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# Impact of the LTE Scheduler on achieving Good QoE for DASH Video Streaming

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*Abstract*—**Dynamic adaptive video over HTTP (DASH) is fast becoming the protocol of choice for content providers for their online video streaming delivery. Concurrently, dependence on cellular Long Term Evolution (LTE) networks is growing to serve user demands for bandwidth-hungry applications, especially video. Each LTE base station's (eNodeB) scheduler assigns wireless resources to individual clients. Several alternative schedulers have been proposed, especially to meet the user's desired quality of experience (QoE) with video. In this paper, we investigate the impact of the scheduler on DASH performance, motivated by the fact that video performance and the underlying traffic models are different from other HTTP/TCP applications. We use our laboratory testbed employing real video content and streaming clients, over a simulated ns-3 LTE network. We quantify the impact of the scheduler and show that it has a significant impact on key video streaming performance metrics such as stalls and QoE, for different client adaptation algorithms. Additionally, we show the impact of user mobility within a cell, which has the side-effect of improving performance by mitigating long-term fading effects. Our detailed assessment of four LTE schedulers in ns-3 shows that the proportional fair scheduler achieves the best overall user experience, although somewhat disadvantaging static cell-edge users.**

## I. INTRODUCTION

The number of LTE cellular subscribers is expected to grow from the current 1 billion to 3 billion by 2019[1], with many users relying on smartphones and tablets to take advantage of the increased speed offered by the currently-deployed LTE technology. Mobile video accounted for 55% of mobile data traffic in 2015 and is expected to hit 75% by 2020[2]. The Quality of Experience (QoE) of video delivered over LTE continues to be a concern, despite the progress made with adaptive protocols for streaming video, such as Dynamic Adaptive Streaming over HTTP (DASH). Video stalls and frequent transitions to low video quality impact user experience, often leading to poor engagement, with users abandoning the video [1]. Improving video streaming performance over LTE is therefore key to ensuring the continued popularity of cellular networks and in satisfying user expectations.

DASH [2] has become the popular protocol for streaming video, especially because of its adaptivity and the ability to traverse NATs and firewalls with the use of HTTP. With DASH, the video is split into segments of short durations (4-10 Sec for mobile systems) and encoded at multiple representations for storage on the content provider's servers (or content delivery network nodes). The DASH client implements a rate adaptation policy to request the segments of video at a quality matching the available bandwidth for the video stream from the source. Multiple adaptation policies have been proposed in the literature to improve the streaming performance in a variety of operating scenarios [3], [4]. In cellular networks, the air interface is often the bottleneck and the manner in which wireless link resources are managed can have a large impact on video delivery. In LTE the air interface is managed by the cellular base station, known as the evolved NodeB, or eNodeB. The scheduler at the eNodeB assigns downstream wireless resources to end-points seeking to balance multiple considerations of throughput, latency and fairness. Of particular concern is the need to ensure reasonable service even to users with low signal strength at the edge of the cell. Thus, the scheduling policy plays a major role in the QoE of video users, motivating our empirical study.

DASH behaviour is influenced by TCP, which is in turn influenced by the LTE scheduler. There are three concurrent control loops in operation here. DASH seeks to adapt at the time scale of the segment duration, and the playout buffer at the client. TCP operates over the time scale of a few round trip times in managing its window size to adapt to the available end-to-end bandwidth. Finally, the LTE scheduler operates over much shorter time scales to assign air interface resource blocks to each end-point, known as user equipment (UE) in cellular network parlance. Additionally, DASH traffic is characterized by ON-OFF behaviour [5] as the playout buffer fills up to pre-defined thresholds, and then waits for a while before having to request the next video segment. It is important to understand the interactions across these three control loops on the user-perceived QoE. Thus we seek to illuminate the impact of the LTE scheduler on user-perceived QoE.

In this study, we implemented a laboratory testbed with real streaming video, in which the LTE network and the LTE eNB scheduling is emulated using NS3. We also implemented different adaptive streaming algorithms including the buffer based approach (BBA) [4], FESTIVE [3] and GPAC[3], an

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[1] http://www.statista.com/statistics/206615/forecast-of-the-number-of-global-hspa-lte-subscriptions-up-to-2014/

[2] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html

[3] https://gpac.wp.mines-telecom.fr/

Open Source multimedia framework. A DASH client requests encoded video from our video server that has stored videos at multiple quality representations. We performed experiments for several operating configurations including multiple different eNB scheduling policies and fading scenarios. We consider different performance metrics including video stalls, quality switches, average quality rate, and overall QoE. Stalls are considered due to their major impact on the the user-perceived impairment of quality [6]. We also considered other visual impairments, such as persistent low quality or frequent switching from one video quality to another. Our performance evaluation shows that when a UE is mobile there are significantly fewer reduce stalls and better average received quality rate, leading to a higher user QoE. We also show that cell-edge users suffer from significant streaming performance degradation with all schedulers. In such settings, we found that proportional fair scheduler leads to the best QoE on average. We also show that LTE uplink scheduler affects the streaming performance due, to the operational nature of DASH.

