2013 IEEE Wireless Communications and Networking Conference (WCNC): MAC

Rate Adaptation and Base Station Reconfiguration for Battery Efficient Video Download

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Abstract - **With increasing usage of mobile devices to watch mobile video, the battery consumption of mobile devices will be dominated by video delivery and playback. In this paper, we develop battery efficient video delivery techniques that vary video transmission rate dynamically depending on *battery and buffer* levels of the mobile device, the channel conditions experienced, and video quality requirements while *maximizing battery life* and ensuring user experience. The proposed dynamic video rate adaptation techniques enable the base station to adapt the Multi Input Multi Output (MIMO) transceiver configurations to reduce battery current required by MIMO components on the mobile device. The proposed techniques also make the base station stop video transmission opportunistically, thereby eliminating the battery load imposed by the mobile MIMO components. Experiments conducted under various network conditions for various video download profiles show that more than 50% improvement in battery lifetime is possible in comparison to conventional video download techniques not aware of battery**.

Keywords - Mobile video; Client buffer; Rate adaptation; MIMO; Base station reconfiguration; Battery consumption

I. INTRODUCTION

Mobile data trends indicate that by 2015, mobile video will contribute to about two thirds of the total traffic, making it the leading multimedia application on mobile devices [1]. As mobile video is a data and compute intensive application, it places significant demands on processing and battery capabilities of mobile devices. While the processing capabilities of mobile devices continue to increase significantly, the incremental improvements in battery technologies will lead to frustratingly lower battery lifetime. Consequently, it is critical to develop techniques that can lower mobile video battery consumption.

It has been shown that RF and baseband components used for video download are major contributors to battery consumption in addition to video decoder and display used for video playback [2]. With the adoption of MIMO technologies that use multiple antennas with power consuming baseband processing, power due to RF and baseband components will likely increase and dominate the power consumption for high bit-rate mobile video applications. Hence, this paper focuses on reducing battery demand imposed by MIMO RF and baseband components while downloading video.

We consider the widely adopted HTTP based video download techniques which buffer video at the mobile device while it is simultaneously being played back [3]. The video buffer provides ***elasticity*** to vary video download rate. Variants of HTTP download such as Progressive Download and Live Streaming determine video download rates depending on changing network conditions so as to avoid stalling, and do not consider the effect of video download on mobile device battery. We develop a new battery aware video download approach that utilizes video buffer elasticity to dynamically adapt the video download rate, sometimes even stopping video download, enabling reconfiguration or idling of the base station RF and baseband components in a manner that reduces or eliminates battery demand of the mobile device RF and baseband components.

Base station reconfiguration techniques have been developed for cognitive radios for dynamic spectrum management [4], which is not the focus of this paper. The focus in [5] was on choosing optimal MIMO parameter set to minimize overall link energy while satisfying bit error rate and throughput. While the above techniques do not consider video delivery, [6] proposed to use Space Time Multiplexing (STM) and Space Time Block Coding (STBC) to reduce video distortion due to wireless video delivery; however, the latter does not address energy consumption. In [7], rate adaptation and corresponding switching between Single Input Multi Output (SIMO) and MIMO is proposed to save uplink RF transmission energy of mobile devices when mobile device is transmitting files. However [7], does not aim to reduce downlink RF and baseband processing battery consumption when mobile device is downloading video, which is the objective of this work.

To the best of our knowledge, this is the first work which proposes to jointly adapt video download rate and MIMO transceiver components to maximize battery lifetime and ensure user experience during video download. In section II, we provide an overview of our battery aware video download approach, including ways the base station can be reconfigured to reduce mobile battery consumption. Section III elaborates the proposed methodology and algorithm to determine video download rate and transceiver baseband configuration. In section IV, we present our simulation framework including several models used, and experimental results which demonstrate the ability of our proposed approach to significantly increase mobile battery lifetime during video download. We conclude in section V.

This work is supported by National Science Foundation Award No. CNS-1116859.

