DOAS: Device-Oriented Adaptive Multimedia Scheme for 3GPP LTE Systems

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Abstract—**The growing popularity of the high-end mobile computing devices – smartphones, tablets, notebooks and more – equipped with high-speed network access, enables the mobile user to watch multimedia content from any source on any screen, at any time, while on the move or stationary. In this context, the network operators must ensure smooth video streaming with the lowest service delay, jitter, and packet loss. This paper proposes a resource efficient Device-Oriented Adaptive Multimedia Scheme (DOAS) built on top of the downlink scheduler in LTE-Advanced systems. DOAS bases its adaptation decision on the end-user device display resolution information and Quality of Service (QoS). DOAS is implemented on top of the Proportional Fair (PF) and the well-known Modified Largest Weighted Delay First (M-LWDF) scheduling algorithms within the 3GPP LTE/LTE-Advanced system. The performance of the proposed adaptive multimedia scheme was analyzed and compared against a non-adaptive solution in terms of throughput, packet loss and PSNR.**

Index Terms—**Long-term Evolution, Mobile Device, Resolution, Downlink Scheduling.**

I. INTRODUCTION

IN the recent years, the mobile communication industry presented a rapid evolution towards the 4th generation of the cellular network technologies represented by the Long-term Evolution (LTE), or LTE-Advanced (LTE-A). Many carriers and vendors managed to launch and enable the LTE/LTE-A services already and many more are planning for the LTE deployment in the near future. With respect to LTE-A, it enhances the spectrum usage in downlink and uplink technologies, and improves cell edge performance when compared with the original LTE system [1][2]. Moreover, both LTE and LTE-A mainly improve the service quality of the current 3G system in terms of throughput, spectral efficiency, latency and so on. Additionally, the LTE/LTE-A makes a smooth and successful transition to all-IP network.

According to the Cisco's forecast in 2013 [3], the global mobile data traffic will be approximately twelve times the current size, increasing with 11.2 exabytes per month in the next five years. From the total global mobile broadband data traffic, the video traffic only will represent two-thirds by 2017. Therefore, the mobile communication technologies, such as LTE, LTE-A, WiMAX and so on, are and will still be facing to the challenges on how to achieve more optimized QoS, higher peak data rate requirements, lower system latency and faster mobility performance.

Since 3GPP does not make a detailed specification for the MAC scheduler in the LTE/LTE-A system and leaves its design and implementation to vendors, researchers have been trying to find the different scheduling algorithms that may improve the LTE system performance significantly. The well-known scheduling algorithm, referred to as M-LWDF, is introduced by Andrews et al. in [4]. The scheduler serves the flow with the highest priority, which is computed based on the queuing delay of the Head of Line (HOL) and the instantaneous rate given at a time instant. The performance of this algorithm was analyzed by Ramli et al. in [5] in the context of LTE systems. The results show that M-LWDF outperforms the Proportional Fair (PF) and the Exponential Proportion (EXP) [6] scheduling algorithms. The above mentioned solutions are focused on QoS for delay sensitive traffic. Liu et al. in [7] propose an energy-aware scheduling mechanism for LTE-A downlink MIMO multi-user system. The proposed energy-efficient proportional-fair metric represents the ratio of the transmission data rate at the Base Station (BS) circuit power consumption during the current transmission. Then the BS optimal power allocation follows a water-filling structure where the water level is determined by the energy-efficient metric and the channel gain. Therefore the higher power allocation will improve the channel condition and cell-edge spectrum efficiency.

However, most of the previous works are designed and implemented at the BS side and do not consider characteristic of mobile devices at the end-user side. Other works focus on service differentiation for other technologies [8][9]. Because of the popularity of the high-performance mobile devices, there is a need for a solution that takes into account the characteristics of these mobile devices, such as screen resolution, battery energy consumption, processor performance, etc. in LTE systems.

In this context, we propose a novel **Device-Oriented Adaptive Multimedia Scheme (DOAS)** that jointly works with the scheduling algorithm (e.g. PF, M-LWDF) in order to make efficient use of the network resources and provide a superior Quality of Experience (QoE) to the multi-screen end-users. DOAS proposes a mobile device classification based on the screen resolution and a quality grading and delivery scheme for LTE-A systems.