The rest of this paper is organized as follows. Relevant background and related work is presented in Section II. The details of our evaluation setup are explained in Section III followed by the evaluation results in Section IV. We conclude in Section V.

## II. BACKGROUND AND RELATED WORK

Several studies, e.g., [7], focus on the performance of LTE schedulers for saturated UDP and/or TCP traffic. However, the dynamics of DASH are different from such saturated traffic. DASH video clients adopt adaptation strategies that consider different inputs such as buffer size, estimated network throughput, and video-specific information. Several papers also point out the negative impact on the streaming performance due to ON-OFF behaviour when multiple video users share a bottleneck link. The dynamics of link sharing extends over multiple layers in the protocol stack, including the quality adaptation logic at the application layer, the transport layer control mechanisms (congestion control and error recovery), and the link layer resource allocation mechanisms. Different video adaptation strategies have been proposed to overcome performance degradations resulting from competing for network resources. These strategies can be classified as buffer based strategies, e.g., [4], and rate-based strategies, e.g., [3]. Network throughput is commonly estimated by averaging over the observed segment delivery rates at the application layer. Buffer-based approaches observe the application buffer from which the client decoder obtains encoded media. As the buffer fills up, the player postpones requesting the next segment for some time.

In LTE networks, the scheduler controls the performance of the link layer as it is in charge of assigning resource blocks (RBs) to end users who have queued packets at the base station. Schedulers can be generally classified as time domain (TD) or frequency domain (FD). TD schedulers allocate all RBs to a single user that has the highest scheduling metric while an FD scheduler assigns the RBs across multiple users for the same transmission opportunity. The design of the scheduling metric has a significant impact on the scheduler performance. Typical schedulers are designed to tradeoff between the achievable cell capacity and system fairness. A Maximum Throughput (MT) scheduler [8] targets maximizing the system throughput by allocating the RBs to the user with the best channel condition, which is established from the channel quality indicator (CQI) periodically reported by the user device. On the other hand, blind equal throughput (BET) maximizes the system fairness by allocating the RBs to users with the lowest cumulative average rate [8] . The Proportional fairness (PF) scheduler [8] is designed to compromise between both extremes by allocating the RBs to users who have the highest ratio of the attainable throughput to the cumulative average rate.

All of the aforementioned schedulers can be classified as quality-unaware. On the other hand, quality-aware aims to integrate service or application quality related parameters in the decision. For example, Priority set scheduler (PSS) is a QoS-aware scheduler that treats users differently by comparing the user average rate to a target rate. The scheduling metric of users with average rate less than the target rate is estimated using TD BET while the other users' metric is estimated using the TD PF metric. The scheduler then multiplex a number of users with the highest metric from both groups are scheduled using FD scheduler as detailed in [9]. Token bank fair queue is another QoE-aware scheduler that is designed to guarantee a minimum rate for different users. Recently, it is proposed to integrate video client buffer-level in the scheduling metric [10], [11] such that users with a low buffer level are assigned higher priority level. This approach would enhance the user QoE of single bitrate video as it helps reducing stalls. However, for adaptive bitrate video the user QoE would also be affected by frequent quality switching due to variations in buffer level for buffer based adaptation strategies or segment throughput for rate-based metrics.

## III. EVALUATION SETUP

### A. Testbed Setup

We evaluate the performance of Dynamic Adaptive Streaming over HTTP (*DASH*) in LTE using real end-nodes and simulated LTE network using the LTE module in NS3. Figure 1 illustrates the physical (lower part) and simulated (upper part) infrastructure in our evaluation testbed. Our server is based on a network attached storage (NAS) node (Synology DS2415+, 2GB RAM, Intel Atom C2538 4-core 2.4GHz) that stores all video segments and media presentation description files. Our six clients include two netbooks (Intel Atom 1.66GHz, 1GB RAM, Ubuntu 14.04) and four Raspberry Pi-2 (ubuntu 15.04). Dash clients are based on *MP4Client*, a multimedia player from GPAC. A master controller node (Intel Core 2 Duo 3.00GHZ, 8GB RAM, Ubuntu 14.04) is implemented to orchestrate the the experiments as detailed below.

