Scalable Multimedia Streaming in Wireless Networks with Device-to-Device Cooperation

Karim Jahed[1], Sanaa Sharafeddine[1], Abdallah Moussawi[2], Abbas Abou Daya[2], Hassan Dbouk[2], Saadallah Kassir[2], Zaher Dawy[2], Preethi Valsalan[3], Wael Cherif[3] and Fethi Filali[3]
[1] Lebanese American University (LAU), Beirut, Lebanon
[2] American University of Beirut (AUB), Beirut, Lebanon
[3] Qatar Mobility Innovation Center (QMIC), Doha, Qatar
{karim.jahed, sanaa.sharafeddine}@lau.edu.lb, {aam68, aia29, had27, sak54}@mail.aub.edu, zd03@aub.edu.lb, {preethiv, waelc, filali}@qmic.com

ABSTRACT

We present a scalable mobile multimedia streaming system with device-to-device cooperation that enables common content distribution in dense wireless networking environments. This is particularly applicable to use cases such as delivering real-time multimedia content to fans watching a soccer game in a stadium or to participants attending a major conference in a large auditorium. The key novel characteristics of our system include seamless neighbor discovery and link quality estimation, intelligent clustering and channel allocation algorithms based on constrained minimum spanning trees, robustness against device mobility, and device centric operation with no changes to existing wireless systems. We demonstrate the functionality of the proposed system on Android devices using heterogeneous networks (cellular/WiFi/WiFi-Direct) and show the formation of multiple clusters to allow for scalable operation. The gained insights will help bridge the gap between theoretical and simulation based research conducted in this area and practical operation taking into account the capabilities and limitations of existing wireless technologies and smartphones/tablets.

1. INTRODUCTION

With the advancements in video coding techniques and mobile communications technologies, streaming real time multimedia content to handheld devices is gaining wide popularity [4, 3, 2]. Modern devices with their powerful processors, high definition displays, and multiple wireless interfaces are capable of handling high quality multimedia content. Yet, video quality can be notably impacted in dense wireless network scenarios, due to air interface capacity limitations resulting from competition for available radio resources. To this end, we focus in this work on utilizing

MM '16 October 15-19, 2016, Amsterdam, Netherlands

ACM ISBN 978-1-4503-3603-1/16/10.
DOI: http://dx.doi.org/10.1145/2964284.2973837

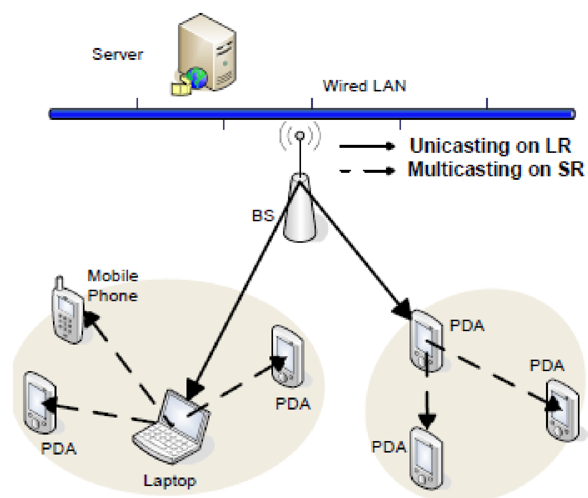

Figure 1: Device-to-device offloading.

device-to-device (D2D) connectivity to offload traffic from the wireless network, whereby mobile devices are divided into cooperative clusters depending on a set of system, geographical, and performance parameters (see Figure 1); in each cluster, a selected master mobile device receives video streams over a long range (LR) interface via WiFi access point (AP) or 3G/4G cellular base station (BS), and forwards them in real time over short range (SR) links to other devices in its cluster. Due to the proximity among cooperating devices and efficiency of short range wireless technologies (e.g. WiFi-Direct), notable performance gains can be achieved in terms of quality of experience and energy consumption[1].

