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A cross-layer approach for real-time multimedia streaming on wireless peer-to-peer ad hoc network

Jun-Li Kuo *, Chen-Hua Shih, Cheng-Yuan Ho, Yaw-Chung Chen

Computer Science, National Chiao Tung University (NCTU), Hsinchu, Taiwan

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ABSTRACT

Peer-to-peer (P2P) live streaming over mobile ad hoc network (MANET) is a state-of-the-art technique for wireless multimedia applications, such as entertainments and disaster recovery. The peers share the live streaming over MANET via multi-hop wireless link, so an efficient data delivery scheme must be required. However, the high churn rate and the frequent mobility baffle the P2P membership management and overlay maintenance. The unreliable wireless connection of MANET leads to the difficulties of large-scale and real-time streaming distribution, and a lack of overlay proximity leads to the inefficient streaming delivery. We present a cross-layer design for P2P over MANET to manage and maintain the overlay, and select efficient routing path to multicast media streams. Our proposed scheme (COME-P2P) integrates both P2P DHT-based lookup and IPv6 routing header to improve the delivery efficiency. Through the cross-layer design, the low layer detects mobility for informing high layer to refine the finger table, and high layer maintains the efficient multicast path for informing low layer to refine the routing table. How to keep stable routing paths for live streaming via IPv6 routing is the main contribution of this paper. The overlay proximity can shorten routing propagation delay, and the hop-by-hop routing can avoid the traffic bottleneck. Through the mathematical analysis and simulation results, COME-P2P can be demonstrated to achieve high smoothness and reduce signaling overhead for live streaming.

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1. Introduction

Mobile devices have been gaining popularity along with wireless multimedia services. Mobile access to the Internet via WiFi, WiMax, 3G, or beyond 3G data network from the fixed infrastructure is prevalent nowadays. However, generally the traditional cellular-based architecture and infrastructure-based communication are not always adequate to satisfy users' requirements today. In many situations, the communications between mobile hosts cannot rely on any fixed infrastructure. For example, the high cost or long setup time of a system installation may be unacceptable in quickly changing environments, such as disaster areas, battle fields, and inter-vehicular communications. It motivates mobile ad hoc network (MANET) which can be expected to operate in the infrastructure-less environment.

In MANET, two mobile nodes can communicate with each other through other intermediate nodes over wireless infrastructure-less network without the centralized administration. The nodes in MANET can self-organize networks and cooperate to establish communications. Users can share resources and files through MANET via network-layer broadcasting or multicasting. However, the flooding in MANET is too inefficient to achieve a large distribution. While the traditional server-client or one-to-many delivery model is not satisfactory to the requirement of real-time multimedia in MANET.

* Corresponding author.
E-mail addresses: estar.cs95g@nctu.edu.tw (J.-L. Kuo), shihch@csie.nctu.edu.tw (C.-H. Shih), tommyho@iii.org.tw (C.-Y. Ho), ycchen@cs.nctu.edu.tw (Y.-C. Chen).

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A single node is impossible to handle the global load of the multimedia service, hence a decentralized approach like peer-to-peer (P2P) technology could be an appropriate solution adopted in such environment. P2P solution can disperse the centralized actions in traditional network to let the edged terminals connect to each other without central control. P2P solution can alleviate single point of failure and overhead on server. However, most of nodes have the limited resources and bandwidth in MANET. The bottleneck of data traffic results in QoS degradation of real-time service. Moreover, the mobility, the shadowing problem, and the high churn[1] rate of MANET nodes become the challenges of maintaining stable connections.

P2P and MANET techniques have been developed by different communities and addressed entirely different requirements. P2P systems are application-oriented overlays and have evolved mainly over the wired Internet so far. By contrast MANET is spontaneous, infrastructure-less wireless networks for mobile terminals. However, both P2P and MANET share some fundamental commonalities such as the decentralized and self-organizing architecture due to the lack of central server, therefore MANET and P2P systems both exhibit a dynamic organization and lack information of user arrival or departure a priori. There are some similarities between MANET and P2P: (1) A peer should collaborate with each other without the centralized server. (2) A peer operates as both host and routing node, as well as sender and receiver in both systems. (3) The topology of P2P and MANET is changing frequently due to the high churn rate. (4) Both MANET and P2P, scalability is the basic requirement. (5) How to deliver or route efficiently is crucial for both of them.

MANET first appeared as DARPA packet radio networks in the early 1970s. P2P systems were initiated in the middle of 1990s. Unfortunately, current P2P systems may be unsuitable for MANET because P2P overlay is based on TCP/IP wired network but the links of MANET change frequently due to the mobility of its wireless nodes. The other differences between P2P and MANET also obstruct the integration of P2P and MANET: (1) P2P refers to the upper layer; MANET refers to the lower layer. (2) In P2P, the logical routing path is established on overlay; while in MANET, the physical routing path is established on MAC layer. (3) Every peer on P2P overlay can receive the incoming streams from multiple sources, but every node in MANET has to deal with the collision of packets from different sources.

In recent years, more and more P2P applications have been implemented in MANET, and hence some new acronyms such as P2P-MANET (P2P over MANET), MP2P (mobile P2P), and WP2P (wireless P2P) have appeared to this network architecture. The challenges of P2P-MANET are concerning both P2P and MANET, thus P2P-MANET needs to accommodate mobility, scalability, extensibility, persistency, consistency, security to support the sharing service. An efficient delivery scheme for voice, image and real-time video streaming are vital for various critical applications such as disaster rescue and survival search. P2P video streaming features the characteristics of high data rate, time sensitivity, and packet loss sensitivity. In the traditional layered scheme, the large overhead and long latency may be unsuitable for P2P-MANET live streaming.

There are several problems of in-time data delivery in P2P-MANET: (1) MANET leads to the churn problem and the frequent mobility problem, both which baffle the P2P membership management and overlay maintenance. This leads to the unstable streaming delivery and the unsmooth playback quality. (2) The unreliable wireless connection of MANET leads to the difficulties of large-scale and real-time streaming distribution. (3) P2P overlay is not proximal to MANET topology, so the far routing leads to the inefficient streaming delivery. Therefore, P2P live streaming cannot work well on MANET.

In this paper, we present a cross-layer approach for P2P live streaming tailored to MANET, called COME-P2P (Cross-layer Overlay for Multimedia Environment on wireless ad hoc P2P). It motivates live streaming for high data rate and time sensitivity on P2P-MANET for scalability, extensibility, and persistency. The goal of COME-P2P is to achieve the high smoothness for live streaming, to shorten the routing propagation delay, and to reduce the signaling overhead.

Our proposed scheme consists of three algorithms. The first algorithm maintains the application layer overlay which is proximal to physical layer topology; the second algorithm provides an efficient routing via IPv6 to achieve the high data rate; and the last algorithm handles the interaction of cross-layer messages to keep an optimized shortest routing path. The integration of P2P overlay and MANET routing can update the cross-layer information to reduce signaling overhead (control overhead), speed up recovery time, and improve streaming stability. The integration also avoids the packet duplication problem because our proposed scheme adopts neither the flooding algorithm nor the off-the-shelf P2P systems.

The paper is organized as follows: Section 2 presents the related works. Section 3 introduces the support to P2P live streaming through the DHT-based overlay over MANET and illustrates our proposed cross-layer scheme. Section 4 presents the analysis of the cross-layer designs and discusses the performance of compared algorithms. In Section 5, the simulation results demonstrate that our proposed scheme works well in P2P-MANET. Section 6 concludes the paper.

2. Related works

P2P networks could be classified into unstructured overlay or structured overlay. The unstructured overlays use controlled flooding, while the structured overlays use distributed indexes. Generally speaking, the unstructured overlays are extremely resilient, but they are not scalable and exhibit long delay. On the other hand, the structured overlays are efficient in membership maintenance, but they are unstable under dynamic environments.

- Unstructured P2P networks such as KaZaA [1] and Gnutella [2] generally use flooding to search peers and files. Gnutella uses the *lifespan* (TTL – Time to Live) to limit the number of visited hops for application level flood-

[1] Movement means the node (peer) leaves from some communication scope; churn means the node (peer) exits from the service.

ing. The lifespan is usually set to 1 or 2 in wireless network. Structured P2P networks such as distributed hash table (DHT) systems use keys or maps to index peers and files.

- DHT has been proven to be an efficient platform for a variety of scalable and robust distributed applications. For example, CAN [3], Chord [4], Pastry [5] and Tapestry [6] have been used successfully in wired P2P networks. However, it is difficult to adapt DHT to the underlying MANET topology. The mapping design of all existing DHTs cannot consider peer's *logical* overlay according to peer's *physical* location.

The *finger table* can locate peers in both unstructured mesh and structured DHT through P2P, and the *routing table* can route packets through MANET. The routing protocols for MANET can be classified into *reactive* and *proactive* routing protocols.

- In proactive or *table-driven* routing protocols, such as destination sequenced distance vector (DSDV) and optimized link state routing (OLSR), every mobile node maintains a routing table with the global information of network topology. Proactive routing enables a node to send the data packet immediately to the destination without the delay for *route discovery*. But a lot of computing cost and bandwidth is required to maintain the dynamic routing tables.
- The reactive or *on-demand* routing protocols, such as dynamic source routing (DSR) and ad hoc on demand distance vector (AODV), every mobile node finds a routing path only when it is necessary. But the sender must broadcast the routing request throughout the whole network to select an appropriate path to the receiver. Reactive protocols have larger delivery delay and are not efficient for heavy traffic.

