AHBP: An Efficient Broadcast Protocol for Mobile Ad Hoc Networks

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Abstract Broadcast is an important operation in many network protocols. It is utilized to discover routes to unknown nodes in mobile ad hoc networks (MANETs) and is the key factor in scaling on-demand routing protocols to large networks. This paper presents the Ad Hoc Broadcast Protocol (AHBP) and its performance is discussed. In the protocol, messages are only rebroadcast by broadcast relay gateways that constitute a connected dominating set of the network. AHBP can efficiently reduce the redundant messages which make flooding-like protocols perform badly in large dense networks. Simulations are conducted to determine the performance characteristics of the protocol. The simulation results have shown excellent reduction of broadcast redundancy with AHBP. It also contributes to a reduced level of broadcast collision and congestion.

Keywords protocol, wireless, broadcast, mobile ad hoc network, connected dominating set

1 Introduction

Broadcast is a common operation in many network protocols and applications. By broadcast, a message is propagated to all nodes in a network. It is useful in delivering messages to users with unknown locations or a group of users whom the source need not know exactly. Broadcast plays an important role in routing, network management and other tasks in mobile ad hoc networks (MANETs). An MANET is a wireless network that is self-organized with many mobile nodes. No static infrastructure such as a wired backbone is available. Due to the limited transmission range of wireless network interface, nodes are required to forward messages for those located outside their radio coverage, thereby forming a multi-hop network. All nodes are free to move around and the network topology may change frequently. Possible applications of MANETs include emergency rescue after a hurricane or earthquake, communication between mobile robots, exchanging information on the battlefield, and so on. The Internet Engineering Task Force (IETF) has established a working group called "manet"[1] to study the network issues in MANETs.

Broadcast is expected to be performed frequently in MANETs. Many on-demand (or reactive) ad hoc routing protocols (e.g., DSR[2], AODV[3], ODMRP[4]) rely on broadcast to discover a route between two nodes or to update group status and multicast routes. Broadcast is also a viable candidate for reliable multicast in MANETs with rapid changing topology[5].

In a broadcast protocol, a node can play one of two roles: receiver or rebroadcasting node. A receiver is just a sink of broadcast traffic, while a rebroadcasting node rebroadcasts the messages it receives. Different protocols use different algorithms to determine the role

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of a node in broadcast. Current approaches for broadcasting in MANETs can be divided into three categories:

- Flooding and its variations, including the location-aided schemes[6,7].
- Cluster-based or dominating set-based schemes[6,8,9].
- Connected dominating set-based schemes[10–12].

Flooding is an intuitive way for broadcast. In flooding, when a node receives a message, it rebroadcasts the message to all its neighbors that are defined as those nodes directly connected with it. This scheme requires minimal state retention except for a mechanism to detect duplicate messages (e.g., by associating a sequence number with each broadcast message). Other merits of flooding include robustness in case of lossy links or in networks with frequently changing topology, and minimal transfer delay, since messages are propagated along the shortest path to each destination. However, without any effective control mechanisms, flooding may result in serious redundancy, contention and collision, which is referred to as *broadcast storm problem*[6].

In cluster-based schemes, mobile nodes are organized into clusters. Only one node is chosen as the head of a cluster and all cluster heads make up a dominating set of the network. Cluster members receive messages from their cluster heads. Cluster heads are responsible for relaying broadcast messages to neighboring heads by unicasting or multicasting. These schemes achieve better scalability than flooding by restricting rebroadcasting nodes within cluster heads.

In contrast with the former schemes, connected dominating set-based schemes attempt to minimize the total amount of broadcast traffic. This is achieved by selecting some nodes that constitute a minimal *connected dominating set* (CDS) of a network to perform rebroadcast. A subset of nodes in a network is a connected dominating set if each node not in the subset is adjacent to at least one node in the subset and the subnetwork induced by the subset is connected. The main point of the current approaches is to construct a subnetwork called spine or virtual backbone that approximates the minimal CDS. However, it is costly to maintain a backbone structure in MANETs with frequently changing topology. Besides, congestion may occur with high probability due to traffic concentration. To resolve these problems, new techniques stressing efficiency and scalability must be developed.

