Location-based Multicast Routing Algorithms for Wireless Sensor Networks in Presence of Interferences

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***Abstract*—Location-based multicast routing (LMR) technique can increase the lifetime and the channel capacity of wireless sensor network (WSN) by reducing the number of duplicated data transmissions and control messages. Previous LMR algorithms can suffer performance deterioration in real deployments because they consider only location of nodes and can transmit packets across concrete walls or other interfering object. To tackle this problem, we propose an interference-aware location-based mulciast routing algorithm for WSNs. In the proposed algorithm, each node adjusts the energy cost for each link adaptively considering the interference effect and uses it for multicast decision in order to minimize the interference impact. Experimental results show that the proposed algorithm improves the delivery and energy performance when the network is affected by interference.**

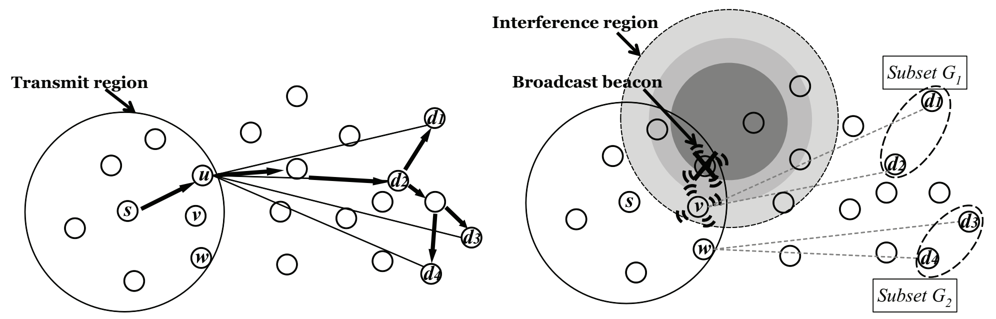
I. INTRODUCTION

Wireless sensor network (WSN) consists of a set of sensor nodes. Common applications of WSN are security monitoring, habitat monitoring, fire monitoring, etc. In such applications, multicast is an efficient routing method for group communication to send messages to multiple sensor nodes. Multicast delivers the messages over each link of the network only once, creating copies only when the links to the multiple destination nodes split. Efficient multicast for sensor networks is critical because of the limited resources of sensor nodes.

There are some flooding based multicast protocols such as the multicast ad hoc on-demand distance vector (MAODV) [7], the on-demand multicast routing protocol (ODMRP) [8] and the adaptive demand-driven multicast routing (ADMR) [9]. These protocols cause large overhead and message, because they have to flood the route request(RREQ) message over the network to discover the destination nodes. If the location information is available, geographical protocol is more efficient than flooding based protocols. Several geographical multicast protocols for wireless ad-hoc networks have been proposed [4]–[6]. These protocols build a multicast tree using the location information and use geographic forwarding algorithm to forward packets down each branch of the multicast tree. However, they are not exploiting the multicast advantage of the wireless transmission. Juan A. et al. proposed the geographic multicast routing protocol (GMR) [10] to improves the forwarding efficiency. GMR divides the destination nodes into subsets to reduce the number of transmissions and delivers a multicast message to the neighbor that is closest to each subset. The authors of GMR also proposed the energy-efficient geographical multicast routing (GMREE) [11] to improve the energy performance. GMREE considers the energy cost and delivers a multicast message to the neighbor that requires the minimum energy to advance to each subset of destination nodes.

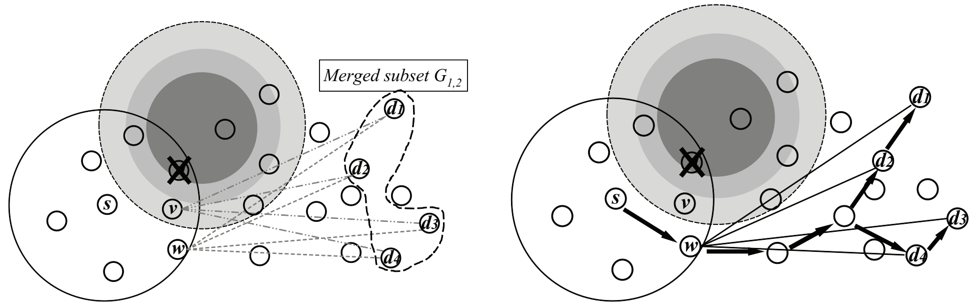
Nowadays many other 2.4GHz devices (e.g. WLAN or Bluetooth) cause more interferences to the sensor-net devices because they use the same ISM-band frequency [12]. Traditional geographical routing protocols can perform poorly because they try to transmit messages across the interferences such as thick concrete walls or other standard wireless devices. GMR and GMREE suffer significant performance degradation due to the interference. When a message is dropped in the middle of the path, the destination nodes of the destination set cannot receive anything. Therefore, the geographical multicast routing protocol has to be designed carefully by considering the interferences in the real-world deployments.

