An Energy-efficient Location-Aware Routing Scheme for Mobile Wireless Sensor Networks

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Abstract

Owing to the availability of Global Positioning System (GPS) and the advancements of high-performance sensor technology, the location-aware routing is receiving interest as a method of routing in Mobile Wireless Sensor Networks (MWSNs). In location-aware routing, each intermediate node independently selects the closest next hop which is closer to the destination using the given location information. Therefore, location-aware routing is commonly regarded as highly scalable and very robust against frequent topological changes. However, limited energy resources and mobility are two main challenges of efficient routing in MWSNs. Once the sensors are scattered, they have to carry out the given task without power supply in a distributed manner. Consequently, energy-efficient mechanisms should be combined with the existing routing protocols to increase a successful data relaying. Therefore, we propose an Energy-efficient Location-aware Routing scheme to reduce the energy consumption and average number of hops for data forwarding to destination. Our scheme deals with three parameters as weight factors for selecting relay nodes: residual energy, predicted position and link expiration time. The simulation results show that the proposed routing scheme is able to find a better solution. Our proposed scheme is useful for minimizing the path length and packet loss ratio.

Keywords: Location-Aware, Mobile Wireless Sensor Networks, Energy Efficient

1. Introduction

Mobile Wireless Sensor Networks (MWSNs) have recently launched a growing popular class of Wireless Sensor Networks (WSNs) in which mobility plays a key role in the execution of the application [1-4]. In many scientific applications, mobile sensors are employed in numerous areas of applications such as battlefield surveillance, remote healthcare, land monitoring for smart farming and environmental monitoring, and so on. The increasing capabilities and the decreasing costs of mobile sensors make MWSNs possible and practical [5].

The routing is one of important problems in MWSNs because routing algorithms play a great role during the whole period of networks [6]. Owing to the availability of GPS and the advancements of high-performance sensor technology, some routing protocols use knowledge of the location of network nodes to provide or augment topology information. These are receiving great interest as a method of routing in MWSNs and also known as location-aware routing or geographic routing (or position-based routing as it is sometimes called).

Location-aware routing protocols are being captured the attention mostly due to its numerous advantages and are currently being thoroughly studied due to their potential application in networks. In addition, location-aware routing protocol is an elegant way to forward packets from source to destination in very demanding environments without wasting network resources. Therefore it is generally considered as an attractive routing method for both mobile wireless ad-hoc and sensor networks (ad-hoc and sensor networks) [7]. It is particularly well suited in environments where the nodes have access to their geographical position [8-9]. Their main characteristic is that they make use of location information for routing decisions.
The general idea of location-aware routing is to select the next hop based on position information such that the packet is forwarded in the geographical direction of the destination [10]. Therefore, location-aware routing is commonly regarded as highly scalable and very robust against frequent topological changes. The most important characteristic of location-aware routing is that forwarding decisions are based on local knowledge. When a sensor node has a packet to forward, it selects the closest available neighbor to a 1-hop neighbor who is closer to the destination than the sender node. This process is repeated based on the location parameter until the data packet reaches the destination. It is not necessary to create and maintain a global route from sender to the destination.

A mobile wireless sensor network is an infrastructure-less temporary network without any centralized administration. In such networks, all nodes are mobile and can be connected dynamically in an arbitrary manner. The connectivity between the source node and neighbors continuously varies due to mobility. A selected relay node might move out of the source node before receiving actual data packet. It can lead to packet loss and increasing latency. Therefore, decreasing network performance due to mobility is also one of challenges of efficient routing in MWSNs [11].

Once the sensors are scattered, they have to carry out the given task without power supply in a distributed manner. Therefore, energy management is one of the top priorities to design an effective routing algorithm because energy efficiency imposes a crucial effect on performance of the entire network. Hence, energy efficient mechanisms should be combined with the existing routing protocols to reduce node failure and improve the network lifetime. Consequently, conserving energy is inevitable in MWSNs using sensors without power supply.

