Maximizing The Lifetime Of Wireless Sensor Networks With Mobile Sink Using Ring Routing Protocol

Mrs.K.Revathi, PG student,
Department of computer science and engineering,
Mookambigai college of engineering,
Trichy,
e-mail:revathicseme@gmail.com

Mrs.C.Sakunthala, Assistant professor,
Department of computer science and engineering,
Mookambigai college of engineering,
Trichy,
e-mail:saku_cs@yahoo.co.in

Abstract— *In a typical wireless sensor network, the batteries of the nodes near the sink deplete quicker than other nodes due to the data traffic concentrating towards the sink, leaving it stranded and disrupting the sensor data reporting. To mitigate this problem, mobile sinks are proposed. They implicitly provide load-balanced data delivery and achieve uniform-energy consumption across the network. On the other hand, advertising the position of the mobile sink to the network introduces an overhead in terms of energy consumption and packet delays. In this paper, propose a Ring Routing, a novel, distributed, energy-efficient mobile sink routing protocol, suitable for time-sensitive applications, which aims to minimize this overhead while preserving the advantages of mobile sinks.*

Keywords*: Mobile sinks, Distributed routing, data dissemination, energy efficiency, mobility, wireless sensor networks*

I. Introduction

In wireless sensor networks (WSNs), energy efficiency is considered to be a crucial issue due to the limited battery capacity of the sensor nodes. Considering the usually random characteristics of the deployment and the number of nodes deployed in the environment, an intrinsic property of WSNs is that the network should be able to operate without human intervention for an adequately long time, since replacing the batteries of the sensor nodes requires significant effort. Due to the converge cast nature of traditional WSN packet forwarding approaches resulting in the concentration of data traffic towards the sinks, the nodes in the vicinity of the static (immobile) sinks are more likely to deplete their batteries before other nodes, leading to the energy hole problem , disruptions in the topology and reduction in the sensing coverage. Moreover, this problem could lead to the isolation of the sinks, hindering the delivery of the sensor data traffic. Mobile sinks are proposed and explored as a possible solution to this problem.

Load-balancing is implicitly provided by the sink mobility, shifting the hotspots around the sinks and spreading the increased energy drainage around the sink, which helps achieving uniform energy consumption that extends the network lifetime. Sink mobility also has security benefits where the mobility makes the sinks more difficult to compromise than static sinks. An attack to the mobile sinks, e.g., sink destruction and sensitive information retrieval, would require an adversary to locate and chase down a mobile sink carrier. In addition, mobile sinks enhances the network connectivity by accessing the isolated portions of the network to retrieve data that might otherwise be inaccessible in a static sink case. Despite its advantages, the sink mobility brings about the problem of sink localization, requiring frequent advertisement of the changing sink position across the network. This operation may result in a significant overhead, which should be minimized to benefit from the energy savings introduced by the mobile sinks. An effective mobile sink routing protocol should also avoid an extreme increase in the sensor data delivery latencies. Especially for the time sensitive WSN applications, the validity of the sensor data depends on its freshness.

To ease the data collection efforts in such scenarios, thus making mobile sinks more applicable, heterogeneous architectures stemming from the marriage of WSNs with other types of networks are also possible. Mobile phones connected to a cellular network are employed as mobile sinks. The advertisement of the mobile sink position to the network is a core problem for any routing protocol. The simplest mechanism to address this problem is flooding. However, flooding type mechanisms are known to introduce a high overhead due to frequent broadcast communications.

