Collaboration in Routing and Velocity Measurement Function to Reduce Battery Consumption for Mobile Ad Hoc Networks

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Abstract

The limited battery resource of mobile devices is an endless problem. The conventional solution, improving battery technologies, is insufficient; we need alternative energy sources to enhance mobile lifetimes. One solution is to utilize cars as intermediate nodes in mobile ad hoc networks. However, the high velocities of cars may seriously degrade network quality. To overcome this, we need an efficient routing protocol that can establish stable routes even if moving cars are used as network components. This paper conducts simulations to evaluate the impact of high speed cars and proposes a novel technology that allows routing to consider vehicle velocity. Extensive simulation results are presented to show the efficiency that can be achieved by our proposal.

1. Introduction

Mobile ad hoc networks, which are constructed on the fly, are likely candidates for realizing the ubiquitous network of the future. However, they also pose many challenges that have to be met to permit successful commercial deployment. The energy consumption of mobile terminals is increasing rapidly due to higher CPU clock speeds and more programs such as gaming, credit function etc. Moreover, transmission speeds (cellular network) are increasing exponentially. It has increased about 1,000 times, from 28.8 kbps in PDC-P in Japan [1] to 10 several Mbps in HSPA, a third generation system [2], in less than 10 years. Unfortunately, battery capacity (energy density) has only tripled in the last 10 years [3–4]. Therefore, offsetting the energy consumption of mobile terminals is a formidable challenge and needs our immediate attention. Given this background, a lot of research has been carried out on energy-aware routing. Ad hoc routing functions are expected to be installed in various types of terminals besides mobile terminals, i.e., vehicles such as cars, buses, and trains, and sensor devices. One interesting approach for offsetting the energy consumption of mobile terminals is to utilize cars as intermediate nodes since they have little or no power restrictions. However, cars generally move much faster than pedestrians and route breaks are more frequent. Therefore, in order to incorporate fast moving terminals like cars into a mobile ad hoc network, we have to design a lightweight routing protocol that can well handle high speeds.

In this paper, we quantitatively evaluate the effect of cars as intermediate nodes and the impact of car speed on service quality by simulations. We propose a novel technology (collaboration of routing and velocity measurement functions (CRV)) that offers stable routes with little overhead. CRV preferentially selects stationary or slow-moving nodes when making end-to-end routes. CRV also preemptively changes the route when a node in a route is found to be fast-moving. It is a very simple approach and very effective as is confirmed by our simulations.

This paper is organized as follows. Section 2 introduces our novel approach for integrating power-rich terminals like cars into mobile ad hoc networks to extend the battery life of conventional mobile devices. Section 3 describes the simulations that examine the impact of car speed on network performance and the drawbacks of prior mobility-aware routing schemes. Section 4 describes CRV in detail. Section 5 presents the advantages of CRV through simulation results.

2. Incorporating cars into mobile ad hoc networks

Current battery-aware routing schemes can be categorized into two approaches. One is to select the minimum battery usage route considering battery consumption for sending and forwarding packets [5]; the other selects only the nodes with greatest remaining battery power in forming the network to ensure longer network lifetime [6]. In this section, we consider the potential of high-speed vehicles like cars as intermediate nodes. As nodes like cars have little or no restriction on power consumption, they can be of good use in minimizing the battery consumption of low-powered mobile devices like PDAs and cellular phones.

2.1. Effect of cars as intermediate nodes for lower battery consumption

We evaluated the effect using cars as intermediate nodes on the battery consumption of mobile terminals of pedestrians. The simulation assessed packet delivery ratio and total battery consumption of common mobile terminals under various conditions such as total number of nodes in the network, percentages of cars and terminals carried by pedestrians, and maximum car speed. The simulation conditions are shown in Table 1. We used QualNet [8] as the simulation tool. The results shown are the average values taken over 500 runs.

Table 1. Simulation conditions.

Parameter	Value
Version of QualNet	3.9.5
Simulation time	500 [sec]
Area size	1,500 X 1,500 [sq. m]
# of nodes	25, 100
(% of pedestrians, vehicles)	(20 – 100 , 80 – 0)
Mobility model	Random way point
	Pause time = 0 [sec]
for pedestrians	Speed = 1.1 [m/sec]
for vehicles	Min. speed = 2.8 [m/sec]
	Max. speed = 19.6 [m/sec]
Routing protocol	AODV [7]
MAC protocol	802.11b
	Tx power = 15 [dBm]
	Data rete = 2 [Mbps]
Data size	512 [bytes]
Data interval	250 [msec]
# of data / session	400
# of sessions	1, 5

Figure 1 shows the packet delivery ratios under various percentages of pedestrians and cars. As shown in Figure 1, the performance increases with the fraction of mobile terminals carried by pedestrians. Here, we found the packet delivery ratio was uniform regardless of MN fraction. The reductions in packet delivery ratio when the percentage of mobile terminals is 80 % (the remaining

20% are cars) are as follows: 98.8 % with 25 nodes and 1 session, 97.2 % with 25 nodes and 5 sessions, 98.5 % with 100 nodes and 1 session, and 98.7 % with 100 nodes and 5 sessions.