P2P has been demonstrated the success in large-scale wired network, especially in file sharing which is popular on Internet. For P2P file sharing, eDonkey [7] and BitTorrent [8] are well known systems. Regarding P2P live streaming, CoolStreaming [9] and AnySee [10] are very popular. In addition, P2P solutions could enormously reduce the maintenance cost of entire system because of peer-paralleling distributed computing. For example, Skype [11] successfully uses P2P technology to deploy the real-time voice service.

2.1. P2P over MANET

7DS [12] (Seven Degrees of Separation) was the first P2P system for mobile devices in MANET. 7DS enabled web-browsing resource sharing in a self-organizing wireless P2P network. Proem [13] used JXTA to build P2P platform for mobile applications over ad hoc WiFi network, but it cannot route through multiple hops.

ORION [14], DPSR [15], MPP [16], Ekta [17], and M-CAN [18] used the off-the-shelf P2P technologies and integrated the ready-made ad hoc routing protocols for wireless file sharing. ORION [14] (Optimized Routing Independent Overlay Network) used TCP (without retransmit) and AODV to guarantee high data rate and low transmission overhead for file searching and downloading. ORION floods messages to maintain structure and query file, and routes data via AODV on demand. DPSR [15] (Dynamic P2P Source Routing) integrated Pastry and DSR to improve scalability of MANET. It replaced ping metric of traditional Pastry with distance metric. MPP [16] (Mobile Peer-to-Peer Protocol) used the Mobile Peer Control Protocol (MPCP), the Enhanced DSR (EDSR) and interlink to reduce the routing overhead. Ekta [17] used Pastry DHT system and UDP connection over DSR routing protocol to achieve an efficient data delivery with the low overhead.[2] M-CAN [18] (Mobile CAN) is a modification based on CAN to avoid occupying a lot of wireless network bandwidth and improve robustness.

2.2. Cross-layer design

XL-Gnutella [19] and three previous researches [20–22] considered the cross-layer design for P2P-MANET. XL-Gnutella [19] (Cross-Layer of Gnutella) promoted a cross-layer scheme of Gnutella over OLSR to reduce singling overhead and improve membership management. A modified FastTrack protocol [22] combined with FastTrack of KaZaA and AODV to reduce signaling overhead and shorten traffic delay due to the integrated approach at network layer.

MADPastry [23], Smart Gnutella [24], M-Chord [26], ORION+ [28], and MAFDC [29] advanced the high bit-rate interest and considered the underlay network dynamics. They used P2P overlay to map MANET topology. MADPastry [23] (Mobile Ad Hoc Pastry) integrated Pastry DHT and AODV to consider physical locality to minimize the traffic overhead. Smart Gnutella [24] used Gnutella and AODV to implement a collaborative virtual environment (CVE) application, and its results showed AODV is better than DSDV for this application. A new version has been presented in 2010 [25]. M-Chord [26] (Mobile Chord) utilized Chord directly to improve robustness in mobile P2P network and another previous research [27] discussed DHT proximity for large scale MANET, however, both of them did not note the routing protocol for MANET. ORION+ [28] used reactive unicast messaging and evaluated *round trip time* (RTT) to improve original ORION for avoiding path failure. MAFDC [29] operated on wireless infrastructure and used the super peer to manage the cluster; as a result, its peer can guess neighbor's mobility and select efficient resource. A modified Gnutella [30] used the routing metric in P2P overlay and used the advertisements from ultra peer to manage overlay efficiently. It can provide higher query success rate, shorter query response time and less energy consumption.

2.3. Instant real-time service

With the development of real-time service, P2P-MANET system emphasized the instant reaction, which includes live streaming delivery, fast lookup process, fast forwarding. For examples, P2PMLS [31] (P2P-leveraged mobile live

[2] When the number of nodes is n, regular DSR loaded $O(n^2)$ routing overhead originally, Ekta improved the overhead to $O(n \log n)$.

streaming) could let the peer receive streaming through cellular wireless network and then share the obtained data with other peers through ad hoc network. MP2PS [32] (Mesh-based P2P Streaming) provided real time streaming over MANET via AODV. A comprehensive study [33] presented a preliminary result which showed that Chord is better than Gnutella for mobility in MANET, and it enhanced the P2P protocol via the control of selective query forwarding, redundancy, and load balance. VICTORY [34] was an implemented project for 3D multimedia on PDA via JXTA, and it provided a concept for service-oriented architecture (i.e. layered framework).

To deal with larger and larger P2P traffic, more and more P2P-MANET systems optimized the P2P management to suit for mobile computing. P2PSI [35] (P2P Swarm Intelligence) used ARA (ant routing algorithm) routing protocol and cross-layer comprehensive messages to derive the routing path. P2PSI recorded routing information and intermediate information in the *pheromone table* to speed up ARA routing. One work [36,37] built an unstructured P2P overlay closer to the physical network via a query-based algorithm, and used OLSR to keep the minimum spanning tree to speed up the lookup process.

2.4. The inconsistency of P2P-MANET

From the development of P2P-MANET, we can discover that the applications are implemented for file sharing service in the pioneering age before 2004, and the layered design is used in these applications which were completed by off-the-shelf DHT approaches and routing protocols. However, a strict layered design is not flexible to cope with the dynamics of P2P-MANET environment. Thus, some recent studies proposed the cross-layer approaches in which the layers interact with each other or are integrated to optimize the delivery or to avoid unnecessary and redundant network traffic [38]. A comparison between P2P systems over MANETs [20] gives a basic theoretical concept and demonstrates that the cross-layer design can offer the significant performance improvement in the MANET environment. In the cross-layer design, each peer could detect its neighbors' mobility to optimize its membership tree in time [39].

Wired P2P real-time streaming and video on demand (VoD) have been developed since 2003, and real time service was developed in P2P-MANET at 2005. It is more difficult to support real time service than to support file sharing due to delay sensitivity. How to deliver message and data efficiently is the key that impacts the quality of real-time service. These applications also adopted the layered design of off-the-shelf approaches at initial time [32].

Some researches used *ultra peer* or *super peer* to build the hierarchical architecture to strengthen P2P overlay and to enhance the data delivery. A super peer means a node that is reliable and stands for a semi-permanent (less migration) and unselfish peer with stable and sufficient upload bandwidth. In P2P-MANET, some works showed the outstanding performance via super peer [22,29]. However, the hypothesis regarding the existence of super peer in P2P-MANET is unreasonable and impractical [40]. To optimize the hierarchical overlay, the super peer may have to locate at a logical overlay far away from its physical topology. Therefore, the utilization of super peer may be unsuitable for P2P live streaming in MANET. In summary, the related works are listed to provide a comparison as Table 1 illustrated.

Table 1
Summary of related works.

Name	Refs.	Year	App.	Methods
7DS	[12]	2001	File sharing	
Proem	[13]	2002	File sharing	
ORION	[14]	2003	File sharing	TCP + AODV
DPSR	[15]	2003	File sharing	Pastry + DSR
MPP	[16]	2003	File sharing	MPCP + EDSR
Ekta	[17]	2004	File sharing	Pastry + UDP + DSR
M-CAN	[18]	2004		CAN
XL-Gnutella	[19]	2005	File sharing	Gnutella + OLSR
–	[21]	2005	Live streaming	
–	[22]	2005	File sharing	FastTrack + AODV
MADPastry	[23]	2005	File sharing	Pastry + AODV
Smart Gnutella	[24]	2006	CVE	Gnutella + AODV
M-Chord	[26]	2006	File sharing	Chord
ORION+	[28]	2007	File sharing	AODV
MAFDC	[29]	2007	File sharing	
–	[30]	2007	File sharing	Gnutella + DSDV
P2PMLS	[31]	2007	Live streaming	
MP2PS	[32]	2008	Live streaming	UDP + AODV
–	[33]	2009	File sharing	UDP + AODV
VICTORY	[34]	2009	Live streaming	
P2PSI	[35]	2009	File sharing	ARA
–	[36]	2010	File sharing	OLSR

– Means that the work has no system name.
Refs. means the cite number at the end of this article.

3. Our proposed scheme

Our proposed scheme is tailored to use cross-layer design to manage overlay in time. We simultaneously contribute to (1) the P2P management over MANET, (2) the cross-layer design for network metrics, (3) the overlay proximity and efficient routing, (4) the large and instant live streaming, and (5) the efficient P2P lookup.

3.1. System overview

The aforementioned studies show that some disadvantages of real-time service are difficult to be overcome in P2P ad hoc network, thus we propose a novel cross-layer P2P scheme for live video streaming in MANET as shown in Fig. 1. There are two characteristics in our proposed scheme: the *enhanced distributed hash table* (EDHT) and *IPv6 routing*. Unlike the traditional DHT, EDHT provides the information for UDP and IPv6 routing, and we call this *path information*, which records the local path from a source peer to other peers through the intermediate nodes.