To minimize this overhead, hierarchical routing protocols have been proposed that determine a multi-tier hierarchy of roles among the nodes. The high-tier nodes acquire and store the fresh sink position. Low-tier nodes query them to retrieve the sink position whenever needed. Such an approach eliminates the need for network-wide sink advertisement and significantly decreases the advertisement overhead. In addition, by minimizing the need for broadcasts, the energy-efficiency of the network is enhanced, since every node in the transmitter's neighborhood have to remain awake less often, decreasing the expenditure in the reception and the processing of the transmitted data. Although the hierarchical architecture decreases the overall energy consumption in the network significantly, due to likeliness of increased traffic through the high-tier nodes, they may be subject to hotspot problems. Replacement of the high-tier nodes with the regular nodes during the WSN operation or adjusting the number of high-tier nodes to be relatively greater, results in the reduction of the extra load on each high-tier node by distributing it over a number of nodes.

In this paper, propose a novel hierarchical routing protocol for WSNs with a mobile sink, named Ring Routing. Some key features and the contributions of Ring Routing as follows:

1. Ring Routing is a routing protocol targeted for large scale WSNs deployed outdoors with stationary sensor nodes and a mobile sink.
2. Ring Routing establishes a virtual ring structure that allows the fresh sink position to be easily delivered to the ring and regular nodes to acquire the sink position from the ring with minimal overhead whenever needed.

3. The ring structure can be easily changed. The ring nodes are able to switch roles with regular nodes by a straightforward and efficient mechanism, thus mitigating the hotspot problem.

4. The mobile sink selects anchor nodes along its path and the anchor nodes relay sensor data to the sink. In case the sink position information obtained by a sensor node loses its freshness, the sensor data is relayed through the old anchor nodes to the current anchor node, preventing packet losses. This mechanism is based on progressive footprint chaining.

5. Ring Routing relies on minimal amount of broadcasts therefore; it is applicable to be used for sensors utilizing asynchronous low-power MAC protocols designed for WSNs.

6. Ring Routing does not have any MAC layer requirements except the support for broadcasts. It can operate with any energy-aware, duty cycling MAC protocol (synchronized or asynchronized).

7. Ring Routing is suitable for both event-driven and periodic data reporting applications. It is not query based so that data are disseminated reliably as they are generated.

8. Ring Routing provides fast data delivery due to the quick accessibility of the proposed ring structure, which allows the protocol to be used for time sensitive applications.

9. No information about the motion of the sink is required for Ring Routing to operate. It does not rely on predicting the sink's trajectory, and is suitable for the random sink mobility scenarios.

Ring Routing uses greedy geographic routing as the underlying routing solution. Geographic routing is scalable and energy-efficient; therefore, it is an attractive routing solution for WSNs. Ring Routing is an energy efficient, reliable routing protocol that provides fast data delivery.

II. RING ROUTING

A novel hierarchical routing protocol for wireless sensor networks with a mobile sink. The protocol imposes three roles on sensor nodes: ring node, regular node, anchor node. Ring nodes form a ring structure which is a closed loop of single-node width. The basis of Ring Routing is (i) advertisement of sink position to the ring, (ii) regular nodes obtaining the sink position information from the ring whenever necessary, and (iii) nodes disseminating their data via the anchor nodes, which serve as intermediary agents connecting the sink to the network. Three simple assumptions are made before going into the details of the protocol:

1. Sensor nodes are aware of their own positions. The position information may be based on a global or a local geographic coordinate system defined according to the deployment area. Determining the position of the nodes might be achieved using a satellite based positioning system such as global positioning system (GPS) or one of the energy-efficient localization methods proposed specifically for WSNs.

2.Every sensor node should be aware of the position of its neighbors. This information enables greedy geographic routing and can be obtained by a simple neighbor discovery protocol.