The remainder of the paper is structured as follow: Section II introduces the system model of LTE downlink, and a framework of the proposed adaptive scheme in Section III. The simulation environment and simulation results analysis are presented in Section IV and Section V, respectively. Finally, the last section draws the conclusions and future research.

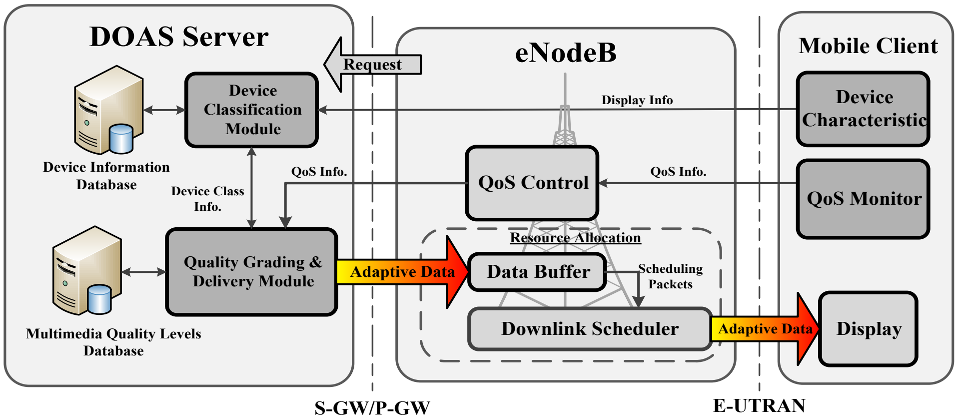

Figure 1. Device-Oriented Adaptation Scheme - Framework

II. SYSTEM MODEL

The LTE network architecture consists of two parts: Evolved Universal Terrestrial Radio Access (E-UTRA) and the Evolved Packet Core (EPC). The E-UTRA provides downlink/uplink interface for the User Equipment (UE) represented by smartphones, laptops, tablets or any other mobile devices. The EPC structure consists of the Evolved NodeB (eNodeB), gateways (e.g. Serving GW/PDN GW) and the core network (e.g. Internet) which is based on all-IP architecture. In the downlink transmission, the Orthogonal Frequency-Division Multiple Access (OFDMA) modulation technology is exploited. The unit of OFDMA referred to as the Resource Block (RB) contains 12 consecutive subcarriers of 180 kHz bandwidth in the frequency domain, and in the time domain it accounts for a 0.5 millisecond time slot [10]. Two consecutive RBs (referred to as the Physical Resource Block (PRB) in this work) are assigned to a user for a Transmission Time Interval (1 millisecond). Moreover, considering a number of downlink data streams and several UEs competing for resources, the scheduler in the BS will allocate the PRBs for each of the data streams on the physical channel in the time-frequency domain based on some specified conditions, such as Channel Quality Indication (CQI) feedbacks, QoS requirements or fairness conditions.

III. DOAS: **D**EVICE-**O**RIENTED **A**DAPTIVE MULTIMEDIA **S**CHEME

A. *DOAS Framework*

The framework of the proposed scheme is illustrated in Figure 1. DOAS is distributed and consist of three parts: the LTE UE side, the LTE eNodeB side and the server side.

The LTE UE side is represented by the mobile client as illustrated in Figure 1 and represents an important component of the DOAS architecture. It consists of several functional blocks as follows: the Device Characteristic block which registers the device information (e.g. screen resolution, operation system information, battery lifetime) once the mobile client is attached to the eNodeB; the QoS Monitor block which periodically provides average throughput, packet loss ratio and other transmission quality information of traffic via the Evolved Packet System bearers [11]; and the Display block which is the screen entity installed in the mobile device that presents the multimedia content to the mobile user.

The LTE eNodeB side consists of: the QoS Control block which is in charge for processing the QoS feedback received from the LTE UE side and for providing the QoS control messages to the server side; the Resource Allocation block mainly consists of the data flows buffer and downlink scheduling mechanisms. The resources, for the adaptive data stream received from the server side, are re-allocated efficiently to the UE sides by the Resource Allocation block.

