# Device-Oriented Energy-Aware Utility-Based Priority Scheduler for Video Streaming over LTE System

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**Abstract**

Nowadays people tend to spend most of their time in front of a screen, and expect to be able to connect to the Internet anytime and anywhere and from any type of mobile device. Therefore, fast surfing speed on Internet, high resolution display screen, advanced multi-core processor and lasting battery support are becoming the significant standards in the nowadays mobile devices. In this context the network operators must be able to differentiate between their multiscreen offerings in order to ensure uninterrupted, continuous, and smooth video streaming with minimal delay, jitter, and packet loss. This paper proposes a novel Device-Oriented Energy-Aware Utility-based Priority scheduling (DE-UPS) algorithm which makes use of device differentiation in order to ensure seamless multimedia services over LTE networks. The priority decision is based on the device classification, energy consumption of the mobile device and the multimedia stream tolerance to packet loss ratio.

**Keywords:** Long-term Evolution, Scheduling Algorithm, Utility Functions, Energy Consumption, Quality of Service

## 1 Introduction

The increasing demand for massive data network consumption, such as music streaming, video streaming, social networking, live gaming, navigation and cloud sync, with the limitation of Quality of Service (QoS) requirements, puts pressure on the next generation mobile networks. The Long Term Evolution (LTE), an evolution of the GSM/UMTS standards which aims to design the all-IP network architecture highly improves the spectrum efficiency and significantly reduces the transfer latency. However, the main challenge that the mobile network operators are facing is the ability to differentiate between the multiscreen offerings in order to provide seamless multimedia experience with minimal delay, jitter, and packet loss, to their customers.

Consequently, in this paper we propose a novel priority-based scheduling technique for multimedia streaming over LTE networks. The proposed scheduler takes into account the QoS constraints of the multimedia application, and efficiently utilizes the information about the device display resolution and energy consumption in order to prioritize the resource allocation and ensure the best multimedia experience to the mobile users.

## 2 Related Works

A Maximum Sum Rate (MSR) scheduling scheme without transmission power adaption was presented in [1], well suited to the limited dynamic power range downlink scenario. However, in the case of unfair sharing of the radio resources and having latency requirements, such scheduling methods are unsuitable. Delay aware downlink scheduling schemes in OFDMA systems are proposed in [2] [3]. These schemes select the highest priority to the user based on channel conditions and the amount of queuing delay for real-time or non-real-time services. Moreover, a q-learning based scheduling scheme proposed in [4] enables fair provision of different throughput in terms of the different classes of users.

Another challenge is the multimedia service delivery with QoS provisioning over the wireless environment where connections are prone to interference, high data loss rates, and/or disconnections. In this context there has been extensive academic research related to adaptation techniques for video streaming especially over wireless networks. Various solutions have been proposed in the literature [5]-[8] that address this problem of streaming video over the Internet while maintaining high end-user perceived quality levels and make efficient use of the wireless network resources.

However, most of the previous works do not consider the attributes of the devices used at the end-user side. The resolution of device display tends to be higher and higher and the limitation of lifetime of battery restricts long-term working of mobile devices. Therefore, this paper proposes a utility-based priority scheduler based on utilities related to resolution of device display, device energy consumption and estimated QoS requirements of the transmitted video stream.

# 2 Device-Oriented Energy-Aware Utility-Based Scheduling Scheme

## 2.1 Resource Allocation Strategy in LTE

In the downlink transmission, an efficient time-frequency modulation technology is exploited, namely Orthogonal Frequency-Division Multiple Access (OFDMA). The unit of OFDMA named Resource Block (RB) contains 12 consecutive subcarriers of 180 kHz bandwidth in the frequency domain, and in the time domain it accounts 0.5 millisecond time slot [9]. Two consecutive RBs referred to as Physical Resource Block (PRB) are assigned to a user for a Transmission Time Interval (1 millisecond). A brief illustration of resource allocation is shown in Figure 1. Considering a number N of UEs competing for resources, by using a scheduler function, each UE will get allocated PRBs on the physical channel in the time-frequency domain based on some specified conditions, such as channel states, QoS requirements or fairness conditions.

