Information Dissemination in WSNs Applied to Physical Phenomena Tracking

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***Abstract*— Several works suggest the use of wireless sensor networks to manage crisis situations. An example of such scenarios is forest fire fighting. In these situations, it is necessary to use efficient mechanisms for disseminating the environmental information captured by sensors. This paper analyzes the behavior of some representative broadcasting techniques when they are used to disseminate to the entire network the occurrence of multiple simultaneous events. The performance evaluation carried out shows that a moderate resource consumption in network devices can reduce the operation overhead.**

Keywords-wireless sensor networks; dissemination; performance evaluation

I. Introduction

One of the most promising applications of *wireless sensor networks* (WSNs) is its application to what is recently being referred to as *situation management* [10]. Situation management deals with dynamic and unpredictable scenarios, where a complex distributed system deployed over a wide area captures real time data from a large number of heterogeneous information sources. The final goal of this system is to provide support for decisions making.

An example of these applications is the EIDOS system (*EquIpment Destined for Orientation and Safety*) [4], in which a large (and dense) WSN is deployed over the area affected by a wildfire by using aerial vehicles. The mission of the network in this case is to directly provide the fire-fighters critical information that can improve their safety and efficiency. Basically, the WSN consists of a set of devices (also called "motes") that are able to capture certain physical magnitudes (temperature, pressure, humidity, etc.) in the environment where they have been deployed, and process and transmit the data acquired through a RF channel.

The most important technical objective in the EIDOS system is the development of a distributed collaborative processing mechanism. Starting from the sensed data, this mechanism allows the network nodes to obtain a simplified representation of the active fire fronts (a fire model), which informs about their localization, shape, speed, etc. This mechanism necessarily relies on an efficient data dissemination technique for propagating the information captured by the sensors.

In this sense, several proposals can be found in the literature to perform the information dissemination in WSNs. In most cases, these techniques have been designed to propagate the occurrence of a single event of interest. However, in phenomena tracking applications (such as the one described), it may occur that, at a given time, several nodes in a dense WSN detect and spread multiple events simultaneously (or almost simultaneously). In our case, every individual event could mean the approach of a fire front to a given location.

In this paper we analyze the behavior of different dissemination mechanisms when they are employed in physical phenomena monitoring tasks. In particular we are interested in evaluating their efficiency in spreading multiple events, the amount of resources required in network devices, and the overhead introduced in the wireless shared medium.

The rest of this paper is organized as follows. First, Section 2 presents some related work in the area of information dissemination in sensor networks. Then, Section 3 details the techniques that we have selected for this study. After that, Section 4 shows some simulation results that allow us to analyze the selected mechanisms. Lastly, Section 5 presents the conclusions of our research and outlines the future work.

II. WSN Dissemination Techniques

Dissemination (or *diffusion*) refers to the way in which the information is routed from the place where it is obtained (the sensor nodes) to the nodes who are interested in it [11]. In many situations the information flows to a single node, which plays the role of network base station. In this case we use the term *collection* or *gathering*. On the other hand, when all the nodes in the network are interested in receiving the information being disseminated (as in our case) the term *broadcast* is used. In [1] and [19], two classifications for these algorithms can be found. The simplest broadcast mechanism is *blind flooding*. Here, each node which owns (or receives) the information to be disseminated transmits it to the medium, so that it can be heard by all its direct neighbors. Thus, this technique ensures, at least in theory, that the information will reach its destination.

However, it is well known that an uncontrolled flooding can be very inefficient, mainly because a given node can receive the same information from multiple neighbors [15]. This phenomenon is known as the *broadcast storm problem*.

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Some *probabilistic-based* techniques, such as *Gossiping* [6], apply probability to control this redundancy. An alternative is that nodes do not rebroadcast the information if they received the same data more than a predefined number of times (*counter-based* techniques) [1]. Another option is to discard a broadcast message if the distance to the transmitter node is less than a threshold, in order that only the furthest nodes from the transmitter retransmits, in turn, the data (*distance-based* techniques). Another possibility is to retransmit if and only if the additional area that would be covered after forwarding the message is large enough (*area-based* techniques) [13].

In many cases, the decision of rebroadcasting the received information is postponed to a later time. This waiting period is usually called RAD (*random assessment delay*) [19]. In this way, if the node receives a new copy of the same message before the RAD ends, the rebroadcasting is canceled, thus avoiding redundant transmissions. The delay can be established randomly, or depending on the distance to the sending node (the greater the distance, the shorter the delay) [20]. The delay can also be calculated according to the area covered by all the copies of the same message received [7], or depending on the perimeter covered by these copies [16]. In the latter two cases, the transmission is canceled when it is no longer necessary.