3.1.1. P2P overlay layer

In our proposed scheme, peers organize themselves via disseminating membership information. Through P2P

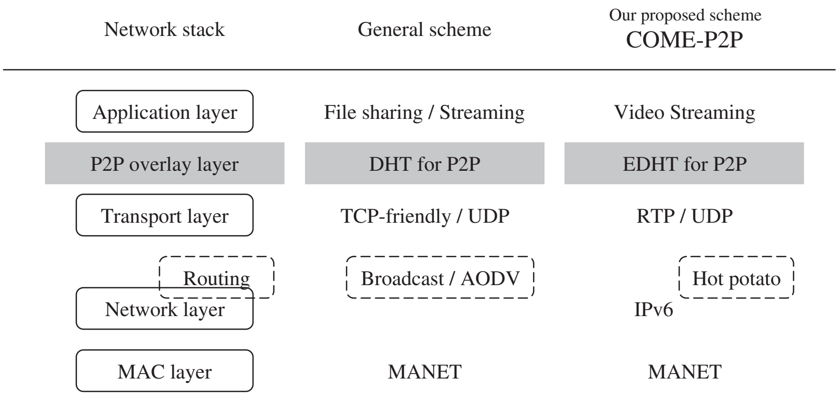

Fig. 1. The proposed cross-layer scheme (COME-P2P).

overlay, every peer maintains an EDHT to know its local members. Whenever a peer joins or leaves, it notices its members actively. Every peer sends *Probe Message* to its members periodically to estimate the latency, which can also indicate the members' movement, available bandwidth and absence. The path information in EDHT is altered to accommodate the mobility and the changing topology according to the latency. As a result, the P2P overlay can be mapped to the physical ad hoc topology in our proposed scheme. The overlay proximity can shorten the data delivery delay and help the cross-layer scheme.

3.1.2. Transport layer

In our proposed scheme, RTP/UDP is used to serve real-time streaming in which packet loss is ignored. In wireless networks, packet loss often happen, hence too many retransmissions usually cause difficulty for stable streaming. A RTP/UDP connection is established through the ping/pong model. RTT is estimated by RTP/UDP packets. Even if RTT is not the best metric to determine link quality, RTT can be estimated simply to know the available bandwidth and the traffic lag without complex computing. The periodic RTT estimation can reflect the network dynamics and is suitable for the computing ability of a mobile node.

3.1.3. Network layer and routing

Regarding the routing, we take scalability into account; we do not consider the flooding scheme because the overhead is much large and the packet collision is unavoidable. We also take latency into account; we do not adopt the traditional ad hoc routing protocols, AODV or OLSR, because they are inefficient for real-time delivery. In file sharing, the traditional ad hoc routing protocols can *pull* data well because of the optimum routing path, but they spend time and overhead selecting routing path, this is unsuitable to *push* large instant data for live multimedia.

In our proposed scheme, the attribute "next hop" of IPv6 is used to forward packets to the destination. The extended *routing header* in IPv6 helps forward packets hop by hop in pre-computed order. Every mobile node can check the *destination* and the *segment left* of IPv6 to determine the next hop. In addition, we implement our proposed scheme on the simplest "Hot Potato" routing protocol, and it uses less overhead on network traffic and less computation on mobile node than other routing protocols. Hot potato scheme checks the next hop of IPv6 packet and forwards it to the destination immediately. As a result, EDHT provides path information of next hop to route the incoming packets in our proposed scheme. However, the major limitation of COME-P2P is that only IPv6-enabled nodes can work.

3.2. Cross-layer routing

Hot Potato routing protocol can forward packet quickly without complicated and lengthy computation, and produce less overhead during routing packet. The routing path will not be changed until the path information is changed. Fig. 2 illustrates how to forward the stream via the proposed EDHT and IPv6 routing. In the topology, node A is a peer which multicasts a streaming data; nodes B, C, D are the intermediate nodes; nodes E and F are the receivers.

(1) A logical P2P path $A \rightarrow E \rightarrow F$ is established in the P2P overlay via the EDHT lookup.
(2) After the latency estimation, a physical routing path *ABDE* is selected because path *ABDE* is shorter than path *ABCE*, path *ABCDE* and so on.
(3) The path information is updated in the EDHT and used to decide the next hop in each peer.
(4) The path information is filled in the attribute "routing header" of IPv6 packet to speed up and stabilize data delivery.
(5) Every mobile node checks the destination of IPv6 packet and forwards it to the next node.

Because the EDHT provides the overlay proximity, the path information can be used for the hop-by-hop wireless IPv6 routing. Every mobile node is considered as a P2P router and follows the routing header of IPv6 packet. The optimal routing path in EDHT can be derived in advance to avoid the far routing via the cross-layer design. Instead of

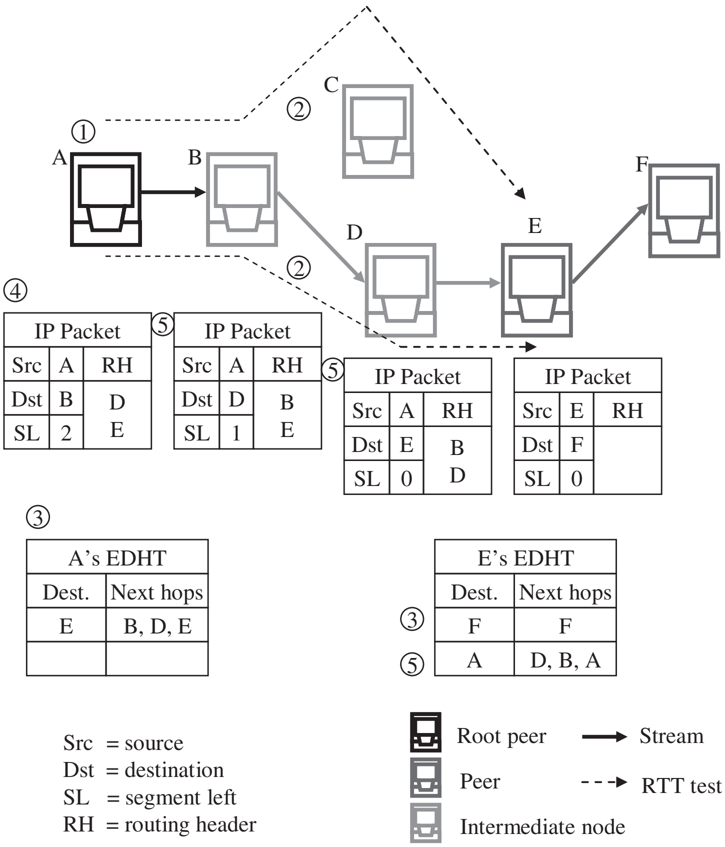

Fig. 2. The proposed EDHT over IPv6 routing.

an on-demand routing in intermediate node, the cross-layer IPv6 routing not only avoids the far routing, but also fastens and stabilizes the large-size video stream. The integration with Hot Potato routing protocol can forward packet quickly without complicated and lengthy computation, and produce less overhead to facilitate routing over MANET.

3.3. Detail procedures of the proposed scheme

In a wireless ad hoc network, every node needs one or many intermediate nodes to make an end-to-end connection due to the limited radio coverage. Every node sends the similar *Hello* messages to collect neighborhood information to form a self-organized network.

3.3.1. Join and cross-layer messages

A new joining peer broadcasts *Request Message* to inform all peers that it has joined the network and requested the multimedia service, we call it the receiver. When a peer (sender) received this message, it sends a *Probe Message* to get the receiver's information and estimates the delivery latency[3] as Fig. 3 illustrated. The receiver may get many *Probe Messages*, it will response ACK to the first several senders because their distances should be shorter. When a sender receives this *Probe ACK Message*, it updates the path information of its EDHT and then sends *Response Message* to the receiver. When the receiver gets the first *Response Message*, it sends *Response ACK Message* which represents its readiness for receiving streaming and rejects other later *Response Messages*. After the sender receives *Response ACK Message*, it pushes[4] data streams to the receiver based on its EDHT. Every peer periodically updates its EDHT including path information to assign the extended routing header of IPv6 packet.[5]

3.3.2. Leave and mobility

When a peer leaves the P2P network, it voluntarily informs its neighbors via a *Left Message*, so that its neighbors can recover the overlay. However, in wireless mobile ad hoc network, the message may get lost. Therefore, in our proposed scheme, all peers multicast periodically *Probe Messages* to maintain indirectly P2P overlay and monitor the neighbors' movements.

Since the cross-layer scheme lets application layer and network layer interact with each other, our EDHT can be updated to adjust the mobile ad hoc network.

[3] Any latency estimation algorithm can be used in the proposed scheme, the RTT estimation is simple with low overhead, it is suitable for mobile device.

[4] Instead of the pull delivery, the push delivery is adopted due to the quick forwarding and the low signaling overhead.

[5] As Fig. 2 illustrated, the destination and the segment left of IPv6 to can be integrated with the routing header to determine the next hop.

