectivity extension and to ensure the QoS expected by the mobile nodes. Several objectives are defined. The first one is to maximize the throughput and Ratio of well-deserved users while minimizing the number of drones deployed and the execution time. The second one is to monitor the location of all MAPs and calculate the total communication costs as well as the finding of the nearest docking station for charging. The third one is to maximize the QoS satisfaction level and the energy efficiency by jointly optimizing user association and power allocation under wireless backhaul link capacity constraint in highly crowded areas with heavy traffic loads. The fourth objective is to identify and compare different MAP placement and user association strategies for different characteristics of temporary events, multiuser interference scenarios, and different levels of network topology information. The firth objective is to track vulnerable road users with roadside units for smart Highway scenarios. The last one is to manage and configure vehicular based MAPs that offer multi-RAT capabilities. The efficient RAT selection and configuration schemes estimate the characteristics of the wireless environment and optimize the selection and management of the available wireless resources in order to provide harmless coexistence and increase the overall performance of the MAP. Another approach proposed in DEDICAT 6G provides context awareness in support of coverage extension by using people counting IoT devices to detect a possible overload of communication networks. This system will provide knowledge about the environment (i.e., devices discovery) and create heat maps with real-time information about the occupation of a given space, which can be used to prevent congestion problems in communications networks.

Last but not least, D4.1 provides first release of mechanisms for dynamic coverage and connectivity extension. This deliverable will be extended in D4.2 with more in-depth results. These innovative components will fuel the proof of concept and demonstrator work package (WP6).

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