Energy Measurements for Mobile Cooperative Video Streaming

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Abstract— **In a classical mobile video streaming architecture, the server is responsible for processing each request from the mobile clients even if those requests are for the same content in the same geographical area. This tends to be resource exhaustive in terms of complexity, radio resources, and energy consumption especially when delivering high bit rate multimedia content. In this paper, we exploit cooperation between network technologies to reduce the load placed on a given multimedia server and reduce the overall energy drain of mobile devices. We consider a set of mobile devices that wish to receive a common video content from a designated video server. The mobile devices organize themselves into multiple Bluetooth piconets. The master in each piconet receives an H.264 encoded video content from the server via an IEEE 802.11 WLAN access point and relays it to its slave mobile devices using standard Bluetooth connections. A prototypical implementation of the proposed model in an experimental testbed is used to perform energy and video quality measurements in real conditions. Results demonstrate notable energy consumption gains while maintaining video quality in various scenarios.**

I. Introduction

Collaboration among mobile users in hot spot areas will be a major component in the evolution path towards the implementation of emerging multimedia applications over heterogenous wireless networks [1], [2]. Several approaches have been proposed in the literature for content distribution in wireless networks with mobile-to-mobile collaboration [3], [4], [5], [6]. In these scenarios, mobile devices are assumed to be in close proximity so they can share data blocks among each other over a short-range wireless interface such as WLAN or Bluetooth. COSMOS [4] uses a dynamic collaborative broadcast algorithm in order to effectively deliver the content to all mobile devices with higher throughput, lower delay, and better fairness in terms of cost sharing. COMBINE [7] uses an opportunistic algorithm for collaborative group selection in order to increase system throughput. The authors in [8], [9] present optimized and heuristic strategies for common content distribution with cooperation among mobile devices. These publications rely on either analytical derivations or simulation studies to do performance analysis. The authors in [10] presented basic experimental measurement results and did not consider standard video codecs.

In this work, we highlight the energy gains of practical cooperative video streaming that exploits the advantages of multi-homed mobile devices equipped with more than one wireless interface. Mobile devices are clustered into multiple Bluetooth piconets with each piconet composed of one mobile device assigned as a master and up to seven mobile devices assigned as slaves. In each piconet, the master connects to the server over a long range wireless connection such as cellular or WLAN, streams the video, and forwards it to its slaves in real time over Bluetooth. We present selected measurement results to quantify the energy consumed in mobile devices during data transmission, data reception, and video processing while acting in either master mode or slave mode.

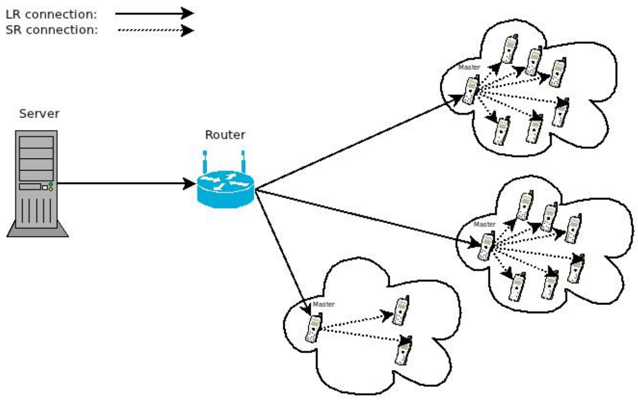

Fig. 1. System model example scenario

This paper is organized as follows. Section II presents a description of the system model. Section III presents an overview of the testbed implementation in addition to the obtained measurement results. Finally, conclusions are drawn in Section IV.

II. System Model

We consider a number of neighboring mobile devices in a hot spot area that are interested in streaming a given video from a server via a wireless access point. The system model is depicted in Fig. 1. The mobile devices are connected to the access point via an IEEE 802.11g wireless interface. Moreover, the mobile devices are assumed to be static and able to interconnect among each other via a Bluetooth wireless interface. Bluetooth is one of the key wireless technologies for ad-hoc connectivity among multiple devices [11], [12]. Bluetooth devices can be organized into ad-hoc personal area networks called piconets, where each piconet is a sub-network composed of up to eight active Bluetooth devices formed of a master node and up to seven slave nodes. Any two nodes can communicate with each other only if they belong to the same piconet. Moreover, communications within a piconet can take place only in two ways: either master to slave or slave to master. Hence, two slave nodes cannot communicate with each other except via the master node.

