Broadcasting in Mobile Ad Hoc Networks

Sangwoo Lee and Chaewoo Lee
Ajou University
Republic of Korea

1. Introduction

Mobile ad hoc networks (MANETs) are self-organizing and the constituent mobile nodes communicate with each other as autonomous hosts in the absence of a fixed infrastructure. Recently, MANETs are deployed to places where the network is required to be promptly established such as military operations and disaster relief. However, the mobile nodes merely operate with limited resources such as processing, communication, and energy. The nodes further have the characteristic of high mobility. Thus, MANET has the properties of frequently route breakage and unpredictable topology changes.

Clearly, these properties make the transmission methods widely used in fixed infrastructures inappropriate for MANET. Broadcasting is an alternative which is a one-to-all transmission method, namely a packet or a message generated by a node, called the source, is sent to all other nodes in the network. Moreover, broadcasting is an important operation in applications performing route discovery (Johnson & Maltz, 1996; Park & Corson, 1997; Pearlman & Haas, 1999; Perkins & Royer, 1999), updating the network knowledge, or sending an alarm signal. However, it seems greedy and excessive in aspect of resource limitation, especially energy which is a major concern in MANET, since the nodes transmit packets in a multi-hop communication manner. Therefore, the energy cost of broadcast packet transmission (i.e., the number of transmissions) should be minimized to conserve the energy of the mobile nodes.

Blind flooding is the most straightforward approach to broadcasting. Specifically, every node in the network forwards the broadcast packet exactly once. It ensures the full coverage of all the network: all the nodes in the network are guaranteed to receive the broadcast packet in case that the network is static and the occurrence of collision and error is not considered during propagation. However, flooding may generate excessive redundant transmissions which cause a critical problem, referred to as the *broadcast storm* problem (Ni et al., 1999), introducing communication contention and collision due to sharing wireless resources and overlapping coverage areas among nodes.

The broadcast storm problem can be readily avoided by reducing the number of retransmissions. In order to alleviate the broadcast storm problem, probability-based, area-based, and neighbor knowledge approaches control the amount of traffic, that is, each node determines whether or not to retransmit the broadcast packet. The probability-based approach controls message flood with a predefined probability or received packet count. Obviously, it resembles blind flooding when the probability that a node retransmits the broadcast packet equals to one. In the area-based approach, each node determines whether or not to rebroadcast the packet with evaluation of its additional coverage area by rebroadcasting. If the additional coverage is less than the threshold, the node abandons retransmitting. This method relies on location or distance information of nodes to determine rebroadcasting. The neighbor knowledge approach utilizes one or two hop neighbor information obtained via periodical hello packets to reduce redundant rebroadcasting. This approach allows retransmitting only when it results in any additional neighbor to be reached.

According to the methods controlling message flood, network overhead can be significantly reduced. However, some problems can occur such as end-to-end delay or latency and unreliability. Each node requires a certain waiting time to examine whether or not to rebroadcast a packet. In the area-based approach, for example, a node sets a random waiting time when a previously unseen packet arrives and it observes the duplicate packet arriving during the waiting time. Since nodes hold a packet for waiting times, the time spent on propagation from the packet origination to reach a node, namely end-to-end delay, increases.

Reliability is considered in a network that nodes are fully connected to others in a single- or multi-hop fashion and the network is static. When a node determines to discard a packet with an examination of the necessity of rebroadcasting, some one-hop neighbors may not receive the packet. Furthermore, the packet is unreachable to nodes which have the sole connection through the neighbors.

More precisely, a perfectly reliable broadcasting with minimizing redundancy is defined as a problem finding the minimum connected dominating set (MCDS) where a connected dominating set states that each node either belongs to the set or has a neighbor which belong to the set and is fully connected to others. Unfortunately, the problem of finding the MCDS is classified as NP-complete even if the global topology information is given (Lim & Kim, 2001; Lou & Wu, 2002).

Some broadcasting schemes form a conjunction of area-based and neighbor knowledge approaches, called hybrid broadcasting schemes, to efficiently resolve redundant transmission, unreliability, and latency. Based on that outer nodes from the sender are prone to have more additional coverage than inner nodes (i.e., area-based approach), the outer takes higher priority of retransmission than the inner: when a node receives a previously unseen packet, it first sets a waiting time determined in inverse proportion to the distance to the sender. Instead of computation of additional coverage to make a determination of packet drop, each node examines whether all its neighbors receive the packet (i.e., neighbor knowledge) to resolve a potential unreliability.

The remainder of this chapter is organized as follows. Section 2 introduces issues in broadcasting. Section 3 reviews previously published broadcasting methods. Section 4 describes hybrid broadcasting schemes. Section 5 concludes this chapter and gives some possible future works.

2. Issues in broadcasting

2.1 The broadcast storm

As mentioned above, flooding is the simplest solution to broadcasting. The fundamental idea behind flooding is that every node participates in transmission of a packet exactly once

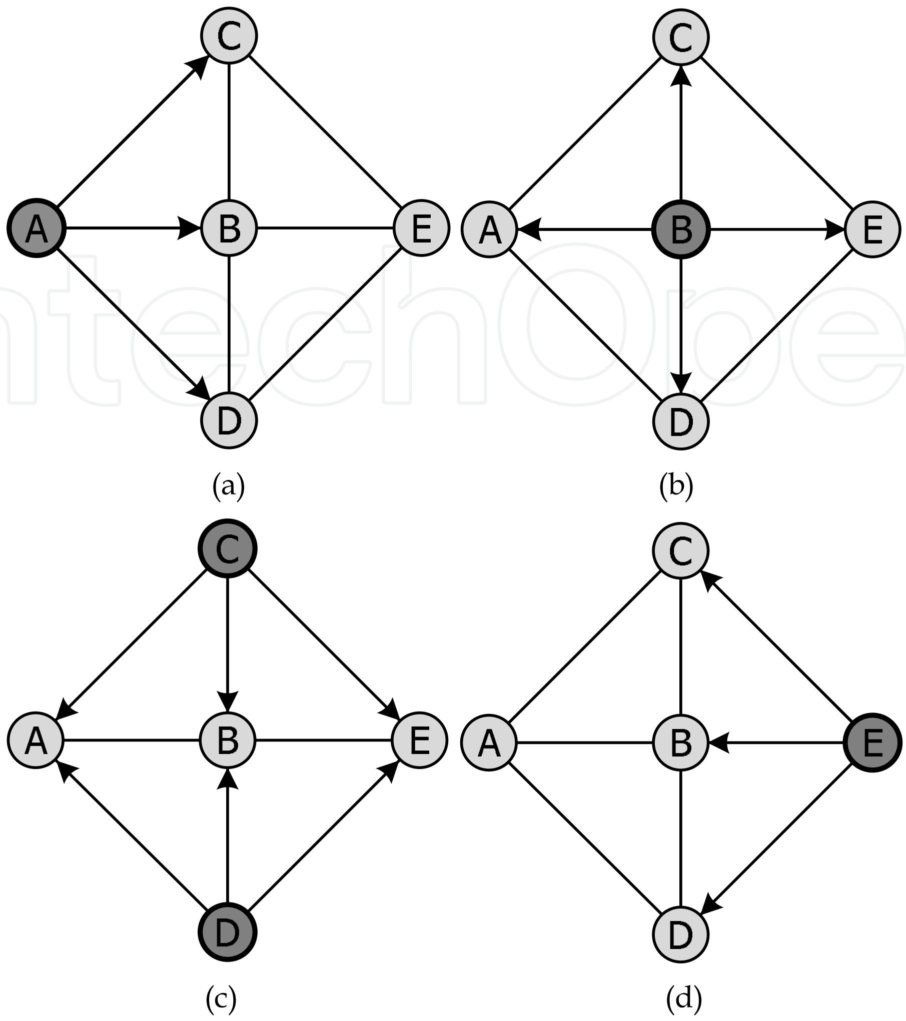


Fig. 1. A sample network with five nodes: (a) Broadcasting by source *A* (b) Optimal broadcasting (c) Redundant broadcasting and hidden node problem without RTS/CTS handshake (d) Redundant broadcasting

to deliver it throughout the network in a multi-hop fashion. Hence, intermediate nodes have the obligation to retransmit the packet. This leads to n transmissions in a network of n hosts for a single packet. It achieves perfectly reliable broadcasting if the communication channel is error-free with no collision.

