UEFA-M: Utility-based Energy Efficient Adaptive Multimedia Mechanism over LTE HetNet Small Cells

Ramona Trestian, Quoc-Tuan Vien, Purav Shah, Glenford Mapp

Faculty of Science and Technology
Middlesex University
London, UK
{r.trestian, q.vien, p.shah, g.mapp}@mdx.ac.uk

Abstract—**The emerging advances in mobile computing devices enable the adoption of new services like video over LTE (ViLTE), augmented and virtual reality, omnidirectional video, etc. However, these new services cannot be technologically achievable within the current networks without a rethink in the network architecture. A simple increase in system capacity will not be enough without considering the provisioning of Quality of Experience (QoE) as the basis for network control, customer loyalty and retention rate and thus increase in network operators' revenue. This paper proposes an <u>U</u>tility-based <u>E</u>nergy e<u>F</u>ficient <u>A</u>daptive <u>M</u>ultimedia Mechanism (UEFA-M) over the LTE HetNet Small Cells environment that combines the use of utility theory and the concept of proactive handover to enable the adaptation of the multimedia stream ahead of the handover process in order to provide a seamless QoE to the mobile user and energy savings for their mobile device. Mathematical models for energy and quality are derived from previous real experimental data and integrated in the adaptation mechanism using the utility theory. The performance of the proposed adaptive multimedia scheme is analyzed and compared against a non-adaptive solution in terms of energy efficiency and Mean Opinion Score (MOS).**

Keywords—Adaptive Multimedia; Quality of Experience; LTE Small cells; Handover

I. INTRODUCTION

Recently the mobile communication industry faced a rapid evolution towards next generation cellular networks represented by Long-Term Evolution (LTE)/LTE-Advanced. However, the mass-market adoption of the high-end mobile devices as well as the new emerging mobile video services such as augmented reality, omnidirectional video, 3D video streaming, etc. led the network operators to adopt various solutions to help them cope with this explosion of mobile broadband data traffic. According to Cisco, by 2021 74.7% of mobile devices will be smart devices generating 98% of mobile data traffic. Moreover, the mobile video traffic (TV, video on demand, Internet and P2P) will account for 78% of the total mobile data traffic [1].

The current networking environment puts pressure on the network operators to rethink their network architecture in order to accommodate the high bandwidth demand while enabling low-latency, wide coverage and high Quality of Service (QoS) levels for the mobile users. Therefore, the next generation wireless systems will integrate various solutions

and technologies, from machine learning to Network Function Virtualization and Software Defined Networks. By transferring the hardware-based network to software and cloud-based solutions the mobile operators could reduce their CAPEX while enabling personalized service experience to their customers.

Fig. 1. LTE HetNet Small Cell – Example Scenario

One widely adopted solution by the network operators is the deployment of small cells within LTE/LTE-Advanced networks. By deploying a LTE Heterogeneous Network (HetNet) small cells environment as illustrated in Fig. 1, it will enable them to avail from improved capacity at low cost. This solution brings many advantages for the network operators allowing them to accommodate more customers while providing QoS. However, at the mobile user side, roaming through a HetNet small cell environment will increase the number of handovers which might impact in a negative way their Quality of Experience (QoE). With the growing popularity of the new emerging video-based services (e.g., Facebook Live, Instagram Stories, etc.) enabling QoE becomes a challenge for the network operators, especially as QoE will become the biggest differentiator between them. Thus, improving only the system capacity is not enough and the customers' QoE must be taken into account.

Another important key parameter which must be considered is the energy efficiency, especially with the limited battery lifetime of the current mobile devices. Apart from the strict QoS requirements of the video-based applications, the

battery lifetime is the main impediments of progress as video is the most power-hungry of applications.

This paper builds on our previous work presented in [2] where we identified the impact of energy consumption for multimedia streaming over a LTE HetNet Small Cells environment, and proposes an Utility-based Energy eFficient Adaptive Multimedia (UEFA-M) Mechanism over an LTE HetNet Small Cells environment that takes into consideration the user's preferences towards video quality vs. energy savings and adapts the multimedia stream.

