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# Coverage Extension as a Service for Flexible 6G Networks Infrastructure

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**Abstract**—In future 6G wireless networks, it is important to ensure that equal opportunity is offered to citizens and businesses regardless of location with a dynamic and efficient expansion of the infrastructure. Dynamic coverage and connectivity extension mechanisms exploiting multiple types of Mobile Access Points (MAPs) during a short amount of time for covering areas that cannot be easily reached, are developed by DEDICAT 6G project. This service is called Coverage Extension as a Service (CEaaS). This paper proposes a system architecture for CEaaS and the functionalities that the DEDICAT 6G platform will offer. This includes context awareness (i.e. knowledge about users and technology recognition), coverage extension decision making (i.e. MAP and swarm operation) and network operation decision making (i.e. MAP-user association and radio access technology selection). Furthermore, performance results of DEDICAT 6G framework for CEaaS are presented.

## I. INTRODUCTION

With dynamic and efficient infrastructure expansion, future 6G networks are envisaged to ensure that equal opportunity is offered to users regardless of location and mobility [1]. This flexible infrastructure could be implemented by using Mobile Access Points (MAPs), which can be dynamically deployable based on the required service. A large volume of research has been conducted in recent years on MAPs such as cars, robots, and drones or Unmanned Aerial Vehicles (UAVs). The concept of MAPs has been used, primarily in military, and also in civilian communications [2]. While Claussen et al. [3] used the concept of self-deploying and wireless MAP, it is shown that self-deployment algorithms significantly reduce the number of required Base Stations (BSs) in a highly dynamic environment (airport). Drones/UAVs will be an important component of B5G networks that can facilitate wireless broadcast or point-to-multi-point transmissions. Sekander et al. [4] investigated the feasibility of multi-tier drone network architecture over traditional single-tier drone networks and identified scenarios in which drone networks can potentially complement traditional RF-based terrestrial networks. Mozaffari et al. [5] introduced 3-Dimensional (3D) cellular networks for integration of drone-BSs and cellular-connected drone-users and latency minimal cell association for drone-users was proposed.

DEDICAT 6G project [6] develops dynamic coverage extension mechanisms exploiting multiple MAPs for covering areas that cannot be easily reached (e.g. hard geo-morphology such as cave forest), where infrastructure, or additional capacity is required only for a finite amount of time (e.g. moving

hotspots like festivals), or where regular network infrastructure has been damaged (e.g. after an emergency like earthquake, fire, terrorist attack). These mechanisms can be triggered by verticals for Coverage Extension as a Service (CEaaS).

The objective of this paper is to provide the system architecture for CEaaS and the relevant functionalities that the DEDICAT 6G platform offers and to present the achieved performance. DEDICAT 6G addresses application specific optimization of deployment, mobility and operation of MAPs and integration of MAPs computation and communication resources. An important result consists of a functional decomposition when providing CEaaS to a vertical business application and a set of optimizations that demonstrate how those identified functional components work together.

The paper is organized as follows. Section II recalls DEDICAT 6G functional architecture for CEaaS and how the system provides CEaaS to vertical business applications. Section III describes the current implementation of our framework while Section IV shows the performance of mechanisms investigated in the project. Section V concludes this paper.

## II. DEDICAT 6G ARCHITECTURE

### A. Functional Architecture

Figure 1 depicts an overview of the DEDICAT 6G functional architecture for CEaaS, highlighting the interactions between the DEDICAT 6G platform and a 5G network infrastructure. We consider a hierarchical network organized in four main domains: Access, far edge, edge and core cloud.

One important feature 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 required. The system must obtain and monitor information on network goals and objectives to be achieved, as well as potential policies. 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 and storage capabilities and available power must also be monitored. The system has to maintain information and knowledge on the context in terms of computation tasks, power consumption requirements, a set of mobile UEs that needs coverage, mobility and traffic profiles of UEs, radio quality experienced by UEs, options for connecting to wide area networks, the locations of docking/charging stations for MAPs and the current locations of UEs and MAPs elements.

