Experimental Evaluation of Handover Strategies in 5G-MEC Scenario by using AdvantEDGE

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***Abstract*—The 5G-MEC architecture increases the heterogeneity and dynamicity of the available resources, presenting unique and competing challenges to researchers, network designers, and application developers. Recent studies indicate AdvantEDGE as an interesting emulation platform to investigate these challenges. The paper presents a particular example of AdvantEDGE usage. A testbed composed of the emulated 5G-MEC architecture and the VideoLAN application allows to analyse the performance of alternative handover strategies, developed by using a multi-objective approach. The study shows how AdvantEDGE allows a deep analysis of the behaviour of the different strategies during the emulated user mobility, giving the possibility of measuring performance parameters at different layers, i.e. IP, application, and end-user.**

***Index Terms*—Multi-access Edge Computing, AdvantEDGE, 5G-MEC Emulation, Handover.**

I. Introduction

The Fifth Generation (5G) of mobile networks and Multi-access Edge Computing (MEC) enable new services but increases the complexity of the performance evaluation of new algorithms, protocols, and applications. The Quality of Experience (QoE) of a service depends on a large number of different parameters such as where the application is deployed, and what is the network performance. In most cases, simplified theoretical or simulation models do not allow accurate estimation of the tested strategy/algorithm/protocol/application performance and the QoE. To help researchers when designing and verifying their solution for deployment across heterogeneous edge networks, a set of emulation tools have been developed. Aral et al. [1] propose a survey of exiting edge emulation and simulation tools, categorizing their capabilities. Gazda et al. [2] summarize the main features of a set of network simulators with edge capabilities, emphasizing the main problems of these tools. [1], [2], and [3] describe key features for an edge emulator that include: 1) capability of interconnection with external nodes (e.g., phone, drone, constrained edge devices, or GPU equipped nodes); 2) emulation of wireless mobility to consider network re-configuration procedures triggered by handover between different wireless access networks (e.g.,4G, 5G, WiFi); 3) edge emulation for edge-native services exploiting the relevant information given by the MEC services (e.g., Radio Network Information Service, Location, etc.); 4) metrics real-time measurement, visualization and post-analysis; 5) extendibility and scalability. As outlined in [2], AdvantEDGE [4] is an open-source edge emulator developed considering these key features. It offers an experimentation environment for researchers, programmers, and network designers to develop edge-native applications and services. AdvantEDGE enables dynamic emulation for a wide range of edge networks, helping to address, in agile iterations, open architecture questions such as where to deploy edge resources and edge application components across them, how to route traffic, and when to trigger a network handover or an application migration. For example, Burbano et al. [5] use AdvantEDGE to embrace realistic network parameters during the system communication, which, through a sidecar attached to each connection, allows them to control parameters such as latency, jitter, packet loss (PLoss), and throughput. Blakley et al. [6] integrate AdvantEDGE with a specially instrumented client application, physical cloudlets and commercial LTE networks to gather application and infrastructure measurements that inform design decisions.

Our paper presents another example of the usage of AdvantEDGE. In particular, we carry out the performance analysis of different handover strategies by considering a multi-objective approach. The analysis has been carried out by using an experimental testbed composed of an emulation of the 5G-MEC system and the videostreaming service. The videostreaming service is composed of the VideoLAN server running in a MEC Host (MEH) and the VideoLAN Client (VLC) running in the User Equipment (UE). The AdvantEDGE features allow the implementation of a mixed real-emulated scenario, which enables the simultaneous analysis of three different classes of performance parameters. These are i) a class reporting the measured data at the transport layer (i.e. packet loss, latency, jitter and throughput) ii) one showing the statistics of the application (frame loss, decoded and dropped block, and outage period), and iii) QoE of the end-user expressed by the Mean Opinion Score (MOS) rating.

The paper is organized as follows. Section II describes the main features of AdvantEDGE and the emulated network scenario, while Section III presents the compared handover

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strategies. Section IV describes the testbed and the performance metrics, while Section V shows the results. Finally, Section VI concludes the paper.