The simulated LTE uses the NS3 default configuration which is highlighted in Table I . A one-way delay of $20ms$ is introduced to the link connecting the remote node and the PGW to simulate the Internet delay to a content server or CDN node at the edge of the mobile network. Our NS3-LTE

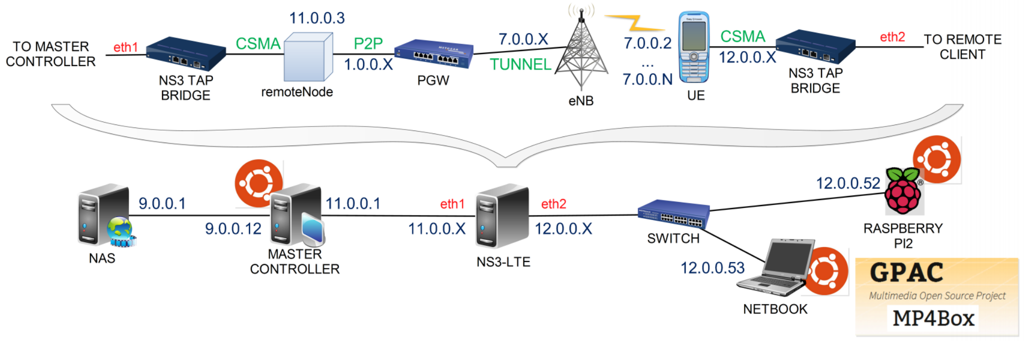

Figure 1: Overview of the Evaluation testbed

Table I: LTE Default Configuration

| | |
|---|---|
| Number of RBs =25 | Bandwidth=5 MHz |
| Pathloss model=Friis | RBG size =2 |
| Tx power of eNode =30 dBm | AMC Model =Prio |
| Tx power of UEs =23 dBm | TTI=1ms |

machine (Intel Core 2 Duo 3.00GHZ, 8GB RAM, Ubuntu 14.04) connects to the real nodes using soft Ethernet bridges and TUN/TAP network interface. We use *brctl* to set up, maintain, and inspect the Ethernet bridge configuration in the Linux kernel and *tunctl* to preconfigure TUN/TAP network interfaces, based on NS3-TAP interfaces. For proper packet routing between the clients and the server, we adopted different routing strategies. From the physical client to the NAS, each node is configured with a default gateway in this direction. To illustrate, each physical client is configured with a simulated UE as a default gateway. Subsequently, each node is configured with the next node in this direction as a default gateway. In the reverse direction, we define static routes at the master controller node for all packets for subnet 12 be routed to “remoteNode”, 11.0.0.3. From “remoteNode” to a respective UE, we implement internal routing via the NS3 script. Additionally, we mangled the packet destination address before being forwarded to LTE PGW and before leaving LTE UE so that the packets can go through the tunnels in the LTE network. These changes are added in the “ipv4-list-routing.cc” source file in the NS3.

Our simulated video sessions use 15 different five-minute videos from the Dash dataset [12][4], where videos are encoded with 4-second segment at the following rates {235, 375, 560, 750, 1050, 1750, 2350, 3000, 3850, 4300}.

In our experiments, we considered three fading models, namely: static, pedestrian mobility (3Km/h) and vehicular mobility (30Km/h). All fading traces are created using the NS3-LTE provided “fading_trace_generator.m” MATLAB script in the LTE source folder of NS3. We evaluated four pertinent schedulers in NS3 including *PF*, *FD-BET*, *FD-MT* and *PSS*. The default configuration is always used for all schedulers. For PSS, we set the target rate to 700kbps, which is sufficient to support the third quality rate (560kbps) which would provide a good video quality across portable devices.