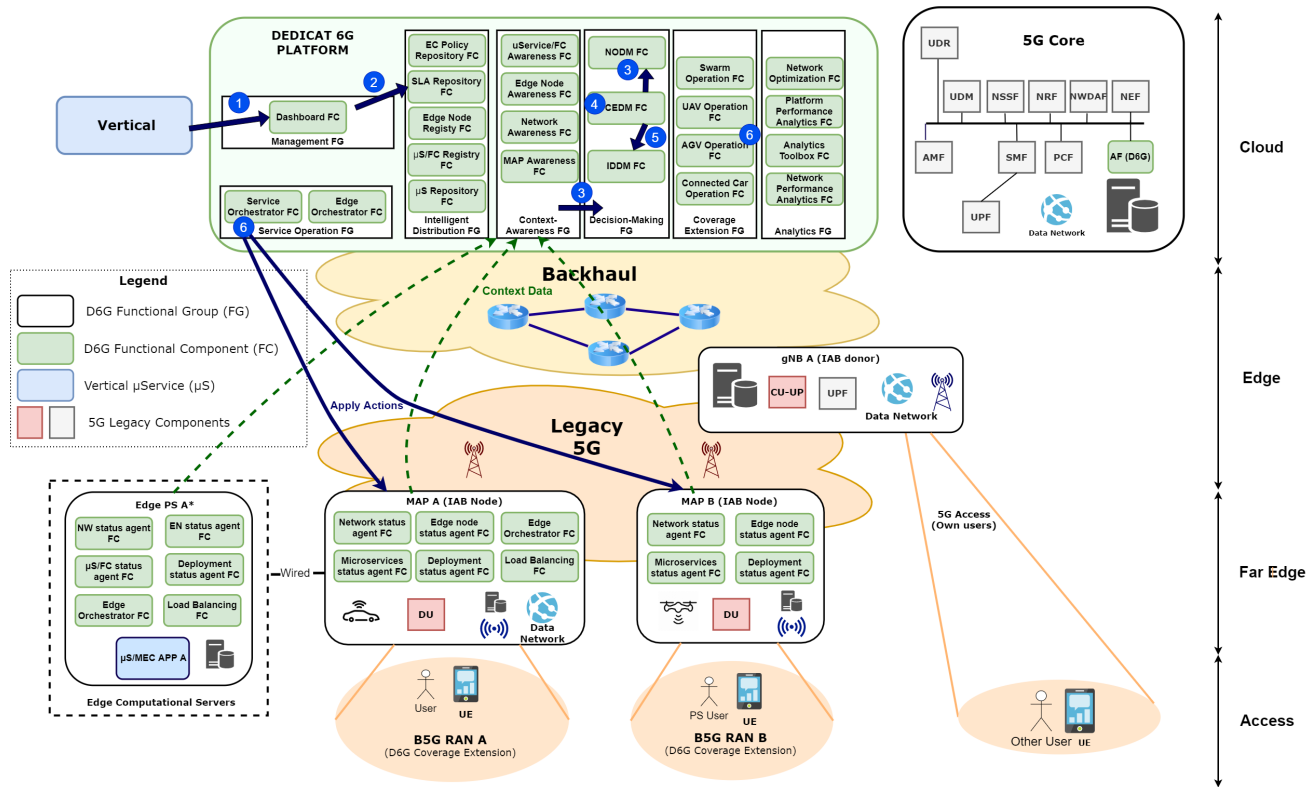


Fig. 1: DEDICAT 6G functional architecture for coverage extension

Another important aspect is to enable the system to make decisions on the MAPs deployment strategies. The key aims of Decision Making (DM) components are to produce the optimal placement of intelligence in terms of data and computation as micro-services, the optimal configuration of the radio network of the MAPs and the MAPs paths (trajectories) that need to be followed, in order to offer adequate QoS levels, in terms of service availability, performance and reliability.

The objective of Coverage Extension DM (CEDM) for static deployment is to find static places for one or more MAPs that fulfil the desired optimization objective. For dynamic deployment, the path between the initial and final destinations is also of interest and some related parameters, such as MAP speed, may be worth for maximizing the operation lifetime. Optimizing the trajectories of the UAVs can be very important in dynamically changing environments. When a MAP is deployed to provide temporary wireless coverage, it is operated as a relay node to relay traffic between a nearby macro BS and end users and the limit of backhaul link capacity can be very challenging. In addition, MAP uses on-board batteries to power its operation (i.e., moving and providing wireless links). Thus, the limitations of the backhaul capacity and battery power will impact decisions and network performance.

