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Experimental evaluation of an on-demand multipath routing protocol for video transmission in mobile ad hoc networks

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Abstract: We propose an on-demand multipath routing algorithm in a mobile ad hoc network for video transmission and evaluate its real world performance in video streaming application. There have been a number of multipath routing protocols extended from AODV which is a well-known single path routing protocol. Multipath routing protocols indicate good performance in the reduction of route discovery latency and unnecessary routing packets in simulations. We show that the route establishment using source route lists provided by us (Hu and Johnson, 2002) can reduce the route discovery latency, select stable routes automatically, and work well for live video streaming without limitation of the hop count based approaches. We evaluate this proposed method compared with the original AODV by using eight laptop PCs and demonstrate live streaming experiments.

Key words: Mobile ad hoc networks, AODV, Multipath routing, Source routes
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INTRODUCTION

Ad hoc networks establish autonomous networks and can cheaply and easily build networks without any infrastructures such as base stations and access points. Wireless nodes act as potential routers so that two nodes can communicate via multi-hop wireless links. In ad hoc networks, link breaks between nodes happen frequently because of movement of nodes and unstable radio features. To cope with frequent topology change under the features, various routing protocols were proposed and submitted as RFCs in IETF. AODV (Ad hoc On-demand Distance Vector) (Perkins *et al*., 2003) has clear advantages in its moderate overheads and route convergence performance. However, AODV forms a single path and must rebuild a route from source to destination when a link break happens. High route discovery latency results in throughput deterioration and received content quality is severely damaged. It is a serious problem for applications such as live streaming which need reliable constant transmission rate.

In order to minimize delay for reconstructing route, some researchers focus on multipath extension of the on-demand routing protocols and evaluate through simulations (Marina and Das, 2001; Motegi and Horiuchi, 2004; Sakurai and Katto, 2004; Nasipuri *et al*., 2001; Rojviboonchai *et al*., 2005). These researches focused on communication that can be recovered instantaneously by using a backup route which does not overlap (disjoint) with the previous (primary) data transmission route. As a result, multipath routing protocols show better performance than single path ones in their evaluations. However, simulation is not enough for analyzing the use of multipath routing protocol in the real world.

In this paper, we extend a single path AODV for multipath and implement it on laptop PCs for live video streaming applications. Our proposal manages a new route update procedure using combined metrics of delay, hop count and disjointness, and selects each intermediate node deliberately. Extensions of RREQ/

RREP packets and routing tables bring not only loop freedom but also more efficient multipath routing performance.

The rest of this paper is organized as follows. Section 2 reviews related work. Section 3 describes our testbed and proposed multipath on-demand routing protocol to be evaluated in this paper. Section 4 presents the results of performance evaluation. Section 5 concludes this paper.

RELATED WORK

There have been a number of experimental evaluations of testbeds and routing protocols in the multi-hop wireless network research area. Improvement of DSR for real-time multimedia streams demonstrates the usage of audio and video over 8 nodes, and have some similarity of research direction like that of ours (Hu and Johnson, 2002). Large-scale experimental evaluation for comparison of four routing protocols was implemented outdoors by using 40 nodes (Gray *et al.*, 2004). This experimentation, however, does not refer to what kind of applications can be used for these protocols. Some researches on mesh networks serving as communication hubs between static nodes focus on metrics of the routes for high throughput (de Couto *et al.*, 2003; Bicket *et al.*, 2005). These routing protocol metrics are novel but the tolerance to link break is not considered as high priority.

There are a number of protocols based on AODV (Marina and Das, 2001; Motegi and Horiuchi, 2004; Sakurai and Katto, 2004) and DSR (Nasipuri *et al.*, 2001) for research of on-demand multipath routing protocols. AOMDV (Ad hoc On-demand Multipath Distance Vector routing) (Marina and Das, 2001) produces multiple loop-free and link-disjoint routes using "advertised_hopcount" and "firsthop" field. A problem of AOMDV is that several efficient routes may be missed by the "firsthop" field. Another problem is lack of expiration function for backup routes. Multipath DSR (Nasipuri *et al.*, 2001) based on source routing determines multiple routes at destination appropriately. Two multiple routes, node-disjoint route and alternate route branched from a primary route, are considered and it is concluded that the latter performs better. Multipath routings applied to streaming video are also proposed (Rojviboonchai *et al.*, 2005; Di'az *et al.*, 2004). AMTP (Rojviboonchai *et al.*, 2005) selects a suitable path for streaming by measuring the quality of multiple paths according to cross layer information and shows high throughputs in simulation.

