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Peer-assisted video on-demand streaming system in practical WiFi-based mobile opportunistic networks

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ABSTRACT

Network convergence paradigm will substantially increase the pervasive use of WiFi-enabled mobile devices such as smart phones (e.g., Android-based mobile and iPhone), e-book viewers (e.g., iPad and Kindle) and personal media players. Although various on-demand streaming services are already available over mobile WiFi-enabled devices, it remains a challenging problem due to WiFi's limited communication range, mobility and user population density issues. In this paper, we extend and enhance our previous work on MOVi (*M*obile *O*pportunistic *Vi*deo-on-demand). In particular, we exploit the use of cooperative content sharing concept in gaining performance advantages. We reinvestigate the previous version of MOVi in more realistic operational environments and propose an improved scheduling algorithm which incorporates *H*-hop blocking and opportunistic download skipping schemes. The scalability of the extended MOVi system is verified by extensive simulations and several experiments with prototype implementation over OMF (c*O*ntrol and *M*anagement *F*ramework)-enabled wireless network testbeds. In terms of the number of supported user, an average of 30% improvement can be achieved while at the same time consuming the same amount of battery power.

1. Introduction

Recent dramatic trends in network convergence lead mobile hand-held devices, such as smart phones, e-books, and personal media players, to be equipped with wireless communication interfaces for broadband access. It is especially noteworthy that WiFi (i.e., IEEE 802.11-based wireless local area network) is taking the leading role for the wireless communication due to its cheap integration cost and almost free-of-charge networking availability. This trend will be accelerated by upcoming industrial standard, WiFi Direct (formerly known as WiFi peer-to-peer) that allows terminal-to-terminal WiFi connections while the infrastructure-based WiFi connections are sustained. Various WiFi-enabled applications are emerging by providing on-demand video streaming services to large numbers of mobile WiFi-devices. It is a challenging task due to its limited wireless communication range, user mobility, and variable user population density.

In our previous proposal (Yoon et al., 2008), we questioned whether providing realtime streaming services is possible over Bittorrent-style content sharing protocols, where the centralized tracker helps mobile nodes to share network resources in content distribution. Specifically, we have proposed MOVi (*M*obile *O*pportunistic *Vi*deo-on-demand), a cooperative video-on-demand distribution and sharing system. MOVi considers the general problem of video-on-demand streaming service within the mobile peer-to-peer paradigm amongst WiFi-equipped devices.

In this paper, we reinvestigate our previous MOVi system in more realistic scenarios and propose an improved MOVi scheduling algorithm. Especially we point out the potential pitfalls in our initial scheduling design, which we have observed from various measurement-based evaluations through practical experiments and computer-based simulations (Yoon et al., 2009; http://www.mytestbed.net/projects/omf-case-studies/wiki/CaseStudy2). Then, we design two additional schemes, *H*-hop blocking and opportunistic download skipping, to reinforce the previous MOVi scheduling algorithm. Through extensive computer simulations, we show that the improved MOVi scheduling algorithm produces up to 30% higher system capacity than the previous version. We also show that the capacity gain can be obtained without increasing total power consumption at mobile nodes. In fact, the evaluation results indicate that the enhanced MOVi consumes only half of power what conventional video-on-demand consumes. We also evaluate the MOVi prototype implementation with two different configurations, i.e., two emulation-based mobile experiments in different indoor testbeds, ORBIT and NORBIT (http://www.mytestbed.net) hosted at WINLAB, Rutgers Univ., U.S. and National ICT Australia (NICTA), respectively. The experimental results provide us the

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micro-scale performance observation of peer-to-peer communication in terms of efficiency and robustness while reaffirming the effective increase in the number of concurrent VoD users.

This paper is organized as follows. In Section 2, we review the proposed MOVi system architecture. In Section 3, we introduce our effort to improve the MOVi system by especially focusing on scheduling enhancements. We evaluate our proposal using computer simulations in Section 4, where the scalability aspect is examined with up to 50 mobile nodes. In Section 5, we then describe our prototype implementation effort and evaluate its performance in two different configurations. We summarize the paper by discussing related work in Section 6.