In GPAC, we implemented two state of the art adaptation algorithms including FESTIVE [3] and BBA [4], specifically BBA2. In summary, BBA implements two buffer-level thresholds. It requests the lowest (highest) video quality if the buffer level is below (above) the low (high) threshold. If the buffer level is between these thresholds, it implements a mapping function that translates the buffer level into a representation quality. BBA implements an adaptive lower threshold that changes depending on future video segments. Additionally, it initially applies a rate-based quality selection strategy to improve the received video quality during the initialization phase. FESTIVE implements a harmonic mean estimator for the network throughput. Additionally, it implements a randomized segment scheduling to improve its rate estimation by probing the network at random instants. Further, FESTIVE implements an adaptive stateful switching strategy by which clients streaming at lower quality can switch the next higher quality faster than clients streaming high video quality. These different components are designed to assist clients sharing a network bottleneck to fairly access network resources. FESTIVE would switch up to the next higher quality if the estimated network throughput is above the current representation rate for $n$ subsequent segments, where $n$ depends on the current quality. Additionally, FESTIVE would switch to the next lower quality if the estimated throughput is below the current quality rate.

The master controller passes relevant simulator configuration (number of users, distance of user, fading model, scheduler, simulation time) and instructs the simulator to start. Once the network is up and running, the master controller passes relevant configuration parameters to the GPAC clients (adaptation algorithm, video information) and activate them. At the end of the experiment, the master controller collects log files from the clients for post-processing.

In our experiments, we use six clients at a distance of { 2.5, 4, 5.5, 7, 8.5, 10}km from the base station, with Client 1 being the closest client to the eNB. We set the simulation time to 10 minutes (twice the video duration) to allow for playback delays due to stalls. Each configuration (scheduler, fading model, adaptation algorithm and video clip set) is repeated five times for each of the six clients. For each repetition we set a different seed point in NS3 which selects a different starting point in the corresponding fading trace file. The performance metrics as shown in the next Section use the average of these five runs.

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[4] www.cs.ucc.ie/misl/research/current/ivid_dataset

### B. Performance Metrics

The performance metrics that we use for evaluating the scheduler and adaptation algorithms are:

- average received video representation rate in Kbps($r_{av}$)
- average number of stalls ($n_{st}$)
- average total stall duration in seconds ($t_{st}$)
- average number of switches ($n_{sw}$)
- average quality switching level ($l_{sw}$), which is the average of the number of changes in quality levels
- average QoE ($\vartheta$) estimated using the DASH-UE model [13], an objective metric derived based on subjective evaluations. In summary, the highest QoE metric value is 100. Lower values would be due to the number of stalls, stall duration, persistence at lower quality representations, and switching down to lower quality. The quality and switching penalties are estimated based on the objective video quality metric that is known for its correlation to subjective video quality evaluation [5].

## IV. PERFORMANCE RESULTS

### A. Adaptation Algorithms

Table II and III show the average performance metrics across all the clients for BBA and FESTIVE, respectively, with different schedulers and fading models. Generally, BBA leads to less stalls in comparison to FESTIVE. We believe that is due to the larger buffer BBA has that makes it more immune to variations in the receive rate due to TCP and scheduler behaviour. Note that using a large client buffer leads to wasting precious air interface resources in situations where a user subsequently abandons viewing the video, as the stored segments are discarded. This can also lead to additional cost to a user by needlessly increasing their data plan cost where usage based charging is adopted. FESTIVE shows slightly higher quality rates in comparison to BBA. Additionally, FESTIVE performs more switches of the representation quality than BBA. We found that FESTIVE, by design, tries to stream the next higher quality if the average estimated network delivery rate is higher than the current quality rate for $n$ segments, where $n$ is proportional to the current quality. In many cases, FESTIVE would instantly switch down if the higher rate cannot be sustained.

With BBA, distant clients tend to have fewer switches than clients close to the base station. Typically, this is because distant clients tend to build their buffer at a slower pace and hence they switch less often to higher qualities. On the contrary, in FESTIVE, cell-edge clients tend to have large numbers of switches as they typically stream low video quality and the stateful switching policy in FESTIVE allows for frequent switching when the streamed quality is low. For example, Figure 4c shows that FESTIVE client 5 performs many switches in the quality when it is streaming the lowest quality rate because FESTIVE allows switching every segment at the lowest rate if the average delivery rate is larger than the current quality rate. After switching up to the higher quality representation, the client often switches back again to the lower quality and sometimes encounters a stall. Similar switching oscillations, yet at a lower rate, are also observed for client 3 and client 1. Note that frequent switching of the quality, especially switching down negatively affects the user QoE.

