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Improvement of Counter-based Broadcasting by Random Assessment Delay Extension for Wireless Sensor Networks

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***Abstract*—Broadcasting is an elementary operation in wireless multi-hop networks. Flooding is a simple broadcast protocol but it causes serious redundancy, contention and collisions. Probability based methods are promising because they can reduce broadcast messages at the cost of slight additional hardware and without any control. In this paper, the counter-based scheme which is one of the probability based methods is focused on as a broadcast protocol, and the RAD (random assessment delay) extension is proposed to improve the original. The RAD extension can be realized by the almost same hardware as the original, so that the strength of the counter-based scheme is kept. Simulation results showed that the RAD extension can reduce the number of retransmitting nodes by about 10% compared with the original scheme.**

I. Introduction

Recent advances in micro-sensors, integrated circuit technology and low-power wireless communications will enable the deployment of extremely small, low-cost sensor nodes. Applications of sensor networks comprising numerous such sensor nodes include remote environmental monitoring, smart spaces, military surveillance, precision agriculture, and so on [1].

A multi-hop wireless sensor network comprises multiple small wireless sensor nodes, each of which is driven by a limited battery capacity. As the number of sensor nodes increases to several hundred or to several thousand, the persistent necessity of changing batteries would be a considerable burden. For that reason, it is highly desirable to reduce the power being used by each sensor node. A salient issue is reduction of the amount of transmitted data because wireless communications at sensor nodes consume more power than any other activity[2], [3].

Broadcasting (diffusing a message from a source node to all nodes in the network) plays an important role in multi-hop wireless sensor networks. This operation is used for path establishment in most of routing protocols. The most straightforward solution for broadcasting is a flooding (simple flooding), in which every node in the network retransmits an unseen received message once. However, the flooding may cause serious redundancy, contentions and collisions, known as a "broadcast storm" problem[4]. This problem leads to high overheads and high energy consumption. To solve the broadcast storm problem, various efficient broadcast protocols have been proposed.

In [5], broadcast protocols including simple flooding are classified into four categories:

1) *simple flooding*
2) *area based methods*
3) *neighbor knowledge based methods*
4) *probability based methods*

In simple flooding, every node retransmits an unseen packet once unconditionally. This scheme requires the least hardware due to its simplicity, but suffers the broadcast storm problem as mentioned above.

Area based methods exploit distance information between nodes or position information of nodes. Such information is useful to reduce the amount of unnecessary rebroadcasts. Nodes, however, need to be equipped with a Received Signal Strength Indicator (RSSI) or a Global Positioning System (GPS). Such additional functions increase the cost of nodes.

Neighbor knowledge based methods require that nodes send "Hello" packets periodically so that they know the neighbor information. According to the neighbor information, the nodes can suppress unnecessary broadcasts. Proactive types of routing for MANETs (Mobile Ad-hoc Networks) such as OLSR(Optimized Link State Routing Protocol)[6] are inherently based on "Hello" packet exchange, which is not a burden. In sensor networks, however, reactive types of routing such as directed diffusion[7] is likely to be used. In such cases, hello packet exchange incurs the large amount of communication overheads.

Probability based methods reduce the amount of unnecessary rebroadcasts though not to the extent of the other methods. This is achieved at the cost of slight additional hardware and without any control messages. Such features are desirable for sensor networks because the cost of nodes can be reduced and scarce wireless resource can be saved. In [5], *probabilistic scheme* and *counter-based scheme* are shown as examples of probability based methods. It is pointed out that counter-based scheme has adaptability to local topologies, more precisely, node density. This fact is supported in [4] where it is shown that counter-based scheme outperforms probabilistic scheme in terms of reachability and saved rebroadcast.

The contribution of this paper is to improve the counter-based scheme by controlling random assessment delay (RAD). In this paper, this improvement is called "RAD extension." As

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shown in IV, the number of retransmitting nodes is reduced by about 10% compared with the original coutner-based scheme.