3.The coordinates of a network center point has to be commonly known by all sensor nodes. The network center does not have to be exact and can be loaded into the sensors' memories before deployment. The ring structure encapsulates the network center at all times, which allows access to the ring by regular nodes and the sink. The network center is marked with an "X" in various example ring structures shown in Fig. 1

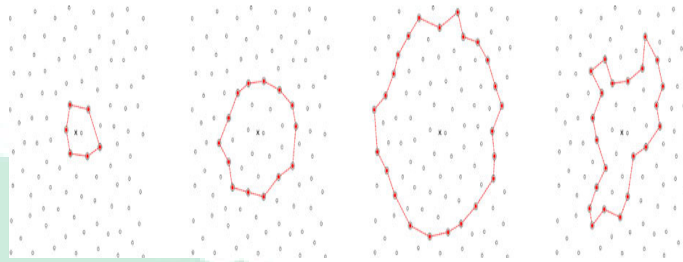

Fig.1 various structures of ring structures. (a) small, (b) medium, (c) large, and (d) imperfect.

1. Ring construction

The ring consists of a one-node-width, closed strip of nodes that are called the ring nodes. As long as the ring encapsulates the pre-determined network center, it can change. The shape of the ring might be imperfect as long as it forms a closed loop.After the deployment of the WSN, the ring is initially constructed by the following mechanism: An initial ring radius is determined. The nodes closer to the ring, which is defined by this radius and the network center, by a certain threshold are determined to be ring node candidates. Starting from a certain node (e.g. the node closest to the leftmost point on the ring) by geographic forwarding in a certain direction (clockwise/counterclockwise), the ring nodes are selected in a greedy manner until the starting node is reached and the closed loop is complete. If the starting node cannot be reached, the procedure is repeated with selection of different neighbors at each hop. If after a certain number of trials the ring cannot be formed, the radius is set to a different value and the procedure above is repeated. An example ring construction scenario is depicted in Fig. 3. The initial ring construction procedure is straightforward and energy-efficient. It does not require a centralized decision entity, hence it is applicable to a pure WSN architecture with a single type of nodes.

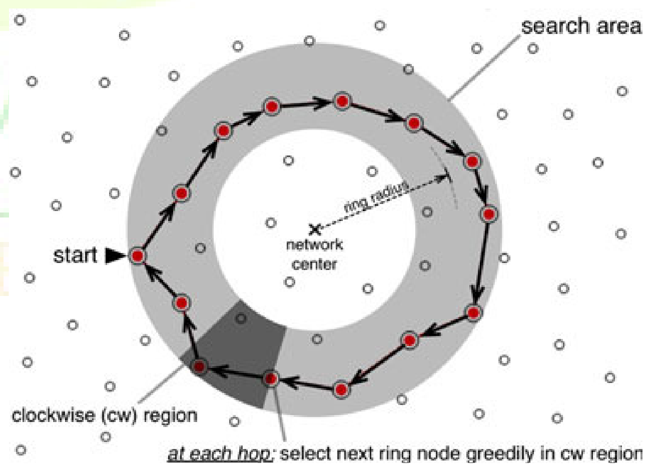

Fig. 2 Ring Construction

After the construction of the ring, neighbor discovery is performed to mark the neighboring ring nodes of each regular node. This step is crucial for the regular nodes to be able to access the ring. Moreover, each node should determine its position with respect to the ring (namely inside or outside the ring). Ring construction is dependent on the location information of the nodes, which is known to contain some inaccuracy based on the utilized technology. In order to provide evidence for the localization error tolerance of Ring Routing, is applied a Monte-Carlo analysis to determine the successful ring construction probability under varying degrees of localization error.

2. Advertisement of Sink Position

The sink moves, it selects anchor nodes (ANs) among its neighbors. The AN serves as a delegate managing the communications between the sink and the sensor nodes. Initially, the sink selects the closest node (e.g., the node with the greatest SNR value) as its AN, and broadcasts an AN Selection (ANS) packet. Before the sink leaves the communication range of the AN, it selects a new AN and informs the old AN of the position and the MAC address of the new AN by another ANS packet. Since now the old AN knows about the new AN, it can relay any data which is destined for it to the new AN. The current AN relays data packets directly to the sink. This mechanism is referred to as the follow- up mechanism.

