車車間通信における位置移動予測ルーティングの実証実験評価

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あらすじ　本報告は、クロス・レイヤ・アーキテクチャーに基づく位置移動予測ルーティング・プロトコル（MP2R）の実証実験による性能評価を行なう。MP2R において、各端末は自端末の位置、速度情報を収集してネットワーク上で配布し、ほかの端末から受信した位置、速度情報を用いてそれら端末の瞬時位置を予測する。尚、予測した位置情報と見積もったリンクコストと負荷を基に、ルーティング・テーブルを更新する。本性能評価において、MP2R を Linux システム上実装し、様々な実証実験を行なった。実験評価結果から、MP2R は転送処理においてリンク品質を考慮することによりパケット・エラー・レートを有効的に削減できることを確認した。また、位置予測による高速ルート切り替えを確認できた。更に、ビデオ・ストリーミング実験結果から、映像がスムーズに流れることで MP2R の実時間車車間通信への応用可能性を示した。

キーワード　位置情報に基づくルーティング、リンク品質、予測、クロスレイヤ設計、車車間通信

Experiment Evaluation of Mobility Prediction Progressive Routing (MP2R) in Inter-Vehicle Communications

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Abstract In this paper we present the experiment results of Mobility Prediction Progressive Routing (MP2R) protocol. MP2R is based the cross-layer design. In MP2R each node learns and distributes its own speed and position, and predicts the instantaneous position of other nodes according to their past speed and position. Then forwarding decision of a packet is locally made with predicted progress, estimated link cost and load of the neighbors. We have implemented MP2R in Linux system and conducted extensive testbed experiments to evaluate its performance. The results show that MP2R can effectively reduce Packet Error Rate (PER) by involving link quality in the forwarding decision and performing fast route switch based on position prediction. The smooth video streaming also indicates that it is feasible to apply MP2R in real time inter-vehicle communications.

Keyword Geographic routing, link quality, prediction, cross-layer design, inter-vehicle communication

I. Introduction

Mobile Ad hoc Networks (MANET) consist of mobile nodes cooperating to support multi-hop communications. MANETs are easy to deploy and have found many applications, such as Inter-Vehicular Communication (IVC), which is known for the guided mobility and the frequent topology variations.

Most of MANET routing protocols are based on the global topology, where route calculation depends on either proactive topology distribution or on-demand route discovery. Typical proactive routing protocols include distance vector protocols (e.g. DSDV) and link state protocols (e.g. FSR [1], OLSR). They adapt to moderate mobility by periodically exchanging topology information. AODV [2] and DSR are known as on-demand routing protocols, where a route is discovered when necessary. They are popular in small-scale networks for the low overhead. Some recent routing protocols also considered link quality in the route selection, either preferring strong links in the route discovery stage [3]-[4], or making the initial route converge to the local optimum by gradually optimizing the active route [5]. When the topology varies too fast without converging, performance of the topology-based protocols may be greatly degraded.

On the other hand, in geographic routing protocols [7]-[11], with the position of the destination known in advance by either the proactive position distribution [12] or the distributed position registration and query [13], each node can make the forwarding decision locally. The greedy forwarding mode usually selects the longest link towards the destination. As a result, the chosen link may have poor quality, and cause frequent retransmissions and packet loss. This is especially obvious when gray zones [6] come into being in times of fading. Then tradeoff should be made between link quality and progress in selecting the forwarding node [14]-[16].

In this paper we propose a Mobility-Prediction Progressive Routing (MP2R) protocol, which is based on cross-layer design. Compared with the existing progressive routing protocols that are mainly suggested for the sensor networks, MP2R applies to the highly mobile IVC scenario and it is distinguished by the following: (i) with mobility prediction and the corresponding link cost estimation, the forwarding decision is based on the instantaneous topology; (ii) The involvement of load in the forwarder selection avoids congestion.

In the rest of the paper, section 2 reviews the related work and point out the research problem. Then in section 3 we present the system architecture and the details of MP2R protocol. Section 4 shows the experiment setup and section 5 presents evaluation results and performance analysis. Finally section 6 concludes the paper.