The main contributions of this paper are as follows:

- UEFA-M is proposed, which combines the *utility theory* with the concept of *proactive handover* to enable the adaptation of the multimedia stream ahead of the handover process and provides a seamless Always Best Experience to the mobile user in terms of quality and energy efficiency.

- Using our previous real experimental data collected in [2] we develop mathematical models for energy and quality, and integrate them in the adaptation mechanism using the utility theory.

- It is shown that the energy consumption can be expressed as a logarithmic increase function of the quality level of the video stream and the quality utility exponentially increases over the throughput following a sigmoid quality utility function in which the shape parameters can be interpolated from the experimental results.

II. RELATED WORKS

Starting with the 3GPP Release-10 [3] mobile data offloading techniques have become a popular solution for the network operators. This is because it enables them to accommodate more mobile users while keeping up with their traffic demands. The offloading technique involves transferring some of the traffic from the core cellular network to Wi-Fi or femtocells at peak times and key locations (e.g., home, office, public HotSpot, etc). Even though this solution brings benefits to the mobile operators, a HetNet dense-small cell environment results in an increased number of handovers for the mobile user which might have a negative impact in terms of QoE. To overcome this, two handover strategies can be identified: *(1) proactive handover* where the handover is triggered well in advance and *(2) reactive handover* where the handover is postponed as long as possible. It has been shown that the proactive handover reduces the packet loss probability when compared to the reactive handover [4], making it more suitable for real-time applications and more energy efficient.

A study presented by Qualcomm [5] shows that LTE-Advanced HetNet with LTE pico-cell solution is the best option over the HetNet with Wi-Fi cells in terms of throughput gain, handover mechanism, QoS guarantee, security and self-organizing features. Moreover, the LTE-Advanced HetNet with LTE pico-cells already achieves seamless handover between the two networks whereas for HetNet with Wi-Fi cells seamless handover is not possible yet as it requires an inter-technology handover.

In terms of energy-efficient interface or network selection, there are many works proposed in the literature. Xenakis et al. [6] propose ARCHON, an energy efficient vertical handover decision algorithm for heterogeneous IEEE 802.11/LTE-A

networks. The algorithm makes use of the 3GPP Access Network Discovery and Selection Function (ANDSF) and enables the multi-mode mobile terminals to select the access point that minimizes the average overall power consumption and guarantees a minimum QoS for the ongoing application.

Lee et al. [7] propose an efficient channel scanning scheme by making use of the IEEE 802.21 Media Independent Handover (MIH) standard [8]. The proposed scheme aims to extend the information and event services of the MIH framework to reduce the number of channel scanning on each network interface as full scanning in a heterogeneous wireless environment takes time and consumes an important amount of energy. Zhang et al. [9] propose a network selection mechanism that increases users' energy efficiency in non-saturated wireless heterogeneous networks. The proposed mechanism makes use of a central server and the ANDSF protocol to provide energy efficiency and to balance the user preferences and their energy requirements. Araniti et al. [10] propose a new handover algorithm in LTE HetNets by making use of green policies to provide an efficient management of the base stations transmitted power and reduce the unnecessary handovers of the mobile devices. Other solutions exploit the use of stochastic geometry when studying the practical implications of small cell deployment in various propagation environment models within the HetNet environment [11][12]. Different studies have shown that the overall user experience may be affected by a wide range of factors including the power consumption [13] as well as the impact of the networking connection on service delivery and user satisfaction, e.g., signal strength [14], reliability, coverage area, network conditions and wireless technology [15] etc.

Despite the amount of research done in the area not much focus has been placed on integrating the Quality of Experience and energy consumption within the handover process in an LTE HetNet small cell environment for the mobile device while performing video on demand.

