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# An AODV Compatible Routing Protocol Using Pseudo Control Packets in Ad-hoc Networks

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Recently, there has been an increasing interest in ad-hoc networks, which are dynamically constructed by collections of mobile hosts without using any existing network infrastructure or centralized administration. Each mobile host plays a role of a router and relays packets for multihop network communications. A recent trend in ad-hoc network routing is the reactive on-demand philosophy where routes are established only when required. Most of the protocols in this category, however, show a long latency in route discovery since the cached routing information will be invalidated even if it is still effective. In this paper, we propose a scheme which is compatible to the existing Ad-hoc On-Demand Distance Vector (AODV) protocol and prevents the cached routing information from becoming invalidated without using any extra control message. We also verify the effectiveness of the newly proposed scheme by simulation experiments.

## 1. Introduction

Ad-hoc networking<sup>9)</sup> has emerged as one of the most focused research areas in the field of wireless networking and mobile computing. Ad-hoc networks consist of only mobile hosts and can be constructed without any wired base station or infrastructure support. In ad-hoc networks, routes are mainly multihop because of the limited radio propagation range, and topology may frequently change since each host moves freely. Therefore, routing is an integral part of ad-hoc communications, and has received much interest from researchers. Recently, many new routing protocols have been proposed for ad-hoc networks<sup>3),4),6),8),10),14)~18)</sup>.

Conventional routing protocols developed for traditional wired LANs/WANs may be used for routing in ad-hoc networks by treating each mobile host as a router. Such algorithms broadly come under the category of *proactive* algorithms<sup>3),14),15),17)</sup> since routing information is disseminated among all the nodes in the network throughout the network operating time. Thus, the proactive algorithms provide the routing information instantly when a mobile host needs to send data packets. However, the flip side for such protocols is that the excessive

routing overhead transmitted is periodic in nature and lacks consideration for the network's mobility. Proactive algorithms perform excellently in packet latency, especially when most of the nodes are in low mobility mode, but in high mobility mode these algorithms perform poorly especially in routing overhead.

Recently, a new style of routing proposed for ad-hoc networks called *reactive* or *on-demand* routing<sup>4),6),8),18)</sup> has been gaining wide attention. Unlike conventional proactive routing protocols, each node in the on-demand routing does not need periodic route table update exchanges and does not have a full topological view of the network. Network hosts cache route table entries only to destinations that they communicate with. The Ad-hoc On-demand Distance Vector (AODV) protocol<sup>18),19)</sup> is one of the on-demand routing algorithms that is receiving the most attention recently and has been extensively analyzed<sup>2),5),20)</sup>. One of the biggest advantages of these protocols is that they produce significantly less routing overhead comparing to proactive routing protocols, especially when most of the nodes are in high mobility mode. However, such reactive routing protocols tend to provide a higher packet latency than proactive protocols in low mobility mode because they start attempting to discover a route to the destination only when they finally want to send data packets. Due to the on-demand nature of the protocols, the long delay of end-to-end data transferring can be costly when the network traffic requires real time de-

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livery (voice, for instance). Likewise, if the session is a best effort, TCP connection, long delay may lead to slow start, timeout, and throughput degradation.

If we inspect the real world mobile model, there is hardly the case where all nodes are in high mobility mode or all nodes are in low mobility mode at the same time. In fact, a dynamic mobile model, in which, parts of its mobile nodes are in high mobility mode and parts of its mobile nodes are in low or static mode, is more likely to correctly reflect a real world mobile model. Taking this into consideration, we believe that a dynamic combination of proactive and reactive techniques which apply adaptively to parts of the mobile model, is more likely to perform better than either approach alone.

Instead of proposing an entirely new protocol which is incompatible with any existing protocols, we analyzed the well-known AODV routing protocol and propose to apply proactive techniques to extensively utilize the effective cached routing information with the reactive protocol in order to make it more suitable for real mobile environments. Our proposed protocol is highly AODV compatible in that it tolerates the existence of mobile hosts which only accept AODV in the network. This enables the coexistence of both protocols at the same time and enhances its robustness of deployment compared to other newly proposed protocols which lack the compatibility with AODV. The “compatibility to the existing protocol” concept is a brand new idea that we have proposed in the ad-hoc routing research field. In this paper, we also compare our proposed protocol with the existing AODV protocol by simulation experiments. We show that, compared to AODV, our proposed protocol performs better in packet latencies and is highly compatible to AODV. Both proactive and on-demand techniques are applied dynamically to improve the use of cached routing information extensively.

The rest of the paper is organized as follows. Section 2 describes the AODV protocol. Section 3 describes our proposed protocol. Section 4 provides performance evaluations of the proposed protocol. Section 5 compares our proposed protocol with related works. Section 6 concludes the paper.

## 2. AODV Protocol

In this section, we give an overview of the

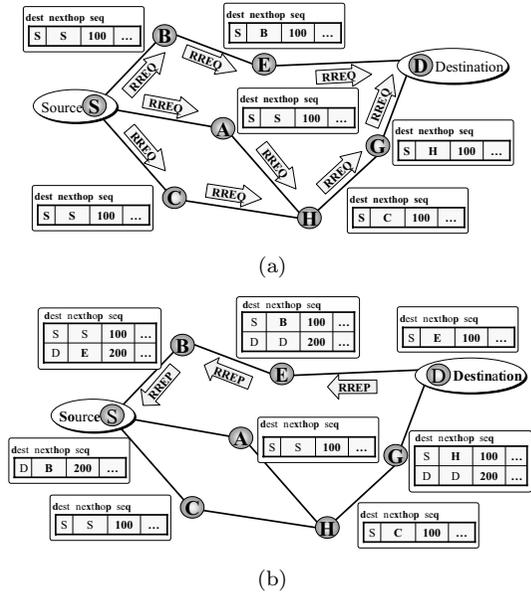


Fig. 1 AODV protocol.

well-known on-demand AODV scheme.