In our proposal, each intermediate node cautiously updates its next hop nodes by choosing efficient RREQ/RREP packets and a source node finally determines multiple routes derived from selected RREP packets. In addition, to diminish packet overhead, a source route list is utilized only during route discovery phase, not during data transfer phase.

PROTOCOL TESTBED AND PROPOSED PROTOCOL

We implement on the following machines the evaluation of our proposed protocol. Each node consists of a set of laptop PC (IBM ThinkPad) with 700 MHz, 256 MB or 800 MHz Celeron CPU, 128 MB of main memory, running the Linux kernel version 2.4.20. The wireless interfaces are Lucent Orinoco IEEE 802.11b card over the orinoco_cs driver. The cards operate with the same channel without RTS/CTS negotiation. Transmission rate is fixed to 2 Mbps to reduce the influence of the gray zone problem known well as a significant problem in actual 802.11 networks (Lundgren *et al.*, 2002). We operate the cards in "Ad hoc demo" mode, in which nodes can communicate mutually without beacons and BSSID (cell) for IEEE 802.11 standard IBSS. Ad hoc demo mode works well over wireless multihop networks compared with IBSS mode because the demo mode does not divide the same routing protocol network into different BSSID network.

We extend Kernel AODV (http://www.antd.nist.gov/wctg/aodv_kernel/) developed by NIST to multipath routing protocol by using a "source route list" which attached to the RREQ/RREP packets instead of special fields such as the "firsthop" of AOMDV. Source route list contributes to reliable creation of multiple paths, efficient management of neighbor nodes and maintenance of multiple candidates for data transmission route even if the overhead slightly increases.

Route discovery extensions

1. Process of RREQ

First, to find routes for a destination node, a source node broadcasts an RREQ packet. When an intermediate node receives the first RREQ packet, similar to AODV, it records a reverse route in its routing table. The intermediate node records its own IP address in the "source route list" field in the RREQ packet and re-broadcasts the packet.

An intermediate node receives a delayed RREQ packet from other neighbors, and then the node checks a source route field in the packet. This packet would be discarded immediately when the field contains the node's IP address, which means detection of a routing loop. If this address check is passed and the packet's hop count is not larger than the one in the routing table entry, the intermediate node accepts the RREQ packet and updates source route lists. Our proposal gives higher priority to the routes established by RREQ than the one-hop routes established by HELLO packet without regard to hop count. In practice, the number of route information stored in the routing table is limited to *MAX_PATH* of which typical value is three. When the packet does not satisfy the update condition, it is simply discarded. Regardless of this decision, the duplicated delayed packet is not re-broadcasted.

The "nexthop", "hopcount", and "route lifetime" fields shown in Fig.1 are stored for route information in each reverse route by each node.

Destination IP
Sequence number
Hopcount
Nexthop
Route lifetime

(a)

Destination IP
Sequence number
(nexthop1, hopcount1, route lifetime1)
(nexthop2, hopcount2, route lifetime2)
(nexthop3, hopcount3, route lifetime3)

(b)

Fig.1 Routing table extension. (a) AODV; (b) Proposal

2. Process of RREP

Any node receiving several RREQ packets generates multiple RREP packets toward a source node by multiple unicasts. In response to the first arrived RREQ packet, the destination node unconditionally accepts the packet and generates an RREP packet to set up a primary route. When the destination receives delayed RREQ packet, the node conditionally accepts the packet according to RREQ extension fields and generates an RREP packet to send along a secondary route. We limit the number of RREP packets to *MAX_PATH*.

The intermediate node that receives the first RREP packet forwards it to any neighbors over the reverse routes toward a source node by multiple unicasts similar to (Motegi and Horiuchi, 2004) and updates its routing table. When these multiple unicasts cause routing loop, it can be easily avoided by using the source route list attached. If the node receives a delayed RREP packet, it updates routing table similar to the RREQ extension case, discarding the RREP packet.

