A Routing Protocol for WSN Based on the Implementation of Source Routing for Minimum Cost Forwarding Method

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***Abstract*—This paper presents a routing protocol for wireless sensor networks (WSN), established on the basis of fundamental concepts in source based routing (SBR) for *ad hoc* networks and minimum cost forwarding (MCF) methods for heterogeneous WSNs. Neither routing tables nor network topology information is maintained at sensor level, which makes the proposed protocol part of the reactive routing protocols class. Despite the lack of network information at the sensor, the packets from the sink node to sensors, and vice-versa, always follow the optimal communication path with minimum cost. Simulation results have shown that the proposed protocol performs better than MCF protocol alone, and nodes always route the packets through the optimal path up to destination. In fact, according to the energy consumption and throughput found by simulation, this protocol improves on the MCF protocol for applications where the sink node, acting as a server or base station (BS), generates significant amounts of network traffic. All results are based on simulations and data treatment performed with OMNet++ 4, Matlab 7 and Microsoft Visual Studio2010(C#) platform tools.**

Keywords-Wireless Sensor Networks; Minimum Cost Forwarding; Source Based Routing,

I. INTRODUCTION

A wireless sensor network (WSN) comprises a large number of sensors equipped with wireless communication ports that are deployed closed or within the phenomenon to be monitored. Recent advances in wireless communication electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes. Small in size and capable of communications over short distances, this emergent technology has opened a wide range of application possibilities. Usefulness can be found in a panoply of areas, such as health, military, industrial and home applications [1][2]. Usually, in a sensor network, sensors cooperate to handover data from the source sensor to the destination. In most systems, a single sink node is responsible for collecting data from all sensors. Still, in numerous situations, this sink node also is a BS node to manage the sensors.

WSNs are *ad hoc* networks, employing techniques for network self-organization and packet routing [3]. However, there are many fundamental differences between the traditional wireless *ad hoc* networks and WSNs *per se*, which makes conventional wireless *ad hoc* network protocols unsuitable for WSN applications. Large number of sensors, proneness to failure, fast changing network topology, limited resources and low-power consumption are examples of such dissimilitude found in WSNs. The literature describes numerous protocol designs targeting specific WSN applications [1][2][3]. Sensor networks are limited-resource systems, therefore a significant amount of effort has been directed to reduce the size of the network part, overall power consumption and to the design of protocols that take these characteristics into consideration.

Routing protocols are classified in two general categories: proactive and reactive protocols [1]. Proactive routing protocols keep track of routes to all destinations in routing tables. LEACH [4], a protocol based on node clustering and PEGASIS [5], a protocol based on a token-passing chain, are two examples of proactive routing protocols. Unlike proactive protocols, reactive protocols acquire routes on demand and avoid saving information about the network topology. Flooding, Gossiping and MCF [6] [7] are examples of reactive protocols.

Traffic in sensor networks displays, in general, a heterogeneous nature [8]. In fact, in most cases, the communication patterns in sensor networks are characterized by:

a. Traffic between the BS node and sensor nodes. This type of traffic has two sources: 1) sensor nodes sending acquired data to the BS node (BS as a sink node); 2) BS node sending control information to the sensor nodes (for configuration of measurement parameters, for example). This type of traffic represents the largest part of the overall communication.
b. Traffic between adjacent nodes: adjacent nodes exchange information data for data transmission, get the conditions, connections, topology and etc.

These conditions need to be considered during the design of a network protocol for sensor networks. This paper proposes a reactive routing protocol where sensors have no information about the network topology, but packets from sensors to BS or vice-versa, always communicate over optimum paths with minimum cost. Since the proposed concept combines source routing with minimum cost forwarding, it is called the Source Routing for Minimum Cost Forwarding (SRMCF) protocol. In this approach, the

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routing information of the packets generated by the BS to be sent to sensor nodes is included in the packets.

The rest of the paper is organized as follows: Section 2 describes the related works. Section 3 describes the main protocol and section 4 explains the network initialization procedure. Section 5 presents and discusses simulation results from the proposed protocol. Section 6 unites the main conclusions drawn from this work.

II. Related Works

The MCF protocol is a good method for routing packets in a reactive sensor network [6][7]. This routing method is a cost field based approach and exploits the fact that the routing direction of data, flowing from sensors to sink, is always known and that cost is always minimum. In this method, sink node starts to setup the network with broadcasting its cost value and all nodes get minimum cost value to reach the sink node. With this method, sensor nodes have neither routing tables nor information about the network topology.

