Source-Initiated Geographical Data Flow for Wireless Ad Hoc and Sensor Networks

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ABSTRACT

A novel source-initiated geographical data flow technique, called Stateless Weighted Routing (SWR), is presented in this paper. Nodes keep only their own virtual geographical position and require no local topological information. Each node calculates the weight of its own. Initially, this value is its relative distance to the sink. Each node decides to retransmit or to drop the packet received by comparing its own weight to the weight of the sender and the weight of the sink, i.e, destination, which are contained in the received packet. The comparison actually provides the mean for stateless routing. Although the weight parameter includes only the distance information for the time being, it may also include QoS (Quality of Service) parameters such as the energy left at the node. QoS will definitely help to increase the lifetime of the system. Having had the feature of being stateless, the technique is made free from the use of excessive communications to handle the routing tables. The SWR provides braided-paths if not multi-paths, naturally which is essential to improve reliability and to serve for the time-critical data. The use of thresholds in retransmissions provides the system with a flexible and energy-efficient data flow. Moreover, to the best of our knowledge, the SWR is known to be the first stateless routing technique running independent of the MAC-layer underneath.

1. INTRODUCTION

Routing without tables can be achieved by using location information of the nodes retrieved from GPS or by applying a localization algorithm. In geographic routing protocols, nodes know their actual or relative positions with respect to a reference point, and share this information with immediate neighbor nodes for routing process. Geographic routing protocols use only local topology information and have not any update overhead. Therefore, they provide scalability in mobile networks with respect to conventional routing protocols.

Geographic routing protocols use greedy scheme or beaconless scheme for routing. In greedy schemes [1]-[4], nodes select the best next node on the route by using the local topology information. Collecting local topology information in greedy schemes consumes more energy than beaconless schemes due to reduced transmissions in the latter one. On the other hand, beaconless routing protocols in the literature propose solutions to be implemented at the MAC layer [5]-[8]. In those solutions, RTS and CTS packets are also used for implementing routing protocol that increases the complexity of the MAC layer. However, sorting routing problem at the MAC layer is against the well-defined communication architecture. Besides that, those solutions become dependent to the MAC layer they use.

In this paper, we propose a novel stateless data flow approach and routing algorithm for wireless sensor networks that is completely MAC-layer independent. Nodes do not have to be aware of local or global topology information. Routing is achieved without keeping tables. Nodes' geographical positions are sufficient for routing process. We introduced a new metric called weight that is derived from nodes' own positions to be used in routing process. The position can be either geographical or relative to a reference point system wide. Instead of the position, the weight value of the transmitting node is inserted into the packet. Each node on the route involves in routing process by considering its weight and the information in the received packet. To limit the number of forwarding nodes, a threshold is set in terms of the weight metric. On a packet receive; a node broadcasts the packet if its weight is between the weights of the transmitting node and the destination node and if also its weight difference greater than the threshold value. Besides that,

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decision to transmit includes QoS parameters such as power-left at the node to keep energy-limited nodes out of the route.

The proposed algorithm, SWR, has the following properties:

- SWR provides scalability by not using routing tables, and by not beaconing.
- SWR simplifies routing process by using a weight metric, and designing an appropriate algorithm for routing.
- SWR decreases calculations, delay, and resource requirements (such as processor and memory) at nodes by using weight metric.
- SWR decrease energy consumption by not beaconing, by using position-based routing based on threshold and considering the energy levels of the nodes.
- SWR provides reliability by using multipaths.
- SWR executes routing process completely in network layer, independent from the MAC layer used below.

In the next section, we review the related work. We give the data flow algorithm in section 3. Performance evaluations are given in Section 4. In the last section we conclude the paper.

2. RELATED WORK

The taxonomy for position based routing algorithms for ad hoc networks is given in [2] and [8]. Surveys of the proposed protocols in the literature are given in [2]-[4], [9], [10]. Formerly proposed position based routing protocols use greedy approach either distance or angle as metric. In greedy approaches, there is a possibility that they may not find the route due to the local topology knowledge, even if there is a path to destination that can be found with global topology knowledge. Besides that, beaconing-based greedy approaches consume excessive energy due to beaconing and introduce control traffic overhead. Furthermore, as the topology changes due to mobility, node terminations, link failures, and energy-saving mechanisms that switch between sleeping and active states, providing proactively local topology knowledge reduces the performance and the scalability. Therefore, stateful protocols are not suitable for these types of networks, e.g. ad hoc networks. However, stateless (table-free) protocols are not affected too much from the topological changes and network dynamics. But, they use broadcasting to find routes as in flooding which wastes resources. Parameter-based schemes can be used to reduce the number of rebroadcasting nodes. Position-based stateless approaches reduce the number of the rebroadcasting nodes by selecting the next rebroadcasting node.