Other techniques assume a priori knowledge of the geographical location of direct neighbors (*location-based* techniques). Then, information is transmitted if and only if the additional area that will be covered is greater than a certain threshold [15]. Another way to control flooding is to use the hierarchy established by *clustering* algorithms, so that the *cluster head* in each group is the only node that forwards the message (*cluster-based* techniques) [15]. Other proposals based on one- or two-hop neighbor knowledge (*neighbor-knowledge-based* techniques) can be found in [17], [18], and [19]. Many authors have also proposed to use hybrid schemes. Some examples are [9] and [12]. In large networks the techniques introduced in this paragraph involve a considerable control overhead, making them less suitable.

Finally, some dissemination mechanisms assume that only a subset of network nodes is interested in receiving the information. For example, in the *directed diffusion* mechanism [8], an initial phase is executed before the information is sent, in which a node propagates to the rest of the network its interest in a particular event. Then, the node that can provide that information answers with the requested data, using the best possible route.

III. MECHANISMS ANALYZED

The EIDOS system described in the introduction section requires the propagation of a large amount of fire detection events to all nodes in a large (and dense) WSN. Therefore, among the discussed dissemination techniques, we have considered the simplest one (flooding), and three delayed mechanisms (random delay, distance-based delay, and area-based delay). In this section we detail the implementation carried out for each of the chosen mechanisms. Before this, some common assumptions are presented.

We assume that every node in the network knows its location, which can be obtained either through a built-in *Global Positioning System* (GPS) receiver, or through a previous localization process (outside the scope of this paper). This location must be broadcasted to the entire network when the node sensor detects an approaching fire front. In addition, all nodes receiving the broadcast message will store the initiator position in some internal data structure, along with a time reference.

To minimize control overhead, we also assume that network nodes neither maintain any hierarchy nor have information about the amount of neighbors or their location.

Finally, regarding to the radio, we assume the use of omni-directional ideal antennas, resulting in circular coverage areas. In all the cases it is used the same transmission power, so these areas will have the same size.

A. Instantaneous Dissemination

This is a classic blind flooding mechanism [15]. When a node receives a message for the first time, it instantaneously retransmits to all its neighbors and, in turn, they transmit the message immediately. The only restriction that we have imposed is not to allow more than one retransmission of the same message by the same node.

The Algorithm 1 shows the actions carried out by a network node after receiving a message (M).

Algorithm 1. *Instantaneous dissemination*

if first copy of M **then**
    forward M
end if

B. Random Delay

This is an improvement over the instantaneous dissemination mechanism, in which the received message is not transmitted immediately, but after a waiting period [19]. The duration of this period (d) is randomly chosen between 0 and a predetermined value (d_{max}). In order to avoid redundant transmissions, if a node receives a new copy of the message before the waiting period ends, the retransmission is canceled. Moreover, as in the previous case, a node only retransmits once the same message.

The pseudo-code shown in Algorithm 2 shows the behavior of a node upon the reception of a message (M).

Algorithm 2. *Dissemination by random delay*

if first copy of M **then**
    d = random(0, d_{max})
    forward M in $t_{current} + d$
else
    if transmission of M is still pending **then**
        cancel transmission
    end if
end if

Note that, at a given time, a node may have several pending messages to send, which forces it to maintain a list to store information related to its pending retransmissions.

C. *Distance-Based Delay*

This mechanism also introduces a waiting period (from 0 to d_{max} seconds) before forwarding the information received. However, in this case the delay is set according to the distance to the sending node [20]. Specifically, the waiting period is inversely proportional to this distance, so that remote nodes will forward the message first, thus covering a larger area.

As before, the reception of a new copy of the message before the waiting period ends results in the cancellation of the retransmission. This is because it is no longer necessary that this node forwards the information due to another node further from the original one has done it before. Furthermore, no node forwards the same message more than once.

In the example of Fig. 1, node A starts the event dissemination. Then nodes B, F, G, H, and I (located on the perimeter of the coverage area) forward the information. The rest of nodes under coverage decide to cancel their own broadcasts after the reception of a second copy of the message.

Note that nodes do not have information about the location of their neighbors, so this technique requires that the sensor nodes incorporate some mechanism that allows them to measure (or estimate) the distance to the message sender. One possibility would be to use the power of the received message, assuming that it will be lower at a greater distance to the sender.