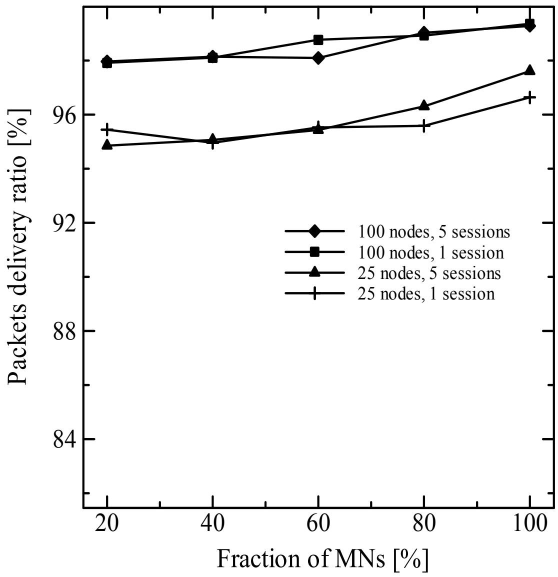


Figure 1. Packet delivery ratio.

Figure 2 shows the total battery consumption of the mobile terminals carried by pedestrians for sending and forwarding packets. As shown in Figure 2, battery consumption is decreased when more cars are utilized as intermediate nodes. The reductions in the battery consumption of mobile terminals when the percentage of pedestrian mobile terminals is 80 % (20% are cars), are as follows; 41.2 % with 25 nodes and 1 session, 46.4 % with 25 nodes and 5 sessions, 51.5 % with 100 nodes and 1 session, and 52.6 % with 100 nodes and 5 sessions.

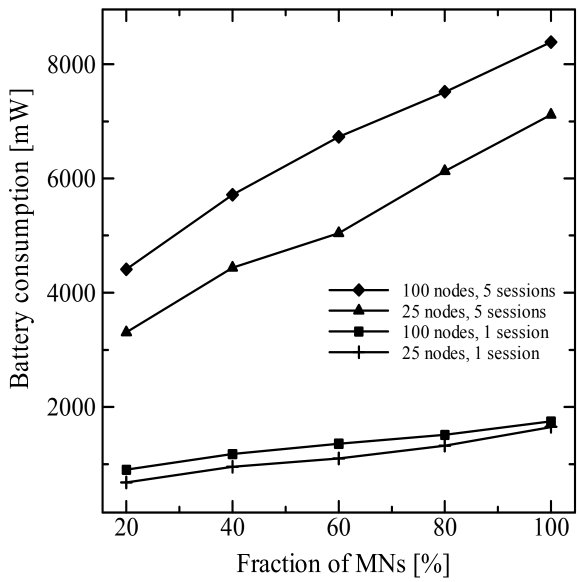


Figure 2. Battery consumption.

The results presented above show that using cars as intermediate nodes can reduce the overall battery consumption of a mobile ad hoc network. In order to maintain connection stability, slow-moving cars should be utilized. Such scenarios could be found near traffic signals, e.g., a traffic intersection.

3. Impact of cars as intermediate nodes and related work on mobility aware routing

We evaluated the impact of using cars as intermediate nodes on the performance of a mobile ad hoc network.

3.1. Performance evaluation

3.1.1. Simulation model: The simulations assessed route stability and network resource usage rates under various conditions such as total number of nodes in the network, sessions generated, and maximum car speeds. The metrics observed were the number of link breaks, the number of RREQs initiated, packet delivery ratios, and control overhead. The simulation modeled a network occupying a 1,500 m X 1,500 m area with 25 or 100 nodes. Two cases were simulated; in one, all nodes were mobile terminals carried by pedestrians. In the other one, 80% of all terminals were cars. This scenario simulates a traffic intersection for the reasons given in Section 2.1. We used ADOV as the routing protocol and 802.11b as the MAC protocol. A random waypoint model was used in the simulation. The speed of mobile nodes was 1.1 m/sec, roughly walking speed, while car speeds ranged from 10km/hour (2.8 m/sec), which is assumed to be the speed in traffic jams, to 70 km/hour (19.6 m/sec). The data packet size was 512 bytes. Packet generation interval was 250 msec. Source and destination nodes were randomly chosen. The number of sessions was 1 and 5. Simulation time was set at 500 sec. We used QualNet as the simulation tool. The results are the average values taken over 500 runs. The simulation conditions are shown in Table 2.

Table 2. Simulation conditions.

Parameter	Value
Version of QualNet	3.9.5
Simulation time	500 [sec]
Area size	1,500 X 1,500 [sq. m]
# of nodes	25, 100
(# of pedestrians, vehicles)	(all, 0), (5, 20), (20, 80)
Mobility model	Random way point
	Pause time = 0 [sec]
for pedestrians	Speed = 1.1 [m/sec]
for vehicles	Min. speed = 2.8 [m/sec]
	Max. speed = various (2.8 - 19.6) [m/sec]
Routing protocol	AODV
MAC protocol	802.11b
	Tx power = 15 [dBm]
	Data rete = 2 [Mbps]
Data size	512 [bytes]
Data interval	250 [msec]
# of data / session	400
# of sessions	1, 5

3.1.2. Impact on route stability: Figure 3 shows the number of RREQs initiated. The increases in the number of RREQs initiated, for maximum car speeds up to 19.6 m/sec compared to the all pedestrian case, are as follows; 77.2 % with 25 nodes and 1 session, 77.2 % with 25 nodes and 5 sessions, 204.3 % with 100 nodes and 1 session, and 188.6 % with 100 nodes and 5 sessions. The increase in the number of RREQ is due to re-routing to offset high mobile speeds. The impact of high mobile speed is more prominent when node density is high.