978-1-4673-5939-9/13/$31.00 ©2013 IEEE

II. BATTERY EFFICIENT VIDEO DOWNLOAD

In this section, we will describe our overall approach towards battery efficient video delivery, followed by different ways of base station and mobile reconfiguration to minimize battery consumption.

A. Overall Approach

Our approach towards reducing battery load is based on the following factors that prolong battery life (minimize battery consumption) [8] of a device: (1) minimizing battery load (current drawn from battery), and duration of load, and (2) idling the battery allowing it to recover charge, and increasing the duration of idling. Our proposed approach affects the above two factors by changing video download rate in the following two ways. A required video download rate is achieved by the base station with suitable configuration of its RF and baseband components, with corresponding mobile device configurations, the latter affecting battery load. Hence, by varying video download rate, it may be possible to reconfigure the base station in a way that reduces the battery load imposed by mobile device RF and baseband processing. Secondly, if for certain periods of time, video download and hence related processing on mobile device can be stopped, the battery load can reduced to just playback load which is much lower than load due to downloading. Due to significant difference in consecutive loads (download + playback followed by playback only load), effect on battery is similar to that of idling thereby enabling battery to recover charge (We show this later in section IVC in Fig. 3b). We term this as “download idle”.

Our approach needs to ensure that (1) the video download rate variation, including periods of idling, is done in a way that does not lead to buffer overflow or underflow (stalling of video playback), so that user experience is not affected; (2) the base station reconfiguration is done taking into account the wireless channel condition (estimated using Signal to Noise Ratio - SNR) and required bit error rate (BER) to achieve the desired video quality.

B. Load Reduction by Base Station Reconfiguration

In this section, we will describe RF and baseband processing components of base station and mobile, their effects on power consumed, and ways they can be reconfigured to reduce battery load. Note we sometimes refer as baseband components both RF antenna chains and baseband components.

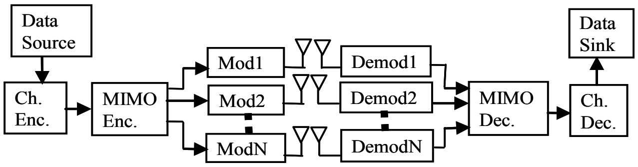

Fig. 1. MIMO Transmitter and Receiver

Fig. 1 shows a MIMO transmitter and receiver. The transmitter consists of channel encoder, MIMO encoder, and set of antennas each with an associated modulator. The receiver consists of antennas, demodulator, MIMO decoder and channel decoder. Tables I and II list some of the possible configuration choices that can be used for MIMO transmitter and receiver. The set of all possible combinations of transmitter and receiver baseband components constitutes the configuration spaces of base station and mobile device respectively. Henceforth we will refer to the combination of transmitter - receiver antennas, channel encoding rate, MIMO encoding, modulation, MIMO and channel decoding algorithms as the *transceiver mode* selected. Next, we provide a high-level overview of relative contribution to battery load of different receiver components and their choices listed in Table II.

TABLE I. MIMO TRANSMITTER PARAMETERS

Convolutional Codes Coding Rate	1, 2/3, 1/2, 1/3
MIMO Encoding	STM, STBC
Modulation Schemes	Binary Phase Shift Keying (BPSK), Quadrature Amplitude Modulation (QAM) - 4QAM, 16QAM, 64QAM
Number of Antennas	1, 2, 3, 4

TABLE II. MIMO RECEIVER PARAMETERS

Number of Antennas	1, 2, 3, 4
MIMO Decoding	Zero Forcing (ZF), K-Best
Channel Decoding	Viterbi Decoding, Turbo Decoding

Among all the MIMO receiver baseband components, the antenna RF chain is the most power intensive, and the battery load can increase significantly with increase in number of antennas. We consider two MIMO decoding algorithms, Zero Forcing (ZF) and K-Best, both of whose power consumption depends on the number of antennas and modulation scheme used; however, ZF is more power efficient but provides less BER performance than K-Best. Note the power consumed by demodulation is included in MIMO decoding, as demodulation is performed as part of MIMO decoding. Finally, power consumed by channel decoding depends on the algorithm used. Viterbi decoding consumes less power than Turbo decoding, but also has a lower BER performance than Turbo [9]. The battery load of a receiver configuration can be estimated by adding the power consumptions of the individual receiver components. We next discuss different ways mobile battery load can be reduced by appropriate base station reconfiguration.