The AN selection and follow-up mechanisms are based on progressive footprint chaining. Progressive AN selection poses a challenge in terms of determining when and how a new AN should be selected, which is closely dependent on continuous link quality estimation. Although in ideal radio channel conditions, distance to the neighboring nodes, calculated via their geographic coordinates, may be indicative of the status of the link, it is rarely the case, since radio link quality is usually affected by many factors other than distance. One of the more resilient methods of link quality estimation is beaconing. In this approach, the sink periodically broadcasts beacon messages, and a link quality estimation metric (e.g., RSSI) is calculated from the reply messages originating from the neighboring nodes. Depending on the value of this metric, the sink can decide whether to change the current AN and which node to select as the new AN. The period of the beacon messages should be tuned according to the mobility and speed of the sink, which are assumed to be known since the sink itself usually makes the mobility decisions.

The AN selection mechanism is shown in Fig. 4. For simplicity, perfect channel conditions (circular communication ranges) are assumed. First the sink selects Node 1 as the AN. Before it leaves the communication range of Node 1 it selects Node 2 as the new AN and informs Node 1. Likewise, when sink is about to leave the communication range of Node 2 it selects Node 3 as its current AN. Thanks to the AN, if a source node acquires the fixed position of the current AN, it can directly send its data to it by geographic forwarding, and the AN relays this data to the sink, completing data dissemination. If the data reaches an old AN, the follow-up mechanism is used to relay the data to the sink. The essence of sink position advertisement is delivering the newly selected AN's position and MAC address information to the ring. Upon selection of a new AN, it sends an AN Position Information (ANPI) packet towards the ring. If the AN is outside the ring, it sends the ANPI packet towards the network center, and if it is inside the ring, it sends it towards a point which resides on the opposite direction of the network center using greedy geographic forwarding. If the ANPI packet on its way arrives at a node which has a ring node neighbor, it is directly relayed to that ring node. The closed loop property of the ring ensures that such a ring node will certainly be reached.

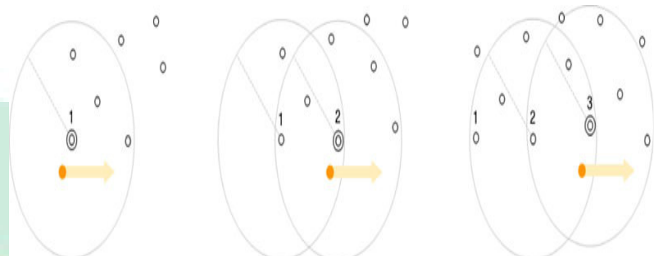

Fig.3 Advertisement of sink position

After a ring node receives an ANPI packet, it shares this information by sending an AN Position Information Share (ANPIS) packet to its clockwise and counter-clockwise ring neighbors. Each ring node receiving an ANPIS packet relays it to the neighbor ring node in the respective direction until the two ANPIS packets sent in the clockwise and counterclockwise directions arrive at the same ring node. At this point all the ring nodes are aware of the position and the MAC address of the AN, and thus the advertisement of sink position to the ring is completed. The ANPI packet is sent to the ring (1), and ANPIS packet is sent around the ring (2) to share the AN position information with all ring nodes. Advertisement of Sink position is depicted in Fig .3.

3. Obtaining Sink Position From the Ring

A source node, that has data available, has to obtain the position of the AN before disseminating data to the sink. The fresh position of the AN is stored in the ring. In order to retrieve it, a mechanism similar to the delivery of ANPI packets to the ring is used. The source node sends an AN Position Information REQuest (ANPIREQ) packet towards the ring (towards the network center if the node is outside the ring, away from the network center if it is inside the ring). The source node's position is also included in the ANPIREQ packet. The ring node receiving the ANPIREQ packet generates an AN Position Information RESPonse (ANPIRESP) packet which contains the current AN's position and sends it to the source node making the request via geographic routing, by using the position of the source node retrieved from the ANPIREQ packet . Upon reception of the ANPIREQ packet, the source node learns the position of the AN and can now send its data towards it There are several packet types which contain the AN position information (ANS, ANPI, ANPIRESP packets).