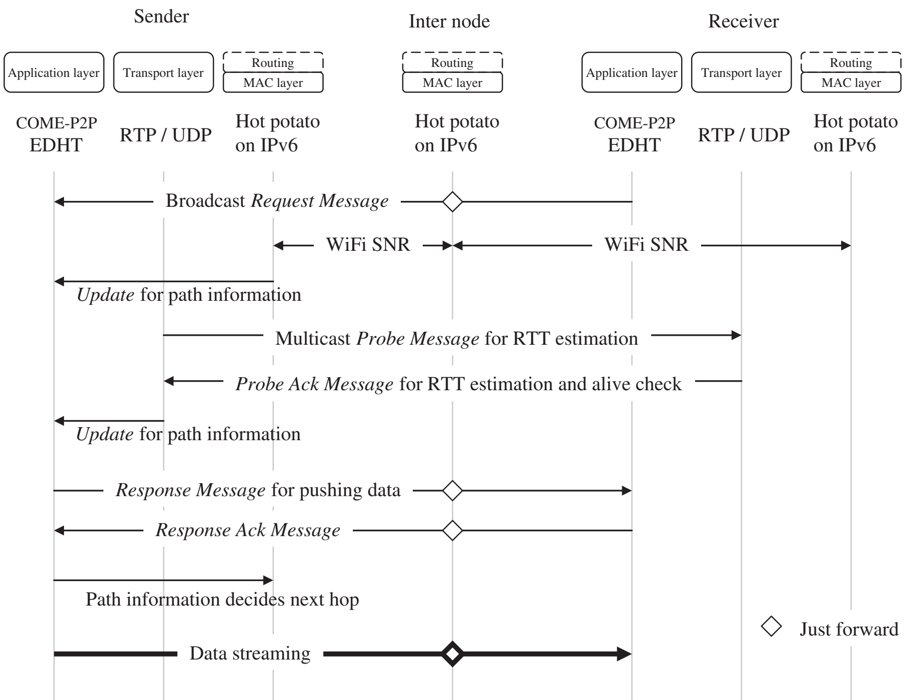

Fig. 3. The proposed cross-layer scheme for packet routing.

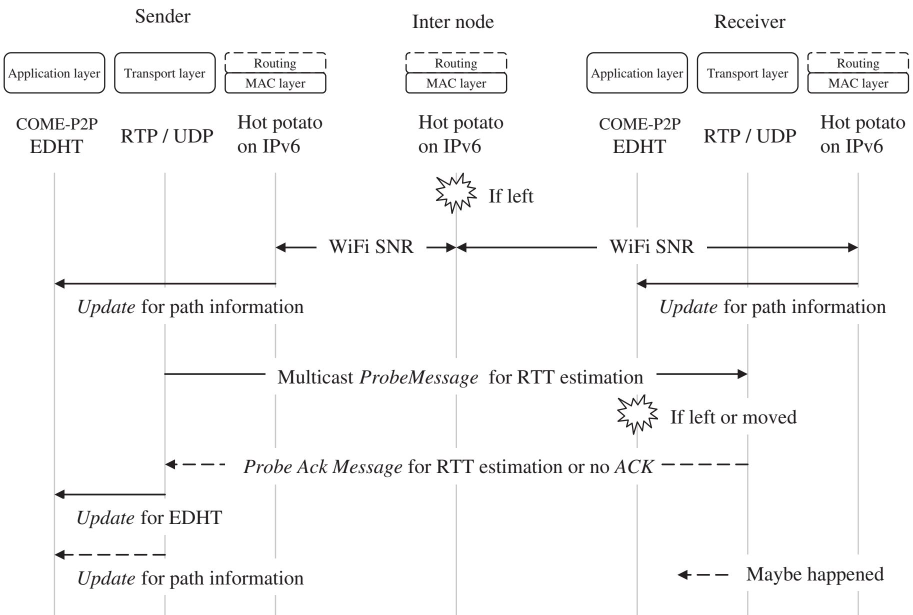

Fig. 4. Our proposed cross-layer scheme for mobile environment.

As Fig. 4 illustrated, if the intermediate node leaves, the signal-to-noise ratio (SNR) would become smaller and smaller. The SNR degradation informs the neighboring peers to update their path information, and the neighboring peers find another intermediate node to maintain the end-to-end connections. If no intermediate node can support, the link breaks down and the receiver will redetect another sender. Ditto, if the sender disappears, the receiver will redetect another sender because of no incoming data.

If the receiver moves, the sender updates its EDHT and path information according to the changed RTT. The sender may reselect the next hop depending on the shortest routing path. Similarly, if the receiver disappears, there will be no ACK back and the sender will update its EDHT to recover the P2P overlay.

If there are more than two intermediate nodes between two peers, and one of the intermediate nodes is not an immediate neighbor of peers, when this intermediate node leaves network, peers cannot detect actively this departure via SNR parameter. Therefore, peers cannot update actively their path information in advance. Peers reselect a routing path reactively when the stream breaks.

In summary, two kinds of approach can perceive peer leaving or moving: (1) every peer voluntarily informs its neighbors upon leaving. The major purpose of this information is for the neighbors re-deriving the routing paths; (2) every peer also periodically multicasts the *Probe Message* to monitor the neighbors' movements. The changed RTT represents the neighbors' movement or the variation of bandwidth, thus the notification is unicasted to all peers on the routing path to re-derive the routing.

3.4. Peer adaptation

A *peer adaptation* is a key point to guarantee QoS for peers, maintain an optimal overlay, and speed up data delivery in P2P network [9]. But the related works have not considered this issue. Generally speaking, peer adaptation is executed to keep smooth quality when the incoming bit rate decreases or is unstable in P2P live streaming. In wireless P2P, we consider that peer adaptation should be executed when RTT becomes longer or SNR becomes lower, because the neighbor may move away. In our proposed scheme, any peer can execute peer adaptation to replace its partner in the upstream or downstream by another peer with shorter RTT. This peer adaptation guarantees that the P2P overlay is proximal to the physical topology, and more advance to detect peer departure.

An ad hoc network topology is shown in Fig. 5a. Node *A*, *D*, *E*, and *G*, form a P2P streaming network, and their overlay is shown in Fig. 5b. Every peer knows its member via its DHT from the overlay. For example, *A* knows *D* but not *E*. If *A* is going to send data to *E*, it will ask its members where *E* is, then it knows that packets can be forwarded through *D* to *E* when *D* answers. By the way, *A* does not know the path *ADE* or *ADGE* for sending packets to *E*.

In the general P2P-MANET scheme, the source decides the logical path to the destination via DHT in the application layer, and AODV decides the routing path on demand. In application layer, both paths *ADEG* and *ADGE* can be applied a stream. As illustrated in Fig. 6a for the path *ADEG*, *A* selects the shortest path via AODV to *D* through *B* or *C* on demand. Similarly, both *D* and *E* also perform AODV to find the shortest path to next hops. This scheme can use AODV to ensure the local optimization, but the stream may be unstable because the path is changed and is selected on demand due to peers' movement.

Our proposed scheme uses EDHT to form P2P overlay and select routing path based on RTT estimation. The path information in EDHT decides the IPv6 hop-by-hop routing path via the cross-layer design. As a result, COME-P2P selects the path *ADEG* and every peer can select its next hop in the application layer as illustrated in Fig. 6b.

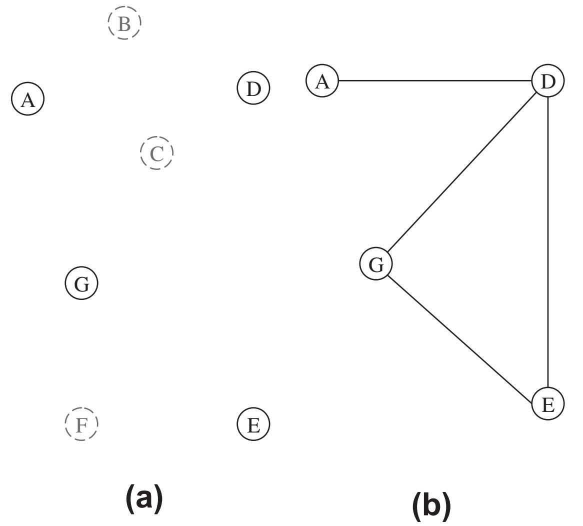

Fig. 5. (a) The physical topology of ad hoc network; (b) The P2P overlay.

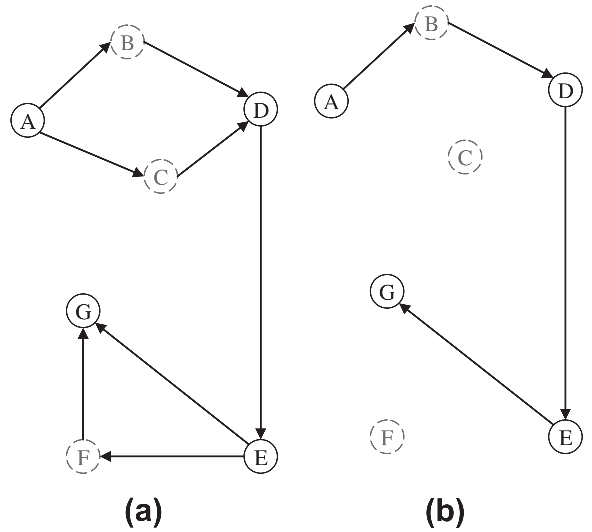

Fig. 6. (a) The stream flow via DHT over AODV; (b) The stream flow via COME-P2P over cross-layer routing.

The traditional DHT can be altered due to peer churn, instead of peer mobility, because P2P technology is developed from the wired network. Therefore, the general P2P-MANET scheme can find the end-to-end shortest path via AODV, but it is unable to inform DHT to look up a new logical path. As Fig. 7a shows, several peers move and ad hoc topology changes. In the general P2P-MANET scheme, *A* can find the shortest routing path through *C* to *D* via AODV, but *D* still forwards chunks to *E* via DHT. In our proposed scheme, EDHT with routing information is altered dynamically and periodically and interacts with network layer, hence *D* forwards chunks to *G* as shown in Fig. 7b. As a result, EDHT can build an overlay with overlay proximity to select the shortest routing path.

