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Research paper

Enabling smarter routing in WSNs with mobile sinks

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Abstract

Wireless sensor networks (WSNs) have been increasingly deployed for ambient data reporting for varied settings. Source to the sink communication is typically multi-hop and intermediate nodes relay packets from the source to the destination. Fast energy drainage from the nodes around the sink can affect the overall network lifetime. Mobile sinks are typically utilized to enhance the lifetime of the WSN. However, mobile sinks can bring more challenges to already constrained WSN. When the sink relocates itself location updates and the route request messages can trigger an excessive amount of traffic within the network. This paper proposes a smart routing protocol that can support sink mobility in WSNs at the same time avoiding the excessive route or location update messages. In most of the cases routes are only updated for the first hop neighboring nodes of the sink. The proposed protocol does not require sink to subscribe to any data in advance. Moreover, sink has the freedom to take any arbitrary path. The overhearing characteristic of the wireless transmission has been exploited in order to reduce the routing overhead even further.

Keywords: *Routing; WSNS; Mobility; Mobile Sinks.*

1. Introduction

Wireless Sensor Networks (WSNs) comprise of low cost, low powered and small sized devices. These devices or nodes are typically deployed in harsh environments. The sensor nodes are involved in detecting/sensing a target phenomenon and reporting it back to the sink. Sensor nodes are usually deployed in a large number and are reporting back to sink via short range wireless interfaces and in a multi-hop communication. With the introduction of mobile sinks this field is attracting all the more focus due to its applicability in potentially a large number of applications like in habitat monitoring, surveillance, battlefield, healthcare etc [1], [2].

WSN is thought to be different from an ad hoc network mainly because of its communication pattern. In an ad hoc network all the nodes typically contact each other; however, in a WSN all the sensor nodes send the data only to the sink. This communication pattern or flow of information has a profound effect on the lifetime of the network. In this multi-hop communication much of the volume of the traffic remains in the neighborhood of the sink. The nodes around the sink are typically acting as the forwarder nodes. These nodes run out of energy faster than any other nodes of the network. This imbalance in the energy depletion would decrease the lifetime of the network as a whole.

One of the solutions to balance the energy usage of the WSN is to use mobile sinks [3-10]. If sink moves within the network it would have different nodes in its neighborhood. In this way the burden of forwarding the messages to the sink would be distributed on whole of the network instead of just staying in a specific part of the network. The movement of the sink can be random [10] or fixed [6], [9]. However, having a mobile sink in the network can be quite costly in terms of overhead for route discovery and maintenance [11]. The use of additional protocol messages that need to be exchanged while the sink is mobile might reduce the advantages of balancing the energy depletion of the network. Moreover, there is a high chance of having more packet loss due to path failure problem. Therefore, routing protocol design is of utmost importance so that the data delivery is kept high at the same time the protocol overhead is reduced to the minimum possible level while the sink is mobile.

This manuscript proposes a novel routing protocol for mobile sink. The objective of the proposed protocol is to effectively reduce the protocol overhead while supporting the sink mobility. The proposed protocol exploits the overhearing feature of wireless transmission in order to avoid sending more control messages to the network. Moreover, beacon messages are used in order to indicate the location of the sink. The proposed protocol makes use of the three levels of flooding techniques that are utilized smartly in order to avoid flooding whole of the network every time a route is required to be constructed between the node and the mobile sink. Each beacon

message contains a Path Update bit that is used to control the overhead messages sent into the network.

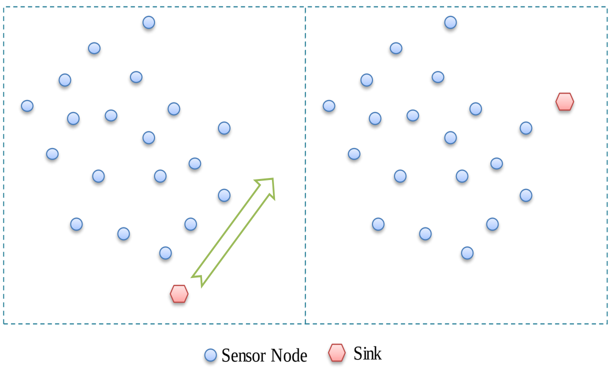

Fig. 1: Sink Mobility in WSNS.