The proposed stateless algorithms [5]-[8] introduce MAC-layer involved solutions for routing, which is contrary to the well-defined communication architecture. They are dependent to MAC layer they use. They use the IEEE 802.11 protocol in MAC layer for medium access control, therefore dependent to the IEEE 802.11. However, in well-defined communication architecture, timing and packet scheduling are the functions of MAC layer. On the other hand, decision of broadcast, multicast and unicast are the functions of network layer. Routing and node addressing should be independent from the MAC layer functions. Combining routing function with MAC layer introduces overhead and makes the routing protocol dependent to the MAC scheme proposed. Moreover, the proposed stateless protocols introduce a computational overhead in MAC/Network layer to schedule the packets and calculate the timers. Their performance is sensitive to the node terminations and nodes' unpredictable come-ups and go-downs.

3. STATELESS WEIGHT ROUTING: SWR

We propose a new novel stateless and beaconless routing algorithm for wireless sensor and ad hoc networks. The difference of our proposal is that routing is completely achieved in network layer rather than MAC-involved solution. No routing table and beacon messaging is used.

Routing could have been completely achieved by using geographical positions. However, instead of geographical positions, we use another value, namely weight value. Each node derives its weight value dynamically from its current position. There are two main reasons for using weight values: first, it aids to routing process and makes it simple to implement, and secondly, it minimizes delay, energy consumption, and processing requirements at nodes in routing decision phase.

The weight function takes the location information (e.g. geographical position, or relative position such as (x, y)) as input and produces the weight value. The weight function can be optimized to optimize the network metrics and the network parameters such as network-lifetime, node lifetime, emergency conditions, silence, etc. Therefore, while providing the routing, some other parameters can be optimized. A simple weight function can be as simple as the following one:

$$f(x,y) = x^2 + y^2 \quad (1)$$

When a node has data to transmit, inserts its and the destination's weight values into the packet, and broadcasts the packet. When a node receives a packet, it compares its weight value with the weight values in the packet. If its weight value is between the transmitting node's weight value and the destination's weight value, it rebroadcasts the packet, or drops the packet otherwise. If the nodes in the operation area are uniformly distributed, less than half of the nodes in the range of the transmitting node rebroadcast the packet.

To reduce the number of rebroadcasting nodes, a threshold value is used and inserted into the packet. Only the nodes those have weight difference greater than the threshold value can rebroadcast the packet. By this way, nodes closer to transmitting node are avoided to rebroadcast. Rebroadcasting nodes are those that make more advances toward the destination. As seen in Algorithm 1, Euclidian distance calculation is not used in this algorithm. Only the weight values are compared. *w(i)* defines the weight of node *i* and *Diff(x,y)* defines the weight differences of node *x* and node *y*.

Algorithm 1 Simplified Data Flow Algorithm

```
Diff(x,y)= |w(x)-w(y)|
if((w(sender))>w(i)>w(destination))and
    (Diff(sender,i) >= threshold) then
    rebroadcast;
```

The threshold value limits the retransmissions and enables only the more robust nodes to retransmit rather than too far and too close nodes.

4. SIMULATION

4.1 Simulation Parameters

In this section we present our simulation results. There is no packet loss due to transmission collisions in or simulation environment. We use the parameters given in [11] to make the results comparable with the proposed evaluations. To provide the double range property, nodes have a sensing range (R_s) 50m and a transmission range (R_c) 100m ($R_c/R_s = 2$). Fifty nodes are uniformly distributed in a well-defined topology [12] over an area 300m x 500m. Network is designed with the methodology defined in [13] and nodes randomly generate packets with a probability of 0.05 pkt/min. Destination (gateway) is positioned at the center of the rectangular area.

We compare the proposed approach with the flooding and "GPSR without perimeter" algorithm. Parameters for GPSR are obtained from the results of [11] with 1 sec periodic beaconing. Default threshold value is set to $R_c/2$ for SWR protocol. The proposed results are the averages of 10 runs of 900 seconds simulation periods. Energy consumption ratios for *idle/receiving* and *idle/transmitting* states are *1/1.05* and *1/1.4.* 1000 joule is given to each node at the startup of the simulation. We mainly focus on the energy consumption and the delay metrics. Detailed results are retrieved as energy consumption in transmission and receive processes for the routing, measurement of the network lifetime, comparison of the remaining energies of the nodes and the system.