In this paper, we present an efficient broadcast protocol based on a distributed algorithm for connected dominating sets in a connected graph[13]. The algorithm starts from the source and selects other nodes as rebroadcasting nodes recursively. Only local topology information is required in the calculation of new rebroadcasting nodes. All the nodes picked out form a CDS of the network. Messages are propagated in the network along with the calculation of the CDS. The protocol is called AHBP, for Ad Hoc Broadcast Protocol. Simulations are conducted to evaluate the performance of the protocol. The simulation results demonstrate that it can reduce the broadcast redundancy significantly.

The paper is organized as follows. Section 2 briefly reviews the related work. Section 3 describes the protocol. Simulation results are given in Section 4 and a summary is provided in Section 5.

2 Related Work

The broadcast storm problem is identified and analyzed in [6], in which the authors classified several schemes, namely probabilistic, counter-based, distance-based, location-based and cluster-based schemes. The probabilistic and the counter-based schemes are simple, but they cannot guarantee a message to be delivered to each node even if all nodes are statically connected and no loss occurs due to collision. Distance-based and location-based schemes require additional facilities (e.g., positioning devices) to support the protocol operations.

The cluster technique has been used to solve many problems in wireless networks. The cluster-based approach uses only topological information to improve broadcast performance. The core-based approach proposed in [8] also belongs to this category. We call these schemes dominating set-based schemes because the cluster heads (or cores) form a dominating set of the network. Although they are scalable and effective in contrast with flooding, they are sub-optimal in terms of message redundancy. Besides, they require additional cost to maintain the cluster structure.

Connected dominating sets have been used to solve the routing problem in MANETs[10,11]. These schemes have been reviewed in [12]. Their main principle is to construct a virtual backbone that approximates the minimum CDS of the network. Due to the dynamic nature of MANETs, it is difficult and costly to maintain the backbone structure. Wu *et al.* proposed a simple distributed algorithm to determine a CDS in a connected graph[12]. Wu's approach can generate a CDS quickly (in 2 rounds), but the CDS size is not optimized and it is costly to update the CDS while the network topology changes frequently.

Multipoint Relaying (MR) is proposed to minimize the overhead of flooding throughout an MANET[14]. In this approach, each router independently selects its MR set from its one-hop neighbors so that their retransmissions cover all its two-hop neighbors. Each MR router periodically broadcasts a Multipoint Relaying Advertisement packet containing its identity, the identities of all its one-hop neighbors, and its MR set. As control overhead is required, it is proposed as an optional mechanism used only when sufficient flooding traffic exists.

Ho *et al.* argued that flooding can be a viable candidate for multicast in dynamic ad hoc networks[5]. The experimental results demonstrate that even flooding is insufficient for reliable multicast when mobility is very high. We believe that by reducing the broadcast redundancy, we can decrease the message loss rate due to contention or collision and potentially enhance the reliability of broadcast.

The problem of broadcasting in multi-hop radio networks has been thoroughly studied and many important results have been obtained in previous work[15,16]. However, these results are obtained in synchronous networks where time of execution is divided into synchronous time-slots (e.g., in time-division networks). In this paper, the broadcast protocol is proposed mainly for asynchronous network where no time-slot is used (e.g., an IEEE 802.11 wireless local-area network).

3 Ad Hoc Broadcast Protocol

3.1 Assumptions and Design Goals

We make the following assumptions in this paper:

• All mobile nodes share a common wireless channel.

• Mobile devices are equipped with omni-directional antennas, so that a message transmitted by a node can be received by all other nodes within its radio coverage.

• All wireless transceivers have the same transmission range. In other words, bidirectional links are assumed, while it is easy to modify our protocol to encompass unidirectional links.

• The service to be provided is the unreliable, best effort delivery of broadcast messages. Messages may be lost, duplicated and delayed. High level protocols are responsible for detecting loss and retransmitting the lost message if required.

We make no prior assumptions on the nodal mobility, the network size, the geographic distribution of mobile nodes, etc. The design goals for the broadcast protocol include:

• Efficiency and scalability. The protocol should reduce the redundant messages to a minimum, while making reasonable tradeoff between efficiency and robustness. It should work well in large-scale mobile ad hoc networks.

• Robustness or reliability. The protocol should try its best to deliver each broadcast message to every receiver, regardless of the mobility of mobile nodes.

• Interoperability with existing routing protocols. The protocol provides broadcast service to routing protocols while the broadcast procedure is controllable for the routing protocols.