Unfortunately, redundancy, contention, and collision can be observed which are referred to as the broadcast storm problem in (Ni et al., 1999). The main reason for redundancy is that the coverage of a node may overlap with others nearly placed. In other words, several intermediate nodes perform redundant transmission in case that all neighbors within the transmission range of the node have already received the packet. Additionally, because of the lack of bandwidth, wireless resource sharing, and the absence of collision detection, redundant transmissions are prone to trigger noticeable contention and collision. The broadcast storm problem seriously worsens if the size of the network increases and nodes are densely distributed. Figure 1 illustrates a network with five nodes. When a broadcast packet is generated and forwarded by source *A*, the packet reaches to all the nodes by node *B* as shown in figure 1(b). Figures 1(c) and 1(d) illustrates redundant broadcasting by nodes *C*, *D*, and *E*. In addition to the redundancy in figure 1(c), the hidden node problem can be found in the network based on contention-based protocols including ALOHA (Abramson, 1970), slotted ALOHA (Saadawi & Ephremides, 1981), CSMA (carrier sense multiple access), and IEEE 802.11.

The broadcast storm problem can be avoided by merely reducing the number of retransmissions of the packet (i.e., packet drop). Thus, the way to drop the packet efficiently is a substantial goal in broadcasting. Several enhancements to flooding are discussed in section 3.

2.2 Unreliability and latency

Apparently, packet drop becomes an essential function in broadcasting to reduce the broadcast redundancy, which is implicit in resource usage, by judging necessity of transmission. The packet drop effectively resolves the broadcast storm problem and even reduces resource usage. Unfortunately, end-to-end unreliability and latency can arise due to packet drop by an incorrect judgement.

Because of the properties of MANET, flooding rarely guarantees perfect reliability. For instance, some nodes are often isolated from the network. In spite of difficulties, a perfectly reliable broadcasting is necessary in some applications (e.g., the localization in (Doherty et al., 2001; Niculescu & Nath, 2001; Shang & Ruml, 2004)). The underlying assumption here is that the network is seen as static or a snapshot of mobile networks with the error-free channel. In this network, flooding ensures the perfectly reliable delivery. However, some nodes in the network may not receive the packet when flooding is implemented with packet flood control. As far as a node on standby for transmission determines the necessity of transmission without global topology information or local announcements representing packet reception from its neighbors, the node is prone to make a poor determination. In general, packet loss occurs by collision and it results in poor reliability as well.

Latency is also introduced from the packet drop which is the time spent from when a packet is originated until it reaches to a node. Each node waits for a certain time to make a determination of retransmission in packet flood control. It is primarily required for appropriate flood control. Furthermore, packet drop is likely to block the shortest path of a packet in sparse networks. In other words, the packet makes a detour to nodes in specific regions.

Typically, many researches aim at minimizing the number of transmission while attempting to ensure the full coverage of the network at the same time. Recently, since end-to-end delay becomes a major issue in designing networks, rapid spread of a broadcast packet is indeed considered as well.

3. Broadcasting in MANET

We now describe some previously published works for the broadcast problem. The broadcasting methods can be classified as blind flooding, probability-based, area-based, and neighbor knowledge approaches (Williams & Camp, 2002).

Blind flooding (Ho et al., 1999; Jetcheva et al., 2001) requires each node to rebroadcast a broadcast packet to all its neighbors and this continues until all nodes retransmit the packet at least once. In order to alleviate the inefficiencies of blind flooding, probability-based methods assign a probability to a node to determine whether or not to rebroadcast. Area-based methods allow a node to rebroadcast a packet if its transmission range sufficiently covers additional area. Neighbor knowledge methods decide the retransmission of the

packet based on local neighbor lists through hello packets. A performance comparison of some of the schemes can be found in (Williams & Camp, 2002).
In this section, we cover probability-based, area-based, and neighbor knowledge approaches which are enhancements to blind flooding.

3.1 Probability-based approach

A probability-based approach attempts to resolve redundancy on the basis of that more duplicate packet receptions promptly deteriorates additional coverage via retransmission. Intuitively, multiple nodes are prone to share similar coverage in dense networks. Figure 2 presents additional coverage by retransmission at node *A*. We assume here that transmission range of each node is identical and omnidirectional. A circle centered at a node represents its transmission range. The additional coverage of node *A* is denoted by shaded area. A scenario is shown in figure 2(a) where node *A* receives a packet from neighboring node *B* and forwards the packet. As seen in figure 2(b), node *A* receives the same packet from both nodes *B* and *C*. In this case, the additional coverage is reduced because coverage of node *A* is covered by nodes *B* and *C* in advance.

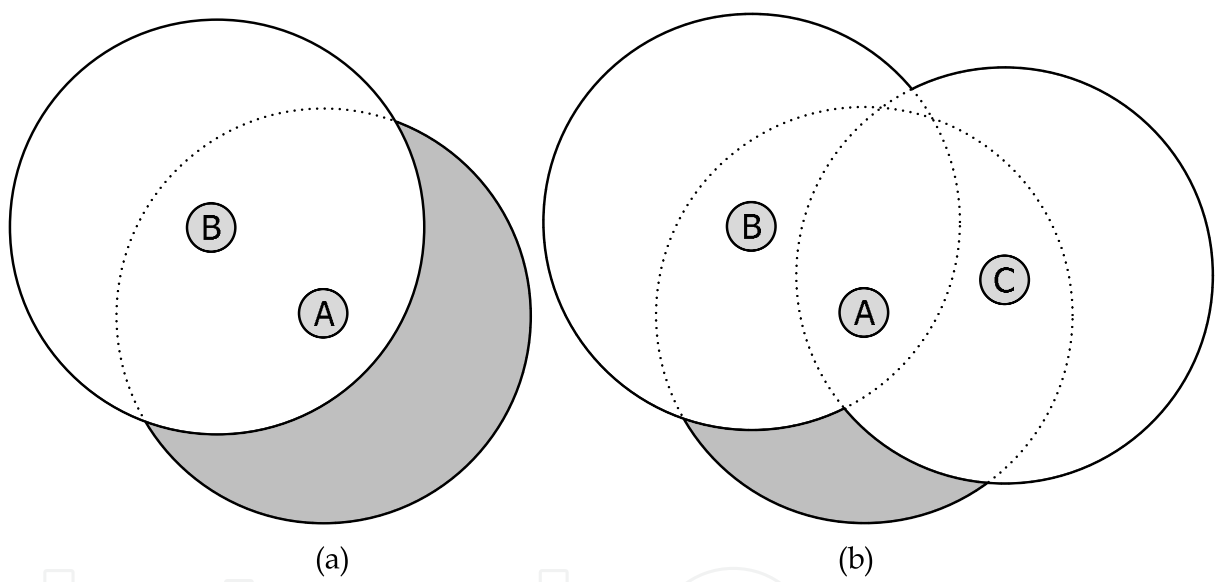


Fig. 2. Additional coverage area by node *A*: (a) A single packet reception from node *B* (b) Duplicate packet reception from nodes *B* and *C*

