Position-based Energy-Efficient Greedy Forwarding in Mobile Wireless Sensor Networks

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Abstract

Mobile Wireless Sensor Networks (MWSNs) is one of the rising technologies for numerous areas of application, such as environmental monitoring, industrial sensing and diagnostics and battlefield awareness. Such wireless sensor nodes are often deployed in remote locations. Thus, energy efficient and reliable data forwarding is important because each node has limited resources. In this paper we propose a position-based energy-efficient greedy forwarding scheme to reduce the energy consumption while increasing the packet delivery ratio for Mobile Wireless Sensor Networks (MWSNs).In our paper, each node decides whether or not to be a relay node by itself considering the remaining energy and mobility. Simulation results show that the energy consumption and the average end-to-end delay can be reduced by selecting relay node considering the energy and mobility.

Keywords: *Position-based routing, Greedy Forwarding, Mobile Wireless Sensor Networks*

1. Introduction

Mobile Wireless Sensor Networks (MWSNs) has led to increased attention as a result of the convergence of a high-performance smart sensor technology and mobile electronic communication technology. MWSNs is one of the rising technologies for numerous areas of application, such as battlefield surveillance, remote healthcare, land monitoring for smart farming and environmental monitoring, and so on [1-4]. Also many of the researchers had focused their research towards different protocols and schemes for disaster management [5].

Position-based routing protocols are currently being thoroughly studied for network in which nodes know their own location because a node utilizes the geographic location information of each sensor node to deliver packets over a network. Because routing decisions rely on the location information of the current node and its directed neighbors, source node as well as the destination node, position-based routing does not require the establishment or maintenance of a specific route. Hence, it achieves relatively lower communication overhead [6-8]. Therefore, geographic routing is an elegant way to forward packets from source to destination in very demanding environments without wasting network resources or creating any impediment in the network design. And it is generally considered as an attractive routing method in terms of scalability for both mobile wireless ad-hoc and sensor networks [9-10].

In position-based greedy forwarding, a sensor node selects the closest available neighbor to the sink as next forwarder regarding location parameter. Indeed, the current packet is forwarded to a 1-hop neighbor who is closer to the sink than the sender node. This process is

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repeated until the data packet reaches the sink. Traditionally, the next forwarder selection is based only on the location parameter. However, a greedy forwarding always takes the shortest local path so that it has a tendency of depleting the energy of nodes on the shortest path [11]. Moreover, the limited lifetime due to the sensor node's battery is a typical problem. That is, it decreases the network lifetime in data transmission. Therefore, it is essential to increase network lifetime in wireless sensor networks [12].

Owing to mobility in WMSNs, some of it neighbors may move out of its transmission range, thus resulting in disruption before the next forwarding process. Thus, a node which is selected as relay node may fail to forward data due to the mobility and the location update interval.

Therefore, we propose a position-based energy efficient greedy forwarding scheme to maximize the delivery rate while minimizing energy consumption. In this paper, all nodes calculate their potential priority value based on their location information, remaining energy and the predicted location considering mobility. Each node decides whether the node itself should be a relay node or not using a qualification score. A closest to the destination with a higher remaining energy node is selected as a relay node. The experimental result shows that the proposed scheme can provide an efficient greedy forwarding scheme in terms of energy consumption and the end-to-end delay.

The rest of this paper is organized as follows. In Section 2, we review some position-based routings in MWSNs. Section 3 presents our greedy forwarding scheme. Next, in Section 4, we present some simulation results in order to evaluate the proposed scheme. Finally, we conclude our paper in Section 5.

2. Related Works

In MWSNs, there is a wide variety of applications which can be categorized as belonging to different areas such as industrial, home, health, environmental, military, automotive and commercial. The network challenges in each area are to some extent similar in the sense that all the routing protocols used in these network applications have to be as fault tolerant, as power efficient and low latency as possible and have to have a high delivery ratio. Also, the production costs of the network need to be kept low.

According to the design issues of a network, some position-based routing protocols offer certain advantages over the others. Whether they are power efficient, guarantee delivery, scale well or are real-time algorithms and take into consideration realistic channels or sensors with power scavenging abilities, each presents a characteristic that would make the protocol more appropriate for a type of application [4].