II. Emulated Network Scenario

AdvantEDGE is Mobile Edge Emulation Platform (MEEP), enabling experimentation with edge computing. In particular, AdvantEDGE facilitates exploring MEC deployment models and their impact on applications and services in short and agile iterations [4]. The MEC APIs provided by AdvantEDGE allow to obtain information on the state of the network scenario. Furthermore, they allow changing the network characteristics and the location of devices on the network by sending API requests. AdvantEDGE allows the emulation of a tree network topology through which to forward packets to and from external services. Moreover, AdvantEDGE allows giving a physical position to the elements in the network, by inserting the geographical coordinates to each of them. By emulating the behavior of a connection, AdvantEDGE influences the data traffic flow with the impairments configured by the link parameters (latency, jitter, PLoss, datarate). In order to simulate a dynamic scenario, AdvantEDGE allows the emulation of the client's movement.

In this study, the scenario consists of one client and one fixed MEH, located in Pisa near the Arno river. The UE can reach a MEH by using three alternative access network technologies: WiFi, 4G, and 5G. Obviously, depending on its geographical position, the UE can also be disconnected from every access network technology and, then, it cannot have access to the MEH services. The path of the UE is shown in Figure 1 using a blue line. In the same figure, the coverage of each network access technology is represented by different colors: WiFi in red, 5G in orange and 4G in blue. The Points of Access (PoAs) of the three technologies are co-located in two geographical points. The coverage radius of WiFi is 200 m, while 500 m and 1000 m is the coverage radius of 5G and 4G, respectively.

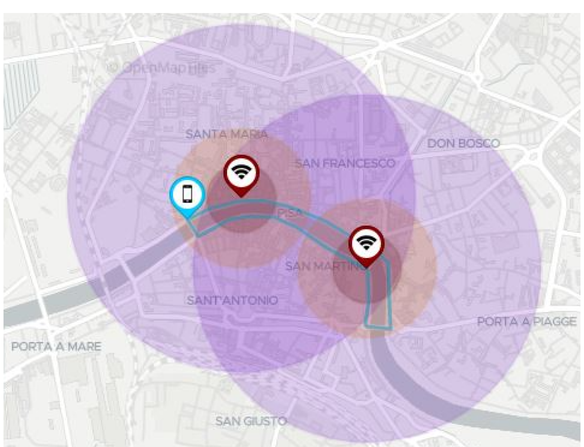

Fig. 1. Map of the scenario considered in the experimental analysis with the AdvantEDGE platform.

The AdvantEDGE representation of the network scenario is shown in Figure 2. The brown boxes are the applications, while the green is the physical UE. The antennas represent the PoAs. The MEC Application runs on the MEH (`edge1` in the figure) connected to a point on the network called `Zone3`.

The *Zone* elements allow to group multiple network locations together. The logical Zone defines intra-zone network characteristics for traffic crossing between these network locations. In the figure, `Operator1` is the Internet Service Provider (ISP) providing the IP connectivity through the three access technologies and the IP services supported by MEC.

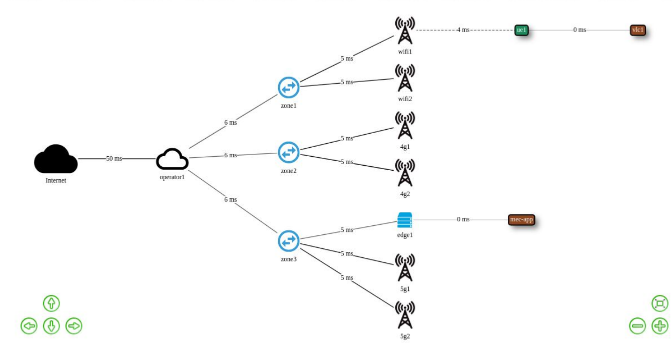

Fig. 2. Network scenario described by the AdvantEDGE GUI.

The graph of the considered network scenario is shown in Figure 3. The attributes related to each link are respectively the PLoss probability, the jitter, and the latency. For each PoA, the figure shows also the available datarate.