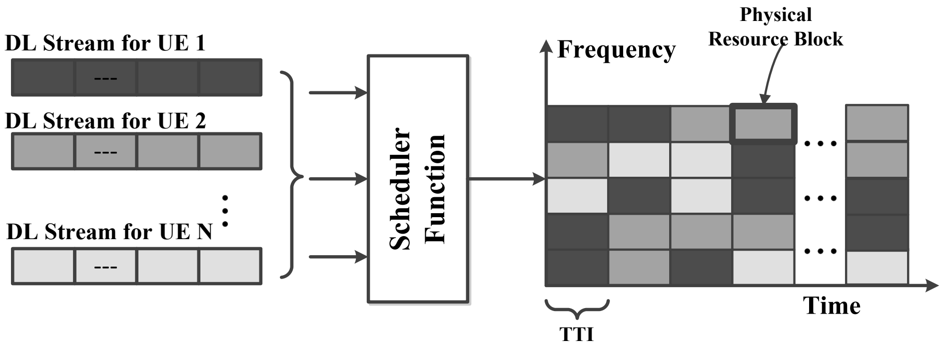


**Figure 1. A brief Description of Resource Allocation**

## 2.2 Scheduling Scheme Utility Function

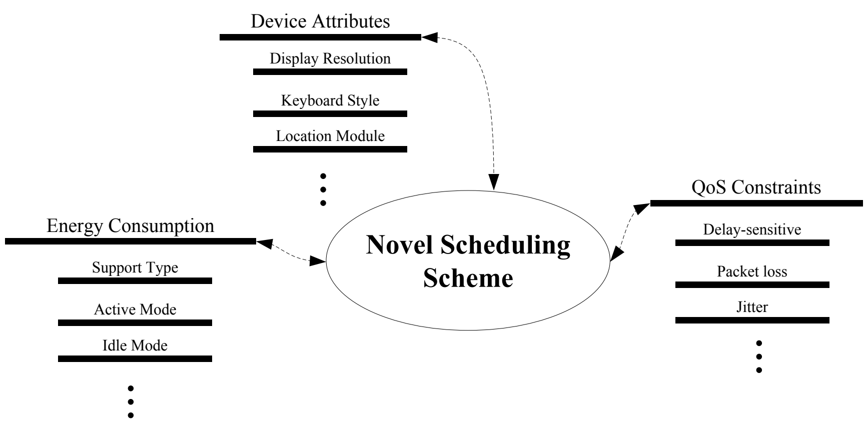


**Figure 2. Novel Scheduling Scheme based on Device Attributes, Energy Consumption and QoS Constraints**

This paper proposes a novel Scheduling Scheme that makes use of the information about the device attributes, energy consumption of the mobile device, and the QoS constraints as illustrated in Figure 2. Therefore, the resource allocation is done based on a utility function defined as in equation (1). The PRB are allocated to the users with the highest utility.

$$U^{i,j}(t) = [u_r^{i,j}(t)]^{w_r} * [u_e^{i,j}(t)]^{w_e} * [u_{plr}^{i,j}(t)]^{w_{plr}} \quad (1)$$

where $U$ is the overall utility for stream $j$ of UE $i$ at current scheduling instant $t$. And $u_r^{i,j}$, $u_e^{i,j}$ and $u_{plr}^{i,j}$ are the utility functions defined for the display resolution of the end-user device, energy consumption of the end-user device and packet loss ratio for UE $i$, stream $j$ at instant $t$, respectively. Additionally $w_r$, $w_e$, and $w_{plr}$ are the weights for the three criteria, and their sum is 1. It has been shown in [10] that the received bandwidth can be mapped to the user satisfaction for multimedia streaming applications by making use of utility functions.