To minimize the power consumption of sensor nodes is hardware or software methods. Several routing protocols have been designed for wireless sensor networks to satisfy energy utilization and efficiency requirement [13-14].

Position-based routing can theoretically be performed based solely on location information of nodes, which can be obtained via the Global Navigation Satellite System (GNSS), where this is available, or via other location services. The source node has to be aware of its own position, the position of nodes within its range of communication (neighbor nodes) and of the destination. Therefore, the required node memory is minimal reducing bandwidth consumption and conserving energy. Nodes use broadcasting (on demand or periodically) to let their one hop neighbors know their location, but discovery floods and state propagation are not needed. So geographic routing results in minimal overhead. Also, because of the localized forwarding process, the network reacts faster, avoiding delays and overall latency [4, 15-16].

Position-based geographic routing scheme for wireless sensor networks have been explored a variety of ways for reliable and energy-efficient packet forwarding [17-19].

Several experimental studies on wireless ad-hoc and sensor networks [20-21] have shown that wireless links can be highly unreliable and that this must be explicitly taken into account when considering higher layer protocols [22].

GPSR (Greedy Perimeter Stateless Routing) [23] is one of the well-known geographic routing schemes that are proposed using perimeter or face routing to route around voids or obstacles when greedy forwarding fails. A node sends the packet to neighbor nodes closed to its perimeter region. After perimeter forwarding, routing states are collected and cached in the nodes for reuse in route recovery. Each node of the network maintains a neighbor table, periodically updated through beacon messages – this results in a lot of data traffic; source's location is piggybacked on all data packets; it is tested in flat (2-D) topologies; it uses 2 methods for forwarding data: greedy forwarding and perimeter forwarding (right hand rule). Nodes try to create a map of the neighbors that have tentative routes to the destination. A node sends the packet to neighbor nodes closed to its perimeter region. After perimeter forwarding, routing states are collected and cached in the nodes for reuse in route recovery. It performs well in a scattering network with few neighbors. It also guarantees delivery, but assumptions such as an ideal 802.11 MAC layer and a static topology. For the mobility study, the random waypoint model was used.

EGR (Energy-Aware Geographic Routing) [11] is designed for mobile environments and makes use of residual energy information in greedy and recovery mode alike. Assumptions of GPS or a location service mechanism are made which can provide the location information for the destination, while that of the neighbors is obtained through beaconing. Also, because nodes are considered mobile, the random waypoint model is used for simulation. (The simulations include the MAC 802.11). In both basic mode as well as when handling voids, the forwarding node is chosen to balance energy consumption by maximizing a weight function which takes into account distance progress (for greedy routing) or angle progress (for face routing) and residual energy. The algorithm needs further investigation in terms of scalability and node density.

EBGR (Energy-efficient Beaconless Geographic Routing) is designed for highly dynamic scenarios with changing topology in which location information is known. The algorithm aims to provide loop-free, energy-efficient sensor to sink routing at low communication overhead. The forwarding process avoids beacons, but uses the RTS/CTS handshaking mechanism and calculates the ideal next-hop relay position on the straight line between source and destination based on an energy-optimal forwarding distance. Each forwarding node chooses as next hop the neighbor closest to the ideal next hop relay position within a predefined relay search region [24].

EAGRP (Energy Aware Geographic Routing Protocol) [25] is a geographic routing algorithm based on greedy forwarding. Nodes have only local knowledge of neighbors' position and energy levels and the location of the destination. The forwarding decision is based on distance calculations and energy levels above a certain threshold. The packet is forwarded to the neighbor closest to destination and with the highest energy level, by first adjusting the transmission power. The objective of the algorithm is to prolong the network lifetime of the sensors and hence the network lifetime.

DGF(Direction-based Greedy Forwarding) [26] handles mobility of nodes in WSNs. DGF proposed an efficient greedy forwarding mechanism based on a new decision metric that considers the distance to the sink, the moving direction and the moving speed of the forwarding candidate neighbors of a sensor node. The moving direction depends on both distance and angle of a neighbor according to the sink between two successive location beacons [4].