When a source needs to initiate a data session to a destination but does not have any cached route information, it searches a route by flooding a route-request (RREQ) packet. To prevent unnecessary broadcasts of RREQs, the source node uses the *expanding ring search* technique as an optimization. In the expanding ring search, increasingly larger neighborhoods are searched to find the destination. The search is controlled by the time-to-live (TTL) field in the IP header of the RREQ packets. Each RREQ packet has a unique identifier so that nodes can detect and drop duplicate packets. An intermediate node, upon receiving a non-duplicate RREQ, records the previous hop and the source node information (source sequence number) in its routing table. Then it rebroadcasts the RREQ packet. **Figure 1** (a) illustrates the propagation of RREQs across the network from source node S to destination node D and the cached routing table of the corresponding node upon receiving the RREQ packet.

An intermediate node sends back a route-reply (RREP) packet to the source if it has cached route information to the destination in its routing table. Otherwise, the destination node sends a RREP via the selected route when it receives the first RREQ or subsequent RREQs that traversed a better route (for instance, a fresher or shorter route) than the pre-

viously replied route. An intermediate node, upon receiving a non-duplicate RREP, records the previous hop and the destination node information (destination sequence number) in its route table. Then it unicasts the RREP packet to the next hop node leading back towards the source. Figure 1(b) illustrates the unicasting of RREPs from destination node D to source node S. When RREP reaches source node S, the route to destination node D is discovered and data packets from source S will be routed along the route (S-B-E-D).

Every routing table entry maintains a route expiration time which indicates the time until which the route is valid. Each time that route is used to forward a data packet, its expiration time is updated to be the current time plus the *active\_route\_timeout*. A routing table entry is invalidated if it is not used by the expiration time. AODV uses an active neighbor node list for each routing entry to keep track of the neighbors that are using the entry to route data packets. These nodes are notified with route-error (RERR) packets when the link to the next hop node is broken. Each such neighbor node, in turn, forwards the RERR to its own list of active neighbors, thus invalidating all the routes using the broken link.

### 3. AODV-SB Protocol Concept

In this section, we present the operation details of our proposed scheme. We name our proposed scheme the *AODV Compatible Stability Based Routing Protocol* (AODV-SB). Since the purpose of our study is to construct a protocol compatible to the existing AODV protocol, our protocol description is based on AODV. Our scheme does not require any modification to the AODV's route discovery and route maintenance mechanisms.

#### 3.1 Link Stability

In this subsection, we introduce the new idea of link stability and utilize this link stability in the AODV protocol. In ad-hoc networks, two mobile hosts can be connected directly to each other by a radio link. This link is disconnected when they move further away from each other, thus making the distance between them longer than the possible communication range. In AODV, a node offers connectivity information by broadcasting local Hello messages. By inspecting the pattern of arriving Hello messages between two connected neighboring mobile hosts, the stability of the link can be es-

timated. Here, we propose a few functions to decide the stability of a link between two nodes. Using current time as  $t$ , we define  $A_{ij}(t)$  as a function that represents at least a Hello message from mobile host  $M_j$  reaches mobile host  $M_i$  within the last  $(t - T)$  period of time.  $T$  represents the Hello message period.

$$A_{ij}(t) = \begin{cases} 1 : & \text{Hello message(s) arrive(s)} \\ & \text{within } (t - T) \\ 0 : & \text{Otherwise} \end{cases} \tag{1}$$

Then,  $B_{ij}^n(t)$  is defined as a function that represents the total number of Hello messages arrived within  $(t - nT)$  period of time. The value  $n$  is a predecided value where it indicates the number of allowed losses of Hello message. This is essential because the Hello message may get lost in radio transmission or fail to arrive in time due to collision or contention problems.

$$B_{ij}^n(t) = \sum_{k=0}^{n-1} A_{ij}(t - kT) \tag{2}$$

The link connection state of two mobile hosts  $M_i$  and  $M_j$  is represented as  $C_{ij}^n(t)$ .  $C_{ij}^n(t)$  is calculated by using  $A_{ij}(t)$  and  $B_{ij}^n(t)$  as follows:

$$C_{ij}^n(t) = \begin{cases} C_{ij}^n(t - T) + 1 & : B_{ij}^n(t) > 0, \\ & A_{ij}(t) = 1 \\ C_{ij}^n(t - T) & : B_{ij}^n(t) > 0, \\ & A_{ij}(t) = 0 \\ 0 & : B_{ij}^n(t) = 0 \end{cases} \tag{3}$$

If the Hello messages from mobile host  $M_j$  arrives continuously,  $A_{ij}(t)$  will equal to 1 and  $B_{ij}^n(t)$  will have a non-zero positive value, thus  $C_{ij}^n(t)$  will increase continuously too. If the Hello message fails to arrive within  $(t - T)$  but there is at least one Hello message that arrives within  $(t - nT)$ , then  $C_{ij}^n(t)$  will be sustained as  $C_{ij}^n(t - T)$ . If no Hello message arrives within  $(t - nT)$ ,  $C_{ij}^n(t)$  will be set to the value zero.

