Performance Analysis of Hybrid-based Packet Forwarding in Wireless Sensor Networks

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***Abstract*—In Wireless Sensor Networks, preserving energy is very important to prolong the sensor node's life. Duty cycle mechanism could preserve the node's energy by providing active and sleep period. However, the uncontrolled duty cycle may affect the delivery rate due to its inconsistency of relay participation in multi-hop packet forwarding. We have observed the effect of duty cycle mechanism to deliver data with a broadcast flooding; which we know that flooding is a fundamental network service for disseminating data. From our observation, controlling a contention window size based on node's density takes an important part in reducing packet collision that leads to a good packet delivery rate. However, in a congested traffic, controlling contention window size based on node's density is not enough because the incoming packet may be congested in packet buffer which is resulting to a packet dropping. Thus, in this paper, we proposed a hybrid-based packet forwarding to increase the reliability of transmission by controlling the number of contention window size based on the node's density and packet buffer information. To preserve the energy of the nodes, we also implemented the probability-based broadcast to suppress the number of unnecessary traffic. We compared our work with broadcast flooding, adaptive contention window size, and distance-based broadcast. From our experiment, Hybrid-based packet forwarding achieved the best performance in packet reception rate and can control the unnecessary traffic better than others.**

***Index Terms*—Wireless Sensor Networks, reliable packet forwarding, buffer overflow, hybrid-based.**

I. Introduction

Duty cycle is considered as one of the good solution to preserve the node's energy in Wireless Sensor Networks (WSN)[1]. Duty cycle scheduling is done periodically to control active and sleep time for WSN devices. This uncertain active and sleep state cause the quick changing of network topology. The predecessor routing protocol, such as dynamic source routing (DSR) [2], is not suitable for this dynamic topology because the information of the route may be invalid if the topology is changing very quickly. Thus, broadcast flooding may be a good choice as a packet forwarding mechanism to deliver data from the source to the sink node [3].

However, the broadcast flooding has so many drawbacks such as creating packet collisions due to relay selection especially in high density nodes. It can be solved by suppressing the number of collision by controlling the packet contention. In [4], they control the packet contention of multi-hop packet forwarding using a counting-based probability model to predict the effective contention window size of transmission. To support this argument, we have observed the effect of contention window size to the performance of packet reception rate (PRR) in duty cycle scenario, which is depicted in Figure 1. The parameter of our experiment is shown in Table I. From this observation, we understand that the duty cycle (DC) is affecting the network performance by reducing the packet reception rate, compared to the performance without DC. Controlling the contention window (CW) size increases the PRR at 5%, 10%, and 15% traffic generation probability. Various works have been performed to improve the throughput with the involvement of CW size and duty cycle analysis [5–8].

Another drawback of broadcast flooding is it tends to create a traffic duplication due to rebroadcasting. In WSN, using unnecessary traffic may drain node's energy. Thus, we need to suppress as many unnecessary transmission as possible. To solve this problem, the probability-based packet forwarding is adopted to preserve the number of relay node candidates[9]. The distance based (DB) packet forwarding can also suppress broadcast relay by filtering the packets based on their distances to the sink [10]. If the relay's distance is larger than the source,

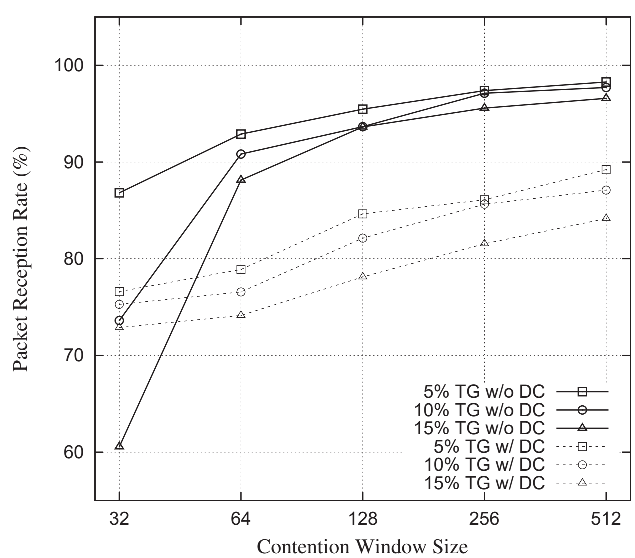

Fig. 1. Observation of CW size to achieve packet reception rate on duty-cycle and non-duty-cycle scheme.

then it will not queue the packet. In this way, the amount of traffic can be cut down.