3. Proposed Scheme

In this paper, the process is localized and distributed so that all nodes involved in the routing process contribute to make a routing decision by them. Receiving packet nodes calculate the Expected Qualification Score (*EQS*) as a metric to determine whether it is qualified forward the packets or not. A candidate node has the lowest value of *EQS* is selected as a relay node. For measuring the qualification, the *EQS* is calculated by the equation below.

$$QualificationE(x) = \alpha \times \left\{ \left(\frac{Energy\_remaining}{Energy\_initial} \right)^{Q\_Distance} \right\} + \beta \times Q\_Mobility \quad (1)$$

where α and β are the modification coefficients to provide different weights for different parameters $(\alpha + \beta = 1)$.

In equation (1), the *Energy_remaining* and *Energy_initial* mean the amount of remaining energy of node and the amount of initial energy, respectively. A node with the highest remaining energy has the highest value of *EQS*.

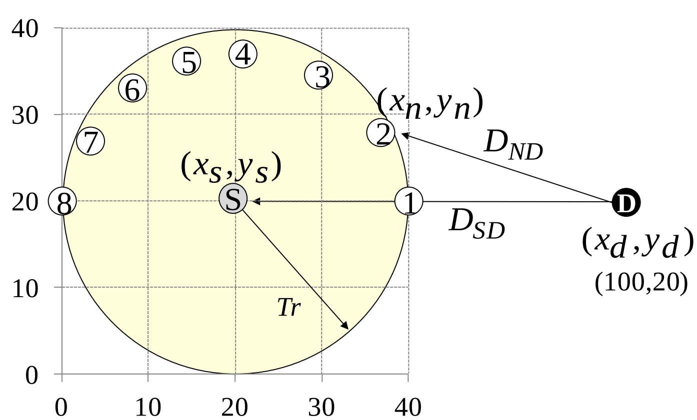
Each weighting factors can be chosen depending on the application and the *EQS* ranges from 0 to 1. In equation (1), the *Q_Distance* is calculated as follows:

$$\frac{T_r + D_{ND} - D_{SD}}{2T_r} \quad (2)$$

where D_{ND} and T_r represent the distance from candidate node to destination and transmission range as shown in Figure (1). Also D_{SD} indicates the distance between source node and destination. D_{ND} and D_{SD} can be calculated by

$$D_{ND} = \sqrt{(x_n - x_d)^2 + (y_n - y_d)^2}$$
$$D_{SD} = \sqrt{(x_s - x_d)^2 + (y_s - y_d)^2} \quad (3)$$

According to the equation (2), the closest node from destination has the lowest value of *Q_Distance*.



N_ID / *Q_Distance*	1	2	3	4	5	6	7	8
Coordination	(40,20)	(36.75, 27.92)	(29.57, 34.56)	(20.85, 37.00)	(14.34, 36.18)	(8.10, 33.08)	(3.25, 26.93)	(0, 20)
Q_Distance	0	0.09	0.30	0.52	0.68	0.82	0.92	1.00
Distance from node to destination	60	63.74	71.92	80.96	87.18	92.82	97.00	100

Figure 1. the value of *Q_Distance*

An optimal relay node is selected by evaluating its *EQS* as a candidate in relation to their energy, the distance and mobility. The relay node candidate closer should be the selected as the optimal relay node.

In second weighting factor in equation (1), the *Q_mobility* is computed considering the mobility as follows:

$$Q\_mobility = Q\_Distance \times P_{SN} \quad (4)$$

where P_{SN} denotes the communication probability between the source and candidate node, which is calculated based on the predicted location.

As shown in Figure 2, given the current location of a node (x_i, y_i), the predicted location of a mobile node after time interval Δt denoted by (x_i', y_i'). A value of time interval Δt means the time difference between the transmitting of actual data after the process of selecting a relay node.

The predicted locations of source and mobile node are (x_i', y_i') and (x_S', y_S'), respectively. They can be computed as follows:

$$\begin{aligned} (x_i', y_i') &= (x_i + \tilde{v}_i \times \Delta t \times \cos\theta_i,\ \ y_i + \tilde{v}_i \times \Delta t \times \sin\theta_i) \\ (x_S', y_S') &= (x_S + \tilde{v}_S \times \Delta t \times \cos\theta_S,\ \ y_S + \tilde{v}_S \times \Delta t \times \sin\theta_S) \end{aligned} \quad (5)$$

where $\tilde{v}$ and θ are the velocity and angle, respectively.