The core of the proposed adaptive multimedia scheme is the server side referred to as the DOAS server. The DOAS server can be divided into two functional modules: the Device Classification Module and the Quality Grading and Delivery Module. The Device Classification Module makes use of the Mobile Device Classification Scheme (MDCS) and the device information database in order to classify the devices based on their resolutions. The device information provided from UE side is processed and classified by MDCS, then stored into the database. The Quality Grading and Delivery Module takes into account the current channel conditions and the device classification in order to grade the quality levels by using Video Quality Grading & Delivery Scheme (VQGDS). Finally an adaptive traffic with respect to proper quality level is selected from the Multimedia Quality Levels Database, and delivered to the eNodeB and then to the UE. The details of MDCS and VQGDS are addressed in the following sessions.

B. *Mobile Device Classification Scheme (MDCS)*

According to a study report by Google in August 2012 [12], most of people spend on average 4.4 hours of their daily leisure time in front of a screen. Only ten percentages of people’s basic media interactions are non-screen based. Therefore, mobile device screen resolution has become a significant factor which impacts the mobile user experience. Additionally, for example, the multimedia server delivers a high quality video traffic with a high data rate to a mobile device having a low resolution, which in turn cannot give a good experience to the user rather it will waste of the bandwidth resources of the system and could cause traffic congestion. In this context, the MDCS provides a classification of the mobile devices based on their screen resolution. The variety of resolutions on mobile devices was investigated and illustrated in Table I [13]. Table I indicates the variety of screen resolutions and the trend of the most common screen resolutions used for accessing the Internet. However, the provided information reveals just a few devices with high resolution, where most of the devices are desktops, laptops and netbooks. It is difficult to classify the mobile devices which include laptops, netbooks, tablets and cellphones. Hence, we also investigated the most of the cellphones and tablets present on the current market. The information is illustrated in Table II and includes 227 device brands and 4914 device models.

TABLE I.
STATISTICS OF BROWSER DISPLAY

	Higher	1024×768	800×600	640×480	Other
2013	90%	9%	0.5%	0%	0.5%
2010	76%	20%	1%	0%	3%
2007	26%	54%	14%	0%	6%
2004	10%	47%	37%	1%	5%

TABLE II.
STATISTICS OF CELLPHONE SCREEN RESOLUTION (2012)

No. of Cellphone brands	No. of Cellphone Models	≥1024×768	(1024×768, 768×480]	(768×480, 480×360]	(480×360, 320×240]	<320×240
227	4914	11	322	93	2099	2389

According to the data listed in Table I and Table II, we classify the mobile devices and divide them into five classes based on their screen size resolution. The highest resolution class (≥1024×768) includes most of the cellphones with high resolution and nearly all of the laptops and netbooks. The classification of mobile devices based on screen resolution is indicated in Table III [14]. Once a new mobile device attaches to eNodeB and intends to request video services, the MDCS will classify this device and VQGDS will deliver the adaptive data stream depending on the device classification.

TABLE III.
CLASSIFICATION OF MOBILE DEVICE BASED ON SCREEN RESOLUTIONS

Device Classes	Class 1	Class 2	Class 3	Class 4	Class 5
Resolution	≥1024×768	(1024×768, 768×480]	(768×480, 480×360]	(480×360, 320×240]	<320×240

C. *Video Quality Grading & Delivery Scheme (VQGDS)*

Video Quality Grading & Delivery Scheme (VQGDS) consists of the Video Quality Grading mechanism and the Video Delivery Control mechanism. The video sources have been pre-coded into a set of video clips with different quality levels (from high to low) and stored in the Multimedia Quality Levels Database. Depending on the MDCS, the Video Quality Grading mechanism an adequate set of video clips with different quality is allocated to the corresponding device class. For example, a video source has been pre-coded into N video clips with the same content but different bitrates (e.g. 1920kbps, 960kbps, 480kbps, 240kbps, 120kbps and so on). Then the video clips from Level 1, representing the highest quality level to Level N, representing the lowest quality level, are assigned to the devices in Class 1. Similarly, the video clips from Level 2 to Level N are assigned to the devices in Class 2. Figure 2 indicates the relationship between different quality levels of the video clips and the different classes of devices.