### B. LTE Schedulers

With static fading, the MT scheduler leads to the worst stall performance as cell edge clients starve for resources. MT is biased to allocate resources to users with the best channel condition. BET comes second to MT with respect to number of stalls but BET's stalls are significantly shorter than those encountered with MT, as BET tries to provide clients with equal average throughput independent of their channel conditions. Typically, base stations implement a version of the PF scheduler due to its ability to maximize the benefit of available system resources without starving end users having bad channel conditions. Alternatively, the base station may implement a quality-aware scheduler to satisfy additional design goals such as rate guarantees, application-based fairness, and/or other application-specific metrics. PSS is one such variant, as it tries to schedule users so that their service rate is close to a predefined target rate - as previously explained it is set to 700kbps in our experiments. Note that the network service rate is different from the representation rate as the latter depends on the application policy.

We also noticed that BET usually leads to a larger number of switches in most of the combinations of fading and adaptation algorithm. This is probably due to trying to equalize the throughput across clients leading to fluctuations in the buffer level and/or segment throughput. On the contrary, MT usually results in fewer switches because edge clients starve resources leading to low buffer level and/or low segment delivery rates. PSS and PF tend to produce switches that are slightly above those for MT.

Figure 2 plots the achievable average quality rate for different BBA and FESTIVE clients with different schedulers in different fading scenarios. Clearly, the average quality rate significantly varies across the clients in different settings. The figure shows that BET does not lead to good quality rates at the application layer for both clients in all fading scenarios. While PSS managed to improve the quality rate of edge clients, PF results in higher quality rates for most of the users in all fading scenarios. MT shows a mixed performance in comparison to PF but it leads to more stalls as previously indicated.

Figure 3 plots the QoE metric for BBA and FESTIVE clients with different schedulers in different fading scenarios. Clearly, the stalls significantly degrades the edge user QoE, especially with the MT scheduler. Additionally, the results also show that trying to maintain an equal throughput across all users independent of their channel condition leads to streaming lower quality video that reduces the overall QoE. The figure shows that PF maintains the highest average QoE metric across all clients for different fading scenarios. More importantly, PF maintains the highest QoE metric for the majority of the clients in comparison to the evaluated schedulers. However, the QoE

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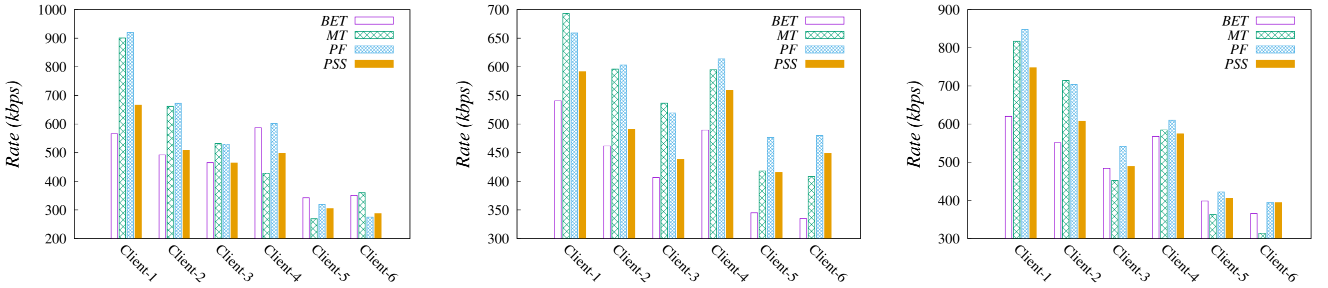
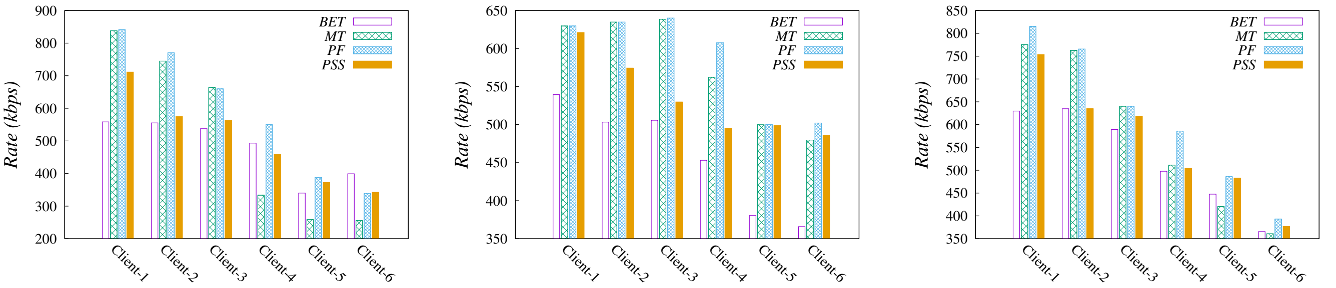
[5] The video quality metric in the presented QoE metric is based on the average VQM per representation.