• Simplicity. The protocol should be so simple that it can be deployed in many types of MANETs (e.g., where nodes are hand-held devices) where both storage capacity and power are limited.

3.2 Conceptual Data Structures

In AHBP, each node maintains two data structures: a duplicate table and a two-hop neighbor table (Fig.1). Entries of the duplicate table record the information about broadcast messages that were recently received by this node. The node uses the table to determine whether a newly received message is a duplicate or not. An entry of the table contains the following fields:

- The source address of a broadcast message that the node receives;
- The sequence number of the message assigned at the source;
- The timestamp of the message when it is received or the remaining lifetime before the entry expires.

The two-hop neighbor table is employed for link state sensing and keeping the topology information about the nodes that are at most two hops away. In the table, a node keeps track of local topology it knows about: a list of adjacent nodes (also called neighbors), a list of adjacent nodes for each neighbor. The local topology information is used in selecting broadcast relay gateways in AHBP. It can also relieve the node from querying a route to a destination which is one-hop or two-hop away. Besides, it can be utilized by routing protocols for route repair.

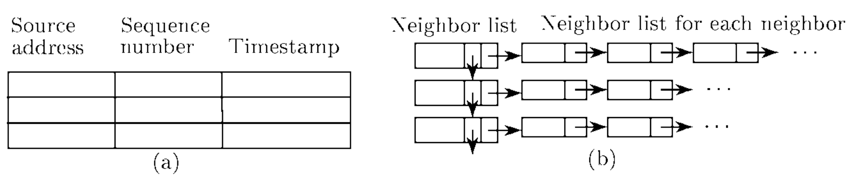

Fig.1. Conceptual data structures in AHBP. (a) Duplicate table. (b) Two-hop neighbor table.

3.3 Link State Sensing

In AHBP, each node periodically broadcasts a HELLO message to all its neighbors every HELLO_INTERVAL. The addresses (or identifiers) of its neighbors are included in the message. By exchanging HELLO messages, a node can learn which nodes are adjacent to it and which are two-hop away from it. When a node receives a HELLO message from one neighbor, say u, it updates its two-hop neighbor table. The update operation replaces the old neighbor list of u with the new one announced in the message.

Each neighbor is associated with a timer. If a node misses HELLO messages from a particular neighbor for a period of MAX_HELLO_PERIOD, it can presume that the neighbor is no longer able to maintain a direct link with it. So, the node can remove the neighbor and its neighbor list from the two-hop neighbor table. Besides, the node can use any physical-layer or link-layer methods to detect link breakages. If it considers that a link has been broken, it proceeds as above. The format of a HELLO message is illustrated in Fig.2(a).

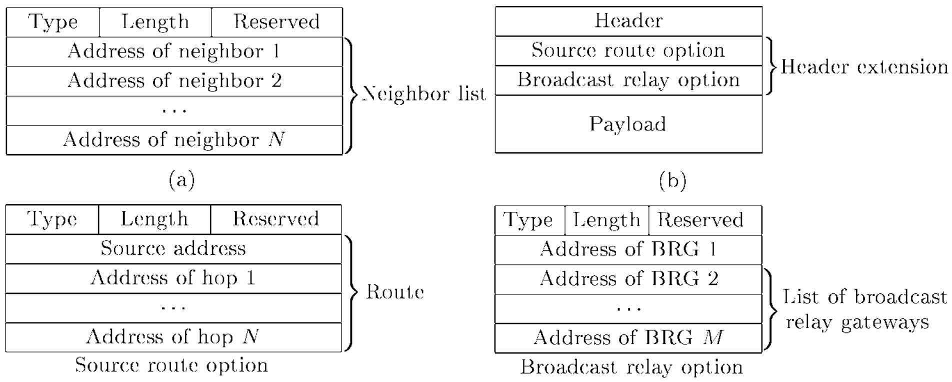

Fig.2. Message format. (a) HELLO message. (b) Broadcast message.

3.4 Protocol Operations

When a node broadcasts a message to all other nodes in an MANET, some nodes are chosen as broadcast relay gateways (BRGs). The message will be rebroadcast by BRGs while other nodes will only act as broadcast receivers. Unlike previous approaches, in AHBP, BRGs are calculated on-demand and no virtual backbone structure needs to be maintained. BRGs are picked out along with the propagation of broadcast messages. Assuming that the network is connected, all BRGs will constitute a connected dominating set.