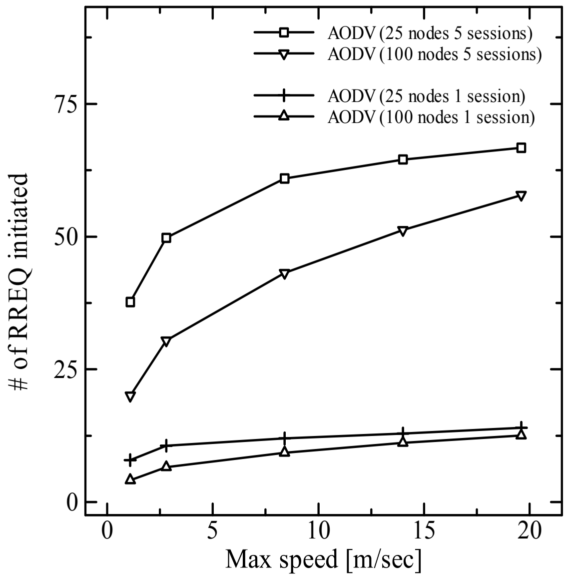


Figure 3. Number of RREQ initiated.

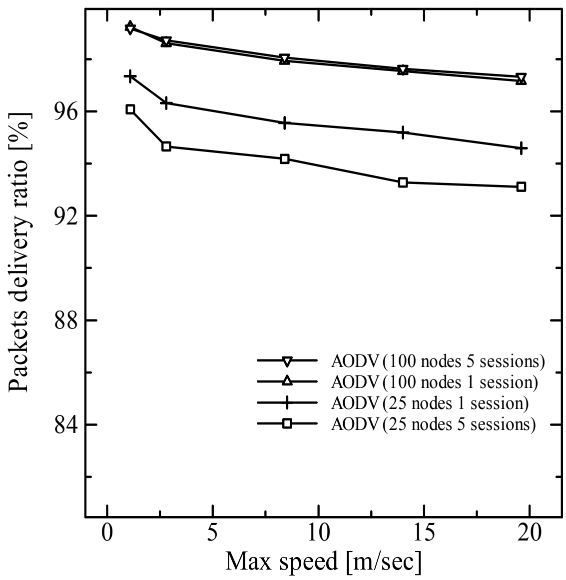


Figure 4. Packet delivery ratio.

Figure 4 shows the packet delivery ratios. As shown in Figure 4, the packet delivery ratios fall regardless of node number as car speed rises. The reductions in the packet delivery ratios for maximum car speeds of up to 19.6 m/sec compared to the all pedestrian case, are as follows; 2.8 % with 25 nodes and 1 session, 3.1 % with 25 nodes and 5 sessions, 2.1 % with 100 nodes and 1 session, and 1.9 % with 100 nodes and 5 sessions. This means that maximum car speed has a greater impact at low node density than at high node density. This is due to the shortage of alternative links at low node density. This simulation used AODV which offers fast re-routing and so re-routing had small impact. However, OLSR has longer re-routing times [9], several seconds to detect a link break and to fix the new route, and so would be more sensitive to speed.

The above results confirm that high car speeds negatively impact route stability regardless of node density and the number of sessions.

3.1.3. Impact on network resources usage rates: Figure 5 shows the control overheads versus car speed for various numbers of nodes (25, 100) and sessions (1, 5). As shown in Figure 5, the control overheads increase with maximum car speed regardless of the conditions, especially in the 100 node, 5 session case. The increases in control overheads for maximum car speeds of up to 19.6 m/sec compared to the all pedestrian case, are as follows; 107.1 % with 25 nodes and 1 session, 86.6 % with 25 nodes and 5 sessions, 237.4 % with 100 nodes and 1 session, and 217.7 % with 100 nodes and 5 sessions. The increase in overheads is due to more control signals, e.g., signals for route discovery including re-routing, being sent to and forwarded over more nodes. This increase in control overhead may degrade network throughput due to the limited wireless resources.

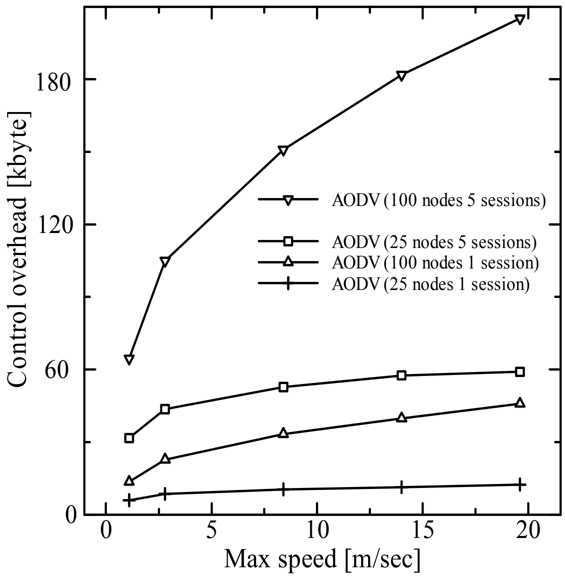


Figure 5. Control overhead.

3.2. Analysis

As shown in Section 3.1.2, route stability decreases as car speed increases. One reason for this is that the routing policy selects minimum hop routes. In the network topology in Figure 6, when packets are sent from node *S* to node *D*, the minimum hop route *S*-*a*-*c*-*D* is selected. However, as node *a* is moving rapidly, the qualities of links *S*-*a* and *a*-*c* tend to fall and the route from *S* to *D* may fail.