In this demo, we aim at bridging the gap between theoretical/simulation studies in this area of research [2, 6, 7] and practical implementation taking into account the characteristics and constraints of state-of-the-art wireless systems and mobile devices (smartphones, tablets). As part of recent related literature, [5] presents the design and implementation of video streaming system for one group of devices that cooperate among each other to download the same content. In [5], however, the work does not address hierarchical and/or multi-hop transmission to address dense environments with large groups of devices. To this end, we have identified and addressed a wide range of implementation challenges that include seamless device discovery with topology formation, intelligent operation to achieve optimized performance with TCP-based unicasting and UDP-based mutlicasting modes supported over both SR and LR links, dynamic operation that accounts for device mobility and channel variations, and scalable design that is customized to dense environments and that does not require modifications to wireless specifications or deployment of video gateways.

2. DESIGN AND IMPLEMENTATION

In this section, we present the overall design of the mobile cooperative multimedia streaming system. The system architecture is composed of three key components: the management server, the content server and the mobile client application. The content server hosts the video files that the client may gain access to. The management server and clients are agnostic to the content server as long as it provides access to the video files through known URIs. The content server can be, for example, a standard HTTP web server, an FTP file server, or an RTSP streaming server. Client devices access the content server over the Internet through a wireless network infrastructure. The implemented testbed supports 3G/4G cellular and WiFi for LR connectivity and WiFi-Direct for SR connectivity.

The management server is the main component in the system architecture as it features peer devices management, optimized group formation with dynamic adaptation, and content management. The mobile client application does not have to be manually configured with the server parameters; the server implements network discovery protocols to allow client devices to automatically discover and fetch the server parameters. The server and client communications adopt a command-response model. The server issues commands to a subset of connected devices, the clients act upon the commands and send corresponding results back to the server. Moreover, for WiFi networks, the management server has an AP control submodule that is responsible for configuring the network's APs (e.g., channel allocation and power management). For optimized group formation, we developed low-complexity algorithms based on minimum spanning tree algorithm, however, with depth constraint to limit the number of hops to two and bounded-degree to limit the number of peer devices per cluster. The bounded degree is particularly important to system configuration with unicasting on the SR to avoid overloading the master device (cluster head) that disseminates the video content to all peer devices within its cluster.

Upon connection, the management server examines the network topology by requesting the list of WiFi-Direct neighbors from all devices. Each device then sends its list of neighbors in addition to perceived performance metrics such as the received signal strength from each device. Based on this information, the server decides on the role of each device in a way that optimizes offloading gains while maintaining high multimedia streaming quality. Next, the sever informs the device about their respective roles whether *master* devices or *peer* devices. Figure 2 shows sample protocol messages between the devices and the management server. Peer devices establish WiFi-Direct connections to their designated master devices that are supposed to relay to them the video from the content server. Finally, the server sends a *play* command with the URI of the video to launch video streaming be it real-time or stored video transmission. At this stage, all master devices connect to the content server and start receiving the video. While the video data is being received, a master device plays the data and simultaneously forwards the received stream to peer devices within its cluster. For SR communication between master and its peers, our implementation supports both options of TCP-based unicasting and UDP-based multicasting. Multicasting is used for larger clusters within the network in order to relieve master devices from many TCP-based streaming connections and thus allow for scalable operation. In the case of multicasting-based SR, a master creates a multicast group using pre-defined multicast IP and port number and informs each connecting peer about the multicast socket address. Due to the fact that UDP is used in multicasting, the master appends a sequence number to each video-data payload to support packet re-ordering and/or re-transmission for better streaming quality. Retransmitted packets if applicable are unicasted to the requesting device.

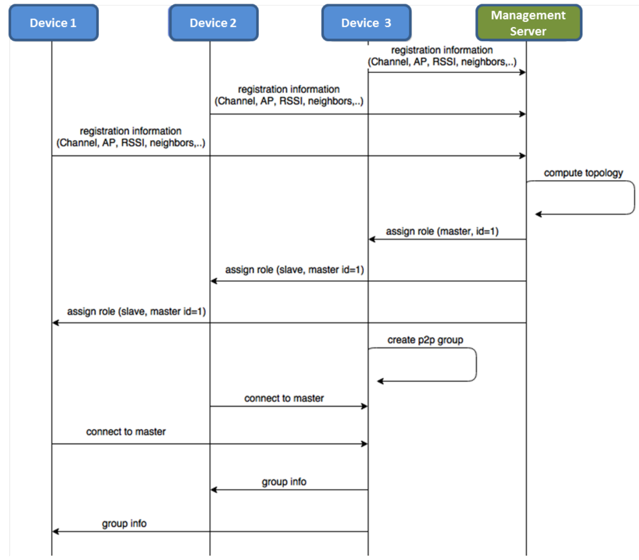

Figure 2: Sample protocol messages.