TABLE III. EXAMPLES OF MODES WITH DIFFERENT DOWNLOAD RATE

Mode A	Coding Rate 1/2, STM, BPSK, 2X2, ZF, Viterbi
Mode B	Coding Rate 1/2, STBC, 4QAM, 2X1, ZF, Viterbi
Mode C	Coding Rate 1/2, STM, 4QAM, 4X4, K-Best, Viterbi
Mode D	Coding Rate 1/2, STM, 4QAM, 2X2, ZF, Viterbi

Multiple transceiver modes may satisfy the same download rate under a given channel condition (SNR) and BER value. Hence, it may be possible to select a transceiver mode which may actually increase the power consumption in the base station, but will reduce the mobile battery load. For example, the two modes A and B listed in Table III result in the same download rate. For the given SNR, mode

B increases the power consumed by the base station as it uses 4QAM modulation scheme which consumes more power than BPSK used in mode A. However, mode B will reduce battery load on the mobile device, as only one receiver antenna is used as opposed to two antennas used in mode A. Note that the reduction in battery load due to reduction in receiver antennas far outweighs any increase in battery load due to higher order demodulation.

The opportunities for finding battery efficient transceiver modes can be increased if the required video download rate can be reduced. Consider modes C and D in Table III. If the video download rate needed is reduced by half, given the same channel condition and BER requirement, mode D can be used instead of mode C. Reconfiguring to mode D will significantly reduce the mobile battery load, as it uses less number of antennas and less power intensive ZF MIMO decoding. Note that download idle is a special case of rate reduction wherein the download rate is made zero thereby reducing the battery load to just the playback load.

Even when download rate cannot be reduced, mobile battery load can be reduced by taking into account the existing channel condition, and required BER. For example, if channel condition improves, for same download rate, it may be possible to reconfigure receiver to use ZF MIMO decoding instead of K-Best if BER requirement is met.

In summary, there can be several ways of selecting transceiver modes to reduce mobile battery load. However, there are several challenges. Firstly, the size of configuration space is large. Secondly, reducing video download rate needs to be done in a way that ensures no stalling at client. And thirdly, any reconfiguration needs to be done cognizant of channel conditions and application BER requirements. In the next section, we propose a methodology which avails of the opportunities, and addresses the challenges, described in this section.

III. METHODOLOGY FOR RATE AND MODE SELECTION

In this section, we will present a methodology and an efficient algorithm to determine the optimal video download rate, and corresponding transceiver mode, that maximize mobile device battery life during video download.

The first key goal of the methodology is to reduce battery load by varying video download rate depending on buffer, battery level and channel conditions while ensuring user experience. The video download rate is selected such that (a) there is no buffer overflow/underflow, thus ensuring user experience, and (b) a transceiver mode can be found that results in reduced battery load. Further, when buffer levels permit and battery level is low (battery has greater need to recover charge), download idling is chosen to maximally reduce battery load.

The second key goal of the methodology is to ensure the desired video quality, when selecting the most battery efficient transceiver mode. Peak Signal to Noise Ratio (PSNR) is used as a measure of video quality. PSNR increases as BER decreases [10], implying that video quality improves as BER decreases. This relationship allows BER to be used as an indicator of video quality. During reconfiguration, depending on channel condition, only modes that satisfy BER requirement are selected.

Next we describe the proposed transmission rate-mode selection algorithm that encompasses the above two goals. Henceforth, we will use the terms transmission rate and video download rate of the mobile device interchangeably.