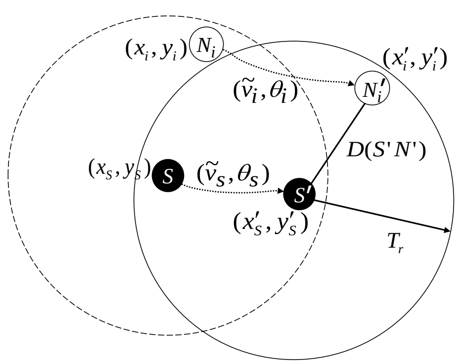


Figure 2. the communication probability

The communication probability P_{SN} is obtained as follows:

$$P_{SN} = \begin{cases} 1, & if \ D(S'N') \le T_r \\ 0, & otherwise \end{cases} \quad (6)$$

As a result of our scheme represented above in equation (1), a higher remaining energy node with the closest to the destination is likely to be a relay node.

Only receiving packet nodes can participate in contention for relaying because their rebroadcasts may give rise to serious broadcast storm. Hearing a beacon from source node, neighbor nodes will compete to relay through a distributed contention process. The probability that a candidate node wins the contention depends on the node's remaining energy, the distance from destination node and mobility. The node with greater remaining energy and closer distance has higher priority to be the optimal relay node.

The proposed selection scheme for the optimal relay node is concluded as follows: Receiving a beacon from source node, a candidate node sets a backoff timer which defines the amount of time that the node must wait before rebroadcasting the packet.

The backoff time δ is calculated as :

$$\delta = \max\_delay \times (1 - EQS) \quad (7)$$

where *max_delay* is a predefined system parameter.

We can see that a candidate node with the lower *EQS* will lead to a shorter backoff time. If a candidate node does not hear any signal from other sensors during its backoff time, it will rebroadcast the beacon signal and other candidate nodes will can their contention. As a result, the node with the highest priority will rebroadcast first and win the competition to serve as the relay node. Note that this distributed relay node selection process is triggered by the reception of a beacon message from source node. Therefore, an explicit time synchronization protocol among the candidate nodes is not needed.

According to equation (7), a node with a small backoff time can be a relay node early. During the backoff time, the rest of nodes which received an announcement message give up rebroadcasting to prevent broadcast storms and they then select the best relay node.

4. Performance Evaluation

We consider that sensor nodes are randomly placed over the two-dimensional field with following assumptions [1]:

• The sensor nodes are mobile but the sink is immobile outside of the network field.

• They can aware the speed, movement direction and the amount of their remaining energy.

• The sensor nodes with global positioning system (GPS) devices can be aware of their location using a localization mechanism [27-28].

• All nodes have identical processing and communication capabilities.

For our experiments, we used energy consumption for the simulation which was based on some numeric parameters obtained from [26, 29]. Table 1 lists the main simulation parameters. Also, we used the radio model that reflects MICA2 motes that is implemented with several adjustable parameters as follows [30]:

$$E_{totoal}(k,d) = (k \times E_{elec} + k \times E_{amp} \times d^2) + (k \times E_{elec}) \quad (8)$$

where $E_{total}(k,d)$ means that the energy consumption for transmitting *k*-bit messages with distance d. Table 1 lists the main simulation parameters.

Table 1. Simulation parameters

Parameter		Values
Network area		1,000*1,000(m)
Sink location		800, 800
Number of nodes		100~400
Radio transmission range		150m
Data	Data packet size	128bytes
	Packet rate	4 packets/sec
	Data rate	1Mbps
Mobility	Model	Random Way Point
	speed	5(m/s)
Initial energy		1 Joule
MAC Layer		802.11
Propagation Model		Two-Ray

To validate the performance, we compare our proposed scheme with GPSR and DGF. Figure 3 demonstrates that our proposed scheme consumes lower than the other schemes. The objective of the algorithm is to prolong the network lifetime of the sensors and hence the network lifetime. DGF proposed a greedy forwarding mechanism based on mobility and location without considering the energy. Then, we can see that our scheme is a more energy efficient forwarding scheme in terms of reducing energy consumption, which is one of the most important factors in wireless sensor networks.