Thus, when a node receives the first copy of a message, it could set the length of the waiting period by using the following expression:

$$d = \left(\frac{P_R - P_{min}}{P_{max} - P_{min}} \right) x \; d_{max} \qquad (1)$$

where P_R is the receive signal power, which varies between P_{max} (transmission power) and P_{min} (minimum reception power).

The Algorithm 3 describes the actions performed by a node after the arrival of a message (M).

Algorithm 3. *Dissemination by distance-based delay*

```
if first copy of M then
    d = [ (P_r – P_min) / (P_max – P_min) ] × d_max
    forward M in t_current + d
else
    if transmission of M is still pending then
        cancel transmission
    end if
end if
```

In the same that way the algorithm that uses random delays, the implementation of this technique requires managing a list of pending retransmissions.

D. *Area-Based Delay*

Among the techniques proposed in this category, we have implemented the ABBA algorithm [16]. As in the two previous cases, after the arrival of the first copy of a message, the receiving node establishes a waiting period. However, the copies received before the period ends do not cancel the message broadcast, but serve to adjust its length. In particular, the delay is set according to the coverage area of the receiving node that has already been covered by all the copies of the same message. Thus, the bigger area covered, the longer waiting periods.

Assuming an ideal case where coverage areas are circular, we can compute the area covered by obtaining the covered arc. For example, in Fig. 2, node C has received a message from node A. The perimeter portion of C covered by the transmission of A is given by the intersection of two circles, and can be expressed through the difference between the initial and final angles. Moreover, the fact of using the same radio circles ensures that at most two segments will remain uncovered within that perimeter, which reduces the amount of information to store at each node.

Note that to allow the updating of the perimeter covered at a receiving node, the received message needs to explicitly include the transmitter position. Obviously, this introduces an additional communication overhead.

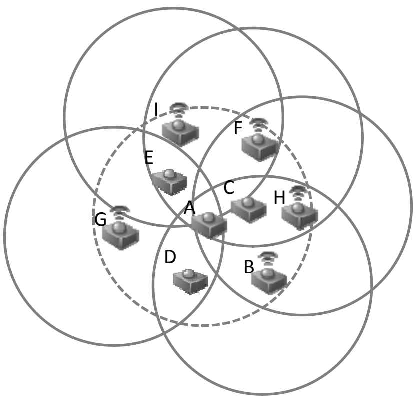

Figure 1. Example of dissemination through the distance-based delay.

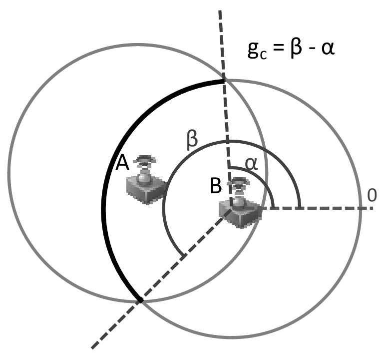

Figure 2. Perimeter of node C covered by a message received from A.

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Upon receiving a message, and after updating the perimeter portion which has been covered by previous copies, the node establishes a temporary delay for forwarding the message, according to the following expression:

$$d = \left(\frac{g_c}{360}\right) \times d_{max} \qquad (2)$$

where g_c is the angle (in degrees) covered. However, the forwarding of a message is cancelled if, before the expiration of the corresponding delay, the whole perimeter has been covered by other transmissions.

The actions to be carried out after receiving a message (M) are detailed in Algorithm 4.

Algorithm 4. *Dissemination by area-based delay*

```
if M has not been forwarded yet then
    compute g_c for M
    if g_c has changed then
        if g_c = 360º then
            cancel transmission
        else
            d = (g_c / 360) × d_max
            forward M in t_current + d
        end if
    end if
end if
```

Obviously, this algorithm requires that each node maintains a list to store the messages waiting to be broadcasted, along with the perimeter not covered yet by previous copies if those messages.

IV. PERFORMANCE EVALUATION

This section analyzes the performance of the four dissemination techniques detailed, from the point of view of their efficiency, resource consumption associated, and overhead introduced.

A. Simulation Environment and Methodology

We have used a simulation environment [5] developed for the EIDOS system. This tool is composed of several independent and interconnected modules, which share information by means of a global MySQL database. In short, first we use FARSITE [3] to simulate a wildfire over a particular area, by using real geographical, environmental and vegetation data. After that, a WSN simulator (developed in Python/TOSSIM [14]) executes the EIDOS application in each network node.