Moreover, our testbed is extended to support robust operation subject to network dynamics with devices joining, leaving, or moving within a given area. This becomes extremely critical when the moving device is a master and thus its mobility might affect the operation of all peers within its cluster. To address this, our mobile application includes a signaling and discovery intelligence module that monitors and exchanges control information with the management server on a regular basis. The control information includes specifically the signal strength with respect to all mobile devices and APs in the vicinity and is used to adapt multimedia streaming strategies with proper recovery mechanisms. On the algorithmic level, we implement localized modifications to our clustering solution to minimize service interruptions and algorithm complexity.

Our mobile application is Android-based and has a friendly user interface with flexible options that can be set by the users. Figure 3 shows a snapshot of the application showing parameter setting view and video streaming view.

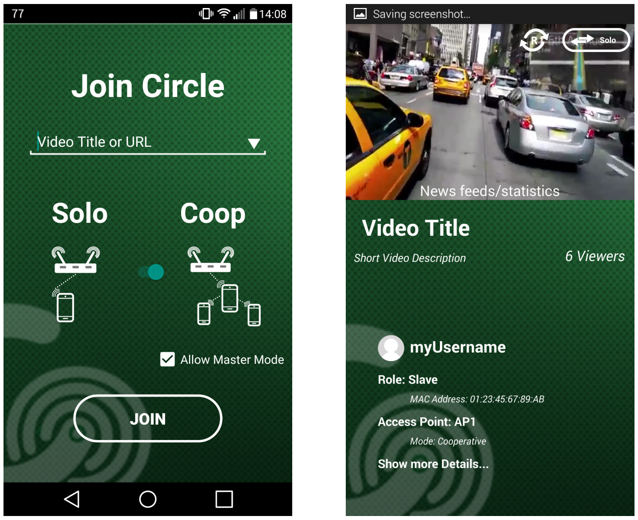

Figure 3: Mobile application interface.

3. CONCLUSIONS

We presented the general design and implementation features of a complete multimedia streaming system that utilizes device-to-device connectivity for traffic offloading in dense wireless networks. Our system implements features that facilitate dynamic, scalable, and robust operation under realistic network conditions and device constraints.

4. ACKNOWLEDGEMENTS

This work was made possible by NPRP grant 7-1529-2-555 from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

5. REFERENCES

[1] L. Al-Kanj, Z. Dawy, and E. Yaacoub. Energy-aware cooperative content distribution over wireless networks: Design alternatives and implementation aspects. *IEEE Communications Surveys and Tutorials*, 15(4):3828–3847, 2013.

[2] S. Almowuena, M. Rahman, C. Hsu, A. A. Hassan, and M. Hefeeda. Energy-aware and bandwidth-efficient hybrid video streaming over mobile networks. *IEEE Transactions on Multimedia*, 18(1):102–115, January 2016.

[3] A. Detti, B. Ricci, and N. Blefari-Melazzi. Mobile peer-to-peer video streaming over information-centric networks. *Elsevier Computer Networks*, 81:272–288, April 2015.

[4] Z. Khan, A. Vasilakos, B. Barua, S. Shahabuddin, and H. Ahmadi. Cooperative content delivery exploiting multiple wireless interfaces: methods, new technological developments, open research issues and a case study. *Springer Wireless Networks*, published online in September 2015.

[5] A. Le, L. Keller, H. Seferoglu, and B. C. et. al. Microcast: Cooperative video streaming using cellular and local connections. *IEEE/ACM Trans. on Networking*, PP(99), December 2015.

[6] E. Yaacoub, Z. Dawy, S. Sharafeddine, and A. Abu-Dayya. Joint energy-distortion aware algorithms for cooperative video streaming over lte networks. *Elsevier Signal Processing: Image Communication*, 28(9), October 2013.

[7] A. Zahran, J. Quinlan, D. Raca, C. Sreenan, E. Halepovic, R. Sinha, R. Jana, and V. Gopalakrishnan. Oscar: an optimized stall-cautious adaptive bitrate streaming algorithm for mobile networks. *Proceedings of the 8th International Workshop on Mobile Video*, May 2016.