In this letter, we propose an interference aware energy efficient location-based multicast routing for wireless sensor networks. In the proposed algorithm, a sender node predicts the energy consumption by considering the interference effect. The sender node then delivers a multicast message to the neighbor with the lowest value of energy/advance to each subset of destinations. Experimental results show that the proposed algorithm outperforms previous algorithms in terms of the packet delivery ratio and the energy.



(a) under no interference

(b) interference detection and calculation of energy/advance of grouped subsets



(c) calculation of energy/advance of merged subsets

(d) selecting the best energy/advance and forwarding packets

Fig. 1. Proposed algorithm example

II. PROPOSED ALGORITHM

A. Interference-aware Energy Model

The proposed algorithm estimates the minimum transmit power by considering the interference power level to forward a packet to where the interference effect are not strong. If the receive power threshold value for a successful reception P_{RX}^{TH} is known, the minimum transmit power, P_{TX}^{min}, can be determined as follows:

$$P_{TX}^{min}(dBm) = P_{RX}^{TH}(dBm) + PL(dB) + \sigma \qquad (1)$$

where PL is the path loss between the sender and the receiver due to the distance and the obstacles; σ is the deviation of the path loss in a fading channel. The received power threshold value can be derived from the signal-to-interference-plus-noise ratio (SINR) model as follows [2]:

$$P_{RX}^{TH} = 10\log\left(10^{(P_N/10)} + 10^{(P_I/10)}10^{\left(\zeta^{TH}/10\right)}\right) \qquad (2)$$

where P_N and P_I denote the noise power and the interference power in dBm; ζ^{TH} is the SINR threshold for a successful reception in dB. The noise power depends on the hardware and can be set manually. The SINR threshold can be obtained from the bit error rate (BER) model. For O-QPSK modulation in the IEEE 802.15.4 standard, P_B is determined as follows [1]:

$$P_B = \frac{8}{15} \cdot \frac{16}{1} \cdot \sum_{k=2}^{16} -1^k \cdot \binom{16}{k} \cdot \exp^{20\cdot\zeta\cdot\left(\frac{1}{k}-1\right)} \qquad (3)$$

From (3), We can obtain the proper SINR threshold which satisfies the IEEE 802.15.4 receive sensitivity requirement and 99% PRR with 20bytes packet size as follows:

$$\zeta^{TH} \approx 0.4021(dBm) \qquad (4)$$

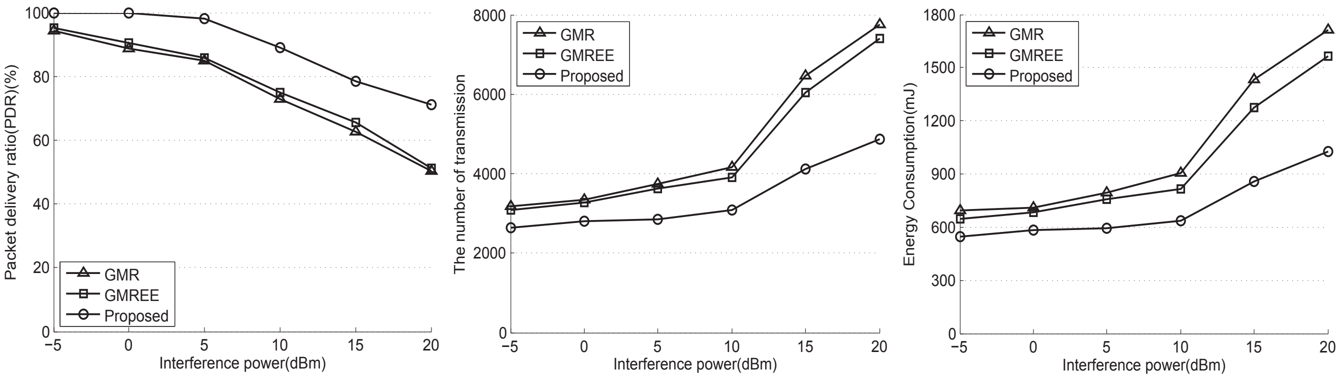
We assume that a transceiver can measure the interference power level. The energy consumption of sender E is determined as follows:

$$\begin{aligned} E \;=\; & E_{TX} \times T_{DATA} + \\ & E_{RX} \times (T_{LIFS} + T_{BO} + T_{ACK} + T_{SIFS}) \end{aligned} \qquad (5)$$

where E_{TX} and E_{RX} denote the power consumption in the transmit mode and the receive mode. T_{DATA}, T_{ACK}, T_{LIFS}, T_{SIFS} and T_{BO} denote the durations of the data packet, the acknowledge packet, the long inter-frame space, the short inter-frame space, and the backoff. The power consumption in the transmit mode is proportional to the minimum transmit power ($E_{TX} \propto$ c $\cdot$ P_{TX}^{min}) the value of c depends on the hardware. Therefore, when a node transmits a packet, the energy consumption value is mostly affected by the interference effect because other values are constant in (5).

B. Energy-efficient Geographical Multicast Routing Algorithm

In the proposed algorithm, every node measures the interference power level periodically and determines the receive power threshold value by using (2). When a node detects the interference effect, it periodically broadcasts a beacon containing the updated receive power threshold value at the maximum transmit power, P_{TX}^{max}. When a node receives the



(a) (b) (c)

Fig. 2. Simulation results for 30 destinations by the various interference

beacon message, it measures the receive power, P_{RX} and calculates the path loss as follows:

$$PL(dB) = P_{TX}^{max}(dBm) - P_{RX}(dBm) \tag{6}$$

The node then determines the minimum transmit power value by using (1) and stores the value in the neighbor table. When a sender has a multicast message destined to a set of destination $D = \{d_1, d_2, d_3, \cdots, d_k\}$ it reads the packet size and estimates energy consumption, E, for each neighbor by using (5). The sender then checks the minimum transmit power value of every neighbor node in the neighbor table. Let N denote the neighbor set. If the minimum transmit power for a neighbor u is larger than the maximum transmit power, the neighbor u is removed from the N. With the new neighbor set N, the sender groups destinations into subsets to find a neighbor that provides the lowest E/ADV. ADV denotes the advance to the destination and is defined as follows:

$$ADV = d(u, d) - d(v, d) \tag{7}$$

where $d(u, d)$ denotes the distance between the current node u and the destination node d. Since the energy consumption value increases as the interference offset becomes stronger, the proposed algorithm can avoid the interference region. After the sender groups destinations into subsets, the initial partition subset $G = \{G_1, G_2, G_3, \cdots, G_m\}$ is initialized. With subset G, the sender checks all pairs (G_i, G_j) as single subset $G_{i,j}$. Two subsets G_1 and G_2 can be merged if there are neighbor nodes providing the lower E/ADV towards all the destination nodes in both subsets G_1 and G_2.

For example shown in Fig.1, if there are no interference effect, the node s forwards a packet to the node u that is closest to the destination set. When the node u and the node v is affected by the interference, they adjust the receive power threshold value and broadcast a beacon containing the receive power threshold value. When the node s received the beacon, it changes the transmit power for the node u and the node v. When the transmit power for the node u is larger than maximum transmit power of the node s, the node s eliminates the node u in the neighbor table. Then, the node s groups destinations into subsets. In Fig.1-(b), the node v has the lowest E/ADV value of the destination d_1 and d_2 and the node w has the lowest E/ADV value of the destination d_3 and d_4. Let a subset of d_1 and d_2 be G_1 and let a subset of d_3 and d_4 be G_2. After grouping destinations into the subset G_1 and the subset G_2, the node s finds a neighbor which provides the lowest E/ADV value of a subset $G_{1,2}$ merging G_1 and G_2 as shown by Fig.1-(c). If there is no neighbor which provide the lower E/ADV value of a merged subset $G_{1,2}$ than the E/ADV value of the subset G_1 and the subset G_2, the node forwards a packet to the node v for the subset G_1 and the node w for the subset G_2. In Fig.1-(d), the node w provides the lower E/ADV value of a group $G_{1,2}$ than the E/ADV value of the subset G_1 and the subset G_2 . As a consequence, the node s forwards a packet to the node w for the destination nodes d_1, d_2, d_3 and d_4.