C. Transmission Rate-Mode Selection (TRMS) Algorithm

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Input: Video bit rate $V_{BR}$, Buffer size $Buf_{Size}$, Buffer level available $Buf_{Lev}$, Video playback time $T_{PBT}$, Idle threshold $I_{Thr}$, Battery level $Bat_{Lev}$, SNR, Application BER, Transmission period $T_{Period}$
Output: Transmission Rate $TR_M$, Mode M (valid for $T_{Period}$)
While (Video download not complete)
 Step 1: Determine optimal transmission rate($TR_{Opt}$),coding rate (CR)
     If $T_{PBT} > I_{Thr}$ && $Bat_{Lev} < Bat_{Low}$; Then Download Idle; $TR_{Opt}=0$
     Else If $SNR \in \{SNR_{High}\}$; Then $TR_{Opt}=TR_{Max}$; $CR \in \{CR_{Max}\}$
     Else If $\{SNR_{Low}\} < SNR < \{SNR_{High}\}$; Then
       N = |SNR, CR Ranges|
       For $N \leq$ Range Index (RI) $\leq 1$
        Rate Reduction Factor $\delta = RI * 1/N$; $0 < \delta \leq 1$
        If $SNR \in \{SNR_{RI}\}$; Then $TR_{Opt} = \delta * TR_{Max}$; $CR \in \{CR_{RI}\}$
        End If; End For
     Else If $SNR \in \{SNR_{Low}\}$; Then $TR_{Opt} = TR_{Min}$; $CR \in \{CR_{Min}\}$
     End If
Step 2: Determine modes that satisfy selected transmission rate
For $1 \leq Mod \leq 4$, /*Mod=1(BPSK), 2(4QAM), 3(16QAM), 4(64QAM)
         $SISO_{Mod}$=(1x1 $T_R$ for chosen Mod)*CR
         $TR_{Ratio} = TR_{Opt}/SISO_{Mod}$
           If $TR_{Ratio} \geq 1$,Then $Ant_{Mod} = \min(TR_{Ratio}, 4)$
           Else $Ant_{Mod} = 0$
           End If
         $\text{Mode-Set}_{Mod} = \{Ant_{Mod}, Mod, CR\}$;  $i = |\text{Mode-Set}|$
 End For
Step 3: Mode selection based on BER
        For $1 \leq j \leq i$,
           $BER_j = f(\text{Mode-Set}_j, SNR)$ /*BER model in section IVA
           If $BER_j \leq BER$
              Then $\text{FeasibleMode-Set}_j = \text{Mode-Set}_{j}'$; $j = j+1$
           End If, End For;
 Step 4: Power estimation of modes
          For each mode $\in$ FeasibleMode-Set
              $P_{FeasibleMode} = P_{RF\_Chain} + P_{MIMO\_Dec} + P_{Ch\_Dec} + P_{Baseband}$
        End For
 Step 5: Minimum power mode selection
          $P_M = \text{Min}\{P_{FeasibleMode}\}$
          Mode M = ($Ant_{Mod}$, Mod, MIMO_Dec, CR)
          $TR_M = Ant_{Mod} * SISO_{Mod}$
End While
```

Fig. 2. Transmission Rate – Mode Selection (TRMS) Algorithm

Fig. 2 shows our proposed transmission rate-mode selection algorithm (TRMS), consisting of five steps as described below. The inputs and outputs of the algorithm are shown in Fig. 2. A video session consists of several download epochs or transmission periods termed T_{Period}. Till the video download is completed, the algorithm steps are applied to each T_{Period}. In step 1, transmission rate and coding rate (CR) are chosen depending on current battery and buffer levels, and SNR. At first, it is determined whether idling is possible. As idling depletes the buffer, it is performed only when buffer levels permit and battery level is low. If download idle is not possible, then range of rates bounded by minimum (TR_{Min}) and maximum (TR_{Max}) transmission rates is calculated using (1), (2) and (3).

$$T_{PBT} = \frac{Buf_{Lev}}{V_{BR}} \tag{1}$$

$$TR_{Min} = \left\{ \begin{array}{l} \frac{V_{BR} * (\lfloor T_{PBT} \rfloor - (T_{PBT} - 1))}{\lceil T_{PBT} \rceil}, 0 \prec T_{PBT} \prec 1 \\ 0, T_{PBT} \geq 1 \end{array} \right\} \tag{2}$$

$$TR_{Max} = \frac{Buf_{Size} - Buf_{Lev}}{T_{Period}} \tag{3}$$