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Rest of the paper is organized as follows. Section II talks about the related work. Section III introduces the proposed routing protocol. Section IV presents analysis of the proposed routing protocol. Section V summarizes key conclusions of this work.

2. Related work

Authors in [11] present a data driven routing protocol called DDRP. They send additional information i.e. distance from the sender to the mobile sink in order to reduce the protocol overhead for already constrained WSN. Similarly, authors in [5] present two efficient data gathering protocols for mobile Wireless Sensor Networks (mWSNs). They claim that both of their protocols can cater sink mobility for light and heavy mWSNs.

Authors in [12] talk about mobility in WSNs and present a delay aware energy efficient routing protocol for WSNs. They exploit path fixed mobile sink They claim that their proposed lightweight location calibration method reduces the control overhead. Furthermore, they claim that reliable data delivery can take place with the help of a mechanism which they call track routing.

[13] talk about option of using mobile nodes in WSNs to harvest data which will eventually increase the lifetime of the network. Authors explore the problem of controlling the mobility of sink node in order to maximize the lifetime of the network. They exploit decision tree and dynamic programming, in their proposed algorithm, to predict an optimal deadline-based trajectory for a mobile sink.

In [14] authors have comprehensively surveyed the data collection schemes of WSNs where sink stays mobile. Authors summarize all those schemes into three categories 1) path constrained 2) path unconstrained and 3) controlled sink mobility-based schemes. They also highlight important challenges being faced by those schemes.

Authors in [15] present a detailed survey on Hierarchical based routing protocol for mobile WSNs. Authors claim that the selection process of the right kind of hierarchical protocol to serve the needs of a particular application is very crucial. They present a detailed classification of these hierarchical protocols based upon several criterion such as mobility pattern, network architecture, path establishment etc.

3. Protocol overview

This section presents the overview of the proposed protocol.

The proposed protocol intends to reduce the number of messages that are sent to the network. These messages can be route request, route reply, beacon etc. With the increase in the messages in the network the batteries of the sensor nodes deplete at a faster rate. The proposed routing protocol has the following characteristics that can help reduce overhead messages:

1) Beacon messages are sent at a regular interval by the sink that helps to identify its position. It will reduce the packet loss rate and increase the reliability of transmission.
2) First hop nodes (FHN) make use of the overhearing feature of wireless transmission in order to avoid triggering flooding into the network
3) Three level of flooding have been proposed. First degree flooding (FDF) triggers path request messages (PREQ) in the first hop nodes. Second degree flooding (SDF) triggers PREQ messages in the second hop nodes. Only N degree flooding (NDF) can send PREQ messages throughout the network, which should be very rare.

Once the sink moves, two nodes get into focus more than any other node. Before the sink node moves and changes its position, the node that served as the main forwarder to the sink can be named as ex-neighboring node (ENN). Whereas, the node that gets to serve the sink as a forwarder after the sink moves can be named as fresh neighboring node (FNN). These nodes can be seen in figure 3.

Note that there might be scenarios where there would be multiple forwarder nodes both in pre and post movement of the sink. However, single or multiple ENN and FNN would operate in the similar fashion.

