Direction-based Greedy Forwarding in Mobile Wireless Sensor Networks

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Abstract— **Geographical routing in mobile wireless sensor networks has attracted big attention in recent years by introducing new challenges. When a node has a packet to forward, it selects the closest available neighbor to the sink as the next forwarder regarding only the location parameter. However, this routing strategy does not consider the topology changes caused by the mobility of nodes, which may degrade performance or cause failures. To overcome this problem, we propose 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 sender node. The moving direction depends on both distance and angle of a neighbor according to the sink between two successive location beacons. Associated with the well-known GPSR routing protocol, our proposal achieved good performance in terms of packet delivery ratio, average path length, control packet overhead and energy consumption.**

Keywords—Mobile sensor networks; geographical routing; node mobility; greedy forwarding.

I. INTRODUCTION

Currently, Wireless Sensor Networks (WSNs) attract the attention of many researchers due to the various challenges imposed by sensor nodes, such as the small amount of available memory, the limited processing capability, the limited lifetime of batteries and the small range of radio transceiver. Moreover, several researches are focusing on mobile WSNs where node mobility is critical to meet applications requirements.

Today, by introducing mobility to WSNs, we can further improve the network capability in many aspects [1, 2]. Since the deployment of WSNs had never been considered completely static, the node mobility problem imposes various challenges to deal with, such as the connectivity, the coverage, the energy consumption and the routing. The later challenge has involved the design of several new protocols, especially geographical routing protocols [3-5]. However, only few of these protocols are designed for mobile WSNs. In fact, the efficient and scalable greedy forwarding is a promising scheme for large-scale WSNs when node locations are available [6]. Indeed, the packet is forwarded to a 1-hop neighbor who is closer to the destination than the actual node. This process is repeated until the packet reaches its destination.

Traditionally, the selection of the next forwarder node is based only on the location parameter assuming ideal link conditions. However, this can degrade the performance of geographical routing in mobile WSNs. The location failure, which results from nodes' mobility, degrades the routing performance or may lead to forwarding failures. Indeed, when a node selects its forwarder node, based only on location information, there may be another neighbor having better conditions according to the sink in terms of location, moving direction and moving speed. This effect is accentuated when the selected forwarder is within the range limit of the sender node, which probably leads to a forwarding failure. In this case it is better to select as forwarder the neighbor ensuring the tradeoff between location, moving direction and moving speed.

To overcome the limits of the existing greedy forwarding schemes proposed for mobile WSNs, we first analyze the impact of node mobility on the routing performance. Then we propose an efficient greedy forwarding mechanism, called DGF (Direction-based Greedy Forwarding), which combines the location information, the moving direction and the moving speed of the forwarding candidate neighbors when a sender node selects the next forwarder of the current packet. We associate the DGF mechanism with the GPSR [3] routing protocol to use in mobile WSNs.

The rest of this paper is organized as follows. Section II presents some geographical routing schemes proposed in the literature for mobile WSNs. Section III discusses the node mobility effect on the greedy forwarding performance. Section IV describes the proposed DGF mechanism for mobile WSNs. Section V evaluates performance of our proposal. Section VI concludes the paper.

II. RELATED WORK

Node mobility arises additional challenges in WSNs. It has to be handled even in quasi-static WSN where few nodes may be mobile. One of these challenges is routing. We distinguish three classes of routing protocols in mobile WSNs based on the type of nodes: 1) protocols for static sensors and mobile sink(s) [7-9], 2) protocols for mobile sensors and static sink(s) [10-14], and 3) protocols for mobile sensors and mobile sink(s) [15]. In literature, the majority of research works have been focused on the first class of protocols, while less works dealt with both the second and the third class.

Luo et al. [7] propose the two-tier data dissemination (TTDD) protocol, which is used to forward a packet from static sensors towards a mobile sink. In TTDD, sinks are assumed to be mobile with unknown and uncontrolled mobility. The data about each event are assumed to originate from a single source. Each active source creates a grid structure dissemination network over the static network, with grid points acting as dissemination nodes. A mobile sink, when it issues queries for information, it sends out a locally controlled flood to discover its nearest dissemination point. Then the query is routed to the source node through the overlay network by suing the dissemination point.