When a node s wants to broadcast a message m, the basic broadcast procedure can be described as follows:

1) From its neighbor set, the node s selects some neighbors as BRGs. Then, s broadcasts the message m to all its neighbors, piggybacking with the information of the BRGs and the route the message passes through. Initially, the route only contains the source address. The format of a broadcast message is shown in Fig.2(b).

2) When a node v ($v \neq s$) receives m, it checks whether the message is a duplicate. If the message is heard for the first time, v delivers m to upper layer protocol and inserts the information about m into its duplicate table. Otherwise, the message is dropped and v stops processing.

3) If v is not a BRG, the processing stops. Or else, v selects new BRGs from its neighbor set, using the information of the route the message traverses and its two-hop neighbor table. Then, v rebroadcasts m to its neighbors, piggybacking with the information of new BRGs and the updated route. The route is updated by appending the address (or identifier) of v to it.

The steps 2) and 3) are recursively repeated until the message is propagated to all possible receivers. The broadcast procedure is completed in a distributed manner. Each BRG will select new BRGs and relay broadcast messages independently.

The BRG selection algorithm is not unique. The only requirement for a node v to select BRGs is that: *For each node which is two-hop away from v, if it is not a BRG, it must be adjacent to at least one BRG*. This condition is required to ensure that the resultant BRGs can make up a connected dominating set of the network, so that a broadcast message can be delivered to each receiver.

Here we use an algorithm which utilizes only the local topology information and the route a broadcast message traverses. Assume a node v receives a broadcast message from r and v is a BRG selected by r. The route is P which contains the addresses of the nodes the message traverses. The set of BRGs selected by v is denoted as $BRG(v)$. The algorithm includes the following steps:

1) Let $BRG(v) = \emptyset$ (empty set). Construct the local topology graph from the two-hop

neighbor table of v. Denote the graph as $GN = (VN, EN)$, where VN is the set of nodes which are at most two-hop away from v, EN is the set of edges between them. (An edge corresponds to a wireless link between two nodes.) In the graph, one endpoint of any edge must be a neighbor of v for v can only educe the topology within the range of two hops from its two-hop neighbor table.

2) Reduce the graph according to the following rules:

a. If $x \in P$, then remove x and its neighbors, and remove the edges associated with them.

b. If both endpoints of an edge are neighbors of v, then remove this edge.

c. If the degree of a node is zero, say, it is an isolated node, then remove it.

3) Denote the set of nodes which are adjacent to v in the resultant graph as $N1$, and the set of nodes which are two-hop away from v as $N2$. If $N2 = \emptyset$, then stop.

4) If there is a node in $N2$ whose degree is 1, then let w be the node adjacent to it. Obviously, $w \in N1$. Otherwise, let w be the node with the maximum degree in $N1$.

5) Let $BRG(v) = BRG(v) \cup \{w\}$. From the graph GN, remove w and the nodes adjacent to w, and remove the edges associated with them. Goto 3).

3.5 Handling Node Mobility

In AHBP, mobile nodes learn local topology through periodically exchanging their neighbor sets every HELLO_INTERVAL seconds. Then the information about a neighbor will be "forgot" after a time of MAX_HELLO_PERIOD if it is not updated. Mobile nodes may move fast, resulting in a network topology changing frequently. Then, inconsistency would arise among two-hop neighbor tables of different nodes. For example, a node may move into the radio coverage of another node which is unconscious of its presence before it transmits a HELLO message. If a node selects another node as a BRG while the latter has moved out its radio coverage, broadcast message would not be delivered to some nodes two-hop away, which weakens the reliability of the protocol. The seriousness of inconsistency is dominated by the node mobility, while the parameter setting can greatly impact the protocol performance. Inconsistency can be reduced with shorter HELLO_INTERVAL, but at the same time more bandwidth is consumed.

To cope with the node mobility, we propose the following rule to improve the performance of the basic AHBP. The AHBP incorporated with the rule is denoted as AHBP-EX in the following sections.

Rule 1. If node v is not a neighbor of u, or u is not in the neighbor list of v, it is probable that there exists a new link between them when u receives a broadcast message transmitted by v. In this case, if u is not a BRG selected by v, u relays the message just like a BRG.