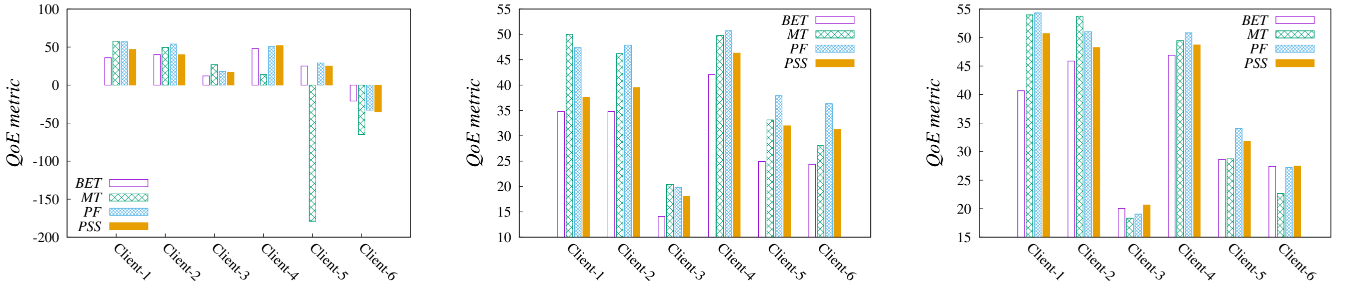


(a) BBA-Static Fading (b) BBA-Mobile Pedestrian Fading (c) BBA-Mobile Vehicular Fading

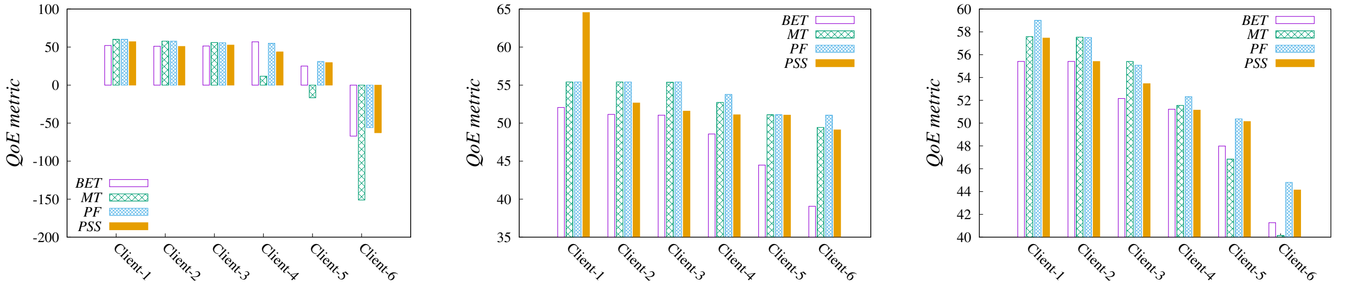


(d) FESTIVE-Static Fading (e) FESTIVE-Mobile Pedestrian Fading (f) FESTIVE-Mobile Vehicular Fading

Figure 2: Average Quality Rate with different Fading Models (Note different Y-axes ranges)



(a) BBA-Static Fading (b) BBA-Mobile Pedestrian Fading (c) BBA-Mobile Vehicular Fading



(d) FESTIVE-Static Fading (e) FESTIVE-Mobile Pedestrian Fading (f) FESTIVE-Mobile Vehicular Fading

Figure 3: QoE for Clients with different Fading Models (Note different Y-axes ranges)

Table II: Average Performance Metrics for BBA with 4-sec segment

(a) Static Fading

| Algorithm | $n_{st}$ | $t_{st}$ | $r_{av}$ | $n_{sw}$ | $l_{sw}$ |
|---|---|---|---|---|---|
| BET | 0.27 | 5.63 | 467.19 | 11.83 | 1.25 |
| MT | 3.97 | 40.55 | 530.89 | 8.04 | 1.07 |
| PF | 0.53 | 2.76 | 553.10 | 9.23 | 1.17 |
| PSS | 0.33 | 3.12 | 454.93 | 9.9 | 1.19 |

(b) Mobile Pedestrian Fading

| Algorithm | $n_{st}$ | $t_{st}$ | $r_{av}$ | $n_{sw}$ | $l_{sw}$ |
|---|---|---|---|---|---|
| BET | 0 | 0 | 429.76 | 11.1 | 1.34 |
| MT | 0.1 | 0.39 | 541.21 | 11.37 | 1.35 |
| PF | 0 | 0 | 558.75 | 11.43 | 1.35 |
| PSS | 0 | 0 | 490.56 | 11.2 | 1.37 |