With the deployment of MAPs comes the problem of dynamic association of multiple users to multiple access points (fixed or moving). Network Operation DM (NODM) optimization includes the most appropriate allocation of users to MAPs as well as selection of nearby docking/charging stations for drone and robot MAPs to ensure connectivity with the appropriate QoS to users. The selection process results

of a tri-partite negotiation between the UE (the initiator), BSs and MAPs. Prior to the negotiation, the DM at the UE side starts to collect information from several Functional Components (FCs): Network awareness (e.g., the total network utility function and network contexts), MAP awareness (e.g., the RSS and AoA for all the MAPs), UE awareness (e.g., other users positions and their last decision) and performance analytics (e.g., the current perceived network performance rate). Once all these data are collected, the DM decides the best association. When UEs are already associated BS/MAPs, the DM decides whether it keeps the association to the existing MAP/BS or to handover to another one. For UEs capable of multi-connectivity, multiple eligible BS/MAPs can be decided. In multiple Radio Access Technologies (RAT) networks, efficient RAT selection is also crucial for resource utilization, QoS and user satisfaction. The RAT resource configuration realizes harmless coexistence between the technologies.

Intelligence Distribution DM (IDDM) brings higher levels of flexibility, programmability and scalability in network management and orchestration, with Software-Defined Networking (SDN) and Network Function Virtualization (NFV). SDN encompasses a set of network management-oriented techniques that focuses primarily on decoupling the actions of the control plane logic from the data plane. This principle allows a high level of flexibility in the system while the logical control of the network can easily be centralised in an external entity, the SDN controller. NFV virtualizes traditional network functions, typically deployed on physical equipment, into software that can be run on servers or devices with computing capabilities, such as Virtual Network Functions

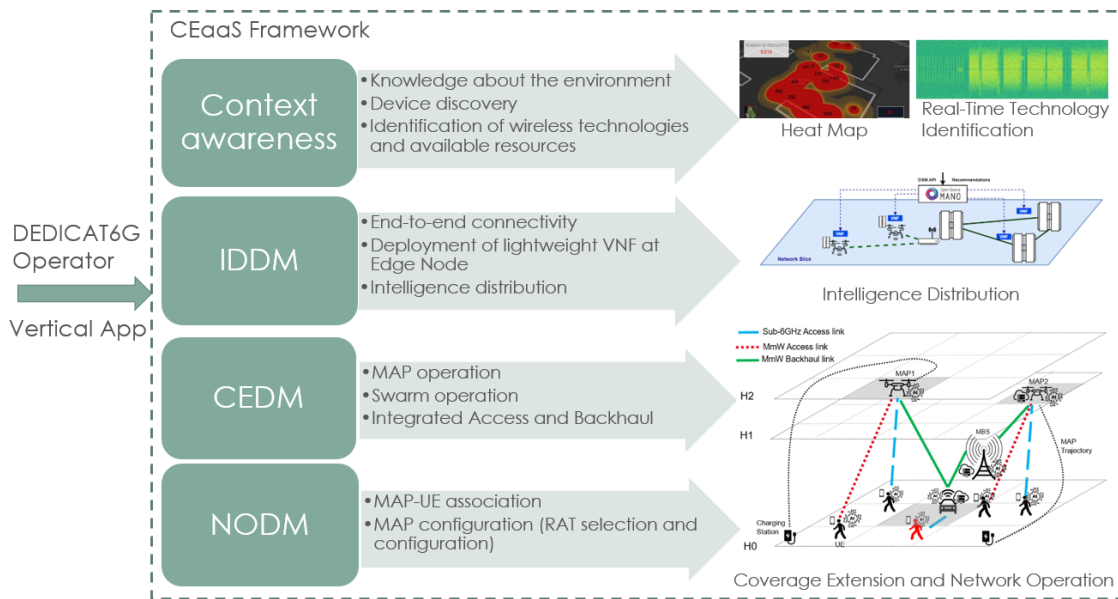


Fig. 2: DEDICAT 6G framework for CEaaS

(VNFs) or container network functions. From an architectural point of view, IDDM is essential in addressing the scalability and dynamism issues of managing computing resources in B5G/6G scenarios, which is particularly critical at the edge and domains. Additionally, IDDM is not only able to consider the distribution of NFV-related intelligence, but also the computational resource consumption of some required FC instances, where specific functionalities are integrated, and vertical applications to enable the correct deployment of CEaaS.