II. Related Work and Problem Definition

A. Link Quality-Aware Routing

To reflect link quality in routing calculation, De Couto et al. suggested the Expected Transmission Count (ETX) metric [4], which is inversely proportional to both the forward and the reverse link delivery ratios. With the ETX metric, the route in the on-demand or proactive routing protocols can be optimized. However, it usually takes much time for ETX to converge, which limits its application to the mobile scenarios. In [5], the link metric is inversely associated with Received Signal Strength Indication (RSSI). A route is maintained by the local route update scheme. It tracks link quality and topology variations in the presence of low/moderate mobility.

B. Position-based Routing

In a typical geographic routing protocol (GFG [7], GPSR [8]), each node exchanges its own position with its neighbors. When forwarding a packet, a node chooses in a greedy way from its neighbors a node as the forwarder that is closest to the destination. This greedy forwarding mode may fail in the presence of local void areas. Then the packet enters the perimeter mode and is forwarded by the right-hand rule in the planar graph [8]. For a large network, a more efficient scheme for routing around the void area is to forward packets along a rough geographic path, specified by the anchors [11].

The general position-based routing protocols have two main demerits: (1) Position inaccuracy in times of high mobility. Blazevic et al. suggested solving this problem by dividing the routing protocol into two parts [11], position-based Termnode Remote Routing and link-state-based Termnode Local Routing. (2) Neglect of link quality. The greedy forwarding mode tends to result in transmission over long weak links. Lee et al. proposed the Normalized ADVance (NADV) [16] metric, a combination of the link quality aware routing and the geographic routing. The link quality is reflected in the link cost, which focused on PER. The greedy forwarding rule is embodied in the progress. Then the tradeoff is done by maximizing the progress normalized by 1-PER. NADV is mainly proposed for dense networks where the nodes move at moderate speeds and the greedy forwarding seldom fails. Similar to most of the local routing schemes, congestion may occur at a node when many packets go through it.

C. Problem Description

Figure 1 shows a typical IVC scenario. Nodes *S*, *E*, *D* move in the same direction and *S* is communicating with *D*. If there is a node at P1, *S* can use it to forward packets to *E*, which further forwards to *D*. When this node does not exist, the route may temporarily break. Instead, *S* may opportunistically use the crossing node *B* as the instantaneous forwarder by predicting the coming timing of *B*. *S* may also select the best forwarder from several potential candidates.

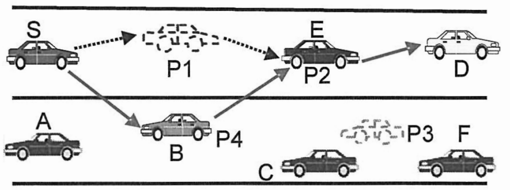

Figure 1 Problem Definition.

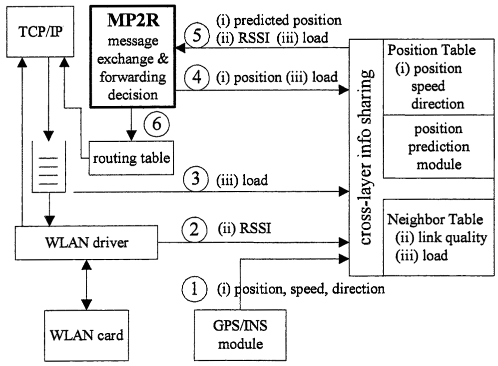

Figure 2 Packet forwarding framework.

III. System Architecture and Protocol

For simplicity, we assume that each node is equipped with a single wireless interface. Figure 2 shows the framework of the cross-layer design inside a single node. Each node builds its own Position Table

(PT) storing positions of all nodes, and the Neighbor Table (NT) recording the link quality to and the load of a neighbor. On this basis each node predicts the position of other nodes and updates its routing table.

A. Information Collection and Sharing

In the system, three kinds of information are used: (i) position (including speed and moving direction) of a node, (ii) link quality (Received Signal Strength Indication, RSSI) to a neighbor, (iii) load at a neighbor, which is associated with the output queue length of a wireless interface.

Each node collects information as follows: ① obtains its own position/speed by the GPS/INS module, and synchronizes itself with Universal Time Coordinated (UTC) clock; ② detects RSSI of a link; ③ treats the queue length as the load; ④ learns the position of all nodes and load of its neighbors. The PT table is accompanied by position prediction module. In step ⑤, link quality to neighbors, load of neighbors, and the predicted positions are used in route calculation. The position distribution is like DREAM in [12].