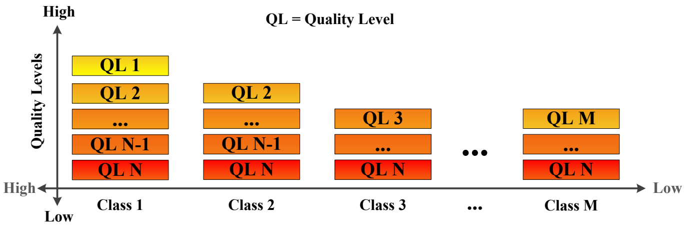

Figure 2. Video Quality Level Allocation With Respect to Different Classes

The other component of VQGDS is the Video Delivery Control mechanism which adapts the delivery of the adequate video stream quality level to the mobile device depending on the QoS conditions of the current channel. In this work, the Video Delivery Control mechanism is following the water-filling algorithm and makes use of the system bandwidth to control the video stream delivery. Initially, the Video Delivery Control mechanism assigns the best quality video stream for a mobile device in a specific class. For example, QL1 video will be allocated for the devices in Class 1 and similarly QL2 video will be delivered to the devices in Class 2. If the available system bandwidth is high enough, the Video Delivery Control mechanism will deliver the highest quality level video stream. If the available system bandwidth is low (increased number of users or sever background traffic), then the Video Delivery Control Mechanism is triggered and the video stream delivery will be adapted to the proper quality level considering the channel conditions. The proper video quality level can be selected by using equation (1).

$$QL^{*}=\begin{cases} QL_{M}\,, & if\ R_{m,k}\in\left[R_{m}^{M},+\infty\right) \\ QL_{n-1}, & if\ R_{m,k}\in\left[R_{m}^{n-1},R_{m}^{n}\right) \\ QL_{N}\,, & if\ R_{m,k}\in\left(0,R_{m}^{N}\right) \end{cases} \qquad (1)$$

where QL_M is the best quality level for the devices in Class M, for example, the best quality level of the devices in Class 3 is QL_3 namely QL 3 listed in Figure 2; similarly, QL_N is the lowest quality level for the devices in any of the Class; n is the index of quality level which $N \le n-1 < n \le M$; $R_{m,k}$ is the available video bitrate of the k th mobile device in Class m, which is computed in equation (2).

$$R_{m,k}\left(t\right)=\Phi_{Avail}\left(t\right)\times\frac{R_{m}^{M}}{\sum_{m=1}\sum_{k=1}R_{m,k}^{M}} \qquad (2)$$

where Φ_{Avail} is the available system bandwidth (kbps) at time instant t; m is the index of the Class and $m \in \{1,2,3,...,M\}$; k is the index of devices in the Class and $k \in \{1,2,3,...,K\}$.

IV. SIMULATION ENVIRONMENT

A. *Simulation Setup*

In this section the simulation setup and the scenarios used to evaluate the performance of the proposed DOAS in comparison with another non-adaptive multimedia delivery scheme are described. The LTE-Sim [15] was used as the simulation platform. Figure 3 illustrates the simulation scenario. It is assumed that the CQI reporting is error free and the downlink transmitting power is allocated to each Physical Resource Block

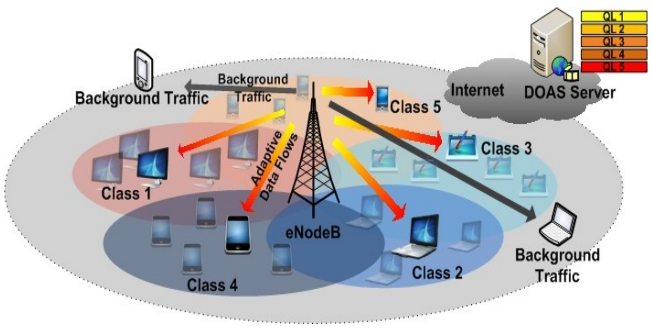

Figure 3. The Simulation Scenario

equally. The scenario considers the coverage area of one eNodeB of a LTE network with the simulation parameters listed in Table IV.

