ePAB: Energy-Efficient, User-Preference Based Adaptive Multimedia Broadcast

Chetna Singhal,* Swades De,†*
* Bharti School of Telecommunications, Indian Institute of Technology Delhi, India
† Electrical Engineering Department, Indian Institute of Technology Delhi, India

***Abstract*—Multimedia broadcast content reception process is energy-intensive. Use of mobile receiver devices with limited battery for such applications calls for reduced energy consumption. This paper presents ePAB – an energy-efficient user-Preference based Adaptive multimedia Broadcast scheme, that optimally clubs the user-preferences for a particular video quality profile, user device types, and the usage scenarios, for adaptive scalable video encoding of the broadcast content. User-preferences are obtained a priori via a subjective test questionnaire, that reflects the acceptance of the users towards a slightly lower video quality (good instead of excellent, and fair instead of good/excellent quality) in order to extend the receiver battery life. By incorporating the preference information in the video encoding, the proposed scheme helps achieve a higher energy saving as compared to the quality maximizing scheme and an improved video reception quality as compared to the energy saving maximization scheme, while adhering to the user preference.**

***Index Terms*—Adaptive multimedia broadcast; scalable video coding; heterogeneous users; energy consumption; user preference**

I. INTRODUCTION

In the current era of affordable high-end mobile devices, there has been a tremendous increase in demand for digital multimedia content reception. With the increasing popularity for digital multimedia broadcast applications like digital television (DTV), it is essential that quality of user experience (QoE) over various kinds of user equipments (e.g., smartphones, tablets, netbooks) and usage scenarios (static - in office/home, or on the move - in car/bus/train, etc.) is acceptably good.

The mobile devices typically have limited battery capacity, but the multimedia applications are energy-hungry. Hence it is also essential to devise mechanisms that enable the users to save their device battery while receiving the multimedia content at a chosen acceptable quality.

Fig. 1 illustrates an example scenario of a multimedia broadcast environment. A multimedia server (DTV source) broadcasts scalable multimedia content to a number of heterogeneous receivers through a base station (BS). The BS serves a wide-range of customer base ranging from stationary plugged-in high resolution devices (e.g. LCD TV, PC, terminal) like U5, stationary plugged-in high resolution devices (e.g. LCD TV, PC, terminal) like U4 to mobile battery-constrained high resolution device like U2, and low resolution device like U1 and U3. Due to wide mobile device heterogeneity and the usage patterns (location, frequency, duration, etc.) several user-side constraints arise in such a broadcast environment. All these constraints can be categorized in terms of receiver display resolution, battery capacity/backup, and usage scenario (mobile or stationary user). On the basis of these constraints varied user-preferences are evolved.

This paper proposes and studies a novel and a unique mechanism for heterogeneous user equipments' (UEs) energy conservation due to adaptive video encoding and SVC layer aware time-sliced transmission. The proposed scheme in addition to energy efficiency, also ensures the QoE is improved and adheres to preferred video quality levels.