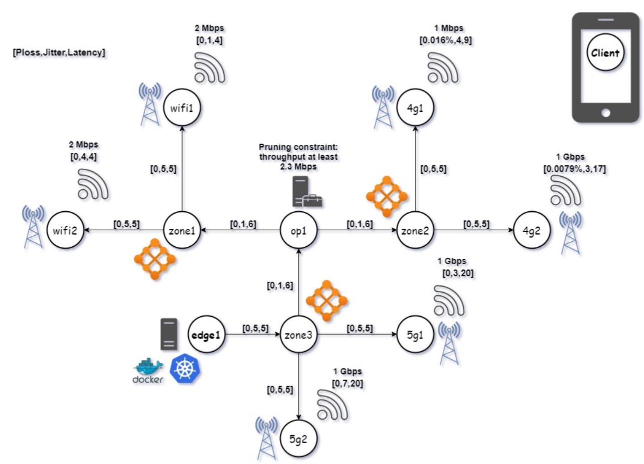

Fig. 3. Graph of the considered network scenario.

Referring to Figure 3, Table I summarizes the value of each metric of the path between the MEH and the UE, as a function of the used PoA. The last row of the table shows the data rate (DR) available on the radio link in the congested scenario (C.S.).

In the study, the GIS API (getGeoDataByName) has been used to obtain information about the geographical position of the UE during its movements. These data allow estimating the distance between the UE and the different PoAs of the

TABLE I
PARAMETERS OF THE PATH FOR LDT AND MDT TESTS.

MEH-UE	WiFi-1	4G-1	5G-1	WiFi-2	4G-2	5G-2
PLoss (%)	0	0.016	0	0	0.0079	0
Jitter (ms)	13	16	13	16	15	17
Latency (ms)	26	31	30	26	39	30
DR C.S.(Mbps)	2	1	1000	2	1000	1000

network. This information is used by the decision algorithm for establishing the PoA giving connectivity to the UE. The Sandbox API (sendEvent) of AdvantEDGE allows changing the PoA to which the UE is connected (i.e. perform the PoA handover) at runtime. The data necessary to build the graph, (i.e. arcs, nodes and the attributes value of the arcs) can be acquired runtime using the API of the MEC architecture. In order to reduce the complexity of the experimental tests, the attributes values of the arcs are assumed to be constant during the experiments. Thus, these values have been manually configured in AdvantEDGE. The control plane procedure for performing handover between PoA of the same technology or between different technology, known as multi-Radio Access Technology (multi-RAT) handover, is not considered by AdvantEDGE. Hence, the delay and some performance issues (e.g., loss of packets or jitter increase) added by this procedure are neglected.

III. Compared Handover Strategies

The experimental analysis compares four different handover strategies, some of these use the following
Decision Algorithm: the set of PoAs that can offer connectivity to the UE is ordered considering the values of PLoss, Jitter and Latency shown in Table I. In particular, the strategy is to select the PoA with the lowest value of the PLoss metric. If more than one PoA has the same lowest PLoss value, the PoA with the lower jitter is chosen. In case these two steps output more than one PoA, the procedure considers the lowest value of the latency. Obviously, depending on the applications, the priority of the metrics used in the decision can be changed.

The compared handover strategies are the following.

- **LTE-only with Default Throughput (LDT)**: This case is the simplest one. The UE can connect only to 4G PoAs. The datarate available in each radio link is set to the default value, which is higher than the minimum datarate required by the application. In this test, the decision of the handover is simply performed evaluating when the UE is outside the coverage range of the serving PoA (i.e., 4G-1 or 4G-2). Then, the new PoA is the nearest one to the UE.
- **Multi-access scenario with Default Throughput (MDT)**: In this case, the three available access technologies are considered. For each technology and for each PoA, the datarate is set to the default value. In other words, the DR C.S. values of Table I are not considered. Exploiting the GIS API information, for each UE position, runtime the set of PoAs able to guarantee the connectivity to UE is defined. This set is the input of the decision algorithm that outputs the selected PoA for the measured UE position. If the PoA returned by the algorithm is different from the serving PoA, the sendEvent of the Sandbox API is generated for performing the handover to the new PoA.
- **Multi-access scenario with Throughput Performance Data and Without pruning (MTPDW)**: Differently from the MDT, in this case it is assumed that the radio links are congested. Then, for each PoA the available datarate is reported in the last row of Table I. However, these values are not considered by the decision algorithm selecting the PoA offering the connectivity to UE.
- **Multi-access scenario with Throughput Performance Data and with Pruning (MTPDP)**: This case is like the MTPDW, with the difference that the decision algorithm will consider the minimum datarate required by the application. In detail, the decision algorithm described above is applied on the subset of the PoAs, which is composed of PoAs providing a datarate higher than the minimum required by the application.