The value of  $C_{ij}^n(t)$  indicates the continuous arrival of Hello messages which infer how frequently mobile hosts  $M_i$  and  $M_j$  are connected to each other by a radio link. We infer that a radio link with a larger  $C_{ij}^n(t)$  is more stable than one with a smaller  $C_{ij}^n(t)$ . If  $C_{ij}^n(t)$  increases above a threshold value  $S_{th}$ , then the link between mobile hosts  $M_i$  and  $M_j$  is regarded as a *stable link*. The total number of stable links that mobile host  $M_i$  has at time  $t$ , is calculated as  $L_i(t)$ . A mobile host with  $L_i(t)$  larger than a threshold value  $K_{th}$  is considered to be a *stable*

node.

Using the concept of these stability functions, we can evaluate the stability of radio links among mobile hosts. By propagating the effective stable link information only among the stable hosts, we may construct *temporal perennial links* adaptively over the static and the low mobility part of the ad-hoc networks. The constructed temporal perennial links will improve the performance of conventional on-demand routing protocol by fully utilizing its cached routing information. At the same time, by ignoring the unstable radio links, unnecessary traffic to propagate the unsustainable routing information is eliminated.

### 3.2 Temporal Perennial Link Construction

In our AODV-SB scheme, we propose two strategies to construct temporal perennial links without introducing any new control message type. We modify the AODV protocol to achieve our goals.

#### 3.2.1 Strategy 1: AODV-SB-RREQ

The first strategy is the AODV-SB-RREQ strategy. We utilize the AODV's RREQ packet to propagate the effective cached routing information among nodes with stable links. The AODV-SB-RREQ strategy consists of three steps.

- (1) Calculating the link stability
- (2) Generating the *pseudo-route-request* (PRREQ) packet
- (3) Forwarding the *pseudo-route-request* (PRREQ) packet

At the first step, a mobile host calculates the link stability of its neighbors by using the functions that we described in the previous subsection.

After that, we go to the second step where mobile host  $M_i$  with  $L_i(t) \geq K_{th}$  constructs the temporal perennial link every *propagate\_check\_interval* period of time. In order to achieve the goal of compatibility to the existing protocol, we introduce a new concept in the on-demand routing research field. We name the concept as the "pseudo-control-packet concept". This is a concept where we modify the existing control packet and disseminate the modified "fake control packet" into the network. Mobile hosts which only accept the existing protocol, will be "deceived" by the fake control packet and process the packet as if it is a real AODV control packet. In order to accomplish the goal mentioned above, we have made

some modifications as described below into the AODV's RREQ packet to make the fake control packet looks real to mobile hosts which only accept AODV packet. We name the modified RREQ packet as the *pseudo-route-request* (PRREQ) packet.

- *Indication Flag*: In order to distinguish between the real RREQ and the fake RREQ, that is PRREQ packet, we need to insert an *indication flag* into the modified RREQ packet where the normal AODV mobile hosts will not notice the indication flag. Since the 13 bit Reserved field in RREQ is always ignored on reception by the AODV mobile hosts, we use 1 bit in this field as an *indication flag* of the fake RREQ packet. In this way, only mobile hosts which install our protocol will look for the indication flag and distinguish between the fake and the real RREQ packet.
- *Fictitious\_ip\_address*: RREQ is originally a packet designed to discover the destination node by constructing reverse paths towards the source node so that the destination node or the intermediate node with valid route information will be able to send back the RREP packet along the reverse paths and setup the forward path toward the destination node. Since the purpose of the fake RREQ is to construct temporal perennial link towards the stable node, we need to find a way to activate the reverse path construction mechanism and at the same time to suppress the forward path setup mechanism. To achieve this goal, we allocate a *fictitious\_ip\_address* into the Destination IP Address field and fill the stable node's IP address into the Source IP Address field in RREQ. The *fictitious\_ip\_address* is a made-up IP address that will reach no mobile host in the whole network. This avoids any generation of unnecessary RREP packet to the PRREQ packet. In this way, normal AODV nodes are deceived by the fake RREQ packet and construct only the reverse path towards the stable node after receiving the PRREQ packet which is actually requesting for an unattainable route.
- *Fictitious\_sequence\_no*: Since the *fictitious\_ip\_address* will reach no host in the mobile network, the sequence number related to the address will not be copied into any mobile host's cached routing table. In AODV, the Destination Sequence Number

field of RREQ is filled with the last sequence number received in the past by the source for any route towards the destination. Thus, a make-up sequence number, *fictitious\_sequence\_no* is used to fill up this field.

- *Aodv-sb-rreq-ttl*: Due to the reason that the PRREQ packet is not to search for a real destination node, it does not have to follow the expanding ring search technique in deciding the range of the packet propagation. In AODV, the TTL field in the RREQ’s IP header is always filled with the value following the expanding ring search mechanism where it is 1 initially, and increases gradually. However, in the PRREQ packet, we set the TTL field in the PRREQ’s IP header to the *aodv-sb-rreq-ttl* value. When this *aodv-sb-rreq-ttl* value is larger than 1, then the PRREQ packet will be allowed to be propagated and penetrate its route information a few hops away from the last stable node.

The third step is to forward PRREQ packets. When a mobile host  $M_i$  receives a PRREQ packet, it first checks whether it has received a PRREQ packet with the same source IP address and broadcast ID. If such a packet has been received, the node silently discards the newly received packet.