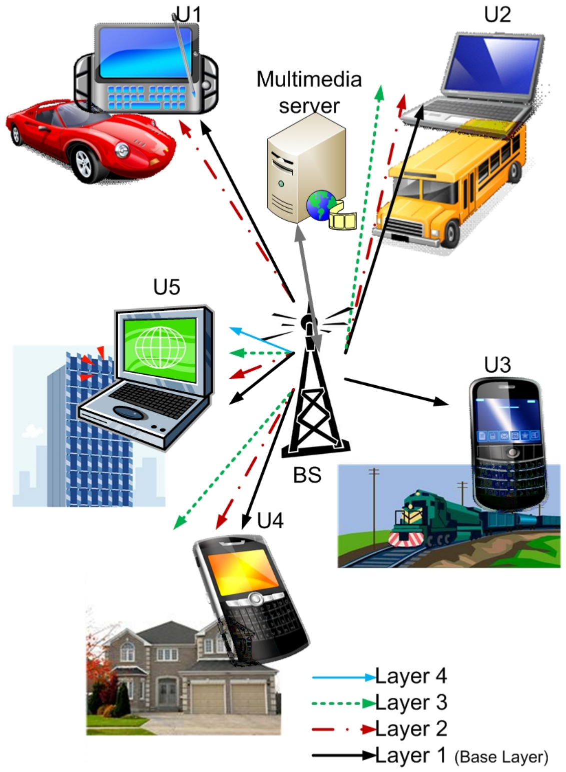

Fig. 1. Multimedia Broadcast - Example Scenario

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A. Motivation

The most prevalent multimedia standard in use is H.264/MPEG-4 AVC [1], [2]. The joint video team of ITU-T VCEG and the ISO/IEC MPEG has standardized the scalable video coding (SVC) [3] extension of H.264/AVC [4], which achieves a rate-distortion performance comparable to H.264/AVC and has the same visual perceived quality achieved with at most 10% higher bit rate [5]. SVC is primarily used for adaptive multimedia services [6]. The scalability is in terms of spatial resolution, frame rate, and quantization level. The content is in the form of video layers, as illustrated in Fig. 1, with the base layer being the most important and essential content that ensures the delivery of a minimum acceptable video quality. The enhancement layers improve the decoded video quality when received in addition to the base layer.

A SVC layer-based energy saving approach for DVB-H systems was proposed in [7], and time-slicing based energy consumption study were performed in [8], [9]. However the device heterogeneity or user-preference based on video quality profile to enhance the end-user experience and receivers' energy saving were not considered. These essential components have been accounted in our proposed mechanism.

The user preference related definitions are given below.

Definition 1. *User preference $\mathcal{P}$ signifies how much a user prefers a particular video quality level in order to save the device battery. According to the mean objective score (MOS) scale [10], the acceptable levels of video quality are 'excellent' (MOS $= 5$), 'good' (MOS $= 4$), and 'fair' (MOS $= 3$). For any user, $\mathcal{P}$ is a measure that is a function of these video quality levels and the corresponding energy savings.*

Definition 2. *Preference score (PS) scale that is used in this study has been devised similar to the MOS scale. PS values and the corresponding significance are shown in Table I.*

TABLE I
PREFERENCE SCORE (PS) SCALE FOR $\mathcal{P}$

PS	Preference level
1	Not at all preferred
2	Less preferred
3	Somewhat preferred
4	Preferred
5	Most preferred

The system architecture that addresses the user preference is discussed in the next section.

B. Contribution

This paper proposes ePAB – an energy-efficient user-Preference based Adaptive multimedia Broadcast mechanism that finds the best quality-energy trade-off using the user-preference based upon their chosen video-quality profile. ePAB is an user-centric approach that makes use of the device heterogeneity (receiver screen resolution and usage scenario, i.e., mobility and place of use) and time-slicing transmission technique to achieve energy efficiency.

However before attempting to reduce the energy consumption while maintaining QoE it is necessary to ascertain user-preferences for acceptable video quality levels for battery saving. To this end, we prepared a questionnaire and conducted a subjective test on user preference adhering to P 910 standard [10], wherein the users' preference is obtained for their acceptance to a lower video quality as against 'excellent' video quality (MOS $= 5$).

In this work, an in-depth study is conducted on the effect of user-preference aware adaptive scalable multimedia broadcast mechanism on energy saving and improved QoE benefits to the heterogeneous users. The main goals of the user-preference study in a multimedia broadcast environment are three fold:

a) ascertain the willingness of users to receive a lower video quality to save device battery;
b) study the variation in preference of users to receive a lower video quality with the possibility of increased device battery saving for the selected video quality profile;
c) develop a parametric mathematical model that approximates the user-preference study observations - to be used in optimization for adaptive SVC encoding.

Our simulation studies using real video sequences indicate that, the proposed ePAB scheme with user preference aware SVC coding optimization offers a significantly improved QoE performance, energy saving, as well as a reasonably controlled subscriber churn rate.

II. ePAB SYSTEM ARCHITECTURE

The system architecture of the proposed ePAB is illustrated in Fig. 2. ePAB is distributed and consists of a server side and a user equipment (receiver) side component.

The user equipment side consists of several components: (1) the device capabilities module which provides the information about the device characteristics (e.g., screen resolution); (2) user video quality profile module that provides the user's selection of a profile that would depend upon the usage scenario; (3) the power manager monitors the battery of the mobile device and takes advantages of the time-slicing techniques to save energy based on its remaining power.

