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Graph splitting based self-organization approach for energy and routing optimization

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ABSTRACT

Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy awareness is an essential consideration. Both self-organization and routing protocols significantly impact the energy consumption and therefore the network life time. This paper surveys recent self-organization and routing protocols for sensor networks and proposes enhanced approaches for low duty cycle and more reliable environment. We compare some of the relays-based protocols in a random graph model. Simulation results will show the impact of a graph splitting approach on the active node set and the topology connectivity. Moreover, we analyze the performance of that approach in terms of transmitted and received packet rate.

KEYWORDS

WSN, MPR, MPR-CDS, Graph split.

1. INTRODUCTION

Smart environments represent the next evolutionary development step in building, utilities, industrial, home and transportation systems automation. The information needed by smart environments is provided by Distributed Wireless Sensor Networks (WSN), which are responsible for sensing as well as for the first stages of the processing hierarchy. The individual devices in a WSN are inherently resource constrained: They have limited processing speed, storage capacity, and communication bandwidth. These devices have substantial processing capability in the aggregate, but not individually, so they must organize themselves and provide a means of programming and managing the network as an ensemble, rather than administering individual devices.

Energy conservation is one of the most challenging problems because batteries have very limited capacities. Two particular important problems are activity scheduling and broadcasting. In activity scheduling problem, some nodes decide to sleep to preserve the energy, but should have an active neighbor to collect messages for them or take over some sensing tasks. In broadcasting problem, one host needs to send a particular message to all the other ones in the network. Broadcasting is applied for publication of services, alarming and other operations. In a straightforward solution to broadcasting, hosts only need to blindly relay packets at least once to their neighborhood. However, this leads to the well-known broadcast storm problem as redundancy and collisions [1,2]. Self-organization protocols are proposed in literature trying to avoid these problems by choosing active and connected nodes set charged of broadcasting and routing [3,4,5,6].

The concept of multipoint relaying [7,8] consists to reduce the number of duplicated re-transmissions when forwarding a broadcast packet. This technique restricts the number of re-transmitters to a small set of neighbor nodes, instead of all neighbors, like in pure flooding. This set is kept small as much as possible by efficiently selecting the neighbors which covers (in terms of one-hop radio range) the same network region as the complete set of neighbors does. This small subset of neighbors is called multipoint relays (MPR) for a given network node. The technique of multipoint relays (or MPRs) provides an adequate solution to reduce flooding of broadcast messages in the network, while attaining the same goal of transferring the message to every node in the network with a high probability.

With so many potential applications, researchers are interested in algorithms to develop "backbones" within these networks reliably and quickly. A backbone, more technically, is a dominating, independent set in the graph of nodes, meaning that the nodes, themselves, are out of one another's range, but would be able to relay information between intermediate nodes. Several graph models have been proposed to impact energy but are connectivity constrained. In this paper, a graph splitting model will be proposed and evaluated.

In this work, we propose to split the entire network into two sub-networks before applying self-organization protocols to minimize the dominating set which leads to reduce the number of retransmission. The paper is organized as follows. Section 2 presents and analyzes different protocols used for self-organization especially, MPR and MPR-CDS (Connected Dominating Set). While, section 3, develops an optimized MPR-CDS model based on a graph splitting approach and evaluates its performances. Finally, section 4 concludes the paper.

2. WSN SELF-ORGANIZATION PROTOCOLS

Self-organization allows devices to recognize their surroundings, cooperate to form topologies, and monitor and adapt to environmental changes, all without human intervention. Subsequently, self-organization in wireless sensor networks provides a variety of functions: sharing processing and communication capacity, forming and maintaining structures, conserving power, synchronizing time, configuring software components, adapting behavior associated with routing, with disseminating and querying for information, and with allocating tasks, and providing resilience by repairing faults and resisting attacks.

2.1. Flooding

A network consists of many nodes, each with multiple links connecting to other nodes. Information moves hop by hop along a route from the point of production to the point of use. In WSNs, each node has a radio that provides a set of communication links to nearby nodes. By exchanging information, nodes can discover their neighbors and perform a distributed algorithm to determine how to route data according to the application’s needs. A basic capability in such networks involves disseminating information over many nodes. This can be achieved by a flooding protocol in which a root node broadcasts a packet with some identifying information. Receiving nodes retransmit the packet so that more distant nodes can receive it. However, a node can receive different versions of the same message from several neighboring nodes.

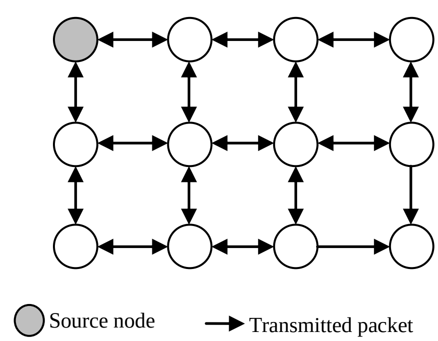

Fig.1. Primitive flooding WSN.