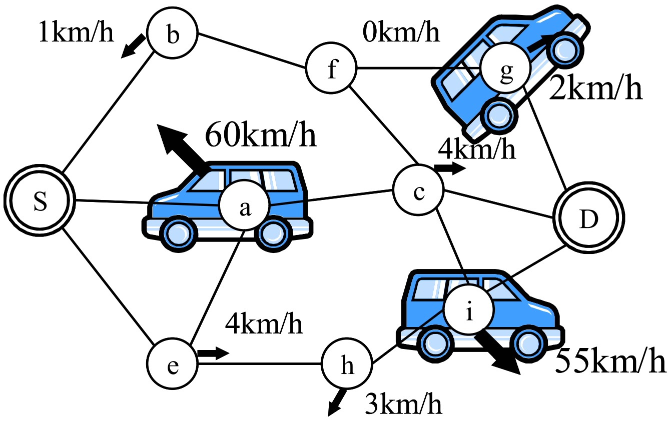


Figure 6. Reason for route failure.

3.3. Related work on mobility aware routing

A variety of schemes have been proposed to eliminate the issue of route discovery dependence on the number of hops [10–15]. Reference [10] makes a proposal based on LAR; it can select stable routes by means of adding velocity information of each intermediate node to the packets used to search for routes. RSR [11] enters relative velocity information and information on the distance between cars into the route request packets. However, RSR overwrites the velocity information hop by hop, which can negatively impacts control overhead. FORP [12] and reference [13] try to increase route quality by considering the time over which sessions can be kept. Reference [14] discovers stable routes by entering the sum of relative velocity of each intermediate node into the route discovery packet and selecting the minimum value at the destination node. In Move [15], stable routes are discovered through the addition of velocity and location information to Hello-Response packets. The above studies select the best route by entering absolute and relative velocity information of each node into route request packets.

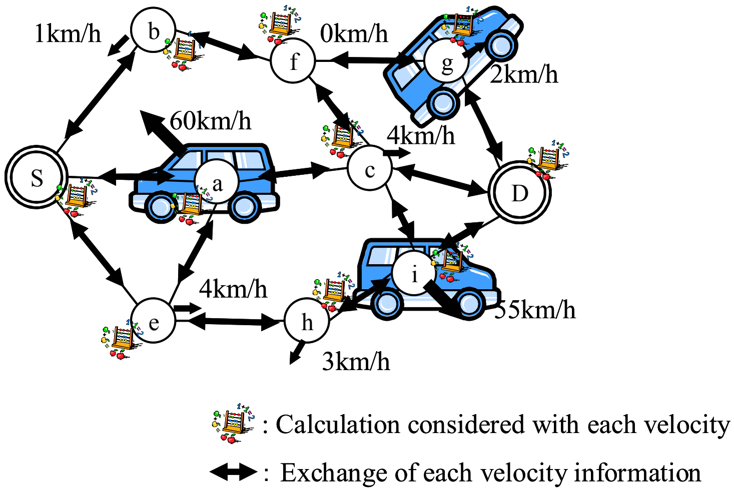


Figure 7. Overview of related work on mobility aware routing.

Concretely, as shown in Figure 7, nodes exchange velocity and link information and the source node selects a stable route considering the velocity information. This approach yields the stable route *S-b-f-g-D*. This process, however, imposes more pressure on the limited radio resources due to the transfer of the additional information, velocity information, in the control packets, and the complexity of calculating route metrics. Moreover, a lot of useless routing information (*S-a-c-D* and *S-e-h-i-D*, etc.) is passed around and processed.

Our proposal differs from related works in the following points; no additional information, such as velocity information, need be put into the control packets, and no complex processing is required. In addition, useless information is not passed around.

4. Collaboration in routing and velocity measurement function

This paper proposes the collaboration in routing and velocity measurement function (CRV) to select stable routes in the most efficient manner. CRV consists of a basic function and an enhanced function.

4.1. Basic function

CRV establishes routes using just those nodes that ensure adequate link quality. In addition, it utilizes the limited radio resources efficiently and avoids complicated processing to discover routes. In CRV, nodes moving faster than a preset threshold deactivate their routing protocol by themselves, so they are never considered as candidates in route establishment. Self-deactivation minimizes the number of control signals needed because route discovery is performed only on nodes that are stationary or slow moving. In addition, CRV does not need to exchange velocity information among nodes and so minimizes control overheads. Figure 8 shows the processing flow of the basic function in CRV. As shown in Figure 8, each node checks its own velocity periodically. Its routing function is activated/deactivated when it moves slower/faster than the threshold.

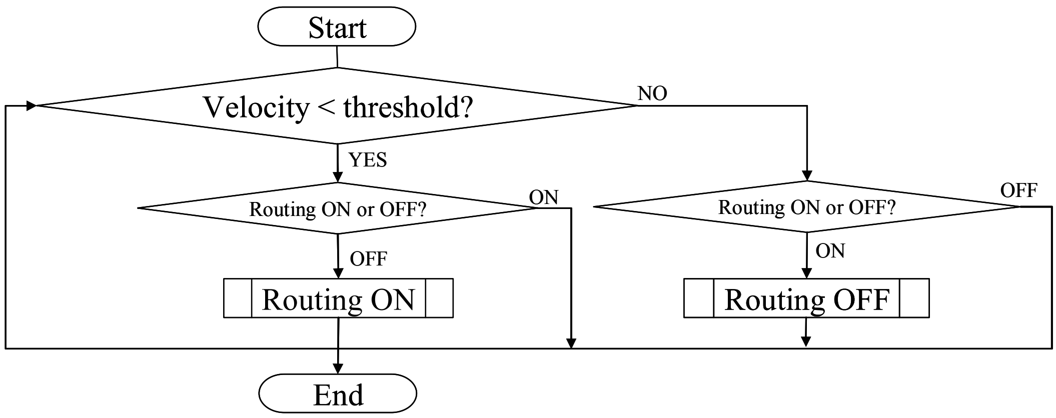


Figure 8. Process flow of basic function.