The rest of this paper is organized as follows: Section II describes the original counter-based scheme. An improved counter-based scheme is proposed in Section III. Section IV presents some simulation results. Finally, conclusions are drawn in Section V.

II. Counter-based scheme

First let us consider expected additional coverage (area which can be newly covered) in simple flooding. Figure 1 shows the characteristics of the expected additional coverage provided by a node to newly rebroadcast after receiving multiple messages including the unseen and the duplicate ones as a function of the number of the received messages[4]. It is read from this figure that the expected additional coverage rapidly decreases with the number of received messages. That is, the more messages a node receives, the less benefit of its rebroadcast becomes.

This fact is involved in the counter-based scheme. A node with redundant messages more than a predefined threshold cancels to rebroadcast. The details of the original algorithm are shown below:

1) When a node receives a broadcasting message for the first time, the node initializes a counter to one, and sets a Random Assessment Delay (RAD) uniformly at random between 0 and $T_{\max}$.
2) If the node receives the same broadcast message during the RAD, the node increases its counter by one. Then, it cancels to rebroadcast if the counter reaches the preset threshold $C_{\rm th}$.
3) After the RAD expires, the node retransmits the broadcast message.

References [4] and [8] show that $C_{\rm th}$ set 4 to 6 is preferable from the viewpoint of the trade-off between reachability and saved rebroadcast. Note that the original counter-based scheme performs the same as the simple flooding in the case of $C_{\rm th} = 1$. Further, The rebroadcast is completed within $T_{\max}$ or halted. In this sense, $T_{\max}$ can be regarded as the maximum rebroadcast delay.

The counter-based scheme can reduce the number of retransmitting nodes just like an area based scheme, with a high arrival rate maintained. And this scheme needs neither hardware like an area based scheme nor additional communication cost like a neighbor knowledge based scheme. For this reason, the counter-based scheme can be regarded as a promising broadcast algorithm for wireless sensor networks.

There are some research efforts to improve the counter-based scheme[9], [10], [11]. In [9], a node sets the value of the counter threshold $C_{\rm th}$ according to the number of its neighboring nodes. Similarly, in [10], a node sets $C_{\rm th}$ according to the distance from the broadcasting node to itself. In [11], the RAD is a function of the the distance from the broadcasting node. These schemes, however, cooperate with a neighbor knowledge based scheme or an area based scheme. Such the cooperations possibly diminish the strength

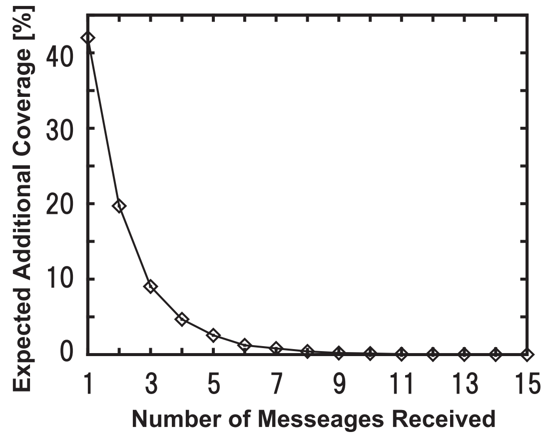

Fig. 1. Relation between the number of received broadcast messages and the expected additional coverage.

of the original counter-based scheme, that is, a very little extra hardware and no control traffic. As shown in Section III, there is still room for improvement without losing such features. This is our contribution in this paper.

III. Proposal Scheme

A. Basic Consideration

In this subsection, the reason why the redundant broadcast occurs in the original counter-based scheme is considered. For example, suppose the case of $C_{\rm th} = 4$ and the node placement shown in Figure 2. In this figure, the source node starts to broadcast. In this situation, the broadcast by the node D is almost futility, that is, the newly covered area is small. This is because the node D exists near to the source node.

