V2MEC: Low-Latency MEC for Vehicular Networks in 5G Disaggregated Architectures

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***Abstract*—5G redefines the network architecture, through the introduction of base station disaggregation, adding up to the overall flexibility for deployments of network elements based on the existing demand. Moreover, through the wide application of Multi-access Edge Computing (MEC), the latency for accessing services offered on top of the infrastructure can be drastically minimized, thus supporting several applications that exchange critical data over the network. Vehicular communications are a type of applications that can highly benefit from the MEC approach, as they need to exchange critical data with road-side infrastructure (V2I). Nevertheless, the technology through which the vehicles exchange data with the infrastructure may cause fluctuations to the network performance observed by the end-users. In this work, we blend the concept of disaggregated 5G base stations with integrated access for non-3GPP technologies, and the MEC concept, by realizing a novel placement for services that is not yet suggested in existing literature. The setup is applied to a vehicular environment, providing the ability to dynamically steer the traffic over multiple technologies serving each user (vehicle) of the network. We implement, deploy and evaluate our solution in a testbed environment, providing proof on reduced latency for accessing the MEC services as well as the role that the technology selection plays for the overall performance observed by the end-users.**

***Index Terms*—Multi-access Edge Computing, Cloud-RAN, OpenAirInterface, testbed**

I. Introduction

The fifth generation of mobile networking (5G) is fostering several advancements in the access, edge and core network, promising to offer higher network capacity with lower latency, allowing a variety of (critical) services to thrive around this ecosystem. Towards stressing its wide adoption, Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications have been considered since the initial design of the protocol, with the target of creating a radio access architecture that matches the needs of all several applications around this ecosystem. 5G also benefits from the wide application of Multi-access Edge Computing (MEC) [1], by serving network users directly from the network edge. Such functionality is highly beneficial especially for resource constrained devices such as vehicles, as they can offload several parts of processing to the network edge. In the MEC concept, heterogeneous technologies reside in the user access network, adding up to the overall network capacity by forming ultra-dense networks.

Along with the full integration of the MEC functionality in the network, 5G brings several new advances in the overall network architecture. The advent of Cloud-RAN design [2] for base stations allows the re-conception of technology solutions like MEC. 5G-New Radio (NR) specifications [3] define the disaggregation of the base stations based on the 3GPP Option-2 split [4], between the Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) of the mobile stack. This creates two entities: the Central Unit (CU), located at the edge, and the Distributed Unit (DU), providing the actual access network. DUs can provide different access technologies (5G NR, 4G LTE or WiFi), served through the same CU. Each CU may control simultaneously multiple DUs, allowing the aggregation of heterogeneous links for serving each client.

Cellular Vehicle to Everything (CV2X) communications can widely benefit from such heterogeneity in the network access layer; given the nomadic behaviour that vehicles show in the coverage areas of base stations, and the need for ample connectivity for their applications (e.g. infotainment, critical communications), network heterogeneity and aggregation of links can be highly beneficial. Although MEC has been considered as a low-latency enabler for 5G, its application is merely mapped to the new network architecture; its integration considers the same placements for the edge resources as in previous solutions (e.g. LTE) despite the new architecture. In this work, we propose and experiment with the MEC service placement closer to the network edge, collocated with the DUs of a disaggregated base station setup, realizing truly the Edge Computing concepts in a vehicular environment. The services provided to the network users are placed at the base station fronthaul, thus minimizing access latency. Such setup is highly beneficial especially for V2I message exchange, as through the integration of Network Functions Virtualization (NFV), the real-time migration of services can be supported.

Through a software prototype implementation, we deploy V2MEC, a disaggregated multi-RAT network with services being directly accessible from the vehicular clients through the DUs of the network. The main contributions of the paper are sumamrized as follows:

- To realize and experimentally evaluate a prototype for accessing services placed directly after the DU of the network.
- To provide proof of the lower latency achieved compared to traditional MEC deployments.
- To evaluate different scenarios that can be used for making decisions on the placement of each service in the network.

