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eM-SON: Efficient Multimedia Service over Self-Organizing Wi-Fi Network

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Abstract: This paper presents eM-SON, an adaptive framework for providing efficient multimedia services over self-organizing, hybrid Wi-Fi networks. In this reconfigurable architecture, multimedia services can be received via a Wi-Fi router, Wi-Fi hotspot, or Wi-Fi Direct (i.e., device-to-device) mode. Experimental studies are performed to obtain user equipment (UE) battery discharge and QoS/QoE parameters for adaptive multimedia service (transmission, reception, and playback) over each of these Wi-Fi configurations. These experiments are conducted on different types of UEs (smartphone, tablets) with multimedia content encoded at several quality and scalability levels, and transmitted on each of the Wi-Fi configurations over varying load conditions and dynamic channel allocation. A centrally-controlled framework is developed to optimize the multimedia content (adaptive transcoding) and network resource allocation (dynamic Wi-Fi configurations and channel allocation) based on the dynamic UE and network resource constraints. The proposed solution combinedly improves the QoS (throughput, number of retransmissions, and delay), QoE, and energy-efficiency performance of the UEs, while effectively serving an increased number of users in the system.

1 Introduction

There has been remarkable technological advancements on hand-held mobile devices (e.g., improved CPU, graphics, display) and wireless transmission technologies (e.g., increased data rates, flexible resource allocation) over the recent years. Additionally, due to increasing affordability and mass-market adoption of these devices, there has been a massive growth in data traffic over the network. The major proportion of this traffic comprises of multimedia services to stationary and mobile customers on their heterogeneous devices. Although the mobile users have a wide choice of high capability devices, one of the main impediments is their battery life. This battery life limitation of the high-end mobile devices represents one of the main contributors to the user dissatisfaction [1].

Cellular and Wi-Fi inter-networking is a recent trend followed by the operators to cater to increasing mobile data traffic. Wi-Fi data offload is estimated to increase to almost 21 exabytes by 2017. In fact, daily data consumption over Wi-Fi has been found to be four times higher than that over cellular network [2]. The prevalence of Wi-Fi technology and its popularity among mobile users makes it a competitive option for serving the rapidly-increasing multimedia service demands. It offers an attractive alternative for suitable in-house, user-centric, and adaptive data service provisioning.

Mobile user equipments (UEs) are increasingly being used for watching videos, online multimedia applications, and digital television. Multimedia services have strict QoS requirements and are energy-intensive. Hence, it is necessary to devise mechanisms that conserve UE battery and offer improved QoE.

1.1 State-of-the-Art and Motivation

On average 90 percent of all mobile users are active Wi-Fi users [3]. Smartphones already have a Wi-Fi feature and can access multimedia service over Wi-Fi at a cheaper cost [2]. The latest devices also have multiple Wi-Fi configurations, such as, 802.11 a/b/g/n/ac, hotspot, and Wi-Fi direct. Wi-Fi direct provides the device-to-device (D2D) communication feature to the smartphone and tablet users. All these Wi-Fi configurations can be adaptively used for multimedia service delivery to the heterogeneous customers.

For mobile-rich multimedia delivery, the mostly-used standard for video is H.264/MPEG-4 AVC [4, 5]. Video scalability can be in terms of spatial resolution and video frame-rate [6]. Energy-aware multimedia delivery to mobile devices have been studied in [7], in the context of cellular networks. Joint QoE- and energy-aware resource allocation for multimedia transmission to mobile devices in cellular networks has been studied in [8]. However, energy-efficiency aspect of Wi-Fi based multimedia service has not been studied yet.

Cellular mobile data offloading through Wi-Fi networks has been studied in [9, 10]. The proposed city-wide Wi-Fi offloading architecture in [9] showed an improved data delivery performance. The study in [10] indicated an increased device battery power saving by delayed Wi-Fi offloading and

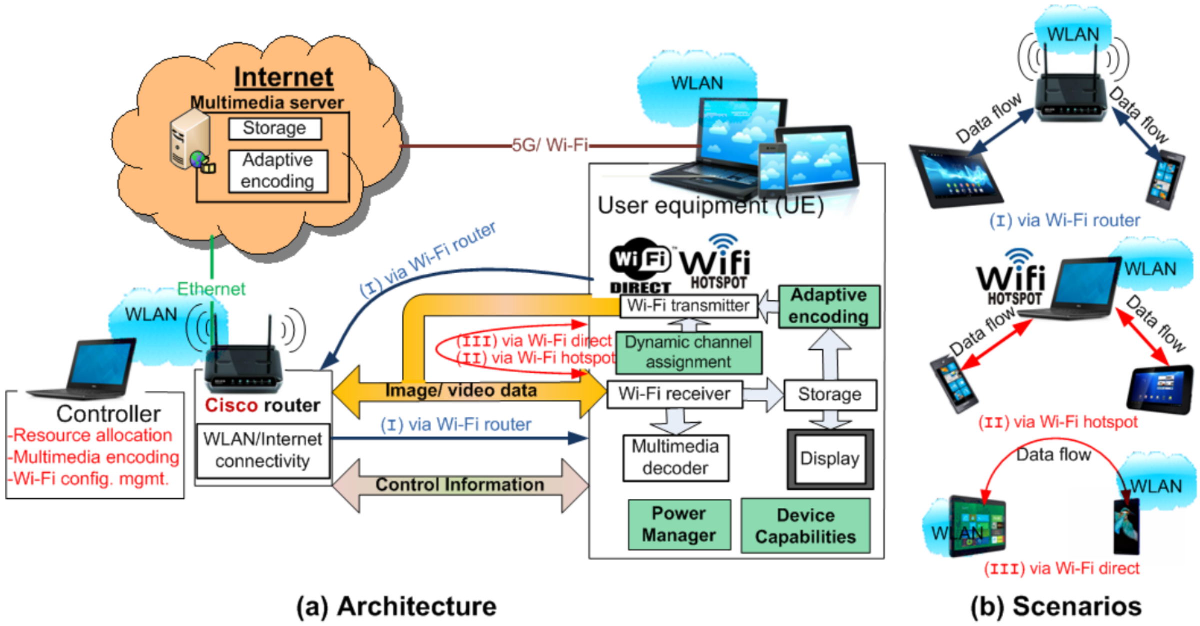

Fig. 1: (a) Architecture; (b) Scenarios.

reduced transmission time over a higher data rate Wi-Fi network. The work in [11] presented a user- and network-centric hybrid policy for mobile data offloading in heterogeneous networks. The self-organizing network (SON) mechanisms enable the operator to manage and optimize Wi-Fi operation [12, 13].