The original counter-based scheme can not always prevent such a redundant retransmission. For example, suppose that each node set its RAD after receiving the broadcast message from the source as shown in Figure 2. In this figure, a circle denotes the communication range of the node at the center. Even though the node D will hear the same messages including the original one four times, the node D rebroadcasts since its RAD expires earlier than those of the node B and C. The node D can suppress the redundant rebroadcast if the node D happens to set its RAD longer than the other nodes. Such a probability is, however, only 0.25 in this case since the value of RAD is chosen uniformly at random. In order to increase success probability, the nodes with more redundant broadcasts had set their RAD longer. Unfortunately, however, the nodes can not predict the number of future received broadcasts at the moment of decision of the RAD.

Let us consider another example shown in Figure 3. In this figure, the node A and B exist near each other, and they set their RAD simultaneously at the reception of the broadcast of the source. Then the RAD of the node A expires at time t_1, and the node C and D set their RAD at the same time. In such a situation, the RAD of the node B tends to expire earlier than those of the node B and C. As a result, the node B possibly rebroadcasts although the area newly covered by the node B is small.

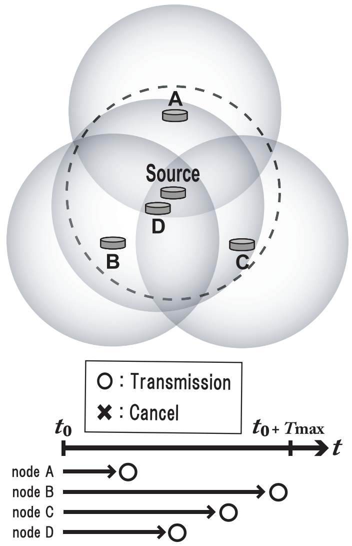

Fig. 2. An operational example of counter-based scheme (the case of one hop, $C_{\rm th} = 4$).

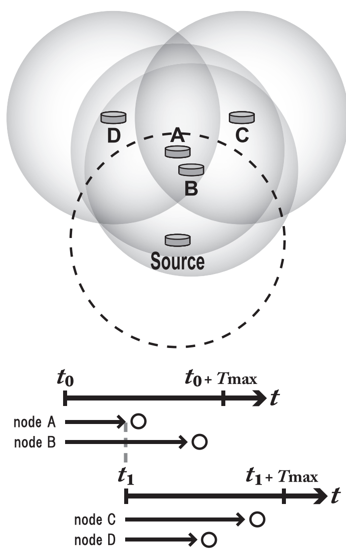

Fig. 3. An operational example counter-based scheme (the case of two hops, $C_{\rm th} = 4$).

B. RAD Extension

The problem considered in the previous subsection comes from the way to decide a RAD. In the original counter-based scheme, each node has no choice but to determine a RAD at random since it does not have any information such as the distance between the source and itself.

To mitigate this problem, we introduce "RAD extension" to the original counter-based scheme. The RAD extension makes nodes receiving more rebroadcasts have longer pseudo RAD. The details of the RAD extension are shown below:

1) When a node receives a broadcast message for the first time, the node initializes a counter to one, and sets a RAD uniformly at random between 0 and ΔT.
2) If the node receives the same broadcast message during the RAD, the node increases its counter by one. Then, it cancels to rebroadcast if the counter reaches the preset threshold $C_{\rm th}$; otherwise it extends the RAD by $\Delta T (= T_{\max}/(C_{\rm th} - 1))$.
3) After the RAD expires, the node retransmits the broadcast message.

Note that the counter-based scheme with the RAD performs the same as the original in the case of $C_{\rm th} = 2$. This is because retransmission will be canceled if even one duplicate is received during RAD.

Similarly to the original counter-based scheme, the rebroadcast is completed within $T_{\max} = \Delta T(C_{\rm th} - 1)$ or halted. The reason why the rebroadcast delay is bounded by $T_{\max}$ can be explained as follows. The initial value of a RAD is chosen over the range from 0 to ΔT. Further the RAD could be extended $(C_{\rm th} - 2)$ times at most. As results, the sum of the initial RAD and its extensions is less than $\Delta T(C_{\rm th} - 1)$.