It is observable that this approach applies only for data sent from the sensor nodes to sink. If the sink node wants to send data to a specific node, other methods like flooding must be employed. In situations where the BS node simultaneously acts as a sink and server, and generates a significant amount of data, then implosion, overlapping and resource blindness problems, resulting from the flooding method, will reduce the network performance. Therefore, MCF is appropriate only for those applications where the sink node has an almost exclusive role of data collector.

For the BS to send data to a dedicated sensor, destination and routing path must be defined at the BS node like in source based routing (SBR) [9]. To implement source routing, the packet contains the address of each node on the routing path. Source routing requires determining the address of all nodes and routing paths from source to destination, as is done in protocols like Dynamic Source Routing (DSR) [9][10] for wireless *ad hoc* network and Link Quality Source Routing (LQSR) [11] developed by Microsoft for wireless mesh networks. DSR and LQSR protocols are reactive approaches and do not need routing tables. These protocols determine a route on-demand when the source node wants to send data to destination node and keep the routing information while communicating.

The source node establishes a route between source and destination nodes by broadcasting a RouteRequest packet. When the destination node receives the RouteRequest packet, it replies with RouteReply packet to the source node. This packet carries the routing path from source node to destination node. During the communication between the nodes, the intermediate nodes route the packets by using the routing information which is carried in the packet headers.

A higher connection setup delay in comparison with table-driven protocols and the absence of a mechanism for local repair of failed links are some of the disadvantages of the DSR and LQR protocols.

III. Description of the Protocol

Consider a wireless network composed of multiple sensor nodes and one BS node. The BS node maintains a table of minimum cost paths from itself to every sensor node in the network. If the BS node needs to send a packet to a given sensor node, over a specific path specified in the table, the intermediate nodes must be aware of the path and route the packet to the correct links. As aforementioned, sensors in a reactive network do not have any information about the network topology. Furthermore, it is impossible to route the packet over a predefined fixed path when nodes have no knowledge about network topology or routing information. However, if the packet carries the path information, like it is done in Trajectory Based Forwarding (TBF) [12] and DSR, then the intermediate nodes can use this information to route the packets to destination node.

Taking into account the heterogeneous traffic in a WSN and making use of minimum cost forwarding and source based routing concepts, a reactive protocol can be designed to have optimum routing in both communication directions (from BS to nodes and nodes to BS).

It should be noted that in this method there is only one routing table at the BS node: the other nodes use the information in that table when the BS node issues a route-packet. The routing of packets, originated from sensor nodes, is based on the minimum cost forwarding method, without resourcing to a routing table. It is necessary that nodes can identify the type of a packet, because the routing algorithms for packets, coming from the BS node and for packets generated by sensor nodes, are different. These algorithms are described below.

A. Packets Sent from BS to Sensor Node

Suppose that the BS node needs to send a packet to sensor N3 in Fig. 1. In a mesh network, there are many paths from BS to each node, but almost always there is only one optimum path that has minimum cost for forwarding packets. Suppose that the minimum cost path, between BS and sensor node N3, is the one shown in bold in Fig. 1. In the present protocol there is a routing table at the BS node that maps each sensor node ID to the minimum cost path from BS to sensor node. This table is formed during the network setup phase.

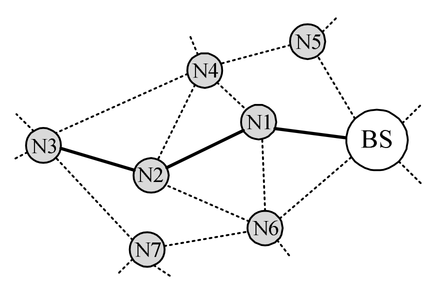

Figure 1. The minimum cost path between the BS and sensor N3

Fig. 2 depicts the proposed format for packets generated by the BS. The packet header includes three fields for routing purposes: a pointer, an offset and path information. The pointer determines the position in the information path for the next node. Each sensor node will decrease it by one unit before sending the packet to the next node. When the Pointer reaches zero, it means that the current node is the destination.

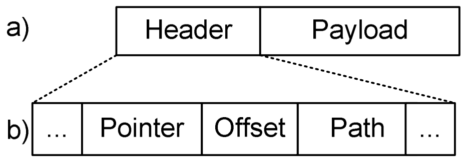

Figure 2. a) Packet generated by BS, b) Header of the packet

The packet header is variable in length and depends on the number of the nodes between the BS and destination nodes. The offset determines the length of the path: the destination node will use it to determine the start position of payload, while intermediate nodes can ignore it.