3.6 Protocol Complexity

Compared with flooding, AHBP requires extra overhead to gather local topology information and calculate broadcast relay gateways. The total control overhead of "hello" procedure is $O(N\Delta/\tau)$, where N is the total number of mobile nodes in the network, Δ is the average node degree, τ is the average period to exchange HELLO messages. Calculating BRGs at one node requires additional computation cost with an upper bound of $O(\Delta_{\max}^3)$, where $\Delta_{\max}$ is the maximal node degree.

Flooding generates $N - 1$ duplicate messages in the ideal case where no loss occurs and the network is connected throughout the broadcast procedure. The number of rebroadcasts in AHBP is just the number of broadcast relay gateways selected. Although we cannot theoretically measure the size of the BRG set that AHBP generates, we can show that our protocol reduces the broadcast redundancy significantly through simulation.

4 Performance Evaluation

We evaluate the performance of AHBP through simulation, using the network simulator *ns*-2 with wireless extensions. We implement the flooding protocol, AHBP and AHBP-EX in *ns*-2.

4.1 Simulation Environment

The *ns*-2 is a discrete event simulator developed by the University of California at Berkeley and the VINT project[17]. For the purpose of studying multi-hop ad hoc networks, it has been modified and extended with mobile wireless modules by the CMU Monarch Project[18]. This simulator has been used to evaluate the performance of ad hoc routing protocols[19].

The signal propagation model uses a concept named reference distance. When a transmitter is within the reference distance of the receiver, a free space propagation model is used where the signal attenuates as $1/r^2$. Outside of this distance, a two-ray ground reflection model is used where the signal falls off as $1/r^4$. (r is the distance between the antennas.) A message is received correctly only when the receiving power level is above both the carrier sense threshold and the receive threshold. Like [19], in our experiments, the physical radio characteristics of each mobile node's network interface were chosen to approximate the Lucent WaveLAN direct sequence spread spectrum radio.

At the link layer, the complete IEEE 802.11 standard Medium Access Control (MAC) protocol Distributed Coordination Function (DCF) is implemented. Each unicast message is transmitted preceded with a Request-to-Send/Clear-to-Send (RTS/CTS) exchange that reserves the wireless channel for transmission and avoids the collisions due to hidden terminals. An acknowledgment (ACK) is returned to the sender if the unicast message is received correctly. The broadcast messages will be sent only when both the virtual and physical carrier senses indicate that the medium is clear, but no RTS/CTS/ACK exchange is applied.

Each mobile node has a position and a velocity and moves about over a rectangular flat space. Nodes move according to the "random waypoint" model[19]. In this model, each node begins the simulation by remaining stationary for PAUSE_TIME seconds. It then selects a random position in the space and moves to the position at a speed distributed uniformly between 0 and MAX_SPEED. When it reaches the destination, a new round of "pause/move" is repeated.

In our simulation, broadcast sources are chosen to be constant bit rate (CBR) sources. In each experiment, SRC_NUM sources are selected randomly. The sources transmit broadcast messages at the rate of TX_RATE. Because AHBP and AHBP-EX require a period to stabilize, each source starts to transmit at a time distributed uniformly between 100 and 280 seconds. The parameter values in our experiments are summarized in Table 1. For each setting of the parameters, we test the performance of AHBP, AHBP-EX and flooding for 10 times with different source sets, and then take the average.

In our implementation, each HELLO message is delayed for a random time distributed between 0 and HELLO_INTERVAL in order to prevent nodes from transmitting HELLO messages simultaneously. Therefore, the average period for a node to exchange HELLO messages is 1.5 ∗ HELLO_INTERVAL. An expired link will be detected only when a node transmits a HELLO message.

The performance metrics we observe are:

• Broadcast Cost: the (normalized) average cost to deliver a broadcast message to all nodes in the network. It is defined as $TX_{\mathrm{all}}/(TX_{\mathrm{src}} * \mathit{Node\_num})$, where TX_{all} is the total number of messages transmitted by all nodes in the network, including the control messages, TX_{src} is the total number of user messages generated by all broadcast sources, and $\mathit{Node\_num}$ is the total number of mobile nodes. TX_{all} is also a metric of the bandwidth consumed in broadcast. In the ideal case where the network is always connected and no message loss occurs, the broadcast cost of flooding will be 1 since rebroadcast is performed once at each receiver.

• Delivery Ratio: defined as $RX_{\rm usr}/(TX_{\rm src} * (Node\_num - 1)$, where $RX_{\rm usr}$ is the total number of non-duplicate messages received by users. The delivery ratio reveals the robustness of the simulated protocol. In the ideal case, the delivery ratio of flooding will be 1.