Here let us consider how the RAD extension works in the previous examples.

Figure 4 shows a similar example to that shown in Figure 2. The node D extends its RAD twice due to the receptions from the node A and C. The counter of the node D reaches $C_{\rm th} = 4$ just after the reception from the node B, so that the node D halts rebroadcasting. The node D will fail only when its initial RAD is the shorter than those of the node A, B and C. Such a probability is 0.25. Thus the RAD extension increases the success probability from 0.25 to 0.75.

Next, Figure 5 corresponds to Figure 3. The node D extends its RAD at time t_1 due to the reception from the node A. At the same time, the node C and D set their initial RAD shorter than ΔT, so that their initial RADs expire by time $t_1 + \Delta T$. The extended RAD of the node D will surely expire after time $t_1 + \Delta T$, so that the node D receives the broadcasts from the node C and D. In the case shown in Figure 5, even if the node B happens to have a shorter RAD than the node A, the node A can suppress rebroadcasting instead of the node B.

As mentioned above, the RAD extension is expected to reduce unnecessary rebroadcasts even if not perfect. In the next section, we show some simulation results to verify the effect of the RAD extension.

IV. Performance evaluation

In order to verify the effect of the RAD extension, we performs simulation experiments by using QualNet[12]. For each parameter setting, 50 trials with different random seeds were executed and the average value of them are plotted in the following graphs.

A. Parameter Settings

A simulation area is set to $100\text{m} \times 100\text{m}$, and sensor nodes are deployed randomly in the area. A base station is placed in the center of the simulation area, and it performs

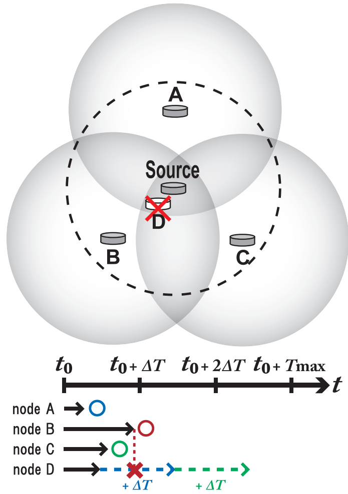

Fig. 4. An operational example of counter-based scheme with RAD extension (the case of one hop, $C_{\mathrm{th}} = 4$).

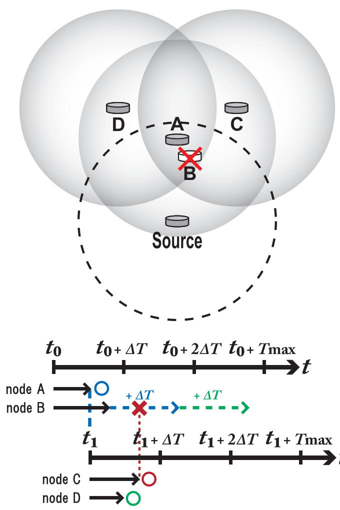

Fig. 5. An operational example of counter-based scheme with RAD extension (the case of 2 hops, $C_{\mathrm{th}} = 4$).

broadcasting. The transmission range is set to about $20\mathrm{m}$. It is assumed that the transmission power is $800\mu\mathrm{W}$, the reception power is $500\mu\mathrm{W}$, the idle power is $0.5\mu\mathrm{W}$, and the battery capacity of each sensor node is $500\mathrm{mJ}$[13]. LPL (Low Power Listening)[14] is used as an MAC (Medium Access Control) protocol. Packet size of a broadcast message is set to 48 bytes.

B. Simulation Results

In this paper, the number of retransmitting nodes, reachability, and latency (shown as end to end delay in the graphs) are used as performance metrics. Here, latency is defined as the time after the base station transmits a broadcast message until the last rebroadcast is completed.

The counter-based scheme has two control parameters $T_{\max}$ and C_{th} regardless of with or without the RAD extension. The longer $T_{\max}$, the less collisions but the larger latency. The value of C_{th} controls the trade-off between the number of retransmitting nodes and reachability.

