Locators of Mobile Sinks for Wireless Sensor Networks

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Abstract

Mobile sinks in wireless sensor networks require an additional communication mechanism of geographic routing. Because the sink's location as the destination in geographic routing is changed dynamically, sinks' location should be propagated continuously though the sensor field for sensor's future data report. However this frequent location updates can drain up the sensor's battery power and increase wireless channel contentions.

As a support to the mobile sinks, we proposed locators for mobile sinks that track current sinks' location. If a sensor reports sensed data to sinks later, it can acquire sinks' location from the locators. The locators are uniformly distributed uniformly to the sensor fields by hash bashed structured replication. Sinks update own location only immediate locators and other locators are fed location information by locators self location propagation.

We implemented our locator protocol with Network simmulator-2 and compared previous work TTDD, a Two-Tier Data Dissemination. Our results show that locators handle multiple source environments with low overhead of location acquisition process.

1. Introduction

A Wireless Sensor Network(WSN) consists of a large number of distributed sensors, each has some computational power, storage and communication capability.[12] This network is used recently at scientific research issues (habitat monitoring[6], seismology[3]), military purposes(detection of enemy movements and hazardous material) , ubiquitous computing environments. These target applications are commonly sensing physical environments with cooperative sensors. These sensors self-organize a network by distributed manner.

Common sensor networks consists of many redundant hundreds or thousands sensor nodes that have capability to communicate each others by wireless trans-receiver such as RF[1], IF or laser[4]. As the users want to look up the networks and to get data, user interface with nodes, *sinks*, are needed. Sinks transfer data to users by satellite networks or wireless or wired Internet services.[5] Because common sensor networks are used by ad-hoc environment, they use specialized network protocol stacks like ah-hoc on demand routing. WSN uses diffusion like data dissemination [8] rather than standard TCP/IP protocols due to limited sensor node computing, storage capability and non infrastructures such as routers.

These data dissemination mechanisms behave data-centric communication. In data dissemination, sink query interests to the sensors diffusion based propagation. After sensors receive a query from the sink, the matched interest is given a unique address.[8] Then this interest is returned to the sink by the reverse path of query propagation. These data packets are forwarded to the sink by tagged address instead of sender's address. During sensor's reporting and forwarding, data can be aggregated to reduce communication overhead.[7]

WSN fundamental routing mechanism is geographic routing. Except flooding based high overhead communication, most of communications use geographic routing due to wireless channel. Sensor nodes are identified local id instead of prefixed IP address and they have own location information. So if node A wants to send data to B, the data packets should be forwarded from location of node A to location of node B.

As WSN cover large area and each sensor nodes have limited transmission range, the packets should be forwarded by other intermediate sensors. At each forwarding hops, a sensor node finds the closest neighbor to the destination location. Until current forwarding node's location reached within the transmission range to the destination this greedy forwarding continues.[9] At the last hop the sensor node sends the data packet directly the neighbor destination node. These neighbor nodes can be maintained by periodic hello packet exchanges. Each sensor node manages neighbor node table by receiving hello packets from neighbor nodes or forwarding packet from a previous hop neighbor node.

Geographic routing[9] can be used successfully as long as the locations of sensor nodes are well known and sensor nodes are relatively static. The techniques that one node knows own geographic location are localization mechanisms. These localizations have been researched well, we assume that each sensor nodes know own location with an ease. The localization methods are as follow: Range free localization, range based localization, like GPS receiver etc.

Most of WSN researches have focused on static sensor nodes but sensor nodes can move at some application area and that mobility makes some problems. For example, inaccurate destination location can makes wrong routing or packet drop due to no more nearest neighbor at some forwarding node. We assume that only sinks moves around sensor field. Because of sensors static establishment, sensor's movement requires somewhat movement device like movable robots. However sinks are interfaces to users, it is necessary to support routing for moving sinks when user traverses sensor fields.

The remainder of the paper is organized as follows: Section 2 discusses several related works. Section 3 describes Locators for mobile sinks and gives detail protocol subscriptions. Section 4 simulation and comparison of TTDD. Section 5 concludes this paper.

2. Related Works

As an example of geographic routing protocol, we introduce GPSR: Greedy Perimeter Stateless Routing for Wireless Networks that geographic routing system for multi-hop ad-hoc wireless networks[9]. GPSR uses only neighbor nodes' location information and destination node's location to decide a next forwarding node.[9] As a node forwards a packet to the closest neighbor for the destination, it eventually reaches to the destination.