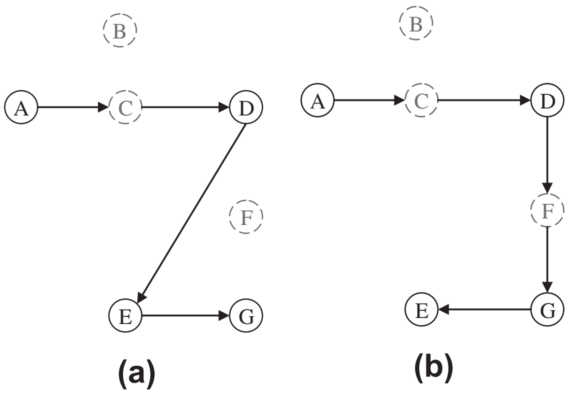

Fig. 7. (a) The stream flow via DHT over AODV; (b) The stream flow via COME-P2P over cross-layer routing.

4. Analysis

We assume that there are n peers in a P2P-MANET, and every peer has c neighbors to deliver data, which is split by k blocks. We denote a node as N, and an edge from N_A to N_B as $E(N_A, N_B)$. The compared schemes are analyzed via their *waiting time*, *routing overhead*, *maintenance load*, and scalability:

- *Routing time*: The time of deriving a routing path.
- *Waiting time*: The time of sender receiving a request to receiver getting the entire data.
- *Routing overhead*: The overhead of total messages is transmitted during the waiting time.
- *Maintenance load*: Each peer requires the maintenance load of P2P overlay when overlay is changed.

4.1. Broadcast

Broadcast scheme floods all messages or chunks to the whole network, and it is a simple scheme for wireless data delivery. A peer broadcasts all what it got to its neighbors.

In the broadcast scheme, every node broadcasts its received chunks. Since each node only stores and forwards chunks, the waiting time equals the interval of flooding, i.e. $O(nk)$. In addition, the routing overhead equals the scale of flooding, it means that n nodes may send duplications to other $n-1$ nodes. Hence, the routing overhead is $O(n^2k)$. In the broadcast scheme, all nodes do not add any load to maintain the system.

Algorithm A: Broadcast in each node

while a *chunk* is received **do**
  check the *chunk ID*;
  if *chunk ID* exists **then**
    drop the *chunk*;
  else
    receive the *chunk* and broadcast *it*;
  end if
end while

4.2. AODV

AODV is a reactive routing protocol to establish a routing path on demand for wireless ad hoc network. In general, AODV costs less to maintain a connection but requires more to establish a connection. The Gnutella-based P2P network over AODV [14,28,32] is a kind of AODV scheme. The Gnutella-based approach floods queries in application overlay and executes AODV to route packets in network layer.

Algorithm B: AODV routing in sender

$N_i = N_{\text{receiver}}$;
$N_j = N_{\text{sender}}$;
Set $A = \text{AODV}(N_i, N_j)$; // use AODV to decide path
while $A \neq \Phi$ **do** // select the first node among set A
    // because of an in-order path
  select the $A[1]$ to form an $E(N_i, A[1])$;
  $N_i = A[1]$;
  $A = A - A[1]$;
end while

In the AODV scheme, the sender must decide the hops along the path to the receiver. The sender always decides the path on demand and notifies the intermediate nodes along the path. The sender spends $O(n)$ broadcasts to find all paths between a sender and a receiver, therefore, the waiting time of the AODV scheme is $O(n)$ broadcasts for k blocks, i.e. $O(nk)$. In addition, the routing overhead equals $O(nk)$ notification messages, it means that all nodes are visited. Since AODV finds the routing path on demand, it does not cause much load to maintain the system.

4.3. DHT over broadcast

Some preliminary studies [18,26] take the off-the-shelf and well-known P2P file sharing applications into the MANET. This DHT over broadcast scheme only considers the overlay maintenance and the peer management.

Algorithm C: DHT routing in peer

// overlay layer
while a *lookup message* is received **do**
  lookup DHT to know the next hop N_i;
end while
// routing layer
while a *chunk* is received **do**
  if *chunk ID* exists **then**
    drop the *chunk*;
  else
    receive the *chunk*;
  end if
  forward the *chunk* to N_i;// forward via broadcast
end while

In DHT over broadcast scheme, every peer maintains a DHT to support P2P overlay, and every peer looks up its DHT in advance to forward message to the next peer. The well-known lookup time of DHT equals $O(\log n)$, and the routing time of the broadcast scheme is $O(\log n)$.[6] Therefore, the waiting time of the DHT over broadcast scheme should be broadcast time for each hop.

$$\begin{aligned}&\text{The waiting time of DHT over broadcast}\\&= (\text{lookup steps} \times \text{broadcast time}) \times k \text{ times}\\&= (O(\log n) \times O(\log n)) \times k = O(k(\log n)^2) \qquad (1)\end{aligned}$$

In addition, the lookup overhead of DHT equals $O(\log n)$, and every next peer needs $O(c)$ broadcast messages, so the routing overhead equals $O(ck\log n)$. However, this scheme needs additionally cost $O(\log n)$ to maintain the DHT.[7]

4.4. DHT over AODV

A pure P2P scheme [12–14] or a layered P2P scheme [15–17] experiences the long waiting time and the large routing overhead [17,20]. Some researches [20,21] consider that application layer and routing protocol should interact or integrate with each other. The DHT-based P2P network over MANET system [22,23] is a kind of DHT over AODV scheme.

In the DHT over AODV scheme, the routing time equals the lookup time adds the AODV routing time. Because the lookup time of DHT is $O(\log n)$ and the routing time of AODV is $O(\log n)$ due to DHT, the waiting time of the DHT over AODV scheme equals $O(k\log n)$ approximately.

$$\begin{aligned}&\text{The waiting time of DHT over AODV}\\&= \text{Peer lookup time} + \text{Data delivery}\\&= \text{DHT lookup time} + \text{AODV time} \times k\\&= O(\log n) + O(\log n) \times k = O(k\log n) \qquad (2)\end{aligned}$$

In this scheme, the routing overhead would be broadcasting k blocks on demand to c neighbors in DHT, i.e. $O(kc)$. However, this scheme needs additional cost $O(\log n)$ to maintain the DHT. An additional cost $O(\log n)$ is required for variation of DHT.

4.5. Hierarchical architecture

Another cross-layer scheme uses the hierarchical architecture to manage P2P overlay. For examples, XL-Gnutella [19] and other systems [22,26,29,41,42] use super peers or ultra peers to monitor the overlay and shorten the newly joining time, query time, and recovery time. The characteristic of hierarchical architecture is that peers play different roles to deal with the different works, i.e. the super peer usually loads more computing overhead and bandwidth traffic than *ordinary* peer. As a result, the efficiency of super peer is a key point to influence the success of hierarchical P2P system.

Algorithm D: Hierarchical routing in sender

```
Ni = getSuperPeer(Nreceiver);
// Ni = a super peer of the receiver
if Ni ≠ Nreceiver then
  Set A = getOrdinaryPeer(Ni);
  // set A = all ordinary peers of a super peer
  while Ni ≠ Nreceiver do
    Ni = A[1];
    A = A − A[1];
  end while
end if
```

We give an example for two-level architecture in the hierarchical scheme. The sender sends message through the super peers, such that sender first routes the message to the super peers. When a super peer receives this message, a super peer routes this message to its ordinary peers. The routing time of both kinds of peer is $O(c)$, so the waiting time of this hierarchical scheme is $O(kc^2)$.

$$\begin{aligned}&\text{The waiting time of Hierarchical architecture}\\&= \text{The routing time for super peer for ordinary peers for } k \textit{ times}\\&= O(c) \times O(c) \times k = O(kc^2) \qquad (3)\end{aligned}$$

In the two-level architecture, c is a constant between $\log n$ and $n^{1/2}$. The routing overhead equals the overhead of two loops, so the routing overhead is $O(c^2)$.[8] However, this scheme needs many messages between super peers and ordinary peers to detect the peer dynamics and maintain this hierarchical architecture. The maintenance load of super peer is much larger than that of ordinary peers. The basic load for overlay of super peer is $O(2c)$, and other algorithms such as path selection, peer adaptation, selection of super peer cost $O(n \log n)$ at least.

4.6. Our proposed scheme

Algorithm E: COME-P2P routing in peer

```
// cross layer
while a lookup message is received do
  lookup EDHT to know the next hop Ni;
  if Ni ≠ Φ then
    select a path to Ni via EDHT's path information
    Set RH = getInterNode(Ni); // RH = routing header
    int SL = the size of RH; // SL = segment left
  else
    ignore this lookup message;
  end if
end while
```

[6] DHT reduces the scale of broadcast to $O(\log n)$ peers, yet $O(n)$ flooding.

[7] When a peer joins or leaves, its neighbors modify $O(\log n)$ entries in their DHT.

[8] Both routing time and overhead of k-level architecture are $O(c^k)$, c should be in $[\log_k n, n^{1/k}]$.

Table 2
A summary of P2P-MANET schemes.

	Waiting time	Routing overhead	Maintenance load	Scalability
Broadcast	$O(nk)$	$O(n^2k)$	0	Bad
AODV	$O(nk)$	$O(nk)$	0	Bad
DHT over broadcast	$O(k(\log n)^2)$	$O(ck\log n)$	$O(\log n)$	Bad
DHT over AODV	$O(k\log n)$	$O(kc)$	$O(\log n)$	Normal
Hierarchical architecture	$O(kc^2)$	$O(c^2)$	$O(c) + O(n \log n)$	Good
COME-P2P	$O(\log n) + O(k)$	$O(c \log n)$	$O(c^2 \log n)$	Good

n = number of peers, c = number of partners of a peer, k = number of blocks of data.