Finally, the fastest RREP for the source node provides a primary route. The others are examined in the source node as well as in intermediate nodes, and some of the routes are accepted as backup routes according to the specific metric. We use "delay metric" (Sakurai and Katto, 2004) currently for this implementation. Data transfer begins just after the primary route is established. Fig.2 is an example of the route establishment by our proposal.

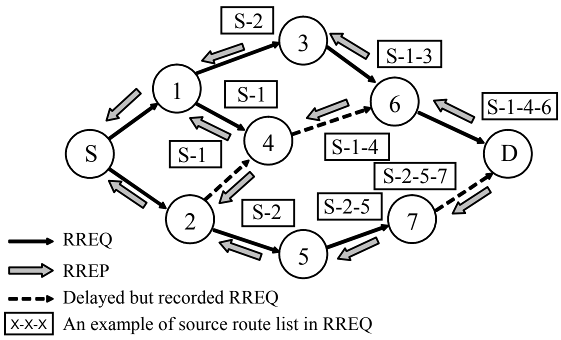

Fig.2 Route discovery extension of our proposal

Route maintenance extensions—process of RERR

When a node cannot receive HELLO messages from neighbors, the node detects link break. If neighbor nodes do not have any backup routes, the nodes invalidate their current routing tables and find precursor lists to send RERR packets to its neighbor nodes. Otherwise, the nodes immediately change a current route to a backup route. Avoidance of re-route discovery contributes to reduction of packet delay and the amount of routing packets in network. In addition, HELLO packets detecting link failure can update the backup route expiration timer and extend its life cycle.

EVALUATION AND DEMONSTRATION

We carry out two experiments to compare our proposal with the original AODV; performance evaluation uses some utilities and demonstration of live streaming uses USB camera.

Performance evaluation

1. Route recovery latency

In this section, we compare route recovery latency using a Ping application over the topology in Fig.3. To compose the network topology in Fig.3, we use "iptables" for MAC layer filtering in our laboratory. Node 1 sends 512 bytes Ping packets at a rate of 10 packets/s to Node 8, and intermediate nodes between a sender and a receiver are randomly chosen by routing protocols. Since the traffic load is moderate (40 kbps), packet losses are not caused by the load over the network. Under this condition, we shut down intermediate nodes to break some links for observing how new route discovery affects on the communication in our implementation.

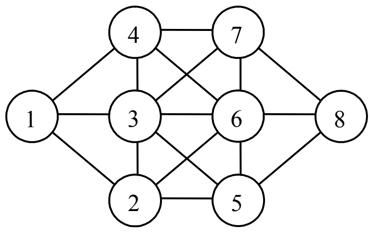

Fig.3 Network topology

Fig.4 represents the average recovery time. When link break occurs, our proposal can reduce the delay of recovery time by changing a primary transmission route to a backup route.

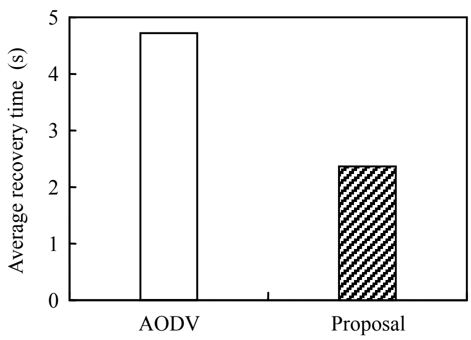

Fig.4 Average recovery time

2. Comparison of throughputs

Next, we evaluate throughputs from Nodes 1 to 8 in Fig.5. The nodes in Fig.5 are placed on the third and fourth floors in an office building. There are a number of routes in Fig.5, which include stable or unstable links. As a characteristic of AODV, the shortest hop but unstable route tends to be selected in route discovery phase or in HELLO message exchanges. For example in Fig.5, Node 1 can see Nodes 2 or 3 which provide 3 hops routes to the destination (Node 8) and sometimes see Nodes 4 or 5 which provide 2 hops routes, AODV on Node 1 chooses Nodes 4 or 5 for next hop many times and then re-route discovery takes place because of unstable links' break.

