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LETTER

A Cross-Layer Design for Wireless Ad-Hoc Peer-to-Peer Live Multimedia Streaming

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SUMMARY Establishing peer-to-peer (P2P) live streaming for mobile ad hoc network (MANET) requires an efficient scheme to deliver the real-time data in the infrastructure-less disaster environment. However, P2P membership management is difficult in the dynamic mobility and resource limited MANET. In this paper, we present a cross-layer design for P2P-MANET which integrates P2P DHT-based routing protocol and IPv6 routing protocol. Therefore, the proposed scheme can manage and recover the P2P overlay as well as selecting efficient routing path to multicast video streaming. The simulation results demonstrate that the proposed scheme performs relatively better than the layered approach or the off-the-shelf design in terms of the playback continuity and signaling overhead.
key words: *P2P-MANET, cross-layer design, IPv6, wireless ad hoc, P2P streaming*

1. Introduction

In the infrastructure-less disaster environment, the peer-to-peer (P2P) group conference over mobile ad hoc network (MANET) can be used to communicate with each other when the rescue crews search the survivors but work separately. However, the dynamic nature of MANET causes many challenges in designing a robust and scalable P2P system. Several works [1]–[5] have been proposed to provide efficient P2P content sharing services in the MANET environment, but they have some limits and drawbacks, especially when providing the live streaming.

ORION [1] used TCP (without retransmit) and AODV to guarantee high data rate and low transmission overhead for file searching and downloading. DPSR [2] integrated Pastry and DSR to improve scalability of MANET. However, the layered approaches had heavy routing overhead and cannot inform network dynamics. M-CAN [3], MAD-Pastry [4], and M-Chord [5], used P2P overlay to manage the wireless peers. However, the off-the-shelf approaches did not deliver efficiently and stably in mobility. MP2PS [6] provided real time streaming over MANET via AODV, however, it lacked proximity of application layer overlay to physical layer topology and efficient route for high data rate. CLAPS (Cross-Layer And P2P based Solution) [7] inherits the tree-based overlay and OLSR extension from MOST (Multicast Overlay Spanning Tree Protocol) [8] for real-time video streaming. CLAPS assumes that the physical routing topology can be provided by OLSR*, which sends cross-layer message to optimize overlay. The source peer maintains a minimum spanning tree as its overlay. The minimum cost is computed via *link distance* packaged in cross-layer message, and the spanning tree is recomputed periodically to keep the overlay proximity. To optimize the overlay proximity and avoid the overlap path in ad hoc routing, the *candidate peer*s are selected as relay node on multicast paths according to the equal link distance. In the simulation, CLAPS adopts UDP as transport layer protocol and WiFi as MAC layer protocol. It considers that the maximum moving speed is 8 m/s and the maximum number of peers is 50.

In this paper, we present a cross-layer approach for P2P live streaming tailored to MANET. Our proposed scheme includes an overlay scheme and a routing scheme. The former is responsible for maintaining the proximity of application layer overlay to physical layer topology; while the latter provides efficiently routing via IPv6 and cross-layer messages to reach the high bit rate and keep the optimal shortest routing path, respectively. The integration of P2P overlay and MANET routing can update network information to reduce signaling overhead, speed up recovery time, and improve streaming stability. Difference from the CLAPS, the proposed scheme achieves the proximity without the support of network layer, and the forwarding table in application layer and routing table in network layer are integrated in the proposed scheme. On the other hand, as the IPv4 addresses are used up, IPv6 will be a promising solution for the next generation network. The proposed scheme is suitable for the future IPv6 network.

2. The Proposed Mechanism

Unlike inefficiency and instability in the layered off-the-shelf schemes**, the proposed scheme adopts a novel cross-layer architecture for video streaming in P2P-MANET shown in Fig. 1. The main component of the proposed scheme is the *enhanced distributed hash table* (EDHT) which is constructed via a cross-layer scheme. The EDHT

*MOST extends the OLSR unicast to support multicast routing. It is a multicast routing protocol, not an overlay protocol. Although MOST uses the minimum spanning tree as its overlay, it does not consider P2P issues. However, the overlay of CLAPS is inspired from the spanning tree of MOST due to the multicast purpose.