Primitive network is based on blind flooding where the packet is retransmitted by all the intermediate nodes (Fig.1). It is simple, easy to implement, and gives a high probability that each node, which is not isolated from the network, will receive the broadcasted message. However, it consumes a large amount of bandwidth and energy due to many redundant retransmissions.

2.2. Multipoint Relay (MPR)

Many techniques are described in the literature to reduce traffic flooding in WSNs. But, each technique is developed for a target application and characterized by its own advantages and weaknesses. Here, we will discuss the "multipoint relaying" mechanisms (MPR and MPR-CDS) as possible solutions. These mechanisms are based on two-hop neighbors' knowledge using HELLO messages defined by the Mobile Ad hoc Network (MANET) [9].

HELLO messages are broadcasted to all neighbors at regular intervals. They contain information about the neighbors and the link state. Fig. 2 describes the process for three nodes A, B and C. Two rounds of HELLO messages are needed to establish the whole one-hop and two-hop neighborhood.

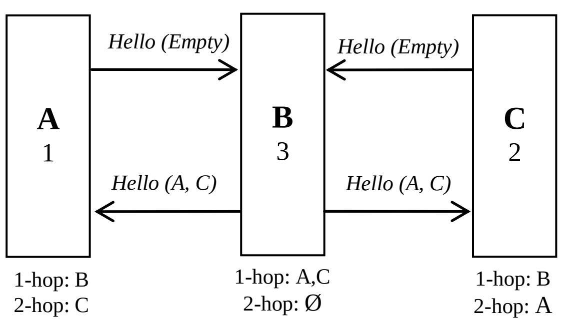

Fig.2. HELLO process.

Multipoint relay was presented as a technique to reduce the number of redundant re-transmission in the wireless sensors networks by electing a special node set to cover the entire network based on the 2-hop neighbors' knowledge. Several rules and algorithms are proposed for this calculation. In this paper, we resort to the greedy [7] MPR set computation described in the algorithm below.

MPR Algorithm [10]

1. Start with an empty multipoint relays set.
2. Add nodes which are the only neighbor of some nodes in the 2-hop neighbors.
3. If there still exist some two-hop nodes which are not yet covered, compute the one-hop nodes degrees and choose the maximum one.
4. Repeat step 3 until all two-hop neighborhoods are covered.

Fig. 3 shows an example where a broadcast message is diffused in the network using the multipoint relays where 7 retransmissions are needed to reach all nodes.

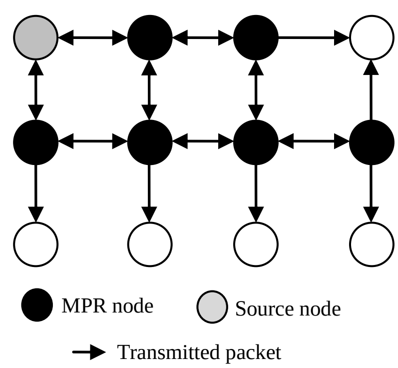

Fig.3. WSN deploying MPR protocol.

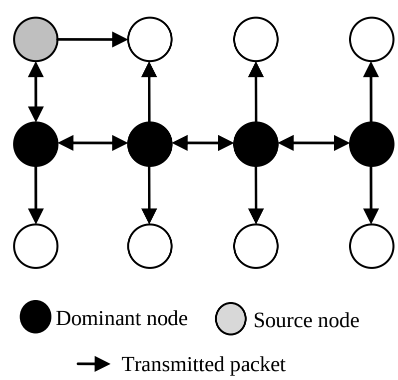

Fig.4. WSN deploying MPR-DS protocol.

2.3. Multipoint Relay – Connected Dominating Set (MPR-CDS)

Adjih and al. proposed a novel extension of the MPR to construct a small CDS source independent using two simples rules based on the node ID and the greedy algorithm [5]. In the present work, the node is selected into the dominating set of the network if:

- It has the largest degree than all its neighbors.
- It is a multipoint relay selected by its neighbor with the largest degree.

The multipoint relays are selected using the greedy algorithm. Nodes with highest degrees calculate their relays and call them to join the CDS at the third round of HELLO messages. Fig. 4 shows the MPR-CDS application for a wireless sensor network composed by 12 nodes where five retransmissions are required to reach the entire network.

3. CDS OPTIMIZING

Bridging the gap between the hardware technology's raw potential and the broad range of applications presents a systems challenge. The network must allocate limited resources to multiple concurrent activities, such as sensing, processing, network supervision and data communication. The potential interconnections between devices must be discovered and information routed effectively from where it is produced to where it is used. In this section, a graph splitting method is developed to meet these requirements and constraints.

