THE CHALLENGES AND THE APPROACHES FOR THE GEOGRAPHIC ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS

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Technological advances in wireless communications and nanotechnologies made use of sensor-involved applications and systems for homeland security and safety more appealing. Application area can be extended from battlefield or security applications such as target detection to humanitarian applications such as disaster recovery, pollution detection, search and rescue, and food agriculture. Scalability and lifetime of sensor based systems primarily depend on techniques used in the MAC-layer and the network layer. Experiments in this area show that the geographic routing protocols appeared to be a promising solution for scalability while addressing the energy-efficiency problem that has to be considered to prolong the lifetime of the system. In this paper, we surveyed the challenges and the proposed solutions and approaches for the geographic routing protocols for wireless ad hoc and sensor networks.

1 Introduction

The emerging technology of sensor and actuator networks is progressively utilized in homeland security, disaster recovery, etc., and are planned to be used intensively in near future. However, the performance is degraded due to some effects peculiar to these networks such as energy limitation and wireless transmission medium. Furthermore, the scalability and the lifetime of the system mainly depend on the techniques used in the MAC-layer and the network layer. Although a number of approaches and algorithms were proposed to enhance the performance, they usually address the needs of a particular environment. In this paper, we reviewed the challenges and the proposed routing algorithms for wireless sensor networks.

As known, the essential aim of a routing function is to convey data to the destination. This is achieved by keeping routing tables of existing topology in infrastructured-wired networks. Such routing tables are kept at each network element and have to be updated to reflect topology changes. In wireless and mobile networks, similar routing approaches have been developed. However, because of the features such as mobility, energy limitations, and link failures peculiar to wireless links and mobile nodes, trying to keep up-to-date routing information causes overhead, reduces performance and lifetime of the network, and introduces scalability problem.

Scalability of a routing protocol is affected by two dominant factors [1]: the rate of topological changes and the number of nodes in the network. In the proposed protocols for mobile ad hoc networks, routing is accomplished by keeping up-to-date whole network topology, failing to be scalable and efficient. Succeeding protocols use the hierarchical structure and local topology knowledge to achieve scalability. Furthermore, they use data aggregation, query-based and energy-based approaches. While most of them compensate the specific requirements, they are not suitable for different environments and varying performance metrics such as scalability, energy, network lifetime, real-time data). The essential reasons of inefficiency are known to be keeping continuously updated local/global routing tables at nodes and excessive energy consumption in routing process. Therefore, routing without using tables became a hot research issue.

Routing without tables can be achieved by using location information of the nodes that can be retrieved from GPS (Global Positioning System) or by applying a localization algorithm. Although position-based routing is not a brand-new idea it is flourished with the emergence of wireless and mobile networks and it is called **geographic routing [1-8]**. In geographic routing protocols, actual or relative positions with respect to a reference point of the nodes are either preset or can be acquired independently in a self sufficient manner. They share this information only with their immediate neighbor nodes for routing process. Geographic routing protocols utilize only local topology information so that no update overhead is introduced. Therefore, they provide a basis for scalability in mobile networks.

2 Geographic Routing Protocols

The taxonomy for position based routing algorithms for ad hoc networks is given in [2] and [8]. Surveys of the proposed protocols are given in [2-4, 10-12]. The proposed protocols for ad hoc networks can be easily adapted to sensor networks because they share similar properties. However, some additional properties of sensor networks should be considered to adapt ad hoc network protocols. First of all, sensor nodes have limited power, memory and processing capabilities. Second of all, sensor nodes and wireless links can alter during the operation. Frequent topology changes provide the driving force to utilize local stateless algorithms that do not require global topology information. As stated previously, sensor nodes can get down easily and unpredictably at any time, forcing to deploy nodes in large numbers. By the way, the phenomena can be sensed more than one node within nearby. These properties enforce to use data-centric approach in WSN. Therefore, the most appropriate protocols for sensor networks are those that discover routes on demand using scalable techniques, while avoiding the overhead of storing routing tables globally or locally and avoiding the overhead of updating these tables according to the topology changes.