One possible way of determining the optimal transmission rate from the range is to evaluate the battery load reduction achieved by each possible transceiver mode at each possible transmission rate, and select the corresponding rate (and mode) that produces the most load reduction. Clearly, the above approach can have a very high run-time complexity, depending on the range of rates, and how large the transceiver configuration space that needs to be traversed.

Instead we propose a more efficient method for rate selection at each T_{Period} using the insights described below. (1) Idling is selected when battery level (1/0 indicates fully charged/drained battery) is low (Bat_{Low}=0.4), and video playback time, T_{PBT} defined by (1), is greater than idle threshold I_{Thr}. (2) When SNR and battery level are high, TR_{Max} is selected as the battery can support the power intensive modes required; (3) As SNR goes low, lower transmission rates (TR_{Max} lowered by the rate reduction factor δ defined in Fig. 2, Step 1) are selected enabling transceiver reconfiguration to choose less power consuming modes. On the contrary, choosing high transmission rates at low SNR will require power intensive transceiver configurations to satisfy application BER requirement; (4) With lower SNR values, CR is lowered to meet the BER requirement. In order to quantize the above insights, SNR and CR values are divided into ranges. The highest and lowest SNR values possible are grouped in to SNR_{High}, and SNR_{Low} ranges respectively. Values in between SNR_{High} and SNR_{Low} are grouped in to 'N' groups; SNR_N, SNR_{N-1}, and so on till SNR_1, with members of each range being greater in value than ones in subsequent ranges. Similarly, coding rate values are also grouped in to ranges; CR_{Max}, CR_N, CR_{N-1}, and so on till CR_1 and CR_{Min}. These insights form the basis of the guiding logic used to select the optimal transmission rate TR_{Opt} and CR as shown in step 1.

Step 2 determines the set of all transceiver modes that satisfy TR_{Opt}. $SISO_{Mod}$ is the transmission rate for mode with 1x1 antenna configuration, modulation scheme Mod and CR. As transmission rate scales directly with number of antennas, modulation order and inversely with CR, the ratio of TR_{Opt} and $SISO_{Mod}$ gives the antenna configuration Ant_{Mod} for the modulation scheme and CR. If Ant_{Mod} is greater than four, it is set to four, choosing the mode that gives maximum transmission rate for the modulation chosen. Similarly, Ant_{Mod} is set to zero if transmission rate required is less than the minimum possible with that modulation. This is done iteratively for all the modulation schemes resulting in Mode-Set, with 'i' number of elements. In step 3, BER values of all the modes selected in step 2 are determined using the BER model (section IVA). Only modes with BER values lesser than or equal to application BER are retained. In step 4, power values of modes that satisfy BER are calculated using the power model (section IVA). Step 5 selects the minimum power mode. In our proposed framework, the mobile device periodically (every T_{Period}) sends battery and buffer levels, besides the measured SNR values, to the base station. The additional data transmitted for battery and buffer levels is nominal, a byte each assuming a granularity of 256 levels, resulting in 1.14mW of power consumption [11] and no more than 0.4% of power overhead even when the least power mode (1x1, BPSK, CR=1, ZF) is selected. The TRMS algorithm which resides in the base station is executed using these new inputs to determine the optimal transmission rate and mode; the base station sends the new mode to the mobile device before resuming transmission at the selected rate using the selected mode. Again, receiving 1 byte of mode information imposes nominal power overhead on mobile device.

