A Robust Flooding Algorithm in Multi-Radio Multi-Channel Wireless Mesh Networks

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Abstract—**Flooding, that is to deliver a packet from one node to all other nodes in the network, is an integral part of many wireless protocols. Flooding is often implemented by a series of broadcasts of each node and this causes some problems such as the broadcast storm and low reliability, by being engaged with the effects of radio signal propagation, e.g., multipath fading and interference. Many researchers have studied these problems over the years, however, most of these studies have been carried out assuming that all nodes in the network are equipped with a single radio interface and utilize only a single channel. This implies that most of the existing mechanisms that enhance the performance of flooding in wireless networks will not work in multi-radio multi-channel wireless mesh networks (MR-MC WMNs). Motivated by this, in this paper, we propose a flooding mechanism that works well in MR-MC WMNs. Our flooding mechanism, which can operate with an arbitrary number of radio interfaces and channels, increases the reliability of flooding while alleviates the broadcast storm problem, using only local information. Through a detailed simulation study, we demonstrate that our flooding mechanism improves both the reliability and the efficiency of flooding in MR-MC WMNs.**

I. Introduction

Wireless mesh networks (WMNs), where nodes connected by wireless links are organized in a mesh topology, have recently attracted much interest as an alternative to a wired infrastructure. WMNs can be connected to various networks such as the Internet, a cellular network, a sensor network or a wireless ad hoc network, and especially when connected to the Internet, they shall have commercial value in that they can expand Internet access at relatively low cost.

WMNs have received much attention from many researchers over the last few years. In particular, improving the network capacity of WMNs has been one of the most popular research topics in the literature for several years. The reason for this is that, in WMNs, achieving high network throughput is an essential requirement because WMNs function as an infrastructure. One effective method of improving the network capacity in WMNs is to utilize multiple channels. This method is to increase the available bandwidth by equipping nodes with multiple network interface cards (NICs) and assigning different channels to different NICs. According to a previous study [7], if using 2 NICs, the network throughput can be enhanced by a factor of 6 to 7 compared to using 1 NIC.

A point that should be carefully considered when using multiple channels is how to assign channels to NICs. This is a very challenging issue, for which it is known as NP-hard problem to find an optimal solution. Also, determining a routing path and scheduling packet transmissions are very challenging issues, as well. Those issues are all well-known and have been studied by many researchers for several years. For instance, the channel assignment problem has been addressed in [7–9], and works in [4–6] have studied joint routing and channel assignment. The scheduling problem has been studied as joint scheduling and routing [12] or joint scheduling, routing and channel assignment [10, 11].

A number of studies have been carried out on multi-radio multi-channel WMNs (MR-MC WMNs), however there still exist some issues in MR-MC WMNs that have not been studied extensively. Flooding in MR-MC WMNs is one of these issues. Flooding, which is to deliver data to all nodes in the network, is an integral part of many wireless protocols. Flooding is often implemented by a series of broadcasting[1] but this method is challenged by the following issues.

The first issue is that the broadcast storm [1], a situation in which some nodes receive redundant packets many times due to blind rebroadcasting, may occur. When this occurs, the number of contending nodes and the probability of collision increase rebroadcasting is generated, resulting in reduced network throughput. Therefore, the broadcast storm problem is an important issue that needs to be addressed in order to maximize the network throughput.

The second issue is that the reliability of data transmission is not guaranteed. In other words, flooding packets may be lost in an environment in which the channel quality is poor or the probability of collision is high. Low reliability of flooding results in performance degradation of mechanisms that exploit flooding because these mechanisms were designed upon the assumption that flooded packets are reliably delivered to all nodes in the network. For this reason, the reliability of flooding should be addressed with an great importance.

The above issues, which were first identified several years ago, have already been studied by many researchers and a number of mechanisms that address these issues have been proposed. In [15–17], the authors have proposed mechanisms that improve the efficiency of flooding by alleviating the broadcast storm problem, while in [19–21], various methods to improve the reliability of flooding have been proposed. The problem is that the proposed mechanisms consider only single-radio and single-channel (SR-SC), thus it is almost impossible to apply these mechanisms to MR-MC WMNs without much change.