IV. Description of the Testbed

The testbed used for the experimental analysis is described in Figure 4. Two physical PCs are used. The most powerful is based on a CPU Intel Core i7-8750H @ 2.20GHz, with 6 virtual CPU cores and 16 GB of RAM. This hardware has been configured to host the AdvantEDGE framework installed in a VirtualBox Virtual Machine (VM) running Linux Ubuntu 18.04 OS hosted by Windows OS. The VM has IP address 192.168.178.145. The same hardware is used as MEH with IP address 192.168.178.200. The MEH supports the entertainment video service, implemented by means of a VideoLAN server [7] running on the Windows OS. The VLC runs in a PC with Windows OS and has IP address 192.168.178.100. Since AdvantEDGE runs on the same PC implementing the MEH, the traffic forwarding is obtained referring to the port number. As reported in Figure 4, the traffic from the external to AdvantEDGE is addressed to the port number 30171, while 30141 is the port number used to forward the traffic from AdvantEDGE to the external node (i.e. the VLC). The MEH streams the video using the MPEG Transport Stream (MPEG TS) protocol, defined in the ISO/IEC standard 13818-1 [8], over UDP. The traffic is modified by AdvantEDGE depending on the network characteristics set on the scenario. As a consequence, the quality of the streamed video might be affected at various degrees. The chosen video used during the tests shows nature landscapes and lasts 334 seconds. Other features of the video are summarized in Table II.

AdvantEDGE uses Grafana dashboard [9] to acquire data during the emulation. In particular, Grafana allows the visualization of different network statistics. Among these, a key statistic is the instant when the handover events happen. The data visualized by Grafana can be exported in `csv` format at the end of the experiment.

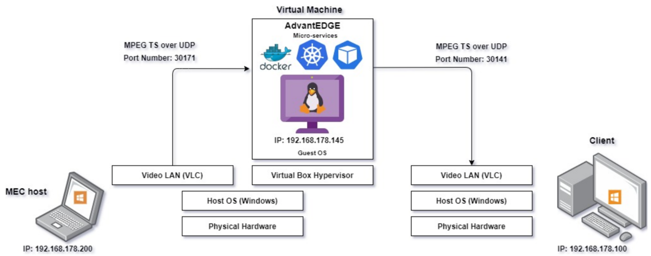

Fig. 4. The testbed.

TABLE II
FEATURES OF TRANSMITTED VIDEO

Codec	Video bitrate	Audio bitrate	Width	Height
H.264	2000 kbps	128 kpbs	1280 px	720 px

A. Performance Metrics

During each test, three different classes of performance parameters have been collected and analyzed. The first class refers to the set of parameters that are given by AdvantEDGE. These are the following:

- **Packet Loss (PLoss)**, defined as the ratio between the number of packets that fail to reach the egress point of AdvantEDGE (denoted as N_E) and the number of packets observed in its ingress point, N_I:
$$Ploss = \frac{\mathrm{N}_I - \mathrm{N}_E}{\mathrm{N}_I}$$
These losses are measured in the AdvantEDGE environment. For each packet and in each link of the network, the packet lost is randomly established with the probability set by the AdvantEDGE user. The observed values do not consider the losses in the link between the external nodes (i.e. MEH and VLC). In the testbed, these losses are zero, because a dedicated 1 Gbps Switched Ethernet LAN is used.
- **Latency**, defined as the time a packet takes to be transferred between the ingress and the egress point of AdvantEDGE. Considering a path composed of more than one arc, the overall latency is the sum of each latency value on the arcs. The AdavantEDGE generates the value of the latency of a packet in each link using a random variable with a Gaussian distribution, where its mean represents the latency value and its standard variation the jitter, provided as configuration parameters for each link.
- **Jitter** represents the measured standard variation of latency.
- **Throughput** is the maximum amount of data that can be transmitted in one second. In AdvantEDGE, a nominal datarate can be set for each link of the emulated network scenario. The reported value instead is measured by observing the selected traffic flow.