The rest of the paper is organized as follows: Section II presents our motivation and indicative related literature. In Section III we briefly present the framework for disaggregated Multi-RAT base stations in the V2MEC context.In Section IV, we present evaluation metrics for the solution and compare

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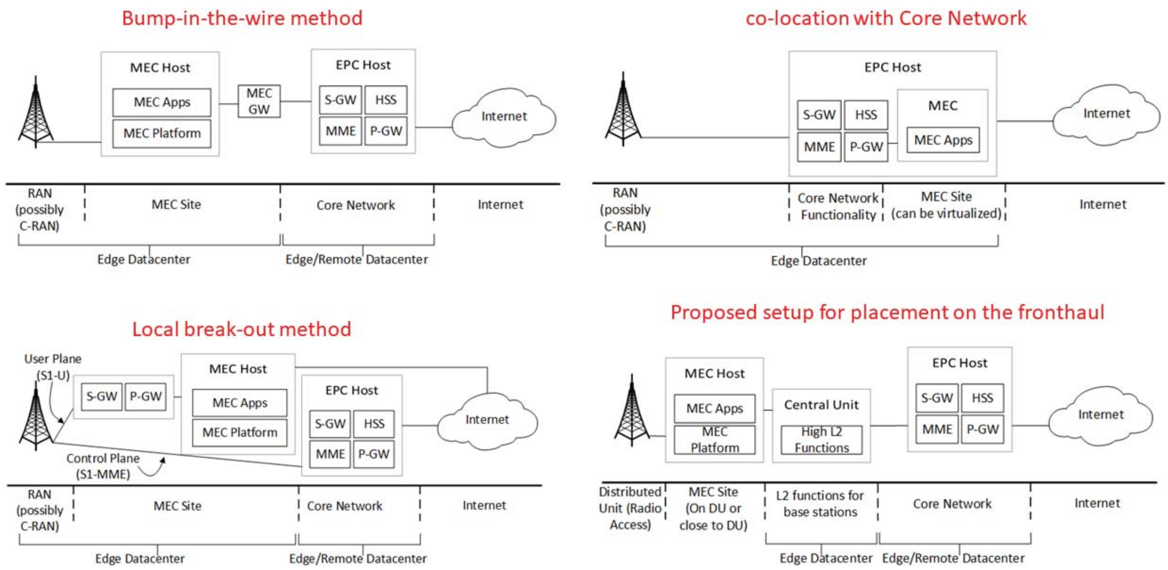

Fig. 1: Existing vs proposed MEC service placement methods

it with legacy MEC placements. Finally, in Section V we conclude and present future directions.

II. Motivation and Related Work

The integration and placement of computing resources as close as possible to the radio access network has attracted a lot of attention lately, with interfaces being developed specifically for integrating MEC functionality in the 5G context [5], [6]. The application of MEC resources for CV2X communications is a topic receiving much of attention in relevant literature due to its capability to minimize service access latency, especially for time critical applications. For instance, in [7] the authors employ MEC resources in order to minimize the end-to-end latency for Vulnerable Road User (VRU) applications. In [8], the authors propose and evaluate their architecture for V2I communications using cellular networks for the communication with the edge services. The authors propose and evaluate the efficiency of their path-establishment framework that traverses traffic through MEC resources in the case of rapid handovers. Similarly, in [9] a detailed framework is presented for service replication across different MEC servers along the path in which the vehicle is moving. Extensive simulations pinpoint the delay benefits for service access, compared to solutions that migrate content re-actively.

Nevertheless, such works employ existing approaches for placing services on the network edge that have been around since legacy protocols (e.g. LTE), with changes being integrated mainly in the network access level. Different methods for deploying and placing MEC-assisted services are suggested by ETSI in [1] and [10], providing guidelines for the maximum delay of the UE to service path for some state-of-the-art 5G applications (e.g. Industry 4.0, eHealth, AR/VR, etc.). Existing proposed placements are summarized in:

1) The *bump-in-the-wire* method, where data-plane traffic is intercepted on the base station backhaul (link with Core Network), and redirected to the MEC applications.
2) Collocating MEC servers and the Core Network (CN) at the network edge. In such a case, IP traffic is intercepted beyond the CN and redirected to the MEC applications.
3) Using a Core Network with a *Local Breakout (LBO)* mode: control plane traffic is redirected to another Core Network instance than the data plane. MEC applications are introduced closer to the edge, collocated with the edge core network instance, and handle only data plane traffic.

A graphic representation of all the suggested placements is illustrated in Figure 1. Although such concepts are introduced in the 4G architecture, they are applied directly to the 5G architecture as well. The most adopted architecture for 5G NR networks is the LBO setup, where capitalizing on the Service Based Architecture (SBA) of the 5G-Core Network, the User Plane Function (UPF) is placed along with the cell at the network edge, offering a direct connection to the Data Network (DN). MEC applications might also be virtualized, enabling further innovations such as their live migration, etc.