If the received PRREQ packet is not discarded, and  $L_i(t) \geq K_{th}$ , then the mobile host performs the following procedures:

- Processing the PRREQ packet: Mobile hosts process the PRREQ packet by following the normal AODV procedure. Source sequence number from PRREQ is copied to the corresponding destination sequence number and the next hop in the cached routing table becomes the node that have broadcasted the PRREQ packet.
- Rebroadcasting the PRREQ packet: In AODV, the TTL field in the outgoing IP header is always decreased by one. Since we intend to penetrate the stable node routing information a few hops away from the last stable node, the TTL field is frozen at the *aodv-sb-rreq-ttl* value, before it is rebroadcasted to its neighboring nodes. Then, the PRREQ packet is rebroadcasted from the mobile host using its own IP address in the outgoing PRREQ packet.

On the other hand, if the mobile host  $M_i$  has  $L_i(t) < K_{th}$ , then it rebroadcasts the PRREQ

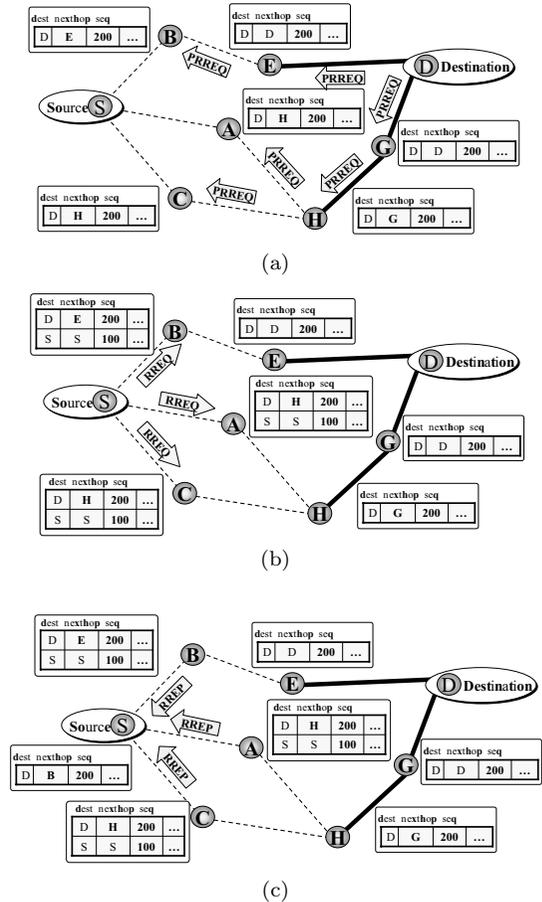


Fig. 2 AODV-SB-RREQ strategy.

packet following the AODV procedure until its TTL value becomes zero.

Figure 2 is an example showing how AODV-SB-RREQ will improve the delay of route discovery. As shown in Fig. 2 (a), temporal perennial links are constructed over the stable links (E-D, D-G, G-H) by using the PRREQ packets. Since PRREQ can penetrate its routing information a few hops from last stable node, routing information is disseminated until reaching nodes A, B and C. Figure 2 (b) illustrates that source node S initiates a route discovery mechanism towards destination node D by broadcasting the RREQ packets. Since intermediate nodes A, B and C have valid cached routing information, they respond to the RREQ packets by generating RREP packets as shown in Fig. 2 (c). A route to the destination node D is discovered instantly and the data packet will be routed along the route (S-B-E-D).

### 3.2.2 Strategy 2: AODV-SB-RREP

The second strategy is the AODV-SB-RREP

strategy. Since the RREP packet is originally a unicast packet which has features differing from the multicast RREQ packet, the modification will be slightly different. The AODV-SB-RREP strategy consists of three steps.

- (1) Calculating the link stability
- (2) Generating the *pseudo-route-reply* (PRREP) packet
- (3) Forwarding the *pseudo-route-reply* (PRREP) packet

In the first step, the total number of stable links for a mobile host  $M_i$  will be calculated as  $L_i(t)$ . Then, the stable host will generate the PRREP packet in the second step. Mobile host  $M_i$  with  $L_i(t) \geq K_{th}$  generates a modified RREP packet every *propagate\_check\_interval* period of time without the arrival of a RREQ packet. We call the modified RREP packet as the *pseudo-route-reply* (PRREP) packet. The PRREP packet is a fake RREP packet with the modifications as described below.

- *Indication Flag*: In order to distinguish between the real RREP and the fake RREP, that is PRREP packet, we need to insert an *indication flag* into the modified RREP packet where the normal AODV mobile hosts will not notice the indication flag. Since the 9 bit Reserved field in RREP is always ignored on reception by the AODV mobile hosts, we use 1 bit in this field as an *indication flag* of the fake RREP packet. In this way, only mobile hosts which install our protocol will look for the indication flag and distinguish between the fake and the real RREP packet.
- *Fictitious\_ip\_address*: The purpose of the PRREP packet is not to answer any RREQ packet, but to activate the cached information towards the destination node. In AODV, the Source IP Address field in RREP is filled with the IP address of the source node which issued the RREQ for which the route is supplied. To achieve our goal, we use the *fictitious\_ip\_address* in the Source IP Address field instead. This prevents the PRREP packet from terminating at a certain mobile host in the network.
- *Aodv-sb-rrep-lifetime*: Since the attribute of the PRREP packet is to construct the temporal perennial links, we set the Lifetime field of RREP to the *aodv-sb-rrep-lifetime* value. In conventional AODV, the Lifetime field of RREP is copied from the mobile host's default *my\_route\_timeout*

value, to indicate the time for which nodes receiving the RREP consider the route to be valid.