Sensor networks have been adapted to data-centric communication than previous the Internet's point to point communication because sensed data are much more important than sensed sensor's identity.[12] GHT, a Geographic Hash Table [12] is a data dissemination algorithm at sensor networks which has a large number of sensors. Sylvia Ratnasamy et al, proposed Data Centric Storage(DCS) that sensed data are stored at a node determined by the name[1] As sensed data are stored at deterministic points by hashed geographic position, DCS could take benefit of efficient query interest overhead by sinks due to no flooding query.

Sylvia proposed timer based Perimeter Refresh Protocol(PRP)[12] to achieve consistency of sensed data for dynamics of sensor networks. In addition, to achieve scalability of high load to given hashed position Structured Replication(SR)[12] was designed. SR replicates a home node to $2^d - 1$ mirrors, at given level d. Mirrors are chosen from geographically symmetric positions to a home node's location at square regions of sensor field.

Grid's Location Service(GLS) is a distributed location service which tracks mobile node locations for ad hoc networks. GLS doesn't need any additional infrastructures due to decentralized operation on their own nodes. GLS can be used even where whole nodes have mobility. Each nodes of the network have responsibility to track some of other node's location and update own location to the other nodes by predefined identifier finding rules.[10] A node sends its position updates to its location servers without knowing exact real address of servers, assisted by a predefined ordering of node identifiers and grid geographic network hierarchies. Location query can be executed similar fashion of position update by predefined identifier lookup.

As the first attempt to solve sink's mobility, Fan Ye proposed Two-Tier Data Dissemination model(TTDD). When sinks moves around, the source sensor nodes that ought to report data to the sink need to know the current sink's position. As a naive solution a sink can propagate own current position to whole networks by flooding but it is not scalable and efficient method. In TTDD, instead of sink's location propagation to whole networks TTDD takes a reverse view point that a source announces new data delivery to whole networks as efficient grid cross points - dissemination points. If a sink wants to get the sensed data, it queries given dissemination nodes by local flooding. If the data dissemination node get the sink's query,it request data download to the original source node by grid axes as reverse path to the data announcement. To support routing to moving sinks the data packets routed by two-tier hierarchial manner. At the higher layer packets are forwarded from the source to the immediate dissemination node[2] along grid horizontal and vertical axes. At the lower layer, packets are forwarded by trajectory forwarding[11]. Sink updates own location to forwarding agent nodes and immediate data dissemination node given a cell. This path is maintained by soft state by periodical sink's update.

As TTDD takes source oriented data announce approach, it has multiple sinks's scalability by eliminate flooding query to whole network and location updates. Since packets are always transferred given axis, it reduces contention of shared wireless medium and can be used as multicast path at the same data to different sinks that share the pathes. If the number of sources is increased, this data dissemination point management can be critical overhead of the system due to the grid structures of data dissemination points for each source sensors.

[1]the name of data can be chosen such as time of the event, event type, event position of sensor the sensor field, etc.[8] The name is a typical term, meta-data.

[2]The most closest dissemination node that received sink's data query.

3. Locators of mobile sinks

3.1 Motivation and Goals

When a sink set on static location, geographic routing mechanisms can be used successfully with initial location information of each of sinks and sensors. But if a sink moves quickly to be out of last hop node's transmission boundary, forwarding a packet from source to a sink can't be executed correctly because the sink can't receive last hop forwarding without any additional reactions. Geographic forwarding can't be executed without a moving sink's location updates to the source or some forwarding nodes. As a naive solutions, one can think periodical flooding of sink's location to whole sensors but it is not efficient and scalable at large sensor networks and multiple sinks environments due to high packet overhead of flooding.

We propose a data dissemination model using geographic routing with *locators* to support mobile sink's geographic routing. Locators are location server sensors [3] that track sinks current position and reply sinks'location query from sensors. As long as source nodes get the current sink's location with low overhead and bounded time from locators, geographic forwarding can be executed successfully. The design goals and rules are as follow.

Sinks should update limited number of sensors own current location instead of flooding to whole sensors. Sensors which send sensed data should be able to acquire current sinks location with bounded time and overhead. Even if source send a packet with inaccurate destination position, that packet should have a chance to be forwarded current sink's position.