TABLE IV.
SIMULATION PARAMETERS

Parameter	Value
Simulation Length	2000 seconds
Number of UEs	Total 30 UEs ;5 Classes; 6 UEs in each Class
UE Mobility	Random Direction; Speed = 3km/h
Cell Layout	Single Cell; Radius = 250 meters
Carrier Frequency	2.1 GHz
Downlink Bandwidth	10 MHz; Number of RBs = 50
Modulation Scheme	QPSK, 16QAM, 64QAM
Physical Transmission	Tx power = 43 dBm; FDD; SISO
Antenna Model	Isotropic Antenna Model
Path Loss Model	Friis Propagation Model
Traffic Model	Near Real Time Traffic; CBR

A total number of 30 LTE mobile devices are considered to perform video streaming from the DOAS server. The LTE mobile users are divided into five classes according to their device capabilities, as previously explained. Each class contains a number of 6 UEs. The geographical location of the mobile devices is randomly generated, so that the devices are randomly spread throughout the network moving at a speed of 3km/h in random directions. The DOAS server stores the video content encoded at five different quality levels. Along with the video traffic generated by the 30 mobile users, there is background traffic generated by some extra users at random periods of time and duration. Based on the network conditions, the DOAS server adapts the multimedia stream accordingly.

B. Video Traffic Model

In order to analyze the performance of DOAS, a Near Real Time Video (NRTV) traffic model [16] is used. Additionally, the truncated Pareto Distribution is considered for modeling the variability of the frame size, with probability density function computed as below:

$$f_X(x) = \begin{cases} \alpha \dfrac{k^{\alpha}}{x^{\alpha+1}}, k \le x < m, \\ \left(\dfrac{k}{m}\right)^{\alpha}, x = m \end{cases} \quad (3)$$

Five video traffic traces, each corresponding to a different quality level are generated by using equation (3). The values for the distribution parameters α , k and m are listed in Table V.

TABLE V.
VIDEO TRAFFIC MODEL PARAMETERS

	QL1	QL2	QL3	QL4	QL5
Video Bitrate	1920kbps	960kbps	480kbs	240kbps	120kbps
Frame Rate	25fps				
Pareto Distribution	α=1.2 k=4800 m=26100	α=1.2 k=2400 m=13100	α=1.2 k=1200 m=6500	α=1.2 k=600 m=3300	α=1.2 k=300 m=1654

C. Occurrence of the Background Traffic

The existence of background traffic in wireless networks is variable. In this scenario we model 100 occurrences of the background traffic during 2000 seconds of the simulation time. In order to do this, the truncated Pareto Distribution Model is used and the appearance variability of the background traffic is simulated by using the Uniform Distribution. The values of the parameters for this particular distribution are given in Table VI.

TABLE VI.
BACKGROUND TRAFFIC MODEL PARAMETERS

	Distribution Parameters
Duration of Occurrence	α=1.2; k=15; m=28; mean≈20(seconds)
Utilization of Background Traffic	Min=5%;Max=95%

D. Benchmark Performance

The proposed adaptive mechanism, DOAS was compared against the non-adaptive when jointly working with two different scheduling algorithms, namely PF and M-LWDF [5]. Thus when DOAS is used, the multimedia server delivers the highest video quality level of each class to the devices within that specific class. When the non-adaptive solution is used, the quality level (the highest encoding rate is 1.920Mbps) is transmitted regardless of the device class. When the traffic becomes congested DOAS will adapt the transmission rate accordingly. Eventually, the evaluation is done in terms of throughput, packet loss, delay and PSNR.