[14] discussed a self-organizing approach using opportunistic infrastructure-mode WiFi network that decreases delay in delivering messages as compared to a single-channel ad-hoc WiFi network. [14] surveys the challenges and use cases of Wi-Fi self-optimizing networks. The challenges in small-cell deployments and state-of-the-art network management techniques have been discussed in [15]. [16] discussed a distributed radio channel assignment scheme in which neighboring home Wi-Fi APs cooperate ando negotiate radio channel selection by taking into account the instantaneous network load of neighboring APs.

The aspects of Wi-Fi based device-to-device (D2D) communication in cellular networks was discussed in [17]. Resource allocation for D2D communication in licensed spectrum has been discussed in [18, 19]. Performance dynamics of group formation for D2D communication using Wi-Fi direct was studied experimentally in [20]. Timing synchronization for D2D systems has been discussed in [21]. Implementation of video delivery using Wi-Fi based D2D communication has been discussed in [22, 23].

To this end we argue that, leveraging Wi-Fi connectivity and self reconfiguration capability of many latest mobile devices for adaptive multimedia content delivery would significantly enhance the network capacity as well as QoE. Efficient multimedia service or the much needed self-organization Wi-Fi network is the need-of-the-hour. It is essential to dynamically take advantage of D2D communication and other Wi-Fi configurations in conjunction with 5G network architecture to improve the multimedia service QoS and QoE performance.

This paper proposes eM-SON – an efficient Multimedia service framework over self-organizing Wi-Fi network. It provides an adaptive solution to cater to UE heterogeneity, device battery constraints, network resource constraints, and optimum usage/support of alternative Wi-Fi technologies/ configurations. The experimental studies motivate and demonstrate the adaptive usage of Wi-Fi configurations, channel allocations, and adaptive multimedia encoding based on UE capability, network load, channel resources, and delay constraints.

1.2 Key Contributions

The proposed eM-SON framework provides multimedia service to heterogeneous users with reduced delay, improved quality, and decreased UE energy discharge.

A key feature of this work is that, through real experiments it investigates the impact of adaptive multimedia encoding and dynamic Wi-Fi configuration selection and adaptive resource (channel) allocation and on QoS, QoE, and UE battery life. The experimental study and the eM-SON architecture discussed in this paper are unique and novel. Self-organizing Wi-Fi network for multimedia service in 5G networks leveraging the Wi-Fi based D2D (Wi-Fi direct) communication is a distinctive concept introduced in this work.

The main features and benefits of the proposed framework are:

1. User heterogeneity is considered in terms of UE resolution and battery capacity;
2. Multimedia content is adaptively scaled and encoded;
3. Dynamic reconfigurability of the Wi-Fi-capable UEs is exploited;
4. Wi-Fi network load is accounted;
5. Delay, number of retransmissions, UE energy consumption, and QoE, are experimentally studied under various Wi-Fi network configurations (D2D, router, hotspot);
6. Throughput is experimentally studied based on dynamic resource (Wi-Fi channel) allocation;
7. Device energy consumption is minimized;
8. Overall throughput is maximized; and
9. Network capacity (number of users served) is increased while guaranteeing the user QoS/QoE.

Our proposed solution provides efficient multimedia services by integrating the dynamic Wi-Fi SON in the overall 5G network architecture. To the best of our knowledge, any solution that *jointly accounts for UE heterogeneity, battery constraint, application delay constraint, and network load*, to improve quality and energy-efficiency, by dynamically selecting Wi-Fi configuration, optimized resource allocation, and adaptive multimedia encoding, is still missing in the literature.

1.3 Paper Organization

The rest of the paper is organized as follows: Section 2 introduces the proposed architecture, experimental setup, scenarios, and related details. The experimental results are presented in Section 3. Section 4 presents the proposed eM-SON framework, and Section 5 contains the system performance results. The paper is concluded in Section 6.

2 System Model

In this section, a brief description of the system architecture, scenarios, and the experimental setup are presented.

2.1 System Architecture

eM-SON is an efficient multimedia service framework over self-organizing hybrid Wi-Fi network. It is an energy and QoS/QoE aware architecture that optimally allocates the Wi-Fi resources (channel) for the dynamic Wi-Fi configuration in the overall 5G architecture. Additionally, it reduces the overall energy consumption of UEs in the system by adaptively encoding the multimedia content based on the UE capabilities and network load conditions, while adhering to the delay constraints of the multimedia applications.

The eM-SON system architecture is shown in Fig. 1 (a). The multimedia content (images/videos) is provided by the multimedia server accessible over the Internet (5G). Additionally, the content may be available at a UE's local storage over Wi-Fi. Wi-Fi router provides the network connectivity to the UEs. It can act as intermediate entity for the data transmission between two UEs, as depicted in scenario (I) in Fig 1 (b). Any other Wi-Fi device can operate as a Wi-Fi hotspot or a Wi-Fi direct device for multimedia service to a UE. The SON architecture is centrally controlled by a controller (a desktop computer or a laptop in our experiment) that is connected to the Wi-Fi router over WLAN. The multimedia content is adaptively encoded (at the server) and sent to the UEs over Wi-Fi. The controller discerns the multimedia transcoding parameters, the mode of operation of Wi-Fi devices (UEs as hotspots or Wi-Fi direct devices), and dynamic channel (resource) allocation for Wi-Fi devices in the network. This is based on the network load, user profiles, and available network resources. Each UE can individually operate as a Wi-Fi hotspot or a Wi-Fi direct device. The control information such as: multimedia service request, device capabilities, battery backup, Wi-Fi configuration (hotspot, Wi-Fi direct) are communicated to the controller through the Wi-Fi router over WLAN. On receiving a multimedia service request, based on the UE capability, network load, and application QoS constraints, the controller assigns a specific Wi-Fi configuration and adaptive multimedia encoding parameters for a particular UE. This control mechanism (at the controller) in the eM-SON framework is explained in Section 4. It is executed at the onset of every new service (multimedia streaming session) as well as periodically, at the end of every group of pictures (GOP) in an ongoing multimedia stream. The controller is a static WLAN device that connects to the multimedia server over internet. The router is connected to the internet using Ethernet broadband coonection and providing the internet connectivity over WLAN. This ensures reliable connectivity between the controller and the server and the UEs.

The scenarios used in the experimental and system performance studies of eM-SON are shown in Fig. 1 (b). Multimedia data can be sent to a UE via a Wi-Fi router, a Wi-Fi hotspot, or Wi-Fi direct. Each of these configurations offer a different QoS and energy performance, that are discussed in Section 3.

Table 1 Two sample F-Test and T-Test results.