Packet forwarding, especially the broadcast flooding, is sensitive to the high density nodes and high traffic. To prove that our solution can handle this problem, we performed the simulation based on high density nodes and high traffic scenario. These extreme condition of network traffic and node's density may affect to the packet buffer overflow which is leading to a packet dropping. Several works related to this congestion control have been performed in [11, 12].

There will be a trade-off between achieving a good packet reception rate and preserving unnecessary transmission of relay nodes in broadcast packet forwarding. Cutting off the traffic may be good for preserving energy of the nodes, but on the other hand, it also reduces the number of relay node's candidates, which leads to the delivery failure. Thus, tuning on some parameters that affecting the network performance, such as tuning on CW size based on node's density and the packet buffer overflow, may give us a better delivery rate. So, in this paper, we present the Hybrid-based (HB) packet forwarding that involving those parameters to achieve better packet reception rate in duty cycle scenario. Moreover, the probability-based broadcast is adopted to achieve less unnecessary traffic that can save more energy for the nodes.

II. Hybrid-based Packet Forwarding

The idea of this solution is tuning-up the parameter to get the better packet delivery rate and to suppress the network traffic. In [4], they proposed the counting-based probability model that can find the effective CW size for broadcast transmission. In their final solution, they stated that to achieve a good packet reception rate, the CW size should be at least as big as the number of the nodes in the system. In that case, we implemented the adaptive window size that can change its CW size regarding to the number of neighboring nodes. The calculation of effective window size is valid only for single packet generation. Thus, to improve the performance of multiple packet generation, we need to set up the CW size to the upper-bound of each existing CW size such as 32, 64, 128, and 256 for a given number of neighbors.

In order to avoid packet dropping, which is caused by packet buffer overflow, we implemented the CW size adjustment based on packet buffer information. So, if the current buffer is reaching a half of buffer size, then increase the CW size into $CW + 16$. As we increase the number of CW size, the buffer should not be increasing to the maximum buffer size. However, CW is not increased if CW>CW_max. CW is reduced to $CW - 16$ if the current_buffer<buffer_size to reset its CW size in a lower network traffic. CW is reset to CW_min if the network traffic becomes the lowest.

We assume most of the traffic is occupied by traffic from the source node (end device) to the sink node (gateway). Thus, giving a node, which is farther to a sink, a chance to be a relay node will be a waste of energy. Thus, we implemented the distance-based prioritization for adjusting CW size to prioritize the nearest node to be selected as relay node. As we used the term of priority, we do not cut off a chance of the farther node to be a relay node candidate. Thus, if the nearest nodes fail to deliver the data, the farther nodes can be a backup relay node.

Extending CW size also creates another problem in consuming more energy. It means more waiting time and process time. If the waiting time is longer than Duty cycle period, then the packet will not be transmitted due to inactive state. To avoid this problem, we try to suppress the number of relay node's candidate by providing a probability-based transmission. The node will transmit a packet with probability p. So if generated $p < p\_threshold$, then packet is not pushed to the packet buffer. Then it will save the energy of the nodes. The full algorithm of Hybrid-based can be seen in Algorithm 1.

Algorithm 1 Hybrid-Based Packet Forwarding Scheme

```
NEIGHBOR_SENSING();                          ▷ broadcast beacons
set CW_min = 32, CW_max = 1024;
set CW regarding to neighbor_sensing()
if (neighbor < 32) then CW = 32;
else if (neighbor < 64) then CW = 64;
else if (neighbor < 128) then CW = 128;
else CW = 256
end if
DC_counter = 0                               ▷ Reset Duty Cycle counter
p = 80                                       ▷ set tranmission probability
procedure RECEIVING_WINDOW()
    if DC_count = threshold then
        ifsleep → node_is_active = true;
        ifactive → node_is_active = false;
    end if
    if (source_dist > relay_dist) then
        backoff = rand(CW);
    else backoff = rand(CW + 16);
    end if
    if (node_is_active & pkt_rcv) then
        if (buffer < thold & rand(100) < p) then
            packet → buffer;
        end if
    end if
    if (buffer_size > thold/2) then
        if (CW < CW_max) then CW = CW + 16;
        end if
    else
        if (CW > CW_min) then CW = CW − 16;
        end if
    end if
    check1^st element of packet buffer;
    if (backoff = 0) then TRANSMIT();
    else backoff = backoff − 1;
    end if
    if (packet_is_generated) then
        backoff = rand(CW);
    end if
end procedure
```