This approach is classified into two categories: probabilistic and counter-based schemes (Ni et al., 1999). The probabilistic scheme controls packet flood with a predetermined probability or dynamic probability based on derived conditions such as node density and distribution (Ryu et al., 2004; Tseng et al., 2001). If the probability is set to a far small value, reliability will decrease in sparse networks and even in dense networks where nodes are randomly distributed. On the other hand, redundant transmission will be introduced if the probability is set far large. Incidentally, the probabilistic scheme resembles blind flooding when the probability is set to one.
The counter-based scheme allows a node to retransmit a packet unless the node has received the redundant packet more than a predefined threshold over a waiting time called random assessment delay (RAD). Upon receiving a previously unseen packet, the node respectively initiates a counter and a timer (RAD) to one and zero. During the RAD, the counter is

incremented by one for receiving each duplicate packet. When the RAD expires, if the counter reaches a threshold or over, the node drops the packet. Otherwise, it rebroadcasts the packet to neighbors.

The probability-based approach is simple to embody with local topology information. Thus, it effectively reduces the broadcast redundancy while the full coverage may not be ensured in dense networks; whereas all nodes are likely to rebroadcast in sparse networks. However, it is difficult to take into consideration the factors of rebroadcasting and reliability to derive a proper probability and the optimal threshold.

3.2 Area-based approach

Typically, additional coverage of a node is dependent on either distance to the sender or locations of the nodes. Suppose two nodes have bidirectional link with identical and omnidirectional transmission range as seen in figure 3. The overlapped coverage area increases as two nodes are more closely located. In other words, additional coverage of a node is maximized when the node is located at the boundary of the coverage of the sender. In area-based approach, a node computes additional coverage based on the coverage of its neighbors and it drops a broadcast packet when the additional coverage is less than a preset threshold. The area-based approach is categorized as distance-based and location-based schemes.

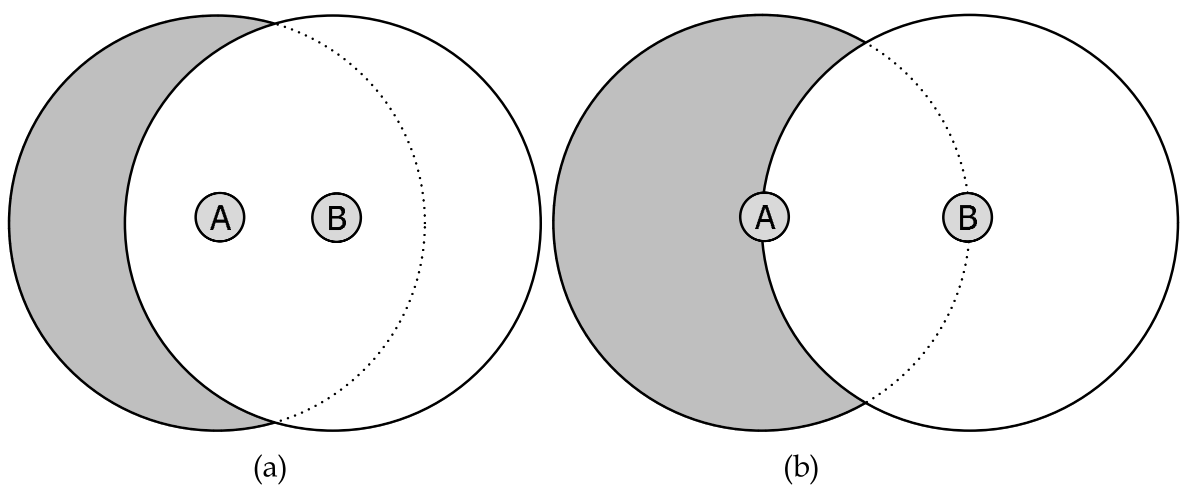


Fig. 3. Additional coverage area by node *A*: (a) When node *A* is closely placed to node *B* (b) When node *A* is placed at the boundary of transmission range of node *B*

The distance-based scheme determines if packet forwarding is necessary through ranging, that is, a process measuring the distance between nodes based on received signal strength, time of arrival, or time difference of arrival. A node initiates a RAD when a previously unseen packet arrives. During the RAD, the node measures the distance to each sender transmitting the packet and compares the distance and a threshold distance. If any of the distance measurements is closer than the threshold, the node stops forwarding the packet.

In the location-based scheme (Ni et al., 1999), each node has the physical location information through global positioning system (GPS) (Getting, 1993) or manual configuration. A node receiving a previously unseen packet initiates a RAD and it accumulates the coverage by the senders of the packet based on the locations of the senders for the RAD. When the RAD expires, the node rebroadcasts the packet if the accumulated coverage is narrower than a threshold.

Geoflood is a location-based scheme introduced in (Arango et al., 2004). Each node sets a RAD when the first packet arrives and defines quadrants with own position as the origin. Upon receiving the duplicate packets for the RAD, the node records which quadrants are covered. When a node receives the duplicates from all quadrants, it decides that retransmission is unnecessary and discards the packet. Otherwise, the node forwards the packet. Let d be the distance from the sender. The RAD $W(d)$ is randomly chosen over a range which is given by

$$W(d) = rand(\max(h(d) - W_{off}, 0), h(d) + W_{off}) \tag{1}$$

where W_{off} is the maximum random offset and

$$h(d) = W_{\max} - \frac{d \times W_{\max}}{R}$$

with the predefined maximum waiting time $W_{\max}$ and the range R of the network. Since outer nodes cover much additional coverage and help the packet propagate faster than inner nodes, shorter times are allocated to outer nodes than inner nodes. Geoflood may seem able to achieve perfectly reliable delivery while reducing the number of retransmissions at the same time. However, there is high possibility to make the packet unreachable to some nodes. Figure 4 depicts the worst case that some nodes may not receive the packet. In this figure, node A receives the identical packet sequentially from nodes B, C, D, and E. Since node A has received from all quadrants, it drops the packet. Thus, nodes in the shaded area are ignored by node A.

The area-based approach attempts to achieve the expected coverage of the network while reducing redundancy through computation of the local coverage area. However, additional devices are requires for ranging or localization in the determination of retransmission. These are likely to be expensive and power-intensive. In aspect of energy usage, this approach may lead to reducing network lifetime that should be primarily considered in MANET.