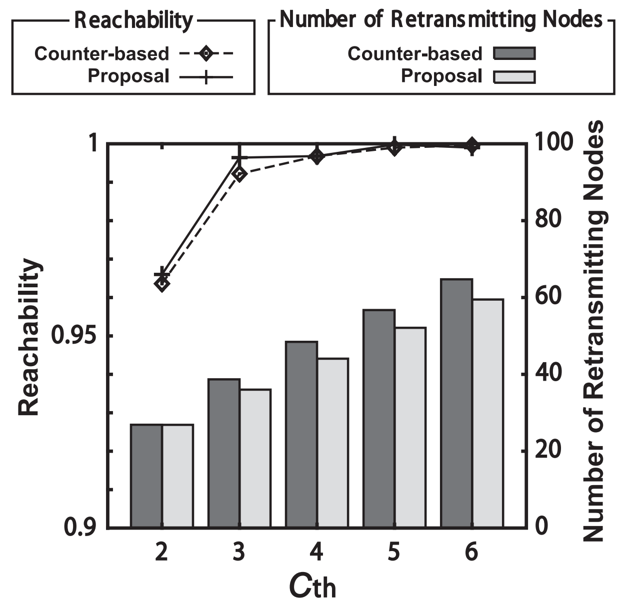

Fig. 6. Counter threshold C_{th} versus reachability and number of retransmitting nodes (number of nodes = 100).

First, the counter threshold C_{th} is varied. Figure 6 shows the number of retransmitting nodes and reachability against C_{th} in the counter-based schemes with and without the RAD extension. In this graph, the number of nodes is set to 100, and $T_{\max}$ is set to 15 s. As shown in this graph, there is no significant difference in reachability, and when C_{th} is 4 or more, the reachability is over 99.5%. On the other hand, the RAD extension reduces the number of retransmitting node by about 10% when C_{th} is set to three or more. As mentioned in Section II, when C_{th} is set to two, number of retransmitting nodes is the same regardless of with or without the RAD extension.

Next, the value of $T_{\max}$ is varied. Here, the number of nodes is set to 100, and C_{th} is set to four. Figure 7 shows the relationship between reachability and $T_{\max}$. It is read from this figure that reachability is hardly influenced by $T_{\max}$. In both the counter-based schemes with and without the RAD extension, reachability drops in the case of too small $T_{\max}$. This is because broadcast messages are transmitted by some nodes during a short period, so that they tend to collide each other. Even though the RAD extension had possibly made this tendency stronger because the initial RAD is chosen in a shorter range, the difference between with and without the RAD extension is not significant. This is because the number of the competing nodes to broadcast decrease as their RAD extensions are repeated.

Figure 8 shows the relationship between the number of retransmitting nodes and $T_{\max}$. The number of retransmitting nodes cannot be reduced enough in the case of too small $T_{\max}$ This is the same reason as reachability. However, the number

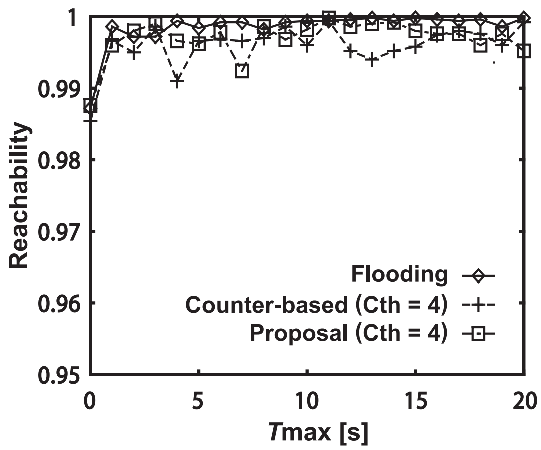

Fig. 7. Maximal value of RAD $T_{\max}$ versus number of reachability ($C_{\mathrm{th}} = 4$).