V. SIMULATION RESULTS

Figure 4 and Figure 5 illustrate the received average throughput and packet loss ratio of the video traffic for each class, respectively. Even though DOAS sends less traffic to devices with lower resolution, it can be seen that it reduces considerably the packet loss ratio for all the devices within the network. When compared with the non-adaptive scheme, DOAS reduces with at least 65% the packet loss ratio when jointly working with PF, and with almost 55% when used with M-LWDF, for the devices in Class 1 only. For the other classes the packet loss ratio is negligible when using DOAS compared to the non-adaptive scheme in both cases with PF or M-LWDF. Since DOAS differentiates the devices into classes and delivers the video streaming accordingly, the average throughput is decreasing between different classes.

In terms of delay, Figure 6 illustrates the average delay for each class. The results show that when using DOAS the delay is significantly reduced when compared with the non-adaptive solution for both cases, when using PF or when using M-LWDF. In order to analyze the quality of received video trace, we exploit the metric, Peak Signal-to-Noise Ratio (PSNR), according to an estimation method in [17]. The average PSNR for each class is illustrated in Figure 7. For example for Class 1, there is an improvement of 22 dB obtained when using DOAS and PF in comparison with the non-adaptive solution. Additionally, DOAS jointly used with M-LWDF achieves seven times improvement in PSNR compared to that of the non-adaptive scheme. Consequently, the video quality obtained when using DOAS with both PF and M-LWDF is significantly improved when compared with the non-adaptive scheme. However, when compared to other device classes the average PSNR for Class 1 is lower, this is because the packet loss ratio for this class is higher when compared to other classes, as illustrated in Figure 5.

VI. CONCLUSION

In this paper we proposed a **D**evice-**O**riented **A**daptive Multimedia **S**cheme that makes efficient use of the network resources and provides a superior Quality of Experience (QoE) to the multi-screen end-users. DOAS differentiates between the mobile devices based on their screen resolution and adapts the video transmission accordingly. DOAS jointly works with the existing scheduling mechanisms (e.g. PF and M-LWDF) for downlink transmissions in LTE systems. Simulation testing results show how DOAS outperforms a non-adaptive solution in heavy network traffic conditions and how DOAS finds a very good trade-off between throughput, packet loss, delay on one side and PSNR on the other. Future work will consider a study on the overhead introduced by DOAS and an extensive comparison analysis with other adaptive mechanisms from the literature.

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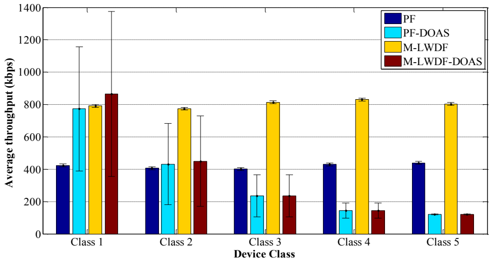

Figure 4. Average Throughput of Video Traffic

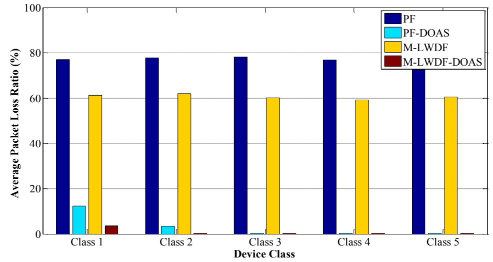

Figure 5. Average Packet Loss Ratio of Video Traffic

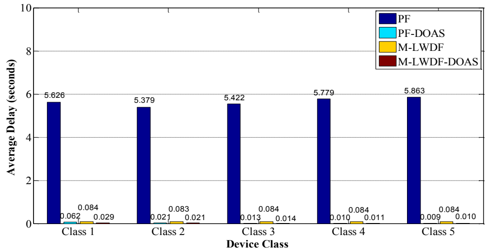

Figure 6. Average Delay of Video Traffic

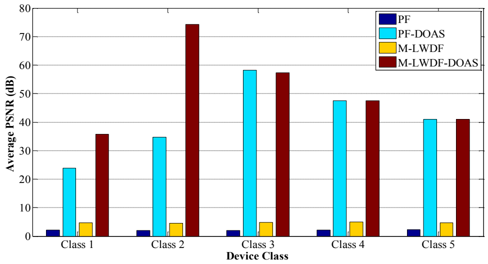

Figure 7. Average Video Quality Results