B. Position Prediction

For each of the position entry in the PT table, its instantaneous position is predicted. Assume a node A's position information at time t_1, $< x_{t1}^A, y_{t1}^A >$, V_{t1}^A, α_{t1}^A, is already known. Its position at time t, the immediate future, is calculated as follows

$$\begin{aligned} x_t^A &= x_{t1}^A + V_{t1}^A \cos(\alpha_{t1}^A)(t - t_1) \\ y_t^A &= y_{t1}^A + V_{t1}^A \sin(\alpha_{t1}^A)(t - t_1) \end{aligned} \quad (1)$$

Position prediction is effective only when nodes move at nearly constant speed in the fixed direction. This is not always true in the IVC scenarios. Then prediction errors occur. When the distance between two nodes are far enough, the prediction error is relatively small and seldom affects the forwarding decision. Big errors may occur when two nodes cross each other at high speeds with big accelerations. However, at such situations the distance between two nodes is short, which makes them less preferred by each other in forwarding packets.

C. RSSI Estimation and Link Cost Calculation

RSSI is a rough estimation of link quality. However, RSSI of a link can only be detected when a packet is received over it. In the system RSSI is recorded together with the distance between nodes. With the predicted position the distance between two nodes can be calculated. Then according to the RSSI-distance table, the instantaneous RSSI can be estimated. We also measured the relationship between RSSI and PER/throughput over a single link, as shown in Figure 3. On this basis the link cost can be calculated from RSSI.

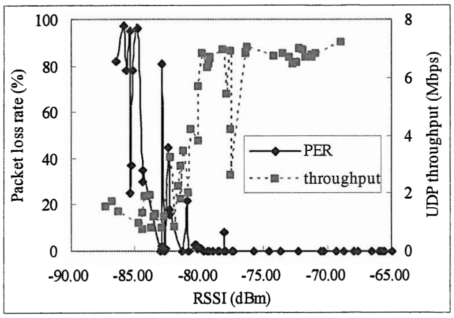

Figure 3 Relationship between RSSI and PER/throughput.

D. Packet Forwarding Decision

When updating routing table, the routing module performs the following procedure to find the best forwarder at that time.

1) Find the Candidate Forwarders

From the PT table, the position of the destination is found, with which the neighbors in the direction towards the destination are obtained, and their progresses towards the destination are also calculated. These neighbors compose a candidate list. When the destination is also a neighbor with a distance d_{dist}, only the neighbors with a distance no longer than d_{dist} are considered.

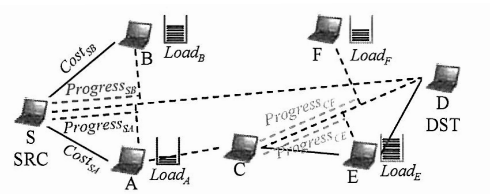

Figure 4 Forwarder selection policy in MP2R.

2) Next Hop Selection

If the candidate list is non-empty, for each of the candidate k in the list, its local metric $metric_k$ is calculated from its link *Cost*, its *Progress* and its *Load*. Figure 4 and Eq.(2) gives an example of forwarder selection for node D at node S.

$$FWD_S = \arg\min_{k=A,B,\ldots} \frac{Cost_{Sk} + \alpha \cdot Load_k}{Progress_{Sk}} \quad (2)$$

When the candidate node is exactly the destination, the load at the destination has no effect on this packet. Then α in Eq.(2) becomes 0 and the local metric is the ratio of the link cost over progress. When the candidate node is not the destination, it has to further forward the packet, after the transmission of all packets in the queue. Therefore its load is involved in the forwarding decision, which plays a load-balance role to alleviate the congestion. Finally from the candidate list the node that minimizes the local metric is selected as the forwarder.

If the candidate list is empty, the network is temporarily split and the progressive forwarding fails. Then the node has to suspend the current transmission. If a node is predicted to come within the communication range in a short time t_{wait}, the packet is held in the queue and a timer is set to this waiting time t_{wait}, after which this packet is supposed to be forwarded. However, if t_{wait} is too long, exceeding the predefined time limit th_{wait}, this packet will be dropped silently.