Motivated by the above consideration, in this paper, we propose a flooding algorithm that works well in MR-MC WMNs. The proposed algorithm, called a robust flooding algorithm in MR-MC WMNs (FAM), alleviates the broadcast storm problem and at the same time increases the reliability of flooding in MR-MC WMNs. Although flooding in MR-MC WMNs has already been studied in [22–26], our study differs from these previous studies in that we studied the reliability issue without making any assumption about link quality, whereas the previous studies either did not address the reliability issue [22–24] or addressed the reliability issue based on strong assumptions about link quality [25, 26]. (We give a brief description of the previous studies in section II.)

This paper is organized as follows. We review related work in section II. The details of FAM is described in section III and section

[1]We use the term "broadcasting" to refer to transmitting a packet whose destination address is a broadcast address, rather than delivering a packet from one node to all other nodes in the network, which is referred to as "flooding" in this paper.

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IV shows results of performance evaluation of FAM. Finally, the main conclusions of this paper are presented in section V.

II. Related Work

L. Li et al [23] studied the broadcast storm problem in MR-MC networks. They modeled a MR-MC network as a directed simple graph and reduced a problem of minimizing the number of flooding packet rebroadcasts to the minimum connected dominating set (MCDS) problem in the graph. Then, based on the algorithm proposed in [18], they proposed a self-pruning protocol that finds an approximate solution of the MCDS problem.

Some other studies [22, 24] addressed the problem of minimizing the worst-case broadcast delay in MR^2-MC WMNs (multi-radio multi-channel multi-rate WMNs). In [22], four heuristic algorithms that construct a low latency broadcast tree were proposed. The simulation results of this work showed the proposed algorithms achieved low latency close to the theoretical optimal, but the problem is that all these algorithms operate in a *centralized* fashion, which implies that they are not scalable with respect to the number of nodes. The authors of [24] presented a four-stage *distributed* algorithm whose basic idea is to construct a CDS (connected domination set) consisting of nodes that can cover all nodes in the network with relatively high rate transmissions and to build a low latency broadcast tree over this CDS.

These works [22–24] are somewhat related to our work in that they studied flooding in MR-MC networks, however, they are fundamentally different from our work. This is because they excluded the reliability issue of flooding from consideration, i.e, they assumed that broadcast packets would not be lost, whereas our work aimed to address the reliability issue of flooding (as well as the broadcast storm problem) in MR-MC WMNs.

M. Song et al [25, 26] addressed the reliability issue of flooding in MR^2-MC WMNs. They divided all links in the network into *bad* links and *good* links, and proposed a two-phase distributed protocol that constructs a local structure by removing *bad* links in the first phase and builds a broadcast tree in the second phase. They claimed that their protocol achieves 100% reliability because the protocol builds a broadcast tree consisting only of *good* links but this claim requires the assumption that no packets are lost on *good* links and there is at least one path consisting only of *good* links between every pair of nodes in the network. Our work differs from this work in that our flooding mechanism, FAM does not depend on such an assumption. Rather than assuming the existence of error-free paths and finding those paths, FAM detects and recovers from packet losses using acknowledgement and retransmission mechanism, based on the consideration that packets may be lost on any link in the network. Another difference is that the overhead of FAM is not affected by the number of flooding sources, whereas the overhead of the protocol proposed by M. Song et al increases in proportion to the number of flooding sources because it constructs one tree per source. Considering that the possible number of flooding sources increases with increasing number of nodes in the network, this difference may result in a difference in scalability with respect to the number of nodes.

III. Algorithm Description

The purpose of this paper is to address flooding issues that have been studied extensively for SR-SC networks but not for MR-MC networks, such as the broadcast storm problem and low reliability. To achieve this purpose, we propose a robust flooding algorithm in MR-MC WMNs (FAM), which functions to increase the reliability and the efficiency of flooding in MR-MC WMNs. It improves the reliability with acknowledgement and retransmission mechanism and makes the number of nodes who rebroadcast the flooding packet as small as possible in order to increase the efficiency. In the following subsections, we describe the details of FAM.