Parameter	Value
α	0.05
F	1.121876
F critical_1	0.416188
F critical_2	3.093911
t Stat	0.000102
Pr$\{T \leq t\}$	0.998916
t critical	2.091119

2.2 Experimental Setup

A real experimental test-bed for energy consumption and QoS measurements of heterogeneous UEs within a Wi-Fi based multimedia service environment has been built as illustrated in Fig. 2. The Wi-Fi configurations studied are: data via Wi-Fi router (I), data via Wi-Fi hotspot (II), and data via Wi-Fi direct (III). Data via Wi-Fi direct mode captures the performance of D2D communication among the heterogeneous UEs.

The experimental test-bed setup (shown in Fig. 2) consists of the following components: (A) a channel sensing software defined radio (SDR) setup, (B) an Arduino Uno [24] board, (C) UEs (acting as Wi-Fi hotspots, Wi-Fi direct devices) with traffic monitoring tool (wireshark, shark root), a Cisco Wi-Fi router, and a laptop which stores the power consumption measurements of the mobile device. The various UEs used for the experiments are discussed in Section 2.2.2. Several additional UEs in every experimental iteration emulate network load by invoking active sessions using a given configuration.

In order to study the UE battery energy consumption, the UE is connected to an Arduino Uno board that is connected to a laptop via USB. The mobile device has a lithium-ion/ lithium polymer battery with several pins. The two pins labeled *positive (+)* and *negative (-)* are of interest. Power consumption of the mobile device is measured by placing a high-precision 0.18 Ω measurement resistor in series between the negative battery terminal and its connector on the phone. This was done by removing the battery of the mobile device and connecting it from outside. The Arduino board was used for measuring the battery voltage as well as the voltage drop on the resistor, to determine the current. A Java application running on the laptop calculates (by using Ohm's law) the device power consumption based on the voltage readings sent by the Arduino board and saves them at a frequency of 1 Hz.

Using the Arduino board we obtain UE's power consumption at kth sec, $Power_k$ (in mW). For a T sec ($k \leq T$) video sequence, the battery energy discharge E [Joule] is given as:

$$E\ [\text{J}] = \frac{\sum_{k=1}^{T} Power_k\ [\text{mW}]}{1000}. \tag{1}$$

In order to average out the environmental and the devices' intrinsic uncertainties, the experimental readings were averaged over several iterations (ten iterations used in this study) to obtain *Device battery discharge (J)*.

By performing F-tests and T-tests on the statistically observed experimental results of two sets of ten iterations each, we ascertain that there is no statistical difference between the values of the two sets of results. The results of these tests are shown in Table 1. The F-test null hypothesis (i.e., variances of two samples are equal) can be rejected if F value (F) < lower critical F value (F critical1) or F > higher critical F value (F critical2). As it can be seen from Table 1, F critical1 < F < F critical2, for both video quality profiles. Hence, we have performed the two sample T-tests with the assumption that the variances of the two sample are

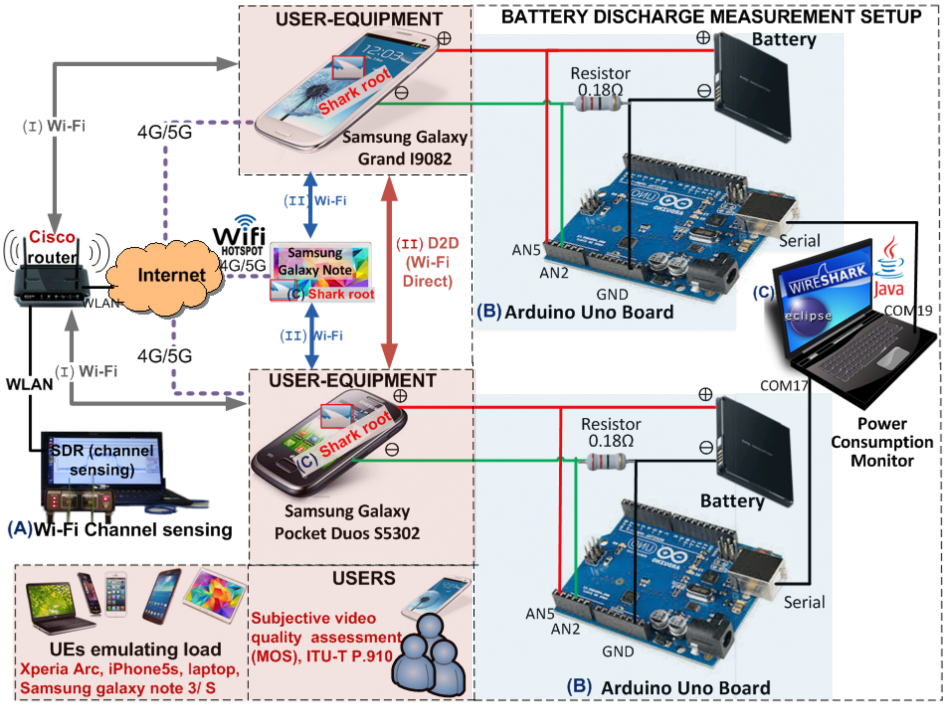

Fig. 2: Experimental setup.