IV. TESTBED EXPERIMENT SETUP

A. Testbed Construction

We will evaluate the performance of MP2R by comparing it against AODV and FSR. Figure 5 shows the system implementation (including routing protocols and the cross-layer module) in Linux environment. The cross-layer module collects RSSI information through MadWiFi driver and position information via the GPS module. It provides the information to routing protocols. Though position and RSSI are not utilized in AODV and FSR, the two protocols also output the position information into log files for later visual display.

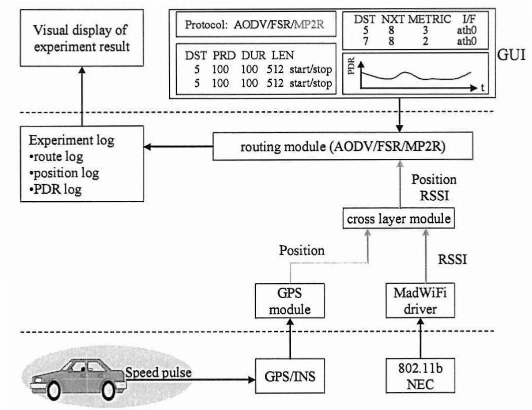

Figure 5 Implementation in Linux environment.


Figure 6 GUI for the testbed experiment.

Figure 6 shows GUI for the testbed experiment, which consists of four parts. From the up-left corner, the routing protocol can be chosen. The up-right part shows the instantaneous routing table. When the communication parameters are set in the bottom-left part at the source node, the bottom-right part at the destination will draw the instantaneous packet delivery ratio.

B. First Experiment Setup

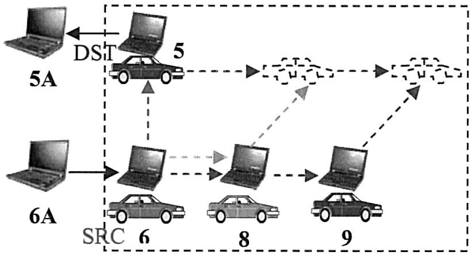

Figure 7 First experiment topology.

Figure 7 shows our testbed which consists of four cars with the communication devices. The network contains both a wireless ad hoc network and the wired extension. The wireless part (inside the dashed box) is composed of four Linux PCs, running the routing protocols. Node 5 and 6 are connected to windows PCs (5A and 6A) via a hub and act as the gateway when the video is streaming between the two windows PCs. In the experiment DST (5, 5A) moves away from SRC (6, 6A) and other nodes are stationary.

The GPS antenna is put on top of the car while other devices are inside the car. NEC Aterm WL54AG wireless LAN card is adopted and its 802.11b mode [18] is chosen in the experiment.

Two metrics are used to compare the routing performance: Packet Delivery Rate (PDR) and video quality. In the PDR test a CBR flow (25 packets per second) is transferred from node 6 to 5. In the video streaming test, the VLC software is used, and a movie is transferred from node 6A to 5A.

C. Second Experiment at a Relatively High Speed

Figure 8 shows the second experiment topology which has five nodes. Four nodes are stationary along the roads and one node (DST) is put inside the car which runs at a relatively high speed. Other settings are the same as in Figure 7.

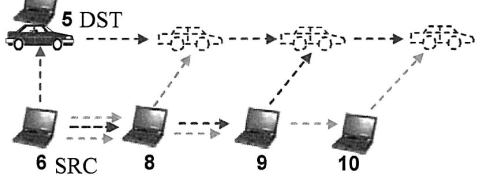

Figure 8 Second experiment topology.

V. EXPERIMENT RESULTS AND ANALYSIS

In this part we will show the experiment results obtained by our testbed. The main purpose of the experiment is to evaluate routing performance under the real IVC environment with potential fading. In our previous work [17] the evaluation of mobility prediction has already been conducted by simulation.

A. Packet Delivery/Error Rate in First Experiment

Figure 9-Figure 11 show the time-series hop count of the route and the corresponding PDR of the three protocols. In MP2R RSSI of the link 6-5 decrease and causes abrupt packet loss around 30s. Then a new forwarder, node 8, is added quickly to the route and the packet loss disappears, as shown in Figure 9. In contrast link quality is neglected in AODV and FSR. The route switch has an obvious lag. From 30s node 5 enters the gray zone of node 6 and packets from node 6 can hardly arrive at node 5. As a result packets get lost after the retransmission limit is reached. The experiment results are summarized in Table 1. It is obvious that MP2R has a much lower average PER compared with AODV and FSR.