III. UEFA-M SYSTEM ARCHITECTURE

A. Proposed System Architecture

The proposed UEFA-M system architecture is illustrated in Fig. 2. UEFA-M is distributed and consists of a server-side module that stores and streams the real-time multimedia content over the LTE HetNet small cell environment to a mobile device. At the mobile device side the UEFA-M client module is integrated into the multimedia client application to receive and display the multimedia stream content.
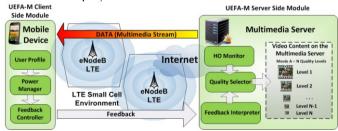

Fig. 2. Proposed UEFA-M System Architecture

The UEFA-M Server-side consists of four sub-modules: Video Content, Handover (HO) Monitor, Quality Selector, and Feedback Interpreter. The Video Content is encoded at different quality levels (e.g., Movie A encoded at N Quality

Levels (QLs) in decreasing order where Level 1 is the highest QL to Level N, the lowest QL) and stored on the server. The HO Monitor, stores information regarding the location of the mobile device and predicts when a handover is going to happen. This information could be collected using the IEEE 802.21 standard that could be collocated with the Multimedia Server or could act as an independent entity. The handover prediction will trigger the Quality Selector which will select the most energy efficient QL to be streamed to the mobile device during the handover process. The Feedback Interpreter receives feedback information from the mobile devices, containing data regarding the user preferences in terms of energy savings and video quality expectations. Based on the received feedback it will trigger the Quality Selector which selects the most suitable QL and adjusts the video delivery data rate sent back to the mobile device.

The UEFA-M Client-side consists of three sub-modules: User Profile stores information about the user preferences, such as energy savings and the expected video quality; Power Manager monitors the mobile device battery level; and Feedback Controller sends control information to the Server.

B. Video Quality Selector

The mobile device sends information about the user preferences and the energy consumption to the UEFA-M server. Based on this information the Quality Selector computes a score for each QL stored on the server. The score is computed using a weighted multiplicative (MEW) score function as defined in (1) [16]:

$$U_{QL_i} = u_{e_i}^{w_e} \cdot u_{q_i}^{w_q} \qquad (1)$$

where U_{QLi} is the score function that calculates the score for QL_i, u_e and u_q are the utility functions for energy and quality, respectively, and w_e and w_q are the weights indicating the user preferences towards energy and quality, respectively, with $w_e + w_q = 1$. The QL with the highest score is selected as the target quality level and is streamed to the mobile device. Previous studies have shown that MEW finds a better energy-quality trade-off for users in a heterogeneous wireless environment in comparison to other multiple attribute decision making solutions [17].

The utility function for the energy, u_e is defined as in (2):

$$u_e(E) = \begin{cases} 1 & , & E < E_{min} \\ \dfrac{E_{max} - E}{E_{max} - E_{min}} & , & E_{min} <= E < E_{max} \\ 0 & , & otherwise \end{cases} \qquad (2)$$

where E_{min} and E_{max} are the minimum and maximum energy consumption (Joule) of the mobile device and E is the estimated energy consumption computed for the current QL. The estimated energy consumption E is modeled in the next section based on the energy measurements collected from a real experimental test-bed from [2].

The utility function defined for the video quality, u_q, is given in (3). The utility function is a zone-based sigmoid quality utility function which has been shown to provide a good mapping of the video QL to the user satisfaction [18].

$$u_q(Th) = \begin{cases} 0 & , & Th < Th_{min} \\ 1 - e^{\frac{-\alpha * Th^2}{\beta + Th}} & , & Th_{min} <= Th < Th_{max} \\ 1 & , & otherwise \end{cases} \qquad (3)$$

where Th_{min} is the minimum throughput needed to maintain a minimum acceptable video quality, Th_{req} is the required throughput to ensure adequate QLs for the video application, Th_{max} is the maximum throughput that maps high user satisfaction to high QL; values above Th_{max} result in higher QLs than most human viewers can distinguish between and thus anything above this maximum threshold is a waste, α and β are positive parameters that determine the shape of the utility function (no unit). The quality utility has no unit and values in the interval [0,1]. The quality utility will be modeled in the next section using real data from subjective test results.