The third step is to forward PRREP packets. When a mobile host  $M_i$  receives a non-duplicate PRREP packet, and it has  $L_i(t) \geq K_{th}$ , then it performs the following procedures:

- Processing the PRREP Packet: The mobile host first compares the destination sequence number in the received PRREP packet with its own copy of the destination sequence number for the destination IP address. The forward route for this destination is created or updated if the destination sequence numbers is greater than the node's copy of the destination sequence number. The next hop to be copied in the routing table is the IP address of the node from which the PRREP is received.
- Rebroadcasting the PRREP Packet: The TTL field will be fixed at the *aodv-sb-rrep-ttl* value. The PRREP packet is rebroadcasted to its neighboring nodes using its own IP address in the outgoing PRREP packet.

On the other hand, if  $L_i(t)$  is less than  $K_{th}$ , then it stops from rebroadcasting the PRREP packet.

**Figure 3** is an example showing how AODV-SB-RREP will improve the delay of route discovery. As shown in Fig. 3 (a), temporal perennial links are constructed over the stable links (E-D, D-G, G-H) by using the PRREP packets. Since AODV-SB-RREP is a conservative strategy, it always refrains from disseminating its routing information beyond the stable nodes. Routing information is disseminated only until reaching nodes E and H. Figure 3 (b) illustrates that source node S initiates a route discovery mechanism towards the destination node D by broadcasting the RREQ packets. Since intermediate nodes E and H have valid cached routing information, they respond to the RREQ packets by generating RREP packets as shown in Fig. 3 (c). A route to the destination node D is discovered instantly and the data packet will be routed along the route (S-B-E-D).

#### 4. Performance Evaluation

To evaluate the performance improvements made by our proposed scheme, we compared the simulation results of the AODV protocol with and without applying our protocol.

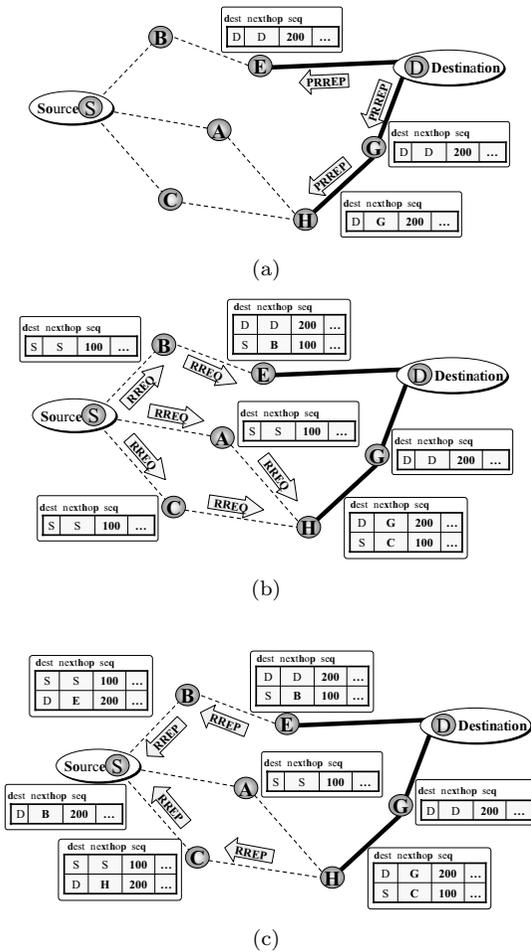


Fig. 3 AODV-SB-RREP strategy.

4.1 Simulation

Our simulation models an ad-hoc network of 50 mobile hosts placed randomly within a 100 meters  $\times$  100 meters area. Currently, there are two leading candidates for the MAC layer role: the IEEE 802.11 MAC protocol and the Bluetooth MAC protocol. We do not limit our proposed network layer protocol to fix into either one of the MAC layer protocols. For simplicity, we use the IEEE 802.11 Distributed Coordinate Function (DCF) as the medium access control protocol in our simulation experiments. The specific access scheme is Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) with acknowledgments. Since it is impossible to simulate all application models for an ad-hoc network, we have focused on a key application of ad-hoc networks—namely, the interconnection of mobile users in an indoor ad-hoc network. At the same time, it is commonly

known that indoor radio signals seldom reach as far as 150 meters due to the fact that radio signals are blocked out by indoor building structures. Thus, we choose a smaller value for the radio propagation range because we believe that this is a more conservative value for a real indoor Wireless LAN radio range. On the other hand, since Bluetooth is becoming popular and it may become the major MAC layer protocol for indoor and outdoor appliances in near future, we believe that setting the radio range of 8 meters is also satisfactory even if Bluetooth is implemented as the MAC layer protocol. Each run has an execution simulation time of 900 seconds after a 100-second warmup time. These parameters could represent, for example, a group of indoor mobile hosts using short-range transceivers in offices or conference rooms.

To simulate constant bit rate sources, we have developed a traffic generator, where 10 traffic sources are maintained throughout simulation runtime. The source-destination pairs are reselected randomly each time they finish transferring data packets. The traffic rate is four packets per second. The size of the data payload is 512 bytes. The value of  $T$ , which represents the Hello message period, takes the AODV Hello interval default value of 1 second.