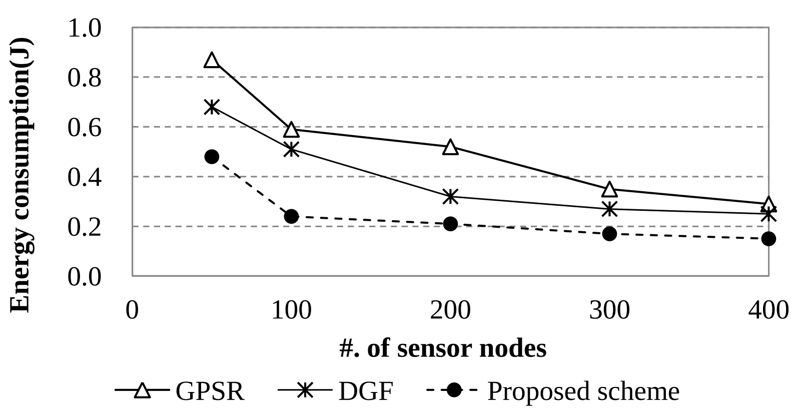


Figure 3. Energy consumption

The average end-to-end delay is shown in Figure 4. As shown in Figure 4, the end-to-end delay is lower than other schemes because a proposed scheme is designed by considering the distance from destination. In addition, in GPSR, the delay might be increased by selecting a closest node to the destination as a relay node considering just distance. In DGF, a relay node is selected based on direction and moving speed of the forwarding candidate neighbors without the predicted location due to the mobility. This result of the simulation also indicates that a proposed scheme is more effective for delay sensitive applications compared to the other schemes.

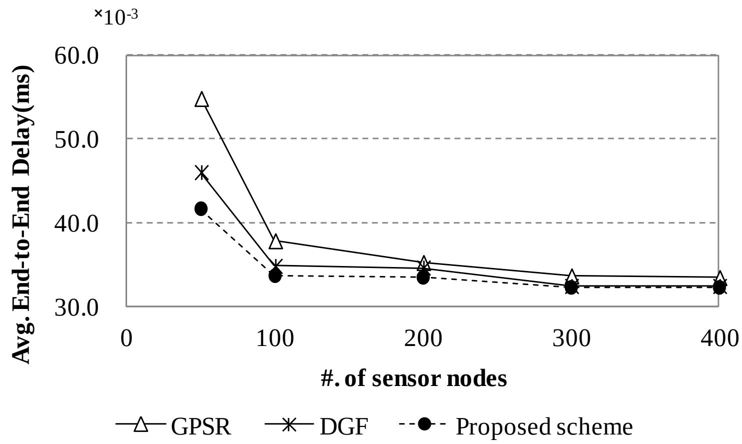


Figure 4. Average end-to-end delay

Figure 5 shows a good performance of proposed scheme in terms of average packet delivery ratio compared to other schemes. This is due to our scheme consider both mobility and the predicted location against the other schemes.

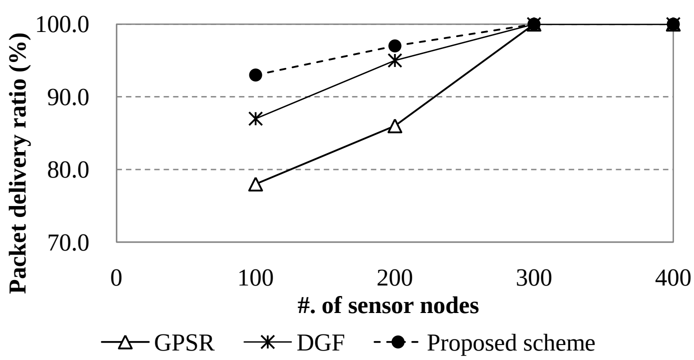


Figure 5. Average packet delivery ratio

5. Conclusion

In this work we presented a position–based energy efficient greedy forwarding scheme for greedy forwarding in WMSNs. The relay node closest to the destination which also has greatest remaining energy is selected as the next relay node and the computation is processed by in a distributed manner. We evaluated the energy consumption as well as the end-to-end delay. Simulation results show that the energy consumption and the end-to-end delay can be reduced while the packet delivery ratio is higher relatively.

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