Our scheme uses EDHT to derive the routing path and monitor the neighborhood movement with overlay proximity. The cross-layer scheme can establish a stable path to serve the live streaming service.

In our proposed scheme, peer's DHT includes the path information of all local members. So, a peer can know the routing path via the next hop from its DHT. Since the EDHT is a DHT-based algorithm, its lookup time equals $O(\log n)$.

$$\text{The waiting time of COME} - \text{P2P} = \text{Path selection} + \text{Data delivery} = O(\log n) + O(k) \quad (4)$$

As above mentioned, the routing overhead equals EDHT's lookup overhead for the next path, so it is $O(c\log n)$. However, the cross-layer scheme costs much load to determine the routing path. Every peer must monitor its local members for peer churn and movement. Therefore, the equation of maintenance load on every peer is:

$$\begin{aligned}\text{The load of members' movement} &= \text{Number of notifications for path reselections} \\ &= c \times O(\log n) = O(c\log n) \quad (5)\end{aligned}$$

$$\begin{aligned}\text{Maintenance load} &= \text{Number of members} \times (\text{DHT's alteration} + \text{members' movement}) \\ &= c \times (O(\log n) + O(c\log n)) \\ &= O(c^2 \log n) \quad (6)\end{aligned}$$

Therefore, our proposed scheme can achieve the short waiting time and low routing overhead, but costs much maintenance load. In P2P streaming service, the data rate is much larger than the signaling rate, so the system should trade this maintenance load to for the instant and stable streaming. As Table 2 illustrated, we summarize the mathematical analysis of the compared schemes to provide a basic overview.

5. Simulation and numerical results

We use OMNet++ 4.0 [43] to simulate the P2P service on WiFi, and use INET [44] to simulate the network behavior including organizing an ad hoc topology and handling messages. We use MF (Mobility Framework) module [45] to simulate wireless MAC layer and use OverSim module [46] to simulate P2P overlay layer. 160 mobile nodes move inside a bounded area of 1000 m × 1000 m square in the simulation construction as Fig. 8 and Table 3 illustrated.

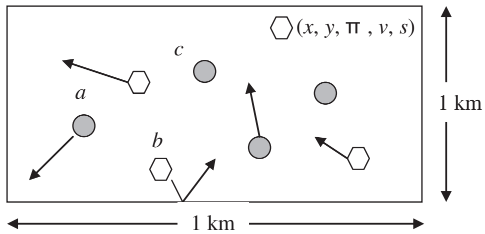

Fig. 8. The simulation environment.

Table 3
The parameters of simulation.

Parameter	Type	Range	Description
x	Natural number	0–1000 m	x-Axis
y	Natural number	0–1000 m	y-Axis
π	Decimal		Moving angle
v	Natural number	0–35 km/hr	Moving speed
s	Binary number	True of false	Turn on or not

We define every wireless node with parameters (x, y, π, v, s) in a simulation environment. The parameters (x, y) represent the coordinate of a node in the simulation square. π represents the moving angle of each node. If a node moves beyond the simulated boundary, π becomes a reflective angle as node b to ensure that every node moves in the simulation square. v represents the moving speed of each node.[9] Every node turns on P2P service to become a peer randomly, s represents whether a node is the peer or not.[10] The nodes connect to each other with the RTS/CTS Data/ACK mechanism. The transmission range is 100 m and the upload/download bandwidth is 1000 ± 200 kbps without any fading interference.[11] We consider single source and single channel, while data rate is 500 kbps.

We compare our proposed scheme, COME-P2P, with four other schemes, such as the pure P2P over WiFi broadcast, the flood-querying Gnutella over AODV, the cross-layer DHT over AODV, and the super-peer hierarchy design. Although Gnutella uses ultra peer to help managing over-

[9] When v is 0, it means the node is static as node c.

[10] If s is true, node a is a member in P2P overlay; otherwise, node b is just a member in MANET topology.

[11] Although the ideal bandwidth of WiFi standard is 11 Mbps, the estimated value we measure is less than 2 Mbps under ad hoc model in reality. As a result, we set the bandwidth 1000 ± 200 kbps without any fading interference.

lay, we differentiate the super-peer hierarchy from the flooding-based Gnutella. We repeat many experiments and get the average across all peers each experiment in simulation results. And a standard deviation (STD) is shown for simulation stability.

5.1. Playback continuity

Our scheme is proposed for P2P live streaming in wireless network, and the simulation configuration is shown in Table 4. Besides the mobility in wireless network, we consider peer joins and leaves, and hence a parameter called *churn rate*, which means the probability of peer churn. The performance is evaluated by a *continuity* metric which reflects the QoE [9]. The continuity means the number of segments that arrive before or on playback deadlines over the total number segments.

5.1.1. Scalability

Scalability is an essential characteristic in P2P-MANET. We demonstrate that the cross-layer design can improve scalability. As Fig. 9 shown, P2P overlay can be adjusted in a wireless environment to manage the peers.

- Four integrated P2P schemes (except broadcast scheme) have the good scalability, and their continuities all exceed 0.7 when the number of nodes is 120. The broadcast scheme performs badly for large scale due to too much duplication.

Table 4
The simulation configuration.

Parameter	Value	Default
The number of nodes	160	
Bandwidth	1000 ± 200 kbps	
Transmission range	100 m	
Video streaming rate	500 kbps	
Buffering time	3 s	3
The number of peers	10–120	90
The moving speed	0–35 m/s	5
The churn rate	0.0–1.0	0.0

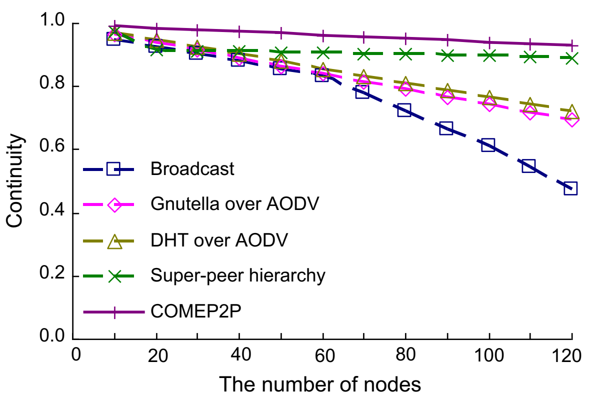

Fig. 9. Continuity vs. the number of nodes.

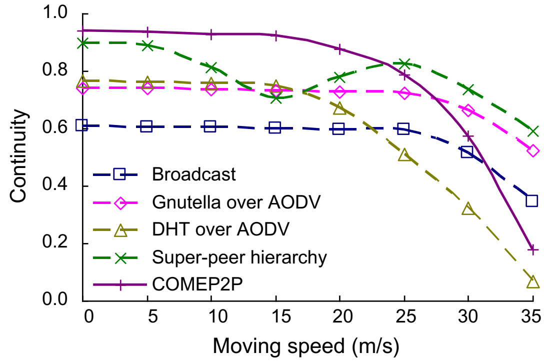

Fig. 10. Continuity vs. the moving speed of nodes.

- The shortest path can be selected on demand in AODV, but the bottleneck may happen in an intermediate node. Therefore, the continuity of AODV is degraded when the number of nodes is large.
- COME-P2P is the best scheme because EDHT balances the load. Also the super-peer hierarchy scheme balances the load via the management of super peers. When the number of nodes increases to 120, the continuity of COME-P2P is 0.93 (STD = 0.008) and the continuity of DHT over AODV is 0.72 (i.e. COME-P2P improves 29%).

5.1.2. Mobility

The movement, mobility and hidden terminal of the peers are three challenges in wireless P2P. In previous researches for both file sharing [35] and video streaming [32], the peers' moving speed influences the performance less. But in our simulated result for real-time streaming, the fast movement impacts the continuity. As Fig. 10 shown, our proposed scheme performs well.

- The broadcast scheme is the most stable scheme against the moving speed. Because the peer always broadcasts in its coverage, a peer can get data in a P2P network everywhere even if it is moving fast. However, the performance declines when the moving speed exceeds 25 m/s[12] because the inherent limit in MANET.
- The Gnutella over AODV scheme also has stable performance against the moving speed. Because Gnutella manages its peers via flooding the control messages, the moving speed affects this reactive scheme less.
- The performance of the DHT over AODV scheme is similar to the performance of the Gnutella over AODV scheme at slow speed but declines quickly when the moving speed rises. Because DHT originally is designed for wired network, it is unable to detect peer's movement, such that the peer cannot find its nearest neighbor to forward data or messages.
- The continuity performance of super-peer hierarchy is saddle-shaped, and a poor performance occurs when the moving speed is between 8 m/s and 22 m/s because of the hierarchical management. As Fig. 11a shows, the

[12] 25 m/s equals to 90 km/h and is similar with the car speed.