IV. SIMULATION FRAMEWORK AND RESULTS

In this section, we describe power, battery and BER models, the simulation framework developed and experimental results obtained by using the proposed video download techniques.

D. Power, Battery and BER Models

The power model is used to determine power requirements of the mobile device for video download and playback. Download power consists of four components, namely power due to RF chain (P_{RF_Chain}), MIMO decoding (P_{MIMO_Dec}), channel decoding (P_{Ch_Dec}) and remaining baseband signal processing ($P_{Baseband}$). P_{RF_Chain} is determined using (4) obtained from relations in [5][12].

$$P_{RF\_Chain} = [(1.8 * 10^{-8} * BW) + 0.061] * Ant_R + 0.1 \tag{4}$$

MIMO decoding power consumption depends on MIMO encoding scheme, number of antennas, algorithm chosen (ZF or K-Best) and modulation scheme used. It is estimated by calculating number of search steps [5] required to decode a symbol and determining number of parallel search engines [13] required to execute the number of steps. As MIMO decoding power is dependent on many factors, for brevity we list in Table IV some representative values when STM is used for transmission, K-Best/ZF (first/second value) algorithms are used for MIMO decoding. We consider only Viterbi channel decoding algorithm in this work; P_{Ch_Dec} estimate is obtained from [14]. $P_{Baseband}$ is given by (5) [5].

$$P_{Baseband} = (1.62 * 10^{-9} * BW * Ant_R) \tag{5}$$

TABLE IV. MIMO DECODING POWER CONSUMPTION VALUES IN MW

Modulation/ Ant_Tx Ant_R	64QAM	16QAM	4QAM	BPSK
4x4	612.5/4.14	336/4.14	38.7/4.14	11.7/4.14
2x2	194.9/0.7	62/0.7	10.5/0.7	2.7/0.7

In (4), (5) and Table IV, Ant_T and Ant_R are number of antennas used at base station and mobile device respectively, and BW is the system bandwidth. Power consumed during playback is due to video decoder and display and is estimated from [15] [16]. The total power requirement at any given time is sum of download power and playback power. In order to estimate the battery consumption due to current drain imposed by download and playback, the RV lithium ion rechargeable battery model [8] [17] is used. Power P obtained from power model is converted to battery load I_{Bat} using (6). We assume that the battery voltage V_{Bat} is constant during discharge. Note that the proposed methodology can be used with any battery model that gives battery level in response to battery load.

$$I_{bat} = {}^{P}\!/_{V_{Bat}} \tag{6}$$

TABLE V. SIMULATION PARAMETERS FOR BER MODEL

Channel Model	Ped B
Bandwidth	5MHz
SNR (dB)	0-40
FFT Size	512 points
Channel Coding	1, 2/3, 1/2, 1/3
Modulation Schemes	BPSK, 4QAM, 16QAM, 64QAM
Antenna Configurations	STM - 1x1, 2x2, 3x3, 4x4; STBC: 2x1, 2x2
MIMO Decoding	Zero Forcing, K-Best
Channel Decoding	Viterbi Decoding

We have developed a BER model using MATLAB to simulate different modes under different channel (SNR) conditions to obtain BER values used by TRMS algorithm to ascertain which modes satisfy the BER requirement. The simulation parameters used are listed in Table V.

