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Enhanced Distance-Based Gossip Protocols for Wireless Sensor Networks

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***Abstract*—Sharing information among nodes is a key function in Wireless sensor networks (WSNs) applications. Gossip protocols can be employed to facilitate data exchange and ensure data delivery to a sink node. In this paper, we propose two protocols to enhance the traditional gossip protocol by providing lightweight distance-based methods for selecting the next optimal node to retransmit a message. The first proposed protocol, NNGossip, uses the nearest neighbor distance measure, while the second, CBGossip, uses the city block distance measures. The major advantage of using these two techniques is that the computation is simple and fast and hence preserves the energy. We evaluated the performance of the proposed protocols against the traditional gossip protocol, Gossiping, and the Fair Efficient Location-based Gossiping protocol, FELGossiping. The experimental results show that using the proposed protocols maximize the network lifetime and insures efficient bandwidth while maintaining the delay at a low level.**

***Index Terms*—Wireless Sensor Networks; Gossip Protocol; City Block; Nearest Neighbor.**

I. Introduction

Wireless sensor networks (WSNs) are composed of several connected sensors. Each sensor is capable of sensing, collecting, processing, and sending or receiving data. However, these sensors have limited resources in terms of energy, bandwidth, and computational capabilities. WSNs have a wide range of applications that require an efficient transmission protocol to transfer data from the source node, when an event is detected, to the sink node. For this reason, gossip protocols are employed to fulfill this requirement. In a traditional gossip protocol, when a message is generated by a source node, most of the nodes in the network participate to ensure that the message is received by the sink node [1]. When a sender node sends a message, it randomly chooses a neighboring node to forward the message, then this neighboring node randomly chooses another neighboring node to forward the message. This continues until the message reaches its destination, the sink node. Hence, the destination node may receive the same packet more than once, resulting in redundancy. In addition, since most of the nodes participate in the sending/receiving processes, a large amount of energy is wasted, which will affect the network lifetime. Therefore, it is crucial to reduce the number of participating nodes. This can be achieved by choosing a small subset of nodes to forward the message based on an optimized election score. Consequently, this reduces the total number of forwarded messages, hence reserving the energy and increasing the network lifetime. There are three fundamental schemes that can be used in calculating the election score: probabilistic, counter, and distance. A probabilistic scheme is the simplest scheme, in which the source node randomly selects a neighboring node and forwards the message to it. In a counter-based scheme, the neighboring node is selected based on the number of hops to the destination node. However, in a distance scheme, the location information is used to select the neighboring node based on distance measures. Our proposed gossip protocol is related to the distance scheme, in which the distance between nodes is estimated using the physical location information. Different distance measures can be used [2]. However, the most common technique is the Euclidean distance. Choosing the proper method to calculate the distance depends on the applications requirements and the sensors computational constraints. Therefore, we choose to use the nearest neighbor and city block distance measures. The major ad-vantage of using these two techniques is that the computation is simple and fast and hence preserves the energy. On the other hand, Euclidean distance requires more computational power; in fact, multiplication and square roots are a bit more complicated than adding and subtracting.

The main contribution of this paper is to propose two new gossiping protocols: the first is based on the nearest neighbor distance measures (NNGossip), and the second is based on city block distance measures (CBGossip). The performance of the pro-posed protocols was evaluated in terms of delay, saved rebroadcast (SRB), stability period (SP) and network lifetime (NL). The performance is compared to those of the traditional gossip protocols (Gossiping) [3] and the Fair Efficient Location based Gossiping protocol (FELGossiping) [4]. The remainder of the paper is organized as follows. Section II discusses the previous work related to gossip protocols. The system design is proposed in Section III. We evaluate the performance of our protocols in Section IV, and Section V concludes the paper.