A. Basic idea

A basic idea of FAM is to designate a certain node as a parent node for each node in the network and let a parent node guarantee reliable delivery of a flooding packet to its child node. A parent node is selected from among neighbor nodes [2] and a mathematical value calculated by using local information is used as a criterion for the selection. Every node in the network learns the mathematical value of each of nodes in the vicinity via local information exchange, and thus every node by itself can know who its parent node and child node is. A detailed description of how the mathematical value is calculated and nodes get to know this value is given in section III-B and III-C.

Given a list of child nodes, a node repeats a rebroadcast of a flooding packet until all its child nodes are confirmed to receive a flooding packet or the number of rebroadcasts becomes equal to a pre-determined maximum number of rebroadcasts. (If a node has no child nodes, it does not perform rebroadcasting, thereby alleviating the broadcast storm problem.) The question is how a parent node confirms that its child nodes have received a flooding packet. FAM lets a child node send an acknowledgement message (ACK) to its parent node so that receipt of a flooding packet can be acknowledged to its parent node. Conditions in which nodes have to send an ACK to their parent node, i.e., in which nodes have to inform their parent node that they receive a flooding packet can be summarized as follows. First, nodes should send an ACK when they receive a flooding packet for the first time. One exception, however, is that a node does not have to send an ACK if it will rebroadcast the received packet through the channel common to its parent node. In such a case, even without an ACK, a parent node can know that its child node has received a flooding packet by overhearing a rebroadcast of the child node.

Second a node should send an ACK when it receives a duplicate flooding packet, if the sender is its parent node and it is included in an *unacked list*. The *unacked list*, written into a flooding packet header by a node who rebroadcasts the packet, indicates a list of child nodes by which the packet is not acknowledged. The second condition cannot happen if an ACK transmission is always successful (because a node sends an ACK when receiving a flooding packet for the first time, by the first condition). However, in reality, an ACK can be lost and this is why this condition is required.

In the rebroadcasting algorithm of FAM, which can operate regardless of the number of communication channels, a node may not rebroadcast the packet, or rebroadcast the packet through some of the available channels, or rebroadcast the packet through all of the available channels, depending on who its child nodes are. (Fig. 1 shows an example of this selective rebroadcast operation.) This means that the number of rebroadcasts varies depending on which nodes are chosen as parent nodes, and therefore the parent node selection is an important issue in terms of the efficiency of flooding. The following subsections describe how FAM addresses this issue, i.e., how FAM chooses a parent node in detail.

B. Mathematical value calculation

As stated in section III-A, FAM uses a mathematical value as the criterion for the selection of a parent node. We now define this mathematical value. This value is defined for every pair of

[2]Neighbor nodes of a certain node n are nodes with which n can directly communicate through at least one of channels available to n.

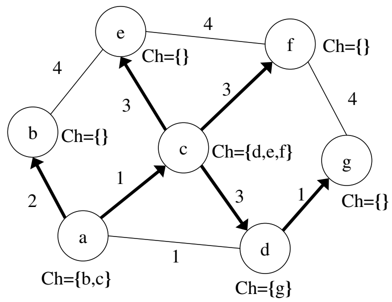


Fig. 1. A selective rebroadcast example. Ch denotes the set of child nodes. Node a will rebroadcast a packet through channel 1 and 2, c will rebroadcast through 3, d will rebroadcast through 1, and the others will not rebroadcast.

neighboring nodes. For a neighbor node j of node i, the value of j as a parent node of i, $M_{i,j}$ is defined as:

$$M_{i,j} = \frac{1 + F2_{i,j}}{F1_{i,j}}$$

The idea behind the definition of M is to make M have a negative correlation with the number of transmissions needed for reliable delivery of a flooding packet, by placing a factor considered to be positively correlated with this number ($F1$) in the denominator while a factor considered to be negatively correlated ($F2$) in the numerator. The reason why we add 1 to $F2$ is that we need to prevent the effect of $F1$ from disappearing where $F2$ becomes zero.