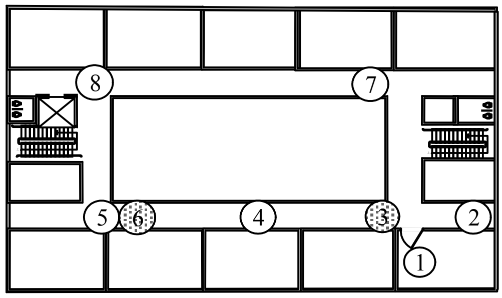

Fig.5 Layout of the testbed. Nodes 3 and 6 are placed on the third floor, and the others on the fourth floor

Fig.6 shows average throughputs, and Fig.7 shows its throughput distribution. In this experiment, we flow TCP streams for 30 s to measure throughputs. In Fig.7, 0 kbps means failures of route discovery. Our proposal has an average throughput of 349 kbps which is 1.2 times that of AODV in Fig.6. The distribution of Fig.7 shows a similar shape between original AODV and the proposal. This is because the

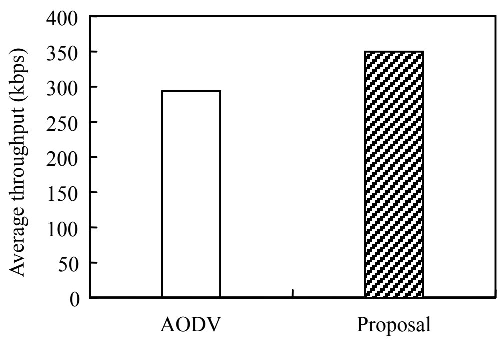

Fig.6 Average throughput

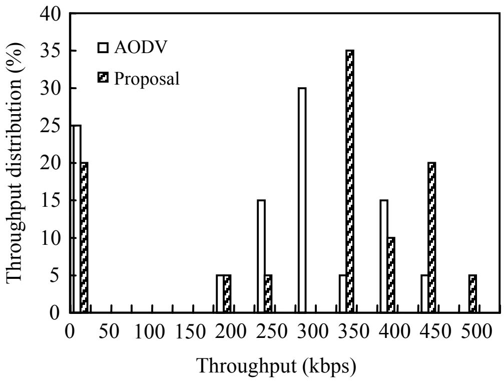

Fig.7 Throughput distribution

routes for transmission converge on a stable route more quickly in the proposal than in AODV.

Demonstration of live streaming

Finally, we demonstrated live streaming, attaching USB camera, Logitech QuickCam Pro 4000, to Node 8 in Fig.5. We used RealVideo which is one of most famous video codec. We set video bit rate to 128 kbps, video size to 320×240 pixels, and frame rate to 15 fps. This configuration keeps good image quality for recognition of objects in front of the camera. Fig.8 shows a captured image from a live camera.

Fig.8 A decoded image of live streaming

When Node 1 which runs RealPlayer demands to connect to Node 8, Node 1 initiates route discovery and requests for video streaming after route establishment.

In case of AODV, the video was played without trouble after a few seconds of connection demanding and buffering. The video quality was not bad and without heavy packet losses. After a while, however, the connection was inadvertently broken and timeout error (picture freeze) happened. As mentioned above, this is due to unstable link selection of AODV which causes its timeout.

On the other hand, our proposal was able to play video without stress similar to AODV. In addition, we could hardly find packet losses in the played video sequence and can observe video for long time without timeouts.

CONCLUSION

In this paper, we implemented a testbed of our on-demand multipath routing protocol and evaluated its performance demonstrating live streaming for sensing applications over the testbed. The routes of unstable links are adaptively replaced with stable routes in the routing tables during communication, and will be utilized as backup routes later. Streaming video is played seamlessly without timeouts when route change has occurred by promptly switching to one of the backup routes. Performance evaluations and demonstrations showed improvement on stable route convergence to original AODV constructing a single path.

As future work, we plan to control transmission rates in MAC layer using received signal to noise ratio with harmonized rate control in the video compression layer. Since simultaneous video transmission over multiple routes does not necessarily show good performance (Ganjali and Keshavarizian, 2004) even if MDC (Multiple Description Coding) is used (Di'az *et al*., 2004) over single radio channel, we also plan to develop transmission of MDC video streams over different radio channels with good load balancing capability.

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