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Grid Based Opportunistic Geocast in Spatially Separated Wireless Sensor Networks

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Abstract

Geocast is a one to many communication, where a packet is delivered to a set of spatially contagious nodes. In military and disaster management application it is a primitive communication service. We propose a Grid based Opportunistic Geocast (GOG) for spatially separated wireless sensor networks with a three tier architecture composing sensor nodes, Mobile nodes (MN) and Data MULEs (DM) with different communication and motor characteristic. MN follow predefined pattern to relay the data, sensed by sensors within the sub network. DM follows a bus pattern visiting every region and relay the data opportunistically across the sub network. In every sub network, an alley node (AN) is elected to forward the data to DM. Simulation shows that the GOG intra and inter routing protocol, reduces control packets and efficiently forwards data packets. The modeling along with simulation results shows that our predictive routing performs better than random broadcast.

Keywords: Data MULE, Grid Topology, Geocast, Wireless Sensor Networks

1 Introduction

Advances in device technology, radio transceiver designs and integrated circuits along with evolution of simplified, power efficient network stacks have enabled the production of small and inexpensive wireless sensor devices. Each node has the capability of sensing, collecting, processing, storing environment information and communicating with neighboring sensor nodes. These small devices can be networked together to enable a variety of new applications that include environmental monitoring, seismic structural analysis, data collection in warehouses, traffic monitoring etc. Such networks collect data (typically infrequently) from the sensors for long periods of time without requiring human intervention. The sensors must be low in cost and work within a limited energy budget. Therefore, in order to achieve network longevity, a primary concern in such networks is power management.

Depending upon the application, sensors may need to be spread over a large geographical area resulting in a spatially separated network. The sensor distribution can be isotropic (uniform spread of sensors) or anisotropic (islands of sensors separated by large distances). Sensors at city intersection, urban application are an example of a isotropic distribution while sensors for habitat monitoring are distributed anisotropically. Possible approaches to ensure connectivity in such spatially separated networks include installing multiple Base Station (BS) or mobile BS or mobile relay nodes like MULE to establish a virtual connectivity among the subnetworks. MULEs (Mobile Ubiquitous LAN Extensions) are assumed to be capable of short-range wireless communication and can exchange data from a nearby sensor or access point they encounter as a result of their motion. Thus MULEs can pick up data from sensors when in close range, buffer it, and relay the data to their points when in proximity.

1.1 Problem Domain

Traditionally WSN is considered to be a single connected network, but in reality spatially correlated node failure, environmental obstacle, emergency deployment may lead to multiple isolated partitions in the WSN. In reality all the nodes in WSN are not symmetric in term of resources, capacity and power it possess. Such WSN are referred as heterogeneous WSN in literature [8]. In this aspect the network model is a combination of both spatially separated and heterogeneous WSN with a combination of static node and versatile resourceful MULE. Hilly rural areas which are less accessible, to disseminate weather report query of those regions, or a warning message, commercial advertisement etc.

demands a special variant of geographic protocol. However, these tasks become cumbersome for a sensor network which is characterized by nodes being geographically distant from each other. In this case, making sensors communicate among themselves and deliver information to a point of interest can be very costly or even prohibitive, especially due to energy restrictions (in case of battery-powered sensors). A possible solution to this problem is to use a Data MULE (DM) or a ferry messenger, to travel to spatially separated areas and connect isolated sub networks. However, it is not necessary for the DM to make physical wait at each sub network to communicate with the sensor node. Hence, MULE only needs to reach the border (one point) of this area to start the data transfer. In this case, the problem of routing MULE is to find a path from where the MULE can collect and forward information from all or a set of sensors. One of the fundamental problems in WSN is Coverage and lifetime, since the sensor node have a limited battery power. Once we deploy the sensor it is very difficult to change the battery power so energy efficient deployment is very important to increase the coverage and lifetime. Some nodes use up their power early because they have heavier traffic load than other nodes, which affects the network lifetime. Grid deployment is an attractive approach for moderate to large-scale coverage-oriented deployment due to its simplicity and scalability. Grid deployment is done by placing sensors row-by row. MNs in every grid (spatially separated area) forward data from SNs (Static Node) and handover to DMs.