**In the layered off-the-shelf schemes, a lack of interaction and integration of routing layer leads to the far routing path and the high signaling overhead, and a lack of overlay proximity leads to the low robustness and low extensibility.

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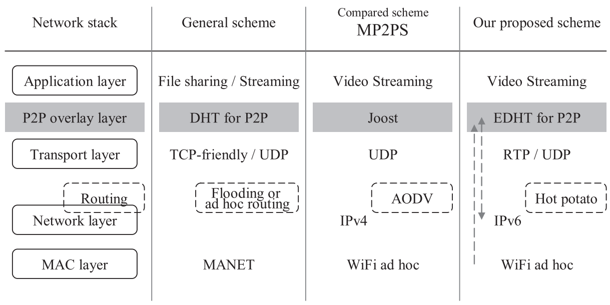

Fig. 1 Our proposed cross-layer scheme.

owns the cross-layer information; therefore, the IPv6 routing protocol can be simplified (i.e., the EDHT in the P2P overlay layer owns the functionality of routing table; hence we need not construct an additional routing table in network layer).

2.1 P2P Overlay Layer

In P2P overlay layer, we use EDHT to give the information for UDP and IPv6 routing, and we call this *path information*, which records the local path from self to other peers. In our proposed scheme, peers organize themselves via disseminating membership information. Through P2P overlay, every peer maintains an EDHT to know its local members. When a peer joins and leaves, it notices its members actively. Every peer sends *Probe Message* to its members periodically to estimate the *round trip time* (RTT). RTT estimation can indicate the members' movement, available bandwidth, and absence. The path information in EDHT is altered to accommodate to the mobility and the changed topology according to RTT. As a result, the logical overlay can be mapped in the physical ad hoc topology in our proposed scheme.

2.2 IPv6 Routing Layer

IPv6 is used to decide routing path mapped P2P overlay to avoid the large overhead or delay insensitivity, 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 to forward packets hop by hop in precomputed order. Every mobile node can check the *destination* and the *segment left* of IPv6 to determine the next hop. In addition, we use the simplest routing protocol "Hot Potato" to implement quickly, and it adds less overhead on network traffic and less computation on mobile node than other routing protocol. Hot Potato checks the next hop of IPv6 packet and forwards to the destination immediately. Hence, EDHT gives path information of next hop to route packets without on-demand routing overhead.

Figure 2 illustrates how to forward the stream through P2P-MANET via our proposed scheme:

(1) Logical P2P path $A \rightarrow E \rightarrow F$ is established from P2P overlay via the EDHT lookup.
(2) After the RTT estimation, physical routing path *ABDE* is selected because path *ABDE* is shorter than path *ABCE*, path *ABCDE* and so on.

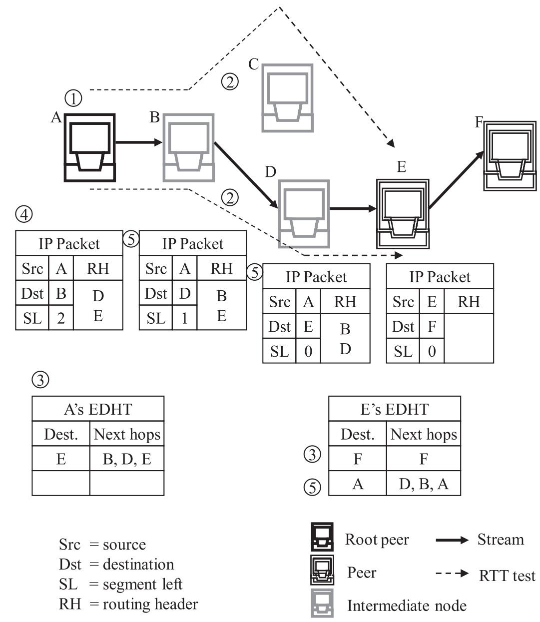

Fig. 2 Our proposed EDHT over IPv6 routing.

(3) The path information is updated in the EDHT and is used to decide the orientation of packets and streams.
(4) The path information is filled in the attribute "routing header" of IPv6 packet.
(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 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.