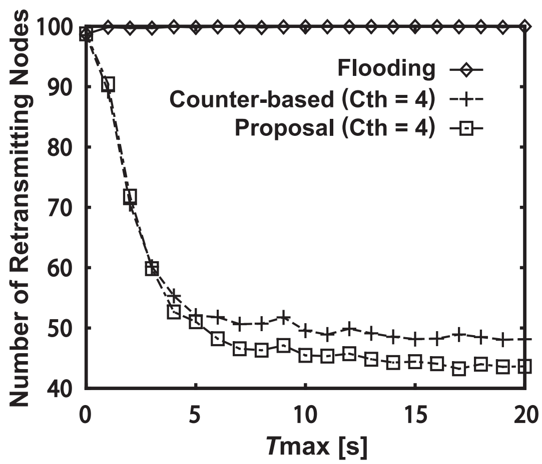

Fig. 8. Maximal value of RAD $T_{\max}$ versus number of retransmitting nodes ($C_{\mathrm{th}} = 4$).

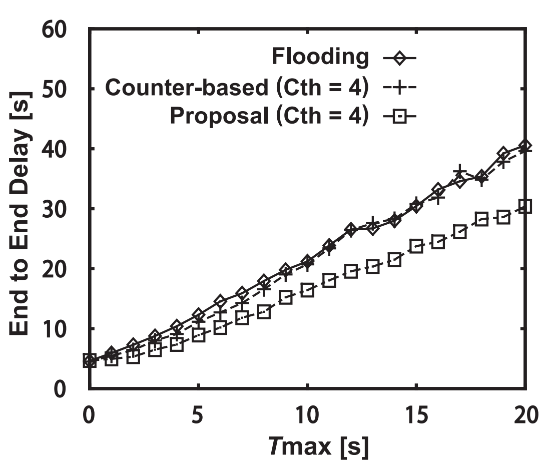

Fig. 9. Maximal value of RAD $T_{\max}$ versus latency ($C_{\mathrm{th}} = 4$).

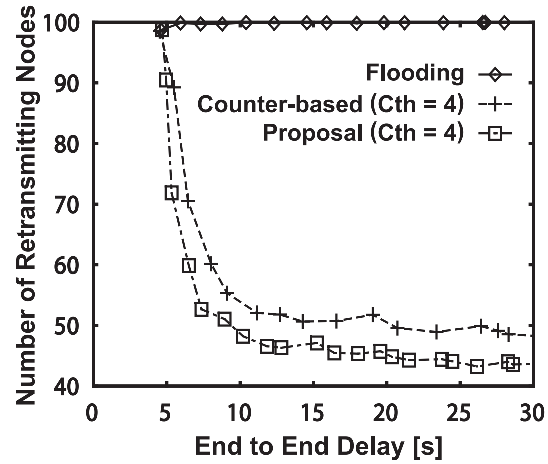

Fig. 10. Latency versus number of retransmitting nodes ($C_{\mathrm{th}} = 4$).

of retransmitting nodes decreases with the value of $T_{\max}$, and the RAD extension outperforms the original counter-based scheme when $T_{\max}$ is set to 5 ms or more.

Next, Figure 9 shows the relationship between latency and $T_{\max}$. It is read from this figure that latency increases linearly with $T_{\max}$. Further, latency in the RAD extension is smaller than the original. This is because the initial RAD is chosen in the smaller range in the RAD extension. This fact encourages a broadcast to diffuse rapidly.

Figure 10 illustrates the relationship between the number of retransmitting nodes and latency. In this figure, it is shown that the RAD extension can suppress the number of retransmitting nodes under the condition of the same latency.

V. Conclusion

In this paper, the counter-based scheme was focused on as a broadcast protocol for wireless sensor networks, and the RAD (random assessment delay) extension has been proposed to improve the original. Simulation results showed that the RAD extension can reduce the number of retransmitting nodes by about 10% compared with the original scheme. The RAD extension can be applicable for any other broadcast algorithms to use the RAD. We will further investigate these cases in the future.

Acknowledgment

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