As for the mobility model, we apply the random waypoint mobility model<sup>2)</sup>. Each node randomly selects a position, and moves toward that location with a randomly chosen speed uniformly distributed between 0 and 5 m/seconds (somewhere between a slow walk and a quick stroll). Once it reaches that position, it becomes stationary for a predefined pause time. After that pause time, it selects another position and repeats the process. We vary the pause time to simulate different mobility degrees. We assume that the local link connectivity is detected by using a MAC layer beacon message. Mobile hosts in the network maintain their link connectivity by observing the arrival of MAC layer beacon messages. If it receives no message for more than  $n$  (allowed Hello loss)  $\times$   $T$  (Hello interval) seconds, then the node will assume that the link to this neighbor is currently broken. Each result point in the graph represents an average of at least 20 runs with identical traffic models, but different randomly generated mobility scenarios.

A send buffer of 64 packets is maintained throughout simulation runtime. A node buffers

**Table 1** Parameter configuration.

Parameter	Value
$n$ (allowed Hello loss)	2
$S_{th}$ (stable link threshold)	4
$K_{th}$ (stable node threshold)	1
$aodv-sb-rreq-ttl$	3
$aodv-sb-rrep-lifetime$	3 (seconds)

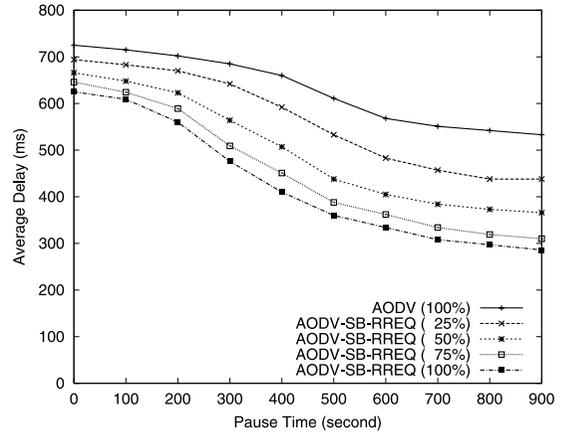
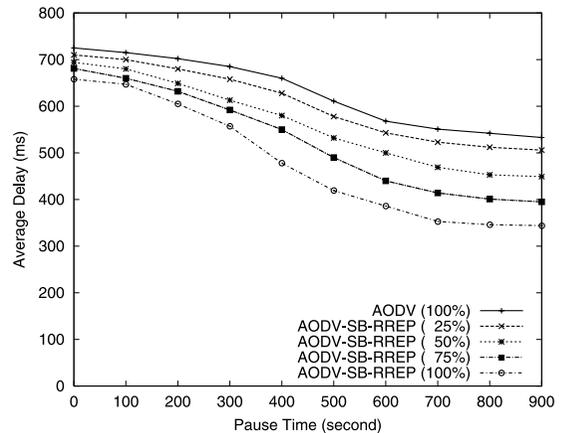
all data packets waiting for a route, e.g., packets for which route discovery has started, but no reply has arrived yet. To prevent buffering of packets indefinitely, packets are dropped if they wait in the send buffer for more than 30 seconds. The interface queue is FIFO, with a maximum size of 64. Data packets are given higher priority than routing packets in the interface queue.

In order to show the significant differences of features in AODV-SB-RREQ and AODV-SB-RREP, we constructed the parameter configuration as shown in **Table 1**. The *propagate-check-interval* value for AODV-SB-RREQ is 5 seconds and 10 seconds for AODV-SB-RREP.

#### 4.2 Results

**Figures 4** and **5** show the average end-to-end delay of data packets for AODV, AODV-SB-RREQ and AODV-SB-RREP. The end-to-end delay of data packets is the time it takes for a data packet to reach its destination from the time it is generated at the source until it is sent to the destination. This includes all the processing delays, route discovery delays, queuing at the interface queue, propagation and transfer times. The average end-to-end delay of data packets in the experiment is calculated by adding all of the end-to-end delay of data packets transferred successfully to their destinations and dividing this value with the total number of data packets transferred successfully. Here, data packets which fail to reach their destination, (after 2 route discovery tries are executed), are not included in the calculation. *AODV (100%)* indicates that all of the mobile hosts in the network are using the AODV protocol. Whereas, *AODV-SB-RREQ/RREP (x%)* specifies that  $x\%$  of the mobile hosts in the network are using the AODV-SB-RREQ/RREP scheme and  $(100 - x)\%$  of the the mobile hosts are using the AODV scheme.

We can see that both of our strategies decrease the average end-to-end delay of data packets compared to AODV's delay. As mobility decreases (i.e., pause time gets longer), performance gains becomes more significant.

**Fig. 4** AODV-SB-RREQ end-to-end delay.**Fig. 5** AODV-SB-RREP end-to-end delay.

Also, AODV-SB-RREQ (100%) yields less average packet latencies, ranging from 14% to 46% less, compared to AODV (100%) as mobility decreases. On the other hand, AODV-SB-RREP (100%) produces less average packet latencies, ranging from 9% to 35% less, compared to AODV (100%) as mobility decreases. The reason is that in a low mobility model, more stable links are available in the network to be constructed as temporal perennial links. Thus, the existence of temporal perennial links speeds up the route discovery process. Also, in the presence of route breaks, the AODV-SB protocol is able to deliver data packets to its destination faster than AODV since the local repair mechanism can be carried out swiftly.