As an example, table I shows the paths from BS to nodes N2, N3 and N4 as presented in the routing table at the BS. The value saved for each node is an ordered list of intermediate node IDs.

TABLE I. ROUTING PATH FOR NODES N2, N3 AND N4 IN ROUTING TABLE

Node	Path
…	...
ID2	ID1
ID3	ID1, ID2
ID4	ID5
…	…

Fig. 3 shows the evolution of the pointer value as the packet passes through different nodes on the path form BS to N3. To send a packet from BS to N3, BS generates a packet with path (ID1, ID2, and ID3) and pointer value 2. When N1 gets the packet from BS, the pointer value is 2. N1 decreases the pointer by one and sends the packet to N2 (since ID2 was the node ID in position 2 as specified by the pointer). When arriving at N2, the packet pointer is 1: therefore the packet will be sent to N3 with new pointer value 0. N3 gets the packet when the pointer is 0: this means that N3 is the destination node.

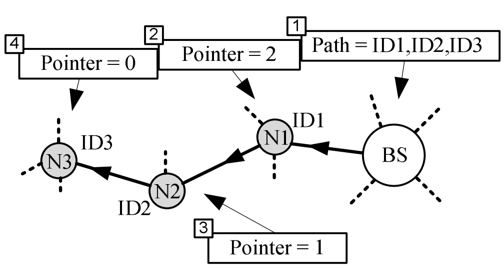

Figure 3. The pointer value in different nodes on the path between BS and N3

It can be seen that with this method sensor nodes can route packets without having information about the destination node and with minimum processing. All the information that they need to select the next node is available in the header, and sensors only select the next node based on the pointer value and the ID list present in the header.

B. Packets from a Sensor Node to BS:

Suppose now that the sensor N3 in Fig. 1 needs to send a packet to the BS node. As will be described later, during the setup phase of the network, to each node is assigned a minimum cost value and the ID of that adjacent node, on the path to the BS that has minimum cost. In this example, assume that the minimum cost neighbour is N2 for N3 and N1 for N2. Then N3 generates a packet that includes the N3 ID and sends it directly to N2. When N2 has a packet that must be sent to the BS node, it will send it to N1. In this example, N1 will send the packet to the BS directly. The received packet includes ID3 as the identification of the source node.

It is clear that the packet header is different for packets sent from the BS node and for those originated from the sensor nodes. In the latter, there is no information about the present path and the size of the header is fixed. Intermediate nodes decide how to handle each packet based on its type.

IV. NETWORK SETUP

Before normal operation, the network must be initialized. The setup phase has two steps. During the first all nodes determine their cost values for communicating with the BS node. During the second step the BS node generates the routing table. The setup processing is as follows.

A. Determination of each Node Cost Value

This step is similar to the minimum cost forwarding back-off process [6], however, differently from MCF; each node now has a unique ID. First all nodes except the BS, set their cost to infinity. The cost can be of any parameter such as hop count, transmission power, consumed energy, processing resources or delay. The BS node associated cost is zero. The BS broadcasts a cost advertisement message to the adjacent nodes. When a sensor node receives a cost message, compares its present cost with the new cost plus the link cost. If the new total cost value is less than its previous cost, the node changes the cost to the new value and saves the sender ID responsible for the advertisement message. The node then broadcasts an advertisement message to the adjacent nodes with its new cost value and ID. This process continues until all the nodes set their cost values to the minimum and introduce themselves to the BS. From the standpoint of the BS, one node does not exist unless it has introduced itself to BS. The BS node has to wait for the setup of the network to finish. The waiting time is set according to the number of nodes and network parameters such as link speed, delay and processing time.

In Fig. 4 example, node N3 has two links with N2 and N4, but the cost value from N2 is lower than the cost value from N4. Therefore, N3 will change its cost to 5 and register

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the ID of N2 as being on the path with minimum cost to the BS node.