Even though these packets and the information contained within them are destined for their ultimate target, the intermediate nodes relaying these packets may obtain the AN position information. Ring Routing uses this ability to its advantage. All intermediate nodes fetch AN position information from these packets and use it for delivering their own data to the AN. Fetching AN position information from the ANS broadcast also avoids unnecessary contact with the ring, since receiving an ANS broadcast means that the sink is very close, and direct communication is certainly the best way for data dissemination.

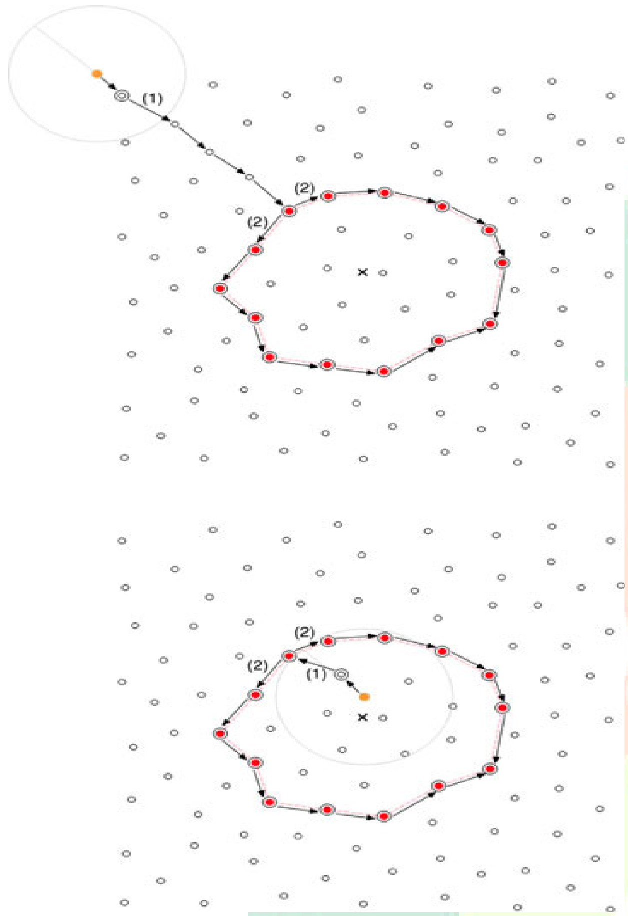

Fig .4 Obtaining sinks position

4. Data Dissemination

Once a source node receives a response (ANPIRESP) to its request (ANPIREQ), it learns the position of the AN and can now send its data directly to it by geographic forwarding. If data reaches an old AN, meaning that the AN has already changed by the time data has arrived at the destined AN, the follow-up mechanism is used to disseminate data to the current AN.

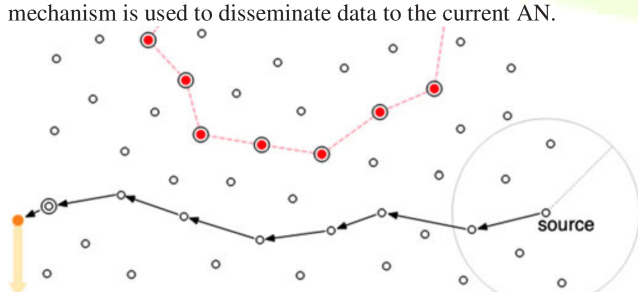

Fig. 5 Data dissemination

5. Ring Change

Ring nodes are susceptible to consume more energy then other nodes since they process AN position information advertisements and requests. They handle more traffic than regular nodes. In order to prevent these nodes from dying quickly, they have to switch roles with regular nodes from time to time. A simple mechanism to do that. The trigger of this mechanism might be a battery level threshold, or it could simply be performed periodically. Since there is no central control entity in a pure WSN architecture, the proposed ring change mechanism works locally, meaning that each ring node is independent to switch its role with regular nodes of its own choosing. When a ring node decides to change its role to a regular node, it selects ring node candidates (among regular nodes in its neighborhood) which will take on the role of ring nodes in its place.