With CRV, the topology shown in Figure 6 changes the logical topology shown in Figure 9. This allows the minimum hop route to be discovered without complex processing.

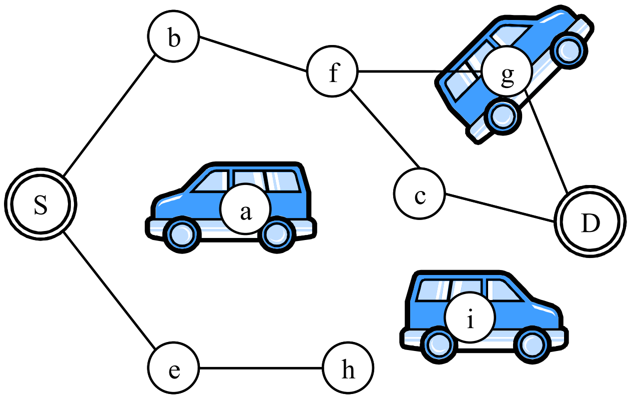


Figure 9. Logical topology with proposal.

4.2. Enhanced function

The basic function of CRV allows a short burst of high speed driving to trigger link disconnection and new route discovery. If an intermediate node moves within the radio transmission range of neighbor nodes, links between the intermediate node and its neighbors can be established even at high speed. Additionally, if the active session is short, a car acting as an intermediate node can still provide a stable route within the short period needed to complete the session even if it accelerates strongly, when the traffic signal changes to green for example. Therefore, we define an enhanced function which allows an active intermediate node to continue to forward packets until the end of the active session. This enhanced function can prevent active routes from disconnecting. Figure 10 shows the flow chart of the enhanced function in CRV. As shown in Figure 10, each node checks whether it is acting as intermediate node or not when its speed exceeds a threshold. If it is active, it forwards data packets but refrains from processing/forwarding control packets. After the session ends, it turns off all routing functions.

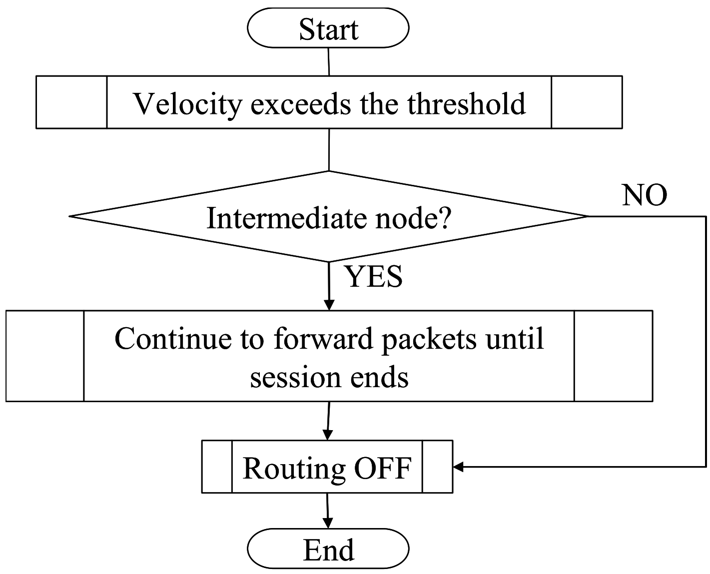


Figure 10. Process flow of enhanced function.

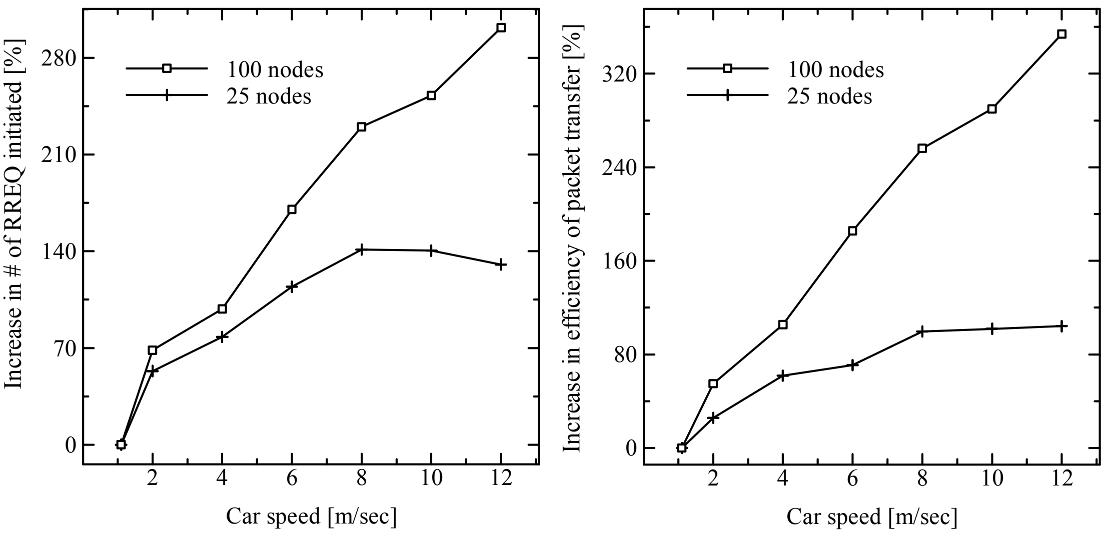
5. Performance evaluation

The simulation model was the same as that described in Table 2. We evaluated AODV with our proposal which consists of only basic (hereafter simply referred to as CRV) , our proposal which consists of basic and enhanced functions (CRV+) and original AODV in terms of route stability, network resource usage rates, and efficiency of packet transfer. Concretely, we verified the number of RREQs initiated to discover a route and packet delivery ratios as the route stability metrics, control overhead as the network resource metric, and control overhead per received packet as the measure of packet transfer efficiency.

