Obstacle-aware On-demand 5G Network using a Mobile Robotic Platform

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***Abstract*—5G has become increasingly popular nowadays, mainly due to its characteristics which enable high data rates and low latency. At the same time, mobile robotic platforms, such as drones and robots, appeared as suitable platforms to carry radio stations, enabling the on-demand placement of 5G communications cells. The main contribution of this paper is an obstacle-aware on-demand 5G network. The proposed solution consists of a 5G radio station (gNB) carried by a mobile robotic platform capable of providing obstacle-aware wireless connectivity to 5G User Equipments (UEs), leveraged by a novel virtual network function – On-Demand Mobility Management Function (ODMMF). ODMMF is designed to integrate the 5G Core network and it allows to monitor the radio conditions provided to the served UEs, while enabling the positioning of the mobile robotic platform remotely by taking advantage of the visual information provided by on-board video cameras. The proposed solution was validated using an experimental prototype, under a representative networking scenario.**

***Index Terms*—5G, Core Network, Mobile Radio Access Network, Network Function, On-Demand Communications.**

I. Introduction

The increasing number of users and the rise of network operators offering extensive coverage bring up the need for more radio resources and Base Stations (BSs) deployed. Moreover, the dynamic nature of some obstacles and the stringent Quality of Service (QoS) levels imposed by emerging applications make the use of fixed BSs and Road Side Units (RSUs) insufficient. This challenge is exacerbated when using millimeter wave (mmWave), Terahertz (THz), and visible light communications which enable ultra-high bandwidth channels if short-distance, line-of-sight wireless links are ensured. The problem is depicted in Fig. 1.

In this context, the use of reconfigurable network topologies is envisioned by 5G and 6G networks, in order to ensure always-on wireless connectivity even when obstacles to radio signal propagation appear. Simultaneously, the use of mobile robotic platforms, including drones and robots, became popular in performing different tasks, especially due to their capability to be deployed anywhere and anytime [1]. From the communications perspective, mobile robotic platforms acting as mobile Radio Access Networks (RANs), combined with non-terrestrial networks, are emerging as a solution to provide on-demand wireless connectivity in 5G/6G networks. In particular, the use of drones has been envisioned under the Integrated Access and Backhaul (IAB) concept, initially defined in 3GPP Release 16, which takes advantage of resources provided by fixed BSs to establish backhaul wireless links [2].

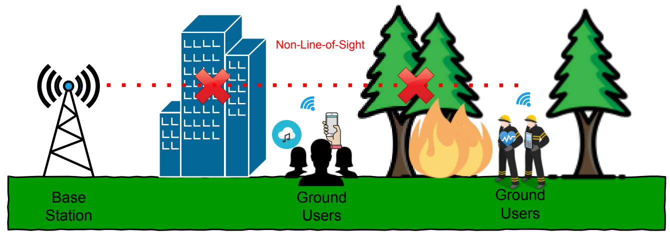

Fig. 1. Obstacles preventing radio line-of-sight between a fixed Base Station and ground users.

Most of the research works addressing the placement of mobile robotic platforms are focused on improving the wireless coverage and capacity, and do not consider the presence of obstacles to radio signal propagation. The provisioning of on-demand wireless networks using mobile BSs that simultaneously consider users' positions and obstacles potentially affecting the line-of-sight has not been addressed to the best of our knowledge [3].

The main contribution of this paper is an obstacle-aware on-demand 5G network. The proposed solution consists in a 5G mobile RAN composed by a radio station (gNB) carried by a mobile robotic platform which is controlled by an On-Demand Mobility Management Function (ODMMF). ODMMF is a novel 5G Core's network function proposed for remotely enabling the positioning of the mobile RAN and monitoring the radio conditions of the served User Equipments (UEs), leveraged by the video cameras carried by the mobile robotic platform. The proposed solution enables the positioning and private management of communications resources owned by a single entity, while providing 5G wireless connectivity anywhere and anytime.

The rest of this paper is organized as follows. Section II presents the related work. Section III describes the proposed obstacle-aware on-demand 5G network. Section IV details the system design. Section V explains the validation carried out. Section VI discusses the pros and cons of the proposed solution. Finally, Section VII refers to the main conclusions and future work.