The server side consists of an adaptive SVC encoding module that encodes multimedia content with the op-

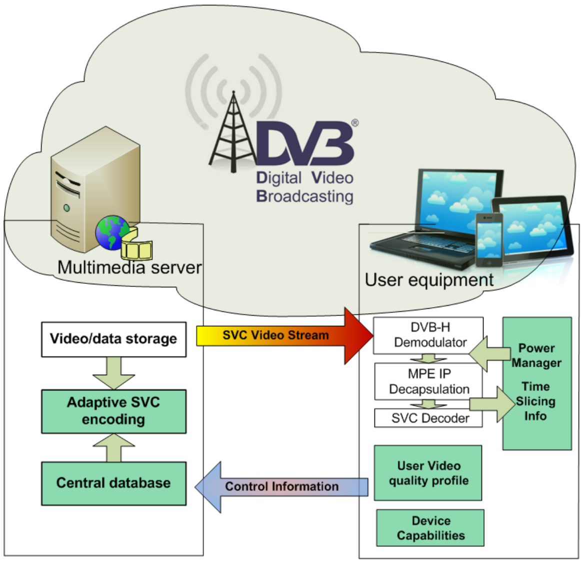

Fig. 2. ePAB System Architecture

timal SVC parameters into scalable video layers. The encoding is done based on the information received from the client related to the UE capabilities, user video quality profile choice (user-preference), energy consumption, etc. The central database module stores all the parameters facilitating the encoding optimization.

Thus, when transmitting the broadcast content, the multimedia server encapsulates the layered encoded video data in real-time transport protocol (RTP) format to IP packets and sends them over the IP network to the UE. The video is encoded based on adaptive optimization. At the network side, the BS uses the IP encapsulator to put IP packets into multiprotocol encapsulation (MPE) frames and prepares the transmission burst as per the time slicing scheme. The DVB-H modulator sends then the layered video content to the radio transmitter for broadcast. At the user equipment side the content is demodulated and displayed.

III. EPAB FORMULATION AND ALGORITHM

The proposed ePAB scheme comprises of two main components, namely, user-preference mathematical modeling and energy-efficient adaptive SVC encoding with time-slicing based transmission. The mathematical modeling of user-preference study is discussed in this section. This user-preference model is subsequently used for adaptive SVC encoding for energy-efficient multimedia broadcast. The energy-efficiency is in terms of UE's energy saving by means of SVC layer aware time-slicing.

A. User-preference study and mathematical modeling

A user-preference data on 25 subjects was collected from the users in the age group of 20-45 years using a questionnaire and the procedure as per the subjective video quality assessment methods in [10]. This pertained to the usage of mobile devices (smart phones, tablets, netbooks, etc.) for viewing videos at different video quality profiles.

Based on the subjective video quality test questionnaire, the average users' PS versus energy saving (PS-ES) trends are shown in Fig. 3 for the 'good' and 'fair' video quality profiles. It can be observed from Fig. 3 that PS is more than '3' (i.e. preference is more than 'somewhat preferred' level) when energy saving offered to the user is more than 20% for 'good' and more than 45% for 'fair' video quality profile user. The PS increases with increase in device energy saving offered to a 'good' or 'fair' video quality profile user.

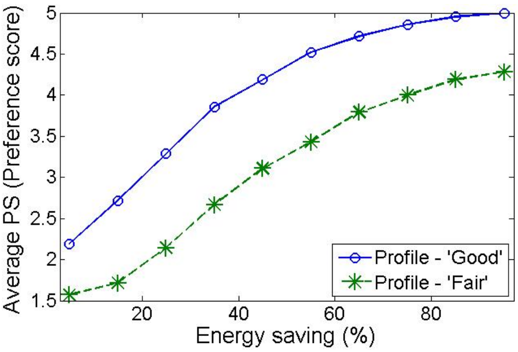

Fig. 3. Average preference score for the 'good' and 'fair' video quality profiles for increasing energy saving, obtained from the subjective test response

Since the statistical user preference data that was collected during the study has a variation with respect to device energy saving values, the PS-ES variation trends for the two video quality profiles follow a similar trend. It is observed that the trends can be best represented by an inverse exponential function. Accordingly, the average PS is modeled as a function of energy saving by using an inverse exponential function for the two video quality profiles ('good' and 'fair') as: $f(y) = \frac{1-e^{-d\cdot y}}{1-e^{-d}}$, where d is the parameter that ascertains the closest approximation of PS-ES variation in Fig. 3 for each of the video quality profiles.