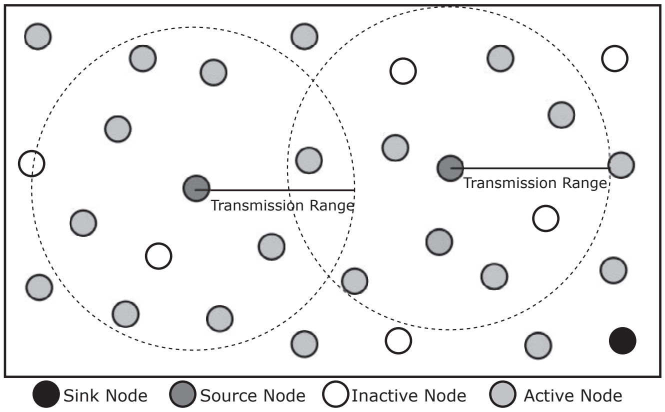

Fig. 2. Broadcast packet forwarding with duty cycle scenario.

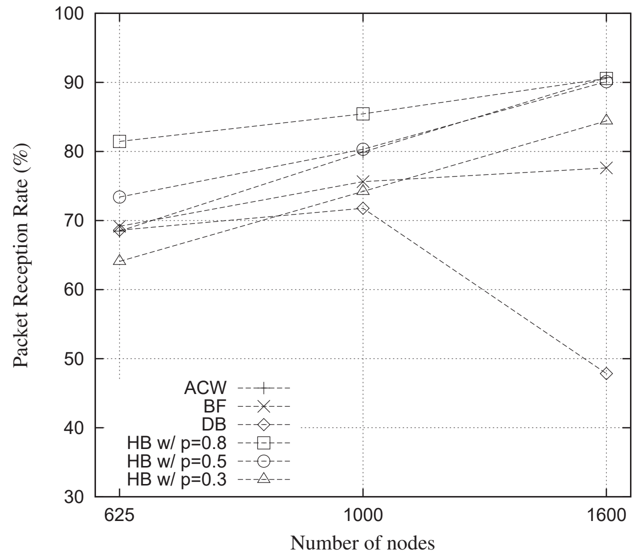

Fig. 3. Packet reception rate of several techniques with various number of nodes (625, 100, 1600).

III. Performance Evaluation

To evaluate our scheme, extensive simulations have been performed with several scenario of traffic generation and node density variations. The parameter of our simulation is mentioned in Table I. In our scenario, which is depicted in Figure 2, we deployed 625, 1000, 1600 nodes on the 500 m $\times$ 500 m area of simulation. The packet is generated every 2 minutes with varied traffic generation from 5%, 10%, and 15% of total number of the nodes. The duty cycle is set by 50% of total 4 minutes duty cycle period. It means the node may active and sleep every 2 minutes. For the simulator, we have implemented our own simulator by using C++ language.

In this simulation, we measured two performance metrics of adaptive contention window (ACW), broadcast flooding (BF), distance-based (DB), and hybrid-based (HB) as the network density is changed. The first metric is a packet reception rate (PRR) to measure the reliability of transmission. The second metric is a transmission attempt to measure the node activity that shows the effectiveness of our scheme in preserving node's energy compared to the other schemes.

The purpose of this simulation is to investigate the effect of our CW size tuning based on node's density and packet buffer information to the performance of packet reception rate. Figure 3 shows the PRR of 4 different techniques in various node's density. Our scheme (HB) outperformed other packet forwarding scheme with $PRR = 80\%$ for $n = 625$ nodes, $PRR = 85\%$ for $n = 1000$ nodes, and $PRR = 90\%$ for $n = 1600$ nodes. HB can maintain its performance gradually as the number of nodes is increasing. It means the CW size adjustment based on node's density and packet buffer information is performing very well. Even though ACW achieved the same result as HB with $PRR = 90\%$ for $n = 1600$ nodes, the CW size adjustment at $n = 625$ nodes gives only 68% of PRR. Density-based performed the lowest with $PRR = 48\%$ for