3.2 Basic locator communication mechanism

Locators contain current sink's location by receiving sink's location update to them. Mobile sinks update their own location periodically R_{update} rates to immediate locators. When a source reports sensed data as a response to the sink's query, it obtains the sink's location by query to known rendezvous point node, the locator. After the location acquisition, sensed data are delivered by an geographic routing such as GPSR, greedy forwarding.

We added additional location information propagation as the forwarding nodes look into sensor's location header. So the forwarding nodes that are belong to a path from the source node and sink node can acquire the sink's location information.

[3]Locators are not additional sensor nodes but normal sensor nodes. Don't misunderstand locators as specialized new hardware sensor nodes.

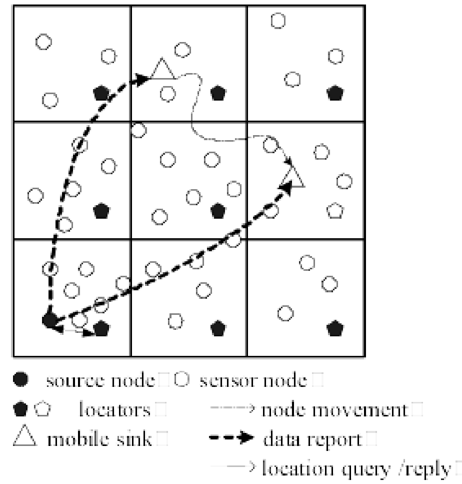


Figure 1. There are one mobile sink and sensor nodes and locators. A source node can report sensed data by geographic routing with a locator.

3.3 Selection of locators

When a sink attempt to query sensor nodes at the first, it should acquire the locators with which can consistently communicate. This locator should be rendezvous point that each sensors and sink know where it is. As a solution, this locator can be selected as geographic hash table's hashed points. [12] The closest node at the given hashed position L is to be the locator.[12]

$L(x, y) \;=\; Hash(\; sink\, id\;,\; era)$

Hash[4] keys are sink id and era. The hashed value is locator's geographic virtual position. Sink id is logical address of one sink not an IP address. The era is a unit time of locator lifetime. This era is used to distribute the load of the given locator's operation to whole the lifetime of sensor networks. As era changed as time goes on, the locator's position is changed to the other node which is the closest to new hashed location. This era can be selected as an hour or day and it is dependant on the lifetime of the sensor networks.

This hash based mechanism can remove the notifications of locator position to whole networks. To avoid single point failure as one locator takes a responsibility to process whole location query and to ensure limited location query to the locator, we replicate positions of locators to the sensor field by Structured Replication[12].

This replication rule is scalable and deterministic. If we want to ensure that one node can take a location information within such as 4 transmission ranges, each locators should

[4]hashed value is scaled to sensor field size

be distributed to the unit division, within jurisdiction of a locator. This unit region is a square of fixed length l_{ld} and one can easily show that the maximum distance of location query will be $\frac{l_{ld}}{\sqrt{2}}$ except border regions. [5]

In other side, sink can just randomly select near to the sink sensor nodes as locators then disseminate that locators' information within sensor queries. In this fashion, we don't have to find the nearest node at the given position when sensors select locators at given hashed position.

3.4 Locator protocols

3.4.1 Location update protocol

When a sink updates current own position to locators, it sends them Location Update Packet(LUP) that contains sink id, current sink location, time stamp of that location, expire time, destination locator position and id. As sensor fields become larger, sinks' location update whole locators can be overhead. Therefore a sink send location update message to immediate four locators, remaind of locators are feed that messages by the propagation rules. This propagation paths selected distributed manner, each locator only send to LUP to one or two immediate locators.

3.4.2 Location update rates

The location update rate should be selected properly to keep the efficiency. Too many frequent location updates can cause unnecessary power consumption for packet delivery. At the other hand, few location update can reduce routing success ratio by inaccurate destination location. The update rate is in proposition of moving sink's velocity. As a sink moves the faster, it send the more frequent location updates to locators. The update rate can't be bigger than sink's localization update(acquire of own position)

When a sink stays within a cell, it doesn't update own location to the locators unless the previous location update is expired by timeout of locators. This timeout can be selected as $\frac{2}{R_{update}}$ to get margin time of Location Update Packet delivery failure. When sink moves to the other cell [6] , it sends a new update message to the locators inclosing the sink.