A user's preference $\mathcal{P}$ depends on the chosen video quality profile as well as the corresponding energy saving. It is defined as follows:

$$\begin{aligned}\mathcal{P}(E) = {} & \tau_{excellent}\cdot\mathcal{P}_{excellent}(E) + \tau_{good}\cdot\mathcal{P}_{good}(E) \\ & +\tau_{fair}\cdot\mathcal{P}_{fair}(E)\end{aligned} \tag{1}$$

where τ is an indicator function. For example, for an 'excellent' video quality profile chosen by a user, $\tau_{excellent} = 1$, $\tau_{good} = 0$, $\tau_{fair} = 0$, and $\mathcal{P}_{excellent}(E) = 5$.

For a 'good' video quality profile chosen by a user, $\tau_{excellent} = 0$, $\tau_{good} = 1$, $\tau_{fair} = 0$. The inverse exponential function that best fits the PS-ES plot with the chosen 'good' quality profile is given as:

$$\mathcal{P}_{good}(E) = \mathcal{P}_{good}^{max} \cdot \left(\frac{1 - e^{-d_{good} \cdot E / E_{max}}}{1 - e^{-d_{good}}} \right) \tag{2}$$

where $\mathcal{P}_{good}^{max}$ is the maximum average PS for a 'good' video quality profile obtained from the study conducted. d_{good} is the parameter for the 'good' video quality profile for the approximate mathematical modeling of the PS-ES function.

For a chosen 'fair' video quality profile, $\tau_{excellent} = 0$, $\tau_{good} = 0$, $\tau_{fair} = 1$, and the corresponding inverse exponential function is:

$$\mathcal{P}_{fair}(E) = \mathcal{P}_{fair}^{max} \cdot \left(\frac{1 - e^{-d_{fair} \cdot E / E_{max}}}{1 - e^{-d_{fair}}} \right) \tag{3}$$

$\mathcal{P}_{fair}^{max}$ is the maximum average PS for a 'fair' video quality profile obtained from the subjective test. d_{fair} is the parameter for the 'fair' video quality profile.

The user preference modeling function $\mathcal{P}$ given by (2) and (3) along with the study based observations are shown in Fig. 4(a) and 4(b) for 'good' and 'fair' video quality profiles, respectively. Here, the inverse exponential function parameters for accurate modeling of PS-ES functions, (2) and (3), are $d_{good} = 2.49$ and $d_{fair} = 0.88$, for 'good' and 'fair' video quality profiles, respectively. The absolute error between the mathematical model and the subjective test for these profiles are respectively 0.67% and 0.76%.

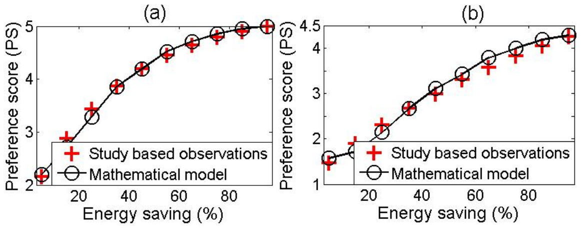

Fig. 4. Study based observation and mathematical modeling for Users' PS for (a)'good' and (b) 'fair', video quality profiles for increasing energy saving

B. Adaptive SVC encoding and time-sliced transmission

SVC can have three kinds of scalability: spatial, temporal, or quality. We categorize subscriber UEs as low resolution (CIF) and high resolution (D1) devices. With the SVC layered and time sliced transmission, the SVC layers are as shown in Fig. 5(a) and the time sliced transmission is according to Fig. 5(b).