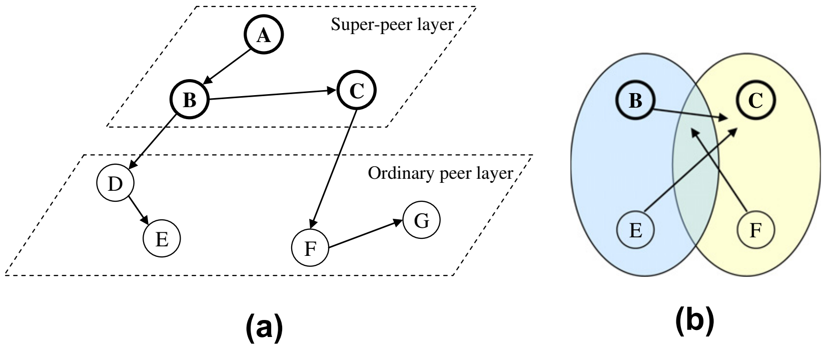

Fig. 11. (a) Super-peer hierarchical architecture; (b) Peer moving.

super peer manages its members, but member may move in the wireless network. Every peer's movement may trigger the super-peer reselection and the switching of ordinary peer. When moving speed is slow, the overlay seems static and the hierarchy scheme has enough time to derive the routing path. When moving speed is fast, the moving peer seems to leave from the original super-peer's area and join another new super-peer's area, as shown in Fig. 11b, peer *E* moves from super-peer *B* to super-peer *C*, and peer *E* leaves super-peer *B* to join super-peer *C*.

However, when moving speed is between 10 m/s and 20 m/s, the peers often locate in the overlap of several super peers' coverage, Fig. 11b illustrates that peer *F* moves to the overlapped area. The judgment of routing path for overlap is ambiguous, and super-peer reselection is performed frequently. As a result, the quality of the scheme degrades in this interval. When the moving speed exceeds 25 m/s, the performance still declines due to the unsettled overlay and wireless environment.

- COME-P2P can use cross-layer information to map the latency-based topology to detect the peer's mobility and derive a stable routing path in advance. For the reason, the continuity of our scheme is the best among all compared schemes in slow moving speed. However, when the moving speed is fast, the aforementioned routing path cannot work well because EDHT changes too frequently. The continuity of COME-P2P performs 0.94 (STD = 0.007) at walking speed (i.e. 2 m/s), and the continuity of DHT over AODV performs 0.76 (STD = 0.050). COME-P2P is 23.7% better than DHT over AODV.

5.1.3. Churn

In P2P network, the frequent peer churn leads to difficulty of keeping a stable overlay. We define the *churn rate* as the probability that a peer joins or leaves for a certain time interval [3,20] seconds. The average remained time of a peer approaches churn rate × time interval. If the churn rate is high, the P2P network is more dynamic and the overlay is much unstable. As Fig. 12 shown, we can demonstrate that peer churn directly impacts the continuity.

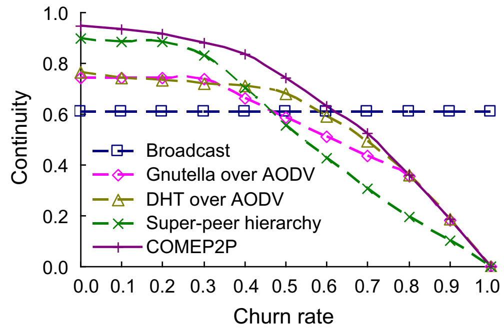

Fig. 12. Continuity vs. the churn rate of nodes.

- In super-peer hierarchy scheme, a super peer leaving is more serious than an ordinary peer leaving. The former leads to the change of hierarchical overlay. A complicated hierarchy can maintain a stable routing path in a static situation, but its performance declines quickly when churn rate increases.
- The cross-layer designs have poor performance when the churn rate is high. Although our proposed scheme is still the best one, it cannot sustain the churn dynamics with too frequently updated EDHT. When churn rate is 0.3, the continuity of COME-P2P is 0.88 (STD = 0.016), and the continuity of DHT over AODV is 0.72 (STD = 0.036). Therefore COME-P2P improves 22.2% comparing with DHT over AODV.

5.2. Signaling overhead

Besides the high continuity, a successful P2P live streaming should have small overhead and low signaling cost especially for wireless connections. We define the *signaling overhead* as the number of non-data packets sent per peer per second.

As Fig. 13 illustrated, the super-peer hierarchy scheme features the highest signaling overhead because of its complicated hierarchical algorithm. Our proposed scheme has more overhead of latency estimation and path information in EDHT than other cross-layer designs. However, the overhead on selecting routing path of COME-P2P is less than

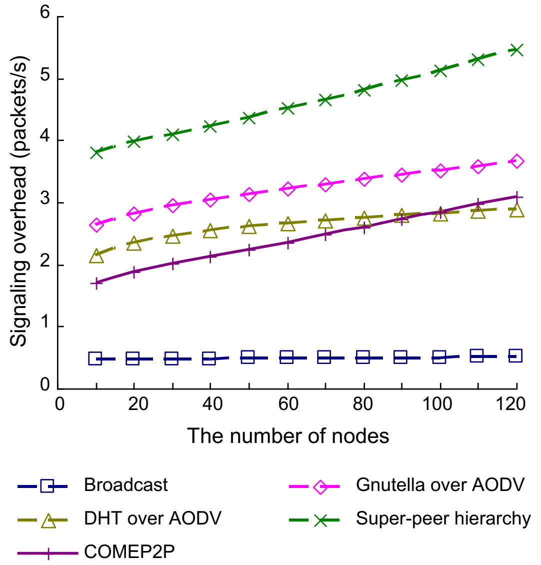

Fig. 13. Signaling overhead vs. the number of nodes.

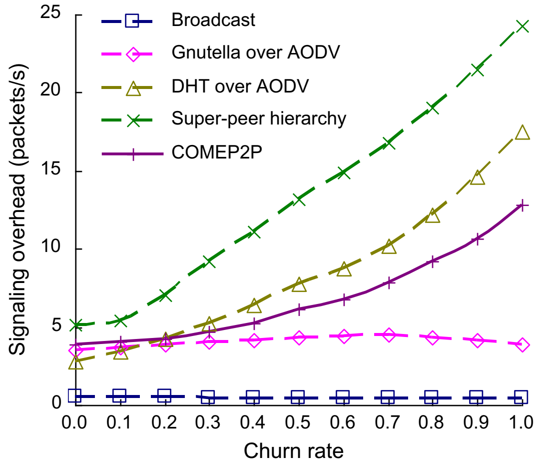

Fig. 15. Signaling overhead vs. the churn rate of nodes.

that in AODV. The broadcast scheme produces less signaling overhead but much more data duplication.

As Fig. 14 illustrates, the moving speed does not affect the signaling overhead of the broadcast scheme because the video streams are always flooded with P2P overlay ignored. On the other hand, the periodical signaling overhead is produced in COME-P2P. The curve of COME-P2P rises flatly because every peer proactively updates path information and reactively reports peers' mobility.

As Fig. 15 illustrates, the signaling overhead of COME-P2P linearly increases when churn rate rises. In our proposed scheme, when a peer joins, its neighbors inform each other to update their EDHTs and derive the routing path; and when a peer leaves, it proactively informs its neighbors. As a result, COME-P2P generates more signaling overhead when peer churn rate is high. Similarly, the DHT over AODV scheme faces the difficulty of peer churn, but it is unable to derive routing path in advance to economize signaling overhead.

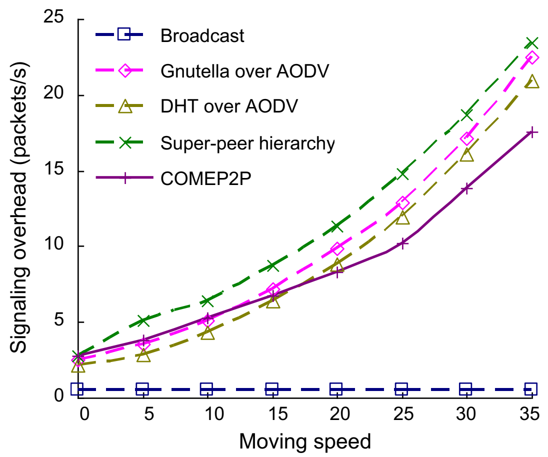

Fig. 14. Signaling overhead vs. the moving speed of nodes.

On the Gnutella over AODV scheme, the signaling overhead increases with the moving speed but not with churn rate. Gnutella manages the overlay by flooding message and pulling video data, hence peer churn will not cause a heavy signaling load. However, peer moving would not change the logical link on Gnutella overlay, hence this scheme performs AODV to visit many unnecessary intermediate nodes.

6. Conclusion

In this paper, we investigate how to improve the performance of video streaming service on wireless ad hoc network, and we present a cross-layer design for P2P live streaming in MANET. Our proposed scheme, Cross-layer Overlay for Multimedia Environment on P2P-MANET (COME-P2P), integrates the routing protocol with P2P protocol for adapting real-time service to the dynamic wireless network. A combination of the Enhanced DHT and the path information is used to manage neighboring peers and derive the routing path for real-time stream delivery. The logical overlay of COME-P2P can be proximal to the physical topology based on cross-layer design. Hence, our proposed scheme can provide a stable routing path for high data rate real-time video service.

In our proposed scheme, a cross-layer integration of streaming service, P2P cooperation, routing protocol, IPv6 and MANET can effectively improve playback continuity when facing scalability, mobility, churn with the reasonable overhead. We demonstrate that COME-P2P has good performance on playback continuity and traffic overhead for live and high quality streaming via both the mathematical analysis and simulation results. From the mathematical analysis, COME-P2P can be proved that scalability overhead increases logarithmically; from simulation results, COME-P2P can be demonstrated to have an approximate 25% improvement than the general schemes.

References

[1] J. Shi, J. Liang, J. You, Measurements and understanding of the KaZaA P2P network, Current Trends in High Performance Computing and Its Applications 639 (2005) 425–429.