#### 2.2.1 Display Resolution Utility

In general, the video stream should be played on a display with an adequate resolution in order to ensure a good experience for the mobile users. As various devices have different characteristics and hence different multimedia stream requirements, in this article, we take into account the device resolution when deciding on the device priority. For example, if the device resolution is high, the scheduler will give a high priority, and then the multimedia server will select a high quality level for the multimedia stream. According to the classification in [11], we define the display resolution utility based on different resolutions range as illustrated in Table 1.

**Table 1. Utilities of Display Resolutions**

| | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|
| **Resolution** | ≥1024×768 | (1024×768, 768×480] | (768×480, 480×360] | (480×360, 320×240] | <320×240 |
| $u_r^{i,j}(t)$ | 1 | 0.75 | 0.5 | 0.25 | 0 |
| | Excellent | Good | Acceptable | Poor | Unacceptable |

#### 2.2.2 Energy Utility

Generally, smaller energy consumption ratios are more preferable. Therefore, the energy consumption utility is defined as below:

$$u_e^{i,j}(t) = \begin{cases} 1 & , \quad e_{i,j} \le e_{\min} \\ \dfrac{e_{\max} - e_{i,j}}{e_{\max} - e_{\min}} & , \quad e_{\min} < e_{i,j} < e_{\max} \\ 0 & , \quad otherwise \end{cases} \quad (2)$$

where $e_{\max}$ is the maximum energy consumption ratio and $e_{\min}$ is the minimum energy consumption ratio among the UEs. And the estimated energy consumption ratio $e_{i,j}$ for UE $i$ for data flow $j$ can be described as in the energy model introduced in [12].

#### 2.2.3 QoS Utility

Packet Loss Ratio is considered for the QoS control in the proposed scheduling scheme. The QoS utility is based on packet loss ratio and is defined as below:

$$u_{plr}^{i,j}(t) = \begin{cases} 1 & , ave\_PLR > target\_PLR \\ ave\_PLR \big/ target\_PLR & , otherwise \end{cases} \quad (3)$$

where $ave\_PLR$ is the average packet loss ratio during a specific time window and $target\_PLR$ is the packet loss ratio tolerance of the video applications.

### 2.3 Utility-based Prioritization Procedure

The proposed utility-based scheduling scheme is distributed and consists of server-side, mobile-device-side and eNodeB-side. The mobile-device-side is mainly responsibility for collecting the device attributes information, energy consumption rate and QoS responses. This control information is then periodically sent back to eNodeB-side. Moreover, the Server-side integrates a Quality-oriented Adaptation Scheme (QOAS) [8] which ensures the proper transmission of the multimedia streams. The server stores different quality levels of the pre-recorded multimedia streams, from lowest to highest. Based on the feedback received from eNodeB, QOAS adjusts the data rate dynamically. The core function of the proposed scheme is deployed in the eNodeB side. It is located between the MAC layer and PHY layer according to the OSI levels. In this context, a flow diagram of the utility-based prioritization algorithm is defined in Figure 3. After the transmission services start, the coming data flows are queuing in scheduling buffer, and the scheduler is aggregating information of the mobile-device-side, such as display resolutions, energy consumption rates. Once the scheduling buffer is not empty, the resource allocation scheme takes into account the packet loss ratios of data flows and the information of the corresponding mobile devices on receiver-side. And then it computes the overall utilities. Consequently, the data flow with the highest utility is allocated and ready for transmission.