Geographic routing protocols use greedy scheme or beaconless scheme for routing. In greedy scheme [1-4], nodes select the best next node on the route by using the local topology information. By periodic beaconing or event-based beaconing, nodes acquire the location information of their neighbor nodes. The transmitting node, selects a node according to either distance-based or angle-based scheme. In distance-based scheme, the objective is to select a neighbor closest to the final destination. In angle-based scheme, the objective is to select a node closest to a virtual line between the transmitting node and the final destination. Collecting local topology information in both beaconing schemes consumes more energy than beaconless schemes because of reduced transmissions in the latter one. On the other hand, beaconless routing protocols 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, addressing routing problem at the MAC layer contradicts with the well-defined layered communication protocol. Besides that, those solutions become dependent to the MAC layer they use.

3 Stateful Geographic Routing Protocols

Formerly proposed protocols use greedy approach either distance or angle as metric. GPRS [1] requires a priori local topology information. Nodes broadcast periodically the beacon messages independent of data packets to provide this information. Receiving neighbor nodes update their neighborhood tables accordingly. On a transmission need, best next node is selected by calculating the distances of neighbor nodes. Beaconing introduces communication overhead and consumes energy. Continuous table updating introduces processing overhead and buffers overflow due to periodic beaconing [13]. While the GPSR finds the shortest paths, it may stick to the local maxima problem. GPSR proposes the perimeter-forwarding mode to circumvent the holes in the network. Perimeter forwarding increases communication overhead and energy consumption. On the other hand, it causes to deplete energies of the boundary nodes, which makes the holes grow larger. Next node selection is based on proactively table keep-up, which is affected from mobile environment. Next node selection also introduces a computational delay at each node to find the best neighbor node.

LAR [14] is a routing protocol based on source routing, employing the position information to enhance the route discovery phase. The route request packets are flooded within the request zone that includes the expected zone of the target. LAR uses flooding and the position information is used to restrict the flooding to a certain area. Flooding introduces communication overhead and consumes energy. On the other hand, due to source routing, it is sensitive to mobility causing reconstruction of the route, which degrades the performance metrics. LAR also keeps network-wide topology information, which makes it memory inefficient.

DREAM [15] is a proactive routing protocol using location information. In DREAM, each node maintains a location table of each node on the network. Each node periodically broadcast its position to inform neighbor nodes. Period is adjusted according to the speed of the nodes. On a packet to send, source node calculates the direction toward the destination and selects a set of next node candidates, then sends the packet to these nodes. If the set is empty, the packet is flooded to the entire network. Periodic beaconing and flooding, in case of empty next node candidate set, introduce communication overhead and energy consumption. It preserves the drawbacks introduced in GPSR. In addition to these, it requires memory greater than GPSR due to network-wide topology information requirement.

Another strategy for greedy forwarding is compass routing, in which the neighbor closest to the straight line between the sender and destination is selected. [16] uses the angle metric rather than distance to select the next node. In addition to the drawbacks of distance-based greedy approaches such as GPSR, it does not avoid loops.

[17] discusses the trade-off between the topology information cost and the communication cost and introduces optimal topology knowledge range for each node to make energy efficient geographical routing decisions. It introduces to approaches, PTKF and PRADA, to decrease the topology information cost. However, the proposed algorithms do not consider the voids.

[18] introduces QoS for delay-sensitive applications proposing an event-driven protocol similar to GPSR. Therefore, drawbacks are similar to the GPSR. On the other hand, only the transmission energy is considered in the energy consumption model. [20] considers the link breakages and proposes a new link metric called NADV to select the next node for constructing more robust routes. It estimates the link costs by using another new sub-layer WISE on top of MAC layer. It considers only the transmission energy in the energy consumption model. It uses the ideal conditions for route construction, which is impractical and unrealistic and only predefined packet error rates are used in NADV. Using a new sub-layer is contrary to the well-defined communication architecture.

3.1 Drawbacks of the Stateful Geographic Routing Protocols

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. On the other hand, 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 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 re-broadcasting nodes. Position-based stateless approaches reduce the number of the re-broadcasting nodes by selecting the next re-broadcasting node. However, they use MAC-layer integrated approaches to achieve this and introduce delay. MAC-layer integrated approaches make them dependent to the MAC-layer used.