4.2 Remaining Energy

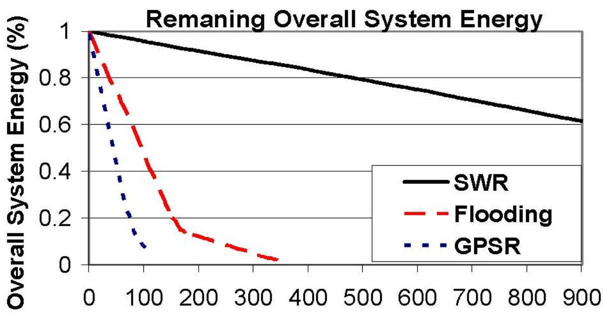

Fig. 1 Remaining energy levels of the protocols.

Table 1 Statistics of the protocols

	Flooding	*GPSR*	*SWR*
Average System Lifetime	*345 sec*	*110sec*	*>900sec*
Time of the First Node Termination	*311 sec*	*80 sec*	*NONE in 900sec*
Average Number of Terminated Nodes on Destination Unreachable	*29*	*9*	*NONE in 900sec*

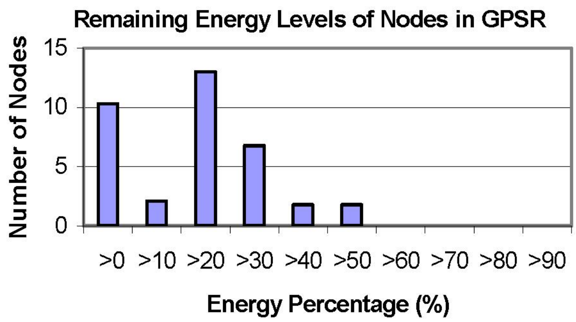

Fig. 2 Remaining Energy levels of the nodes in GPSR when the GPSR protocol fails to find a route at time 80sec.

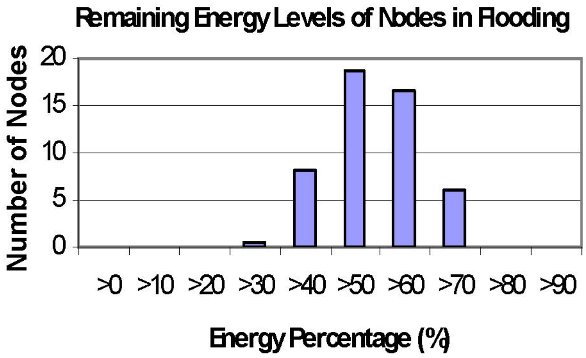

Fig. 3 Remaining Energy levels of the nodes in flooding when the GPSR protocol fails to find a route at time 80sec.

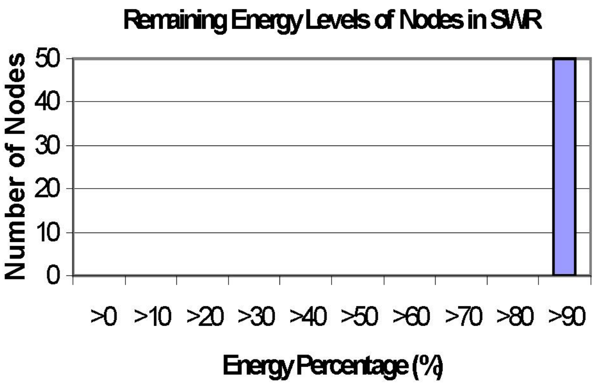

Fig. 4 Remaining Energy levels of the nodes in SWR when the GPSR protocol fails to find a route at time 80sec.

We observed both the remaining energy level of the system and the remaining energy levels of the nodes. It is seen in Fig. 1 that GPSR protocol depletes the system energy very quickly. The simulation ends after 110 seconds failing to find routes. The overall system energy of the flooding is a little better than GPSR protocol, causing the system to live longer than GPSR. GPSR depletes most of its energy at the beaconing, while the flooding depletes its energy on routing process. The observed system energy in GPSR protocol is according to the beaconing period with 1 sec. The system will live longer in GPSR protocol than flooding when the beaconing interval is extended. SWR protocol continues to live when the simulation ends after 900 sec. The remaining system energy in SWR is higher than GPSR and flooding for each second. In SWR, the energy is consumed only in routing processes. The energy consumption decreases linearly in SWR. However, the energy consumptions in GPSR and flooding seems to decrease slowly after a sharp decrease when the system about to deplete its overall energy. The reason is that nodes begin to terminate at the break points and exhausted nodes` energy is not included to the system energy. In SWR, none of the nodes terminates at the end of the simulation.