Table 1. Parameter Setting in Simulation

Parameter	Description	Default value
HELLO_INTERVAL	Period for a node to exchange HELLO messages	15 seconds
MAX_HELLO_PERIOD	The maximal time before a neighbor is considered disconnected	20 seconds
NODE_NUM	Number of mobile nodes (Network size)	60
SRC_NUM	Number of broadcast sources	10
TX_START_TIME	Time when a source starts to transmit	distributed uniformly between 100 and 280 seconds
TX_RATE	Transmitting rate	1 message every 10 seconds
SIM_TIME	Total simulation time	900 seconds
PAUSE_TIME	Pause time between two consecutive movements	200 seconds
MAX_SPEED	Maximal moving speed	20 meters per second
TX_RANGE	Wireless transmission range	250 meters
LENGTH	Length of the space	1000 meters
WIDTH	Width of the space	300 meters
BROADCAST_JITTER	Time to jitter a local broadcast to avoid collision	0.0001 seconds

4.2 Simulation Results

4.2.1 Performance with Network Size

Fig.3 shows the relative performance of flooding and our protocols with respect to network size. The simulation results are obtained on 10 sources transmitting at the rate of 1 message every 10 seconds. The maximum speed of mobile nodes is 20m/s (average speed 10m/s) and the pause time is set to 200 seconds.

As shown in Fig.3(a), AHBP and AHBP-EX can reduce the broadcast cost drastically. While the average broadcast cost is about 40% for AHBP-EX, it reaches only about 20% for AHBP. These results highlight the effectiveness of our protocols and prove that the broadcast redundancy can be reduced greatly by selective rebroadcast.

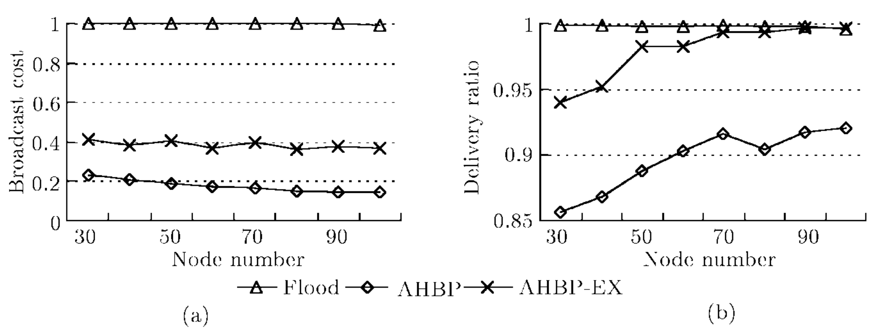

Fig.3. Performance comparison with respect to network size. (a) Comparison of broadcast cost as a function of network size (node number). (b) Comparison of delivery ratio as a function of network size (node number).

The delivery ratio of flooding remains above 99.6% in our experiments. The delivery ratios of AHBP and AHBP-EX increase when the network scales large. This is because the network becomes dense with the increasing of node number in a fixed-size area and a mobile node is more likely to be covered by a broadcast relay gateway. In AHBP, user messages can be delivered to more than 85% destinations. This ratio is greater than 90% when the node number exceeds 60. For AHBP-EX, the delivery ratio is above 98% when the node number increases up to 50. It achieves better performance than AHBP with nearly doubled broadcast cost. With the growth of network size, the delivery ratio of AHBP-EX comes close to that of flooding, while its cost remains lower than 40%. This demonstrates the powerful capability of AHBP-EX in reducing broadcast redundancy, especially in large dense networks.

4.2.2 Performance with Mobility

Fig.4 shows the relative performance of broadcast protocols with respect to mobility. The simulation results are obtained on MANETs with 60 nodes.