2 Related Work

A. Mobile MULE

Many approaches are proposed for deployment of sensor nodes, routing and data MULE interaction. Subodh et al., had followed a grid based approach for deployment of SNs [1]. First we divide the given area in to different grids such that length and width of each grid is equal to the sensing range of the sensor. Deployment of sensors concentrates in balancing the overall network traffic. Wang and Zhang [2] had analyzed several sensor deployments and computed their efficient coverage areas, coverage area ratios and the relation between the number of sensors and efficient coverage area ratio. Deployment types include square, triangle, hexagonal .Sensor nodes are placed on the vertices of these geometric shapes. Of these deploying in square pattern gives an efficiency of 75% (efficient coverage ratio). In [3, 6] data collectors/relays are considered to federate disjoint network segment. Similarly MULE for data collection with the objective of path minimizing in SS-WSN are discussed in [4, 5]. Mkhwanazi et al., had proposed a protocol for inter-cluster communication that uses ORP (Optimal Relay Path) [7] algorithm. This is applicable when the sender and receiver MULEs are not in the same cluster. The sender MULE uses the ORP algorithm to find the optimal path and the optimal time to send the message to the intermediate/receiver MULE. Performs well in sparse network and deals with heterogeneous MULE.

B. Geocasting

Geocasting can broadly be classified on their approaches based on pure flooding, directed flooding and routing with flooding [9]. There is literature which implements geocast as a variant of multicast but it can be too costly if the network is very dynamic. Henceforth geocasting is mostly implemented in two phases: unicast routing phase and the restricted flooding phase as in VSFG [10]. A grid based routing is presented in [11] where the forwarding is based on dividing the network in quadrants. This approach assumes all the nodes static. Geocast for data dissemination in mobile sink is proposed in [12]. Sinks are assumed to be contagiously moving together. To best of our knowledge geocast is not considered in disjoint network, we propose a geocast algorithm for spatially separated WSN, where an event detected by a node has to intimate to a geographical region in a Internet of Things (IoT) manner. The WSN still has base station for monitoring and administrative purpose.

3 Grid Based Opportunistic Geocast

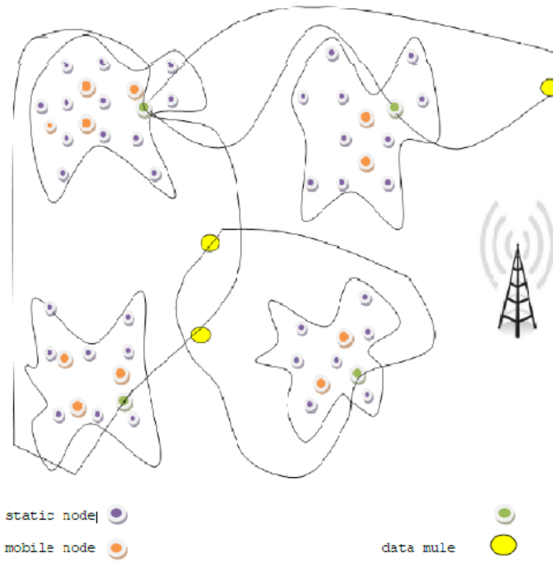

Fig. 1. Architecture of SS-WSN

Figure 1 shows a spatially separated wireless sensor network (SS-WSN). Here every partition is considered as a sub network. Initially SNs are deployed in grid format in each sub network. The MNs dynamically wander in between the rows of the grid and it follows a predefined pattern to cover the sub network. DMs are MNs that have large covering range. They load and unload data between sub networks. They follow a trajectory of a bus mobility pattern between a set of sub networks, such that they have inter contact points with each other at regular inter contact time interval. These inter contact points help in handing over the packet to the DM that is destined to travel towards the geo region. The source node initiates the process of geocasting a packet in the region of interest identifying the sub network to which it belongs. The DM that visits after the transmission starts and respond with an acknowledgement to source will be the DM leader. Source sends the geo packet to DML, it passes the geo packet and the information regarding the DML to other DMs. It visits their corresponding sub networks and forwards geo packet to the nearest MN. That MN becomes alley node (AN) in the sub network. The AN is responsible for geocasting the packet in the RoI via other MNs.

Algorithm for DML Election: When the source node initiates the transmission, it sends the geo packet to the data MULE via an AN. The data MULE that first acknowledges becomes the data MULE leader and gets the geo packet.

```
If result needed
     flag=0
    while(!geoAckPacket)
       Source broadcasts geoPacket
       flag=1
   Endwhile
  If(flag==1)
    Source send geoPacket to DML
 Endif
Endif
```

Algorithm for DMs Interaction: A prediction table is tabulated for first T seconds such that it contains the data MULE ID and the interaction time in it. Here T = (ts-tf), ts is the start time of prediction prototype and tf is the end time of prediction prototype This table is used to predict the next interaction time of the data MULEs so as to forward the data.

```
if(Data MULEs interact)
  Enter ID,location and timestamp into prediction table
end if
If(DM has geo-packet)
    Send geo-packet
else
    Send hello packet
Endif
```

Algorithm for AN selection: An AN is chosen by the data MULE when it relays the geo packet to the subnetwork. Initially the DM broadcast a hello packet to the subnetwork it visits. A MN that is nearer to DM receives it and sends an Acknowledgement packet. This MN becomes the AN and sends the ‘alley Message’ to other MNs. When more than one MN contends to become AN, the final selection is done in a distributed manner based in the key and a random number.