As the spatial and temporal scalability is already incorporated in the layered SVC time sliced transmission, the further optimization is in terms of the SVC quality scalability that depends on the quantization parameter (QP). Based on the parametric video quality model in [11], the QoE for any user, Q_i is given by (4), where QP is the quantization parameter, t_i is the frame rate for user i, λ and g are video specific parameters. Q_{max} is the maximum video quality when it is encoded at minimum quantization level q_{min} and highest frame rate t_{max}.

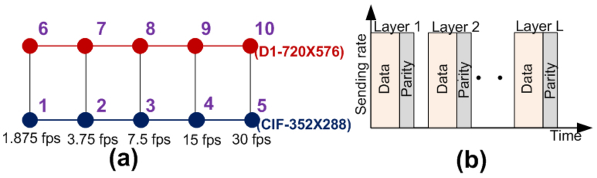

Fig. 5. (a) SVC layer structure; (b) time-sliced transmission

$$\begin{aligned} Q_i = Q(q, t_i) =& Q_{max} \cdot Q_{t_i}(t_i) \cdot Q_q(q), \quad \text{with} \\ Q_{t_i}(t_i) =& \frac{1 - e^{(-\lambda \cdot t_i / t_{max})}}{1 - e^{-\lambda}} \\ Q_q(q) =& \frac{e^{(-g \cdot q / q_{min})}}{e^{-g}} \\ q =& 2^{(QP-4)/6} \end{aligned} \tag{4}$$

In time-slicing based SVC broadcast, the UEs know a priori the specific layers constituted in the IP packet before receiving the burst. The time-slicing based transmission enables the energy saving for the UEs by allowing them to switch off their radio receiver when not receiving certain SVC layers. The energy saving for user i, E_i is given by (5), where $\mathcal{H}$ is the overhead duration (typically 100 ms [7]), b is the burst size of the base layer (bits), $R(q, t_i, s_i)$ is the rate (in bps) of SVC video received that is encoded with q quantization level, t_i frame rate, and s_i spatial resolution.

$$E_i = 1 - \frac{R(q, t_i, s_i)}{R} - \frac{\mathcal{H} \cdot c \cdot R(q, t_{min}, s_{min})}{b} \tag{5}$$

Since the optimized video encoding is transmitted in a SVC video layer aware time-sliced manner, and time-slicing governs the extent of energy-saving for the subscribers' UE. Hence, obtaining the optimal video encoding parameters based on subscribers' quality profiles, device type, and QoE constraints, helps in increasing subscriber UEs' saving.

The optimization problem for the ePAB is defined as:

$$\begin{aligned} & \underset{QP}{\text{maximize}} \sum_{i=1}^{N_{served}} E_i \\ & \text{subject to } Q_i \geq 0.25, \ 1 \geq i \geq N_{served}, \text{ and} \\ & \mathcal{P}_i(E_i) \geq 3, \ 1 \geq i \geq N_{served} \end{aligned} \tag{6}$$

where N_{served} is the number of users receiving video with quality $Q_i > 0.25$, out of the total N subscribers, Q_i is the quality of video received by user i given by (4), $\mathcal{P}_i(E_i)$ is the PS for user i given by (1), and E_i is the energy saving for user i due to time-slicing based transmission, given by (5).

Note that, the underlying constraint on $\mathcal{P}_i(E_i)$ in (6) for ePAB ensures that the video quality getting delivered and the energy saving offered to the receiver is at least 'preferred' by the subscriber.

IV. RESULTS AND ANALYSIS

A. *Simulation settings scenarios*

For the simulation study, we have considered broadcast of a 300 frames Harbor test video sequence with parameters $\lambda = 7.38$ and $g = 0.06$, to a set of 300 randomly distributed users. The proposed ePAB scheme has been analyzed over various scenarios enlisted in Table II, with different proportions of users having selected a different video quality profile (fair, good, or excellent), and having different device resolution (CIF or D1).

TABLE II
SIMULATION SCENARIOS, WITH VARIABLE RATIOS OF USERS (IN %) OF DIFFERENT RESOLUTION CATEGORIES (CIF OR D1) SEEKING DIFFERENT VIDEO QUALITY PROFILES (EXCELLENT, GOOD, OR FAIR)

Scenario	CIF resolution			D1 resolution		
	Excellent	Good	Fair	Excellent	Good	Fair
1	25	12.5	12.5	25	12.5	12.5
2	10	20	20	10	20	20
3	40	5	5	40	5	5

B. *Performance metrics*

The proposed ePAB mechanism has been examined in terms of the following metrics.