Fodor et al. [8] propose a gradient-based routing protocol (GBRP) to use mobile sinks that move in order to decrease the energy consumption of the whole network. In GBRP, sensor nodes maintain a list of neighboring next hops that are in the right direction towards the closest sink. The protocol uses a restricted flooding to update the locations of the mobile sinks. The principle behind this is to register by each node the cost between the appropriate sink and the given node and to update these routing entities only when the relative change is above a threshold.

Wang et al. [9] propose a mobile sink cluster-based routing protocol (MSRP) for WSNs. The protocol operates in four phases: clustering, registering, dissemination and maintenance. The network is divided into multiple clusters during the first phase. The mobile sink which comes into the communication range of a cluster-head is registered into this cluster using the second phase. Once the mobile sink is registered, it receives from the cluster-head all sensed data in the cluster during the third phase. Possible new sensors are added to the cluster and the cluster-head is reelected during the fourth phase.

Yang et al. [10] propose a dynamic enclose cell (DEC) routing algorithm to decrease the routing overhead by constructing cells with sensor nodes in order to retain stable the WSN in high mobility. This protocol groups the nodes into cells and develops the routing path using the cells boundaries. When the nodes are moving, only the adjacent cells of the moving nodes are reconstructed. In this way, the negative impact of the node mobility is minimized. The DEC algorithm consists of four schemes: neighbor beacon exchange, cell discovery, cell routing path update and cell routing selection.

Arboleda et al. [11] propose a cluster-based routing (CBR) protocol for mobile WSNs using zone-base information and a cluster-like communication between nodes. It is based on two stages: route creation and route preservation. The first stage discovers a route between a source and a sink, but the second stage repairs the route when it is defective. The CBR protocol is based on the formation of non-overlapping square zones. Each node is placed in a zone and can obtain its zone ID based on its location parameters. The sensors in a common zone form a cluster and each cluster has one of the mobile nodes acting as cluster-head. This later acts as an aggregator node, receiving and forwarding messages to its neighbor cluster-heads, and maintains information about both the routes and the nodes in a zone.

Lambrou et al. [12] present a routing scheme in hybrid WSN that forwards packets to mobile nodes. The scheme objective is the delivery of event detection messages that contain information about position of the detected event in the sensor field. The routing of such messages can be easily achieved using a geographical routing based on greedy techniques towards a fixed base station. Moreover, this later easily requests information about a specific region or even a single static node using the position information.

Santhosh-Kumar et al. [13] propose an adaptive cluster-based routing (ACBR) scheme for mobile WSNs by including mobility as a new criterion for creation and maintenance of clusters. This work is considered as an improvement of the works proposed in [16, 17]. The ACBR protocol consists of two phases: set-up and steady-state.

Nasser et al. [14] propose a Zone-based Routing Protocol for mobile WSNs (ZoroMSN) based on zone construction, route maintenance and zone-head election. This protocol is efficient in WSN with low mobility of nodes, where clusters are formed using the mobility patterns of sensors. ZoroMSN acts as a hybrid routing protocol, where communication between nodes in a zone is proactive and between zone-heads towards the sink is reactive. The ZH is selected based on the mobility factor of each sensor in the zone, which is defined as the average number of times that a node moves from one zone to another during a given period of time.

Saad et al. [15] propose an energy efficient routing algorithm called Ellipse-Routing. Using a region-based routing, the proposed algorithm builds a virtual ellipse thanks to the source and destination position. So, only nodes within this ellipse can forward a message towards the destination. Then, the algorithm was extended in order to take into account errors in node location.

Although the above-resumed works play important roles in improving the performance of the geographical routing in mobile WSNs, the design of new routing solutions is still a challenging research area. Thus, the DGF mechanism is proposed in Section IV taking into account the mobility of nodes in WSNs. The DGF mechanism is associated with the well-known GPSR protocol and the obtained protocol is called GPSR-MS (GPSR with Mobile Sensors). The major difference between GPSR-MS and the above-summarized protocols includes the following aspects:

- The proposed GPSR-MS protocol operates without organizing the network into clusters, while the majority of existing protocols for mobile nodes are cluster-based where the maintenance consumes the limited resources of nodes.