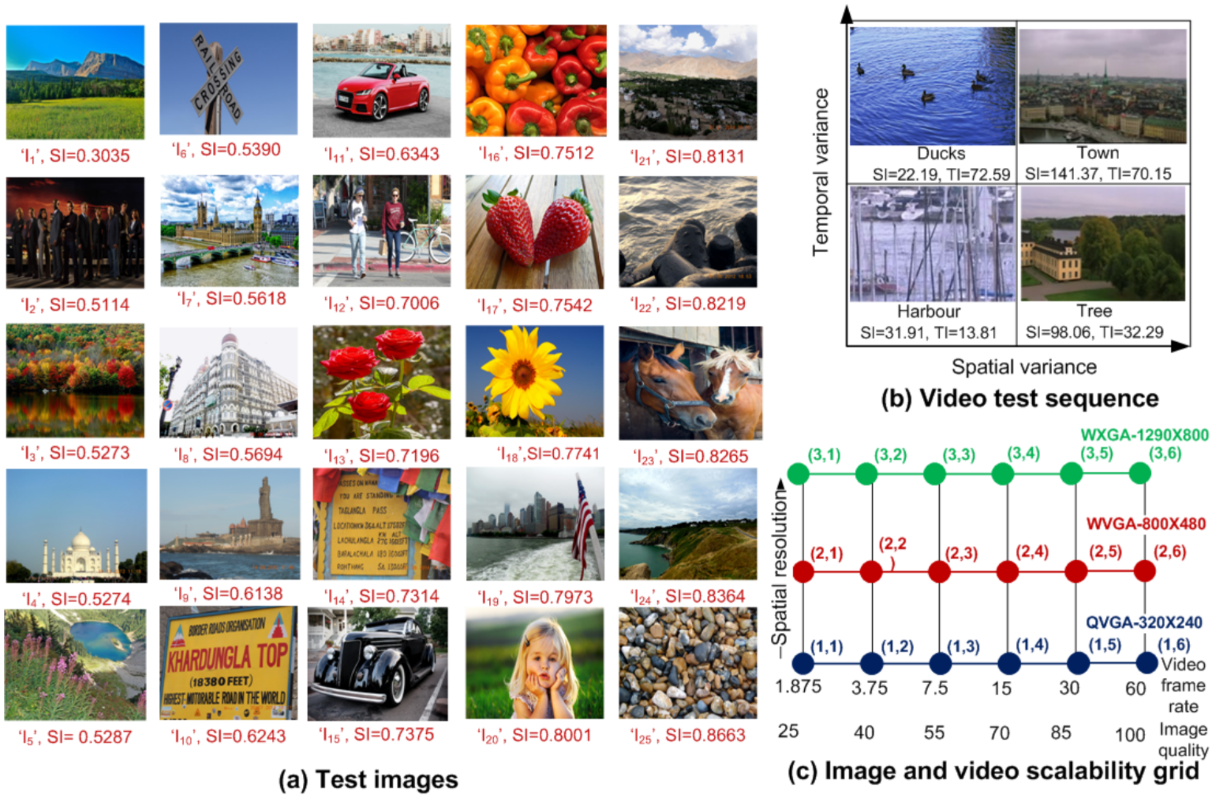

Fig. 3: (a) Test images; (b) Test videos; and (c) Multimedia (image/ video) scalability.

equal because there is not enough evidence to reject the F-test null hypothesis at the significance level $\alpha = 0.05$. The T-test results similarly, in Table 1 indicate that T-test statistics (t Stat) < T-test critical value (t critical) and the p value (Pr{T $\leq$ t}) > α. This accepts the T-test null hypothesis (i.e., there is no statistical difference between the average of two samples) and demonstrates that there is no statistical difference between the average results provided by the two independent sets of ten iterations iterations for experimental study. This finding is stated with a high level of confidence, 95% (the

Table 2 Subjective video quality (QoE) corresponding to MOS.

MOS	QoE value	Quality level
1	0	Bad
2	$(0.0 - 0.25]$	Poor
3	$(0.25 - 0.5]$	Fair
4	$(0.5 - 0.75]$	Good
5	$(0.75 - 1.0]$	Excellent

significance level $\alpha = 0.05$). The energy consumption measurement is conducted at the transmitter and the receiver for image/video transmission using Wi-Fi Direct. Additionally, energy consumption measurement is also conducted at hotspot device. The number of devices being served by the hotspot is based on the load condition (emulated by the number of active sessions by additional UEs in the network). The number of devices served by the same Hotspot depends on the load considered in the corresponding configuration. While, the D2D is only between a pair of selected devices and multiple such D2D pairs that are simultaneously streaming content between themselves based on the network load that is being considered.

To study the UE energy consumption, delay, and data retransmission performances, each of the scenarios shown in Fig. 1(b) is tested with varying load conditions and adaptive source coding. Network load for a given Wi-Fi configuration is emulated by increasing the simultaneous transmissions of multimedia traffic among the UEs within range.

The video QoE is obtained from subjective video quality testing in accordance with subjective assessment methodology recommendations, ITU-R BT 500-11 [25] and ITU-T P.910 [26]. Absolute Category Rating method [26] has been used for subjective video quality tests, wherein video sequences ($\sim$10 sec) are presented one at a time in a random order. These sequences are spaced by a $\leq$ 10 sec voting time, during which the subjects (40 subjects from diverse geographical locations and age groups) evaluate the quality of sequence shown, on a five-level mean opinion score (MOS) scale, given in Table 2. Each instance of subjective quality assessment on each test device has been conducted independently to avoid any bias.

Wi-Fi is based on IEEE 802.11g/n-2.4 protocols and uses 14 channels, spaced by 5 MHz, in the frequency range 2.4 - 2.5 GHz. Number of connections (within range) and signal strength over a Wi-Fi channel, determine the effective data-rate that can be provided to a user on that channel. In order to develop an efficient resource allocation mechanism, we have conducted the Wi-Fi channel sensing experiments using software defined radio (SDR).

Wi-Fi scan is used to get information about the signal strength and the Wi-Fi channel usage during multimedia streaming by the mobile devices and the Wi-Fi router. Wi-Fi channel information is recorded during repeated iterations (ten for each Wi-Fi configuration and several load conditions) of the experiment.

2.2.1 Test Images and Video Sequences: The experimental study has been conducted using twenty-five test images (I_1 – I_{25}) and four test video sequences ('Town', 'Tree', 'Harbour', and 'Ducks'). The test images have a diverse normalized spatial perceptual information (SI) [27], spanning $(0.3, 0.9)$, and are shown in Fig. 3(a). Each of the test video sequence has a different spatial and temporal variance. The snapshots of these video sequences along with their SI and temporal perceptual information (TI) measures are shown in Fig. 3(b). TI and SI measures are defined in ITU-T P.910 [26] as:

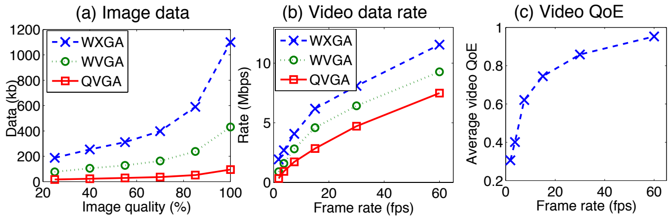

Fig. 4: Impact of scalability (c.f. 3(c)) on: (a) image data volume, (b) video data rate, and (c) average video QoE.

$$\begin{aligned} SI &= \max_{time}\{std_{space}[Sobel(F_n)]\} \\ TI &= \max_{time}\{std_{space}[M_n(i,j)]\} \qquad (2) \\ &\text{where } M_n(i,j) = F_n(i,j) - F_{n-1}(i,j). \end{aligned}$$

SI measure is the maximum value (in the time series, i.e., $\max_{time}$) of standard deviation over the pixels (std_{space}) in each Sobel-filtered frame (F_n at time n). Motion difference feature, $M_n(i,j)$ is the difference between pixel values over successive video frames. $F_n(i,j)$ is the pixel luminance located at i^{th} row and j^{th} column at time n. TI measure is the maximum over time ($\max_{time}$) of the standard deviation over space (std_{space}) of $M_n(i,j)$ over all i and j.