### B. CEaaS System Use-Case

The DEDICAT 6G system provides CEaaS to vertical business applications, meaning that a third-party application would request explicitly an extension of the radio coverage with specific QoS requirements in order to be able to run the application while fulfilling its QoS. The various steps between FCs are illustrated in Figure 1 and described as follows:

- 1) A vertical application (e.g. a public concert organizer) requests a temporary coverage extension for the duration of its event in order to allow video sharing, and online video coverage. The request is coupled with a set of technical constraints, e.g. number of targeted attendees, event location, type of traffic and target traffic per UE.
- 2) This step focuses on the Intelligence Distribution Functional Group (FG) like registries and repositories for the MEC and associated look-up /discovery functions plus Service Level Agreements (SLA) and migration policies storage. A SLA negotiation takes place between both parties, leading to a set of technical objectives to be met by the DEDICAT 6G platform. This set is the main input to the CEDM.
- 3) The CEDM instruments the NODM with QoS targets, which in turn will configure the network in order to fulfill the QoS objective (e.g. involving network slicing).
- 4) The CEDM decides about the nature of MAP involved and their deployment (number of MAPs and their location).

Edge Node Awareness (and related agents) and Edge Node Registry FC are involved in building up a context used for the IDDM decision process.

- 5) The CEDM instruments the IDDM where information distribution is also required, either to support the deployment and execution of specific vertical FCs or to support purely telecom-related aspects. The Edge Node Awareness FC and associated agents are involved in creating a context used for the IDDM decision process.
- 6) Finally, the operation of the MAPs, services, and MEC is performed. Coverage Extension FG supports the dynamic coverage extension like MAP dynamic ad-hoc routing, autonomy management, placement management. Service operation translates decisions into readable instructions or commands for external agents, e.g. NFV Orchestrator. The load balancing functionality is applied to the service and networking components required for the distributed nature of the micro services to be onboarded.

### III. DEDICAT 6G FRAMEWORK FOR CEaaS

Figure 2 illustrates the implementation of DEDICAT 6G framework for CEaaS. In this section, we mainly focus on context awareness (i.e. knowledge about UEs and RATs), CEDM FCs (i.e. MAP and swarm operation) and NODM FCs (i.e. MAP-UE association and RAT selection).

#### A. Context Awareness

DEDICAT 6G has developed a context awareness module for device discovery. A new type of enhanced Internet of Things (IoT) devices is proposed to estimate the number of users in a coverage area by short-range signal scanning techniques (e.g., Bluetooth [7] or Wi-Fi signals [8]). These devices monitor what is happening and draw a heat map related to the number of users present at a given time at a designated point. This strategy works like a people counter [9], whose application is to detect a crowd at a given location. It can be used to detect a possible overloading of communication

networks due to the presence of a high number of users. The people counter is performed by IoT devices through the knowledge of media access control (MAC) addresses detected and the received signal strength in the coverage area [9]. To collect the data generated by each IoT device, the context awareness module uses a standard messaging MQTT (Message Queuing Telemetry Transport) protocol. It simplifies the collection of data from the sensors, the publication of the different values obtained and the remote configuration of the nodes. Depending on the data analysis, this context awareness module can explicitly request CEaaS, support CEDM/IDDM/NODM decisions and make MAP deployments more efficient.

Bernardos et al. [10] predicted that spectrum management and utilization will become more flexible and dynamic compared to today's static and conservative approaches. In the 5.9 GHz ITS band, multiple RATs, such as 5G NR, LTE, and Wi-Fi, can be used for vehicle-based MAP deployment along with the incumbent V2X technologies. DEDICAT 6G proposes a knowledge-building process which is used to sense the traffic from co-located RATs. The knowledge-building process deploys a Technology Recognition (TR) solution that can recognize a wide range of wireless technologies. The proposed TR model is formulated by extending the TR model of [11] considering co-located LTE and WiFi transmitters operating at 2.4 GHz. In this paper, we propose and evaluate a TR model that can classify LTE, 5G NR, and ITS-G5 transmissions in the ITS band. The statistics of each identified technology can be used to estimate and predict the traffic characteristics of each technology [12], which can be used as an input to develop a spectrum sharing scheme.