(c) Mobile Vehicular Fading

| Algorithm | $n_{st}$ | $t_{st}$ | $r_{av}$ | $n_{sw}$ | $l_{sw}$ |
|---|---|---|---|---|---|
| BET | 0 | 0 | 497.78 | 10.67 | 1.37 |
| MT | 0.03 | 0.04 | 540.65 | 9.53 | 1.25 |
| PF | 0 | 0 | 586.48 | 11.13 | 1.35 |
| PSS | 0.07 | 0.15 | 536.34 | 11 | 1.39 |

Table III: Average Performance Metrics for FESTIVE with 4-sec Segment

(a) Static Fading

| Algorithm | $n_{st}$ | $t_{st}$ | $r_{av}$ | $n_{sw}$ | $l_{sw}$ |
|---|---|---|---|---|---|
| BET | 1.37 | 11.78 | 480.64 | 17 | 1 |
| MT | 6.28 | 43.71 | 524.80 | 14.24 | 1 |
| PF | 1.1 | 11.18 | 591.24 | 19.07 | 1 |
| PSS | 1.2 | 12.60 | 503.71 | 22.07 | 1 |

(b) Pedestrian Fading

| Algorithm | $n_{st}$ | $t_{st}$ | $r_{av}$ | $n_{sw}$ | $l_{sw}$ |
|---|---|---|---|---|---|
| BET | 0.033 | 0.62 | 458.00 | 26.83 | 1 |
| MT | 0 | 0 | 574.15 | 22.27 | 1 |
| PF | 0 | 0 | 585.80 | 22.67 | 1 |
| PSS | 0 | 0 | 534.23 | 21.8 | 1 |

(c) Vehicular Fading

| Algorithm | $n_{st}$ | $t_{st}$ | $r_{av}$ | $n_{sw}$ | $l_{sw}$ |
|---|---|---|---|---|---|
| BET | 0 | 0 | 527.53 | 23.53 | 1 |
| MT | 0 | 0 | 578.50 | 18.97 | 1 |
| PF | 0 | 0 | 614.30 | 17.93 | 1 |
| PSS | 0 | 0 | 561.81 | 20.93 | 1 |

gap between cell-edge and cell-center remains large with the PF scheduler in the static fading case. This could be critical as many people tend to watch videos when at home or in cafes etc. The figure also shows that FESTIVE clients enjoys a better QoE, especially in the mobile fading scenarios.

### *C. Mobility Impact*

One of our key observations is that mobility improves the application stall performance with a negligible impact on attained average video rate and switching dynamics. We believe that variable fading dynamics triggers the scheduler to treat clients differently over time leading to such improvement in comparison to static fading scenarios. Although, the results also indicate that FESTIVE performs more switches with mobility, our analysis indicates that such increase is due to session abort that leads to smaller number of switches as the clients download fewer segments. We found that our streaming client aborts the session when it fails to fetch a segment due to a network connectivity issue. With static fading, we found that both FESTIVE and BBA clients abort 22%-30% of the sessions. The streaming clients download on average 85-93% of the video segments for different schedulers. On the contrary, the clients downloaded 99.9% of video segments with mobile fading scenarios. Figure 2 shows that the rate of distant users significantly increases with mobility with a negligible impact on users close to the base station for all schedulers except the closest two user when MT is used. The improvements in representation rates and stall performance leads to noticeable QoE boost for edge users across all schedulers as shown in Figure 3. Hence, these results suggest that edge users with static fading channels may be disadvantaged in a mixed user configuration.

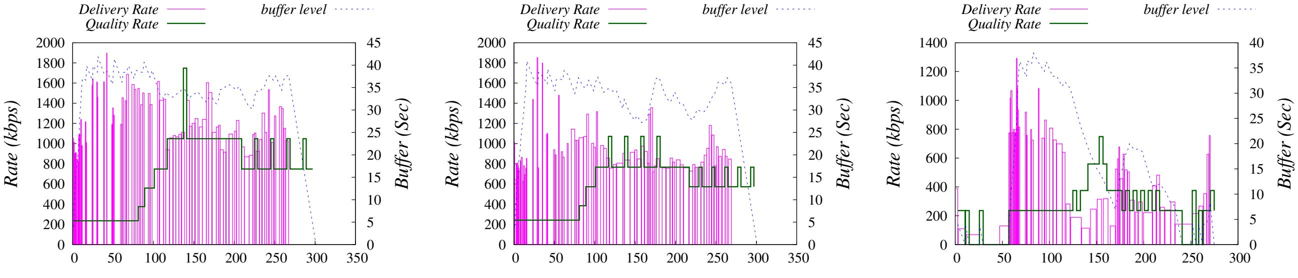
### *D. Interaction between DASH and Scheduler*