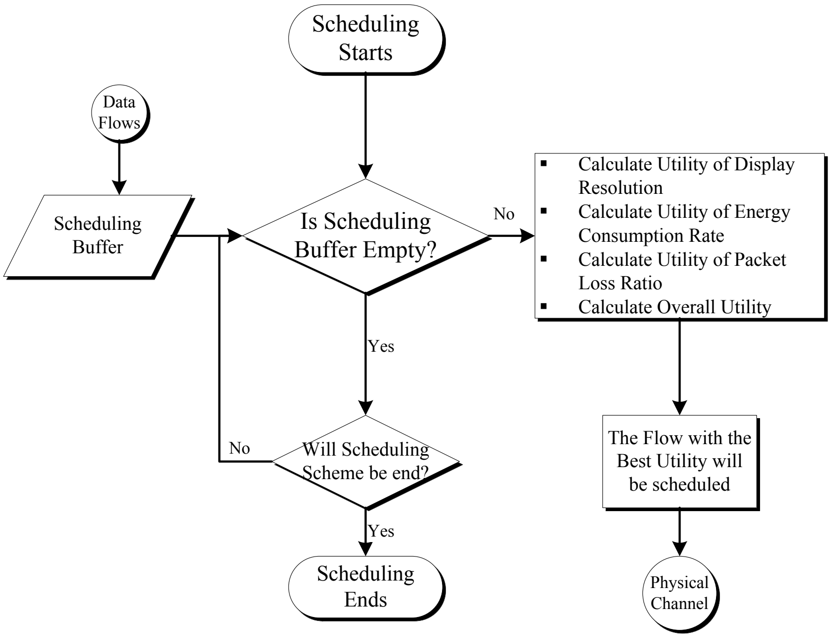


**Figure 3. Utility-based Scheduling Procedure**

## 3 Simulation Environment

**Table 2. Simulation Parameters**

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| **Number of eNodeB** | 1 | **Modulation Scheme** | QPSK, 16QAM, 64QAM |
| **Number of UEs** | 5,10,15,20,25,30,35,40,45,50 | **Transmission Power** | 20 dBm |
| **Topology** | Single Cell | **Transmission Mode** | SISO |
| **User Location** | Random Distribution | **Antenna Model** | Isotropic Antenna Model |
| **Cell Radius** | 1000 meters | **Path Loss Model** | Friis Propagation Model |
| **Carrier Frequency** | 2.0 GHz | **UE Speed** | 3 km/h |
| **Downlink Bandwidth** | 10 MHz | **Traffic Model** | H.264, Best effort flows, CBR |
| **Number of RBs** | 50 | **TTI** | 1 millisecond |
| **Cyclic Prefix** | 7 Symbols | $t_w$ | 10 TTIs |

Table 2 lists the simulation parameters used in order to create the simulation environment and validate the. It is assumed that the CQI reporting is error free and the equal downlink transmitting power is allocated to each Physical Resource Block. LTE-Sim [13] is used as the simulation platform, and the parameters of the simulator configuration are listed in Table2. The simulation scenario involves a QOAS server, one eNodeB and several different types of UEs. The goal of these tests is to evaluate the performance of the proposed scheduler compared with the Proportional Fair (PF) Scheduler and Multiclass Modified Largest Weighted Delay First (M-LWDF) scheduler [3], in terms of system throughput or cell throughput, cell packet loss ratio and QoS metrics of videos. The Proportional-Fair Scheduler and M-LWDF are briefly described as in the following equations:

$$scheduling\_metric_{PF}(t,\varphi) = {r_i(t,\varphi)}/{R_{ave}(t,\varphi)} \tag{4}$$

$$scheduling\_metric_{M-LWDF}(t,\varphi) = \gamma_i \cdot W_i(t) \cdot r_i(t,\varphi) \tag{5}$$

where $r_i(t,\varphi)$ represents the instantaneous rate on PRB $\varphi$ for user $i$ at time $t$ , and $\gamma_i$ is a constant whose value is adjusted to different delay requirements of different data flows. $W_i(t)$ is the head of line packet delay of user $i$ at the scheduling instant $t$ and $R_{ave}$ is the moving average of the throughput over a transmission window size $t_w$ . The metrics given by equation (4) and (5) decide the resource allocation priority. For example, the data flow for a user with the highest metric value is given higher priority in resource allocation.