Nodes fail to find routes due to gaps composed by the terminated nodes (Table 1). It is seen in Fig. 2 that when the GPSR fails to find any route, the other nodes almost have depleted their energies. This means that energy consumption has been diffused over the all system nodes. Similar results are observed in flooding (Fig. 3). Due to flooding, all nodes participate equally to the routing process. This makes the nodes have almost equal energy levels. On the contrary, in SWR, all nodes have higher energy levels with 90% (Fig. 4).

Similar results are observed when the flooding fails to find a route at 310sec (Fig. 5-6). In flooding (Fig.5), almost all nodes deplete their energy. On the contrary, nodes in SWR preserves their energy (Fig. 6). In SWR, nodes' remaining energy is uniformly distributed when the simulation ends at 900sec. (Fig. 7).

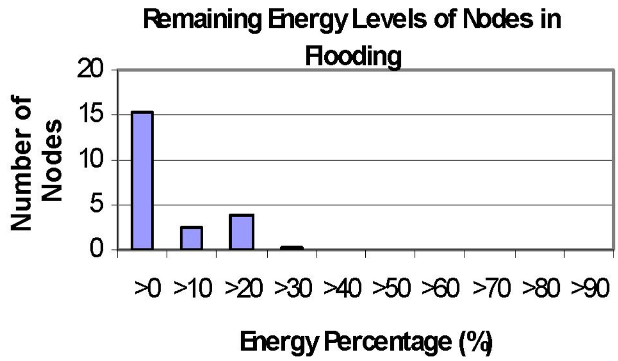

Fig. 5 Remaining Energy levels of the nodes in flooding when the flooding protocol fails to find a route at time 310sec.

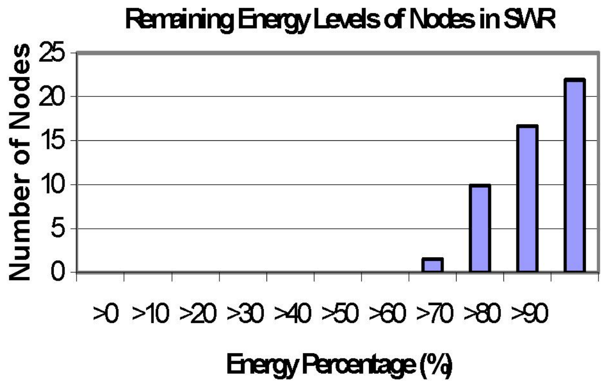

Fig. 6 Remaining Energy levels of the nodes in SWR when the flooding protocol fails to find a route at time 310sec.

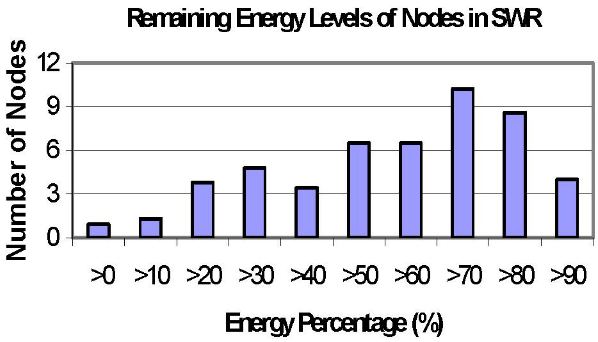

Fig. 7 Remaining Energy levels of the nodes in SWR when the simulation ends at time 900sec.

5. CONCLUSION

In this paper, we propose a novel stateless routing algorithm for MANET and WSN. To enable the proposed data flow approach, we introduce the weight metric, which decreases the energy consumption, and resource requirements such as processor and memory at nodes. Routing is achieved completely in network layer according to the ISO OSI Reference model. Being independent of the MAC-layer makes SWR applicable with any MAC-layer underneath, and makes it unique as providing this property while the other protocols in the literature propose MAC-layer involved routing solutions. We demonstrated that without any topology information, SWR forwards the packet to the destination over multiple-paths to provide reliability. Performance results show that the SWR prolongs the network lifetime longer than flooding and GPSR, and has lower energy consumption. Comparing the remaining energy levels at the nodes, the SWR over performs both flooding and the GPSR. SWR appears as a simple and effective technique. Future research includes the network with multiple gateway (sink) nodes.

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