The second class refers to the subjective QoE that is observed by the end user during the service. The considered parameter is the MOS, which represents the mean of the absolute score given by the customers according to their satisfaction during the visualization of the video. As recommended by the ITU-T P800 standard [10], an Absolute Category Rating (ACR) is used to score the experience by using a five-point category-judgement, from 1 (Bad) to 5 (Excellent).

The last class contains a set of parameters given by the VLC. These parameters show the quality of the data transmission between the VideoLAN server and the VLC. The considered parameters are the following:

- **Decoded blocks** represent the number of encoded blocks that the VLC decoder converted into an uncompressed format.
- **Dropped blocks** are the number of dropped blocks. A drop can occur when the received blocks are not synchronized among them due to a delay in a network, or when a packet containing information about the video stream is lost.
- **Lost frames** refer to the number of lost frames during the reproduction of the streaming. These losses may occur when a block is lost or when the video decoder is unable to decode blocks.
- **Outage period** is defined as the amount of time during which the received video is stuck on the screen.

B. Preliminary Tests

The preliminary analysis is devoted to establishing the performance obtained in the best condition and to detecting the presence of some transient periods. During these preliminary tests, some anomalies were always noticed in the first 17 s of the video service. These anomalies can be related to the time required by the PC hosting AdvantEDGE to overcome the overloading faced during the set up of AdvantEDGE. Indeed, AdvantEDGE requires the running of different virtualized software modules connected to each other, which represent a heavy requirement for the hosting PC resources. Thus, all the shown performance results are collected by neglecting the first 17 s of the experiment.

The reference performance is obtained by running an experiment in ideal conditions. During this test, the UE is connected to a 5G PoA without movement. No losses, no jitter and no delay are configured in the paths of AdvantEDGE. The communication between the VideoLAN server of the MEH and the VLC is ideal, i.e. without packet loss, and with negligible jitter and delay, both added by the connection outside AdvantEDGE. In this ideal condition, the VLC graphical interface showed 19749 decoded blocks and 9903 displayed frames.

V. MEASUREMENT RESULTS

A. Strategies with No Constraints on Throughput

These two experiments refer to the case where each PoAs can offer the maximum datarate, i.e. the last row of Table I is not considered. In other words, the assumption is that the datarate of each link is higher than the traffic rate generated by the VideoLAN server.

1) LDT strategy: Figure 5 shows the observed latency for each packet, and its average values estimated over a moving window of 20 samples, when the simple LDT strategy is applied. As described in the legend, the vertical lines show the handover performed by the UE. The handovers can be deduced from the color change of the vertical lines.

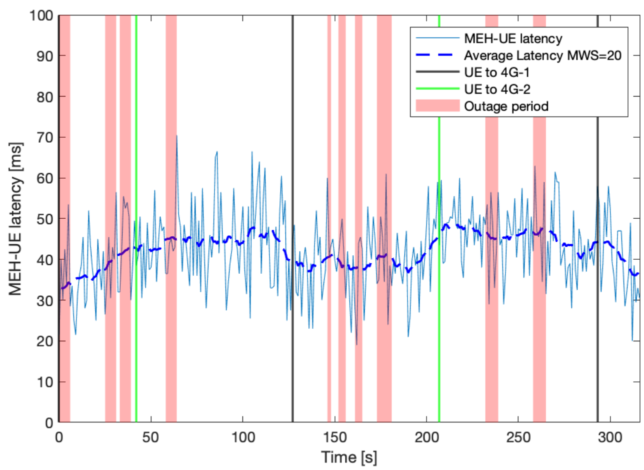

Fig. 5. Latency and Handover events - Case LDT

The red vertical bars of the figure indicate the observed outage period during the experiment. The figure shows that the outage periods are more frequent when the UE is connected to the PoA 4G-1. Indeed, this PoA has a packet loss probability higher than that of the PoA 4G-2 (see Table I).