5.1. Threshold in simulation model

We executed a preliminary simulation for determining the threshold for activating/deactivating the routing function in our proposal. We assessed different thresholds at fixed car speed, by examining the number of route discovery messages and the efficiency of packet transfer. The other simulation conditions were the same as in Table 2.

Figure 11-(a) shows the relative increase in the number of route discovery messages and Figure 11-(b) shows the relative increase in the efficiency of packet transfer in the condition that 80% of the terminals are cars as compared to the all pedestrian mobile terminal case. We set 4 m/sec as the activation/deactivation threshold, as it provides a reasonable increase in efficiency with a relatively small increase in RREQ number initiated..



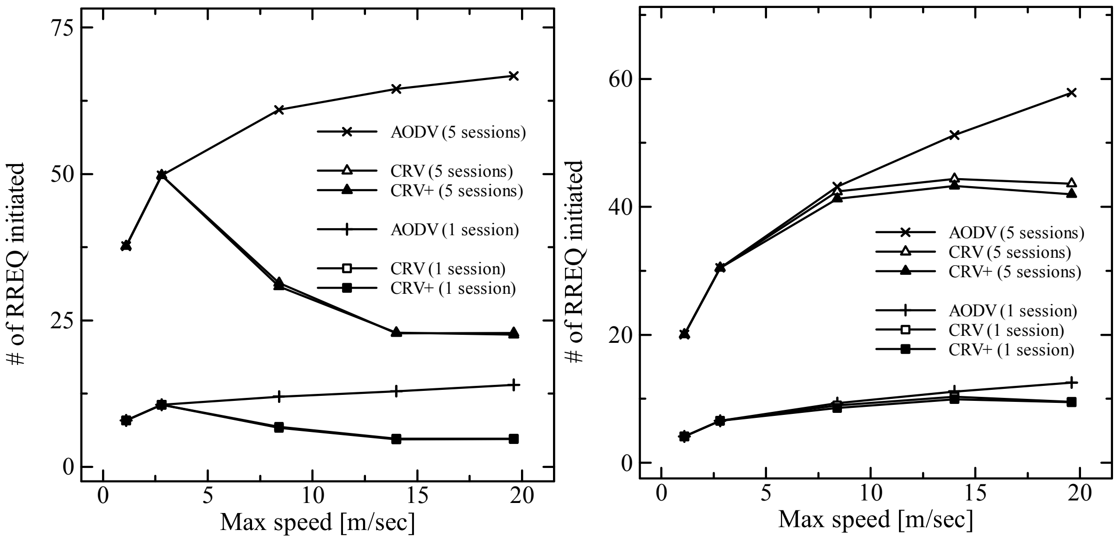
(a) Increase in # of RREQ initiated (b) Increase in efficiency of packet transfer

Figure 11. Evaluation for threshold.

5.2. Impact on route stability

Figure 12 shows the number of RREQs sent for various maximum car speeds. As shown in Figure 12, we confirmed that CRV and CRV+ are effective under all conditions regardless of the number of nodes and sessions. The impact with 25 nodes is significant. The addition of CRV and CRV+ to AODV reduced the number of RREQs, on average, for 25 nodes as follows; 28.0 % on CRV, 29.0 %

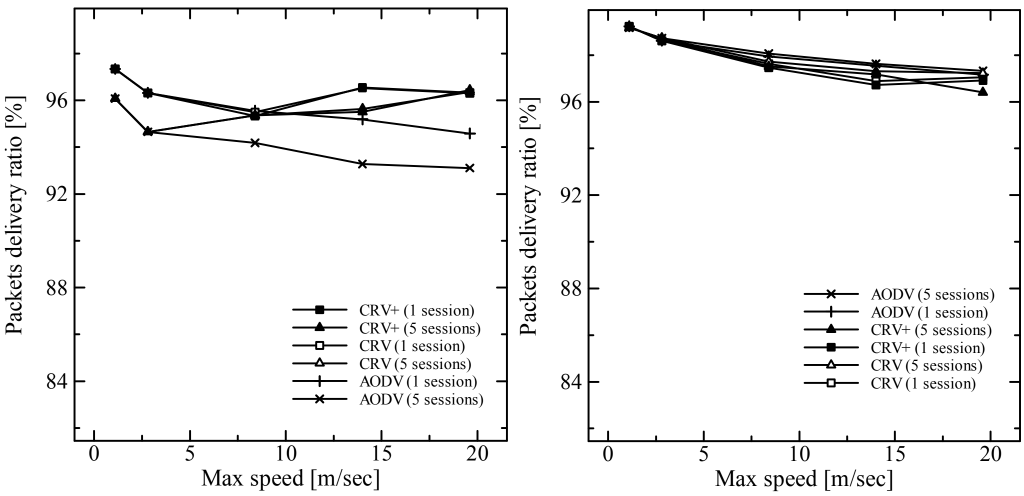
on CRV+. This is because more links were broken at the sparse node density, and more route discovery messages were generated for re-routing. CRV+ is better than CRV because it prevents unnecessary link breakage due to vehicle acceleration. Our proposal with the speed threshold of 4 m/sec yields the same performance as original AODV. This is because CRV+ can select stable routes and greatly reduce the number of route breaks so fewer RREQs are needed.