$F1_{i,j}$ is defined as the expected number of transmissions of node j for delivering a flooding packet to node i with near-perfect (0.99) reliability. A value of $F1_{i,j}$ is obtained from the following equation.

$$0.01 = (1 - LQ_{j,i})^{F1_{i,j}}$$

$LQ_{i,j}$ denotes the quality of the link from node i to node j. LQ ranges from 0 to 1 and is measured in a similar way as described in [2] and [3], that is, by exchanging sequence-number-stamped packets with neighbor nodes. $F1$, which decreases as link quality increases, is placed in the denominator of M and used for calculating $F2$.

$F2$, a factor reflecting the "wireless broadcast advantage" property [22] —the property that a transmission by a node can be received by all nodes which are within communication range and use the same channel—, is expressed as the product of two terms. For neighboring nodes i and j, the first term of $F2_{i,j}$ is the number of nodes who use channel $c_{i,j}$ among neighbor nodes of j except i, where $c_{i,j}$ denotes a channel shared by i and j. We denote the set of such neighbor nodes of j (i.e., neighbor nodes of j who use channel $c_{i,j}$ except i) by $N_{i,j}$ and thus the first term is denoted by $|N_{i,j}|$.

The second term is defined as the average value of $Q_{j,k}$ for all nodes k in $N_{i,j}$. $Q_{j,k}$ is a value that quantifies how much node k can be helped by transmissions of node j to receive a flooding packet. Suppose that T_k indicates the expected number of transmissions that should be performed by a parent node of k in order to deliver a flooding packet to k with near-perfect (0.99) reliability. Then, $Q_{j,k}$ is defined as a ratio of T_k of when j does not transmit a flooding packet to T_k of when j transmits a flooding packet $F1_{i,j}$ times.

$$Q_{j,k} = \frac{\log\ 0.01}{\log\left(\frac{0.01}{\max\{(1-LQ_{jk})^{F1_{i,j}}, 0.02\}}\right)}$$

where max {a,b} = the maximum of a and b. Note that we use $\max\{(1-LQ_{jk})^{F1_{i,j}}, 0.02\}$ instead of $(1-LQ_{jk})^{F1_{i,j}}$ in order to place limit on the value of $(1-LQ_{jk})^{F1_{i,j}}$ so that $Q_{j,k}$ does not have a negative value.

Since $F2_{i,j}$ is the product of $|N_{i,j}|$ and the average of $Q_{j,k}$ for all nodes k in $N_{i,j}$, $F2_{i,j}$ is expressed as:

$$F2_{i,j} = \sum_{k \in N_{i,j}} Q_{j,k}$$

C. Information exchange

Every node in the network obtains the value of M for every pair of nodes within two-hops, through the following local information exchange. Each node i first calculates $M_{j,i}$ for all its neighbor nodes j using the link quality information and channel assignment information provided by the underlying channel assignment protocol. Then, it delivers the calculated values of $M_{j,i}$ to all nodes within two-hops. It does not matter which method is used for the information delivery but the most straightforward method is to periodically broadcast a packet containing not only M values calculated by the transmitter itself but also M values calculated by neighbor nodes of the transmitter (if known). We use this method in our simulated experiments.

In addition to the values of M for every pair of nodes within two-hops, the locations of all nodes within two-hops are also known to every node in the network. This information is obtained by letting each node deliver its location, along with the M values, to all nodes within two-hops. The location of each node is assumed to be known to itself by GPS or localization schemes such as presented in [13, 14].

Every node writes its location into the flooding packet header if it is the first sender of a flooding packet, i.e., if it is a source node of flooding. By doing this, all nodes in the network get to know the location of a source node of flooding when they receive a flooding packet.

D. Parent and child node selection

Given the values of M for all pair of nodes within two hops, the locations of all nodes within two-hops, and the location of a source node of flooding, every node in the network determines for itself who its parent node is and whose parent node it is, i.e., who its child node is. Fig. 2 shows the decision algorithm in the form of pseudo-code. Line 7-12 shows that, among all nodes j in C_i, node i chooses a node that has the highest value of $M_{i,j}$ as its parent node. Line 13-22 shows that node i sets its neighbor node j as its child node, if i is in C_j and the value of $M_{j,i}$ is the highest among the values of $M_{j,k}$ for all nodes k in C_j.