Algorithm for GOG Routing

The data MULE communicated to a MN in the subnetwork, with which it has strong communication link. The RSSI of the received signal is determined to decide the quality of the link. This MN becomes the alley node (AN) for any current interaction between the subnetwork and the MULE. The routing between the subnetworks always passes via an AN and MULE and for routing within the subnetworks a MULE is not required. Henceforth, the routing is divided in two phases. Intra routing: routing within the subnetworks and Inter routing: routing across the subnetwork with the help of the MULEs. Intra routing involves message passing between source node to AN and AN to RoI. The source node could be a static node or a mobile node. The message hops from one MN to the other, until it reaches the vicinity of an AN or the RoI GOG Intra Routing: Once the delegated AN whereabouts are broadcasted in the subnetwork, intra routing can proceed otherwise the source has to wait for the opportunity of MULE arrival. Consider the packet transmission between a source node U and an alley node S. During the process of transmission from a mobile node to other mobile, if a node w is the one hop neighbor, then U autonomously determines whether W is in the angle of two tangents elicited from u to s movement territory estimated region. The node W is within this territory if the angle satisfies the equation 1 and 2

$$d(u,w) \leq r d(u,w) \leq r \tag{1}$$

$$\arcsin\left(\frac{d(u,w)^2 + d(u,s)^2 - d(w,s)^2}{2d(u,w)\,d(u,s)}\right) \leq arccos\left(\frac{r_u}{d(u,s)}\right) \tag{2}$$

r is the communication range.u,s,w are MNs.'u'-source 's'-dest 'w'-intermediate, d(u,v) is the distance between node u and v and r_u is the estimated radius of MULE's movement territory. If the above formula is satisfied data is forwarded to the intermediate MN 'w' from 'u'.

```
if(MN recvdall data)
  draw tangent from MN to CH's sensing range
  while(!(CH recvdData))
  if(neighbouris within the angle)
    forward the data
  endif
  endwhile
endif
```

Algorithm for GOG Intra Routing: Data MULE receives the data from the AN when it visits the subnetwork if AN has data to be delivered. Otherwise the data MULE continues to move in its path.

```
DM sends query to AN
wait(threshold interval)
if(pkt received within interval)
```

DM collects packet and moves in its path
else
DM moves in its path.
endif

4 Experimental Results

To evaluate the performance of the proposed system, we simulated with topology for a 1200m x 1200m network region. The region is divided into 5 spatially separated areas having 30 static nodes each thus totaling to 150 static nodes. Every subnetwork has maximum 5 mobile nodes so as to cover a subnetwork. 3 data MULEs are used to relay the data between the subnetworks and deliver it to the AN in the destination subnetwork. The source and the RoI are located in different subnetworks. We simulated the wireless sensor network to get the number of packets that are successfully reaching the RoI through the data MULEs. The simulation is run by changing the number of mobile nodes in a subnetwork. We also simulated the intra Routing protocol to find the number of data packets reduced when compared to normal broadcasting method to deliver the data via mobile nodes. The delay involved is also calculated.

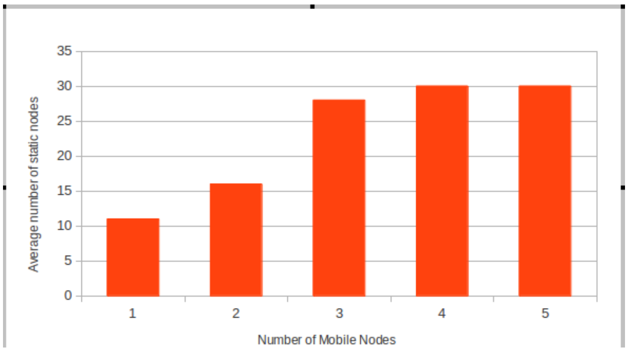

Fig. 2. Number of mobile nodes Vs Average number of static nodes

To find optimal number of MNs for considered coverage area, MNs are increased till complete coverage is obtained. In figure 2, Number of MNs is taken along X axis and average number of SNs covered in a sub network along Y axis. When the number of MNs is increased, coverage increases. When only one MN is deployed, 36.6% of area is covered. On increasing MNs, area covered by them increases. A drastic increase is seen when MNs is increased from 2 to 3. Complete coverage is obtained with 4 MNs. Thus optimal number of MNs to cover a sub network is found.