In this work, we exploit the piconet formation capability of the Bluetooth standard in order to divide the mobile devices

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into multiple piconets or clusters; in each cluster, one mobile device will be assigned a master role (denoted as the cluster head), whereas the other mobile devices will be assigned a slave role (denoted as peers). The cluster head will be responsible for streaming an H.264 encoded video from the server via WLAN connection and then forwarding it in real time to its peers in the same piconet over Bluetooth connections. Protocol design for the considered system model faces several challenges that include intelligence to manage connectivity and content distribution based on the capabilities of existing wireless technologies, to exchange needed state information between the mobile devices and the server, and to cluster the mobile devices into cooperating groups and to identify the cluster head in each group.

III. Experimental Results

A prototype experimental testbed is implemented using a modular approach which facilitates enhancements and extensions to test cooperation protocols, design alternatives, or intelligence options. In the testbed implementation, the client application is implemented on the Android platform and the server application on a GNU/Linux platform, both using Java and C programming languages. IEEE 802.11g is used as the long range wireless interface for server-to-mobile connectivity and Bluetooth as the short range wireless technology for mobile-to-mobile connectivity. Once a video streaming session starts, no other peers can join the active session. In the testbed, we use the FFmpeg library to facilitate video processing and libx264 to encode H.264 video streams. The FFmpeg library is the most rich open source library in terms of number of codecs, muxers, and demuxers supported. In this section, we present selected experimental results based on the system model described in Section II to examine the processing and energy requirements of cooperative video streaming among mobile devices as compared to traditional video streaming.

A. Video Processing Delay Measurements

In order to evaluate the impact of cooperative video streaming on video quality metrics, we present the average running time of the major video processing components performed at a master mobile device. We experiment using a given video stream encoded at 25 fps using H.264, a resolution of 480x270, and muxed in an mp4 container. Table I presents the time required by each video processing process along with its standard deviation.

	Average time in ms	**Standard deviation**
Decoding	56.95	1.80
Encoding	87.94	2.78
Demuxing	1.09	0.03
Muxing	4.51	0.14
Rendering	19.04	0.60
Pixel conversion	14.57	0.46

TABLE I

H.264 VIDEO PROCESSING AT A MASTER MOBILE DEVICE

Results show that the different video processing components require almost fixed time. The additional operations needed in a general cooperative setup as compared to the non-cooperative setup are basically encoding and muxing. Each of the latter operations is executed once at the master node and delivered to all peer nodes. In case all mobile devices in one piconet share the same channel characteristics, the encoding operation at the master node deems unnecessary since the same copy of the received encoded frame is forwarded to the peers. However, we opted to keep a general implementation that accommodates peers with different channel characteristics. The encoding process, nevertheless, takes the longest time as compared to the other video processing components at the master node; it is due to the encoding that the total processing delay at master nodes doubles while keeping the processing delay at the peer nodes intact. Being invariable for the complete streaming lifetime, the additional time consumed by the encoding process at the master node does not cause glitches in the video quality. The impact caused by this delay is the need to increase the playout delay at the peers by the same amount to maintain the same video experience.

B. Energy Consumption Measurements

In this section, we evaluate the energy consumption gains of the cooperative video streaming architecture and compare it with a traditional streaming scenario where the same copy of the video is unicasted to reach requesting mobile device. To perform energy measurements, we connect a resistor to the positive battery terminal and collect power measurements using a data acquisition unit from National Instruments (NI-M6251) that monitors the voltage drop across the resistor.