TABLE I
Simulation Parameters

Parameters	Value
Area of simulation	500 m $\times$ 500 m
Number of nodes	625, 1000 (default), 1600
Transmission range	100 m
Data rate	250 kbps
Payload	200 Bytes
Packet buffer size	32
Packet generation probability	5% (default), 10%, 15%
Duty Cycle (active and sleep every 2 minutes)	50%
Packet generation period	2 minutes
Fix CW size	32, 64, 128, 256, 512
Transmission Probabiliy (p) for HB	0.8, 0.5, 0.3
Slot	320 us
Number of Iteration	10 simulations

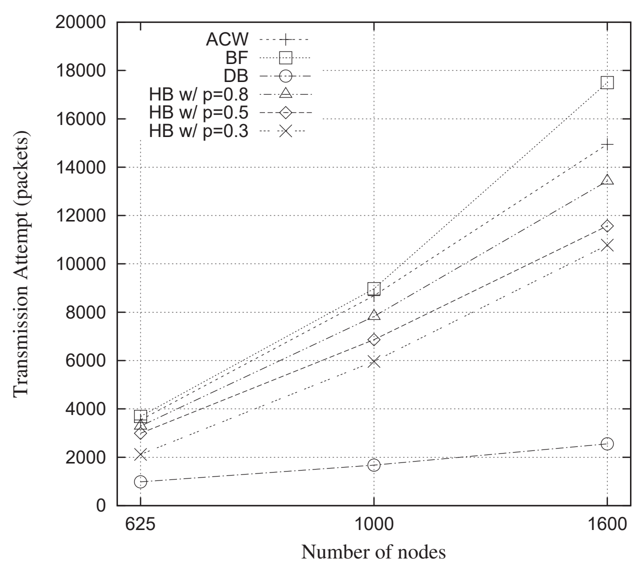

Fig. 4. Average transmission attempt of all nodes in our experiment.

$n = 1600$ nodes. The performance of BF is similar to the result given by Figure 1 in $CW = 32$ with $PRR = 70\% - 80\%$. HB achieved better PRR than ACW because it can adjust its CW size based on the condition of its packet buffer. Moreover, as the transmission probability (p) is decreased in HB, the PRR is also decreased. It means reducing the relay node's candidates by giving a small number of transmission probability may reduce the reliability of transmission.

In Figure 4, the node's activity is measured in term of the transmission attempts occurred. The purpose of this measurement is to investigate the effect of giving transmission probability in suppressing relay node's candidate to the transmission attempt occurred in the system. The lowest transmission attempt achieved by DB because it can cut off almost half of the relay node's candidate. Since the number of generated packet is very high and the CW size of DB is around 32, so its PRR is the lowest among others. It means the energy saving on DB is useless compared to the PRR that is gained. HB can achieve better result compared to the others except DB in this performance metric. By tuning the transmission probability ($p < 0.8$), we can see that it can achieve better suppression but it sacrifices the PRR. From this observation, the packet buffer information and node's density can also adjust the value of transmission probability to achieve better PRR and reduce network traffic.

IV. Conclusion

In this work, we observed that the contention window size increases the performance of PRR and the duty cycle degrades it. From our study, we proposed a hybrid-based packet forwarding to increase the reliability of transmission by controlling the number of contention window size based on the node's density and packet buffer information. We performed the performance analysis of several broadcast techniques such as broadcast flooding, adaptive contention window size, distance-based broadcast, and hybrid-based packet forwarding. Our hybrid-based packet forwarding outperformed other packet forwarding schemes in achieving good PRR and maintain its performance gradually as the number of nodes is increasing. We observed that as we reduce the transmission probability in HB, the PRR is decreased. On the other hand, the reduction of transmission probability in HB gives a good result in reducing network traffic. From this observation, the packet buffer information and node's density can also adjust the value of transmission probability to achieve better PRR and reduce network traffic. As future work, we are going to evaluate the effectiveness of our method to the underwater wireless sensor networks and compare this method to the existing routing protocols for underwater wireless sensor networks.

Acknowledgment

This work was supported in part by the BK21 plus program (NRF-2016R1D1A1A09918974) and in part by Basic Science Research Program (NRF-2015R1D1A1A01061118), both of which are funded through the National Research Foundation (NRF) by the Ministry of Education of Korea.

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