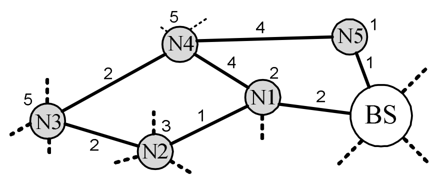

Figure 4. Forwarding along minimum cost

B. Routing Table Creation in the BS Node

As mentioned before, there is only one routing table for the whole network at the BS node. This table has information about all optimum paths with minimum cost values between the BS node and other nodes. The table creation step proceeds as follows:

When a node changes its cost value to a new value (during the setup of the network or even during normal operation of the system), it sends a message with its ID to the adjacent node from which it had calculated its own cost value. The receiver node adds its ID to the received message and sends it back to the next adjacent node along the optimum path. Eventually, when the BS receives the message, it has a message form the source node that includes the IDs of the nodes in the path between the source node and server node. The server node (BS) will save the IDs as a routing path in the row of the routing table, corresponding to that particular source node. This way, sensor nodes and sink node collaborate in the creation of the routing table. It should be noted that the same process will be performed during the normal network operation if a cost value, of a given node, changes. The cost value of nodes can change when a link or node failure occurs or still when a node gets a cost advertisement message with a lower cost value than their previous cost.

Fig. 5 shows the routing path creation for node N3, supposing that N1 and N2 are the nodes with minimum cost value to BS node, on the path between the N3 and BS. Table I shows the value of that row belonging to N3 with ID3 in the column "Node" of the routing table.

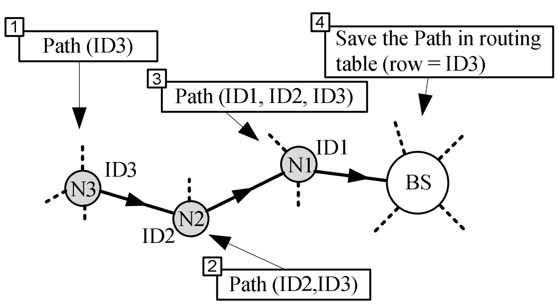

Figure 5. The cost value of N3 has changed

If a link or node failure occurs during normal operation, the cost value of the nodes and their related routing path in BS must be updated. For example, suppose that the link between N3 and N2 in Fig. 4 fails, so that the previous cost value of N3 is not valid anymore. Then N3 starts the process of getting a new cost value by changing its cost value to infinity and sending a cost request message to adjacent nodes. In this case, it obviously gets a new minimum cost value from N4. Now the new path with minimum cost between N3 and BS goes through N1 and N4. After the change in cost value, the routing path related to N3 in the routing table of BS is updated as mentioned in step B. Note that the cost value of the nodes located closer to the BS than the failing link are not affected. The process for updating the cost value after a node failure is similar.

V. SIMULATION AND RESULTS

In the above sections the routing protocol and the setting up of the network were exposed. This section presents the simulation results and the respective performance of a WSN using the proposed protocol. The results are compared with one employing the MCF protocol, and were obtained by implementing both protocols with OMNet++ 4. Matlab 7 and Microsoft Visual Studio 2010 with C# were also used to create the network and help on the analysis of the data from OMNet++.

The sensors were randomly scattered in a square area and remain fixed throughout the simulation. Table II shows the simulation parameters.

TABLE II. SIMULATION PARAMETERS

Parameter	Value
Sensor nodes	50, 100
Network area (m2)	100×100
The averages size of the packets generated with nodes (byte)	150
Packets maximum length (byte)	256
Antenna reach (m)	10
Processing delay (ms)	1
Nodes buffer size (byte)	1k
Simulation time (s)	30

The evaluation metrics are network throughput and energy consumption in terms of packet generated by BS node, when all the sensor nodes and BS node simultaneously generate packets. Another item in analysis is the average packet header size created by the BS node in terms of the number of sensor nodes in the network.

Fig. 6 shows the throughput of networks with 50 and 100 nodes using the proposed protocol. For comparison, the throughput for the same network, using the MCF protocol, is also shown. Results were collected for different amounts of traffic generated by the BS node. The results show that due to the use of optimum path information, during communication, SRMCF achieves higher throughput than MCF. Furthermore, for the range analysed, the throughput is almost constant with increasing data-rate.

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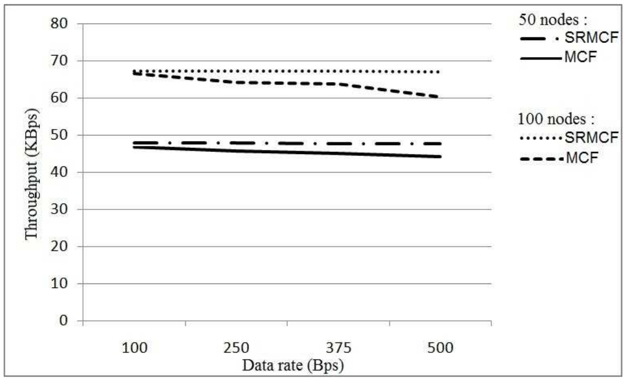

Figure 6. Throughput of the network in terms of the data rates of the packets generated by the BS node

In fact, with the proposed protocol, the traffic generated by the BS node is similar to the traffic of the other nodes. In contrast, the MCF protocol floods the packets from BS to nodes and increases the unwanted traffic in the network. Usually, increasing the traffic augments the probability of collisions and consequent packet loss, decreasing the network throughput.