# 4 Testing and Performance Analysis

For the testing purpose we assume that the QOAS server stores a number of three pre-recorded multimedia quality levels: low quality (e.g., 128kbps), medium quality (e.g., 242kbps), and high quality (e.g., 440kbps). Based on the device characteristics we classify the UEs in three different classes as presented in Table 3. Each class has a corresponding requirement of the multimedia quality level.

Using the simulation parameters listed in Table 2, we conducted a set of different simulation scenarios in which we vary the number of UEs from 5 to 50 which are distributed randomly in a single cell of 1000 meters radius. Each experiment was run three times with different random seeds, which can help to generate the more accurate results with random traffic patterns and path loss distribution. The same simulation conditions were kept when analyzing each of the three schedulers.

**Table 3. UE Classification**

| Type of UE | Class 1 | Class 2 | Class 3 |
|---|---|---|---|
| **Display Resolution** | 480×360 | 768×480 | 1024×768 |
| **Energy Capacity** | 5920W | 7770W | 48000W |
| **Target Packet Loss Ratio** | 2% | 1% | 0.1% |
| **Video Trace** | 128kbps | 242kbps | 440kbps |
| **CBR traffic** | 1Mbps | 1Mbps | 1Mbps |
| **Best effort traffic** | Infinite buffer | | |

Figure 4 illustrates the system packet loss ratio for the video traffic only, with the increase number of users and for each of the scheduling mechanisms. The results are the average values of the three simulation runs. It can be seen that the proposed DE-UPS mechanism outperforms the other two schemes like PF and M-LWDF. For example when having 50 users competing for resources, DE-UPS will reduce the packet loss by 51.8% when compared to M-LWDF.

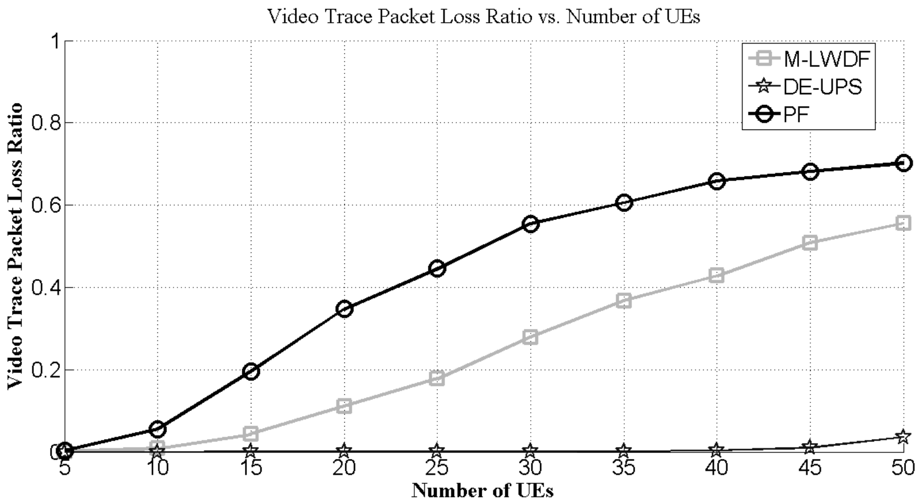


**Figure 4. Video Trace Packet Loss Ratio vs. Number of UEs**

Figure 5 illustrates the cell throughput of the video trace application under different numbers of UEs. The slops of the curves of PF and M-LWDF become decreasing when the number of UEs is larger than 15. However, the curve of DE-UPS trends to be gentle while the number of UEs is over 45 and the cell throughput could be increasing after 50 UEs. The results show that UPS outperforms PF and M-LWDF in terms of cell throughput. For example when having 50 users competing for resources, DE-UPS will increase the cell throughput by 164.4% when compared to M-LWDF. Additionally, we show a detailed performance comparison of DE-UPS, PF and M-LWDF in Table IV. The experiment with 50 UEs is taken into account for the analysis. And the numbers of different types of UE are generated randomly. Average throughput, energy consumption and packet loss ratio are computed for the different classes of UEs.