With the emergence of Cloud-RAN, the mobile networking stack has been redefined and split at different levels [11]. Yet, the split at the higher layer 2 of the stack (between PDCP and RLC) has been standardized in the 5G NR specifications [3]. As already mentioned, these specifications define the Centralized Unit (CU) that runs the upper OSI layer 2 functions and can be instantiated at an Edge Datacenter managing one or multiple Distributed Units (DUs), that may be of heterogeneous type and integrate the lower Layer 2 and 1 functions. The disaggregation of the base stations at such layer (PDCP) enables the integration of multiple technologies to the cell; the LTE WiFi Aggregation Adaptation Protocol (LWAAP) [12] considers controllong WiFi cells from the PDCP layer of the base station. This functionality is drafted in the 5G-NR specifications, providing hooks for the integration of non-3GPP and legacy technologies (such as LTE) as DUs [3].

Despite the base station disaggregation, edge deployments do not move the services closer to the DU; in the best case,

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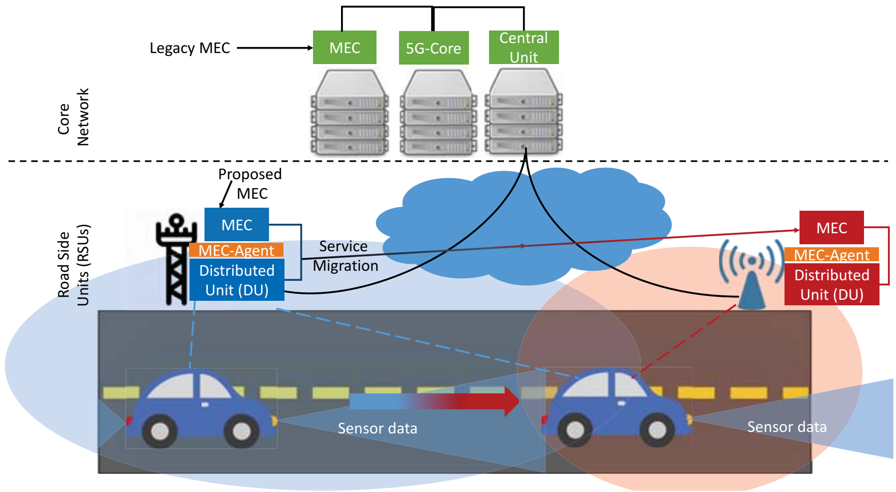

Fig. 2: Target architecture for MEC placement in vehicular networks (V2MEC): MEC services are colocated with the DUs of the system, at the road-side units offering significant less latency for reaching the services hosted at the MEC site.

the services are collocated with the CU [10], intercepting backhaul traffic (*bump-in-the-wire* or *LBO* method). In this paper, we build upon this idea, and experiment with services placed closer to the true edge, providing low latency access for vehicular users to edge resources (V2MEC). Moreover, we experiment with different placements of services that their delivered Quality of Experience (QoE) is affected by the network latency in order to reveal the decisions that can be taken for instructing a service migration from one location closer to the clients or switching the access technology in a per-user basis, that minimizes their network access time. Figure 2 presents our high-level architecture with the proposed placements for service placement. Features such as technology aggregation and dynamic switching of technologies through which the end-users are connected to the cell are highly beneficial for a vehicular environment. We leverage our prior works in [13] that introduces multi-technology base stations and in [14], that offers services on the fronthaul of disaggregated 4G networks.

III. System Architecture

The system architecture has been designed around three entities: 1) a CU that manages multiple heterogeneous DUs, 2) DUs, orchestrating the communication with the CU and the MEC services, supporting multiple wireless access technologies, and 3) a MEC Agent which communicates with the CU for the exchange of control information and the DUs for receiving and transmitting data to the wireless network. The MEC agent can be collocated with the DUs of the network, or be deployed at another datacenter in close proximity to the multiple DUs in the network. Our contributions are developed around the OpenAirInterface platform [15], which provides a software implementation of the LTE stack.

A. CU-DU design principles

According to the 5G-NR standards, disaggregated 5G base stations might address several different technologies. Hence, the standardized split is in the higher OSI stack layer 2, between Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) layers. One CU may concurrently manage multiple DUs, but each DU is only managed from a single CU. Therefore, in such setups serving concurrently a single UE through multiple technologies can be supported, just by redirecting traffic to the DU that the CU selects. Similarly for the uplink case, the UE can select the DU based on different criteria, e.g. the load of the cell, the perception that it has for the provided Quality of Service (QoS), etc.

