A Fuzzy Logic-Based and Distributed Gateway Selection for Wireless Sensor Networks

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Wireless sensor networks are resource-constrained because of the difficulty of recharging the devices. In order to prolong the network lifetime, the nodes relaying packets should carefully be selected. In a scenario where multiple sinks (gateways) are available, this selection is extended to decide to which sink the sources should send their data. We propose a distributed algorithm in which the the path to the sink is dynamically decided using an anycast transmission scheme. In these schemes, multiple candidates are available to retransmit the frames. They determine their own goodness of being the next hop for every online transmission. The estimation is supported by a fuzzy-logic based system which takes into account the connectivity of the source, the connectivity of the candidate and the candidate's residual energy. The simulation results show that our proposal reduces the energy consumption of the wireless network and the end-to-end delay of the transmissions.

1 Introduction

Nowadays, there are numerous applications where sensors are used. In order to make their sensed information available for their processing, sensors communicate with a sink [1]. The sink may be also connected to a Gateway which allows the data to be accessed from the Internet.

In most applications, sensors are needed to be auto-sufficient as long as possible. In this sense, one requirement is prolonging the sensor lifetimes. Sensor lifetimes are limited because of their reduced battery and because of the difficulty of recharging them. Taking into account this restriction, several techniques are usually applied in the design of sensor applications. Firstly, the energy consumption derived in the transmissions is diminished by the support of multihop communications. In this scheme, sensors collaborate retransmitting others' packet. Thus, the

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packet is forwarded by intermediate nodes which send it to the final destination through a route. This cooperation is easily achieved in a wireless environment. In contrast, a serious drawback is present: a node consumes some energy by receiving and analyzing data frames sent in their reception range, even when the node is not the destination of the data frame. To overcome this drawback, sensors may turn off and on their transceiver when needed [2]. The activation of the sensors can be synchronous or asynchronous. In the synchronous schemes, the activation of two nodes is triggered simultaneously. Although this kind of activation ensures the sending of the packets along the path, it is hard to ensure the synchrony in the wireless nodes. Alternatively, asynchronous nodes wait for their next hop to wake up. In this paper we will focus on asynchronous wireless sensor networks. In particular, we aim at defining a criterion to select the sink (gateway) when multiple ones are available. The selection is performed in a distributed way as every relaying node executes this criterion when retransmistting. The goal of our criterion is twofold: (i) to reduce the energy consumption of the nodes and (ii) to diminish the end-to-end delay in the transmissions. As multiple factors impact on these two parameters, a fuzzy logic-based algorithm is used [3].

The rest of the paper is structured as follows. Section 2 describes the anycast transmission. Section 3 describes our proposal. The algorithm is evaluated by means of simulations, as shown in Section 4. Finally, Section 5 draws the main conclusion of our work.

2 Anycast Transmission in Wireless Sensor Networks

In the multihop paradigm, nodes need to be provided of a routing protocol to become aware of the paths to the destination [5]. We assume that nodes execute a routing protocol which provides multiple routes to the sinks. In particular, the routing protocol offers the shortest routes to every sink. From this information, a node are able to construct its forwarding list, that is, the set of potential nodes (known as candidates) that could act as relay nodes to retransmit its packets to any sink [4]. Once the forwarding list is determined, an opportunistic/anycast routing paradigm could be applied. This kind of routing, based on the dynamic selection of the relaying nodes, is useful to increment the packet delivery ratio in wireless network [6]. The transmission of a frame works as follows. Firstly, the source transmits a preamble. In order to avoid the inclusion of the forwarding list in every preamble, the forwarding lists are periodically exchanged among the nodes. Upon reception of the frame, the neighbours check if they are candidates of the source (this can be done just by the awaken nodes). If so, they respond to the preamble with a specific frame. The time to respond to the frame depends on the priority assigned to the candidate. This is done to ensure that just one candidate will retransmit the frame. Once the source receives the frame, it triggers the data emission. The reception in the selected candidate is confirmed with an ACK message.