The multimedia content is to be served to heterogeneous users with varied UE capabilities, battery constraints, load conditions, and application delay sensitivities. Fig 3 (c) shows the scalability grid for the multimedia content (images and videos) in terms of spatial-resolution, temporal frame rate for videos, and quality level for images. Three spatial resolution category UEs, namely, wide extended graphics array (WXGA, 1290×800 resolution), wide QVGA (WVGA, 800×480 resolution), and quarter vector graphics array (QVGA, 320×240 resolution) are considered. Also, six temporal frame rates for videos are considered: 1.875, 3.75, 7.5, 15, 30, and 60 frames per second (fps), and six quality levels for images: 25, 40, 55, 70, 85, and 100%.

2.2.2 Test Devices: The UEs that have been used for the experiments are listed along with their technical specifications in Table 3. The heterogeneity aspect of these devices is in terms of: display resolution, Wi-Fi feature support, battery capacity, and operating system. Device heterogeneity is ensured by using a diverse set of test devices as can be seen from Table 3.

The android devices were rooted for the experiments, in order to capture the traffic trace. This enabled the study of QoS performance (delay, retransmission) with varying image and video quality and encoding parameters, as well as different Wi-Fi configurations and associated network loads. All the images and test videos were transmitted to all the test devices for the experimental study.

3 Experimental Results

The image data volume, video data rate, and video QoE vary with adaptive quality and scalability encoding of multimedia content. This is shown in Fig. 4. The image data volume increases with increasing quality level and spatial resolution, as shown in Fig. 4(a). The video rate and average QoE for all video sequences increases with increasing frame rate of the video, as depicted in Fig. 4(b) and 4(c), respectively. The QoE variation for each test video at each resolution level is similar and Fig. 4(c) shows the average over three resolution levels (WXGA, WVGA, and QVGA).

Fig. 5 shows the impact of image quality variations and Wi-Fi configuration on device battery discharge, delay, and

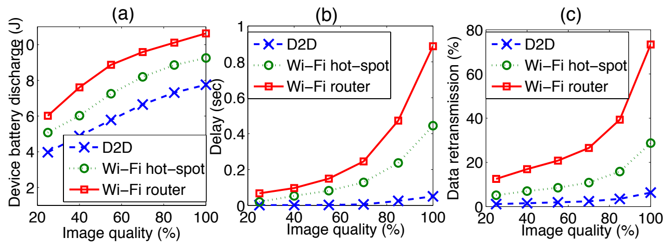

Fig. 5: Impact of image quality variations and Wi-Fi configuration on: (a) Device battery discharge, (b) Delay, and (c) Data retransmissions.

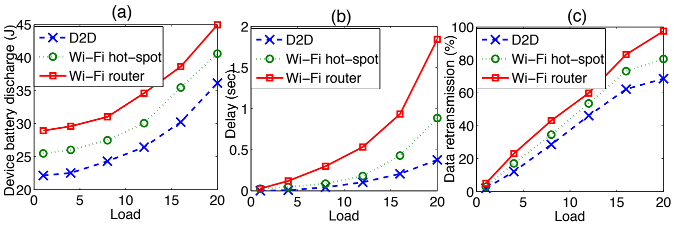

Fig. 6: Impact of Wi-Fi configuration and load on: (a) device battery discharge, (b) delay, and (c) retransmissions, averaged over 25 test images.

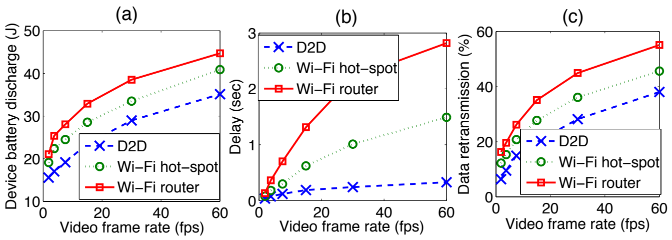

Fig. 7: Impact of video frame rate variations and Wi-Fi configuration on: (a) device battery discharge, (b) delay, and (c) data retransmissions.

proportion of data retransmissions. It is seen that Wi-Fi direct (i.e., D2D) configuration results in lesser device battery discharge, reduced delay, and lower retransmission overhead, as compared to the other two Wi-Fi configuration (i.e., via router and via hotspot), for all images and quality values.

Fig. 6 shows the impact of network load and Wi-Fi configuration on device battery discharge, delay, and proportion of data retransmissions. It is noted that Wi-Fi direct (D2D) configuration also outperforms the other two Wi-Fi configurations (i.e., via router and hotspot) in terms of lesser device battery discharge, reduced delay, and lower retransmission overhead, for all network load conditions.

The results on impact of video scalability and network load for video service over each of the three Wi-Fi configurations, are shown in Fig. 7 and Fig. 8, respectively. Again, similar to the case of image transmission over Wi-Fi, for video as well, D2D configuration outperforms the other two for all video scalability values and network load conditions, in terms of delay, battery discharge, and retransmissions. It is also observed from Fig. 7(a) and Fig. 8(b) that with an increase in network load conditions (number of simultaneous active sessions in a given Wi-Fi configuration) there is a surge in the device energy consumption for all three Wi-Fi configurations.

Fig. 9(a) shows the 14 channels available for Wi-Fi transmissions in the 2.4GHz range. Experimentally the Wi-Fi channel is scanned for the set-up shown in Fig. 9.1. Correspondingly, Fig. 9(b) shows the signal strength and signal

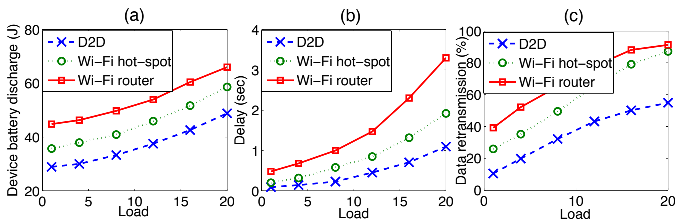

Fig. 8: Impact of Wi-Fi configuration and system load on: (a) device battery discharge, (b) delay, and (c) data retransmissions, averaged over test videos.

quality of each Wi-Fi channel. Fig. 9(c) shows the conventional usage of each channel in the 2.4GHz Wi-Fi range. Wi-Fi channel usage is defined as the proportion of Wi-Fi connections using a particular channel. Since, a considerable overlap is visible (seen in Fig. 9(a)) among the Wi-Fi channels within the range, the Wi-Fi devices by default select one of the non-overlapping channels 1, 6, and 11, as is seen from the Fig. 9(b)-(c). However, Fig. 9(c) shows the non-uniform usage of the Wi-Fi channels. This impacts the effective capacity (throughput) of the overall Wi-Fi network, and has been discussed in detail with results in Section V-A. Hence, the efficient resource (channel) allocation is essential an important component in self organizing Wi-Fi network framework.