In [13], we detail our contributions with the F1 over IP (F1oIP) protocol, introduced as a communication framework between the CU and DUs. The implementation supports integration of non-3GPP DUs (e.g. a WiFi DU), by appropriate handling of the transmitted information to/from the CU. As in vehicular environments different types of data can be exchanged (e.g. time critical from sensors/infotainment), different flows of data can be assigned to different technologies based on the available capacity and latency of each link.

B. DU-MEC communication

In order to incorporate services over the fronthaul, we need the appropriate interfaces between the DUs and the MEC platform that is hosting services/applications. In [14], we developed a protocol for DU to MEC communication and introduced a *MEC Agent* component. The agent generates and exchanges the appropriate messages with the DUs, and receives and delivers the respective payload destined for services hosted at the MEC site. The solution is similar to the *bump-in-the-wire* method by ETSI, though we progress beyond that work and place the service between the CU and DUs. The MEC service can also select the technology through which each UE is served in a per-packet basis, enabling the dynamic selection of the links per UE from the MEC's perspective. More details on this process are given in the next subsection.

C. Addressing clients over multiple technologies

As our setup is considering base stations disaggregated inside Layer 2, a mechanism is needed in order to properly

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address the UEs through the different DUs inside this layer. Each UE is establishing end-to-end Layer 3 connections with the Core Network (CN) or the services placed at the MEC. When the cellular UEs are attached to the network, they are addressed by the base stations using a Radio Network Temporary Identifier (RNTI). RNTIs map the data plane traffic for each client to logical, transport and physical channels. In the contrary, non-3GPP devices use MAC addresses.

In order to cope with this incompatibility, we developed control-plane signaling as follows: whenever a new client associates with the cellular DU and a RNTI is allocated, it is broadcasted to all the different DUs and MEC agents in the system as a *rnti_inform* message. The message includes information about the RNTI of the UE, an identifier for which client of the multi-RAT network is, and through which DUs it can be served. This information is used for mapping the RNTI and the IP address allocated by the Core Network to the UE. Similar messages are spawned whenever a UE is using a non-3GPP DU for the first time. With this approach, we ensure that all the entities of the network (MEC Agents, CU, DUs) are aware of all the clients and the DUs through which they can be served. In case of a UE using more than one technologies, the information is passed on the message, creating a mapping between the non-3GPP MAC address and RNTI used for cellular connection. A full description of this procedure and the control plane signaling between these entities of the network are presented in our prior work [16]. Through this functionality, we can address through the MEC part of the network all the UEs that are served through the disaggregated base station architecture. This means that the Agent might send the service traffic only to a set of pre-selected DUs, used for forwarding the traffic to the end-user.

D. MEC Service Virtualization

As mentioned, the MEC Agent orchestrates the communication of the services running on top with the DUs of the network. Whenever the agent receives MEC destined traffic, it decapsulates and injects it to the MEC service. The hosted MEC services are containerized, using Linux Containers (LXC) or Dockers, as they can be dynamically instantiated. Using LXC containers has multiple benefits as it allows each hosted service to be addressed with a new address at a new container that can be migrated to other hosts if needed. As LXC places all the hosted containers under a single bridge on the edge host, the MEC agent injects traffic to this bridge, destined to the MAC address of the container implementing the requested service. Through the aforementioned RNTI-IP mapping, multiple UEs can use the service, even when connected through different access technologies.

IV. System Evaluation

In this section, we describe the experimental setup and findings from evaluating the proposed scheme. As we mentioned, the framework has been developed around the OpenAirInterface platform that provides a software implementation of the cellular stack. Since currently NR support in the platform is very limited, we execute our experiments using a disaggregated cell with the LTE technology. As initial commercial deployments of 5G-NR in non-standalone mode indicate that the latency gains are in the range of 10% compared to LTE [17], we focus the experiments on the LTE technology for which the platform is performing in a more stable manner. Moreover, we incorporate a WiFi device as a DU, using the software module developed in [13]. We deploy the framework at the NITOS testbed, a remotely accessible facility located in Univ. of Thessaly, Greece [18]. We employ seven nodes from the testbed as follows: 1) one equipped with a compatible SDR front-end (USRP B210) for running the LTE DU software, 2) one with a WiFi card for running the WiFi DU, 3) three generic nodes for running the CU, OpenAirInterface Core Network and MEC Agent software respectively and 4) two more equipped with LTE dongles and WiFi cards for using them as our multi-homed UEs. Since the testbed does not offer mobility for the wireless nodes, we focus on a static setup, and delve into performance metrics from the deployed scheme.