(a) Case of 25 nodes (b) Case of 100 nodes

Figure 12. Number of RREQs initiated.

Figure 13 shows the packet delivery ratios for various maximum car speeds. As shown in Figure 13, the value of CRV was not so large in this simulation. This is because AODV takes very little time to change routes when a route is broken, so fewer packets are lost. Note that if we utilize routing schemes that take a long time to change routes such as OLSR, CRV would offer higher packet delivery ratios.

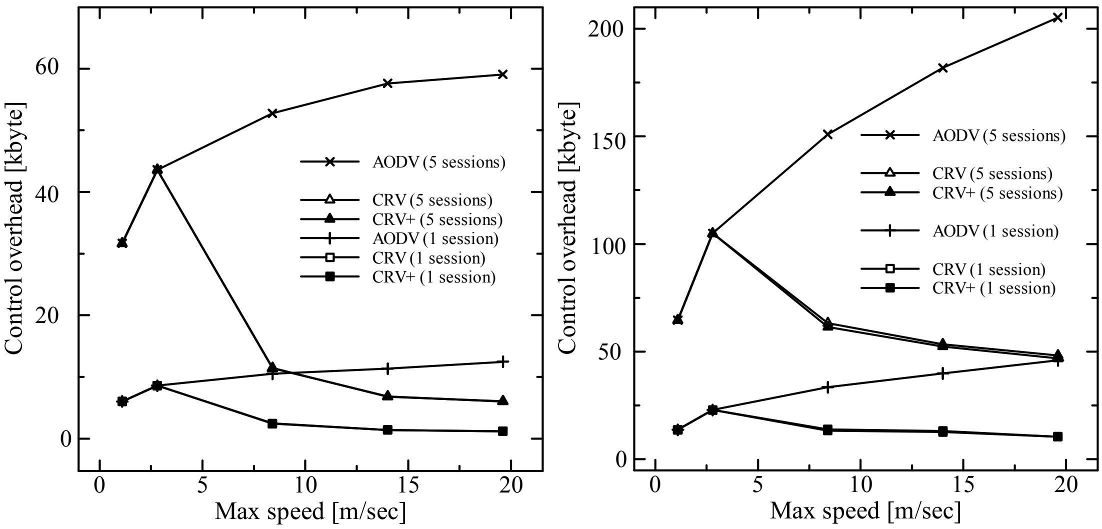


(a) Case of 25 nodes (b) Case of 100 nodes

Figure 13. Packet delivery ratio.

5.3. Impact on network resource usage rates

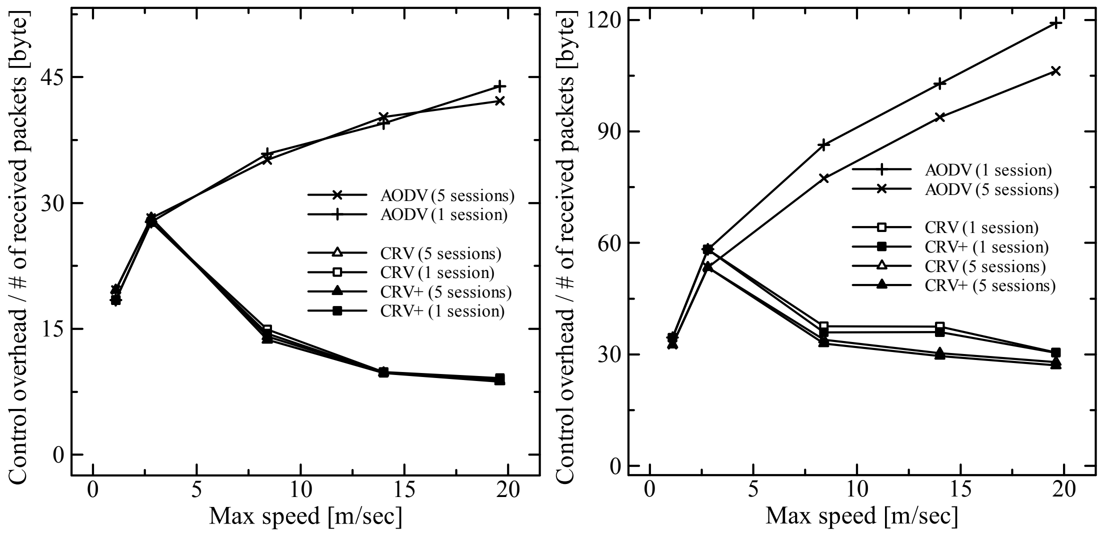
Figure 14 shows the control overheads for various maximum car speeds. As shown in Figure 14, CRV is useful regardless of the number of nodes and sessions. CRV and CRV+ decreased the control overheads on average by 54.4 % on and 54.9 %, respectively.



(a) Case of 25 nodes (b) Case of 100 nodes

Figure 14. Control overhead.

5.4. Impact on packet transfer efficiency



(a) Case of 25 nodes (b) Case of 100 nodes

Figure 15. Efficiency of packet transfer.