C. Handover Monitoring

The UEFA-M mechanism is based on the proactive handover approach defined in [19] and illustrated in Fig. 3.
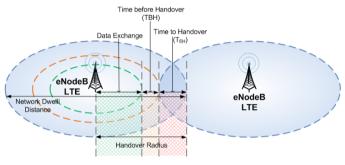

Fig. 3. Handover Radius Example

The coverage area of an access point could be divided into three regions, such as: (1) the Data Exchange range which defines the area where the data transmission takes place; (2) Time before Handover (TBH) where the mobile unit gets ready for handover and (3) Time to Handover (T_{EH}) representing the region where the handover takes place. The network dwell time (NDT) is the time that the mobile unit spends in the coverage are of an access point. All this data can be estimated based on the information on the position, direction and velocity of the mobile user [20]. Based on this, the HO Monitor module in the UEFA-M server, estimates the TBH. When the mobile unit enters the TBH region it triggers the Quality Selector which adapts the video QL to a more energy efficient QL during the handover process until the handover was executed and the mobile unit is connected to the new access point.

IV. MODELING THE UTILITY FUNCTION

A. Experimental Test-bed and Results

In our previous work [2] we have investigated how the handover process impacts the energy consumption of a mobile device while performing video streaming over an LTE small cell environment. A real experimental test-bed setup was built as illustrated in Fig. 4, and the energy consumption of the mobile devices was recorded while performing video streaming under two scenarios: without handover and with

handover. The results were collected for five different quality levels of the video stream. A summary of the results is presented here while the details can be found in [2].
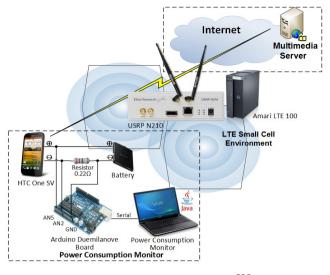

Fig. 4. Experimental Test-Bed Setup [2]

Subjective tests were also performed where a number of 27 non-expert subjects assessed the video quality of the selected quality levels. The subjective Mean Opinion Score (MOS) mapped to the perceived quality along with the characteristics of the five quality levels are listed in Table I. The energy measurements for the two scenarios and for each quality level are summarized in Table II.

TABLE I. MULTIMEDIA QUALITY LEVELS

Quality Level	Overall Bitrate [Kbps]	Resolution [pixels]	Frame Rate [fps]	Subjective MOS	Perceived Quality
QL1	1920	800x448	30	4.80	Excellent
QL2	960	512x288	25	4.56	Excellent
QL3	480	320x176	20	4.02	Good
QL4	240	320x176	15	3.57	Good
QL5	120	320x176	10	3.33	Fair

TABLE II. AVERAGE ENERGY CONSUMPTION MEASUREMENTS

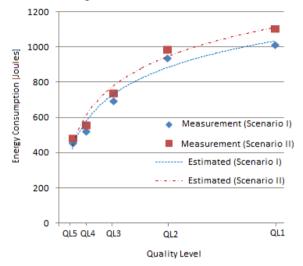| Scenario I – Video Streaming Without Handover					
	QL1	QL2	QL3	QL4	QL5
Avg. Energy [Joules]	1015.00	943.84	697.86	524.44	461.25
Scenario II – Video Streaming With Handover					
	QL1	QL2	QL3	QL4	QL5
Avg. Energy [Joules]	1106.6	988.8	740.4	557.4	484.8

B. Modelling the Energy Consumption

The energy consumption measurements from the experimental test-bed in [2] and summarized above, are used to model the energy consumption pattern of a mobile device as a mathematical equation given by (4) and illustrated in Fig. 5.