- In the existing cluster-based protocols, the greedy forwarding mode is not applied, while the GPSR-MS protocol is based on this scalable and efficient mode.
- Few of existing protocols are designed for WSNs with mobility of nodes. Therefore, the GPSR-MS protocol strengthens this class of protocols. Our objective is to maximize the packet delivery ratio with the minimum consumption of node resources.

III. NODE MOBILITY IMPACT ON GREEDY FORWARDING

In this section, we present the impact of nodes' mobility on the next forwarder selection. Majority of geographical routing protocols use greedy forwarding techniques to route packets in a WSN. To make their routing decision, they use only the locations of the forwarding candidate neighbors, the sender and the sink.

In greedy forwarding, the selected next-forwarder is the closest neighbor to the sink in term of distance based only on the nodes' location. But the mobility of nodes causes the problem of location information freshness inside the neighbors table of each sender node. This may result some routing decisions failures. This problem can be resolved by broadcasting location beacons. But when node mobility increases rapidly, the beaconing overhead grows also rapidly.

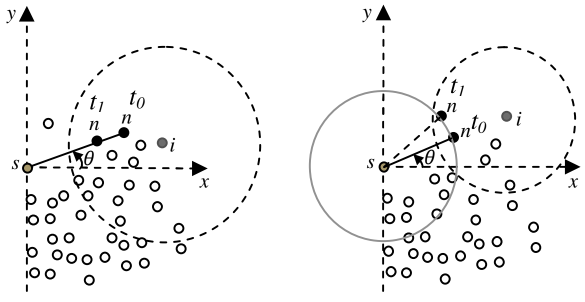
When the nodes move, the greedy forwarding mode does not often guarantee positive progression of packets towards their destination. Thus, when a sender node selects its next forwarder, this later may not be available because it moved. In the other hand, another node can come into the sender neighborhood, but it is not considered when selecting the next forwarder because it was not detected by the sender node. This situation has its importance when the non-detected node is the closest neighbor to the sink.

In addition, the moving direction and the moving speed of nodes may be the raison behind the obsolete table. Also, mobile nodes can repair holes that appear in a WSN due to their moving propriety. Then the greedy forwarding will use the shortest paths.

These greedy mode weaknesses induce packet losses, delivery delays and excessive energy consumption. Indeed, the use of only distance to select the intermediate forwarders has limits in dynamic environments caused by nodes' mobility. However, the use of periodic and frequent location beacons cannot resolve the problem because it creates packet collisions, overloads the network and consumes more energy. Consequently, some packets will be lost and other packets will be delayed. Therefore, the next-forwarder selection in a node must consider multiple metrics of its neighbors, such as the moving speed, the moving direction and the distance to the sink. The objective is to obtain a geographical routing protocol that maximizes the packet delivery ratio, minimizes the average path length and reduces the control packet overhead.

IV. PROPOSED DGF MECHANISM

To handle node mobility in mobile WSNs, the proposed DGF mechanism uses a new decision metric when selecting the next forwarder of the current packet. This metric considers the moving direction, the moving speed, and the distance to the sink of forwarding candidate neighbors of the sender node. The DGF mechanism supposes that each node moves with an angular variation according to the sink. However, each node i has an angle θ which is formed by neighbor n, sink s, and the horizontal axis passing by s, as shown in Figure 1. The moving direction of node n, between two recent times t_0 and t_1, is calculated by combining both its two last distances and angles to sink s. Neighbor n may become near to (or far from) the sink in terms of both distance and angle.



(a)

(b)

Figure 1. Neighbor moving: (a) s approaches sink s in term of distance and (b) n moves away from sink s in term of angle.

To show the neighbor direction evolution, the DGF mechanism combines the angle and distance parameters of neighbors. In Figure 1, the moving direction of neighbor n is calculated by node i using the two later parameters. The DGF mechanism operates in two main phases: neighbors' information update and next forwarder selection. Note that we suppose a WSN with a static sink and mobile nodes, each node knows its neighbors' positions, and sink's position thanks to the network initialization phase. Also, each node has a table (TABLE I) which contains information about its neighbors, such as location, moving speed and moving direction.