### B. Network Operation Decision Making

Network Operation Decision Making considers both MAP-UE Association and MAP configuration. A large volume of research has been conducted on UE-BS association for fixed BSs. For example, Sana et al. [13] studied user association based on multi-agent reinforcement learning in which users act as independent agents based on their local observations and learn to autonomously coordinate their actions in order to optimize the network sum-rate. DEDICAT 6G proposed an extension of this work in [14] for deciding the number and the optimal location of MAPs which maximizes the throughput and ratio of well-deserved users while minimizing the number of drones deployed and the execution time. We optimize the user association to map UEs to both sub-6GHz and mm-wave band and to guarantee the UEs' QoS requirement. Our proposed solution jointly considers inter-cell and intra-cell interference, user mobility, and user traffic request during the optimization. As a result, the proposed solution adapts well by design to dynamic networks with mobility, dynamic traffic, and varying number of UEs. Other MAP-UE association strategies are investigated in DEDICAT 6G framework. An user association strategy is proposed in heterogeneous MAP-assisted networks with machine learning. The objective 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. An important characteristic of MAP placement is awareness of different

trade-offs, e.g. between MAP swarm size and target user utility maximization with given optimization constraints. In regard to this, also the centralization degree of the MAP placement algorithm is important which can vary from fully centralized to fully distributed frameworks. In general, some parts of the selected multi-objective functions (e.g. network cost minimization) may be more reasonable to perform in a centralized fashion while some other parts in a distributed fashion (e.g. user utility maximization).

In 6G networks, different technologies can operate in wide range of licensed and unlicensed spectrum, as far as efficient coexistence scheme is deployed [15]. In this direction, DEDICAT 6G develops a knowledge-building process for deriving information about the wireless environment that can be used for RAT selection and configuration, as well as enabling coexistence and incumbent protection. For a newly activated MAP, specific RATs can be selected based on MAP capabilities, applications/services traffic demands, and/or identified characteristics of the wireless environment. As multiple MAPs with multi-RAT capabilities can be dynamically set up close to each other, it is important to set up coexistence mechanisms to ensure fairness, optimal sharing of the spectral resources between different co-located RATs, and protection of potential incumbents like C-V2X PC5 and ITS-G5. Hence, the selected RAT(s) has to be properly configured by a RAT configuration scheme which is used to optimally utilize the available spectrum. DEDICAT 6G aims to formulate efficient RAT selection and configuration schemes based on the results obtained in the knowledge building.

### C. Coverage Extension Decision Making

MAP operation includes managing mobility, adjusting orientation and tilt, and receiving status reports on ongoing operations. Swarm operation FC performs self-organizing functions as an ad hoc network (including access and backhaul links), MAP placement, MAP path optimization to achieve placement within the constraints of the CEDM coverage area, and self-management of resources, including autonomy (e.g. how often and where a MAP should return to its docking station).

DEDICAT 6G studies a complex optimization problem to decide on the deployment of MAPs to provide appropriate QoS connectivity to mobile nodes and find (i) the optimal positions to which each MAP should move, (ii) the path or trajectory that each MAP should follow to reach the target position, (iii) the selection of nearby docking/charging stations for the MAP drones and (iv) the configuration of the MAPs' radio network. DEDICAT 6G first focuses on how to deploy MAPs, i.e. the optimal number and 3D positions of MAPs in continuous space. MAPs can then dynamically move close to the area where users are concentrated or where more service is requested. Thus, MAPs trajectories can take into account typical trajectory constraints, application-based deployment optimization, and ground user mobility in dynamic and changing environments. DEDICAT 6G also involves a joint optimization of NODM and CEDM (i.e. multiple UAVs 3D placement and user association) taking into account (i) MAP mobility, (ii) MAP radio network configuration, (iii) node allocation to MAPs and (iv) the resource allocation for wireless access and backhaul.