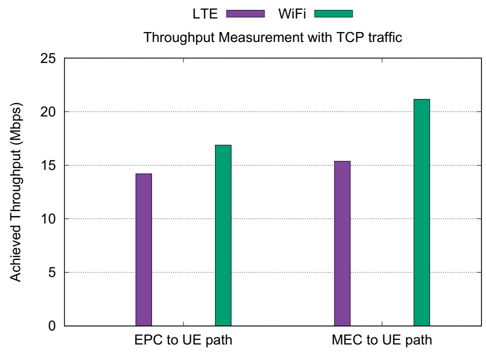

Fig. 3: Service to UE maximum TCP throughput

The latency times between the nodes using the Ethernet links are approx. $250ms$ (mapped to the blue cloud in Figure 2) whereas we configure the wireless parameters of the channels to settings that offer to us a more stable setup (5MHz SISO mode for LTE, 40MHz IEEE 802.11n in 2.4GHz for WiFi). We experiment with two different placements of the service: 1) placement with the DUs of the network and 2) collocation with the Core Network, one of the proposed deployments by ETSI. The respective achieved speeds over each UE for reaching the services at either the fronthaul or the Core Network (Evolved Packet Core - EPC) are provided as a reference in Figure 3.

We evaluate the overall scheme for the latency time for reaching the MEC service versus a traditional deployment of the service on the EPC (or beyond), and 2) the video streaming quality for multiple users for Dynamic Adaptive Streaming over HTTP (DASH), when placing the video server either with the DUs or at the EPC, accessed through different RATs.

Figure 4 shows measured latency over the different links when placing the service at the DUs, the Core Network, or emulating its placement on the Internet with injected latency of 5 and 10 ms. Usually, in production deployments the Core Network is not placed so close to the edge as in our testbed experiments, but is preferred to be instantiated in the datacenter

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of the network provider. Therefore, we provide measurements for the link with/without varying latency in the backhaul (link between the CU and the CN). ETSI in [19] has defined the requirements of several 5G applications/services (in terms of latency, throughput, etc.) running on the MEC of a Cloud-RAN and our proposed solution is demonstrating achieved latency times of less than 10ms for the LTE technology, rendering it as a feasible solution for executing several 5G applications even on a legacy network. WiFi access on the other hand is demonstrating lower latency times; this is due to the less complicated design and processes that the protocol implements. Nevertheless, in a non-ideal environment other than our testbed environment, with high external interference, WiFi is prone to lower performance and thus these times may change in a non-deterministic manner.

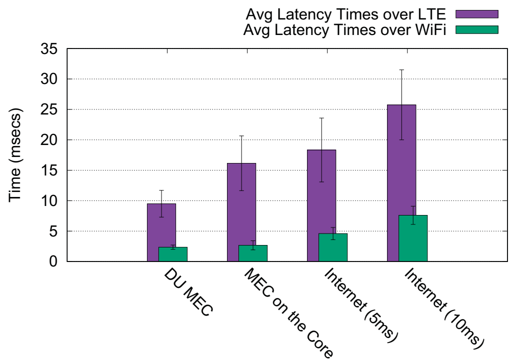

Fig. 4: Average latency measured

For the second part of the evaluation, we experiment with two UEs, connected simultaneously with LTE and WiFi. The UEs request video samples from a server placed either at the Core Network (collocation with the Core) or the MEC server (collocation with the DUs). For testing video services, we use a MPEG-DASH server [20], streaming videos of varying resolution (video is broken down to 1 sec segments with qualities up to 1080p). This means that for each second of the video, the client requests a segment from a set of different transcodings. The server is running through an Apache2 service, in the MEC Agent containers and the CN for comparing their performance. According to the descriptions of the available video segments and the video requesting algorithm running on the application, the video is downloaded to the client. We use VLC as the end-user application, based on the policies that are described in [21]. The policy that we use for streaming the video is the following: for each video segment, VLC estimates the channel's download rate. For the next segment to be downloaded, it requests the video with rate equal to the download rate. In the case that it does not exist (video coding rate can be lower than the channel rate), it requests the next lower available. For the cases that the video buffer is less than 30% occupied, the client requests the lowest available representation. Through this policy the quality that each client requests is shown, based on their network view.

We plot the requested video-rate based on its understanding of the underlying wireless channel. This scenario is showing results of how the application provider could discriminate between different subscription plans of clients, allowing certain subscribers to access the same service located at the edge datacenter contrary to the rest. Since our experiments indicate that the access technology plays a significant role in the UE application performance, we experiment with both technologies and for all the different placements of the service.