Data MULE Interaction

In figure 3 Number of packets is taken along Y-axis and time is taken along X-axis. Once the DM receives the packet, it has to relay it to other Data

MULEs. This is done in two techniques-without prediction and with prediction. By recording the interaction

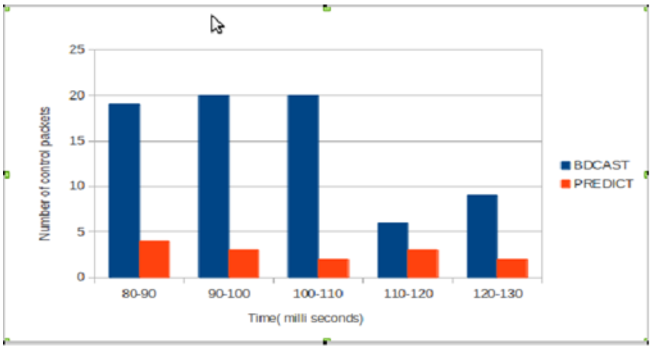

Fig. 3. Time Vs Number of Control Packets

time of data MULEs for predefined time, future interaction can be predicted.63% of control packets are reduced with prediction.

GOG Intra: Delay

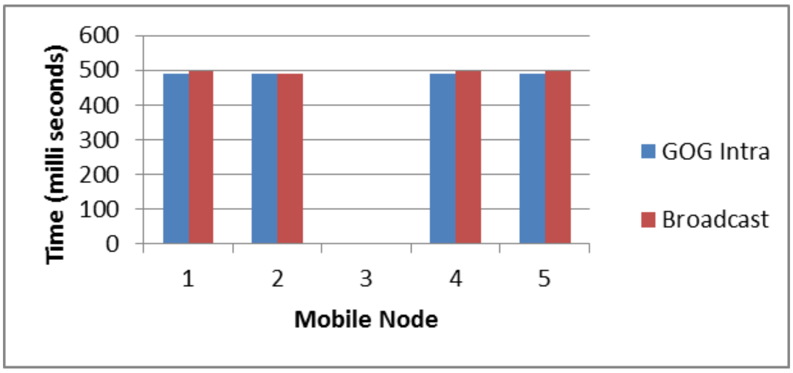

Fig. 4. Mobile Node Number Vs Time

In figure 4, MN is taken along X-axis and time is taken along Y-axis. MNs forward the data to AN. As node 3 is the AN, it takes the value 0 for response time. From above graph response time for all MNs is lesser in IRP whereas in broadcasting time is more. The response time using IRP is 24 milliseconds lesser than broadcasting technique

B. Transmission Cost

In figure 5 number of data packets is taken along X-axis and Mobile node ID is taken along Y-axis. All MNs forward the data to AN. As node 4 is the AN, it takes the value 0 for number of data packets. GOG Intra is more efficient compared to broadcasting. Here, the packets is forwarded only to the nodes that are on the path to destination. Hence forth the transmission cost is reduced by 29.8%.

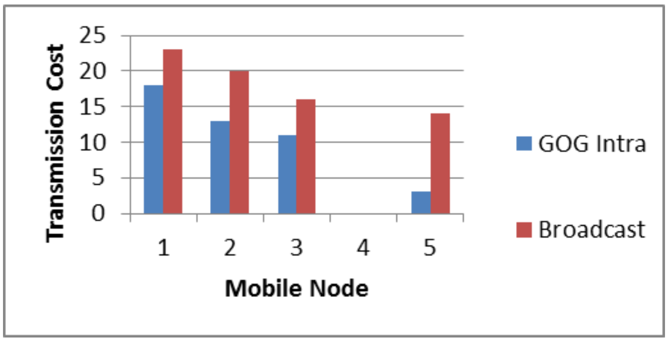

Fig. 5. Mobile node number Vs Number of data packets

5 Conclusion

In this paper, we have explored the geocast in spatially separated areas and dynamic forwarding path to RoI. This will help the common people in informing about the flash floods alarms to many villages located across endangered river banks. This will also be useful in military application where camps are spatially separated with group of mobile soldiers who wander within the camp and tankers which move across the camp. We have used both static and MNs in a spatially separated area Data MULEs follow the bus pattern mobility and relay the data between these regions. We have used the grid pattern for deployment of SNs as it seems to be more efficient compared to random pattern. The performance evaluation the control overhead reduces the transmission cost and improves packet delivery ratio.

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