Essentially, it is important to note that the device battery discharge, delay, retransmissions, and throughput, are affected by Wi-Fi configuration selection, video scalability/image quality, and network load. Hence, it is necessary to develop a framework for self-organizing Wi-Fi network to centrally control the Wi-Fi device mode of operation, Wi-Fi channel allocation, and multimedia transcoding parameters for an improved multimedia service to heterogeneous UEs. To this effect, we discuss an innovative framework, namely, eM-SON in the next section.

4 eM-SON: Efficient Multimedia Service over Self-Organizing Wi-Fi

From the experimental results presented in Section 3 we note that, the UE battery energy consumption depends on the multimedia scalability level s, Wi-Fi configuration w, and w's network load l_w, where,

$$w = \begin{cases} 1, & \text{transmission via Wi-Fi router} \\ 2, & \text{transmission via Wi-Fi hotspot} \\ 3, & \text{transmission via Wi-Fi direct} \end{cases} \quad (3)$$

$$l_w = \{x \in \mathbb{N} | 1 \leq x \leq 20\} \quad (4)$$

$$s = \left\{ (\mathcal{R}, f) | \mathcal{R} = \begin{cases} 1, & \text{if WXGA} \\ 2, & \text{if WVGA} \\ 3, & \text{if QVGA} \end{cases}, \right. \quad (5)$$

$$\left. f \in \begin{Bmatrix} \{1.875, 3.75, 7.5, 15, 30, 60\} \text{ if, video} \\ \{25, 40, 55, 70, 85, 100\%\} \text{ if, image} \end{Bmatrix} \right\}$$

In eM-SON, which is a centralized Wi-Fi SON framework (architecture discussed in Section 2.1), the controller decides the UE participation, its Wi-Fi configuration w_i, and application-level scalability s_i. For each user i, the objective is to obtain s_i and w_i to achieve UE energy saving and QoS

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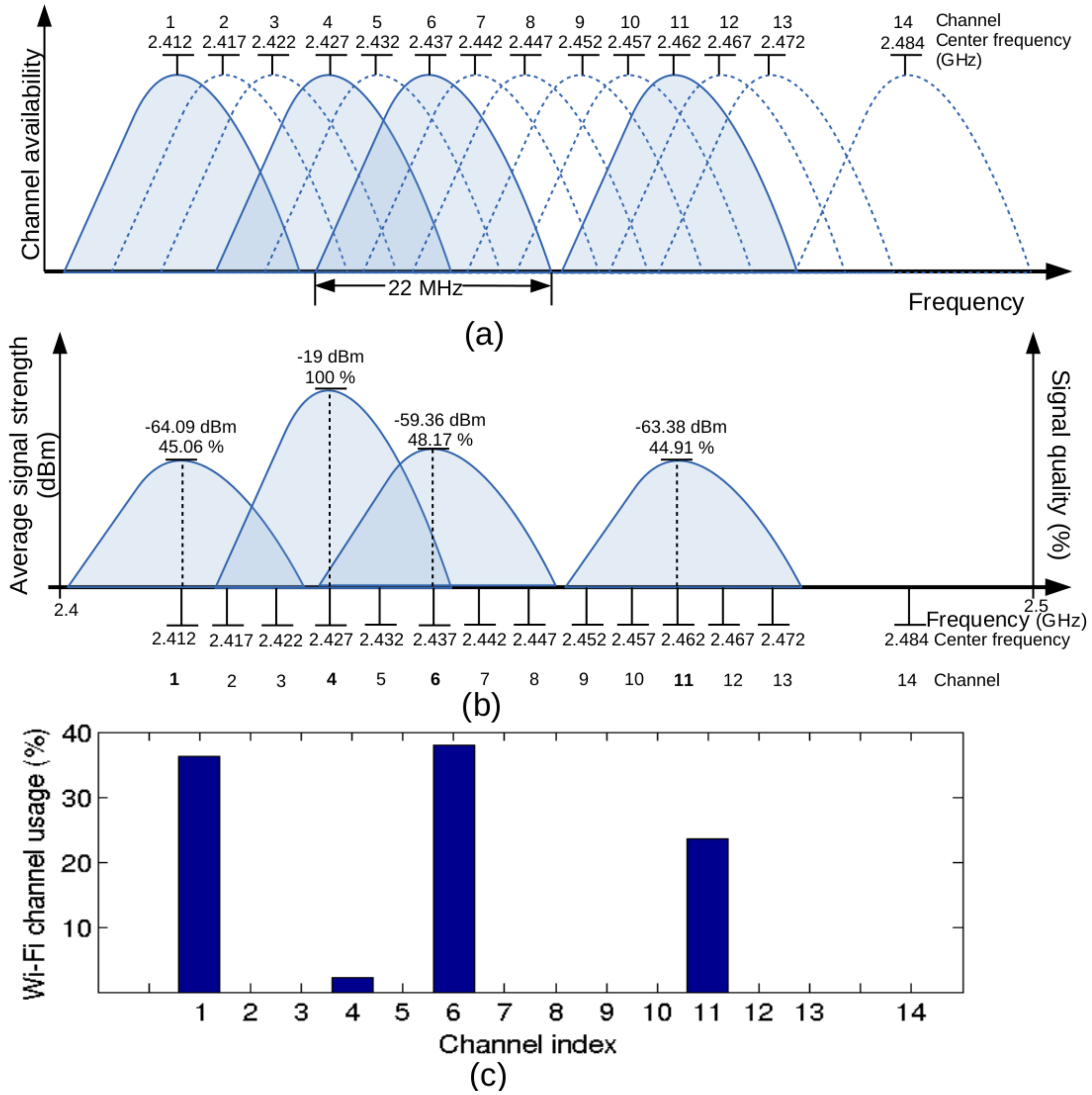

Fig. 9: (a) Wi-Fi channel allocation. Experimental results: (b) signal strength, signal quality; (c) individual Wi-Fi channel usage.

Table 3 Test devices and their technical specifications [28].

