SIFLOW: A Data Centric Routing Protocol in Wireless Sensor-ActuatorNetworks

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***Abstract*—In Wireless Sensor and Actuator Networks (WSANs), the collaborative operation of sensors enables the distributed sensing of a physical phenomenon, while actuators collect and process sensor data and perform appropriate actions. In this paper, the coordination and communication problems in WSANs with mobile actuators are studied. A hybrid location management scheme is introduced to handle the mobility of actuators with minimal energy expenditure. WSANs are deployed in different classes of applications for accurate monitoring. Due to the high density of nodes in these networks, it is likely that redundant data will be detected by nearby nodes when sensing an event. Since energy conservation is a key issue in WSANs, data fusion and aggregation should be exploited in order to save energy. Under the restrictions of sensor networks, the SIFLOW requires only the most basic functions and reasonable resources to achieve reliable packet delivery. In this case, redundant data can be aggregated at intermediate nodes reducing the size and number of exchanged messages and, thus, decreasing communication costs and energy consumption. In this work, we propose a Data Routing Protocol for data-centric Aggregation, called SIFLOW, that has some key aspects such as a reduced number of messages for setting up a routing tree, maximized number of overlapping routes, high aggregation rate, and reliable data aggregation and transmission. Results indicate clearly that the routing tree built by SIFLOW provides the best aggregation quality when compared to other algorithms. The obtained results show that our proposed solution outperforms in different scenarios and in different key aspects required by WSANs.**

***Index Terms*—Aggregation, Data-Centric, Routing Protocol, Wireless Sensor Networks.**

I. INTRODUCTION

Wireless Sensor and Actuator Networks (WSANs)are distributed wireless systems of heterogeneous devices referred to as sensors and actors. Actuators collect and process sensor data and consequently perform actions on the environment. In most applications, actuators are resource rich devices equipped with high processing capabilities, high transmission power, and long battery life.. A WSAN consists of hundreds orthousands of sensor nodes deployed in a geo-graphical region. These devices sense physical or environmental conditions, such astemperature, sound, vibration, pressure, motion, or pollutantsat different locations [1], [2], [3]. WSANs have been used inapplications such as environmental monitoring, homelandsecurity, critical infrastructure systems, communications,manufacturing, and many other applications [4], [5].Sensor nodes are energy-constrained devices and theenergy consumption is generally associated with the amountof gathered data, since communication is often the mostexpensive activity in terms of energy. For that reason,algorithms and protocols designed for WSANs shouldconsider the energy consumption in their conception [6]. Moreover, WSANs are data-driven networks thatusually produce a large amount of information that needs tobe routed, often in a multihop fashion, toward a sink node.Given this scenario, routing plays an important role in thedata gathering process.

A possible strategy to optimize the routing task is to usethe available processing capacity provided by the intermediatesensor nodes along the routing paths. This isknown as data-centric routing.For more efficient and effective data gathering with aminimum use of the limited resources, sensor nodes shouldbe configured to smartly report data by making localdecisions. For this, data aggregation is aneffective technique for saving energy in WSANs. Due to theinherent redundancy in raw data gathered by the sensornodes, in-networking aggregation can often be used todecrease the communication cost by eliminating redundancyand forwarding only smaller aggregated information. Since minimal communication leads directly to energysavings, which extends the network lifetime, data aggregation is a key technology to be supported byWSANs. In this work, the useof data aggregation is twofold: 1) to take advantage ofdata redundancy and increase data accuracy, and 2) toreduce communication load and save energy.

II. ROUTINGPROTOCOLS IN WIRELESS SENSOR NETWORKS.

There are a number of routing protocols namely

- Proactive or Table Driven Routing Eg. Low Energy Adaptive Clustering hierarchy protocol (LEACH)
- Reactive or On-Demand Routing Eg. Threshold sensitive Energy Efficient sensor Network(TEEN)
- Hybrid Routing Eg. Adaptive Periodic TEEN (APTEEN)

Further, routing protocols can be classified as Location based, Data-centric, Hierarchical, Mobility-based, Multipath-based, Heterogeneity-based, Quality of service (QoS) based protocols, according to the participation style of the nodes

a. DATA AGGREGATION

In the context of WSANs, in-network data aggregation refers to the different ways intermediate nodes forward data packets toward the sink node while combining the data gathered from different source nodes. A key component for data aggregation is the design of a data aggregation aware routing protocol.

b. CLUSTER-BASED PROTOCOL

Nodes are divided into clusters. Special nodes,referred to as cluster-heads, are elected toaggregate datalocally and forward the result of such aggregation to thesink node. In the Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm [7], clustered structures are exploitedto perform data aggregation. In this algorithm, clusterheadscan act as aggregation points and they communicatedirectly to the sink node. In order to evenly distributeenergy consumption among all nodes, cluster-heads arerandomly elected in each round.LEACH-based algorithmsassume that the sink can be reached by any node in onlyone hop, which limits the size of the network for which suchprotocols can be used.

c. FLOODING

The flooding is a traditional routing scheme. It uses broadcasting with multi-hop delivery to extend the packets to the whole network. It is an easy-to-implement routing scheme, and it is suitable for various network types, node distributions and environments. But the unlimited broadcasting the packets in the flooding scheme will cause the broadcast storm.