Therefore, we propose an energy-efficient location-aware routing scheme aiming at selecting intermediate nodes for conserving energy and reducing latency for MWSNs. In this paper, each node calculates their weight for decision whether to be a relay node or not based on residual energy, mobility and expiration time in a distributed manner. As the energy efficiency imposes a crucial effect on routing performance, the residual energy is regarded as one important factor. Also our scheme is designed considering mobility for reducing packet loss. Each node decides whether the node it should be a relay node or not using a weight based on the predicted location. Upon receiving a packet, all nodes wait and dynamically adjust its waiting time based on the value of weight to avoid collision. In this paper, a node has a higher residual energy and a shorter distance to the destination is selected as a relay node, while the expiration time with source node is long. The experimental result shows that the proposed scheme can provide an efficient forwarding scheme in terms of energy consumption and the path length.

The remainder of this paper is organized as follows: Section 2 describes several location-aware routing for MWSNs. The energy-efficient location-aware routing scheme is elaborated in Section 3. Section 4 evaluates the proposed scheme. Finally, the paper concludes in Section 5.

2. Related Works

Location-aware in MWSNs has attracted attention in terms of scalability for large-scale WSNs [12-13, 16]. Location-aware routing for WSNs have been exploring a variety of ways for reliable and energy efficient packet forwarding. Location-aware geographic routing can be divided into proactive and reactive methods: with a proactive method, routing information is maintained independently of actual data communication. With a reactive scheme routing information is acquired on-demand when there is data to forward [10].

Proactive (table driven or pre-computed) routing is achieved by creating lists or tables with destinations and possible paths towards the destinations. Periodically, these lists are distributed to nodes in the entire network, updating the link states. It makes use of broadcast techniques for the nodes’ data updates and for route creation. Through this mechanism, proactive routing creates a lot of traffic, consumes excess bandwidth and a lot of power. Delays can also occur because of the slow network reaction to node mobility. Reactive routing (demand driven) can be a lower cost option than proactive because it does not use periodic broadcasts and initiates route discovery only when a message has to be sent, thus traffic decreases and overhead is reduced. However, using flooding and Route Request packets (blind broadcasts) does result in energy expenditure and high latency. Scalability issues and network clogging can appear because of flooding [7, 14-15].

Early research of geographic routing includes DREAM [16] and LAR [17] that proposed constrained flooding. The expected zone is defined by predicting the boundary of the
destination node’s movement. In both protocols, prediction is made based on the time difference between sending data and the location information’s update, as well as the destination node’s speed \([18]\).

Greedy Perimeter Stateless Routing (GPSR) \([19]\) 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.

Contention-Based Forwarding (CBF) \([10]\) is a beacon-less algorithm which consists of two forwarding phases: contention, in which a node is determined as next hop through a timer-based function, and suppression in which other candidates are held back from forwarding the packet. The next hop is selected through a distributed contention process based on the actual positions of all current neighbors. The drawbacks of this algorithm are the lack of a recovery method when forwarding in greedy mode in an empty area and the packet overhead created by broadcasts.

Energy Efficient Geographic Routing (EEGR) \([20]\) is a geographic routing algorithm takes into account sensor position error. Nodes’ location is estimated with a certain error \(\varepsilon\). The communication probability is calculated based on the location error. The algorithm uses a metric which defines communication costs between neighbors. It sends messages along paths having the best trade-off between communication probability, progress and energy consumption. Shortest path, from sensor to base station, can be computed with Dijkstra algorithm.

Direction-based Greedy Forwarding (DGF) \([21]\) 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.

Energy Aware Geographic Routing Protocol (EAGRP) \([22]\) 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 \([7]\).