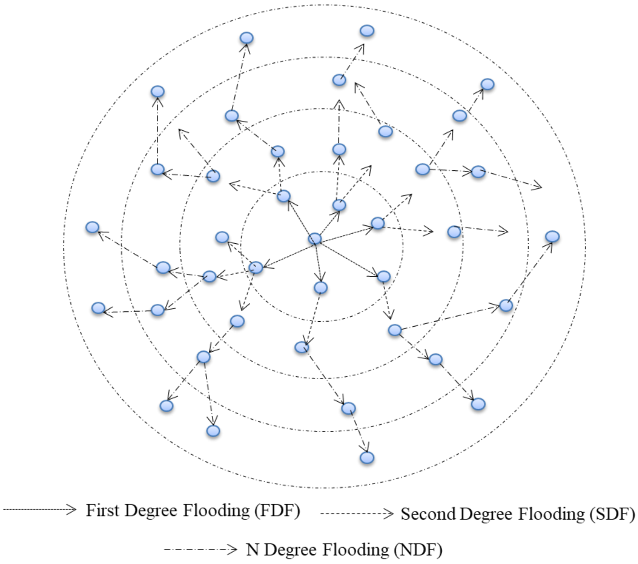

Fig. 2: Three Level of Flooding.

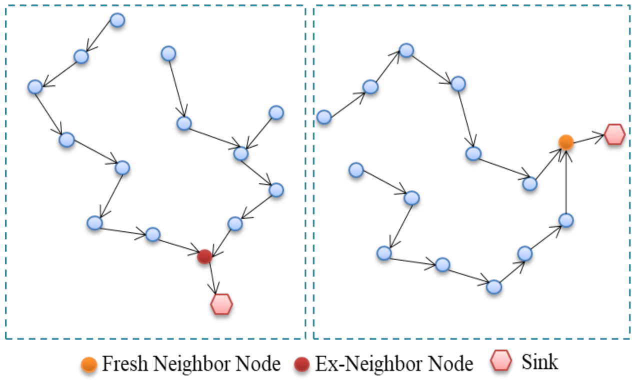

Fig. 3: Mobile Sink with Fresh and Ex Neighboring Node.

a) Network Model

We assume a homogenous network. The network comprises of sensor nodes and sink nodes. Both sink and sensor nodes are equipped with short range radios and have same communication range. In order to have a long-range communication multi hop communication has to be used. The sink is assumed to be mobile. We further assume that each sink sends a beacon message to its neighboring one hop sensor nodes. This bacon message helps sensor nodes know that they can send the report message directly to the sink i.e. sink is in their range. None of the nodes have any location information and the sink can move arbitrarily i.e. there is no fixed path for its movement

b) Protocol Design

Sensor nodes normally direct all the traffic towards the sink in response to the query sent by the sink. One of the advantages of mobility of the sink is that the energy depletion of the nodes in the network gets somewhat balanced. It helps in enhancing the lifetime of the network.

The sink in the proposed protocol sends a beacon message after a regular interval. FHNs have a timer for the beacon message. Once the beacon message has been received FHNs reset the timer. The beacon message has the following important information:

1) Timestamp
2) Sink ID
3) Path Update
4) Number of hops

Timestamp	Sink ID	Path Update	Number of hops

Fig. 4: Frame Format of the Beacon Message.

Timestamp serves to differentiate the new beacon from the old beacon. It will be particularly useful once the sink relocates itself. Sink ID is for the identification of the sink, it can be useful if there are multiple sinks in a network. Path Update is useful for sinks mobility. It comprises of a single bit. Number of hops defines how far the sink is from a particular node in terms of hops. Initial value of Number of hops field is 0.

Table 1: Fields of the Beacon Frame

Timestamp	Differentiate new and old message
Sink ID	Identifies the sink (useful in case of multiple sinks)
Path Update	Sinks uses it once it gets mobile
Number of hops	Distance of sink in terms of hop count

For simplicity let us assume that the initial path has been setup for each node from and to sink. The route discovery could have done using different approaches like a greedy approach.

Let us take a scenario where node A is serving as ENN. The next hop routing table entry for ENN points to the sink. All the packets reach the sink via node A. Sink broadcasts its beacon at regular interval. The timestamp of the beacon serves to differentiate each beacon from the other. Every time a beacon is received node A resets its timer. The path update bit is set to ‘0’ by default. Now let us assume that the sink moves to a new location and FNN is now node B. There can be two situations that can arise from the movement of the sink. Let us look at them one by one.