2. MOVi system overview

MOVi (Yoon et al., 2008) is designed with the principle of "*centralized state tracking and control with decentralized data distribution*" in mind. Figure 1 shows the general architecture of MOVi. It comprises two logical components: mobile client nodes, called as `MOVi Clients` (MCs) and a `MOVi Server` (MS). One MS and a set of associated MCs compose each `MOVi Domain`. In MOVi, we assume that all the contents are fragmented into multiple equal-sized segments (i.e., chunks in peer-to-peer networks) and initially available from content repositories such as local caches and external storages of MS. We note that each segment normally consists of several hundreds of packets. Upon the MS receiving on-demand requests from MCs, a series of video segments, initially available from the MS, is transferred to a number of MCs. All MCs cooperate to download all segments of an entire video content by relaying received segments to the neighbor MCs. Although a pair of sender and receiver nodes are being collocated within a direct communication range, in the infrastructure mode WLANs (IEEE 802.11 WG, 1999), all transmissions from nodes must be forwarded first to the associated AP and then transferred to the destination nodes. In this case, the cooperative video content segments relay from MCs to others may be inefficient. In fact, each relay of packets consumes wireless channel resources two times when compared with the downloads from the MS. To avoid this, MOVi uses the proposed Inter-BSS (Basic Service Set) Direct Link Setup (iDLS) protocol (Yoon et al., 2007) to set up direct peer-to-peer connectivity, which allows direct communications between MCs. By using iDLS, MCs can preserve the membership with an associated AP without the switching overhead (i.e., in the order of seconds due to switching from infrastructure to ad hoc mode and vice versa Chandra and Bahl, 2004).

The iDLS protocol is motivated by the standard Direct Link Setup (DLS), defined in IEEE 802.11e Quality-of-Service (QoS) enhancements (IEEE 802.11e WG), to remove the dependency on the AP and facilitate direct communications across BSSs. By setting up both permanent and temporary Service Set IDentifiers (SSIDs), iDLS can construct direct link communications temporarily using a randomly generated unique SSID value and keeping the basic IEEE 802.11 protocol unchanged. Instead of defining Over-the-DS MAC control frame type and message exchanges for inter-AP communication, iDLS assumes that the management of direct communication is maintained inside the end applications. In this paper, we design two different types of end applications to manipulate iDLS sessions, which is located at the MC and the MS, respectively. As depicted in Fig. 1, the former is the `MOVi Application`, and the latter is the `MOVi Scheduler`.

The `MOVi Application` at each MC serves as a temporal cache to help content diffusion inside each `MOVi Domain`. It also acts as a channel state monitor by periodically observing link quality with its neighboring MCs and updating any noticeable changes in the link quality to the MS. The periodic content request carries the noticeable changes in a form of piggybacking. In doing so, the control overhead can be minimized to maintain a connectivity map of link qualities between MCs (i.e., the relative location of MCs). For video streaming, each MC downloads the request segments in order of playout sequences. Once the MC receives all segments that make up a temporal portion (e.g., frames) of video stream, these segments are handed to the media player for playout. If there are missing segments for *to-be-playout* video frames, the MC sends immediate on-demand requests to the MS so that we can receive the missing segments in a timely manner. From the periodic updates and content request messages, the `MOVi Controller` at the MS can derive the connectivity map, evaluate the QoS measure, and track the status of content cache in all MCs within its domain. Therefore, the MS has an overall view of its domain while each MC cares local information only.

The `MOVi Scheduler` at the MS coordinates the segment-based scheduling by opportunistically triggering content segment transfers between pairs of MCs based on the connectivity map.

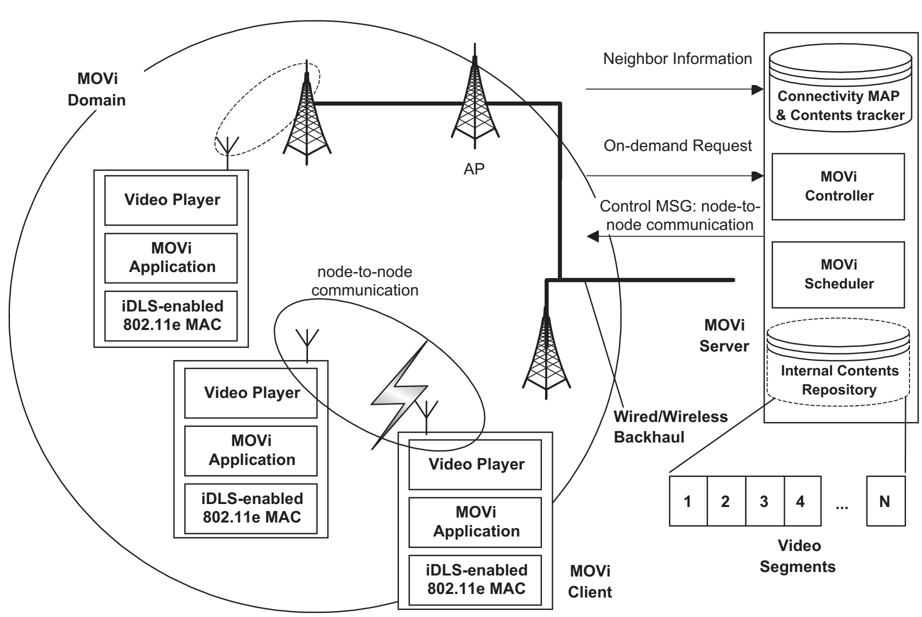

Fig. 1. Illustration of MOVi and its architectural components.