2.3 Detail Procedures of the Proposed Scheme

In 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 similar *Hello* messages to collect neighborhood information to form a self-organized network. If a node joins the P2P-MANET and uses the streaming application, it broadcasts *Request Message* to inform all peers that it joins and requests service, we call it receiver. When a peer (sender) receives this message, it sends a *Probe Message* to know the receiver and estimates a RTT as Fig. 3 illustrated. The receiver maybe get many *Probe Message*s, it responses ACK to first some

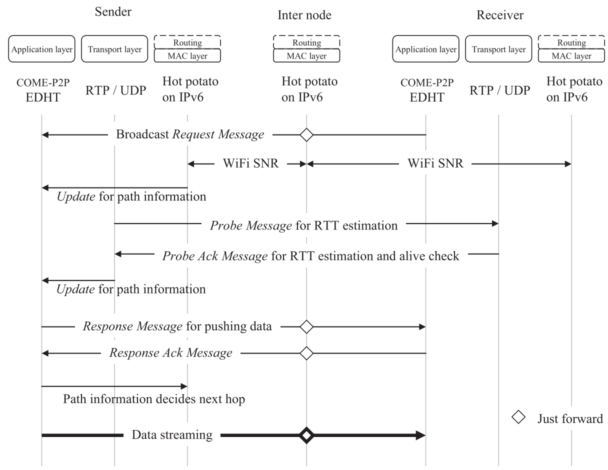

Fig. 3 Our proposed cross-layer scheme for packet routing.

senders because their distances should be short. 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* to be ready for receiving streaming and rejects the other later *Response Messages*. After the sender receives *Response Ack Message*, it *pushes* data streaming to the receiver according to its EDHT. Every peer periodically updates its EDHT including path information to assign the "next hop" attribute of IPv6 packet.

When a peer leaves from the P2P network, it voluntarily informs its neighbors via a *Left Message* and its neighbors can recover the overlay. However, in wireless mobile network, the message may be lost. Therefore, in our proposed scheme, all peers multicast periodically *Probe Messages* to maintain P2P overlay and monitor the neighbors' movements. Therefore, EDHT can gain the network estimation from low layer to maintain P2P overlay and help IPv6 routing.

3. Performance Evaluation

3.1 Analysis

We compare our proposed scheme with other schemes including MP2PS [6] and the flood-querying over AODV. We assume that there are n peers in a P2P-MANET, and the routing discovery of ad hoc protocol is completed in advance. We discuss the *routing complexity* in the comparison.

In flood-querying over AODV, a peer searches a source via flooding query, whose complexity is well-known $O(n)$. Every query is forwarded on demand by intermediate node via AODV, whose complexity is well-known $O(\log n)$ [9]. Therefore, the routing complexity of flooding over AODV is $O(n \log n)$.

In MP2PS, a peer searches a source via DHT-based approach, whose complexity is well-known $O(\log n)$. MP2PS adopts AODV as the ad hoc routing protocol. Therefore, the routing complexity of MP2PS is $O((\log n)^2)$.

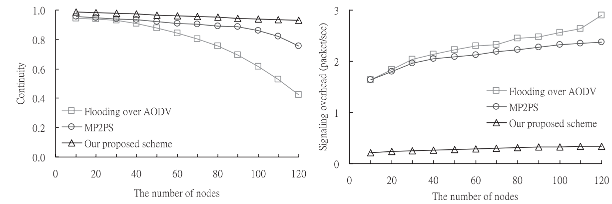

Fig. 4 P2P-MANET performance in terms of scalability.

In our proposed scheme, a peer searches a source via EDHT, which inherits DHT, thus its complexity is $O(\log n)$. The routing path is derived from EDHT to avoid the choice of on-demand intermediate node. The complexity of IPv6 routing via Hot Potato protocol is $O(1)$. Therefore, the routing complexity of proposed scheme is $O(\log n)$.

The high routing complexity can impact the low routing efficiency and heavy routing overhead. In the following section, we use *continuity* [10][†] to evaluate the routing efficiency and use *signaling overhead* to evaluate the routing overhead[††].

3.2 Simulated Results

We use OMNet++ 4.0 [11] to simulate the P2P service on WiFi without any fading model. We choose IEEE 802.11b as MAC protocol and RTP/UDP as transport layer protocol[†††]. The mobile nodes are randomly distributed over an area 900 m × 900 m and every mobile node moves with arbitrarily direction in the area. All mobile nodes have the same static moving speed in an experiment, and the moving speed is variable at different experiments repeatedly. The radio transmission range of a node is 150 m, the video packet size is 1000 bytes, the signaling packet size is 60 bytes, and the data rate of streaming is 450 kbps (constant bit rate)[††††]. There is only one sender node in the simulation, and receiver nodes are selected randomly depending on churn rate.