S. no.	Device	Battery specifications	Operating system	Resolution	Wi-Fi features
1.	Samsung Galaxy Y Duos Lite (GTS5302)	Li-Ion 1200 mAh, 3.7V, 4.4 Wh	Android 2.3 (Gingerbread)	240×320	802.11 /b/g/n, hotspot
2.	Samsung Galaxy Duos (I9082)	Li-Ion 2100 mAh, 4.35V, 7.98 Wh	Android 4.2.2 (Jellybean)	480×800	802.11 a/b/g/n, hotspot, Wi-Fi direct
3.	Samsung Galaxy Tab 3.8.0 (SM-T311)	Li-Ion 4450 mAh, 3.8V, 1691 Wh	Android 4.2.2 (Jellybean)	800×1280	802.11 /b/g/n, hotspot, Wi-Fi Direct
4.	Samsung Galaxy Tab S 10.5 (SM-T805)	Li-Ion 7900 mAh, 3.8V, 30.02 Wh	Android 4.4 (KitKat)	1280×800	802.11 a/b/g/n/ac, hotspot, Wi-Fi Direct
5.	Sony Ericsson Xperia Arc	Li-Pol 1500 mAh, 3.7V, 4.81 Wh	Android 2.3 (Gingerbread)	800×480	Wi-Fi 802.11 b/g/n, hotspot
6.	Apple iPhone 5S	Li-Pol 1440 mAh, 3.8V, 5.92 Wh	iOS 8.4	640×1200	Wi-Fi 802.11 a/b/g/n, hotspot

guarantee, which can be stated as:

$$\begin{aligned} &\text{minimize}_{s_i, w_i} E(w, l_w, s) \\ &\text{s.t.} \quad d(w_i, l_{w_i}, s_i) < \mathcal{D}_i \end{aligned} \tag{6}$$

where $E(w, l_w, s)$ is the UE energy consumption, $d(w_i, l_{w_i}, s_i)$ is the delay, and $\mathcal{D}_i$ is the application delay constraint for user i. $E(w, l_w, s)$ and $d(w_i, l_{w_i}, s_i)$ have been obtained experimentally, as explained in Sections 2.2 and 3. For video call $\mathcal{D}_i < 250$ ms, and for video streaming $\mathcal{D}_i < 2$ sec [29].

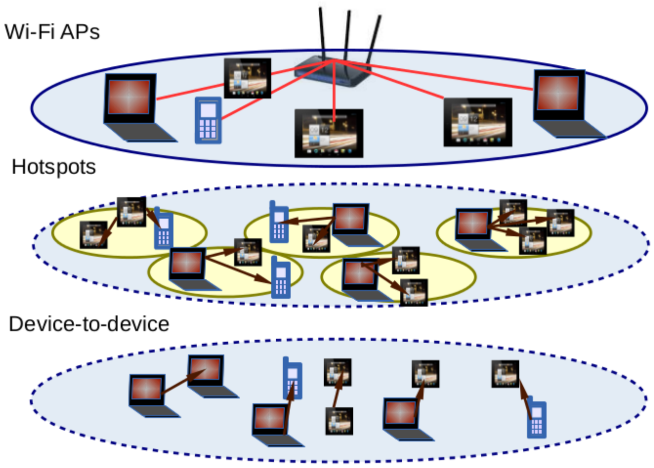

Fig. 10: Hierarchical representation of self-organizing Wi-Fi network.

In this framework, the participating mobile devices for Wi-Fi configuration, such as HotSpot, have sufficient battery backup. For each Wi-Fi based multimedia transmission to user i, the objective is to maximize the overall throughput by allocating suitable Wi-Fi resource (channel) c_{w_i}, based on w's load l_{w_i}. This is subject to the rate constraint of user i's multimedia request at scalability level s_i is satisfied by the channel allocated for w_i, which can be stated as:

$$\begin{aligned} &\underset{c_{w_j}}{\text{maximize}} \sum_{j=1}^{\mathcal{D}} \mathcal{R}(c_j, l_{w_j}) \\ &\text{s.t.} \sum_{i=1}^{n_j} R(s_i) \leq \mathcal{R}(c_j, l_{w_j}) \\ &\quad\;\; \sum_{j=1}^{D} n_j = N \end{aligned} \tag{7}$$

where, $R(s_i)$ is the scalable video rate based on the scalability level s_i, and shown in Fig. 4(b). $\mathcal{R}(c_j, l_{w_j})$ is the throughput corresponding to (c_j, l_{w_j}) allocation for Wi-Fi device j $(1 \leq j \leq \mathcal{D})$ having a configuration w_j. The system has N users and $\mathcal{D}$ Wi-Fi transmitting devices.

We have devised an efficient resource (channel) allocation algorithm for self-organizing Wi-Fi network based on water-filling model (ensures equalization among Wi-Fi channels) for hierarchical architecture in communication systems. Conceptually, this a multi-tiered architecture, depicted in Fig. 10. The Wi-Fi APs are at the top tier and has a larger coverage area. There are several devices that are dynamically configured as hot-spots inside the range of AP that constitute the next lower layer in the hierarchy. The lowest layer in the hierarchy comprises of device-to-device (Wi-Fi direct) communicating Wi-Fi devices. Based on the level of hierarchy the channels are allocated to each level Wi-Fi transmitting device, in a sequential water-filling manner. The following algorithm executes at the controller and assigns an efficient Wi-Fi channel $c_j \in \mathcal{C}$, $1 \leq j \leq \mathcal{D}$, where $\mathcal{C}$ is the set-of feasible non-overlapping Wi-Fi channels.

Algorithm 1. *Efficient Wi-Fi channel allocation for self-organizing Wi-Fi network*

Input: $\mathcal{C}$, $1 \leq i \leq N$, w_i, s_i, n_j, l_{w_j}, $1 \leq j \leq \mathcal{D}$

1. **for each** $\omega = 1$ to 3
   - **for each** $j = 1$ to $\mathcal{D}$
     - $k = 1$
     - if $w_j = \omega$ and $k < |\mathcal{C}|$, then
       - if $\sum_{i=1}^{n_j} R(s_i) \leq \mathcal{R}(c_j, l_{w_j})$, then
         - $c_j = k$
       - $k = k + 1$
     - if $k = |\mathcal{C}|$
       - $k = 1$
2. For each new participating Wi-Fi device, repeat step 1

Output: c_j, $1 \leq j \leq \mathcal{D}$

end

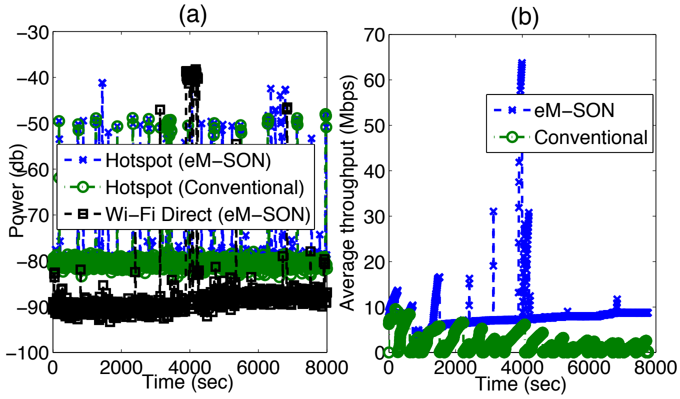

Fig. 11: Overall comparative system performance between conventional Wi-Fi and eM-SON, in terms of: (a) Signal power (dB), (b) Average throughput (Mbps).