Since AODV-SB is highly AODV compatible, this scheme will still work even if mobile hosts which only allow AODV exist in the network. We investigate the effect where mobile hosts

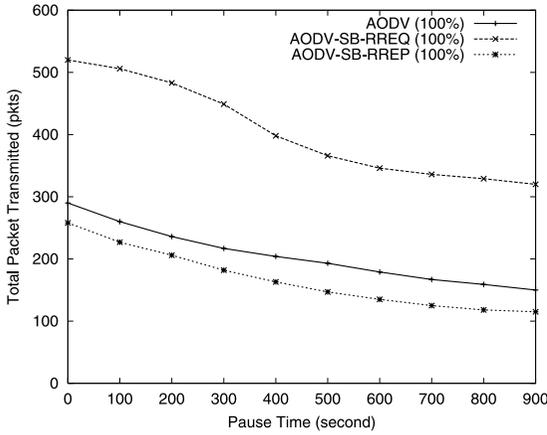


Fig. 6 Total RREQ packet transmitted.

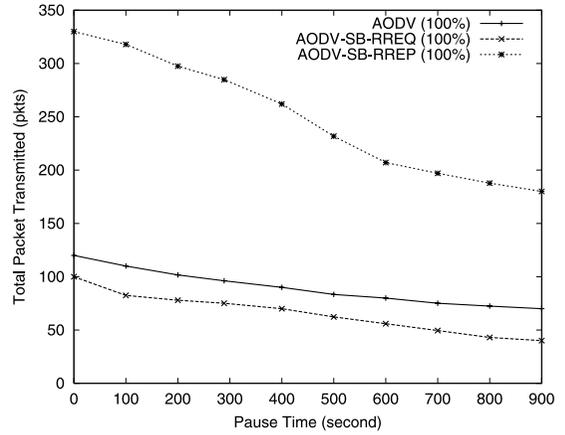


Fig. 7 Total RREP packet transmitted.

with AODV and mobile hosts with AODV-SB are mixed in the network. As we can observe from Figure 4 and 5, both strategies produce significantly less average end-to-end delay as the percentage of nodes with AODV-SB increases from 25% to 75% in the network. The existence of more AODV-SB nodes in the network enables the construction of temporal perennial links to be carried out more efficiently.

Nevertheless, AODV-SB-RREP (25%) only decreases the average end-to-end delay from 2% to 5% compared to AODV (100%). On the other hand, AODV-SB-RREQ (25%) decreases the average end-to-end delay significantly from 4% to 18%. This shows one of the differences between AODV-SB-RREQ and AODV-SB-RREP. AODV-SB-RREQ allows the propagation and penetration of PRREQ packet information a few hops away from the last stable host whereas AODV-SB-RREP cannot do this since the RREP packet is originally a unicast packet. Thus, we can infer that AODV-SB-RREQ, as an aggressive strategy, performs better when there is a high percentage of AODV nodes in the network. On the other hand, AODV-SB-RREP, as a conservative strategy, performs better where there is a low percentage of AODV nodes in the network.

Average total numbers of RREQ, RREP, and RERR packets transmitted per route in the network are presented in Figures 6, 7 and 8, respectively. Each hop-wise transmission of a routing packet is counted as one transmission. The PRREQ transmission is counted as one RREQ transmission and the PRREP transmission is counted as one RREP trans-

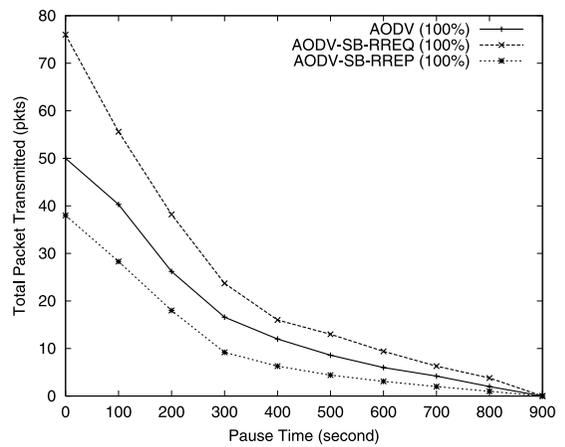


Fig. 8 Total RERR packet transmitted.

mission. As expected, AODV-SB-RREQ transmits more RREQ control packets compared to AODV as shown in Figure 6. However, interestingly enough, AODV-SB-RREQ reduces the transmission of RREP throughout the network as shown in Figure 7. Likewise, AODV-SB-RREP transmits more RREP control packets and less RREQ control packets compared to AODV. The reason is that the construction of temporal perennial links shortens the hop distance for a mobile host to discover its destination host. From Figure 8, AODV-SB-RREQ generates more RERR packets than AODV because of its aggressive features in propagating routing information. Whereas, AODV-SB-RREP generates the least RERR packets since it is conservative in route information propagation.