II. Related Work

Gossip is crucial for WSN applications, therefore; many of the previous work were focusing on enhancing the traditional gossip protocols. An analysis study of gossip protocols was proposed in [5]. The authors used a probabilistic model to investigate the number of rounds required by the gossiping protocol to form a connected network. They employed the Probabilistic Symbolic Model Checker tool (PRISM) for their analysis and found that randomness in each gossip round causes a loss of information. In [6], the authors compared randomized gossip, broadcast gossip, and collection tree protocols. Their performance was measured in terms of communication overhead, accuracy, latency, and energy consumption. The experiment was run on a network simulator, Castalia. However, randomized gossip outperformed the other algorithms since it has the least latency and overhead. A novel distributed optimization framework to improve energy efficiency in large-scale buildings was proposed in [7]. The authors used a generalized gossip protocol in the framework as a robust distributed optimization technique. The experimental results indicated that the proposed framework reduced the overall energy consumption. In [8], the authors did not propose a new algorithm. In fact, they presented an analytical study of gossip-based message dissemination schemes that can be used for service dissemination. The performance was measured under different network conditions with a uniform neighbor selection over the entire nodes in the network. The study shows acceptable results in random selection and small overhead in smart selections. In contrast to the above previous works, which used a probabilistic scheme for their gossiping protocol, the authors in [4] employed the counter method and proposed a Fair Efficient Location-based Gossip protocol (FELGossiping) for WSNs. The performance of the proposed protocol was compared with other protocols in terms of packet loss, live nodes, energy consumption, and delay. The results showed that FELGossiping outperforms the other protocols. A fuzzy logic distance-based gossip protocol was proposed in [9], which used a distance scheme (Chebyshev distance measure). The results show that the proposed protocol enhanced the performance of the WSN and maximized its lifespan. Although it used the Chebyshev distance measure, which is simple to compute, the use of fuzzy logic consumes more computational resources, which is a scarce resource that needs to be preserved in WSNs. Based on the above, most of the work discussed in the literature has focused on preserving energy and prolonging the network lifetime. However, in this paper, in addition to addressing the energy consumption issue, we also aim to address the band-width and computational constraints by using the nearest neighbor and city block distance measures, which are simple, fast to compute, and do not require high cost computation.

III. System Design

We model the WSN as a connected graph $G(V, E)$, where V is the set of vertices that represents the sensing nodes and E is the set of edges that represents the existence of a direct connection between the nodes. The location of a node is defined as (x, y). These nodes are randomly deployed in a rectangular area. The proposed system components, depicted in Fig. 1 and , are as follows:

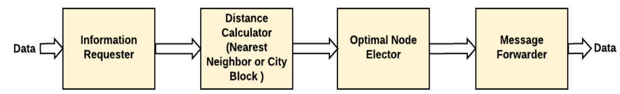

Fig. 1. Proposed system components

1) Information requester: Its role is to send a broadcast message to the neighboring nodes and request their remaining energy and location information.
2) Distance calculator: Its role is to use the location information to calculate the distance between the node and its neighboring nodes, and between the sink node and the neighboring nodes. Two distance measures are used: the city block for CBGossip and the nearest neighbor for NNGossip.
3) Optimal node elector: Its role is to calculate the election score for each neighboring node and select the neighboring node with the highest score value.
4) Message forwarder: Its role is simply forwarding the message to the selected optimal node.

When a source node has a new data to send to the sink, it will use the proposed gossip protocols to ensure the delivery of the message. The process is as follows:

1) The source node will first send a message to its neighboring nodes requesting the following information:
   a) Residual energy (RE): which is the remaining energy of the neighboring node.
   b) Location (x_i, y_i): which is the location of the neighboring node.
2) Upon receiving the above information, the distance (Dis) between the node and its neighboring nodes is calculated using the city block distance formula (D_{CB}) for CBGossip and the nearest neighbor distance formula (D_{NN}) for NNGossip, as follows:

$$D_{CB} = |x - x_i| + |y - y_i| \quad (1)$$

$$D_{NN} = min(|x - x_i|, |y - y_i|) \quad (2)$$

3) Next, the distance between the neighboring node and the sink node $(SinDis)$, and the distance between the source node and the sink node (D_{Sink}) are calculated using the city block distance formula (D_{CB}) for CBGossip and the nearest neighbor distance formula (D_{NN}) for NNGossip, as described above.
4) After that, we calculate the election score based on the following function (FEL):