II. Related Work

In the literature, there are different solutions using mobile robotic platforms and the 5G technology. In [4], a 5G network based on the OpenRAN architecture is employed for video streaming applications, taking advantage of an

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Unmanned Aerial Vehicle (UAV). The proposed network consists of a multi-cell RAN where three BSs were deployed to serve UAVs acting as UEs. This solution demonstrates the OpenRAN concept and its ability to maximize network performance, while meeting targeted QoS requirements.

In [5], a solution that takes advantage of Edge computing for Internet of Things (IoT) based scenarios is proposed. The use of Multi-access Edge Computing (MEC) is introduced to provide cloud-computing capabilities within the RAN. The authors envision the use of Edge computing to meet strict QoS requirements. As such, mobile robotic platforms may be an enabler for this purpose.

The particular characteristics of UAVs and how they should coexist in the sky in a safe and reliable manner are explored in [1]. Metrics such as time efficiency and power consumption were studied, in order to emphasize the potential advantages of UAV-based networks when compared with conventional networks. The authors argue that the Wi-Fi technology may be not sufficient to meet the communications requirements of emerging applications. This work also shows the potential benefits of using the 5G technology and generic mobile robotic platforms, in order to provide on-demand wireless networks.

The use of an optical camera or synthetic aperture radar has been envisioned in [6], in order to locate ground obstacles and an eavesdropper. Similarly, a multi-modal system, composed of ground robots for ground sensing purposes and a UAV for capturing aerial images, is proposed in [7]. The ground-air communications are carried out through Light-Emitting Diode (LED) camera communications, which also allows the UAV to visually identify the ground robots. A solution to track the location of UEs and estimate the orientation of antenna beams using Reference Signal Received Power (RSRP) measurements is proposed in [8]. However, it does not consider mobile BSs.

While UAVs take advantage of their altitude to enable potential line-of-sight to the users, they typically do not take advantage of visual information to avoid obstacles to radio signal propagation. Mobile robotic platforms using video cameras on-board may allow for detecting the positions of users seeking for wireless connectivity while enabling radio line-of-sight. As such, a mobile RAN which can be remotely positioned on-demand will be a step forward to enable flexible, reconfigurable, and sustainable wireless access networks, which are envisioned by 5G and 6G networks.

III. Obstacle-aware On-Demand 5G Network

Our proposed solution considers a UE demanding 5G wireless connectivity. For that purpose, a wireless link is established between the UE and the mobile RAN which is composed of a gNB carried by a mobile robotic platform, as depicted in Fig. 2. In order to enable the UE to access the Internet, the mobile RAN exchanges data traffic with the 5G User Plane Function (UPF), through the *N3* interface.

For controlling the positioning of the mobile robotic platform and monitoring the quality of the wireless links established between the mobile RAN and the served UEs, we propose a novel On-Demand Mobility Management Function (ODMMF).

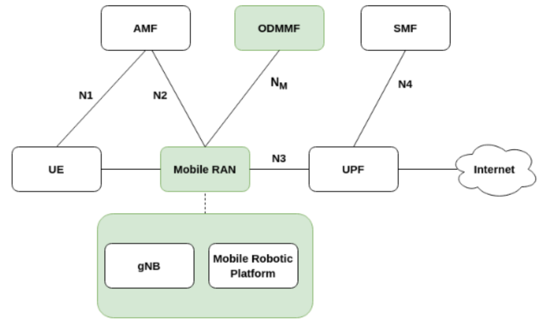

Fig. 2. 5G system architecture with the ODMMF network function.

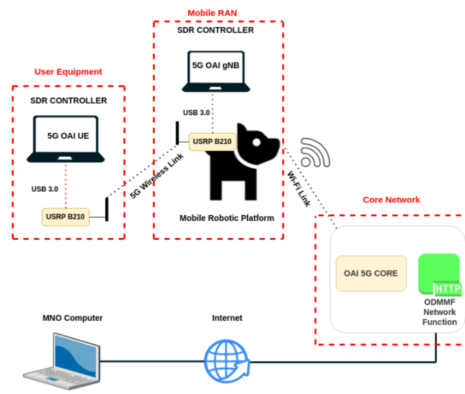

Fig. 3. Overview of the system designed to validate the proposed solution [11].