A candidate set for a parent node of a certain node i, denoted as C_i, consists of neighbor nodes of i closer to a source node of flooding than i. (line 1-6). The aim of restricting the candidates for a parent node to neighbor nodes closer to the source node is to avoid the formation of a *loop*, a situation in which a node becomes an ancestor [3] of the node itself. (Fig. 3 shows an example of a *loop*.) In FAM, nodes can be guaranteed to receive a flooding packet only if the source node is their ancestor. However, if a *loop* occurs, some nodes cannot have the source node as an ancestor, resulting in a decrease in the reliability of flooding. For instance, in fig. 3, suppose that node a is a source node of flooding. Then, only b can receive a flooding packet, i.e., all other nodes except a and b cannot receive a flooding packet. This is why FAM prevents *loop* formation using the distance to a source node of flooding.

One drawback of restricting the candidates for a parent node by the distance to a source node of flooding is that the candidate set may be empty. If such a situation occurs, FAM designates all neighbor nodes as a parent node irrespective of the value of M and the distance to a source node of flooding. This is conservative but the best way to

[3] A parent node of a certain node i is an ancestor of i, and a parent node of an ancestor of i is also an ancestor of i.

```
• i : A node that excecutes this algorithm
• s : A source node of flooding

foreach neighbor node j of i
    if j is closer to s than i
        add j to set C_i

    foreach neighbor node k of j
        if k is closer to s than j
            add k to set C_j

M_max ← 0
foreach j ∈ C_i
    if M_{i,j} > M_max
        M_max ← M_{i,j}
        max_id ← j
set node max_id as a parent node

foreach neighbor node j of i
    if i ∉ C_j
        continue
    is_maximum ← 1
    foreach k ∈ C_j
        if M_{j,k} > M_{j,i}
            is_maximum ← 0
            break
    if is_maximum = 1
        set node j as a child node
```

Fig. 2. A parent and child node selection algorithm

guarantee reliable delivery of a flooding packet even when a *loop* occurs. (Note that a *loop* may occur when the candidate set is empty as the distance to a source node of flooding is ignored.)

The above decision algorithm is executed when a node receives a flooding packet, because the construction of a candidate set for a parent node requires the location of a source node of flooding. (Recall that the location of a source node is obtained from a flooding packet header.) Once a parent and a child node decision is made as a result of the above algorithm, the rebroadcasting algorithm described in section III-A is executed, resulting in reliable delivery of a flooding packet to a child node.

IV. PERFORMANCE EVALUATION

In this section, we demonstrate that FAM improves the reliability and the efficiency of flooding through simulated experiments. We have extended NS-2 simulator [27] to support multi-radio and multi-channel and have used it to perform simulations. Simulations have been conducted for three flooding mechanisms. One is FAM and another one is simple flooding, that is a mechanism by which every node in the network rebroadcasts the flooding packet one time. The other one, with which we compare FAM in order to demonstrate the efficiency of the parent node selection scheme of FAM, is identical to FAM except that a parent node is *randomly selected* from among neighbor nodes closer to a source node of flooding, which is called FAM/RAND.

A. Simulation environment

The environment in which the simulation takes place is as follows. In a 1 km * 1 km rectangular area, various numbers of nodes (10, 20, 30, 40, 50) whose communication range is 250 m are randomly distributed. All nodes are equipped with 2 IEEE 802.11 NICs and the number of communication channels is 12. The channel assignment is done in a random fashion, under the condition that different channels are assigned to each of NICs of the same node and the network is not partitioned due to the channel assignment. A link error is varied in terms of packet error rate (PER). PER is configured for each link and the value of PER of each link is randomly selected from the range [0.1, PER_{max}], where PER_{max} is one of 0.3, 0.4 or 0.5. During the simulation, which runs for 1 hour, one node is randomly chosen as a source node of flooding every minute and the chosen node initiates flooding.