3 Fuzzy Logic- Based Criterion to Select the Relaying Node

In the anycast routing scheme, nodes should be assigned of a priority according to their convenience to act as the next relaying node of an on-line data frame. In particular, in the anycast routing, nodes delay its response to the preamble for a pause time. We propose this pause time to be inversely proportional to the goodness of the node to act as the next relay node. For us, the optimum relaying node is the node that forces the minimum energy consumption. The consumption of a transmission depends on the number of frames exchanged among the nodes. As the nodes need to wait for their next hop to wake up, the most convenient relaying node is the one whose next hop is active. Additionally, it is necessary to consider the energy of the nodes so that the network lifetime can be prolonged. In general, the best next hop is the one with the greatest number of neighbours connecting to the Gateway and with the biggest remaining energy. According to these conditions, we estimate the convenience of a node to act as the relaying node by means of a fuzzy logic-based system. The fuzzy-logic based system is a Mandani system with three inputs and one output. For the scenario to evaluate (described in the next Section), the crisp inputs are:

- Neighbours. It represents the number of neighbours that connect the candidate to any Gateway. This parameter is classified in three groups: FEW, MEDIUM and MANY. In order to ease the inclusion of fuzzy logic in sensors, the selected membership functions are lineal. In particular, for this input, the membership functions are reflected in Figure 1.

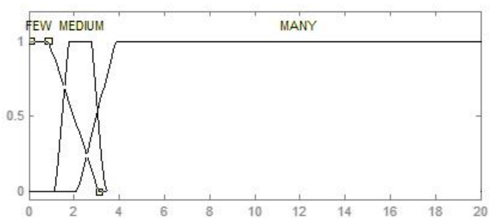

Fig. 1 Membership function for the variable Neighbours.

- Candidates. It corresponds to the number of candidates that the source has. According to this variable, the nodes are grouped into: FEW; MEDIUM and MANY. The membership functions for this input are depicted in Figure 2.

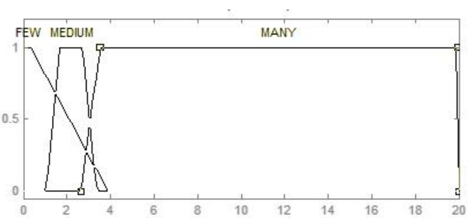

Fig. 2 Membership function for the variable Candidates.

- Energy. It is related to the percentage of remaining energy in the candidate's battery. The membership functions are shown in Figure 3.

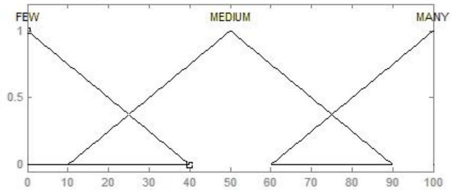

Fig. 3 Membership function for the variable Energy.

- In this system, the output corresponds to the suitability of the node to be the relaying node. The out is classified as: 'RETX' and 'NORETX' as shown in Figure 4. When the output is 'RETX', it means that it is an appropriate relaying node. Alternative, when the output is 'NORETX', it is preferable to select another node as the relaying node.

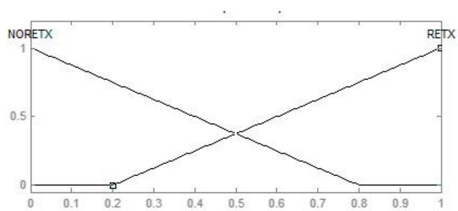

Fig. 4 Membership function of the Output.

Once the output is defuzzified, its value varies from 0 to 1. The defuzzyfication threshold is 0.5. The rules, summarized in Table 1, are and-type rules. An empty space in the table indicates that the input is not considered for the rule.