3.4.3 Location query/reply protocol

When a source node doesn't know the destination sink location or previous the sink's location is expired by no feedback of locators or sinks due to idle data transfer, it request location query to the closest locator from locators that can be calculated by given hash function as 3.3. When the source received the reply , it save the location information of the sink to the sink location table. If the source can't get reply packet from given locator position, it retries to query LUP to other immediate three locators in turn. The query packet includes source id, source location, sink id. If a source can't get a Location Reply Packet from given time as one second, find and ask to the further locator.

A locator sends a Location Reply Packet(LRP) as an reply to a Location Query Packet to the source. LRP includes sink id, sink position, time stamp of this location and expire time, locator id, locator's position . If the source get the LRP it can directly communicate with the locator and sink by their id and location.

3.4.4 Location piggyback protocol

If a sink changes its cell by movement,it piggybacks own location into the normal data packets. So far we explained only locators get sinks' current location information, but normal nodes also can get the location information while they forwarding LUP,LRP, packets. As locator protocols are implemented as new packet header, every nodes which deliver packets can decide the packet type. If the packet is a LUP or LRP or piggy-backed data packet, the forwarding nodes extract that location information and save it at the sink location table.

4. Performance evaluation

4.1 Implementation

We used the network simulator ns-2.26 [2]to evaluate our locator protocols. Each sensors are implemented as a wireless mobile node. 802.11 MAC was used for media access control for easy development of our protocol and TTDD's previous code[7] compatibility though wireless sensor networks don't use 802.11. We made a simple greedy forwarding agent.

We implemented greedy forwarding agent that simply forward a packet to the destination with id. Each sensor nodes' routing agents have a one hop neighbor table by periodical hello messages with 2 seconds interval. That table's entry has neighbor id, location , last received packet time. If we can't consecutive two hello messages we discard that neighbor as dead. Each forwarding nodes forward a packet to the closest neighbor by setting common header's next hop to that neighbor unless that packet exceeds hop counts or

[5] We assume that sensors ask locations to the closest locator. One sensor's enclosing 4 locators are positioned at the corner of $l_{ld} \times l_{ld}$ square. Therefore the maximum distance of sensor to locator can be calculated as half of diagonal length.

[6] A unit square region of grid whole sensor field. The width should be smaller than one sensor node's transmission range. We set the width about 100 meters at 250 meters node transmission range

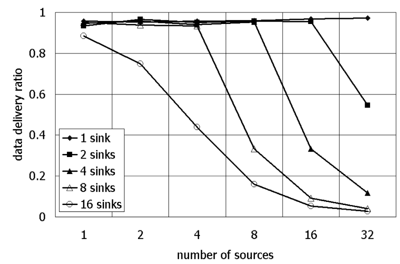
[7] TTDD was developed on ns-2.16 version, so we changed minor environment setting and codes. TTDD was not compatible with SMAC.

forwarding agent's receiving packet. If a packet to the destination is in the *last hop forwarding range* $0.8\times$ transmission range , it find the destination node in the neighbor table. The last hop forwarding range is shorter than transmission range for the margin of inaccurate destination location and destination node's movement.

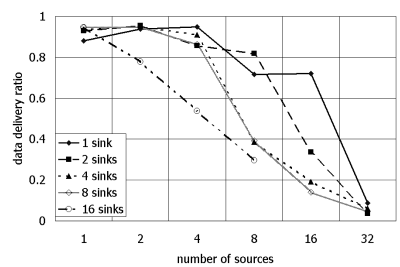
The initial locator query or update packets that have no destination id is set to UNKNOWN_ADDRESS. If that destination packet is forwarded within forwarding range and the forwarding node can't find a closer neighbor node, it takes as own packet and reply to the sender. If that node find the closest node, then it forwards packet to the closest node to the destination.

Sinks update own location with 5 seconds interval at the stationary condition. They acquire own location 2 times per one second and remember the last cell which is $20M \times 20M$. As a sink change own the cell, it updates own location to the locators.

We adapted subscribe model as data delivery of sensors. Randomly selected sensors report dummy 100 bytes data to whole sinks periodically. Sinks' mobility is created by straight line movement towards randomly selected destination location. Sensor's positions are picked up by the uniform random variables of given topology width.