1) Churn rate: It is represented in terms of the number or percentage of subscribed users lost ($N_{subscribers\ lost}$) due to poor service (MOS $<$ 3). A user is considered as served if it at least receives 'fair' (MOS $\geq$ 3, $Q > 0.25$) video quality. Although the service provider always strives to provide a higher overall QoE to increase its revenue, often some users are not able to even get the 'fair' video quality and are then considered lost (churned out of the service provider). A scheme is considered better if it has a lower churn rate.

2) Profile based users' proportion served, $S^{profile}_{served}$: It is the proportion of users of each video quality profile being served with quality as per their profile and device type (CIF or D1 resolution). This is defined as: $S^{profile}_{served} = \frac{N^{excellent}_{served}+N^{good}_{served}+N^{fair}_{served}}{N}$, where $N^{excellent}_{served}$ (respectively, N^{good}_{served} and N^{fair}_{served}) is the total number of 'excellent' (respectively, 'good' and 'fair') video quality profile users receiving at least 'good' (respectively, 'good' and 'fair') QoE video.

3) Average QoE, $\mathcal{Q}$: The weighted average parametric video quality for the various scenarios of the Table II is obtained to evaluate the overall received video quality of different types of users in the system. It is defined as $\mathcal{Q} = \frac{\sum_{i=1}^{N} Q_i}{N}$, where N is the total number of subscribed users and Q_i is the subjective video quality of the received video at user i.

4) Average energy saving, $\mathcal{E}$: The weighted average energy saving for the various scenarios of Table II is determined to evaluate energy saving in a given scheme for different types of users in the system. It is defined as, $\mathcal{E} = \frac{\sum_{i=1}^{N} ES_i}{N}$, where N is the total number of subscribed users and ES_i is the energy saving at receiver i.

C. *Simulation results*

Performance of the proposed ePAB scheme is compared with the two other approaches, namely, E$_{max}$ scheme wherein the energy saving is maximized (subject to the video quality served to the users is at least 'fair') and Q$_{max}$ scheme that maximizes the QoE of the served users. Tables III and IV show the relative performance of the three schemes in terms of the four performance metrics described in Section IV-B. Note that, neither E$_{max}$ nor Q$_{max}$ consider the user PS.

TABLE III
QUALITY AND ENERGY SAVING PERFORMANCE FOR SCENARIOS IN TABLE II OF $\mathcal{Q}$ AND $\mathcal{E}$ PARAMETERS FOR Q$_{max}$, E$_{max}$, AND ePAB SCHEME

Scenario Table II	$\mathcal{Q}$			$\mathcal{E}$		
	Q$_{max}$	E$_{max}$	ePAB	Q$_{max}$	E$_{max}$	ePAB
1	0.616	0.424	0.547	0.832	0.957	0.931
2	0.504	0.273	0.424	0.920	0.961	0.941
3	0.897	0.617	0.773	0.834	0.916	0.902

TABLE IV
CHURN RATE (%) AND PROFILE BASED USERS' PROPORTION SERVED, I.E., $S^{profile}_{served}$ FOR Q$_{max}$, E$_{max}$, AND ePAB SCHEME

	Q$_{max}$	E$_{max}$	ePAB
Churn rate (%)	34.67	15.33	21.00
$S^{profile}_{served}$ (%)	65.33	48.00	79.00

It is seen from Tables III and IV that ePAB on average, results in 24.68% higher $\mathcal{Q}$ than in E$_{max}$ scheme, and 39.43% lower churn rate and 7.98% higher $\mathcal{E}$ compared to the Q$_{max}$ scheme. Since a service provider aims at the QoE delivered and the number of users served, ePAB is observed to be better than E$_{max}$ scheme as it delivers on average 24.68% higher $\mathcal{Q}$ than E$_{max}$ with approximately 6.69% lesser number of customers served.