4 Stateless Geographic Routing Protocols

An early example of the stateless broadcasting protocols is introduced in [5] which define a contention-based forwarding scheme (CBF) that selects the next-hop through a distributed contention process using biased timers. All nodes those receive a packet check if they are closer to the destination than forwarding node and set their timers according to the progression toward the destination. Best suitable nodes respond faster than the other nodes. Forwarding node selects the best candidate node as next node from the responding nodes set. In this approach, next node selection phase introduces greater delay and energy consumption on route construction phase with respect to greedy approaches. In greedy approaches, a priori topology knowledge produces overhead and energy consumption, but the delay and energy consumption on route construction phase is notable low. On the other hand, in CBF, rebroadcast decision is based on RTF/CTF (Request To Forward/Clear to Forward) packets and timers, which are completely processed in MAC-layer. Used energy models are not defined in [5] and it does not consider the energy-efficiency.

In [6], a beaconless routing algorithm (BLR) is proposed which is very similar to CBF in [5]. [7] proposes another beaconless position based routing protocol by guaranteeing the delivery of the packets. The Guaranteed Delivery Beaconless Forwarding (GDBF) protocol selects appropriate next node by means of RTS/CTS packets. Forwarding node broadcast the RTS packet to its neighbors and the neighbor nodes compete with each other to forward the packet and set a timeout depending on their suitability. After timeout, nodes send CTS back to the forwarding node by using the suppression technique. Forwarding node decides one of the neighbor nodes as next node and forwards the message to that node. Guaranteed delivery is provided by the recovery mode when the greedy mode fails. When the greedy algorithm reaches to local minima (no CTS response), the algorithm shifts to the recovery mode. The drawbacks are the same as in [7]. On the other hand, it is a completely MAC-layer solution for the routing.

[5], [6] and [7] are very similar to each other in terms of next node selection. A different approach is proposed in [8]. [8] proposes a Dynamic Delayed Broadcasting Protocol (DDB). DDB allows nodes to make locally optimal rebroadcasting decisions by Dynamic Forwarding Delay (DFD) and make better nodes to rebroadcast first suppressing the transmissions of other nodes. However, it cannot avoid multiple transmissions and introduces delay. On the other hand, at each receive process; nodes have to recalculate/adjust their timers, which is computationally complex. Since packet scheduling is achieved in MAC layer, on each receive process, a MAC layer – Network layer – MAC layer interoperation is executed, rescheduling the packet transmission each time. Even, a scheduled packet can be canceled after many calculations and scheduling. However, it is stated as a cross-layer approach, it involves MAC layer operations.

4.1 Drawbacks of the Stateless Geographic Routing Protocols

All of the proposed stateless algorithms introduce MAC-layer involved solutions for routing, which is contrary to the well-structured communication architecture. They are dependent to MAC layer they use. They generally use the IEEE 802.11 protocol in MAC layer for medium access control. 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. In well-defined communication architecture, 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 unpredictable come-ups and go-downs of the links.

5 CONCLUSIONS

In recent years, routing in sensor networks has gained great important due to its effects on the system-wide performance. Sensor networks introduce unique challenges peculiar to it due to sensor nodes in addition to the challenges peculiar to the wireless and ad hoc networks. In this paper, we survey the geographic routing protocols proposed in the literature. Geographic routing protocols appears to be a promising solution for the scalability and lifetime of sensor based systems primarily depending on techniques used in the MAC-layer and the network layer. Geographic routing protocols utilize only local topology information so that no update overhead is introduced. In stateful geographic routing protocols, nodes broadcast periodic beacon messages to provide local topology information. On a transmission need, best next node is selected either by calculating the distances of neighbor nodes or by calculating the angle between the neighbor nodes and the destination. Beaconing introduces communication overhead and consumes energy. However, stateless protocols are not affected too much from the topological changes and network dynamics. But, they use broadcasting which wastes resources. Secondly, they use MAC-layer integrated approaches to select best next node and introduce delay. MAC-layer integrated approaches make them dependent to the MAC-layer used. To provide energy efficiency and the scalability, routing protocols need to use location information more intelligently. Utilization of location information in routing algorithms to provide scalability remains as an open research issue.

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