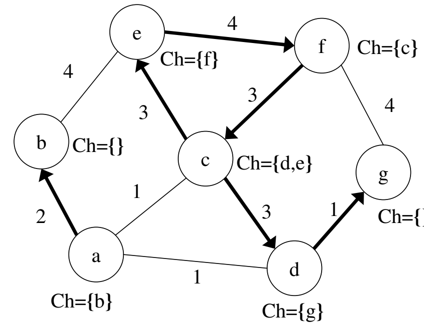


Fig. 3. A *loop* example. There occurs a *loop* consisting of node c, e and f.

B. Metrics

The simulation results are quantified by using the following three metrics. The first metric is *delivery ratio*, which is defined as the ratio of nodes that receive a flooding packet to all nodes in the network. The second one is the number of bytes transmitted per node during flooding, denoted as *bytes*. (Note that the number of bytes of ACKs and periodic broadcasts for the information delivery is also contained in *bytes*.) Lastly, in order to evaluate the reliability and the efficiency of flooding in a combined way, we utilize reliability-cost metric (RCM) [20], which indicates communication cost required to make *delivery ratio* greater than or equal to 0.99. RCM is expressed in terms of *delivery ratio* and *bytes*. Let R denote *delivery ratio* measured in the simulation. Then, the expected number of floods required to make *delivery ratio* greater than or equal to 0.99, F is calculated from the following equation assuming that F cannot be less than 1.

$$F = \begin{cases} 1 & \text{if } R >= 0.99 \\ \dfrac{\log\ 0.01}{\log\ (1-R)} & \text{otherwise} \end{cases}$$

Given F, RCM is defined as:

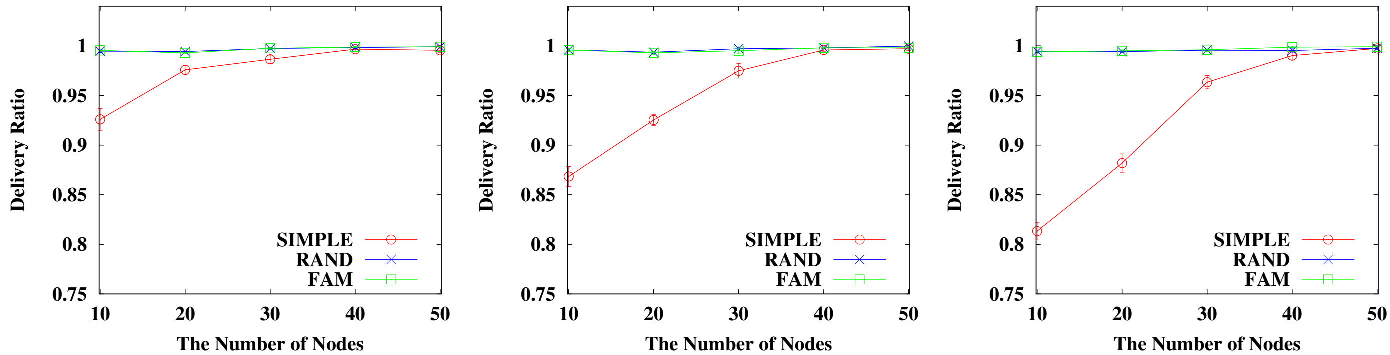
$$RCM = F * Bytes$$

C. Simulation results

Now we describe and analyze the simulation results, which are averaged over 10 runs with different random seeds and presented with 99% confidence intervals [4]. Note that, in the figures in this section, SIMPLE and RAND represent simple flooding and FAM/RAND, respectively.