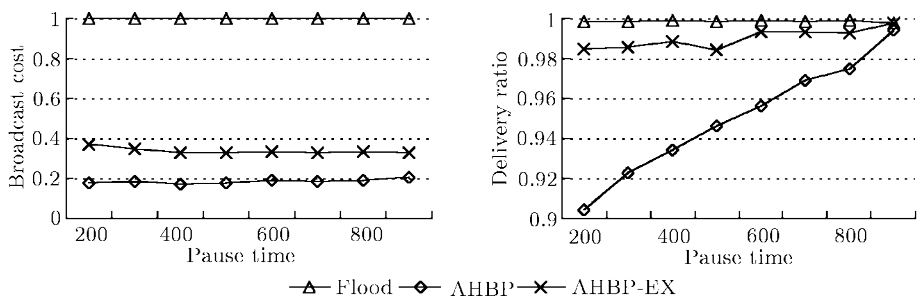

Fig.4. Performance comparison with respect to mobility.

Compared with flooding, the broadcast costs of AHBP and AHBP-EX remain low regardless of pause time. Both the broadcast cost and the delivery ratio of flooding are close to 1. The delivery ratio of AHBP increases linearly with the increasing of pause time. For AHBP-EX, it remains above 98% in all cases and increases slightly when the node mobility becomes lower. The pause time of 900 corresponds to no motion. In this case, AHBP and AHBP-EX achieve the delivery ratio close to that of flooding. Though AHBP is designed mainly for MANETs, it is also an efficient broadcast protocol for static networks.

The results shown in Fig.5(a) and (b) are obtained under the scenarios where the maximal moving speeds are set as 2m/s and 40m/s respectively. Comparing these results, we observe that the performance of flooding and AHBP-EX is steady at different moving speeds. The delivery ratio of flooding is close to 1 in all cases, while AHBP-EX remains above 98%. For AHBP, it performs better at lower moving speed.

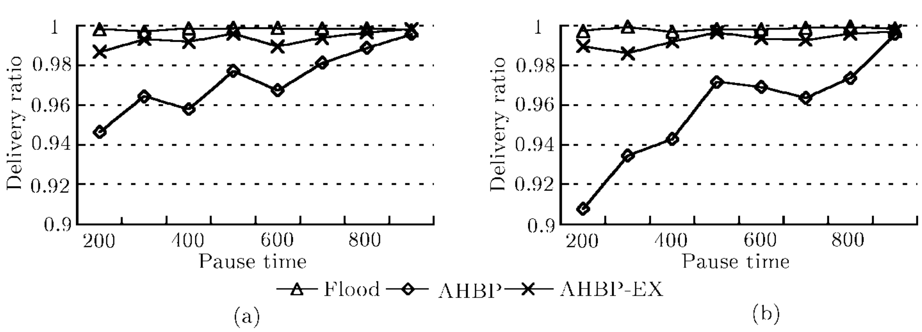

Fig.5. Delivery ratio with different maximal moving speed. (a) Maximal moving speed = 2 m/s. (b) Maximal moving speed = 40 m/s.

4.2.3 Performance with Network Payload

The network payload can be measured by two values: the source number and the average transmitting rate. The simulation results under different network payloads are shown in Fig.6.

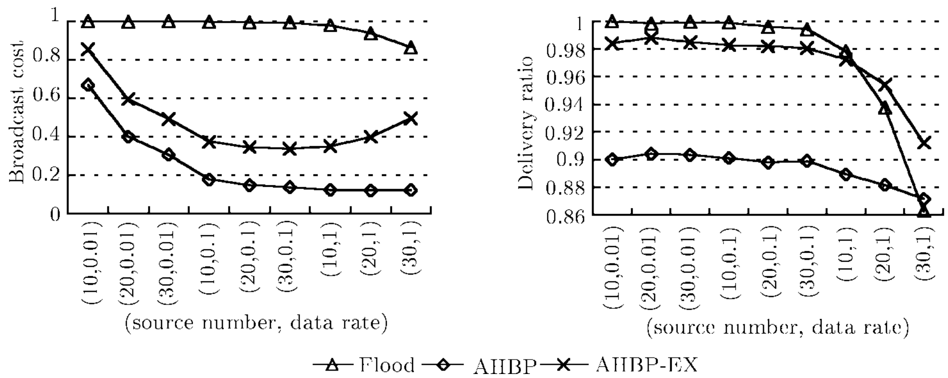

Fig.6. Performance comparison with respect to network payload.

With light network payload, the broadcast cost of AHBP and AHBP-EX is dominated by the overhead of "hello" procedure. In this case, the advantage of rebroadcasting with selected broadcast relay gateways is not apparent. However, with the increasing of network payload, more rebroadcast can be saved by AHBP and AHBP-EX.