1) Neighbors' information update: Each node broadcasts periodically a 1-hop location beacon informing its neighbors about its geographical position. The period of this beacon can be fixed according to the nodes' moving speed. Thanks to these beacons, each node updates a local table containing information about all neighbors. We added to this table three new fields to record moving speed, angle and moving direction of each neighbor. TABLE I shows the structure of the neighbors table of a node. We also added a specific field into the location beacon, where the structure is given in TABLE II, to convey the moving speed of a node to all its neighbors.

TABLE I. STRUCTURE OF A NEIGHBORS TABLE

Field	Mission/Content
ID	Identifier of a neighbor node
Position	Coordinates of a neighbor i (x_i, y_i)
Direction	Neighbor moving direction
Speed	Neighbor moving speed
Angle	Neighbor angle (θ) calculated according to the sink
ExpTime	Expire time of a neighbor in the table

When a node i receives a location beacon B from its neighbor n, it checks the existence of n in its neighbors table T. If node n does not exist, node i inserts information concerning n in T (TABLE I), else it calculates the old and new direction of neighbor n by using the formulas (1) and (2) respectively, where $DirT(n,s)$ represents the old direction calculated using T, $AT(n,s)$ is the old angle calculated using T, $DirB(n,s)$ is the new direction calculated using B and $AB(n,s)$ is the new angle calculated using B. The distances $DT(n,s)$ and $DB(n,s)$, between neighbor n and sink s, based on locations that are extracted from T, respectively from B, are given by the respective formulas (3) and (4). Note that $x_{n,T}$ and $y_{n,T}$ are locations of n in T, $x_{n,B}$ and $y_{n,B}$ are locations of n in B, x_s and y_s are locations of s in sender node i.

$$DirT(n,s) = DT(n,s) * AT(n,s) \tag{1}$$

$$DirB(n,s) = DB(n,s) * AB(n,s) \tag{2}$$

$$DT(n,s) = \sqrt{(x_{n,T} - x_s)^2 + (y_{n,T} - y_s)^2} \tag{3}$$

$$DB(n,s) = \sqrt{(x_{n,B} - x_s)^2 + (y_{n,B} - y_s)^2} \tag{4}$$

The angles $AT(n,s)$ and $AB(n,s)$, represented by θ in Figure 1, are calculated according to the trigonometric quadrant in which neighbor n is located by using the respective formulas (5) and (6) based on the $Arctg2(y,x)$ function of the C++ language. Once the above calculations are done by a node i, it updates all information concerning each neighbor n in its table T.

$$AT(n,s) = \tag{5}$$
$$\begin{cases} \frac{\pi}{2} - Arctg2(y_{n,T} - y_s\,, x_{n,T} - x_s)\,; & \text{IF } x_{n,T} \geq x_s \text{ AND } y_{n,T} \geq y_s \\ \frac{\pi}{2} + Arctg2(y_{n,T} - y_s\,, x_{n,T} - x_s)\,; & \text{IF } x_{n,T} < x_s \text{ AND } y_{n,T} \geq y_s \\ -\frac{\pi}{2} - Arctg2(y_{n,T} - y_s\,, x_{n,T} - x_s)\,; & \text{IF } x_{n,T} < x_s \text{ AND } y_{n,T} < y_s \\ -\frac{\pi}{2} + Arctg2(y_{n,T} - y_s\,, x_{n,T} - x_s)\,; & \text{IF } x_{n,T} \geq x_s \text{ AND } y_{n,T} < y_s \end{cases}$$

$$AB(n,s) = \tag{6}$$
$$\begin{cases} \frac{\pi}{2} - Arctg2(y_{n,B} - y_s\,, x_{n,B} - x_s)\,; & \text{IF } x_{n,B} \geq x_s \text{ AND } y_{n,B} \geq y_s \\ \frac{\pi}{2} + Arctg2(y_{n,B} - y_s\,, x_{n,B} - x_s)\,; & \text{IF } x_{n,B} < x_s \text{ AND } y_{n,B} \geq y_s \\ -\frac{\pi}{2} - Arctg2(y_{n,B} - y_s\,, x_{n,B} - x_s)\,; & \text{IF } x_{n,B} < x_s \text{ AND } y_{n,B} < y_s \\ -\frac{\pi}{2} + Arctg2(y_{n,B} - y_s\,, x_{n,B} - x_s)\,; & \text{IF } x_{n,B} \geq x_s \text{ AND } y_{n,B} < y_s \end{cases}$$