Figure 4 illustrates the interaction between the application and scheduler control loops. . Figures 4a-4c plots the received quality rate, segment delivery rate, and buffer level for FESTIVE clients under static fading and proportional fair scheduler while Figures 4d-4f show the same for BBA. Since BBA buffer is never filled during the experiment time, BBA client never enters OFF state and continuously requests segments. On the contrary, most FESTIVE clients manage to fill in their buffer at some stage and consequently, they enter OFF state. These OFF periods can be identified by blank spaces between average segment delivery date boxes. Clearly, the large buffer size of BBA enables its clients to download all video segments and close the connection with the server around 150 sec while FESTIVE remains connected for longer times up till 260+ sec. Note that both BBA and FESTIVE clients would temporarily have no data in the base station buffer between the last packet of a segment and the first packet in the following segment. While these later gaps (several tens of milliseconds) are much smaller than the application OFF period, they remain relatively large time gaps to the scheduler time scale.

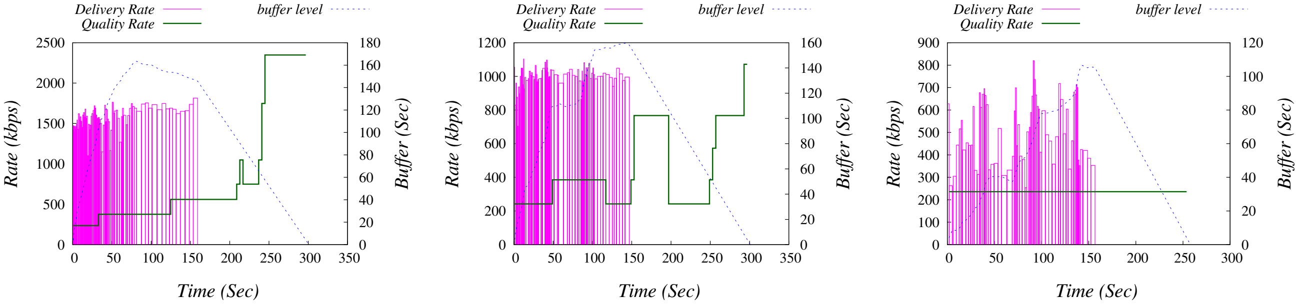
Figure 4c shows another interesting observation as the buffer is not full but large inter-segment inactivity gaps are also observed in the downlink. This delay gap is estimated as the time difference between the transmission time of segment $n$ request and the reception time of segment $(n-1)$. Our analysis shows that such delay are on average 65milliSec for client 1 while they average around 1.4Sec for client 5. This delay basically consists of the application processing time at the client and the access delay for the uplink to transmit the request. Hence, the large difference indicates that uplink scheduling algorithm also has a noticeable impact on DASH performance as it intervenes with client-server interaction.

## V. CONCLUSIONS

LTE capacity and coverage is on the rise to accommodate the increasing bandwidth demand from users due to the pervasiveness of resource-demanding applications, such as video. DASH has been adopted by many content providers as a default video streaming technology to accommodate the variations in network conditions by adapting the video quality. In this paper, we investigated the impact of LTE scheduling policy on the performance of DASH using our laboratory testbed using real video content and clients, with an NS3 emulated LTE network. Our results indicate that user mobility within a cell mitigates the effects of long-term fading on video



(a) FESTIVE-client 1 (b) FESTIVE-Client 3 (c) FESTIVE-Client 5



(d) BBA-Client 1 (e) BBA-Client 3 (f) BBA-Client 5

Figure 4: Quality rate, delivery rate, and buffer level for PF with Static Fading, and 4-sec segment

delivery, unlike for static users at the cell-edge where fading effects are significant. Additionally, a proportional fair scheduler generally achieves a better QoE in comparison to other LTE schedulers. We also show that uplink scheduling could also affect the performance of DASH due to the interaction between video client and server at segment boundaries. As future work, we expect to consider developing scheduling and traffic management techniques to improve the user QoE in LTE networks.

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