Table III summarizes the observed performance parameters.

TABLE III
OBSERVED PERFORMANCE PARAMETERS - CASE LDT.

Decoded Block	16133	**Outage period (%)**	11.98
Displayed Frame	8725	**Outage period 4G-1 (%)**	26.03
Lost Frames	1178	**Outage period 4G-2 (%)**	11.07
MoS	2	**Average latency (ms)**	42.36

The percentage of the outage period corresponds to 38 s, while the observed average length of the outage periods is 5.8 seconds. These periods negatively influenced the QoE, as shown by a MOS value equal to 2. The periods related to the two PoAs are calculated as the ratio between the observed outage period when the UE is connected to 4G-1/4G-2 and the total time of connection with PoA 4G-1/4G-2.

2) MDT Strategy: The results obtained with the MDT strategy are summarized in Figure 6.

During the experiment, no outage period has been observed. The quality of the video was high without any disturbing interruption.

These results can be easily explained. Indeed, the only interruptions that could occur might be caused by the overloading of the MEH PC (due to limited resources), or during the brief intervals of the connection between the UE and the 4G-2 PoA, which has the highest packet loss probability. During this test, 23 handover events were observed, compared to 4 handover events of LDT. This observation shows that the decision algorithm solve the issues related to bad quality of connection, activating handover between PoAs. However, this approach could cause problems if the handover between the different PoAs takes a too long time (more than the video buffer time).

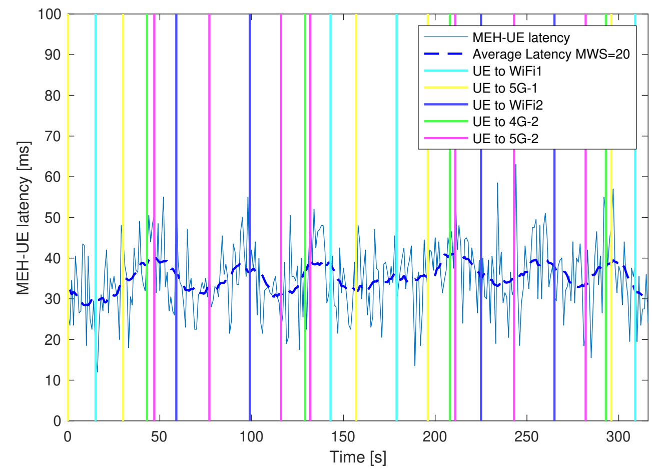

Fig. 6. Latency and Handover events - Case MDT

After the transient period represented by the first 17 s of the test, no lost frame is observed. During the transient period, 176 frames have been lost. The average latency is 35.15 ms.

B. Strategies with Constraints on Throughput

With respect to the previous cases, in these experiments the datarate of the link between each PoA and the UE is set to the values reported in the last row of Table I. Hence, some PoAs do not guarantee a datarate higher than the average video bitrate, which is equal to 2.32 Mbps.

1) MTPDW Strategy: During this experiment, the decision algorithm is applied to the whole set of PoAs able to guarantee the connectivity to UE. No selection of the PoAs subset offering a minimum throughput is performed. Hence, the decision algorithm could choose a PoAs that does not satisfy the throughput requirements of the video service. This scenario leads to outage periods and also to events where a low quality of the video is observed.

As shown in Table I, the PoAs that do not satisfy the throughput requirements WiFi-1, 4G-1 and WiFi-2. The paths using these PoAs fail to guarantee sufficient throughput for forwarding the video traffic at the streaming bitrate speed.

Figure 7 shows the obtained results in terms of measured throughput. In the figure, the vertical lines with different colors represent the handovers between PoAs.