$$FEL = (RE/E) + (1/Dis) + ((1 - SinDis)/D_{Sink}) \quad (3)$$

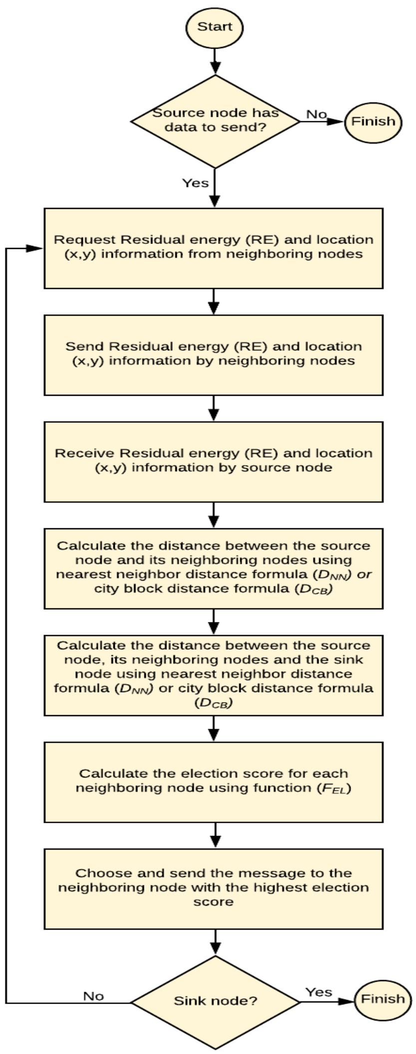

Fig. 2. Flowchart of the proposed protocols

where E is the initial energy.

5) Finally, the source node selects the neighboring node with the highest election score and forwards the message to it.
6) When the message is received by the neighboring node, steps 1 to 5 are repeated until the message reaches the sink node.

The above steps are summarized in Fig. 2.

IV. Evaluation

To evaluate the performance of our proposed protocols, NNGossip and CBGossip, we used Java RMI for the simulation and compared our protocols with the traditional gossip protocol (Gossiping) and FELGossiping. The topology of nodes was randomly deployed in an 80m 60m area with one sink located at the center of the area (40m, 30m). The sensed transmission limit was 20 m. All sensor nodes had the same initial energy 0.5J. We also used different numbers of nodes: 20, 40, 60, 80, and 100. For performance evaluation, we calculated the following metrics:

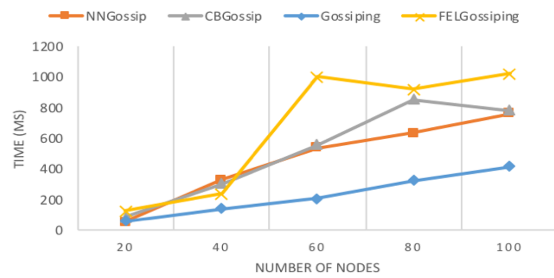

Fig. 3. Average delay time

1) *Delay*: This is average time difference between the sending time, when the message is sent by the source node, and the receiving time, when the message successfully arrives at the sink node.
2) *Saved rebroadcast (SRB)*: We use this metric to capture the bandwidth utilization. The SRB is defined as follows:

$$SRB = (v - n)/v \tag{4}$$

Where v is the total number of nodes that receives the message and n is the total number of nodes that retransmit the message [10].

3) *Stability period (SP)*: This is the time from the beginning of the network simulation until the death of the first node. This metric is represented by showing the number of rounds until the death of the first node [11].
4) *Network lifetime (NL)*: This is the time from the beginning of the network simulation until the death of the last node. Similar to the SP metric, this metric is represented by the number of rounds until the death of the last node in the network [11].

A. Results and Discussion

To assess our proposed protocols, NNGossip and CBGossip were compared with traditional gossip protocol (Gossiping) and FELGossiping.