5 eM-SON System Performance Results and Discussions

The system-level performance study is necessary to evaluate the gains of eM-SON in comparison to the conventional Wi-Fi scheme [6, 30] for providing multimedia service to heterogeneous users. The conventional scheme streams the video to UEs based on channel condition or the device capability. The conventional scheme lacks, while the eM-SON scheme includes, the provision for adaptive selection of Wi-Fi configuration and transcoding (adaptive encoding) of multimedia content based on device capabilities, application delay constraints, and network load. In addition to this, eM-SON is expected to inherently benefit from the dynamic usage of D2D (Wi-Fi direct) configuration to deliver an improved multimedia service.

5.1 *System-level Experimental Study of Throughput performance*

Using the SDR channel sensing, the signal power for multimedia transmission over eM-SON and conventional Wi-Fi system is recorded for a multi-user system (twenty-five Wi-Fi users). Furthermore, the throughput is recorded based on the traffic traces obtained from the Wireshark tools on each of the Wi-Fi devices. The results are recorded over several iterations (ten) and over several minutes (150 min.). The signal power (is observed on the SDR channel sensing device) of hotspot and WI-Fi direct during multimedia transmission in eM-SON framework and the hotspot in conventional Wi-Fi framework, is shown in Fig. 11(a). The average throughput observed during multimedia transmission (obtained from traffic traces) in eM-SON and convention WI-Fi system is shown in Fig. 11(b). It is evident that eM-SON results in higher signal power levels during transmissions (on average 12.73% for the hotspot and 38.39% for the Wi-Fi direct) for multimedia transmission and effectively higher throughput (on average 27.47%) than the conventional system by efficient Wi-Fi resource (channel) allocation and configuration selection (hotspot or D2D).

5.2 System-level Simulation Study

To study the overall system performance of eM-SON, uniformly randomly distributed heterogeneous Wi-Fi devices with random multimedia service requests have been considered over 500 iterations (95% confidence interval) and with minimum of 2 and a maximum of 200 Wi-Fi users. All Wi-Fi devices are optimally configured in one of the three Wi-Fi modes (i.e., AP, hot-spot, or Wi-Fi direct) and video scalability levels are adaptively governed by the central controller, based on the experimental study results (discussed in Section 3) and eM-SON framework (discussed in 4). We have ensured that the simulation parameters and scenarios are coherent for the comparison between the conventional and eM-SON scheme. For the simulation study we have used a mix of the test devices that were used in the experimental study. The uniformly distributed users initiate heterogeneous requests for multimedia (image/ video) content.

The simulation framework has been designed to closely reflect the actual scenario by incorporating the experimentally (described in Section 2.2) obtained QoS/QoE and energy-consumption values experienced by Wi-Fi devices, under the given system load conditions, Wi-Fi configuration, UE spatial resolution, and the multimedia content (i.e., test videos and images). The controller ensures the system scalability by balancing the load across the Wi-Fi network by dynamically selecting the Wi-Fi configurations and adaptively encoding multimedia content for the heterogeneous UEs. Thus, although it is infeasible to experimentally evaluate the system with more than 2 up to 200 randomly distributed heterogeneous Wi-Fi users exhaustively (i.e., over 500 iterations, with 95% confidence interval), the trends of the simulation-based system performance gains would reflect the actual system performance under realistic settings.

The eM-SON performance has been compared with respect to the conventional Wi-Fi scheme at different system loads. The advantage of eM-SON is reflected in Fig. 12. It is noted from the plots that, eM-SON effectively reduces the delay (on average, by 73.69%), reduces the device battery discharge (on average, by 69.01%), improves QoE (on average, by 41.46%), and serves more customers (on average, by 64.21%) as compared to the conventional scheme.

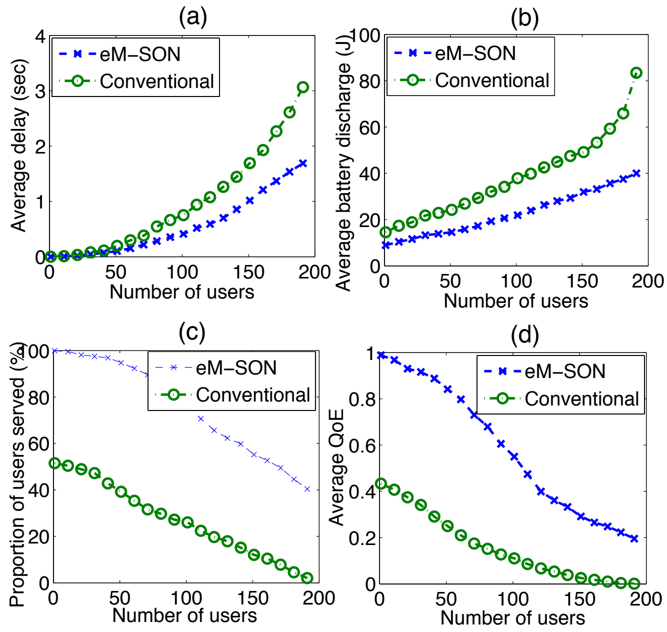

Fig. 12: Overall comparative system performance between conventional Wi-Fi and eM-SON, in terms of: (a) average delay, (b) average battery discharge, (c) proportion of users served within the delay constraint, and (d) average QoE, as the number of users in the system increases.

6 Concluding Remarks

This paper has introduced eM-SON – a novel energy and QoS/QoE aware adaptive multimedia service framework over hybrid Wi-Fi SON – that caters to heterogeneous users and dynamic usage of multiple Wi-Fi configurations and resources (channel) on present-day smart devices. Experiments have been conducted to study the impacts of adaptive multimedia encoding, Wi-Fi configuration (including Wi-Fi direct (D2D) mode), channel resource allocation, and network load, on QoS performance and device energy discharge. The objective of eM-SON has been to minimize the device battery discharge and maximize the overall throughput while adhering to the user QoS/QoE requirements. The experimental eM-SON system performance results demonstrate an improvement in multimedia QoE, reduced delay, higher energy efficiency, higher throughput, and increased number of served users, in comparison with the conventional scheme.

As an extension work, we would further study revenue-based dynamic participation models for Wi-Fi devices.

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