Case 1: First situation is that sink moves to a location where both ENN and FNN are in communication range of each other. ENN waits for the beacon from the sink. If it does not receive the beacon and timer expires then ENN would know that the sink has changed its location. It would wait now for a random amount of time. After sink reaches to the new location it then sends its beacon and it would set the path update bit. FNN receives the beacon and when it sees that the path update bit is set it would reply to the sink by sending back the same beacon. Since ENN is in the transmission range of FNN it would overhear the beacon and would know that the sink has moved and it is just in the neighborhood. It would send an acknowledgement message to the sink. ENN will then update its routing entry and will change the next hop to FNN. This procedure will ensure that the sink location is passed on to the ENN without sending or exchanging a lot of messages or triggering any flooding. This can enhance the lifetime of the network.

Case 2: Second situation would occur once sink moves a bit far away from ENN. In this case ENN and FNN would not be in communication range of each other. The same procedure would first be repeated in this situation too; however, as ENN and FNN are out of communication range sink will not receive the acknowledgement message from ENN. After waiting for some random time sink will re-broadcast its beacon. Now, FNN receives the beacon message with path update bit set for the second time it will trigger FDF by re-broadcasting the beacon message. The update path bit would be set and it would add one to the number of hops field. As ENN is not next hop neighbor of FNN the first hop neighbor of FNN would trigger another FDF (technically it will be SDF). Now if the ENN receives this beacon it would send an acknowledgement to the sink. This time the acknowledgement is sent via a broadcast. The neighboring nodes would also receive the broadcast from ENN and therefore would discard beacon. However, after a certain amount of time if no acknowledgement is received the second hop nodes would trigger another FDF. This process would repeat (NDF) unless ENN is found. This would reconstruct the path back to the sink. This step by step FDF would try to limit the overhead messages sent into the network.

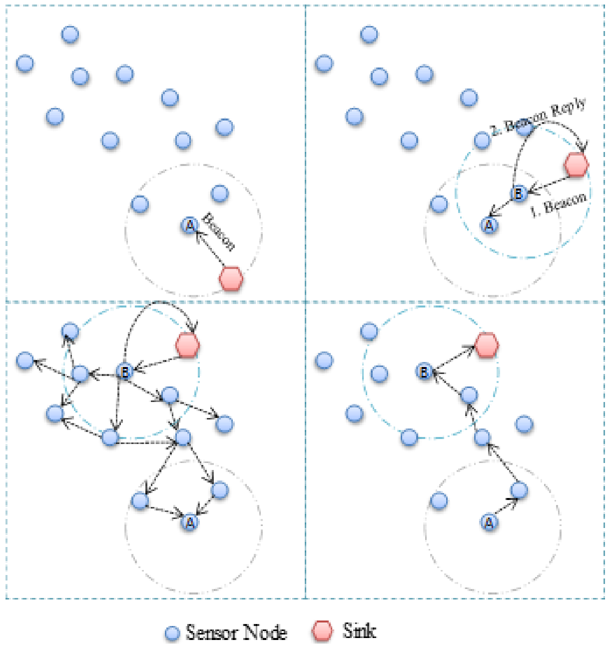

Fig. 5: Different Scenarios of Sink Mobility.

4. Analysis and discussion

A WSN is a constrained network where nodes have limited resources. Most of the routing protocols try to enhance the lifetime of the WSN by trying several optimization approaches. With a mobile sink the number of control messages are thought to be more in comparison to the WSNs with a static sink [14]. This increase in the network traffic might put a burden on the already constrained network. Therefore, the proposed protocol makes use of smart routing technique once the sink gets mobile. Following measure are taken in order to control the flow of messages into the network:

1) Use of periodic beacon messages help to minimize the route requests triggered from the sensor nodes.
2) Appropriate value of beacon timer used by sensor nodes can further reduce the route request messages
3) Option of having multiple levels of flooding can help avoid large scale flooding of the network.
4) Use of overhearing characteristics of wireless medium helps in reducing the influx of messages to the network.