#### D. Intelligence Distribution Decision Making

The DEDICAT 6G project assumes as intelligence every software-based part that can consume computational resources available on the nodes of a B5G network scheme. Three different types of intelligence are considered in this context, DEDICAT 6G FC instances, VNFs based on ETSI's NFV principles, and Verticals apps to exploit the MEC capabilities of the 5G ecosystem. In CEaaS it is especially relevant to put the spotlight on the first two types of intelligence. First, it is essential to deploy concrete FCs along the network fabric to perform their corresponding functionalities in order to enable CEaaS. For this purpose, the DEDICAT 6G architecture relies on the IDDM FC to calculate the best locations to accommodate the intelligence taking into account the current state of the computational and network contexts. DEDICAT 6G considers as one of its main pillars the research and development of novel intelligence distribution techniques to be applied in a dynamic and changing network ecosystem. And secondly, combination of control-data decoupling in network management and virtualisation-based orchestration techniques is essential for successful end-to-end connectivity and coverage extension in B5G networks. DEDICAT 6G investigates techniques to automate the correct configuration of a connection from the core platform in coverage extension operations. We focus on instructing NFV Orchestrator (NFV-O) to set up the service/network portion to enable ad-hoc connectivity when the connectivity area needs to be extended or moved. We also involve deploying lightweight VNFs at edge nodes or far edge nodes, such as drones or robots. DEDICAT 6G supports the configuration of 5G/RAN components and enables runtime operations or post-installation reconfigurations. Last but not least, IDDM FC will not directly implement the changes in the system but will provide optimal recommendations. The Service Orchestrator FC is in charge of first translating those instructions into the correct form, and ultimately interacting with the external entities to implement the corresponding actions. Hence, DEDICAT 6G is investigating and developing concrete modules to support such interactions with some of the trending 5G-based control plane tools, such as ETSI OpenSource MANO or Kubernetes.

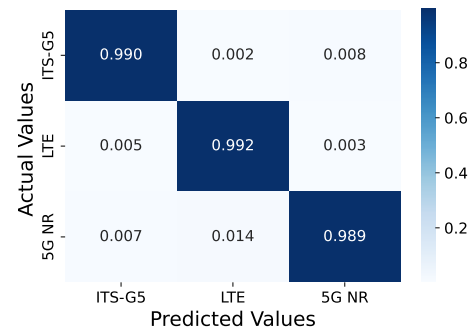
### IV. RESULTS

#### A. Knowledge Building

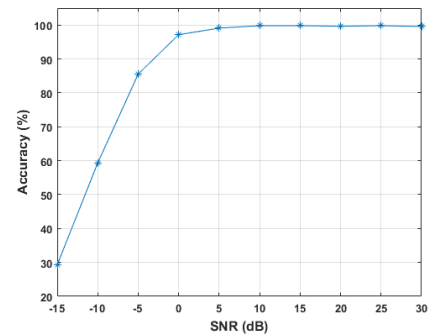
An efficient spectrum sensing mechanism is required to enable dynamic spectrum management of 6G networks [15]. In this section, we present the performance of the spectrum sensing TR model used for the environment knowledge building process. The TR model is trained and validated based on dataset collected from LTE, 5G NR and ITS-G5 technologies. In the data collection phase, samples of each signal type are received and collected at a sampling rate of 20 Msps and a center frequency of 5.9 GHz with 10 MHz bandwidth. For each technology, the dataset and a description of the dataset collection are available as an open source<sup>1</sup>. The dataset contains 7500 examples for each technology. Initially, the collected IQ samples are pre-processed by introducing Additive White Gaussian Noise (AWGN) with -15, -10, ...,

<sup>1</sup><https://gitlab.ilabt.imec.be/mgirmay/dataset-LTE-5GNR-ITS-G5>

30 dB SNR (Signal to Noise Ratio) levels. This pre-processing is introduced to evaluate the performance of the TR model on different channel conditions. After the AWGN is introduced, FFT (Fast Fourier Transform) of the IQ samples is used to train and validate a Convolutional Neural Network (CNN) based TR model. Using FFT of the IQ samples as an input leads to higher accuracy due to the more distinguishable frequency domain features of the signal. This makes the FFT pre-processing essential for ITS band spectrum sharing, where the high accuracy is required to identify and protect safety critical information transmitted by the V2X users. The structure of the CNN model and the implementation details are described in [11]. The CNN in [11] was modified to take into account three distinct classes, namely LTE, 5G NR, and ITS-G5, and the new dataset was collected at the 5.9 GHz ITS band.



(a) Confusion matrix at 10 dB SNR.



(b) Classification accuracy at different SNR.