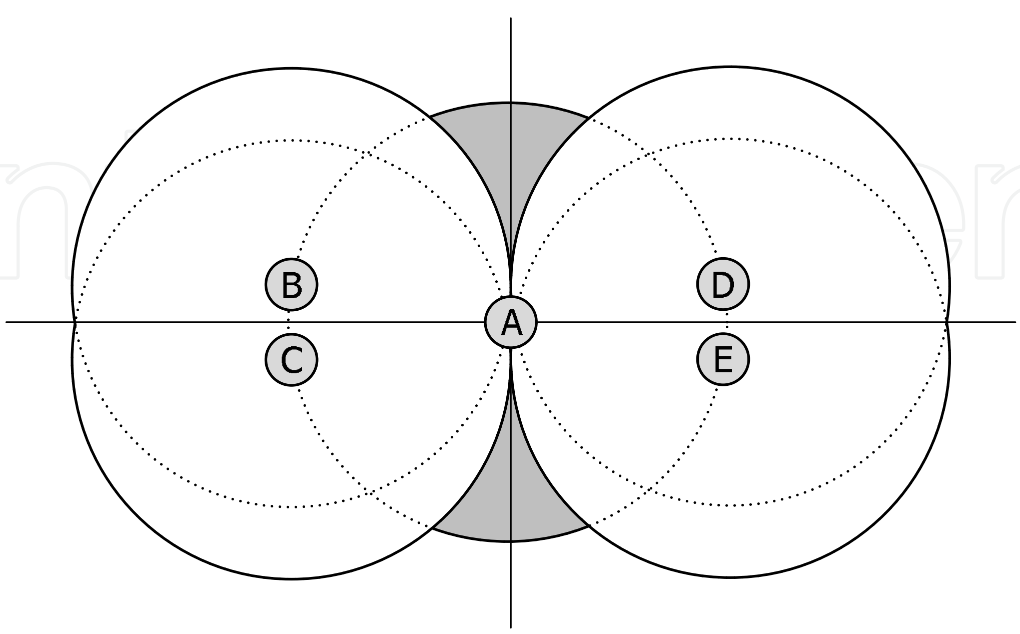


Fig. 4. Worst case that the packet is unreachable to the shaded area

3.3 Neighbor knowledge approach

A neighbor knowledge approach alleviates the broadcast redundancy based on the local topology information in one-hop or two-hop. Additionally, when the network topology is static, it achieves the perfectly reliable delivery. In order to obtain knowledge of one- or two-hop neighbor, it is necessary that each node periodically emits a hello packet to inform its existence to the neighbor.

(Lim & Kim, 2001) proposed two simple schemes called *self pruning* and *dominant pruning*. Self pruning employs one-hop neighbor knowledge for broadcasting. Each node manages the neighbor list via a periodic hello packet. The node piggybacks the list in the broadcast packet when it performs retransmission. The neighbor, which receives the forwarded packet including the neighbor list of the sender, examines whether there is a difference between its neighbor list and the sender's list. In other words, $N(A) - N(B) - \{B\} = \emptyset$ where $N(A)$, $N(B)$ respectively represent the list of sender A, the list of neighbor B. If the examination says true, the neighbor renounces broadcasting since this indicates that there is no additional node covered by the neighbor. Otherwise, the packet is forwarded with updating the neighbor list. Whereas self pruning only exploits the knowledge of neighbors directly connected to the sender, dominant pruning requires the knowledge of neighbors within two-hop from the sender. In addition to the knowledge extension, the authority to make a determination of retransmission for the neighbors is given to the sender in dominant pruning. The sender selects some or all of one-hop neighbors, which covers all other nodes with the minimum number of transmissions. It then marks the IDs of the selected nodes in the forward list of the packet for retransmission. Since each node belonging to the forward list broadcasts the packet once, the minimized forward list states the minimum number of transmissions. Figure 5 shows the sets of nodes within two-hop from the sender A. In this figure, node B is the former sender before the current sender A. The sets $N(A)$ and $N(B)$ present respectively neighbors within the coverage range of nodes A and B. The set of neighbors within two-hop from node A is denoted by $N(N(A))$. Thus, in dominant pruning, the sender A should determine the forward list from the set $N(A)$ to cover the set

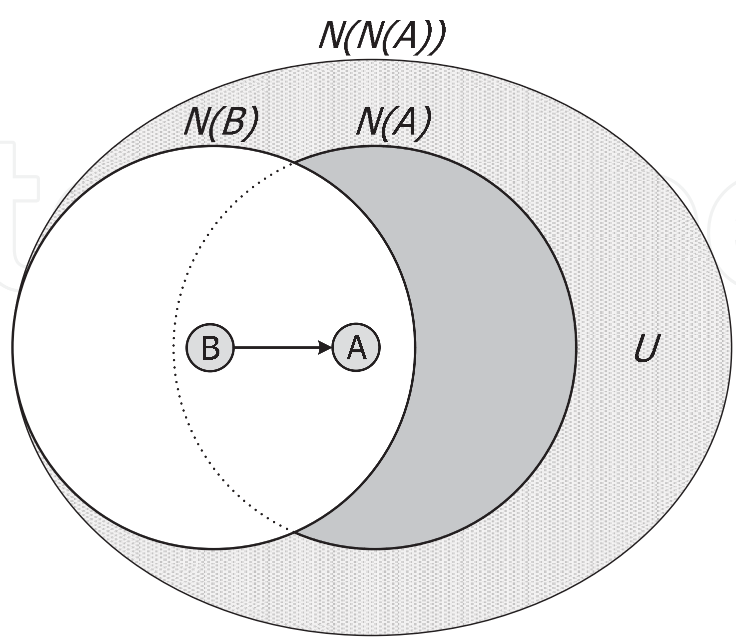


Fig. 5. Dominant pruning

$U = N(N(A)) - N(B) - N(A)$. As the former sender B sets the forward list that helps the packet reachable to two-hop distance from node B, namely $N(N(B))$, the forward list for the current sender A is selected into the set $N(A) - N(B)$ denoted by the shaded area in figure 4. This is the set cover problem, which is NP-complete, to minimize a set F of nodes subject to $\bigcup_{C \in F}(N(C) \cap U) = U$ and $F \subseteq N(A) - N(B)$. The set F is approximately obtained with the greedy set cover algorithm.

(Peng & Lu, 2000) described *scalable broadcast algorithm* (SBA) in which each node forwards the broadcast packet including the neighbor list covered by the transmission. Once node A receives the broadcast packet m from node B, node A discards the packet promptly if $N(A) \subseteq N(B)$. If not, the node initiates a covered node set $N_m(A) = N(B) \cup \{B\}$ and sets a waiting time W, which is randomly chosen from uniform distribution $U(x)$ between 0 and x, given by

$$W = U(\Delta \times W0) \tag{2}$$

where Δ is a small constant delay and

$$W0 = \frac{1 + d_m(A)}{1 + d(A)}$$

with the maximum degree $d_m(A)$ of neighbors of node A and the degree $d(A)$ of node A. During the waiting time, upon receiving the duplicate packet from node C, node A updates the covered node set such that $N_m(A) = N_m(A) \cup N(C) \cup \{C\}$. When the waiting time expires, it examines whether $N(A) \subseteq N_m(A)$. If the set $N(A)$ either belongs or equals to the covered node set $N(A)$, node A determines that retransmission is unnecessary and discards the packet. In other words, all the neighbors placed in the coverage area of node A have already received the broadcast packet. Moreover, a random waiting time is dynamically determined according to the degree of a node: a node with more neighbors waits shorter.