All the abovementioned measures help to reduce the number of messages being sent to the WSN. It eventually balances energy depletion throughout the network and enhances its lifetime.

Table 2: Important Legends

Legend	Usage
N	Number of nodes in a given WSN
M	Number of control messages being sent in a given WSN
S	Mobile Sink Node
E	Average residual Energy level of the given WSN
M_p	Number of messages sent using proposed flooding technique
M_r	Number of messages sent using regular flooding technique

Suppose that there are ‘N’ number of nodes in a WSN. Under a normal scenario of sink mobility let us assume that ‘M’ number of control messages are being sent to the network to trace the sink (‘S’) and to send data to it. The obvious relationship that can be figured out is:

$$M \alpha N \tag{1}$$

The above equation can be written as:

$$M = C N \tag{2}$$

Here 'C' represents a constant value which varies between 1 and n i.e. 1< C < n. The value of 'C' should be selected by keeping several factors in mind like density of the network, throughput etc. The value should not be too high since it will mean a lot of messages are being sent to the network.

For simplicity and comparison purpose let us suppose 'E' represents the average energy level of the whole WSN. This energy level can be represented with the following summation expression:

$$E = \sum_{k=0}^{N} Ek$$

Here 'Ek' represents the energy level of each node of the WSN.
With the high value of 'M' we should expect a low value of 'E'. The following equation explains this relationship:

$$E \propto 1/M \qquad (3)$$

In other words when there is a huge influx of messages in the network it will have a huge impact on the energy level of the nodes since a lot of energy will be utilized in receiving, processing and transmitting messages.

The above equation can be expressed as:

$$E = D / M \qquad (4)$$

Here 'D' is a constant and its values can vary between 1 to n.

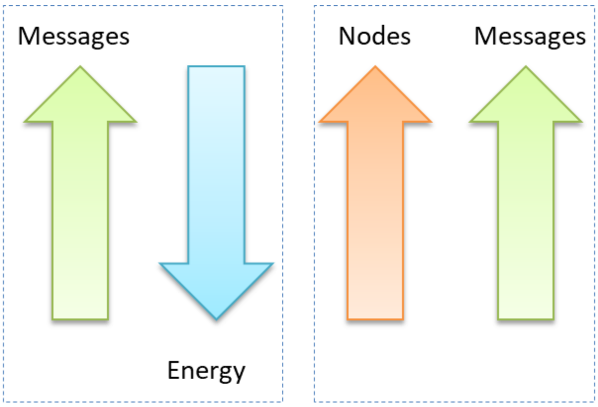

Fig. 6: Trend in Energy, Nodes and Messages for A Given WSN.

The analysis that has been discussed so far is focusing on the regular flow of the traffic with a mobile sink with an assumption that quite a large number of control messages are being sent to the WSNs and the all the network is flooded with those messages. The protocol that has been proposed in the paper suggests multi-level flooding approach. Let's take the example shown in figure 7. For the sake of analysis, suppose there are nine nodes in a given WSN. In case of a regular flooding technique a total of seven control messages will be sent to the network. Whereas in proposed first degree flooding only three messages will be sent. Please note that the number of messages sent in the second degree flooding in this particular example are the same as of a regular flooding technique. However, WSNs generally comprise of tens and thousands of nodes. We can now focus on two outputs

1) If third hop neighbors exist (which in most of the cases do exist) using second degree flooding will result in almost half of the messages in comparison to using a regular flooding technique.
2) In the given example if the network information is available with the first hop nodes the messages will be reduced to half in comparison to the regular flooding

From the above discussion we can infer the following:

$$M_p = M_r / H \qquad (5)$$

Here 'H' is a constant number that can vary depending upon various characteristics of the given network. In our particular example the value of 'H' is nearly equal to two.