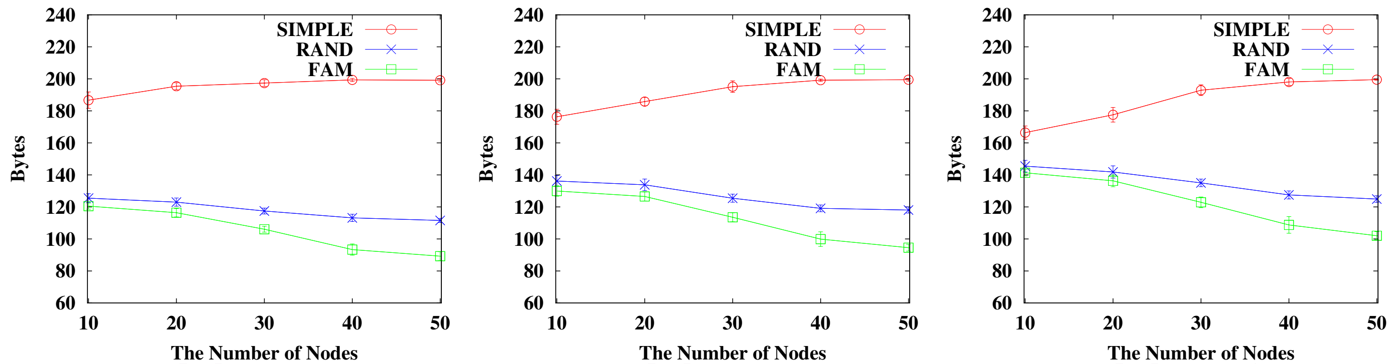
1) Delivery ratio: Fig. 4 shows *delivery ratio* of the three flooding mechanisms as a function of the number of nodes and PER_{max}. The figure shows that *delivery ratio* of simple flooding decreases as the number of nodes decreases, or as PER_{max} increases. An increase in PER_{max} can be interpreted as a general deterioration in the quality of the links, and therefore it is natural that *delivery ratio* of simple flooding decreases with increasing PER_{max}. The reason why *delivery ratio* of simple flooding decreases with decreasing number of nodes is that a decreased number of nodes reduces the average number of neighbor nodes, resulting in a decrease in redundancy. Contrary to simple flooding, FAM and FAM/RAND

[4]Confidence intervals for all data are shown as vertical lines but, for some data points, the vertical lines are so small that they are obscured by the symbol



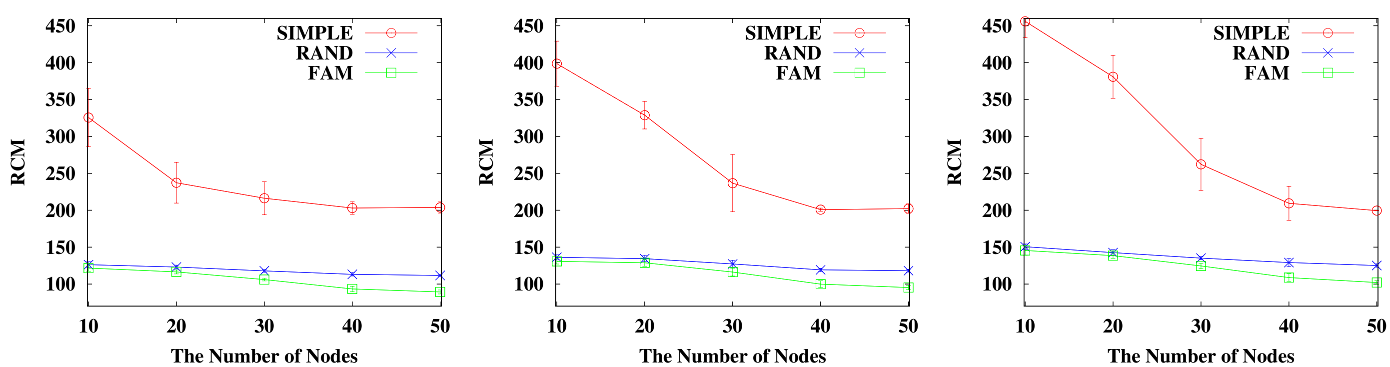
(a) PER_{max} = 0.3 (b) PER_{max} = 0.4 (c) PER_{max} = 0.5

Fig. 4. *Delivery Ratio*



(a) PER_{max} = 0.3 (b) PER_{max} = 0.4 (c) PER_{max} = 0.5

Fig. 5. $Bytes$



(a) PER_{max} = 0.3 (b) PER_{max} = 0.4 (c) PER_{max} = 0.5

Fig. 6. RCM

achieve *delivery ratio* very close to 1 regardless of the number of nodes and PER_{max}. Although *delivery ratio* of FAM and FAM/RAND is slightly lower than the ideal *delivery ratio*, that is 1 (because a few flooding packets are lost due to the limited number of retransmissions), we think that the difference is so small that it can be neglected.