Figure 15 shows the efficiency of packet transfer for various maximum car speeds. Although CRV slightly reduced the number of received packets, it decreased the control overhead dramatically as shown in Figure 14. Therefore, the average packet transfer efficiency with CRV is 26. 9 bytes, that with CRV+ is 26.5 bytes, while with original AODV it is 54.8 bytes. This confirms that CRV and CRV+ raise the efficiency of packet transfer and can utilize the limited radio resources more efficiently.

The above results show our proposals, CRV and CRV+, enhance route stability, network resource usage rates, and the efficiency on packet transfer. While related works [10–15] can establish stable routes, they cause heavy overheads such as wasting wireless resources because they exchange velocity information or unusable link information exchange between nodes, and complex calculations are needed to select routes based on the velocity information as described in Section 3.3.

The threshold of routing activation/deactivation, set at 4 m/sec in this simulation, should be set with consideration of node densities and the mobility model. Concretely, in the case of a sparse network or high-speed movement, if the threshold is set too low, the number of nodes running the routing protocol will become so small that no energy-saving routes may be established at all. On the other hand, in the case of a dense network or low-speed movement, if the threshold is set too low the number of nodes running the routing protocol would become so large that network performance would be degraded by more frequent collisions. As described, it is important to optimize the threshold depending on the situation such as node density and the mobility model.

6. Conclusion

This paper has shown that it is reasonable to utilize cars as intermediate nodes in mobile ad hoc networks with the goal of enhancing the battery life of conventional mobile terminals. However, the affect of car speed on network performance must be considered in order to ensure communication quality. This paper evaluated this in terms of route stability and network resource usage rates and showed the drawbacks in related works proposed to alleviate the negative impact of high speed movement, i.e., extra information exchange and complexity of route selection. We then proposed the collaboration in routing and velocity measurement function (CRV) to achieve stable routes without the drawbacks of existing schemes. In the proposal, each node checks its own velocity, and activates or deactivates the routing protocol if its speed falls under or exceeds a speed threshold. Additionally, an enhanced version of our proposal can avoid unnecessary link breaks due to sudden increases in vehicle speed. Simulations showed the effectiveness of CRV; i.e., a 51.3% improvement in packet transfer efficiency on average is possible due to a reduction in the exchange of useless control packets. We will investigate adding a situation-aware threshold to our proposal in future work.

7. References

[1] Association of Radio Industries and Business (ARIB), http://www.arib.or.jp/english/index.html/.

[2] The 3rd Generation Partnership Project (3GPP), http://www.3gpp.org/.

[3] K. Takeno, M. Ichimura, K. Takeno, and J. Yamaki, "Energy Conservation and Management Methods for Mobile Phone Li-Ion Battery Packs," IEICE Transactions on Communications, Vol. E87-B, No. 12, pp. 3430–3436, Dec. 2004.

[4] J. A. Paradiso and T. Starner, "Energy Scavenging for Mobile and Wireless Electronics," IEEE Pervasive Computing, Vol. 4, No. 1, pp. 18–27, Jan. 2005.

[5] K. Scott and N. Bambos, "Routing and Channel Assignment for Low Power Transmission in PCS," Proceedings of IEEE International Conference on Universal Personal Communications (ICUPC 1996), Vol. 2, No. 29, pp. 498–502, Sept. 1996.

[6] S. Singh, M. Woo, and C. S. Ranghavendra, "Power-Aware Routing in Mobile Ad Hoc Networks," Proceedings of ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM 1998), pp. 181–190, Oct. 1998.

[7] C. E. Perkins, E. M. Royer, and S. R. Das, "Ad Hoc On-Demand Distance Vector (AODV) Routing," RFC3561, Oct. 2003.

[8] Scalable Network Technologies, Inc., QualNet Network Simulator, http://www.scalable-networks.com/.

[9] T. Clausen and P. Jacquet, "Optimized Link State Routing Protocol (OLSR)," RFC3626, Oct. 2003.

[10] W. Li, H. Murata, S. Hirose, and S. Yoshida, "Mobile Ad-Hoc Network Routing Protocol Using Velocity Information," Proceedings of International Symposium on Information Theory and Its Applications (SITA 1999), pp. 893–896, Dec. 1999.

[11] M. Yoshida, K. Arai, S. Asami, and T. Miki, "Relative Speed-Based Routing (RSR) for Car Ad-Hoc Networks," IEICE Transaction on Communications, Vol. J88-B, No. 8, pp. 1434–1443, Aug. 2005, (in Japanese).

[12] W. Su and M. Gerla, "IPv6 Flow Handoff in Ad-Hoc Wireless Networks Using Mobility Prediction," Proceedings of IEEE Global Telecommunications Conference (GLOBECOM 1999), pp. 271–275, Dec. 1999.

[13] N. C. Wang and Y. L. Su, "A Power-Aware Multicast Routing Protocol for Mobile Ad Hoc Networks with Mobility Prediction," Proceedings of IEEE Conference on Local Computer Networks, Nov. 2005.

[14] S. Furusho, T. Kitasuka, T. Nakanishi, and A. Fukuda, "Node Mobility Aware Routing for Mobile Ad Hoc Networks," IEICE Transactions on Communications, Vol. E87-B, No. 7, pp. 1926–1930, July 2004.

[15] J. Lebrun, C. N. Chuah, D. Ghosal, and M. Zhang, "Knowledge-Based Opportunistic Forwarding in Vehicular Wireless Ad Hoc Networks," Proceedings of IEEE Vehicular Technology Conference (VTC 2005-Spring), Vol. 4, pp. 2289–2293, May 2005.

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