ODMMF, which is deployed in the 5G Core network, is connected to the mobile RAN through a new proposed N_M interface. N_M aims at taking advantage of the Application Programming Interfaces (APIs) provided by commercial mobile robotic platforms available [9, 10], which enable their movement control in real-time. It also allows to access and control the video feed provided by multiple video cameras using Hypertext Transfer Protocol (HTTP), which enable awareness regarding the environment surrounding the mobile robotic platform, including the location of the UEs in need of 5G connection.

The protocol stack of the N_M interface consists of the following layers: 1) HTTP/2, which allows for accessing the data through the *World Wide Web*, and enables stateless requests and responses; and 2) Transport Layer Security (TLS), which is used for security purposes at the transport layer, while offering encryption and privacy. These two layers operate over the TCP/IP protocol stack.

IV. System Design

The system designed to validate the proposed solution is depicted in Figure 3 [11]. It is composed of three main components, which are controlled by a Mobile Network Operator (MNO) through the Internet: 1) User Equipment; 2) 5G mobile RAN; and 3) 5G Core network.

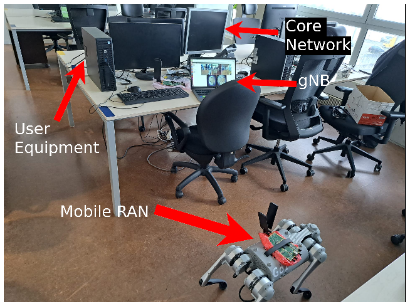

Fig. 4. Experimental prototype of the designed system [11].

The open-source OpenAirInterface (OAI) software [12], currently developed by OpenAirInterface Software Alliance (OSA), was employed to implement the UE, gNB, and Core network, since it enables a 5G standalone network and is widely used by the community.

A. 5G Core Network

The 5G Core network was implemented using *Docker* containers, which use a smaller amount of resources when compared with Virtual Machines (VMs). An *Intel NUC5i5MYBE* Next Unit of Computing (NUC) was used to deploy the 5G Core network. The wireless link employed for exchanging control information between the 5G Core network and the mobile RAN was Wi-Fi. Wi-Fi was used due to its ubiquity and flexibility, but any other reliable wireless communications technology that can be used by the TCP/IP protocol stack is suitable.

Our 5G Core network includes the standard OAI 5G Core and the new proposed ODMMF network function. An ODMMF user can observe two *Web* pages: 1) a *Web* page for remote control of the mobile RAN (cf. Fig. 5); and 2) a *Web* page which presents in real-time the status of the 5G wireless links established with the UEs served by the mobile RAN, including wireless statistics (cf. Fig. 6).

B. 5G Mobile RAN and User Equipment

The UE and gNB were implemented in Software-Defined Radios (SDRs). The Universal Software Radio Peripheral (USRP) B210 SDR model [13] was used, due to its cost-effectiveness and popularity across the community. Each SDR was connected to a host computer through a Universal Serial Bus (USB) 3.0 interface. Two dipole antennas attached to each USRP B210 were also employed [14]. The 3.6 GHz carrier frequency was considered.

The Go1 Edu Robot [10] mobile robotic platform, developed by *Unitree*, was chosen to carry the gNB, acting as the mobile RAN. It includes multiple video cameras on-board, which allow to provide the visual information required by the ODMMF network function, as well as an API that enables controlling the movement of the mobile robotic platform through HTTP.

The experimental prototype of the designed system is depicted in Fig. 4.

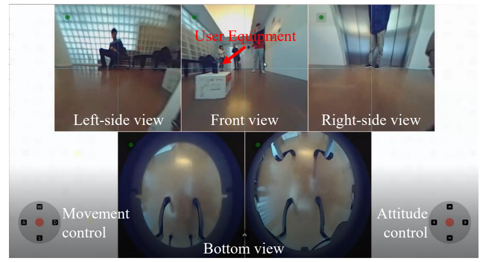

Fig. 5. *Web* interface made available by ODMMF to control the positioning of the mobile RAN, leveraged by the video cameras carried by the mobile robotic platform.

Radio Statistics Web Page

You have a 5G connection!

The MCS value is currently: 9

The BLER value is currently:0.00086

Mobile Phone details

IMSI: 2089900007487

KEY: fec86ba6eb707ed08905757b1bb44b8f

Country Code: Portugal

OPC: C42449363BBAD02B66D16BC975D77CC1

The base station is able to ping the Core Network!