(Qayyum et al., 2002) described *multipoint relay* (MPR) where each node selects a small subset of neighbors, namely MPR set, using knowledge of neighbors within two-hop distance from itself. If a node receives the packet and belongs to MPR set of the sender, the node rebroadcasts the packet. The optimal MPR set covers all one- and two-hop neighbors with a minimum number of one-hop neighbors. Since the network topology dynamically changes, each node requires to reselect appropriate MPRs when a change of the local topology is detected through periodic hello packets. Denote the set of one-hop neighbors of node A by $N(A)$ and the set of two-hop neighbors of node A by $N(N(A))$. Let the selected MPR set of node A be $MPR(A)$. The heuristic selection for MPR set is stated as follows:

1. Initiate an empty multipoint set, namely $MPR(A) = \emptyset$
2. Select nodes in $N(A)$ as MPRs which are only neighbors in $N(N(A))$ and include these MPRs in $MPR(A)$
3. While there still exist uncovered nodes in $N(N(A))$ by $MPR(A)$, add a node of $N(A)$ which covers the maximum number of the uncovered nodes to $MPR(A)$
4. Repeat steps (2) ~ (3) until all two-hop neighbors are covered by $MPR(A)$

The neighbor knowledge approach resolves the broadcast redundancy acquiring the local topology information. Thus, this approach efficiently reduces excessive redundant transmissions while attaining the goal of reliable broadcasting. Unfortunately, since each node periodically emits a hello packet to acquire the local topology, more overhead is generated than other approaches.

4. Hybrid broadcasting scheme

This section covers two broadcasting schemes based on a hybrid concept of area-based and neighbor knowledge approaches. These schemes requires the local knowledge of one-hop neighbors from the sender. Therefore, each node emits a hello packet periodically to directly connected neighbors to inform its presence. The underlying assumptions are that each node knows its physical location and all the nodes have an identical, omnidirectional antenna: a pair of nodes has a bidirectional link when the nodes are placed within the transmission range of each other.

Specifically, in the area-based approach, outer nodes have shorter waiting times than inner nodes to enlarge coverage area and to spread the packet rapidly. Geoflood, for example, allocates the minimum waiting time to the farthest node from the sender. However, the farthest node should hold the packet for the waiting time although it becomes the sender earlier than any other candidate after the previous sender. Further, other candidates should wait for more than necessity. Thus, high latency occurs in sparse networks and even in dense networks.

(Lee & Ko, 2006) introduced *flooding based on one-hop neighbor information and adaptive holding* (FONIAH) to reduce latency and unreliability. Each node accumulates hello packets from all its neighbors and makes the neighbor list in advance. When a node receives a previously unseen packet, it initiates a waiting time which is inversely proportional to the distance from the sender. During the waiting time, the node holds the packet and eliminates the IDs of neighbors transmitting the duplicate packet from the neighbor list. When the waiting time expires, the node discards the packet if the neighbor list is an empty set; whereas it forwards the packet for the rest.

In FONIAH, a waiting time $W(d, d_{max})$ is stated as a simple linear function:

$$W(d, d_{max}) = W_{max} - \frac{d \times W_{max}}{d_{max}} \tag{3}$$

where W_{max} is the predetermined, constant maximum waiting time. d is the distance from the sender. d_{max} is referred to as the maximum distance, which is the distance from the sender to the farthest one-hop neighbor of the sender. When the sender forwards the packet embedding the maximum distance, all its one-hop neighbors become candidates with different waiting times. Therefore, the candidates have relative waiting times. In other words, the farthest candidate from the sender rebroadcasts immediately as the packet arrives wherever it is placed.

Generally, the additional coverage of a node is dependent on both the distance from the sender and the location of the node. Therefore, although two nodes are located at the same distance from the sender as seen in figure 6, one covers more area than the another. In this figure, two nodes C and D receive the identical broadcast packet after retransmissions of nodes A and B. Since nodes C and D are placed at the boundary of the range of node B (i.e., the sender), both nodes have the same waiting time in FONIAH. That is, collision between nodes C and D occurs. Thus, one has to wait for more than its waiting time to help another's retransmission successful. This raises a question of which node should rebroadcast first.

In (Jaegal & Lee, 2008), *efficient flooding algorithm for position-based ad hoc networks* (EFPA) gives an answer to this question to attain the goal of the area-based approach, namely to enlarge the coverage area with less retransmissions. In figure 6, although nodes C and D

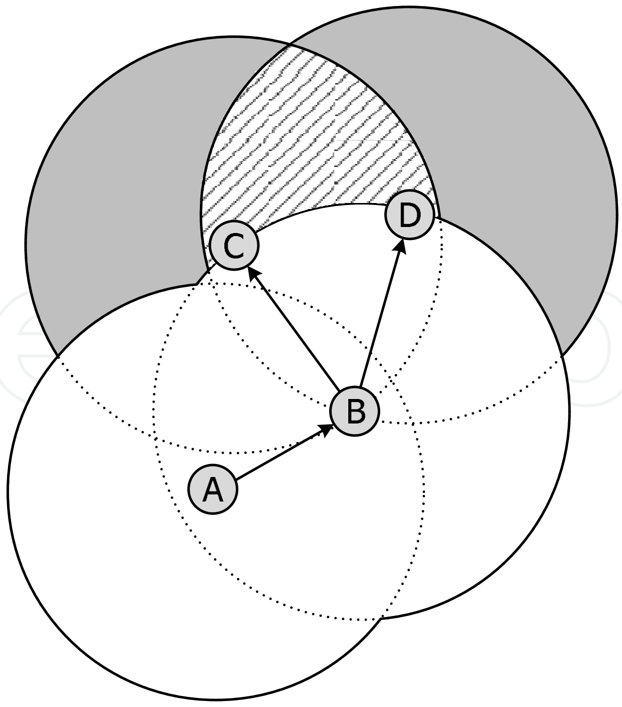


Fig. 6. A scenario where two nodes are placed at the boundary of the sender

have the same distance to the sender *B*, each additional coverage is different. The sender *B* has already covered the same amount of the coverage of nodes *C* and *D*, whereas the coverage of node *C* overlaps with the coverage of the former sender *A*. Thus, a node covers more additional area as it is farther away from the former sender. In other words, a node which corresponds to the direction of packet transmission has more additional coverage than other nodes.

EFPA utilizes the concept of a direction of packet transmission to reduce redundancy and to spread a packet rapidly throughout the network. EFPA proceeds in three phases: priority node selection, waiting time allocation, and packet drop. Once a node receives a packet with priority given by the sender, it immediately retransmits the packet to all its neighbors. Otherwise, a node with no priority examines the necessity of retransmission during a waiting time.

Each node collects the locations and the list of all one-hop neighbors via hello packets in advance. When a node (i.e., the current sender) decides to retransmit the packet, it calculates the distance to each one-hop neighbors and the direction of packet transmission from the former sender. The current sender embeds the ID of a node, which is the farthest towards the direction of packet transmission, in the packet. Figure 7 depicts the direction of packet transmission and priority node selection. Nodes *A* and *B* are the former and the current senders, respectively. The direction is merely determined as the line extension between the former and the current senders. As can be seen in the figure, node *C* is closer to the boundary of the range of the sender *B* than node *D*. However, the priority is given to node *D* since it is reached the farthest towards the direction of packet transmission.