Fig. 3: Performance of the proposed TR.

Figure 3 shows the TR performance in terms of confusion matrix and classification accuracy. In the performance evaluation, 70% of the total dataset are randomly selected and used for training while the remaining 30% samples are used to validate and test the CNN model. Figure 3a shows the confusion matrix of the proposed TR model at 10 dB SNR, while Figure 3b illustrates the classification accuracy of the TR model for various SNR values from -15 to 30 dB. For SNR values of 0 dB or higher, we can observe that the TR model can effectively distinguish the technologies, exceeding a classification accuracy of 97%. This TR-based knowledge building process can be used to enable efficient and dynamic spectrum sharing in future 6G networks.

#### B. Joint MAP Placement and UE-MAP Association

In this section, we present the performance of a joint CEDM and NODM. Our goal is to find the optimal number

of MAPs to deploy, the optimal positions of the MAPs, the radio network configuration of the MAPs, and the dynamic association of multiple UEs to multiple access points. UEs are mobile with multi-connectivity (sub-6GHz and millimeter wave bands) and interference is taken into account to obtain a complete solution. As detailed in [14], we propose to explore the cell by randomly deploying MAPs in a 3D grid and give a score to each location based on the user's QoS improvement by the deployed MAPs. MAPs are then deployed to the best location iteratively until all QoS constraints are satisfied. Our solution also proposes a multiple cooperative agent mechanism for MAP-user association using reinforcement learning. Once all MAPs are deployed, each agent is trained to maximize the overall network performance and solves the complex interference problem. Figure 4 shows the performance in terms of average network log sum-rate and average percentage of UEs with satisfied QoS as a function of the number of UAVs in the associated smart highway scenario. This scenario is made with 40 UEs and up to 9 MAPs moving through 36 positions at 3 altitudes (i.e. 10, 35 and 60m) in a 200m by 200m area. The UEs are initially distributed uniformly on four one-way roads surrounding two points of interest and travel at speeds between 10 and 60 km/h. Outgoing UEs can re-enter in the area of interest and maintain a constant number of UEs. Figure 4 illustrates the trade off between MAPs deployment and UE QoS. The AI model increases the network sum-rate of 61% compared to a standard MAX-SNR algorithm.

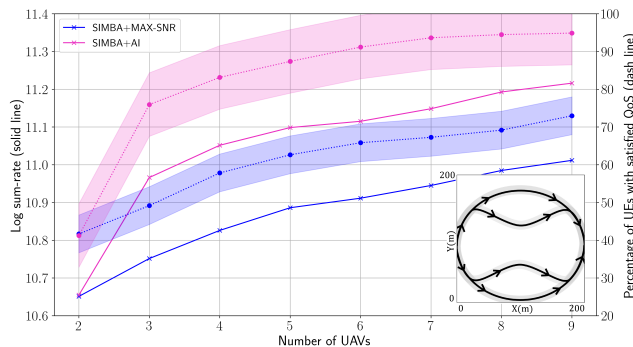


Fig. 4: Average network log sum-rate and average percentage of UEs with QoS satisfaction as a function of the number of deployed UAVs for a smart highway scenario.

## V. CONCLUSIONS

The emerging 6G architecture will be dominated by operator services enabling dynamic topology changes of the network infrastructure to better adapt to time-varying user traffic needs. Thus, in this paper, we introduce a new service called Coverage Extension as a Service for a dynamic and efficient expansion of the infrastructure by using mobile access points. This service is powered by the framework of DEDICAT 6G project. The context and situation awareness module provides two functionalities: device discovery (i.e. a heat map related to the number of users present at a given time at a designated point) and technology recognition (i.e. identifying technology and predicting the traffic characteristics for a better spectrum usage and RAT selection). These modules provide essential information for making decisions exploiting MAPs (e.g. how

to manage MAPs and its associated users). Then we propose a joint optimization of MAP placement and network operations. This highlights the impact on the network performance of flexible and dynamic networks infrastructures. In future work, DEDICAT 6G framework will be extended with various AI-based approaches to address CEaaS for different use-cases (e.g., smart highway, smart warehousing, public safety and enhanced experience of temporary events). A particular attention will be paid to the management of dynamic networks. Moreover a experimental proof of concept will be developed to validate the technology enablers.

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