Fig. 6. ODMMF *Web* page showing the successful 5G connection established between the mobile RAN and the UE.

V. System Validation

In order to validate the proposed solution, a representative use case was employed. It considers a Mobile Network Operator (the system user) that aims to position the mobile RAN so that 5G connectivity can be provided to a UE, using the experimental prototype shown in Fig. 4. This use case considers that the user is remotely located and has access only to the video feed made available in ODMMF.

Firstly, the mobile robotic platform carrying the gNB was positioned ten meters apart from the UE, which is a high enough distance so that the UE is outside the transmission range of the communications cell enabled by the gNB. The relatively short distance is due to the limited transmission power possible with the SDR models available, which aims at avoiding interference with commercial 5G network deployed, while allowing proof-of-concept validation.

Then, the ODMMF *Web* interface was accessed by the user through a *Web* browser, in order to position the mobile robotic platform closer to the UE and monitor the 5G connection in real-time (cf. Fig. 5).

When the SDRs implementing the UE and gNB were capable of synchronizing and communicating with each other, the UE was able to connect to the on-demand 5G network. The information related with the 5G link established between the UE and the mobile RAN was autonomously updated in ODMMF (cf. Fig. 6).

To validate the UE's ability to access the Internet through the tunnel interface created through UPF, several Internet

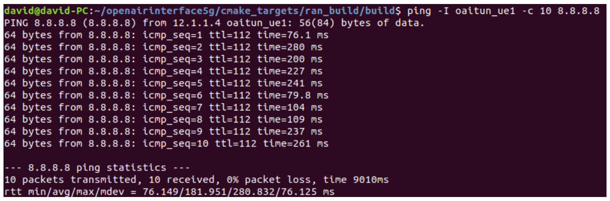

Fig. 7. Successful connection of the UE to the Internet, considering the *Google's* public DNS server as the remote host.

Control Message Protocol (ICMP) packets were sent to *Google's* public DNS server, which are depicted in Figure 7.

A video demonstrating the proof-of-concept of the proposed solution, considering a commercial off-the-shelf smartphone, is available in [15].

VI. Discussion

The experiments carried out allowed to validate the proposed obstacle-aware on-demand 5G network, which takes advantage of the capability provided by a mobile robotic platform to position a mobile RAN on-demand. Moreover, the achieved implementation allowed to show that the proposed ODMMF network function enables an on-demand network that is fully compatible with the architecture of 5G networks.

ODMMF in its current version considers human intervention to remotely control the mobile RAN positioning, based on the visual information provided by the video cameras on-board the mobile robotic platform. The use of algorithms capable of determining autonomously the position of the mobile robotic platform is worthy of being considered as future work. Moreover, algorithms capable to detect UEs autonomously, while avoiding the collision of the mobile robotic platform with obstacles will allow to minimize human intervention and the associated Operational Expenditure (OPEX) costs.

Regarding the experimental prototype considered, despite USRP B210 is recommended by OpenAirInterface to deploy a 5G network, the tests carried out showed the main limitations associated with this SDR model. USRP B210 uses a USB interface to establish a physical connection with the host computer; this interface degrades significantly the system performance, especially when other USB devices are connected to the same computer. For this reason, alternative SDR models that use an Ethernet connection to the host are recommended.

VII. Conclusions

We propose an obstacle-aware on-demand 5G network, composed of a gNB carried by a mobile robotic platform which is controlled by a novel On-Demand Mobility Management Function (ODMMF) deployed in the 5G Core network. ODMMF makes available two *Web* pages so that a Mobile Network Operator is able to 1) monitor the 5G wireless links established between the mobile RAN and the served UEs, and 2) control the positioning of the mobile RAN, leveraged by the video cameras carried by the mobile robotic platform. The experimental tests performed allowed to validate the proposed solution, showing that a Mobile Network Operator can reconfigure the 5G network on-demand, in order to provide 5G connectivity to UEs outside the coverage of fixed BSs.

As future work, we aim to evolve the ODMMF network function so that both the detection of UEs demanding 5G wireless connectivity and the control of the mobile robotic platform movement can be done autonomously.

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