(a) Locators



(b) TTDD

Figure 2. The success data delivery ratio

4.2 Results

We experimented at various source data report interval to see how many data reports can be delivered. One data packet size is 100 bytes. We set one sink and varied number of sources to see the effect of increasing traffic as connections increase. Because capacity of this wireless channel is limited, up to 80 data/sec can be transferred without delivery ratio degradation. There are 169 nodes at 2km $\times$ 2km which send 2 data per one second.

We evaluated basic data dissemination scenario as Fig. 2(a), Fig. 3(a). We have selected the metric of the performance of Locators as delivery ratio, total consumed energy. At the first, delivery ratio can be taken the sufficient operations of our protocol and strong indication of scalability. Most of packets are dropped by congestions, degradation of data delivery ratio means worse scalable feature of the system. Second, total consumed energy can be the metric of efficiency of routing protocol and low control overhead. At a given data delivery ratio and traffic, rest portion of total consumed energy can be counted as control and routing states management overhead.

The overall performance of locators is dependent on traffic strength at given positions for shared wireless channel environments. As the wireless channel IEEE 802.11 MAC's maximum bandwidth is 2Mbs, a large number of sinks or sources make data delivery success ratio worse. As the number of sinks increases, the pressure of bandwidth to a source would reduce the delivery ratio by congestions. We can see that barrier for performance degradation point number of sources and number of sinks is about 30 from Fig. 2(a).

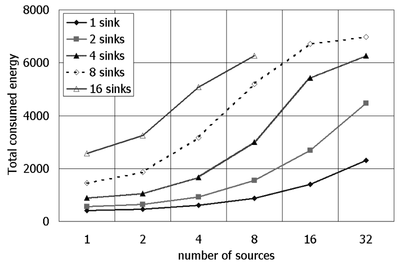
Total energy consumption is increased as the number of sources and sinks increases as shown Fig. 3(a). As the number of sinks increase, the high traffic causes congestion and more queueing delay.

TTDD's metrics are shown roughly above figures, we appended the performance of TTDD on data deliver ratio, total consumed energy as Fig. 2(b), Fig. 3(b).

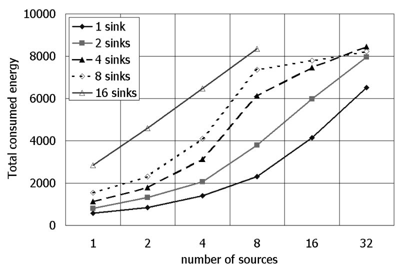
4.3 Discussion

the data dissemination with locators is energy efficient and has lower delay and higher data delivery success ratio in comparison to TTDD when there are many redundant sensors and a few sinks. These strong features are come from direct communication from the source to sink at data delivery. Because modified greedy forwarding is used, most of packets are delivered successfully except over congestion condition.

Most of TTDD's energy consumptions are caused by routing state management such as local flooding source queries from sinks and initial excessive hello packets. If we have eliminated these hello packets, we could get



(a) Locators



(b) TTDD

Figure 3. Total energy consumptions

less energy consumptions of TTDD. In TTDD announces each source nodes announce sensed data to dissemination nodes, this can be high overhead as the number sources increases. Our locators protocol have a little weak performance at high multiple sinks with a few source nodes because TTDD doesn't need additional mechanisms except forwarding agents for the added sinks. But number of locators should be supplemented as the number of sinks increases.

We could avoid trajectory forwarding at the most of cases as sink's frequent periodical location updates. If sinks can't update own locators within reasonable latency, inaccurate destined packet can be generated and it will effect low performance of our protocols. However we simulated the mobility of sinks to 50 m/s, realistic sinks could not encounter this condition of trajectory forwarding.

5. Conclusion

In this paper we proposed locators for mobile sinks that can support data dissemination of wireless sensor networks. To support data dissemination for the mobile sinks, we added locators that track the current location of sinks.

Locators are selected by deterministic geographic hash function and replicated uniformly in to the whole sensor fields. Because most of sensors can acquire sink's position within bounded region from this deterministic position's locators, geographic routing can be processed efficiently.

Data dissemination with locators is scalable to the number of sources and it is reasonable condition at most of sensor networks' applications.

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