We demonstrate that the cross-layer design can reach scalability as Fig. 4 shown. Our proposed scheme improves 25% continuity and reduces 86% overhead than MP2PS at 100 nodes. The EDHT is suitable for P2P live streaming, and the IPv6 routing is suitable for ad hoc routing, thus the integration of cross-layer design can improve continuity and reduces overhead.

In wireless network, the mobility problem leads to a difficulty of keeping a smooth playback. As Fig. 5 shown, the cross-layer design can be appropriate for the mobility.

[†]Continuity means the number of segments that arrive before or on playback deadlines over the total number segments.

[††]Signaling overhead equals the number of routing signaling packets sent by per peer per second.

[†††]In wireless network, packet loss often happens, thus many retransmissions may keep a stable streaming difficultly. Therefore, RTP/UDP is used to apply to real-time streaming and ignore packet loss.

[††††]To compare with MP2PS, we characterize the delivery principle, the overlay construction, and streaming factors on Joost [12], [13].

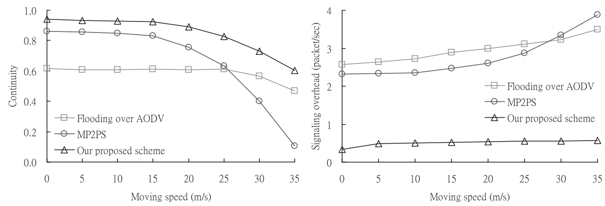

Fig. 5 P2P-MANET performance in terms of mobility.

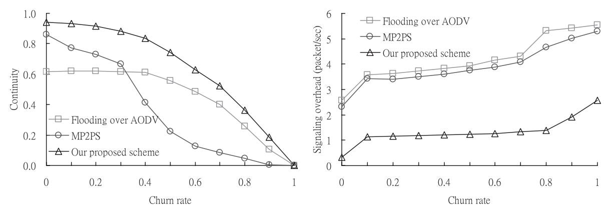

Fig. 6 P2P-MANET performance in terms of churn.

Due to the overlay maintenance and routing proximity of our proposed scheme, it can maintain high continuity and low overhead where mobile nodes move. Our proposed scheme improves 18% continuity and reduces 80% overhead than MP2PS averagely.

In P2P network, the peer churn leads to a difficulty of keeping a stable overlay. We define the *churn rate* equals the probability that some peer joins or leaves. As Fig. 6 shown, our proposed scheme is suitable for a dynamic MANET, because the cross-layer design speeds up recovery time and improves streaming stability. When churn rate is 0.5, our proposed scheme still improves 52% continuity and reduces 67% overhead than MP2PS.

There are three disadvantages of the flooding query scheme and MP2PS: inefficient routing for live high-bit-rate streaming, high on-demand routing overhead, low mobility and far routing problem in the off-the-shelf P2P-MANET protocol. The simulation results demonstrate that the cross-layer integration of EDHT and IPv6 can avoid the disadvantages.

Fast moving speed and high churn rate cannot produce much overhead to crash this system. Our proposed scheme loads linearly signaling overhead and has continuity improvement with velocity. The proposed EDHT really maintains neighborhood and interacts cross layers for deriving routing path. Via integrated with routing header in IPv6 routing, the signaling overhead is less than 1% over total streaming traffic. The overlay proximity is suitable for dynamic MANET and improves routing efficiency.

4. Conclusion

In this paper, we present a cross-layer design for P2P live streaming in MANET. Our proposed scheme integrates the routing protocol with P2P protocol for the dynamic wireless network. A combination of the Enhanced DHT, the path information, and IPv6 routing protocol can manage neighboring peers. It can also derive the optimal routing path for real-time delivery because the logical overlay is proximal to physical topology in the proposed scheme. Hence, our proposed scheme can provide the stable routing path to improve playback continuity for high data rate and low latency in real-time video service when facing scalability, mobility, churn with the reasonable overhead. Although this proposed scheme is not suitable for IPv4 network nowadays, an integration with mobile IPv6 will be an extension in the future.

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