E. *Simulation Framework*

A C based simulation framework was developed to estimate battery consumption during video download and playback. This framework allows different video delivery techniques to download different video sequences under varying network conditions and video quality requirements.

TABLE VI. VIDEO DOWNLOAD SIMULATION PARAMETERS

Video Characteristics	Video Bit Rate V_{BR} = 4.12Mb/s
	Video Sequence 1: {80s, 80s, …., 80s} Video Sequence 2: {60s, 69s, 57s, 47s, 47s, 67s, 52s, 62s, 46s, 68s, 55s, 75s, 74s, 64s, 60s, 76s, 73s, 66s}
Client Characteristics	Video Buffer Size = 25.2 MB (48s)
	Playback Current (Decoder + Display) = 34mA
	Idle Threshold: {45s, 20s, 15s}
SNR (dB)	High: 40, Low: 9, Variable: Uniform Distribution in the range 0–40
BER	10e-6

Table VI lists the simulation parameters used in our experiments. Video characteristics specify the video bit rate and the sequence of videos watched. Video sequence 1 consists of 30 videos each of 80 seconds duration. Video sequence 2 consists of video segments of varying duration, a pattern representative of "video snacking" wherein the viewer begins to watch a video and then switches to a new video without finishing the current video. Client characteristics enumerate buffer size, playback current requirements and idle threshold values. Table VI also lists different network conditions (high, low and variable SNR) and high quality (BER) requirements used for simulation.

The simulation framework for battery aware video download techniques consists of power, battery, BER models, and TRMS algorithm and simulation time counter. When video download is initiated, the simulation time counter is started. For each simulation counter step, the TRMS algorithm determines the transmission rate and corresponding mode depending on the current battery, buffer levels, channel condition (SNR) and application BER. In our experiments, simulation step is fixed at 1 second, though it can be made longer or shorter. The power consumed by selected mode is calculated using the power model. The resulting battery load along with playback load is used by the battery model to provide battery level. If the viewer switches to a new video or current video is completely downloaded, new video download begins. This continues till battery is completely drained. The simulation counter at this instant gives battery lifetime when user downloads and watches chosen video sequence under simulated network and quality conditions.

We use the same framework to simulate HTTP Progressive Download except that, instead of using TRMS algorithm, we fix the desired transmission rate to maximum value determined using (3), and select mode that satisfies the rate and BER requirement. If no such mode exists, then the mode that gives highest rate (lower than maximum rate desired) at given SNR and BER value is chosen.

F. *Experimental Results*

Next, we present results obtained by simulating different video sequences downloaded under different network conditions and high video quality requirements (Table VI). Figs. 3 and 4 show the effects on battery load, level and lifetime while using HTTP Progressive Download (HTTP-PD, shown in red) and our proposed Battery Aware HTTP Progressive Download (BAHPD), first showing the gains achieved by transceiver reconfiguration (BAHPD-R, shown in blue) and then with transceiver reconfiguration and download idling (BAHPD-RI, shown in green).