3. Proposed Scheme

In our proposed scheme, all nodes participate in the next relay node selection process and the forwarding decision is based on the level of energy, level of latency and level of connectivity. When a node receives a packet, it can wait for a while to refrain from excessive channel accessing. In this paper, we use the value of weight as the waiting time. Suppose a node \(i\) receives a packet from the source node. Node \(i\) can calculate and adjust their waiting time \(WT\) as follows:

\[
WT_i = Waiting\ Time_{Max} \times (1 - Weight_i)
\]  

where \(Waiting\ Time_{Max}\) is predefined maximum waiting time. According to equation (1), a node with small \(WT\) can early forwarding because its waiting time is short. During the waiting time, the rest of the node received data packet gives up forwarding to prevent the broadcast storms.

Each node decides whether to be a relay node or not by evaluating the weight itself. The node with the lowest weight is selected as a relay node. The weight of node \(i\), \(Weight_i\) can be computed as follows:

\[
Weight_i = w_1 \times L_{\text{Energy}} + w_2 \times L_{\text{Latency}} + w_3 \times L_{\text{Connectivity}} \sum_{i=1}^{3} w_i = 1
\]

where \(w_1\), \(w_2\) and \(w_3\) are the corresponding weighting factors \((w_1, w_2, w_3) > 0\). Each weighting factor can be chosen depending on the application. In addition, the weight \(Weight_i\) ranges from 0 to 1.
As a result of our scheme represented above in equation (2), the closest to destination with higher residual energy node is likely to be a relay node.

The first weighting factor in the equation (2), $L_{\text{Energy}}$ denotes the ratio of the residual energy of the initial energy. $L_{\text{Energy}}$ is defined as:

$$
1 - \frac{E_{\text{Residual}}}{E_{\text{Initial}}}
$$

where $E_{\text{Residual}}$ and $E_{\text{Initial}}$ mean the amount of residual energy of a node and the amount of initial energy, respectively. A node with the highest residual energy has the lowest $L_{\text{Energy}}$. According to the above equation (2), a node closer from destination with high residual energy has lower weight.

Assume two arbitrary nodes $i$ and $j$ can communicate directly with each other with the transmission range $Tr$. Let $(x_i, y_i)$ be the coordinates of a mobile node and $(\overrightarrow{v}_i)$ be that of the motion parameter. Also node $i$ moves to the moving angel $\theta_i$ with speed $v_i$. The motion parameters $\overrightarrow{v}_i$ and $\theta_i$ can be expressed by $(x_i, y_i)$ and $(v_i, \theta_i)$ respectively, as shown Figure 1.

![Figure 1. Location changes due to movement of nodes](image)

In second weighting factor in the equation (2), $L_{\text{Latency}}$ denotes is calculated as follows:

$$
1 - \frac{T + D(D, S') - D(D, N')}{2T_i}
$$

where $D(D, S')$ represents the distance between the destination and the predicted location of the source. Also $D(D, N')$ indicates the distance between the destination and the predicted location of mobile nodes. Given the current location of a node $(x_N, y_N)$, the predicted location of a mobile node after time interval $\Delta t$ is denoted by $(x'_N, y'_N)$. A value of time interval $\Delta t$ means the time difference between the transmitting of actual data after the process of selecting a relay node. The predicted location of a mobile node and the source node, $(x'_N, y'_N)$ and $(x'_S, y'_S)$ can be computed as follows:

$$(x'_N, y'_N) = (x_N + v_N \times \Delta t \times \cos \theta_N, y_N + v_N \times \Delta t \times \sin \theta_N)$$

$$(x'_S, y'_S) = (x_S + v_S \times \Delta t \times \cos \theta_S, y_N + v_S \times \Delta t \times \sin \theta_S)$$

The last weighting factor in the equation (2), the duration $L_{\text{Connectivity}}$ can be calculated as followings:

$$
1 - \frac{\text{LET}}{\Delta T_{\text{interval}}}
$$

where $\text{LET}$ represents Link Expiration Time and $\Delta T_{\text{interval}}$ means the transmission period. Due to mobility, it is possible that a selected relay node might be out of transmission range of the source node. It is reasonable that a node has long expiration time with source node is selected as a relay node for reducing the packet loss and transmission delay.
The mobility factor $LET$ was used in \cite{4, 23} to calculate the connection duration between two adjacent nodes. Considering the computation complexity, the $LET$ is adopted in this paper and can be calculated based on their speed and direction of movement.