[2] M. Portmann et al., The cost of peer discovery and searching in the Gnutella peer-to-peer file sharing protocol, IEEE International Conference on Networks 537 (2001) 263–268.

[3] S. Ratnasamy et al., A scalable content-addressable network, Computer Communication Review 31 (4) (2001) 161–172.

[4] I. Stoica et al., Chord: a scalable peer-to-peer lookup service for Internet applications, Computer Communication Review 31 (4) (2001) 149–160.

[5] A. Rowstron, P. Druschel, Pastry: scalable, distributed object location and routing for large-scale peer-to-peer systems, IFIP/ACM International Conference on Distributed Systems Platforms (2001).

[6] B. Zhao, J. Kubiatowicz, A. Joseph, Tapestry: a fault-tolerant wide-area application infrastructure, Computer Communication Review 32 (1) (2002) 81.

[7] O. Heckmann, A. Bock, The eDonkey 2000 Protocol. Multimedia Communications (KOM) Technical Report, 2002.

[8] J.A. Johnsen, L.E. Karlsen, S.S. Birkeland, Peer-to-peer networking with BitTorrent. 2005.

[9] S. Xie et al., Coolstreaming: design, theory, and practice, IEEE Transactions on Multimedia 9 (8) (2007) 1661–1671.

[10] X. Liao et al., AnySee: peer-to-peer live streaming, IEEE International Conference on Computer Communications 3337 (2006) 2411–2420.

[11] S. Baset, H. Schulzrinne, An analysis of the Skype peer-to-peer Internet telephony protocol, IEEE International Conference on Computer Communications 3337 (2006) 2695–2705.

[12] M. Papadopouli, H. Schulzrinne, Effects of power conservation, wireless coverage and cooperation on data dissemination among mobile devices, in: ACM International Symposium on Mobile Ad Hoc Networking and Computing, 2001.

[13] G. Kortuem et al., When peer-to-peer comes face-to-face. Collaborative peer-to-peer computing in mobile ad hoc networks, International Conference on Peer-to-peer Computing 105 (2002) 75–91.

[14] A. Klemm, C. Lindemann, O. Waldhorst, A special-purpose peer-to-peer file sharing system for mobile ad hoc networks, IEEE Vehicular Technology Conference 3551 (2003) 2758–2763.

[15] Y.C. Hu, S.M. Das, H. Pucha, Exploiting the synergy between peer-to-peer and mobile ad hoc networks, Hot Topics in Operating Systems (2003).

[16] R. Schollmeier, I. Gruber, F. Niethammer, Protocol for peer-to-peer networking in mobile environments, International Conference on Computer Communications and Networks 622 (2003) 121–127.

[17] H. Pucha, S. Das, Y. Hu, Ekta: an efficient DHT substrate for distributed applications in mobile ad hoc networks, IEEE Workshop on Mobile Computing Systems and Applications 217 (2004) 163–173.

[18] G. Peng et al., M-CAN: a lookup protocol for mobile peer-to-peer environment, International Symposium on Parallel Architectures, Algorithms and Networks 645 (2004) 544–549.

[19] M. Conti, E. Gregori, G. Turi, A cross-layer optimization of Gnutella for mobile ad hoc networks, ACM International Symposium on Mobile Ad Hoc Networking and Computing 25 (2005) 343–354.

[20] G. Ding, B. Bhargava, Peer-to-peer file-sharing over mobile ad hoc networks, IEEE Annual Conference on Pervasive Computing and Communications Workshops 264 (2004) 104–108.

[21] E. Setton et al., Cross-layer design of ad hoc networks for real-time video streaming, IEEE Wireless Communications 12 (4) (2005) 59–65.

[22] B. Tang et al., An integrated approach for P2P file sharing on multi-hop wireless networks, WiMob 2005: IEEE International Conference on Wireless and Mobile Computing Networking and Communications 487 (2005) 268–274.

[23] T. Zahn, J. Schiller, MADPastry: a DHT substrate for practicably sized MANETs. Workshop on Applications and Services in Wireless Networks, 2005.

[24] A. Boukerche, A. Zarrad, R. Araujo, A smart Gnutella overlay formation for collaborative virtual environments over mobile ad hoc networks, IEEE International Symposium on Distributed Simulation and Real-Time Applications 269 (2006) 143–151.

[25] A. Boukerche, A. Zarrad, R. Araujo, A cross-layer approach-based Gnutella for collaborative virtual environments over mobile ad hoc networks, IEEE Transactions on Parallel and Distributed Systems 21 (7) (2010) 911–924.

[26] M. Li, E. Chen, P. Sheu, A chord-based novel mobile peer-to-peer file sharing protocol, Frontiers of WWW Research and Development – Apweb 3841 (2006) 806–811.

[27] R. Kummer, P. Kropf, P. Felber, Distributed lookup in structured peer-to-peer ad hoc networks, The Move to Meaningful Internet Systems 4276 (2006) 1541–1554.

[28] A. Abada et al., A novel path selection and recovery mechanism for MANETs P2P file sharing applications, IEEE Wireless Communications and Networking Conference 4472 (2007) 3475–3480.

[29] C. Huang, T. Hsu, M. Hsu, Network-aware P2P file sharing over the wireless mobile networks, IEEE Journal on Selected Areas in Communications 25 (1) (2007) 204–210.

[30] H. Park, W. Kim, M. Woo, A Gnutella-based P2P System using cross-layer design for MANET, Proceedings of World Academy of Science, Engineering and Technology 22 (583) (2007) 163–168.

[31] J. Zhang et al., P2P-Leveraged mobile live streaming, International Conference on Advanced Networking and Applications Workshops/ Symposia 1046 (2007) 195–200.

[32] N.N. Qadri, M. Alhaisoni, A. Liotta, Mesh based P2P streaming over MANETs, Mobile Computing and Multimedia 25 (2008).

[33] D. da Hora et al., Enhancing peer-to-peer content discovery techniques over mobile ad hoc networks, Computer Communications 32 (13–14) (2009) 1445–1459.

[34] D. Giakoumis et al., Search and retrieval of objects over a distributed P2P network for mobile devices, IEEE Wireless Communications 16 (5) (2009) 42–49.

[35] R. Hwang, C. Hoh, Cross-layer design of P2P file sharing over mobile ad hoc networks, Telecommunication Systems 42 (1–2) (2009) 47–61.

[36] N. Shah, D. Qian, A new cross-layer unstructured P2P file sharing protocol over mobile ad hoc network, Advances in Computer Science and Information Technology 6059 (604) (2010) 250–263.

[37] N. Shah, D. Qian, An efficient structured P2P overlay over MANET. ACM International Workshop on Data Engineering for Wireless and Mobile Access, 2010, p. 57–64.

[38] M. Bisignano et al., P2P over Manet: a comparison of cross-layer approaches, International Conference on Database and Expert Systems Applications 862 (2007) 814–818.

[39] M.K. Sbai, E. Salhi, C. Barakat, A membership management protocol for mobile P2P networks, in: International Conference on Mobile Technology, Application and Systems, 2009.

[40] V. Lo et al., Scalable supernode selection in peer-to-peer overlay networks, International Workshop on Hot Topics in Peer-to-Peer Systems 113 (2005) 18–25.

[41] J.-H. Lee, et al, An energy-effective routing protocol for mobile P2P systems, in: International Symposium on Wireless Pervasive Computing, 2009.

[42] H. Qu et al., A network coding dynamic node selection method in mobile peer-to-peer network, Computer Network and Multimedia Technology (2009).

[43] A. Varga, OMNET++ 4.0. <http://www.omnetpp.org>.

[44] INET Framework. <http://inet.omnetpp.org>.

[45] Mobility Framework for OMNeT++. <http://mobility-fw.sourceforge.net/hp/index.html>.

[46] OverSim for OMNeT++. <http://www.oversim.org>.

Jun-Li Kuo his M.S. degree in Computer Science and Information Engineering from National Central University, Taiwan in 2006. He is a Ph.D. student in Computer Science at National Chiao Tung University, Taiwan. His research interests include peer-to-peer network and wireless multimedia.

Chen-Hua Shih is currently a Ph.D. candidate in computer science at National Chiao Tung University, Hsinchu City, Taiwan. He received his B.S. degree in computer science and information engineering at National Central University, Jhongli City, Taiwan. His research interests include peer-to-peer network, QoS, mobile IP, wireless networks, and network protocols.

Cheng-Yuan Ho is a R&D manager in the Advanced Research Institute, Institute for Information Industry, Taipei, Taiwan. His research interests include the design, analysis, and modeling of the congestion control algorithms, mobile and wireless networks, high speed networking, P2P networks, real-flow test, and quality of service. Ho received his Ph.D. in Computer Science from National Chiao Tung University, Hsinchu, Taiwan in 2008.

Yaw-Chung Chen received his B.S. degree from National Chiao Tung University, Hsinchu, Taiwan, his M.S. degree from Texas A&M University, Kingsville, Texas, USA, and his Ph.D. degree from Northwestern University, Evanston, Illinois, USA. In 1986 he joined AT & T Bell Laboratories, where he worked on various exploratory projects. He is currently a professor in the Department of Computer Science, National Chiao Tung University, Hsinchu, Taiwan. He is also the director of Information Industry Institute/National Chiao Tung University Joint Research Center. His research interests include Internet Protocols, fast mobility management, P2P systems and green computing.