We will first examine the scenario when the mobile device is experiencing good network condition (high SNR). Fig. 3a shows the battery load resulting from downloading and viewing a single 80s video. As HTTP-PD delivers video at maximum download rate without attempting to choose battery efficient modes, it results in maximum battery drain. BAHPD-R also downloads at the maximum rate possible, but by choosing battery efficient modes, battery load is reduced. The green line shows the effect of BAHPD-RI, additionally performing download idling. Since SNR is high, we use a high threshold of 45s allowing most of the buffer to fill before idling is initiated. Battery load reduces to minimum (playback load) during download idle, allowing battery to recover charge. Fig. 3b shows the effect on battery level, when the simulation is started with battery level of 0.2. HTTP-PD causes maximum decrease in battery level, followed by BAHPD-R and BAHPD-RI. Note that for BAHPD-RI, download idle followed by transmission results in alternate fall and rise in load with corresponding rise and fall in battery level, clearly indicating that the battery

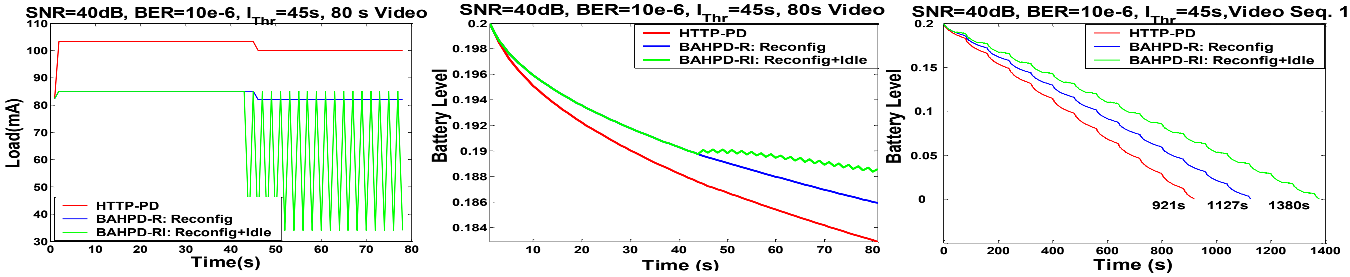

Fig. 3. Effect of downloading and viewing (a) 80s video on battery load; (b) 80s video on battery level; (c) video sequence 1 on battery level and lifetime

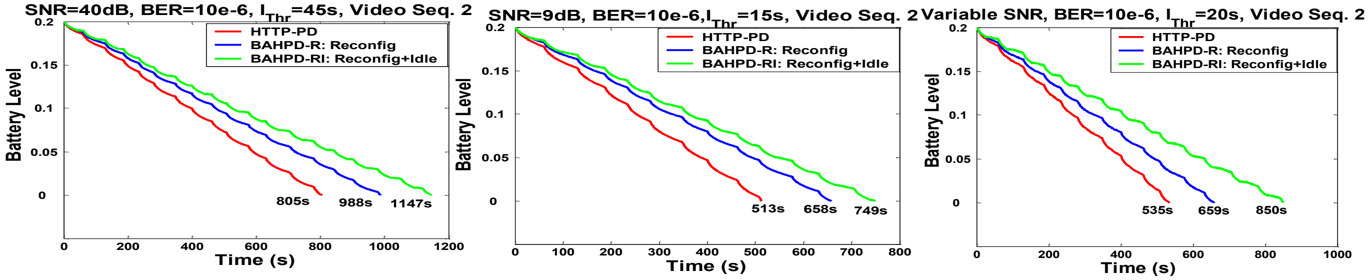

Fig. 4. Battery level and lifetime when downloading and viewing video sequence 2 under (a) High; (b) Low; (c) Variable SNR conditions

recovers charge as a result of download idling. Fig. 3c shows the battery lifetime (total video viewing time) possible starting with battery level 0.2 while viewing video sequence 1. Battery lifetime is significantly increased from 921s using HTTP-PD to 1127s using BAHPD-R, and to 1380s using BAHPD-RI representing gains of 22% and 50% respectively. Similarly, when video sequence 2 is downloaded, BAHPD-R and BAHPD-RI achieves 23% and 42% gains in battery lifetime, as shown in Fig. 4a.

While downloading video sequence 2 under bad network condition (low SNR), HTTP-PD uses power intensive resources to achieve the data rate and application BER as it attempts to deliver video at maximum rate possible. In this scenario, BAHPD-R reduces video download rate enabling transceiver to use lower power modes, BAHPD-RI lowers download rate and idles when buffer levels permit. At low SNR, as buffer fills up slowly due to reduced download rate, a low idle threshold value of 15s is chosen. Fig. 4b shows 28% and 46% increase in battery lifetime using BAHPD-R and BAHPD-RI respectively.

Next we perform experiments under variable network conditions (Table VI) obtained by randomly varying SNR between 0 and 40dB. Fig. 4c shows that BAHPD-R and BAHPDRI achieves gains of 23% and 59% respectively while downloading and viewing video sequence 2.

V. CONCLUSION

We proposed a novel battery aware HTTP video download scheme aimed at increasing battery lifetime of mobile devices while downloading and viewing high quality video, an application that is predicted to permeate mobile usage in the future. We showed that significant increase in battery lifetime and video viewing time is possible using the proposed techniques.

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