Fig. 7 shows the network energy dissipation plot for the SRMCF and MCF protocols and for various values of generated packets by BS node. The simulation results are for 50 and 100 nodes.

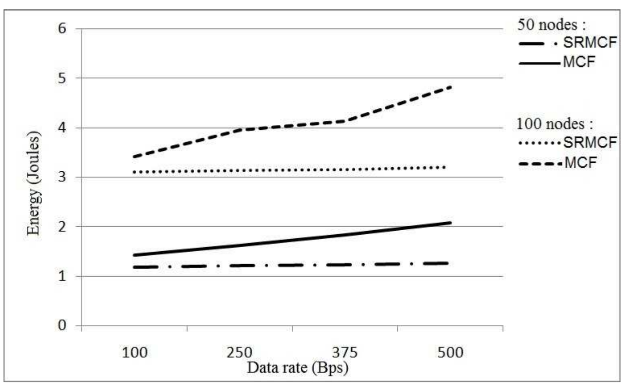

Figure 7. Energy consumption of the network.

The energy consumption during data transmission depends on distances between the nodes [13] and usually is in the range of a few nano joules per each communication bit in WSN applications (10.8 nJ/bit reported in [14]). After the network setup is finished, each node starts to send packets to the BS node, at 1kBps data rate. The BS node randomly selects nodes and sends packets to them. It can be seen that, for the same conditions, the MCF protocol leads to a larger energy dissipation that furthermore increases faster with increasing data-rate. This is consequence of the flooding method used by MCF to send packets from BS to the nodes. In contrast, the proposed protocol sends the packets directly from BS to the node over the optimum path.

The SRMCF packet header size, generated by BS, is variable and depends on the number of nodes in the paths between the BS and destination nodes. When the BS needs to send data to adjacent nodes uses a minimum length of 5 bytes for the header. Fig. 8 shows the average header size for networks with 100 to 1000 nodes. The figure implies that although the number of nodes increases 10 times, the average header size increases only by a factor of 2.26.

The effect of a variable header size has been taken into account in the energy dissipation simulations by considering the energy dissipated for each. In our simulations, the maximum packet size is 256 byte, so a one–byte filed is enough to specify the packet length. Both SRMCF and MCF have a fixed 5-byte header for packets generated by the sensor nodes. Both protocols have a relatively small header size in relation to the overall packet size.

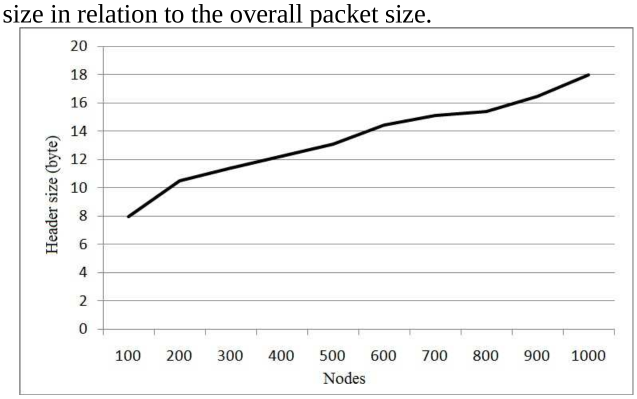

Figure 8. Packet header size

VI. CONCLUSION

This paper describes a routing protocol for wireless sensor networks based on the inclusion of routing information in the packets when minimum cost forwarding method is used. With the proposed protocol, and except for the BS node, there is no need to maintain explicit forwarding path tables in the intermediate nodes. The routing table on BS is formed in the network setup phase and updated after any change in network topology reported by sensor nodes. The intermediate nodes get routing information from the packets originating from the BS without having to know the network topology. In comparison with the MCF protocol, the traffic from sensor nodes to BS is the same, but the traffic from BS node to sensor nodes achieves better performance without significant changes on the sensor nodes side.

The simulation results indicate that not only the proposed protocol has higher throughput than MCF, but also dissipates less energy.

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