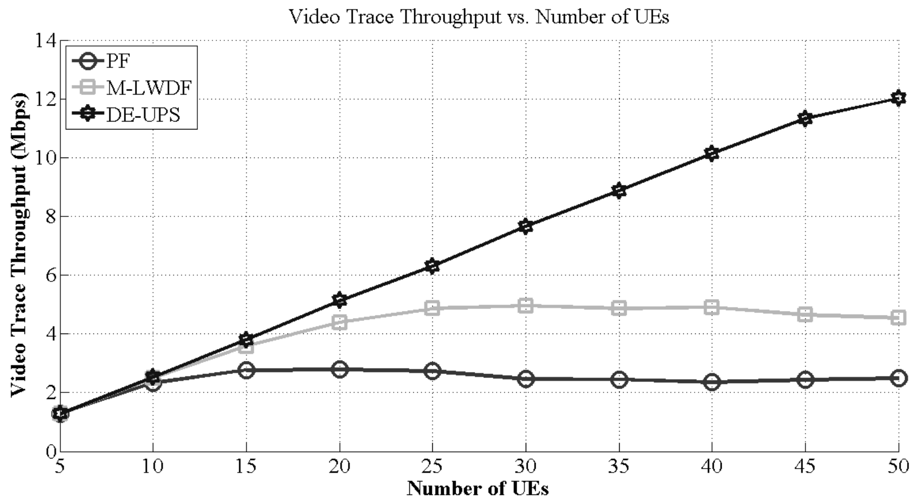


**Figure 5. Video Trace Throughput vs. Number of UEs**

Table 4 lists the average throughput including the video traffic, CBR traffic and infinite buffer traffic, the average packet loss ratios, and the average estimated energy consumption for each class of UE. The results show that DE-UPS provides a higher priority for the UEs appertaining to the class with high multimedia quality requirements. Thus, because of the device-oriented nature of the proposed solution the system throughput scheduled by DE-UPS is higher than the others. Moreover, the system packet loss ratio of DE-UPS is lower than the others under the same heavy load conditions.

**Table 4. Analysis of Comparison Results from Simulation with 50 UEs**

| Type of UE | | Class 1 | Class 2 | Class 3 |
|---|---|---|---|---|
| **Number of UEs** | | 15 | 23 | 12 |
| **PF** | Avg. Throughput (Mbps) | **16.38** | **16.51** | **16.64** |
| | Ave. Energy Consumption (mW/s) | 0.28 | 0.43 | 0.14 |
| | Avg. Packet Loss Ratio | 0.97169 | 0.97173 | 0.97180 |
| **M-LWDF** | Avg. Throughput (Mbps) | **20.84** | **20.97** | **21.10** |
| | Avg. Energy Consumption (mW/s) | 0.35 | 0.54 | 0.18 |
| | Avg. Packet Loss Ratio | 0.95911 | 0.95914 | 0.95922 |
| **DE-UPS** | Avg. Throughput (Mbps) | **21.50** | **21.62** | **21.75** |
| | Avg. Energy Consumption (mW/s) | 0.36 | 0.56 | 0.18 |
| | Avg. Packet Loss Ratio | 0.95758 | 0.95743 | 0.95721 |

# 5 Conclusion and the Future Works

In this paper we proposed a novel downlink scheduling mechanism for LTE systems when performing video streaming services. The proposed solution is based on a utility function which combines the device characteristics (e.g display resolution) and the energy consumption rate of the mobile device over the transmission channel. With respect to the simulation results and performance analysis, the proposed algorithm allocates a higher number of UE served with acceptable quality in a single cell when compared with the other existing solutions, such as M-LWDF and PF. Future work will consider the fairness between different service types.


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