III. EXPERIMENTAL RESULTS

We compare the performance of the proposed algorithm with GMR and GMREE in large scale network by using the ns-2 simulator. In simulation, we use the log distance path loss model. The path loss at a distance d is defined as follows:

$$PL(d) = PL_0 + 10\eta \log d/d_0 + X_\sigma \tag{8}$$

where PL_0 is the path loss at the close-in reference distance d_0, η is the path loss exponent, and X_σ is a zero mean Gaussian distributed random variable with standard deviation σ. In the simulation, we placed 1000 sensor nodes randomly in an area of $1000 \times 1000m$ and two 802.11g nodes at (500,500). Each 802.11g node transfers MPEG-4 video file to another by using the Poisson traffic model with 800-byte packet size and 56kbps rate based on [3]. We considered 6 interference power level;-5dBm, 0dBm, 5dBm, 10dBm and 20dBm, whereas a single source node and the various number of multicast destinations;15, 20, 25 and 30. A source node and destination nodes were also randomly selected from the set of sensor nodes. Figure 2 shows the packet delivery ratio (PDR), the number of transmission and the energy consumption as a function of the interference power.

GMR and GMREE shows the lower PDR than the proposed algorithm in Fig.2-(a). GMR and GMREE causes high packet losses, since they forward packets through the interference region by not considering the interference effect. As we mentioned above, a multicast message, originated from one source node, has to be delivered to a set of destination nodes. If one multicast message, destined to multiple destination nodes, is dropped in the middle of the route, the PDR decreases more than one single message being dropped. A sensor node need the more transmit power to send messages to the neighbor node under the interference effect than under the no interference effect. The proposed algorithm estimates the necessary minimum transmit power and finds the neighbor node which cannot receive messages at the maximum transmit power of the sensor node due to the interference effect. Therefore, The proposed algorithm show the better PDR performance.

We measured the number of transmission, which means total transmit number of all nodes in route from a source to all destinations. The source transmits multicast packets periodically to the destination set until all destinations of the set receive 30 and more packets. Fig.2-(b) shows the results of the number of transmission. The number of transmission of GMR and GMREE is much larger than the proposed algorithm. The proposed algorithm finds neighbor nodes in strong interference region and eliminates the neighbor nodes from the neighbor table. When interferences are detected, the proposed algorithm can transmit packets to neighbor nodes in the weak interference region. However, GMR and GMREE transmit packets through the strong interference region because of not considering interference. The source of GMR and GMREE has to transmit more packets and the relay nodes of GMR and GMREE retransmit packets more than the proposed algorithm due to many packet losses. the stronger the interference power is, the larger the number of transmission of GMR and GMREE is.

Fig.2-(c) shows the energy consumption as varying interference power level. GMREE shows the better energy performance than GMR. GMREE considers the energy cost and take into account the minimization of the energy. However, GMREE shows the lower energy performance than the proposed algorithm. Since GMREE sends packets to the neighbor nodes in the interference region and causes high packet losses, it tries to retransmit packets many times. If the number of transmission increases, the consumed energy also increases. GMR and GMREE consume a lot of energy because of many retransmissions. The proposed algorithm estimates the minimum transmit power with considering the interference effect and transmits packets at the minimum transmit power. The proposed algorithm selects the neighbor nodes less affected by the interference and it reduces the retransmission by the packet losses. The consumed energy in transmit mode is proportional to the transmit power. By setting the minimum transmit power, the proposed algorithm can save consumed energy. From the results, we confirm that the proposed algorithm can efficiently mitigate the performance degradation due to the interference effect.

TABLE I
PARAMETER VALUES.

Parameter	**Value**	**Parameter**	**Value**
d_0	1m	T_{LIFS}	24us
PL_0	40dB	T_{SIFS}	8us
η	2.7	T_{ACK}	32us
σ	2dB	E_{TX}	$\leq 52.2mW$
M	2dB	E_{RX}	59.1mW
Data Rate	250kbps	P_N	95dBm
P_{TX}^{max}	0dBm	P_{TX}^{min}	-33dBm

IV. CONCLUSION

The proposed algorithm estimates the minimum transmit power by considering the interference effect and eliminates neighbors in strong interference region in other to avoid the interference region. It groups destinations into subsets to find a neighbor with the lowest energy cost and forwards packets to the neighbor. The proposed algorithm is examined by using the simulator, and the results show that it outperforms GMR and GMREE in terms of the packet delivery ratio, the number of transmission and energy consumption.

ACKNOWLEDGMENT

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST) (No. 2009-0089304).

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