$$E_i = t(r_d \cdot \ln(Th_i) - r_t) \qquad (4)$$

where E_i is the estimated energy consumption (Joule) for the quality level i, t (seconds) represents the estimated duration of the multimedia stream, r_d is the energy consumption rate for

data/received stream (Joules/Kbyte), Th_i is the throughput (kbps) required for quality level i, and r_t is the mobile device's energy consumption per unit of time (Watt). It can be noticed that for both scenarios, the energy consumption pattern presents a logarithmic increase as the quality level of the video stream is increasing.
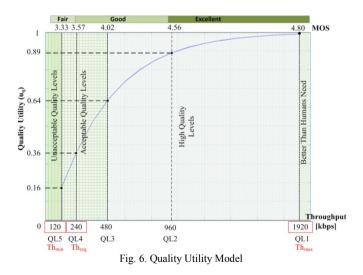

Fig. 5. Energy Consumption Pattern

The parameters r_d and r_t are device specific and can be stored on the device in the *user profile*. In this work the parameters are determined from the experimental setup where the energy measurements were conducted on a HTC One SV mobile device.

C. Modeling the Quality Utility

The results of the subjective study [2] are used to model the quality utility. Fig. 6 illustrates the relationship between the quality utility defined in (3), received throughput (quality levels) and the MOS.

Fig. 6. Quality Utility Model

Based on the choice of quality levels' characteristics and the properties of the sigmoid function, the two parameters α and β are computed such that two conditions are satisfied: (1) for Th_{max} (1920kbps) the utility has its maximum value; (2) the

second order derivate of u_q is 0 for Th_{req} (240kbps). Where Th_{req} is defined as the throughput before which the sigmoid function is convex and after which the function becomes concave. Thus, $\alpha = 2.49$ and $\beta = 0.073$ and the quality utility function is modeled as in (5).

$$u_q(Th) = \begin{cases} 0 & , & Th < 0.120 \\ 1 - e^{\frac{-2.49 Th^2}{0.073 + Th}} & , & 0.120 <= Th < 1.920 \\ 1 & , & otherwise \end{cases} \quad (5)$$

V. RESULTS AND DISCUSSIONS

A. Test Case Scenario

In order to test the performance of the proposed solution, a test case scenario is considered, as illustrated in Fig. 7. A mobile user is roaming within an LTE small cell environment while performing video on demand. In the first stage, the UEFA-M solution at the multimedia server will select the best value quality level to be streamed to the mobile user based on the user preferences. When the user reaches the TBH region the UEFA-M will trigger again the adaptation mechanism which will adapt the quality level to an energy efficient one until the handover process is complete. In this case, during the handover process the adaptation mechanism will adapt the quality level to QL5 ('Fair'), as previous subjective studies [21] have shown that users would mainly prefer to adapt to a 'Fair' quality if there is a need of adapting the quality level of a video stream to conserve the energy of the mobile device. Once the mobile user is connected to the new access point, the quality level will be adapted back to the one prior the handover process.
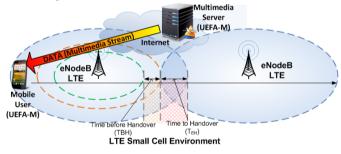

Fig. 7. Test Case Scenario

B. Impact of User Preferences

The user preferences are reflected in the weights for energy (w_e) and quality (w_q) and give an indication on the user's interests towards energy savings or video quality, respectively. Based on the user preferences, UEFA-M computes a score for each quality level i stored on the server using the U_{QLi} score function defined in eq. (1). The quality level with the highest score is then selected for transmission.

Fig. 8 illustrates the variation of the U_{QL} score values for each of the five quality levels and for different quality and energy weights. Knowing that $w_q + w_e = 1$, when the quality weight (w_q) is varied between 0 and 1 (with 1 representing an quality-oriented user), the energy weight will also vary between 1 (with 1 representing an energy-oriented user) and 0.