As we can see, when the data rate is low (< 0.1), the delivery ratios of three protocols do not change much and remain at the level of 99.5%, 98% and 90% respectively. However, with high data rate, their performance becomes worse. With higher network payload, more collisions will occur, which results in more message losses. AHBP-EX performs better than flooding with heavy payload. This can be explained with the fact that AHBP-EX can reduce a lot of redundant messages, which contributes to a reduced level of collision and congestion.

4.2.4 Performance with HELLO Interval

In AHBP, HELLO_INTERVAL and MAX_HELLO_PERIOD are two important parameters that can greatly affect the protocol performance. We conduct some experiments to study the effect of different parameter settings on the protocol performance.

In our experiments, the HELLO_INTERVAL is set to 20s and 15s respectively, while the value of MAX_HELLO_PERIOD varies from 5s to 35s (Fig.7). From the simulation results, we observe that the setting of MAX_HELLO_PERIOD has greater influence on the protocol performance. The broadcast cost of AHBP is about 20% of that of flooding in all cases. For AHBP-EX, with the increasing of MAX_HELLO_PERIOD, the broadcast cost decreases from 92% (MAX_HELLO_PERIOD=5s) to 21% (MAX_HELLO_PERIOD=35s). The delivery ratio of AHBP-EX remains high (above 99.4%) while the MAX_HELLO_PERIOD is less than 15 seconds. It decreases when the MAX_HELLO_PERIOD becomes larger. For AHBP, it is shown that the parameter MAX_HELLO_PERIOD is closely correlated with HELLO_INTERVAL. The delivery ratio is poor when the value of MAX_HELLO_PERIOD is too small or too large. An optimal setting of MAX_HELLO_PERIOD could be obtained near the value of HELLO_INTERVAL.

When the MAX_HELLO_PERIOD is small, the topology knowledge learned by the "hello" procedure will be "forgot" quickly, which results in that more nodes will perform rebroadcast operation in AHBP-EX. It transforms into flooding when the MAX_HELLO_PERIOD is small enough that all topology information learned is expired before the information can be utilized to calculate broadcast relay gateways. With the increasing of MAX_HELLO_PERIOD, more rebroadcast will be reduced, which leads to less broadcast cost, as shown in Fig.7. However, the inconsistency of topology information also becomes serious and the delivery ratio is reduced. Network manager should make a reasonable trade-off between the network cost and broadcast reliability. This can be achieved by choosing appropriate values of HELLO_INTERVAL and MAX_HELLO_PERIOD.

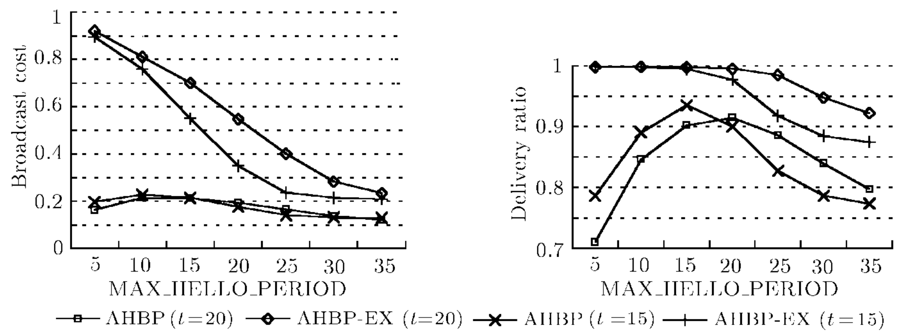

Fig.7. Performance with respect to HELLO_INTERVAL and MAX_HELLO_PERIOD.

5 Summary

This paper presents a new approach for efficient broadcasting in mobile ad hoc networks. The proposed protocol called AHBP can relieve mobile nodes from the broadcast storm problem arising from flooding. In the broadcast procedure, some nodes are selected as broadcast relay gateways to perform rebroadcast operation. The protocol can reduce broadcast redundancy significantly and can be adjusted to make a balance between broadcast cost and reliability. We believe such a protocol offers some important advantages. First, it reduces the broadcast redundancy and saves the network bandwidth. Secondly, it is easy to incorporate it with the existing network protocol suit. As the procedure to exchange HELLO messages has been adopted in many wireless protocols, AHBP will add little overhead in implementations. Furthermore, though the protocol is proposed mainly for MANETs, it can also be applied in static networks to provide efficient broadcast service.

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