Then, the duration when two sensor nodes stay connected, $LET$, is predicted as follows:

$$LET = \frac{- (ab + cd) + \sqrt{(a^2 + c^2)r^2 - (ad - bc)^2}}{a^2 + c^2}$$  \hspace{1cm} \text{(7)}$$

where $a = v_i \cos \theta_i - v_j \cos \theta_j$, $b = x_i - x_j$, $c = v_i \sin \theta_i - v_j \sin \theta_j$ and $d = y_i - y_j$. If two nodes have zero relative velocity, i.e., $v_i = v_j$ and $\theta_i = \theta_j$, the link will remain forever as $LET$ will be $\infty$. If $LET/\Delta T_{\text{Internal}}$ is greater than 1, the value is treated as 1.

4. Performance Evaluation

For our experiments, we set $1000 \times 1000$ (m) network configuration and sink node is placed at coordinates (800, 800). We used a network topology and energy consumption for the simulation which was based on some numeric parameters obtained from \cite{12, 21, 24}.

The initial energy of each node is set by 1 (J). To simulate different node densities, the number of sensor nodes varies from 50 nodes to 250 nodes. The transmission range is fixed at 150 (m). We use the Random Waypoint Model and the speed of mobile nodes varies from 2 to 20 (m/s). The data packet size is 1Mbps with a payload of 128 bytes with a constant rate of 4 packets per second.

The basic assumption in our proposed scheme is the availability of a positioning device such as a GPS receiver at each mobile node. We consider that sensor nodes are randomly placed over the two-dimensional field with the following assumptions \cite{25}:

- The sensor nodes are mobile but the sink is immobile.
- The sensor nodes can be aware of their location using a localization mechanism \cite{26}.
- They can aware the speed, movement direction and the amount of their residual energy.

To validate the performance, we compare our proposed scheme with GPSR and EAGRP.

Figure 2 demonstrates that the proposed scheme consumes lower than other schemes. The objective of the algorithm is to prolong the network lifetime of the sensors and hence the network lifetime. GPSR does not consider the residual energy. The metric of EAGRP for 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. Therefore, the EAGRP consumes relatively little energy. Then, we can see that proposed 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 2. Energy consumption](image-url)
Figure 3 shows a good performance of the proposed scheme in terms of average path length compared to other schemes. This is due to that proposed scheme considered both mobility and the predicted location against other schemes. When the density is high, the average path length has shown similar result because connectivity is guaranteed regardless of mobility above a certain densities.

![Figure 3. Average path length](image)

Figure 4 shows the packet loss ratio of three schemes. As can be seen from the graph, the packet loss ratio of comparison schemes is overall high when mobility is high. On the other hand, the value of the proposed scheme is lower compared schemes. By considering link expiration time, our proposed scheme allows selected relay node to avoid being out of transmission range of the source node before receiving the actual data packet. In contrast, the basic location-aware routing, GPSR, performs significantly worse under mobility.

![Figure 4. Packet loss ratio (%)](image)

5. Conclusion

We have proposed an energy-efficient location-aware routing scheme for conserving energy and fast forwarding operations in MWSNs. We use the following three weight factors; residual energy, predicted position according to mobility, and link expiration time. Our proposed scheme is featured by reflecting the predicted position and checking of forwarding weight to acquire priority. In conclusion, our scheme reduces the energy consumption and the path length as compared with other schemes that didn’t consider both energy and mobility, which are important issues in mobile environments.
Consequently, we found that our scheme is highly beneficial in achieving effective energy consumption for MWSNs. Nonetheless, our scheme still needs to be improved in various conditions and applications. As part of our future work we will extend our scheme to enhance other performances for MWSNs.

6. References