In order to obtain realistic results, the simulator incorporates a noise and interference model and the Friis *free-space* signal propagation model. We have modeled the *Crossbow Iris* radio [2], applying a transmission power of 3 dBm and a minimum reception power of -90 dBm. Under these conditions, we obtain an approximate radio range of 87 meters. The simulated protocol for media access control is basic CSMA [14].

In each simulation run, network nodes were distributed randomly in a square area of 400 × 400 meters. We have considered network sizes of 100, 300, 500, 600, 800 and 1000 nodes, with an associated density or connectivity degree (average number of direct neighbors) of 11.9, 35.77, 62.93, 71.87, 97 805 and 124.09, respectively.

For each experiment, we simulate the spreading of a forest fire in the deployment area, so that the fire reaches all the nodes of the network (without burning them). Every time a node detects the proximity of a fire (by a sudden rise in the sensed temperature), it broadcasts its position to the entire network. For localization purposes, we have assumed that all network nodes are equipped with a GPS receiver. For the execution of random-, distance- and area-based mechanisms the value of d_{max} parameter has been set to 5 seconds.

Finally, in order to increase the representativeness of the results shown, each experiment was repeated several times for each of the dissemination techniques studied, showing here the average values.

B. Simulation Results

First of all, Fig. 3 (a) shows the efficiency of the dissemination mechanisms analyzed, expressed as the average number of events received by each node, in function of the network degree. As the upper bound of this statistic matches the network size, Fig. 3 (b) shows the same results, but normalized according to that bound.

Note that, in general, an increment in network density penalizes all mechanisms. In particular, the instantaneous algorithm is quite efficient at a low network density, but its benefits are quickly reduced as the density increases. The random algorithm has a lower efficiency in a low density network, but it is not as sensitive to an increment in density

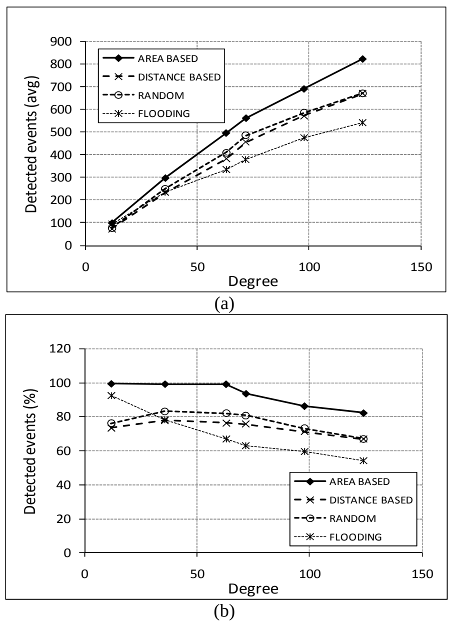

Figure 3. Efficiency of the dissemination mechanisms.

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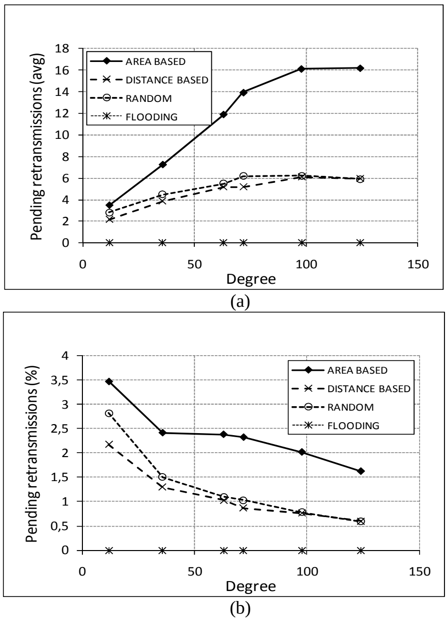

Figure 4. Amount of pending retransmissions at each node.

as the previous algorithm is. The distance-based algorithm behaves like the last one, although slightly worse because it produces more collisions (this issue is discussed later). Finally, the area-based algorithm obtains the best performance, being optimal at low and medium densities.

Next, Fig. 4 shows the amount of events pending to be forwarded at each node, for the different evaluated mechanisms, and in function of the network degree. Note that the storage of these pending retransmissions consumes memory resources at the devices. Fig. 4 (a) shows average values, and Fig. 4 (b) shows the same results, but normalized according to the number of events propagated during the complete simulation run.

Obviously, the instantaneous algorithm does not consume any resource at the nodes. In the remaining algorithms, the total amount of outstanding retransmissions tends to stabilize as the network degree increases (a), thus the relative percentage tends to decrease (b). It may be noted that the random- and distance-based algorithms have a similar behavior, while the area-based has slightly higher requirements.