During the measurements, all non-essential background processes are killed and unless otherwise required, all wireless interfaces are switched off. Moreover, the master device is put in a low-power state. Table II presents the measured power (energy consumed per unit time) of an idle mobile device, with all network interfaces off, with WiFi on, and with Bluetooth on. The table shows that an idle Bluetooth interface causes minor increase in energy consumption while an idle WiFi interface results in almost 15% increase.

	Average power (mW)	Energy increase
Network interfaces off	391.70	0 %
WiFi On	449.13	14.67%
Bluetooth On	397.04	1.36%

TABLE II

POWER CONSUMPTION OF A MOBILE DEVICE IN IDLE MODE

	Energy consumption (Joules)
WiFi Video Transmission	61.29
Bluetooth Video Transmission	57.25
WiFi Video Reception	52.69
Bluetooth Video Reception	39.18
WiFi/BT Cooperative Video	65.80

TABLE III

ENERGY MEASUREMENTS AT A MASTER MOBILE DEVICE DURING VIDEO STREAMING OPERATION OVER 60 SECONDS PERIOD

Table III documents the energy consumed during video streaming at the master mobile device. In the “WiFi Transmission” and “Bluetooth Transmission” scenarios, we stream a local video file via WiFi and Bluetooth, respectively, while all other interfaces are off. Similarly, in the “WiFi Reception” and “Bluetooth Reception” scenarios, we receive a video from the server over WiFi and Bluetooth, respectively. In the “WiFi/BT Cooperative” scenario, we receive a video over WiFi from the server and retransmit it to a peer over Bluetooth. All these scenarios involve video processing at the master node including decoding, demuxing, video rendering, and pixel conversion. Added to that, encoding and muxing is performed in the scenarios that entail transmission.

In Fig. 2, we plot the communications energy consumed at the master node for different piconet sizes ranging from one peer up to seven peers. Communications energy includes energy consumed by WiFi and Bluetooth receptions and transmissions, respectively. We realize a conservative increase in the energy consumption of the master node as the piconet size increases; the master experiences a 46% increase in energy consumption when re-streaming the video to seven peers.

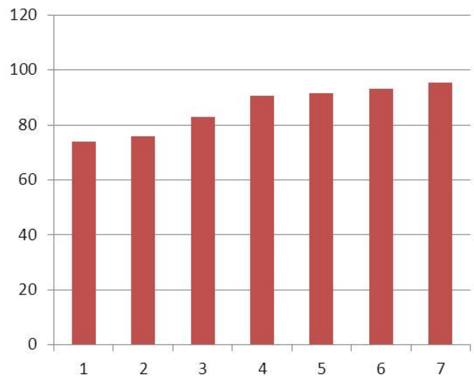

Fig. 2. Total energy consumed (in Joules) by the master node as a function of the number of peers per piconet, including communications, idle, and processing energies

Fig. 3 compares the total communications energy consumed by the cooperative video streaming system compared to the traditional streaming scenario. Results show that cooperative video streaming leads to notable energy reduction especially for large piconet sizes.

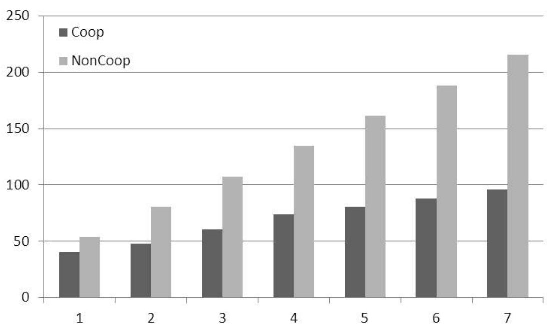

Fig. 3. Total communications energy consumed (in Joules) by all mobile devices within one piconet

IV. Conclusion

We considered a hybrid mobile peer-to-peer/client-server system model to exploit cooperation between different network technologies, namely Bluetooth and IEEE 802.11g. We presented measurement results based on a practical implementation of cooperative video streaming scenario in order to evaluate its performance in realistic scenarios. Performance results highlight the incurred video processing delays in addition to the obtained energy consumption gains as a function of the number of mobile devices. This work serves provides useful insights for optimizing the performance of cooperative video streaming protocols in real scenarios.

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