Fig. 3 presents the average delay time, which is the time difference between the sending and receiving times in microseconds. It clearly shows that the delay time was affected by the size of the network and thus, increased as the number of nodes in-creased. Furthermore, the traditional gossip protocol (Gossiping) performed the best in varying number of nodes. The reason is the method used for next hop selection, which does not require any additional computation. However, for NNGossip, CBGossip, and FELGossiping, a function was used, as discussed in Section 3, for selecting the next optimal node and hence, required some additional computation time, which in turn increased the delay time. However, CBGossip achieved less delay time than NNGossip and FELGossiping. On the other hand, NNGossip maintained an acceptable delay time, as the number of nodes increased, compared to the other protocols.

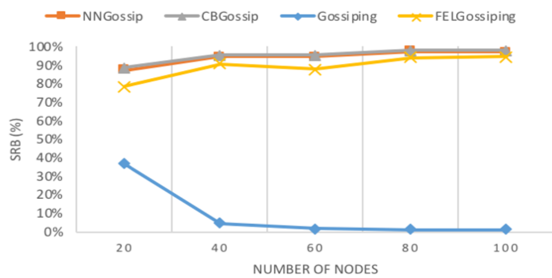

Fig. 4. Saved rebroadcast

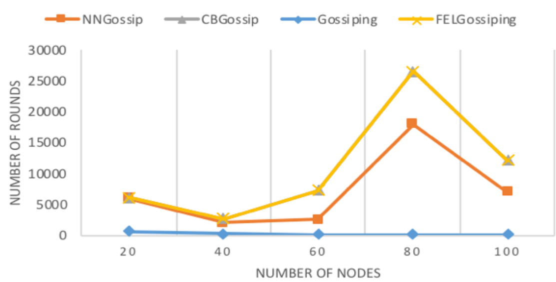

Fig. 5. Stability period

Fig. 4 shows the effects of network size on the SRBs achieved by the four different protocols. We can see that both NNGossip and CBGossip outperformed the traditional gossip (Gossiping) and FELGossiping in all different scenarios. This is mainly because of the method used in selecting the next node to retransmit the message, which is based on energy and distance measurements using the city block distance formula (D_{CB}) and the nearest neighbor distance formula (D_{NN}). As demonstrated by the results, for both NNGossip and CBGossip, the percentage of SRB increased as the number of nodes increased. Consequently, a considerable amount of bandwidth was efficiently utilized.

The simulation results in Fig. 5 show that CBGossip and FELGossiping have maximized the network stability period and hence, nodes stayed alive for longer and consumed less energy. In addition, the NNGossip improved the stability period com-pared to the traditional gossip protocol (Gossiping).

Fig. 6 plots the network lifetime, in terms of the number of rounds, for each protocol. From the figure, we can see that NNGossip and CBGossip outperform the other protocols. Also, the network lifetime of our proposed protocols increased as the number of nodes increased. This is because as the number of nodes increased, the number of messages, being forwarded by other nodes, decreased and thus, the overall energy was preserved. However, NNGossip, compared with other protocols, prolonged the network lifetime.

V. Conclusion

In this paper, we proposed a lightweight method for selecting the next optimal node using an election score. Instead of using the Euclidean distance, the election score calculation is based on the residual energy and the distance, obtained using

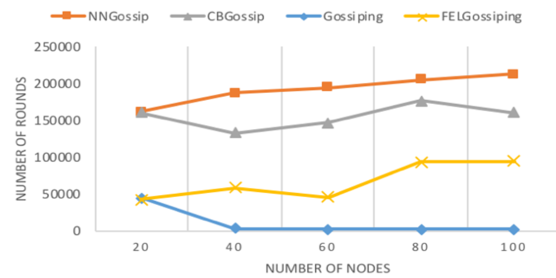

Fig. 6. Network lifetime

city block and nearest neighbor formulas. In the simulation setup, we compared the proposed variations named as NNGossip and CBGossip with the traditional gossip protocol and FELGossiping and evaluated their performance in terms of the delay, SRB, SP, and NL. The results showed that NNGossip and CBGossip maximized the NL and reserved the bandwidth with an acceptable amount of delay.

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