Finally, Fig. 5 shows the effect of the dissemination mechanisms on the wireless medium, through the amount of sent messages, duplicates and collisions per node, and in function of the network degree. It can be seen that the instantaneous algorithm generates a high overhead in the channel (a), producing a large number of collisions (b). This leads to a very few duplicated messages (c), and a low redundancy in the information transmitted (d). This algorithm forwards (once) all the information received, getting the worst possible efficiency of the performed transmissions (e).

The random algorithm is the one which transmits less information, keeping a low level of collisions and duplicated messages. With a moderate redundancy, it gets the highest efficiency of the information transmitted in low density networks.

The distance-based algorithm behaves like the former one, except that it has a slightly higher number of collisions. This is because the random distribution in time of the broadcasts is uniform, while the spatial distribution tends to increase with distance. The consequence is that the distance-based algorithm gets a slightly lower efficiency.

Finally, in the area-based algorithm, the amount of messages sent is not so sensitive to the network density, being the best starting from certain degree. Moreover, the number of collisions is negligible (b), so that the amount of duplicated messages is higher than the obtained by other algorithms (c), obtaining a redundancy that increases linearly (d). Finally, this algorithm presents the best efficiency in the transmissions made for dense networks (e).

V. CONCLUSIONS AND FUTURE WORK

In this work, we have studied the behavior of some representative dissemination techniques when they are used to broadcast multiple events in a dense WSN during the task of monitoring a physical phenomenon.

From the analysis carried out it is shown that the technique that uses transmission delays based on area is the most efficient, in terms of the amount of events that it spreads. Moreover, from the point of view of the media access level, this mechanism exhibits the best behavior, at the expense of certain resource consumption in network devices. However, we found that the use of a reliable broadcast on a not reliable access level does not guarantee the propagation of all the events.

As future work, we plan to consider using fusion techniques in order to reduce the amount of information to propagate. Our goal is to define some kind of representation which allows grouping a large number of geo-referenced events in a single data structure to spread.

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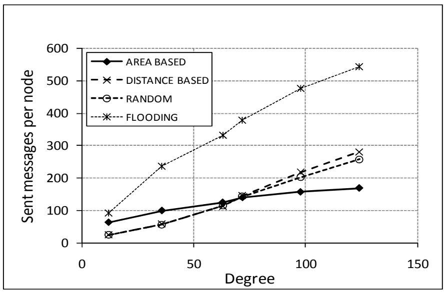
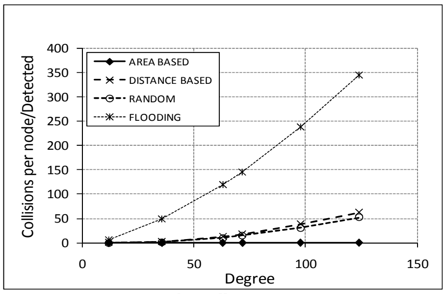
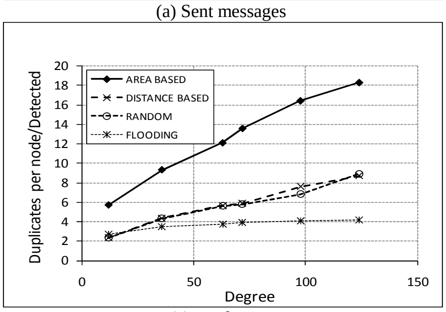


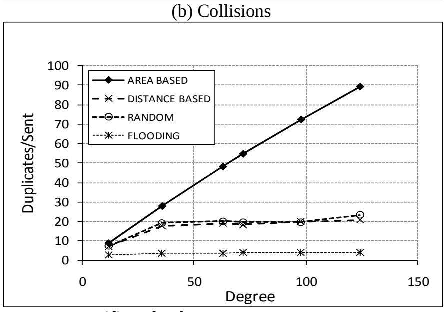
(a) Sent messages



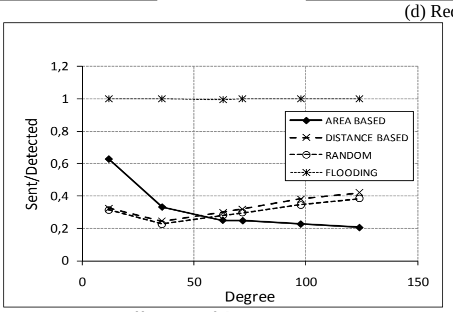
(b) Collisions



(c) Duplicates



(d) Redundancy in transmissions



(e) Efficiency of the transmissions

Figure 5. Channel overhead caused by the dissemination mechanisms.

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