For example for $w_e = 0$ then $w_q = 1$, meaning that the user is interested in the quality of the video stream only without caring about energy savings. This is can also be noticed in Fig. 8, where for $w_q = 1$ ($w_e = 0$), the U_{QL} score function has the highest value for QL1. When the user is interested in energy savings only, then $w_q = 0$ ($w_e = 1$), and the U_{QL} score function has the highest value for QL5 and the lowest value for QL1.

From Fig. 8 it can be noticed that QL2 maintains a similar rank score across all the quality weights and therefore indicates a more stable choice overall. The defined U_{QL} score function helps at achieving a good trade-off between energy consumption and video quality based on the user preferences.
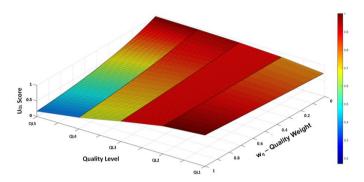

Fig. 8. U_{QL} Score Function with varying User Preferences

C. Energy vs. Quality Trade-off

To study the energy-quality trade-off for the test case scenario in Fig. 7, two UEFA-M user types are considered based on user preferences: (1) $w_q = 0.2$ and $w_e = 0.8$ for energy-oriented user and (2) $w_q = 0.8$ and $w_e = 0.2$ for quality-oriented user. UEFA-M makes use of the mathematical models developed from the real experimental setup as explained previously, to adapt the quality level of the multimedia stream based on the user's context. For the energy-oriented user, the UEFA-M quality selector will start streaming the QL4 and when the user reaches the TBH region it will adapt to QL5 until the handover process is executed. After the connection to the new access point is established, the video quality is adapted back to QL4. For the quality-oriented user, the UEFA-M score function selects the QL2 for streaming until the user reaches the TBH region when it adapts to QL5. After the handover is executed the quality level is adapted back to QL2.

The average estimated energy consumption computed using the proposed mathematical model in eq. (4) is illustrated in Fig. 9 for each of the two considered scenarios along with the cases for non-adaptive solutions when streaming any of the five quality levels. In the case of UEFA-M energy-oriented user, up to 9.5% energy savings can be achieved when compared to streaming a non-adaptive QL4, with a decrease in MOS as low as 1.96%, but still perceived as 'Good' by the user. For the UEFA-M quality oriented user, up to 18.5% energy savings could be achieved when compared to streaming a non-adaptive QL2, with a decrease of 8.9% in MOS but still perceived as 'Good' by the user.
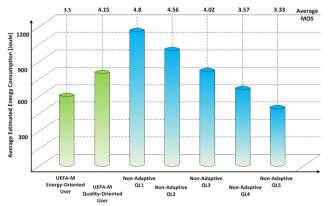
Fig. 9. Average Estimated Energy Consumption for the Test Case Scenario

CONCLUSIONS

This paper investigates the scenario of a mobile user performing video on demand while roaming through a LTE HetNet small cells environment facing the problem of increased number of handovers which might impact in a negative way the Quality of Experience (QoE) and the energy consumption of the mobile device. To this end, the paper proposes UEFA-M, an Utility-based Energy eFficient Adaptive Multimedia Mechanism over LTE HetNet Small Cells environments. UEFA-M combines the utility theory with the concept of proactive handover to adapt the multimedia stream ahead of the handover process to conserve the energy of the mobile device while enabling Always Best Experienced mobile users. This is done to compensate for the increase in power consumption during the handover process as well as to reduce the impact of other QoS related parameters (e.g., increase in packet loss rate) on the user perceived quality. Moreover, real experimental data is used to deriver mathematical models for energy and quality which are then integrated in the adaptation mechanism using the utility theory. The performance of the proposed mechanism was compared against a non-adaptive solution in terms of energy efficiency and Mean Opinion Score. The results show that UEFA-M enables a significant amount of energy to be saved during the handover process by switching the video quality level without sacrificing the overall users' Quality of Experience.

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