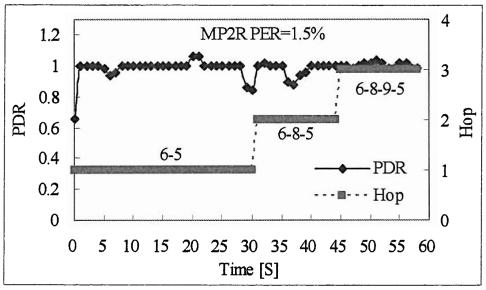

Figure 9 Time-series PDR of MP2R.

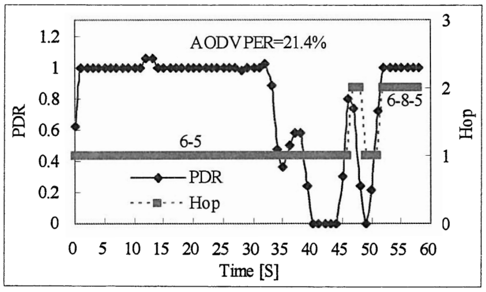

Figure 10 Time-series PDR of AODV.

Table 1 Summary of experiment results

PER	Exp1	Exp2	Exp3	Exp4	Aver
AODV	21.4%	33.6%	9.2%	15.0%	19.8%
FSR	12.4%	12.6%	14.0%	8.5%	11.9%
MP2R	1.50%	0.61%	2.50%	0.81%	1.36%

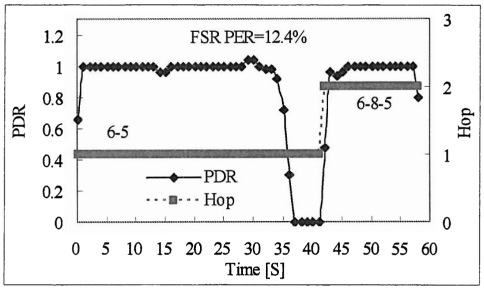

Figure 11 Time-series PDR of FSR.

B. Video Streaming in First Experiment

In the video streaming test, the same video file (in WMV2 format) is played at the source node (6A). By the multi-hop path the video is transferred to the destination (5A), replayed there and recorded in the files. MPEG TS is adopted as the encapsulation method in the transfer.

Figure 12 shows from left to right the results of AODV, FSR and MP2R respectively. In the top the videos corresponding to different routing protocols are replayed almost simultaneously. In the bottom the movement of the cars on the electronic map and the instantaneous path are displayed, from which we can see the route switch timing. At the timing when the picture in Figure 12 was taken, the route of MP2R becomes two hops while in AODV and FSR the route is still one hop. As a result in the top we can see that the picture of MP2R is very good while errors begin to occur in those of AODV and FSR. These experiments show that MP2R can support real time services.

C. Packet Delivery Rate in Second Experiment

Figure 13 shows PDR of the three routing protocols and the corresponding route over the electronic map. While the route is still two hops in AODV and FSR, the route already changes to four hops in MP2R. That is, MP2R reacts faster to topology variations than AODV and FSR, by involving both link quality and position prediction in route calculation. As a result, AODV and FSR have obvious packet loss while packet loss is almost avoided in MP2R.

VI. CONCLUSION

We have evaluated the Mobility Prediction Progressive Routing (MP2R) protocol in Inter-Vehicle Communications scenario. MP2R makes use of the relative mobility of the nodes to increase the connectivity, and the routing decision is made based on the predicted local topology the estimated link cost. Testbed experiments show that involving link quality and predicted position in the forwarding decision can effectively reduce packet loss. The result of video streaming also indicates the feasibility of utilizing MP2R for real time communications.