Figure 5 shows the plotted VLC rates for the different placements of the video server accessed through different technologies. When both of the clients use the LTE channel and request video from the MEC and the Core Network (CN) servers concurrently, we observe that the UE requesting from the MEC service gets better video quality (purple and green lines in Figure 5a). The node requesting from the fronthaul service quickly converges to the highest rate (6 Mbps) whereas the node requesting at the Core Network barely gets over 3 Mbps. We see that at approx. 15 seconds of experimentation, both UEs drop their requested rate to the minimum possible, due to the fact that their buffer is emptied. However, when they request video samples again, the MEC requesting UE is getting the highest possible performance. For the experiment when both UEs use only WiFi to access either the MEC or the EPC server (gold and red lines in Figure 5a), we observe that both of them quickly fill their buffer and request very rapidly the best video representation available. This fact is happening due to the slightly better capacity and lower latency of the WiFi medium for our experiments, as shown in Figure 3.

When we introduce one WiFi UE, we see that regardless of where the service is deployed (MEC/CN) the WiFi UE is able to very quickly converge to the highest video representation available (Figure 5b). We see that for the same cases, the LTE UE requests the highest representation available. However, in the scenario that the LTE UE is requesting the data at the MEC service, the rate is reached very rapidly in the experiment (less than 10 seconds) whereas for the case that the LTE UE is requesting at the EPC service, it takes just over 30 seconds to request the highest video representation available. This is happening entirely due to the location of the service closer to the edge, as both buffers quickly fill with over 70%.

V. Conclusion

In this work, we proposed, developed and evaluated V2MEC, a framework for dynamic selection of the technology through which each UE is served from the Edge in a vehicular environment. Starting from a disaggregated Cloud-RAN deployment, we experimented with a novel placement of the services, for which our experimental results show up to 60% minimization in the service access latency time. Moreover, we experimented with different placements of the service and demonstrated how in conjunction with the wireless technology selection, it can impact the UE's QoE.

In the future, we foresee extending the scheme to include a machine-learning process for the live migration of the services to different edge hosts. As the framework is compatible with the NFV principles for the services being deployed at the edge, it has the potential to off-the-shelf support a follow-me approach for the services offered to vehicular users. Through monitoring the traffic patterns of each UE at the core network,

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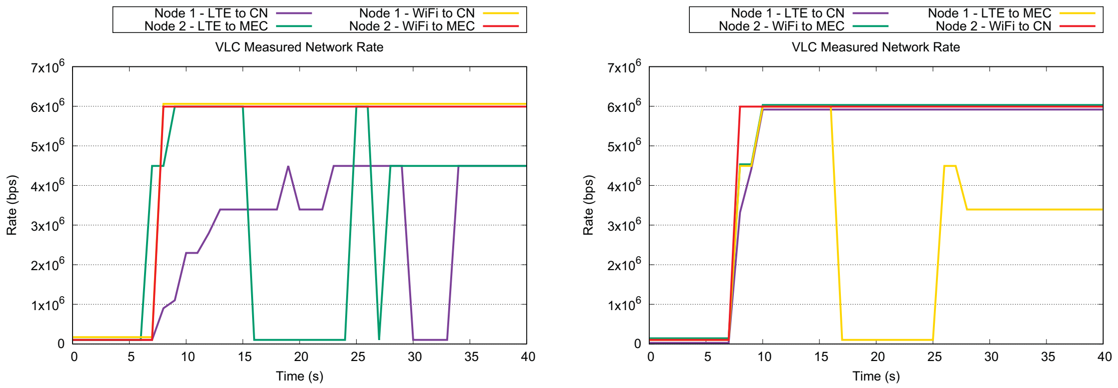

(a) VLC Rate - 2 experiments with UEs using the same access technology, requesting from different servers

(b) VLC Rate - 2 experiments with UEs using different access technology, requesting from different servers

Fig. 5: VLC rates for different placement of the service and different technologies at the UEs

and taking into consideration the wireless conditions at each DU and reported channel qualities from the clients, we plan to develop an algorithmic scheme in order to define where each service shall be placed, for ensuring each UE's QoE. This service instantiation can take place in a completely seamless to the UE manner, by exploiting the migration features of the containers hosting the network servers and using a DNS spoofing method at each DU in order to redirect the requests of each user to the new location of the service. A similar approach can be further applied in order to define the balance between the DUs for transferring the traffic to each UE.

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