Table 1 Fuzzy rule set

Neighbours	Candidates	Energy	Output (Retransmit)
FEW	NOT(MANY)	NOT(MANY)	NO
MEDIUM	NOT(MANY)		YES
MANY			YES
FEW	FEW	MANY	YES
NOT(MANY)	MANY	NOT(MANY)	NO

4 Simulation Results

To evaluate the effectiveness of the proposed anycast technique, we have modelled the wireless sensor network in Matlab [7] considering a Free Space propagation with no losses in the transmission but with a delay of 0.03 seconds.

In this way, two nodes are connected if the distance between them is lower than the transmission range (which is set to 50 m). The source is always the same for all the transmissions. It is connected to 4 gateways by paths of 3-hop length which are depicted in Figure 5. These paths are not always available since nodes follow a sleep/awake cycle whose active time is 1 second and the mean sleep time is set to 5 or 10 seconds (two sets of experiments are executed for each mean sleep time). They follow a Rayleigh distribution for the sleep time.

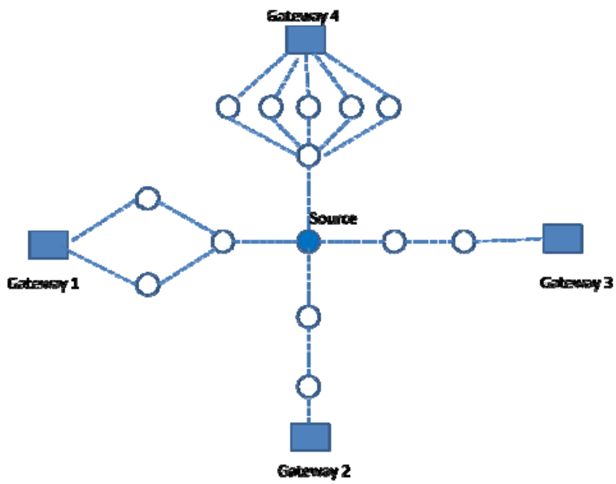

Fig. 5 Routing paths from the source to the Gateways.

Concerning the battery, in every simulation, nodes are assigned a random value for the remaining energy in their batteries. Assuming Mica2 nodes, nodes are powered by AA batteries whose maximum energy is 27MAs. For the cost of operation, we utilise the estimations derived in [8]. In this way, the sending of the preamble incurs in 0.17 mAs while its reception consumes 0.096 mAs. Transmitting the data frame leads to 1.7 mAs while receiving it leads to 0.96 mAs. We assume that the routing protocol has already been executed so their impact is not taken into account for our experiments. In our experiments, 1000 data frames are sent from the source to the any sink. We evaluate the performance of two anycast paradigms: our proposal based on a fuzzy logic based system and random anycast in which the candidate is selected randomly. For each mean sleep time (5 and 10 seconds), we run 10 simulations.

Using the fuzzy logic-based system, the energy consumption for each data frame is reduced 1.25% when the mean sleep time is 5 seconds and 3.25% when the mean sleep time corresponds to 10 seconds. Concerning the delay, the fuzzy logic-based system also improves the network performance. In particular, the end-to-end delay is reduced in 5.2% and 7.5% for a mean sleep time of 5 seconds and 10 seconds respectively. As we can see, the most important benefits are related to the end-to-end delay. This is due to the fact that using nodes with a large number of candidates increments the probability of having awaken nodes in the path but the receiving nodes not belonging to the path consumes part of their energy on the reception.

5 Conclusions

This paper has presented a novel scheme to dynamically select the path to any Gateway available in the scenario. The algorithm is supported by an anycast transmission technique. This mechanism to select the relaying node from the candidate list is supported by a fuzzy-based logic system which takes into account the connectivity of the candidate, its distance to the Gateway, its remaining energy and the number of available candidates. By means of simulations, we have demonstrated the effectiveness of our algorithm as our scheme is able to reduce the energy consumption per transmission. As future work, we intend to implement the protocol in a network simulation where realistic propagation conditions and realistic battery performance are taken into account.

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