The dashed red lines give the reference value of the traffic generated by the VLC application. This value has been obtained by measuring the traffic throughput in ideal network conditions, i.e. with no loss and very high datarate in each

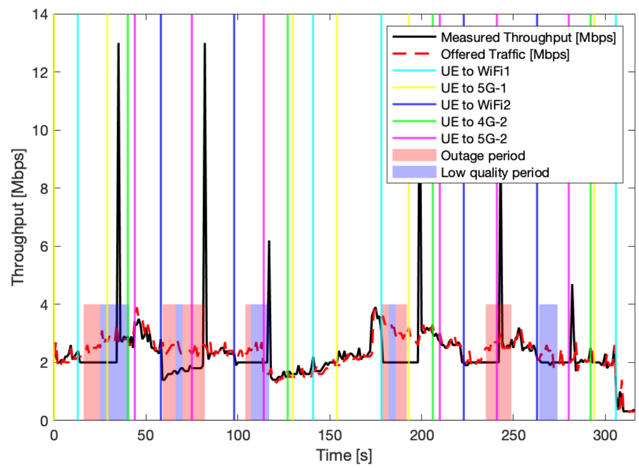

Fig. 7. Bitrate, Handover events and Low Quality events - Case MTPDW

network link. In the figure, the outage periods are represented by the red bars, while the low quality periods are represented by the blue bars.

Figure 7 clearly points out the correlation between the quality of received video with the measured throughput. Indeed, when the UE is connected with one of the three PoAs with a datarate lower than the required datarate, low quality events and/or an outage period occur.

The playout buffer of VLC is set to 1 s. When this buffer is emptied and the new contents arrive too slowly, due to the insufficient throughput guaranteed by the path, an outage period occurs. VLC shows the contents, as soon as the buffer is filled up again. Obviously, when the throughput is insufficient, the time it takes to fill up the buffer is longer than the time it takes to empty it. Hence, the video is not fluid and looks like a set of pictures, showing a low quality.

TABLE IV
OBSERVED PERFORMANCE PARAMETERS - CASE MTPDW.

Decoded Block	15363	**Outage period (s)**	55
Displayed Frame	7925	**Outage period (%)**	13.88
Lost Frames	1978	**Low Quality Period (s)**	44
MoS	1	**Low Quality Period (%)**	17.35

In the figure, the peaks of the measured throughput (black line) are related to buffered traffic in the network that is delivered to the UE as soon as the UE connects to a PoA with enough throughput. The other performance parameters as summarized in Table IV.

2) MTPDP Strategy: In this experiment, the input of the decision algorithm is the subset of PoAs having a datarate higher than 2.32 Mbps (i.e., the measure average throughput of the video application), i.e. 5G-1, 5G-2 and 4G-2.

Figure 8 shows the results obtained with the MTPDP strategy. The figure clearly points out that there is no outage period and not even low quality events. The throughput of the selected paths is always higher the requirements of the video service. The quality of the video is high, therefore the MOS score is 5. Except for the frames lost during the transient phase, no losses have been reported by the VLC statistics.

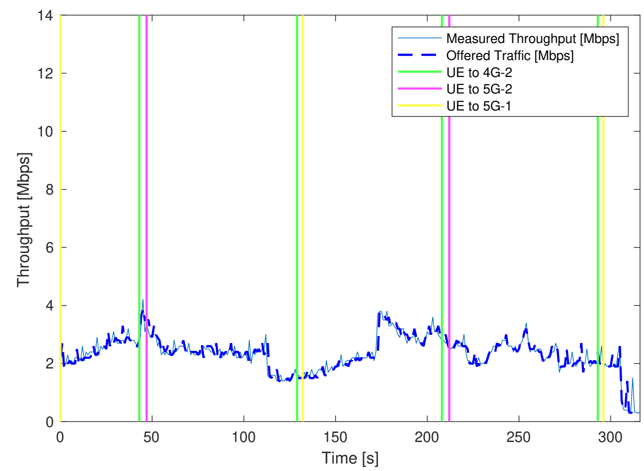

Fig. 8. Handover events, Measured Throughput and Offered Traffic - Case MTPDP

VI. Conclusions

The presented experimental analysis shows the large set of data that can be acquired with AdvantEDGE emulator interconnected with external devices. The presented analysis points out the performance enhancements given by the multi-objective strategy that considers the minimum throughput guarantee. As shown by the results, the QoE is maintained during the movement of the UE or the degradation of the network conditions.

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