The flooding routing protocol has three deficiencies

1) Implosion: Because the nodes in the flooding scheme deliver thepackets by broadcasting, the same packet may achieve the same node via different routes. When a sensor node receives a packet, it will not check the packet if it has received the packet before. This character makes the duplicated packets sent to the same place.

2) Overlap: When these two sensors detect same event, they may both send a data of this event to the sink. This may cause that the duplicated information of an event is sent to the sink.

3) Resource blindness: When a sensor transmits packets in flooding, sensor nodes don't change their actives, even if the sensor nodes don't have much power to operation.

d. GOSSIPING

Gossiping is proposed to address some critical problems of the flooding scheme [8]. In the gossiping scheme, the source randomly chooses some of its neighbors to send packets. This improves the problem of heavy packet overhead in the flooding scheme. However, it may cause another problem, the long packet delay. Because the sender randomly selects the subset of the result in a router neighbors to transmit data, the selected sensors may result farther than the shortest path between the sender and the sink. Hence, this may extend the packet delay time.

e. FLOSSIPING

The flooding scheme is proposed after the flooding and the gossiping routing protocols. It combines the approaches of these two routing schemes. This protocol uses single branch gossip with low-probability random selective relaying (LPRSR) to achieve packet delivery. In the flossiping, when a source is ready to send a packet, it randomly selects a neighbor to deliver this packet in the gossiping mode. At same time, other neighbors of the source listen to the message and generate random numbers. If the generated numbers are smaller than a threshold which the source decides and saves in the packet header, the corresponding neighbors will broadcast the packet. This routing mode taken by these unselected neighbors is referred to as the flooding mode. This combination improves the heavy packet overhead in the flooding, and the packet delay problem in the gossiping. However, the power consumption and packet delay time in the flossiping are those of the flooding and the gossiping routing protocols.

III. SINGLE GOSSIPING WITH DIRECTIONAL FLOODING ROUTING PROTOCOL (SGDF)

Single Gossiping with Directional Flooding routing protocol (SGDF) solves the problems in the flooding and flossiping protocols. The SGDF can be divided into two stages. In the first stage, it initializes the network to make each sensor generate the gradient related to the sink. The gradient is a value counting the number of hops to the sink. In the second stage, also known as the routing stage, the SGDF uses single gossiping and directional flooding routing schemes to deliver packets. By using the schemes, we will later show that the SGDF exhibits high packet delivery ratio, low message complexity, and short packet delay. It improves the performance of the network when compared with the two benchmark protocols. We further explain the details of the two stages in the following.

IV. NETWORK TOPOLOGY INITIALIZATION

After the sensor nodes are randomly distributed in a specific area, the SGDF starts the initialization scheme. At first, the sink broadcasts a “hello” message to its neighbors. The hello message contains the information about the address of the sink, hop count from the sink, and the threshold (TH). The address of the sink is fixed but the hop count is not. The hop count which sets to one in the hello message by the sink is used for each node to calculate about its gradient. The threshold TH is a number between 0 and 1. It is used for the node to decide if it will get into the flooding mode in the routing stage. After the sink broadcasts the message, its immediate neighbors will receive it and get the sink address, and the hop count. When the sensor receives the message, it checks if it already has a gradient. If it hasn't yet, the sensor saves the hop count of the hello message as its gradient. Each node will increase the hop count value by one. The new hot count is placed back into the packet to replace the old one. The neighbors further broadcast the hello message to their neighbors.

If the gradient already exists when a sensor receives the hello message, the sensor compares the hop count of the message with its gradient. The sensor replaces the gradient by the hop count in the hello message if latter is smaller than the former. Then, the node adds one to the hop count of the hello message and broadcasts it. The node discards the message if the hop count of the hello message is greater than or equal to the gradient of the node. This situation occurs when the hello messages arrive via different routers. The gradient only keeps track of the best route. After repeating the above steps, the scheme completes the initialization of the network when all sensors receive this message at least once. Each node knows its related distance to the sink in term of the gradient.

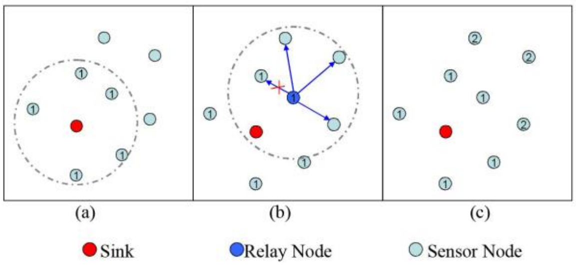


Fig.1 Network Initialization

Figure 1 shows that the sink broadcasts the hello message to its neighbors, and all its neighbors store the information of the hop count in their own memory. Then, they will add one to the hop count of the hello message, and rebroadcast it. In Figure 1(b), we can see that one of the sink's neighbors receives the hello message and becomes a relay node for the hello message. The hop count of the hello message is now 2. Then, the neighbors of the relay node receive the message and compare the hop count of the message with their gradients. The node will drop the message if the hop count of the message is not smaller than its gradient as one node discards the hello message in Figure 1(b). After repeating the steps, the network completes the initialization as shown in Figure 1(c). After the initialization, the hop counts of the neighbors of a node can be equal to, smaller by one, or greater by one than the hop count of the node itself.