2) Next-forwarder selection: This phase aims to enhance the greedy mode of GPSR by handling parameters of the mobile nodes. Thus, we propose a new routing factor combining three parameters: 1) the distance $DT(n,s)$ between neighbor n and sink s, 2) the moving direction $ABDir(n,s)$ of the neighbor n and 3) the moving speed $Speed(n)$ of neighbor n. When a node i has to send a packet to sink s, by using a greedy forwarding, it selects from its neighbors table node n having the smallest $DBFactor(n,s)$ given by Formula (7), where the direction $ABDir(n,s)$ is given by Formula (8). Note that this direction is calculated using the formulas (1) and (2). When $ABDir(n,s)$ is equal to 1 then n is static. When it is greater than 1 then n approaches the sink. When it is less than 1 then n moves away from the sink.

$$DBFactor(n,s) = \frac{DT(n,s) * ABDir(n,s)}{Speed(n)} \tag{7}$$

$$ABDir(n,s) = \frac{DirT(n,s)}{DirB(n,s)} \tag{8}$$

TABLE II. STRUCTURE OF A LOCATION BEACON

Field	Mission/Content
ID	Identifier of the node that sent a beacon
Position	Location of the node that sent a beacon
Speed	Moving speed of the node that sent a beacon

V. PERFORMANCE EVALUATION

We first implemented and evaluated the traditional GPSR protocol using ns2 [18] with mobility of nodes. Then we associated the proposed DGF mechanism with GPSR and evaluated in same conditions the resulting protocol (GPSR-MS). Since GPSR can handle mobility of nodes by reducing the location beacon period, we evaluate performance of this protocol under four values of this period (2ms, 3ms, 4ms and 5ms) and obtained the results which are shown in the graphs as GPSR(2), GPSR(3), GPSR(4) and GPSR(5), respectively. This period is set to 5ms for the GPSR-MS protocol.

In our simulations, we used a terrain 600m×600m with 350 mobile sensors deployed randomly. Then they move according to Random Waypoint Model (RWM) with a random speed in [5-20] m/s to simulate the mobility in realistic environments. The sink is placed at the center of the terrain and 12 sources are selected randomly. Each source generates one CBR flow with a rate increased gradually from 1 to 12 p/s. For each rate and at the end of the simulation time, we measure the packet delivery ratio, the control packet overhead, the average path length and the network energy consumption per delivered packet. Table III gives the parameters settings used in our simulations.

Compared to GPSR in Figure 2, our GPSR-MS protocol achieves a better packet delivery ratio, especially when the rate is less than 5p/s. The number of packets dropped in

GPSR is important when a beaconing period is large (5ms). Figure 3 shows a good performance of GPSR-MS in term of average path length compared to GPSR. This is due to our DGF mechanism which dynamically selects as forwarders the neighbors that move toward the sink.

TABLE III. SIMULATION ENVIRONMENT SETTINGS

Bandwith	200 Kbps
Playload	32 Bytes
Terrain	600m × 600m
Number of nodes	350 nodes
Node Speed	Random in [5-20] m/s
Node Radio Range	40 m
MAC Layer	802.11
Radio Layer	RADIO-NONNOISE
Propagation Model	TWO-RAY
Simulation Time	224 sec
Mobility Model	RWM Version 1

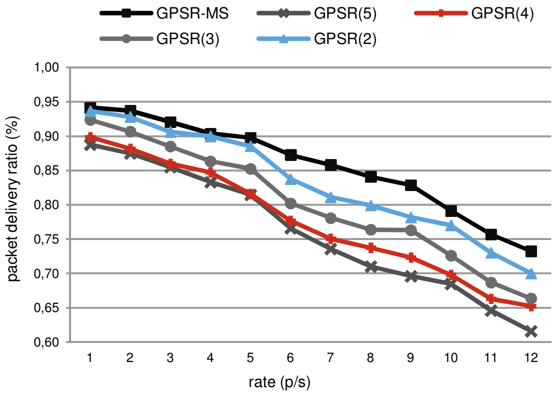


Figure 2. Performance in delivering data packets.