Figure 8 shows an example to describe the difference of packet delivery between two cases where one considers the direction of packet transmission and another does not. These two cases are primarily based on the distance between nodes to determine waiting times: a waiting time is inversely proportional to the distance. In the case where nodes consider a direction of packet transmission, node n_1 which receives a packet from the source

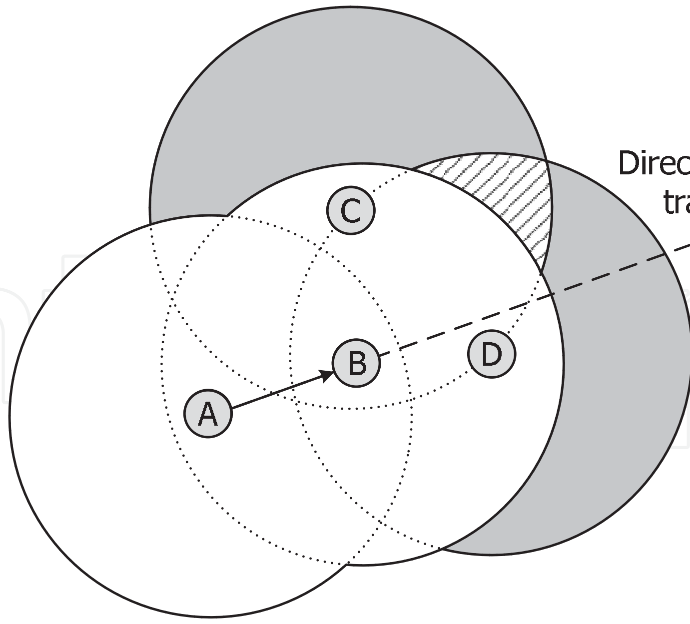


Fig. 7. The direction of packet transmission and priority node selection

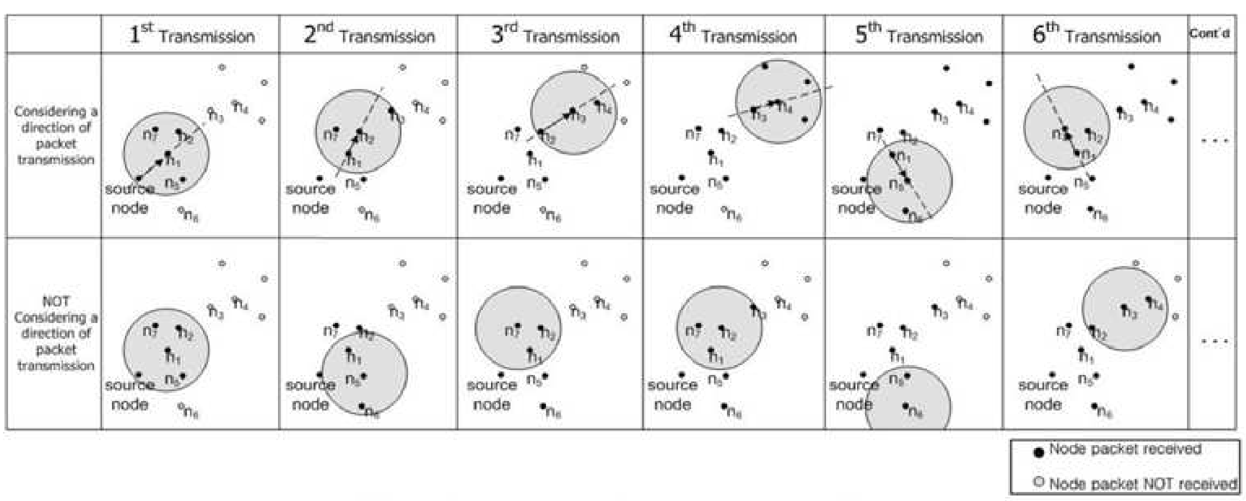


Fig. 8. Comparison of transmission procedure by whether a node considers a direction of packet transmission or not [taken from (Jaegal & Lee, 2008)]

rebroadcasts it to all its neighbors n_2, n_5, and n_7. The source receives the packet as well, but here it is neglected since it has already transmitted once. After retransmission of node n_1, nodes n_2, n_3, and n_4 as priority nodes deliver the packet in order. Nodes n_5 and n_7 retransmit the packet after their waiting times expire. On the other hand, in the case where nodes do not consider a direction of packet transmission, node n_5 becomes the sender after node n_1 because it has the shortest waiting time among the candidates, that is, node n_5 is the farthest node from node n_1. The rest of nodes also deliver the packet after own waiting time.

The priority is embedded in a packet by the sender. When candidates except for the priority node receive the packet, they set their own waiting times determined in inverse proportion to the distance from the sender as follows.

$$W(d,R) = W_{\max} - \frac{d \times W_{\max}}{T} \quad (4)$$

where W_{max} is the predetermined, constant maximum waiting time. d is the distance from the sender. T denotes the transmission range of the sender. Typically, the transmission range T of each node is assumed as identical. Thus, a waiting time is merely a function of the distance from the sender.

During the waiting time, each node examines the necessity of retransmission based on neighbor knowledge. Specifically, a packet is transmitted with the list of its one-hop neighbors of the sender. A node receiving the packet eliminates nodes of its neighbor's list that are included in the list of the sender. If all its neighbors are removed from the list, the node discards the packet since all the neighbors have already received the packet. Let $N(S)$ be the neighbor set of the sender S and $N(R)$ be the neighbor set of a receiver R. The packet drop is stated as follows:

1. If node R receives the duplicate packet from node S, the neighbor list of node R updates the list, namely $N(R) = N(R) - N(S) - \{S\}$
2. If node R has the empty neighbor set $N(R) = \emptyset$, it drops the packet
3. Whereas repeat steps (1) ~ (2) until the waiting time expires

In (Jaegal & Lee, 2008), the performance comparison of blind flooding, geoflood, FONIAH, and EFPA was well researched with metrics: average number of transmissions, average delay, and flooding completion time were used to capture broadcast redundancy, end-to-end latency, and time spent on packet delivery throughout the network, respectively. The simulation was performed using (ns-2, 1999) with GPSR (greedy perimeter stateless routing) (Karp & Kung, 2000). Nodes are randomly deployed in an experiment region of 2000m × 2000m. Each node transmits a packet with IEEE 802.11 MAC protocol and has the identical transmission range of 250m. Figures 9, 10, and 11 depict the performance of blind flooding, geoflood, FONIAH, and EFPA. Irrespective of the maximum waiting time, blinding flooding requires a node to rebroadcast a packet without a waiting time. Thus, this simplest approach has less delay than other schemes in spite of the heaviest overhead. An area-based scheme (geoflood) and its enhancement (FONIAH) have similar reduction on the number of transmission with increase of node where W_{max} = 0.05sec and W_{max} = 0.35sec When the maximum waiting time is set to 0.05sec, the difference between the time spent (including average delay and completion time) of geoflood and FONIAH is small, whereas noticeable

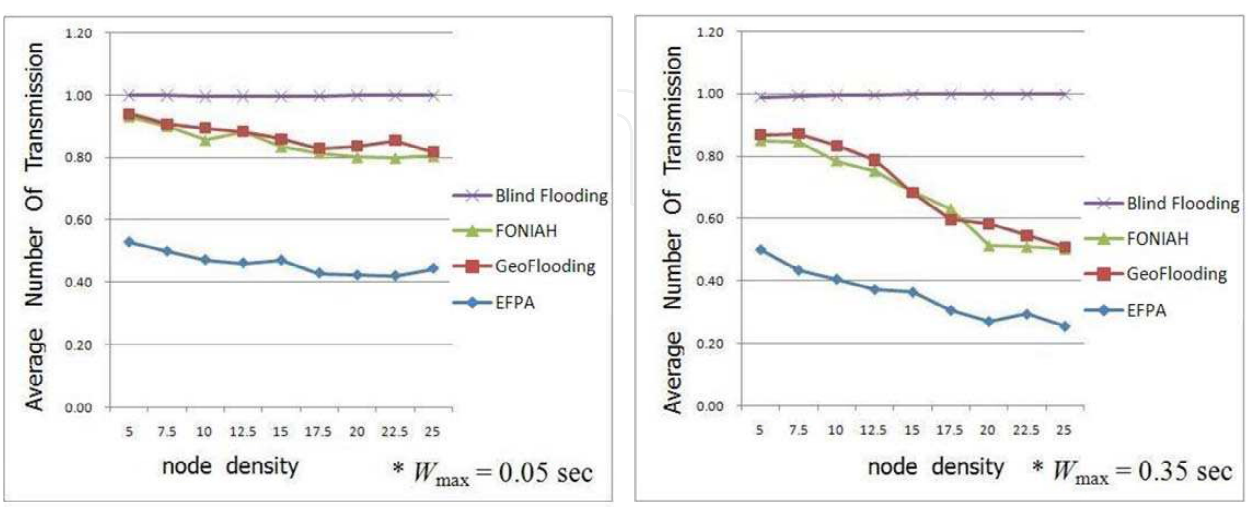


Fig. 9. Average number of transmissions with varying the maximum waiting time as 0.05sec and 0.35sec [taken from (Jaegal & Lee, 2008)]