Figure 9 gives the average total number of RREQ, RREP and RERR packets transmitted

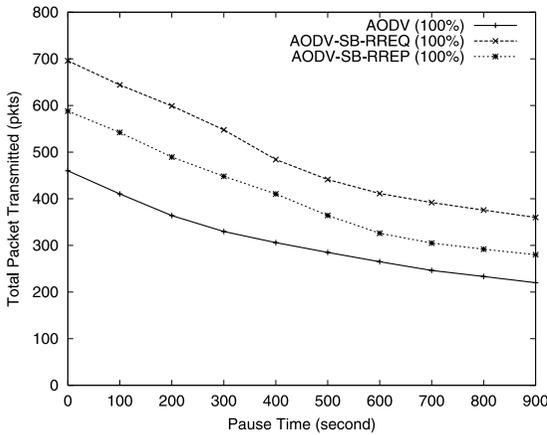


Fig. 9 Total routing packet transmitted.

per route. AODV-SB-RREQ transmits 51% to 66% more routing packets than AODV. We can learn from this result that we need to sacrifice some routing overhead in order to improve data packet latency and protocol effectiveness. Whereas, AODV-SB-RREP produces about 23% to 36% more routing packets compared to AODV. The reason for this reduction of total routing packets in AODV-SB-RREP is that we may reduce the dissemination of PRREP by taking a larger value for the propagation and timeout period of the temporal perennial links. We may infer from these results that, compared to AODV, AODV-SB provides significantly lower latencies while producing a moderate increase in control packets.

## 5. Comparison with Related Works

Several research groups have proposed various clustering protocols for ad-hoc networks so far<sup>1),3),11)~13)</sup>. The clustering protocols differ from other protocols in the type of addressing and network organization scheme employed. The main idea in conventional clustering protocols is that, by having a cluster head or an upper level node controlling a group of mobile hosts, a framework for code separation (among clusters), channel access, routing, and bandwidth allocation can be achieved. To achieve this goal, a cluster head selection algorithm is utilized to elect a node as the cluster head using a distributed algorithm within the cluster.

However, the existing conventional clustering protocols require periodic refreshing of neighborhood information and tend to introduce quite a large amount of communication maintenance overhead. Therefore, the passive

clustering protocol was proposed to improve the efficiency of conventional clustering protocols<sup>7),21)</sup>. The main idea of the passive clustering scheme is to bring down the communication maintenance overhead while managing clusters in ad-hoc network.

Compared to the conventional clustering protocols and the passive clustering protocol, our proposed protocol contrives the routing scheme on a very different point of view although all of them try to manage the routing information of mobile hosts in groups.

Firstly, conventional clustering protocols and the passive clustering protocol are cluster-formation protocols. Whereas, our proposed protocol is a cluster-free protocol. We agree that by forming clusters in networks, we may reduce the redundant rebroadcast effect in flooding and enhance the scalability of the routing protocol. However, the disadvantage of having a clustering scheme is that frequent cluster head changes can adversely affect routing protocol performance since nodes are busy doing cluster head selection rather than packet relaying<sup>20)</sup>. On the other hand, with our proposed protocol, no cluster head is needed and the cluster head selection mechanism, which has a heavy control packet cost, is eliminated. Each stable node in our proposed protocol manages its own routing information by propagating their own routing information in the periphery stable nodes.

Secondly, compared to the passive clustering protocol, our proposed protocol has different goals in improving ad-hoc network routing efficiency. The passive clustering protocol tries to improve the existing clustering schemes by bringing down communication maintenance overhead. Whereas, our proposed protocol tries to improve the existing on-demand schemes by shortening the packet latency in ad-hoc networks. So far, many research groups have focused their works in reducing the communication maintenance overhead in ad-hoc networks and we agree that it is an important issue in ad-hoc networking. However, we believe that the long delay of end-to-end data transferring in on-demand routing protocols is also an indispensable issue that should not be overlooked. The long delay of end-to-end data transferring can be very costly in ad-hoc networks when the network traffic requires real time multimedia delivery.

Thirdly, although the passive clustering protocol modifies AODV protocol to fulfill its goal

of constructing clusters in the network, it is not compatible to AODV. In the case where there is a mixture of the normal AODV mobile hosts and the passive clustering mobile hosts in the network, the Cluster Head Election operation and the Gateway Selection operation, which are crucial in passive clustering protocol, may not be well functioned since they follow the First Declaration Wins (FDW) rule. Besides, the cluster convergence operation may not be carried out successfully if some of the mobile hosts in the network do not comprehend the passive clustering rules. On the other hand, we have carefully designed our proposed protocol with consideration of AODV compatibility in order to enable the coexistence of both protocols at the same time. So far, many researchers have proposed various new protocols for ad-hoc network. However, our study is the first work which raises the "compatibility to the existing protocol" issue in the ad-hoc network routing research.

## 6. Conclusions

In this paper, we have proposed a new routing protocol, AODV-SB which combines the proactive and reactive techniques dynamically in order to improve the use of cached routing information extensively. The proactive technique is applied into parts of the network where mobility is relatively low and reactive technique is applied into the network where mobility is relatively high. By propagating the effective stable link information only among the stable hosts, we construct temporal perennial links adaptively over the static and the low mobility part of the networks. By ignoring the unstable radio links, unnecessary traffic to propagate the unsustainable routing information is eliminated.

We have also proposed the new compatibility concept which enhances the robustness of deployment and tolerates the existence of mobile nodes which only accept the existing AODV protocol. In order to realize AODV compatibility, we introduced the pseudo-control-packet idea. AODV-SB-RREQ is an aggressive strategy that performs impressively in existing networks with a high percentage of AODV nodes by producing a lower packet latency. Whereas AODV-SB-RREP is a conservative strategy that performs better in existing networks with a low percentage of AODV nodes by giving a lower routing overhead. Simulation re-

sults indicate that AODV-SB outperforms the on-demand AODV protocol in packet latency while maintaining a moderate increase of control packet.

As part of our future work, we are considering other methods to reduce the routing overhead while maintaining low packet latency. We are also planning to implement and evaluate our proposed method in a practical platform.

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