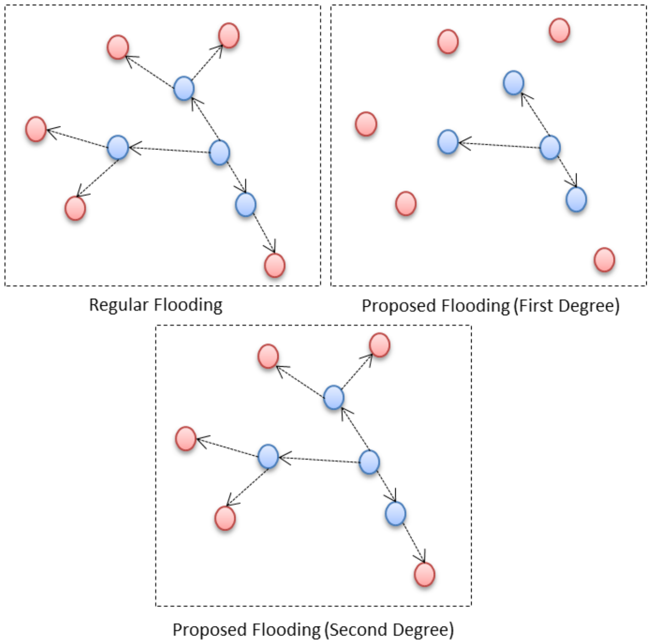

Fig. 7: Comparison of Regular and Proposed Flooding Techniques.

The following figure explains that as the number of nodes increase the messages using both regular and proposed flooding techniques increase. However, the messages using the proposed technique increase quite slowly in comparison to the other technique.

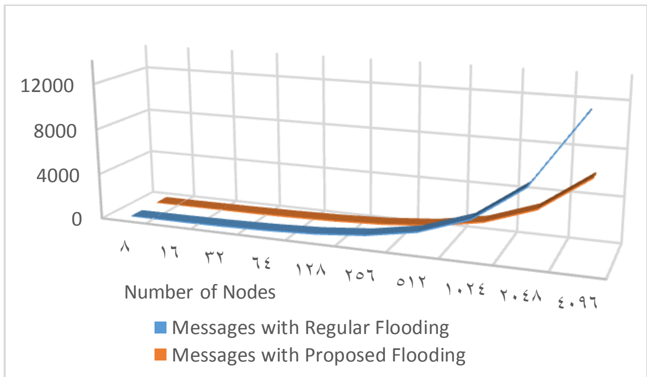

Fig. 8: Comparison of Number of Messages sent to the WSN.

5. Conclusion

This paper presents a routing protocol that can support mobility of sinks in a WSN. The suggested protocol is simple yet powerful enough to provide the reliable data delivery from source to the sink. If all the nodes in a WSN are static it would reduce the network lifetime due to imbalance in energy depletion. Presented protocol enables the sink to move arbitrarily throughout the network. This movement helps in balancing the energy consumption of the network hence enhancing its lifetime. Also, the protocol helps nodes to stay alive longer thus making sure that there are less broken paths within the network which in turn increases the reliability of the source to sink communication. Beacon messages are used by the sink to advertise its presence to its first hop neighboring nodes. Different fields in the beacon message help to control the number of messages that need to be sent to the network. Three levels of flooding schemes have been suggested. Depending upon the requirement the necessary flooding scheme is triggered. This control of flooding and messages helps to reduce the protocol overhead. It would enhance the lifetime of the network by reducing the energy consumption of the nodes. Furthermore, with the help of the analysis it has been proved that the proposed protocol can significantly reduce the number of control messages and eventually will prolong the lifetime of the network. As part of the future work, this protocol will be tested using some simulation tool.

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