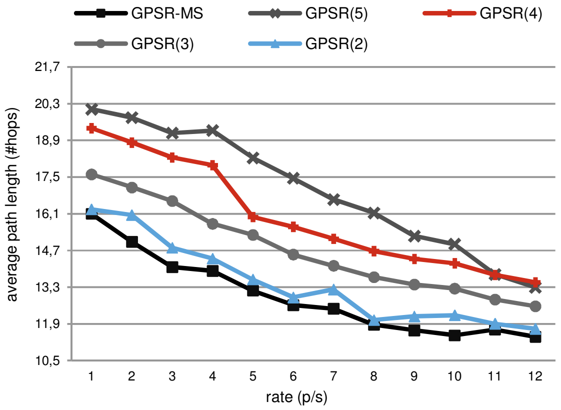


Figure 3. Performance in reducing the paths length.

Note that when the location beacon is not large (2ms), the average path length is reduced in GPSR because tables of neighbors are frequently updated. Consequently, GPSR generates more location beacons which overload the sensor network (Figure 4) and consume excessive energy of nodes (Figure 5). On the other hand, GPSR-MS delivers more data packets, generates less control packets and manages correctly the limited energy of nodes.

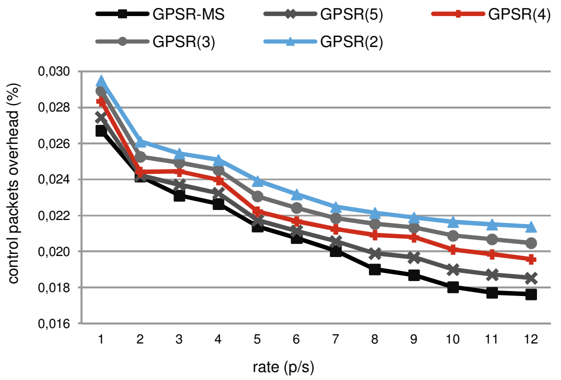


Figure 4. Performance in reducing control packets.

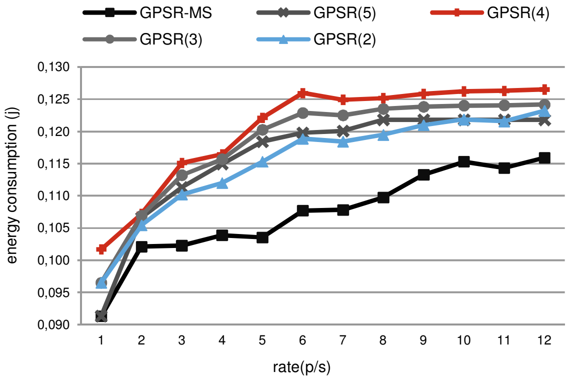


Figure 5. Performance in economizing energy of nodes.

VI. CONCLUSION

Existing geographical schemes using greedy forwarding in mobile WSNs still have problems as mentioned above (Section III). To contribute on solving these problems, we have proposed the DGF mechanism that handles mobility of nodes in WSNs. It is simple to implement, saves the network resources and could be associated with various geographical routing protocols. The merit of our proposal is that the current packet is forwarded to the best neighbor node in terms of distance, moving direction and moving speed according to the static sink. We have associated the DGF mechanism with the well-known GPSR protocol and the resulting protocol, called GPSR-MS, has achieved good performance compared to different versions of the original GPSR. Indeed, GPSR-MS delivers more packets, broadcasts less control packets, uses the shortest routing paths and economizes much energy of nodes. Our future work will evaluate performance of GPSR-MS with the group mobility concept.

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