With the newly selected ring nodes, the two properties of the ring have to be preserved: encapsulation of the network center property and closed loop property. Also the ring node candidates have to be selected according to the current ring change direction (expanding or collapsing). In order to preserve the closed loop property of the ring, the ring candidates have to make a connection (single hop or multi-hop) between the ring node's clockwise and counter clockwise ring neighbors. This could be achieved by running a shortest path algorithm on the search space of neighbors in the current ring change direction.

After ring candidates are determined, a simple geometric check has to be done to ensure that network center is still encapsulated by the ring. After these two procedures are completed, the ring node broadcasts a ring change (RC) packet that informs the ring candidates of their new role. At this point, the ring node drops the role ring node and becomes a regular node. The last step is for the new ring nodes to inform their neighbors of their new role. Moreover, all regular nodes in the vicinity should update their position with respect to ring (inside/outside) information, in case the ring passes over them. This could be done by retrieving and using the ring change direction information available in the RC broadcast packet. The pseudo code of the procedure executed when a ring node decides to change its role.

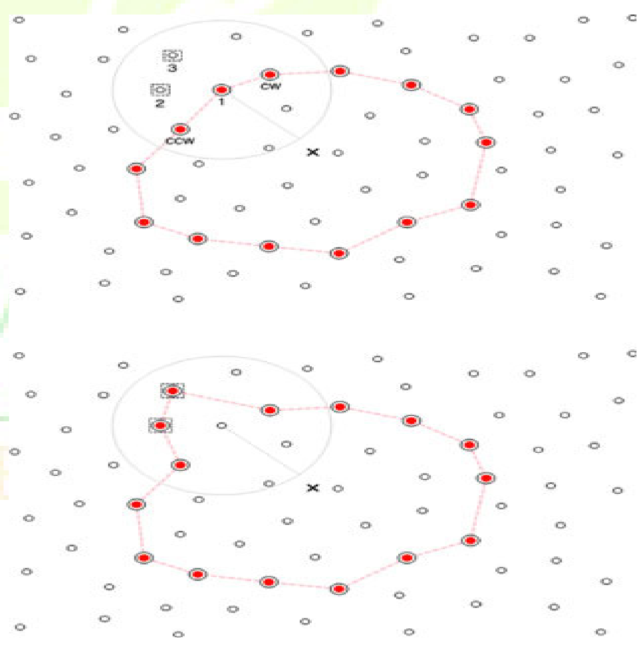

Fig. 6 Ring change

III Conclusion

A novel mobile sink routing protocol, Ring Routing, by both considering the benefits and the drawbacks of the existing protocols in the literature. Ring Routing is a hierarchical routing protocol based on a virtual ring structure which is designed to be easily accessible and easily reconfigurable. The design requirement of protocol is to mitigate the anticipated hotspot problem observed in the hierarchical routing approaches and minimize the data reporting delays considering the various mobility parameters of the mobile sink.

In the future, want to modify Ring Routing to support multiple mobile sinks. Even though the current definition of Ring Routing is easily adaptable to operate with multiple on the ring and generating ANPIRESP packets with the position information of the sink closest to the source node; this would merely be an adaptation without considering the benefits of using multiple sinks. A rational and effective modification would utilize the advantages of multiple sinks with additional mechanisms and structures. Therefore, in future wish to propose extensions and modifications to Ring Routing so that it operates even more efficiently with multiple mobile sinks. Such an approach is necessary to justify the extra cost of deploying additional sinks to the WSN. In addition to that, we wish to explore different mobility patterns such as nomadic or controlled sink mobility other than the constant speed sink mobility.

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