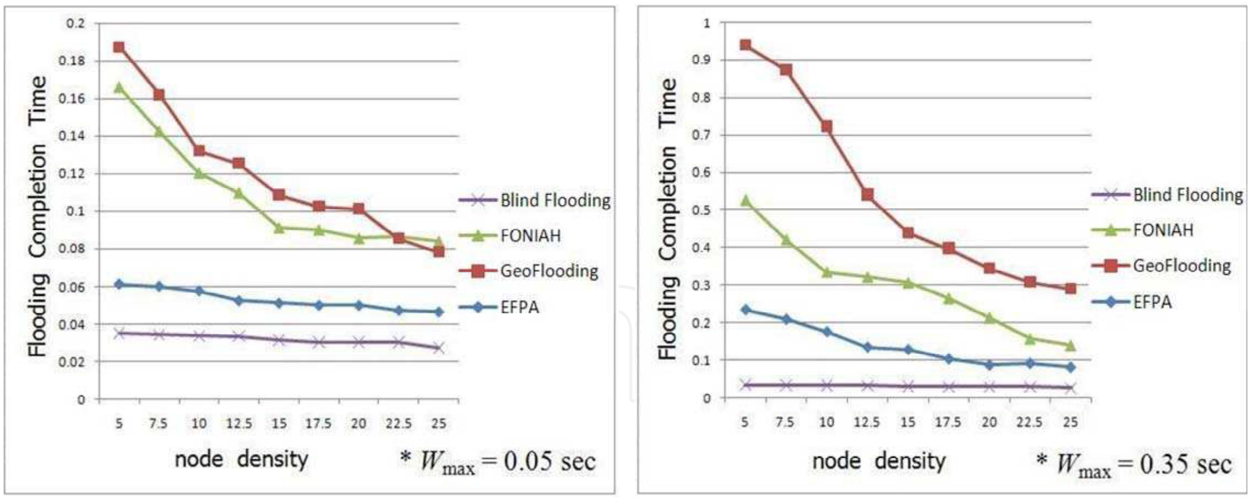


Fig. 10. Average delay with varying the maximum waiting time as 0.05*sec* and 0.35*sec* [taken from (Jaegal & Lee, 2008)]

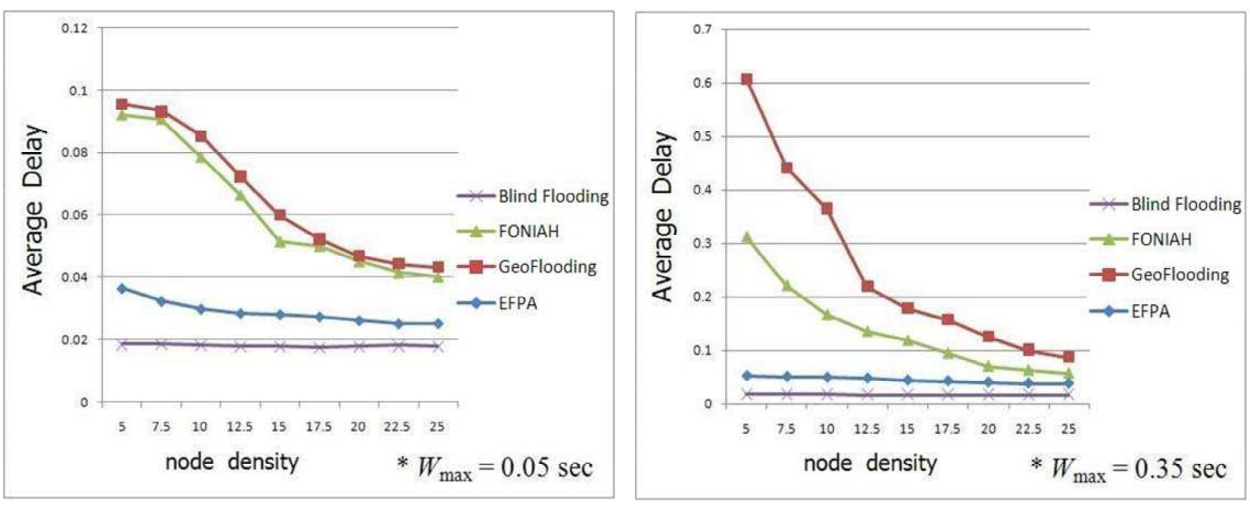


Fig. 11. Flooding completion time with varying the maximum waiting time as 0.05*sec* and 0.35*sec* [taken from (Jaegal & Lee, 2008)]

difference occurs in case when W_{max} = 0.35*sec*. Latency and completion time of FONIAH are considerably lower than those of geoflood as nodes are densely deployed. EEPA achieves rapid delivery throughout the network as fast as blind flooding and it noticeably alleviates the number of transmissions.

5. Conclusion

In this chapter, we discussed the issues behind supporting efficient broadcasting for MANET and previously published broadcasting schemes. The key argument of efficiency in broadcasting is reducing the amount of overhead introduced during the propagation of a packet to nodes in the network. The reason is that MANET is one of resource-constrained networks such as mobile networks and wireless sensor networks. More precisely, collision and contention are likely to occur due to wireless resource sharing under the condition that the resource is strictly limited. In addition to the problems, energy consumption is an important consideration.

The optimal reliable broadcasting is known as NP-complete even if each node has the global topology information. Hence, many of the broadcasting schemes require each node to listen to redundant packets during a short waiting time to examine the necessity of transmission. Since the waiting time may be a factor increasing end-to-end delay, some broadcasting schemes employs the concept of a hybrid approach to alleviate delay granting a priority to help a node rebroadcast immediately.

With the enhancement of the broadcasting approach, the performance has been considerably improved. Unfortunately, most broadcasting schemes presented here barely ensure the feasibility and practically in the real world because of the underlying assumptions such as static network model and error-free communication. Moreover, using extra devices such as ranging measurements and GPS is costly and power-intensive. Therefore, significant research effort is needed with consideration of high mobility and energy conservation.