Since, energy saving of the mobile devices is desired by the subscribers, and the service provider strives to serve more number of users. Hence, ePAB is superior to Q$_{max}$ scheme as ePAB provides on average, 7.98% higher $\mathcal{E}$, and serves on average 17.30% more number of customers. Although ePAB results in approximately 13.49% lower QoE than Q$_{max}$ scheme, it ensures that the QoE delivered and the energy saving offered to the UE is at least 'preferred' by the subscribed user.

The user-preference adherence advantage of ePAB over Q$_{max}$ and E$_{max}$ schemes is evident from the Table IV in terms of the profile based users' proportion served, i.e., $S_{served}^{profile}$ parameter. ePAB serves the highest proportion of total subscribers as per their profile, i.e., on average ePAB serves 17.30% and 39.24% more users (adhering to user profile) as compared to Q$_{max}$ and E$_{max}$ schemes respectively.

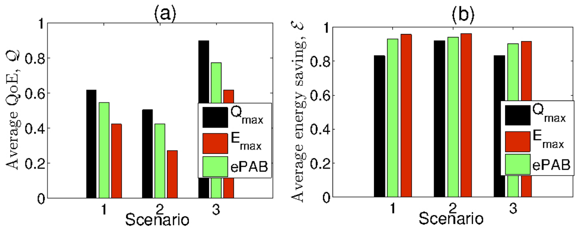

Fig. 6. (a) Average QoE, $\mathcal{Q}$, (b) Average energy saving, $\mathcal{E}$, for scenarios of Table II

Fig. 6(a) shows bar graph plot of average QoE, $\mathcal{Q}$, and Fig. 6(b) shows bar graph plot of average energy saving $\mathcal{E}$ for the scenarios of Table II. Note that, among the three schemes, E$_{max}$ scheme results in the lowest average QoE of the three schemes, and Q$_{max}$ scheme results in the lowest average energy saving. It is also evident from the Fig. 6 that, in terms of $\mathcal{Q}$ and $\mathcal{E}$ ePAB results in an intermediate performance of the E$_{max}$ and Q$_{max}$ schemes.

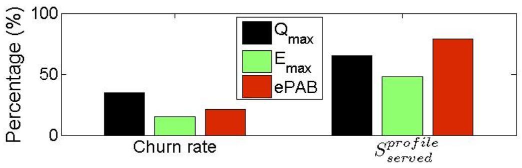

Fig. 7. Churn rate (%) and Profile based users' proportion served, i.e., $S_{served}^{profile}$ (%) for Q$_{max}$, E$_{max}$, and ePAB scheme

Fig. 7 shows bar graph plot of churn rate (%) and profile based users' proportion served i.e., $S_{served}^{profile}$ (%) for Q$_{max}$, E$_{max}$, and ePAB schemes. It can be seen that ePAB's churn rate is less than Q$_{max}$ scheme and $S_{served}^{profile}$ is the highest as compared to E$_{max}$ and Q$_{max}$ schemes. Although churn rate of ePAB seems slightly higher than E$_{max}$, E$_{max}$ serves only a small proportion (only 48%, i.e., 39.24% less than ePAB) of users as per their profile. It is thus implied that ePAB surpasses E$_{max}$ and Q$_{max}$ schemes in terms of serving more users according to their device capabilities and user video quality profile, in accordance to user-preferences.

Thus, overall, the ePAB offers a superior adaptive broadcast scheme that enables the subscribed users to save device energy and also get a better QoE according to their preference, usage scenario, and device resolution.

V. CONCLUSION

This paper has presented a study of user preference for a video quality profile with respect to mobile device energy saving while receiving multimedia content. An energy-efficient, user preference based adaptive multimedia broadcast scheme, called ePAB, has been proposed. It uses the analytical user-preference model based on a priori statistical preference score study on the users for obtaining optimal SVC encoding parameters. Additional energy saving is achieved based on SVC time-sliced transmission. In contrast with the pure QoE aware approach Q$_{max}$, a considerably higher energy saving and a lower churn rate are achieved with ePAB. Also, a significantly higher QoE results from using ePAB scheme as compared to the purely energy saving maximization approach E$_{max}$. An additional advantage of ePAB over Q$_{max}$ and E$_{max}$ has been its adherence to the user preference on video reception quality to at least the 'preferred' level while it serves more proportion of subscribers.

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