2) Transmitted bytes: In the previous section, we have shown that FAM improves the reliability of flooding regardless of node density and link quality. Now the question is how much it costs to improve the reliability of flooding. Fig. 5 gives an answer to this question by presenting *bytes* as a function of the number of nodes and PER_{max}. According to Fig. 5, *bytes* of simple flooding varies between 165 and 200, and an aspect of the variation is very similar to that of *delivery ratio*. (In fact, *bytes* of simple flooding is proportional to the *delivery ratio*.) This happens because *bytes* of simple flooding consists of only flooding packet transmissions and only nodes that receive a flooding packet can rebroadcast the packet. Compared to simple flooding, FAM shows 22-60% less *bytes*. With less *bytes* than simple flooding, FAM achieves not only nearly equal *delivery ratio* to simple flooding (e.g., where the number of nodes is 50), but also greater *delivery ratio* than simple flooding (e.g., where the number of nodes is 10). Variations in *bytes* of FAM are characterized by two aspects. The first aspect is that *bytes* increases as PER_{max} increases, which can be explained by the fact that the average number of retransmissions increases with increasing PER_{max}. The second aspect is that *bytes* decreases as the number of nodes increases. This aspect arises because an increase in node density leads to an increase in the wireless broadcast advantage, i.e., an increase in the number of nodes that can receive the transmission of one node, and this results in a reduction in costs that each node has to pay for reliable flooding. FAM shows less *bytes* compared to FAM/RAND, as well. This result demonstrates the efficiency of the parent node selection scheme of FAM. The reason why the difference between *bytes* of FAM and FAM/RAND increases with increasing number of nodes is that the gain achieved by taking the wireless broadcast advantage into consideration when selecting a parent node increases as the number of nodes increases.

3) RCM: In this section, we evaluate joint reliability and efficiency of the flooding mechanisms by comparing RCM of them. See fig. 6 for RCM of the three flooding mechanisms as a function of the number of nodes and PER_{max}. For all the cases shown in fig. 6, RCM of FAM is more than 54% smaller than that of simple flooding. One notable point is that the differences between RCM of FAM and simple flooding show a wide variation. (The difference of RCM between them ranges from 98 to 312.) This wide variation is caused by the fact that RCM increases exponentially with decreasing *delivery ratio*. Since, as shown in Fig. 4, *delivery ratio* of simple flooding decreases with decreasing number of nodes or increasing PER_{max} while FAM always achieves *delivery ratio* very close to 1, the difference between RCM of them increases rapidly with decreasing number of nodes or increasing PER_{max}. In the case of FAM/RAND, RCM differences from FAM are quite small compared to the case of simple flooding. This is because FAM/RAND achieves nearly equal *delivery ratio* to FAM irrespective of the number of nodes and PER_{max} and therefore a difference between RCM of FAM/RAND and FAM is only determined by a difference of *bytes* between them.

V. Conclusions

In this paper, we have proposed a distributed algorithm for improving the performance of flooding regardless of the number of interfaces and channels. The proposed algorithm, FAM consists of two phases. In the first phase, a node dynamically decides who its parent node and child node is using as a decision criterion a mathematical value reflecting link quality and the wireless broadcast advantage. Then, in the second phase, a node reliably delivers a received flooding packet to its child node (if it exists), using an optimized acknowledgement and retransmission scheme. Through simulations, we have shown that FAM achieves near-perfect reliability irrespective of link quality and node density, at much less cost compared to simple flooding. In terms of RCM, FAM has shown a 54-72% performance improvement over simple flooding.

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