6. References

Abramson, N. (1970). The Aloha System-Another Alternative for Computer Communications, *Proceedings of the Fall Joint Computer Conference (AFIPS'70)*, pp. 281-285, Montvale, Nov. 1970

Arango, J.; Degermark, M.; Efrat, A. & Pink, S. (2004). An Efficient Flooding Algorithm for Mobile Ad-hoc Networks, *Proceedings of IEEE Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt'04)*, Cambridge, Mar. 2004

Doherty, L.; Pister, K. S. J. & Ghaoui, L. E. (2001). Convex Position Estimation in Wireless Sensor Network, *Proceedings of the 20th Annual Joint Conference of the IEEE Computer and Communications Societies*, pp. 1655-1663, ISBN 0-7803-7016-3, Anchorage, Apr. 2001

Getting, I. A. (1993). Perspective/navigation-The Global Positioning System. *IEEE Spectrum*, Vol.30, Iss.12, Dec. 1993, pp. 36-47, ISSN 0018-9235

Ho, C.; Obraczka, K.; Tsudik, G. & Viswanath, K. (1999). Flooding for Reliable Multicast in Multi-hop Ad Hoc Networks, *Proceedings of the 3rd International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications (DIAL-M'99)*, pp. 64-71, Seattle, Aug. 1999

Jaegal, C. & Lee, C. (2008). An Efficient Flooding Algorithm for Position-based Wireless Ad Hoc Networks, *Proceedings of the International Conference on Convergence and Hybrid Information Technology*, pp. 13-20, ISBN 978-0-7695-3407-7, Busan, Nov. 2008

Jetcheva, J. G.; Hu, Y.; Maltz, D. A. & Johnson, D. B. (2001). A Simple Protocol for Multicast and Broadcast in Mobile Ad Hoc Networks. *Internet Draft of the Internet Engineering Task Force (IETF): draft-ietf-manet-simple-mbcast-01.txt*, Jul. 2001

Johnson, D. B. & Maltz, D. A. (1996). Dynamic Source Routing in Ad Hoc Wireless Networks, In: *Mobile Computing*, Tomasz Imielinski & Henry F. Korth, pp. 153-181, Kluwer Academic Publishers, ISBN 0792396979, Boston

Karp, B. & Kung, H. T. (2000). GPSR: Greedy Perimeter Stateless Routing for Wireless Networks, *Proceedings of the 6th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom'00)*, pp. 243-254, Boston, Aug. 2000

Lee, S. & Ko, C. (2006). An Efficient Neighbor Based Broadcasting for Mobile Ad Hoc Networks, *Proceedings of the International Conference on Computational Science (ICCS'06)*, pp. 1097-1100, ISBN 978-3-540-34381-3, Reading, May 2006

Lim, H. & Kim, C. (2001). Flooding in Wireless Ad Hoc Networks. *Computer Communications Journal*, Vol.24, No.3, Feb. 2001, pp. 353-363, ISSN 0140-3664

Lou, W. & Wu, J. (2002). On Reducing Broadcast Redundancy in Ad Hoc Wireless Networks. *IEEE Transactions on Mobile Computing*, Vol.1, Iss.2, Apr.-Jun. 2002, pp. 111-122, ISSN 1536-1233

Ni, S.; Tseng, Y.; Chen, Y. & Sheu, J. (1999). The Broadcast Storm Problem in a Mobile Ad Hoc Network, *Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom'99)*, pp. 151-162, ISBN 1-58113-142-9, Seattle, Aug. 1999

Niculescu, D. & Nath, B. (2001). Ad-hoc Positioning System (APS), *Proceedings of IEEE GLOBECOM 2001*, pp. 2926-2931, ISBN 0-7803-7206-9, San Antonio, Nov. 2001

Park, V. D. & Corson, M. S. (1997). A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks, *Proceedings of the 16th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM'97)*, pp. 1405-1413, ISBN 0-8186-7780-5, Kobe, Apr. 1997

Pearlman, M. R. & Hass, Z. J. (1999). Determining the Optimal Configuration for the Zone Routing Protocol. *IEEE Journal on Selected Areas in Communications*, Vol.17, Iss.8, Aug. 1999, pp. 1395-1414, ISSN 0733-8716

Peng, W. & Lu, X. (2000). On the Reduction of Broadcast Redundancy in Mobile Ad Hoc Networks, *Proceedings of the 1st Annual International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc'00)*, pp.129-130, ISBN 0-7803-6534-8, Boston, Aug. 2000

Perkins, C. E. & Royer, E. M. (1999). Ad-hoc On-demand Distance Vector Routing, *Proceedings of 2nd IEEE Workshop on Mobile Computing Systems and Applications*, pp. 90-100, ISBN 0-7695-0025-0, New Orleans, Feb. 1999

Qayyum, A.; Viennot, L. & Laouiti, A. (2002). Multipoint Relaying for Flooding Broadcast Messages in Mobile Wireless Networks, *Proceedings of the 35th Annual Hawaii International Conference on System Sciences*, pp. 3866-3875, ISBN 0-7695-1435-9, Big Island, Jan. 2002

Ryu, J.; Kim, M.; Hwang, S. & Han, K. (2004). An Adaptive Probabilistic Broadcast Scheme for Ad-Hoc Networks, *Proceedings of the 7th IEEE International Conference on High Speed Networks and Multimedia Communications (HSNMC'04)*, pp. 646-654, ISBN 978-3-540- 22262-0, Toulouse, Jun.-Jul. 2004

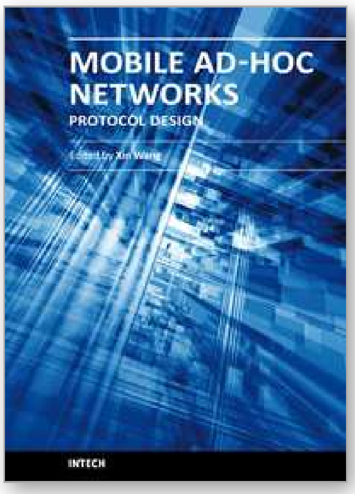
Saadawi, T. & Ephremides, A. (1981). Analysis, Stability, and Optimization of Slotted ALOHA with a Finite Number of Buffered Users. *IEEE Transactions on Automatic Control*, Vol.26, Iss.3, Jun. 1981, pp. 680-689, ISSN 0018-9286

Shang, Y. & Ruml, W. (2003). Improved MDS-based Localization, *Proceedings of the 23rd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM'04)*, pp. 2640-2651, ISBN 0-7803-8355-9, Hong Kong, Mar. 2004

Tseng, Y.; Ni, S. & Shih, E. (2001). Adaptive Approaches to Relieving Broadcast Storms in a Wireless Multihop Mobile Ad Hoc Network, *Proceedings of the 21st International Conference on Distributed Computing Systems*, pp. 481-488, ISBN 0-7695-1077-9, Mesa, Apr. 2001

Williams, B. & Camp, T. (2002). Comparison of Broadcasting Techniques for Mobile Ad Hoc Networks, *Proceedings of the 3rd ACM International Symposium on Mobile Ad Hoc Networking and Computing*, pp. 194-205, ISBN 1-58113-501-7, Lausanne, Jun. 2002

THE CMU MONARCH GROUP. Wireless and Mobility Extensions to ns-2. http://www.monarch.cs.cmu.edu/cmu-ns.html, Oct. 1999



Mobile Ad-Hoc Networks: Protocol Design
Edited by Prof. Xin Wang

ISBN 978-953-307-402-3
Hard cover, 656 pages
Publisher InTech
Published online 30, January, 2011
Published in print edition January, 2011

Being infrastructure-less and without central administration control, wireless ad-hoc networking is playing a more and more important role in extending the coverage of traditional wireless infrastructure (cellular networks, wireless LAN, etc). This book includes state-of-the-art techniques and solutions for wireless ad-hoc networks. It focuses on the following topics in ad-hoc networks: quality-of-service and video communication, routing protocol and cross-layer design. A few interesting problems about security and delay-tolerant networks are also discussed. This book is targeted to provide network engineers and researchers with design guidelines for large scale wireless ad hoc networks.