V. SIFLOW ROUTING.

The main goal of this algorithm is to build a routing tree with the shortest path that connect all source nodes to the sink while maximizing data aggregation.Instead of sending the "hello" message we can send signals. In the above routing algorithms we had a single sink. Instead of having a single sink we can have multiple actuators(mobile sinks) which acts as relay nodes. So here instead of having full responsibility for the sink the neighboring relay nodes can collect data and send them to the sink. To avoid redundancy of data in various sinks we can delete the send message in the sensor nodes and keep it empty. The empty nodes collect other datas and send it to the sinks which are near to them.

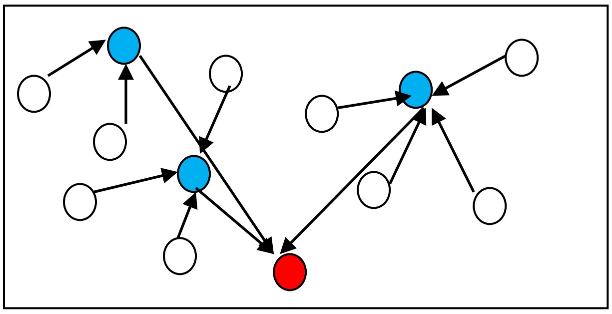
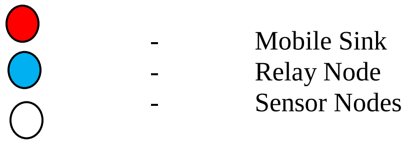


Fig. SIFLOW routing



Consider the Mobile node as M_i and empty node as E. Now from the large number of mobile sinks select one sink as static and send all the mobile sinks data to that particular static sink so that energy can be saved. Also datasare aggregated and we are able to collect all sensed datas. The relay nodes are indicated with r_n.

If r_n= =" " then
No relay nodes have data.
Send a negative signal to M_i
Collect data from the nearby sensor nodes
Else
Transfer the contents to M_i
End if

VI. SIMULATIONS

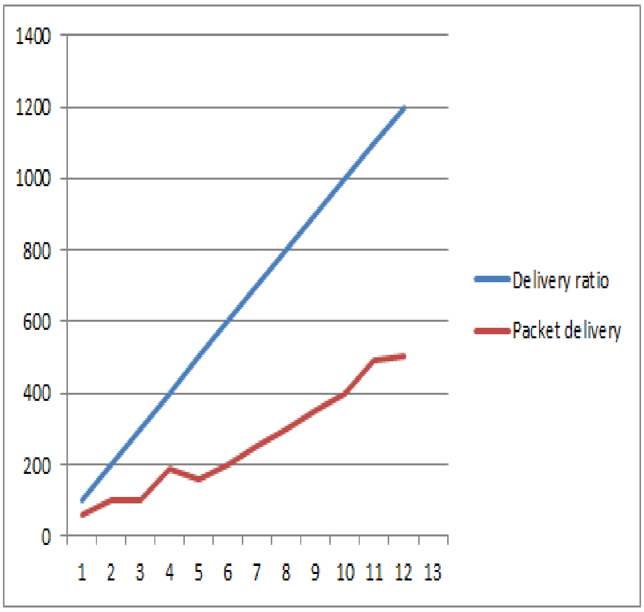
In this section, we evaluate the routing overhead, the packet delivery ratio and the packet average delay of the SIFLOW routing protocol. The routing overhead means the total number of packets sent during the simulation time. The packet delivery ratio is defined as the ratio of the number of the packets received by the sink to the number of the packets sent by the source.

Packet delay time = The packet average delay/ average time.

Delivery ratio = $P_{RS}+P_{SS}$

P_{RS} is the ratio of packets received by the sink and P_{SS} denotes the packets send by the source.

Furthermore, the sensor nodes are randomly distributed in a 10000m x 10000m area. The sensing range of each sensor node is 3000 meters. Each simulation sets a signal, and the traffic has constant bit rate (CBR) of 1 packet of 128 bytes per second. The wireless bandwidth is 50kbits/sec between each node. Each simulation lasts for 600 seconds, and each result is averaged over 100 random topologies. In the simulation, the packet lost rate is set to 3%.The below diagram clearly shows the less packet loss with maximized data transmission.



SIFLOW protocol send less data packets when the communication failures probability increases. This happensbecause when a packet is lost due to communication failures the packets are not retransmitted and do not reach the sink as shown in the above fig. Communication failure is decreased, thedelivery rate is increased to deliver all aggregated data that have been sent. In summary, SIFLOW delivers aggregated data reliably with the best performance when compared to Flossiping, Flooding and Gossiping.

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