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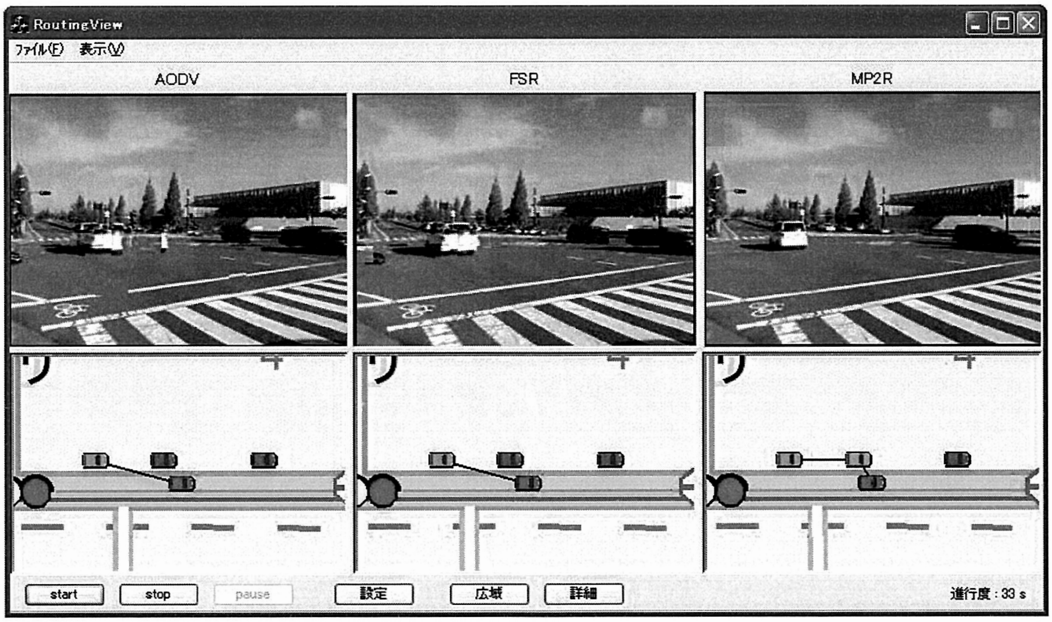

Figure 12 Comparison of video streaming among AODV, FSR and MP2R.

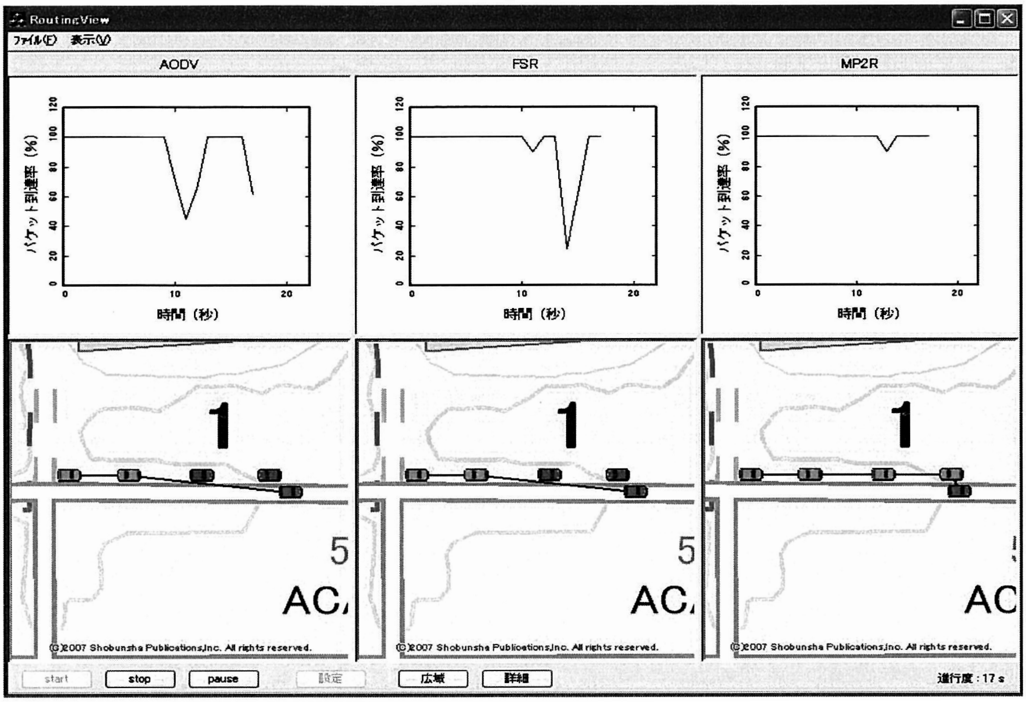

Figure 13 Comparison of packet delivery ratio among AODV, FSR and MP2R.