3.1. Graph creation

The graph creation algorithm is an iterative process which creates *n* vertices with random x and y coordinates between 0 and 1. When working with a square, all coordinates within [0,1] are acceptable. We compute the Euclidian distance from the origin of the square in order to know whether or not a coordinate is within the acceptable bounds of that area (square). An efficient method to connect the nodes is to divide the graph into smaller pieces and connect the nodes only within these pieces or "cells". An intelligent graph division can minimize the number of connections which would overlap between "cells" and save even computation.

3.2. Graph splitting

Let G = (V,E) be a graph with a set of nodes V and a set of edges E. The number of nodes in G is denoted by N. The degree d(u) of a node u is the number of edges adjacent to u (number of neighbors). $\boldsymbol{L}$ and $\boldsymbol{l}$ are the length and the width of the random graph, respectively. All nodes have the same coverage radius R.
We define $\boldsymbol{p}$ as:

$$p \triangleq \frac{R}{\sqrt{L \times l}}$$

The setting of $p \in [0.4,1]$ ensures that generated graphs are connected with high probability [10,11]. In these simulations, we study the impact of $\boldsymbol{p}$ on the CDS size. For $\boldsymbol{N}$=200, $\boldsymbol{l}$=200 and $\boldsymbol{R}$=80 and a variable $\boldsymbol{L}$. The simulation results of the MPR-CDS are shown in the figure 5.

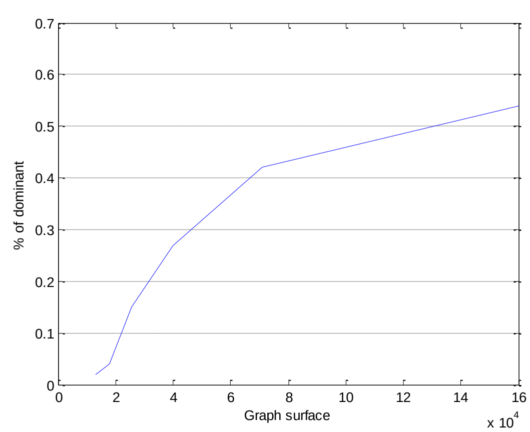

Fig 5. The CDS for the MPR-CDS in a variable graph Length.

We observe that the percentage of dominants decreases with the length because ***p*** increases and therefore the probability of graph connectivity increases too. We conclude that by reducing the length of the graph, we optimize the CDS set. Therefore, we will focus, in the rest of this paper, on the impact of the global graph splitting into many elementary sub-graphs.

3.3. Rank split

We assume that during HELLO message process, nodes are able to calculate their ranks defined as follow:

Definition**:** The rank of node *u*, ***rank*****(*u*)**, is the minimum number of hops between source node and node *u*.

The source node (sink node) has the rank zero. HELLO packet contains the number of hops between the node and the sink. The nodes will receive many distances and they have to take the minimum. The ***MaxRnk*** is the greatest rank in the network.

We split the global graph G into two sub-graphs G1 and G2. For each node *u*:

$$\begin{cases} u \in G1 \text{ if } rank(u) \leq MaxRnk/2 \\ u \in G2 \text{ if } rank(u) > MaxRnk/2 \end{cases}$$

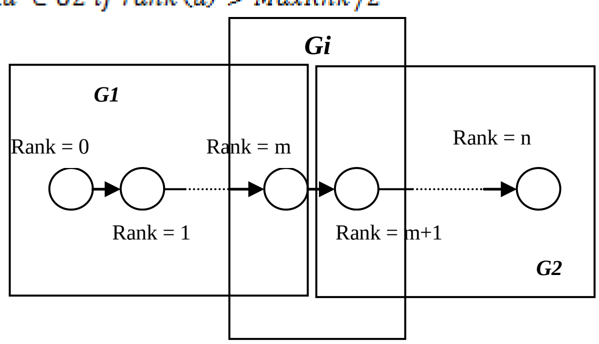

Fig.6. Graph decomposition concept.

Applying the MPR-CDS for G1 (CDS1) and G2 (CDS2). The CDSs are connected while the global CDS for the graph G is not connected. We propose to create a new sub-graph Gi (CDSi) in the interface of G1 and G2 to connect the CDSs. The global CDS becomes:

$$CDS = CDS1 \cup CDS2 \cup CDSi$$

3.4. Simulation environment

To simulate the graph splitting approach, a simulator was developed in MATLAB. It generates a random topology in a rectangular area with L=1000, l=200 and R=80. The global graph connectivity is checked by a simulation of blind flooding. CDS connectivity check uses the same process as global graph where only the dominants have the right to diffuse. The delivery rate (DR) describes the number of nodes which receive at least one copy of message used in the connectivity checks. The simulation process is described by the following flowchart:

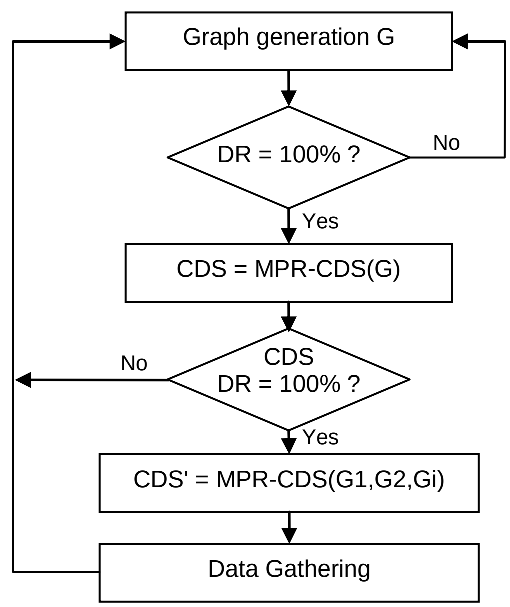

Fig.6. Simulation flowchart.

3.5. Results analysis

Figure 7 shows the simulation results of 100 connected graphs which have been decomposed with ranks. For low density ($N < 100$), the probability to keep DR = 100% is around 50%. While, for $N \geq 100$ nodes, this probability increases substantially reaching more than 95%. Also, we note that during the splitting process, a risk to create isolated clusters appears for low density graphs. This risk decreases with the increasing of the number of deployed nodes.

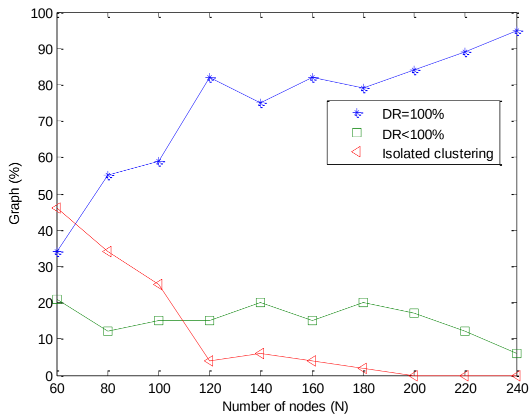

Fig.7. Connected Graphs face to decomposition.

Figure 8 shows the difference between the MPR-CDS with and without graph splitting. The CDS size is performed after the graph splitting. This difference is due to the reduced graph area and to the nodes which don't consider many of one-hop and two-hop neighbors in the CDS calculation.

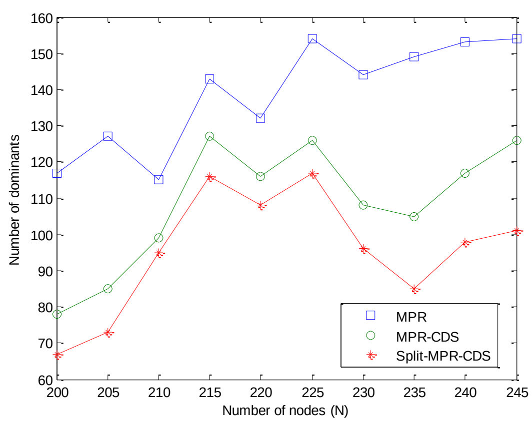

Fig.8. Dominants set for MPR, MPR-DS and sub graphs with MPR-DS.

The CDS set is responsible to control the network. It allows transmitting and forwarding both traffic and control messages [9] to reduce the number of passive listening (while not concerned). Figure 9 shows the number of received message in the entire network per cycle assuming that only one node sends a message every cycle. Consequently, the received messages are reduced by 40% when splitting the graph and applying MPR-CDS compared to the classic MPR-CDS.

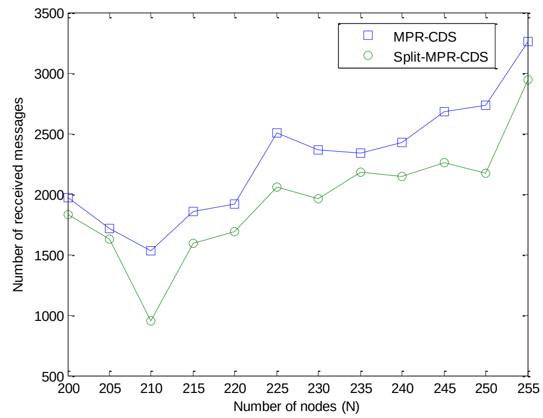

Fig.9. Received messages per cycle.

4. CONCLUSIONS

This paper introduced a new concept to optimize the MPR-CDS by splitting the network graph into many elementary sub-graphs. It reduces the dominant set in order to minimize the number of retransmitted packet in the network. The idea has been simulated using different scenarios and comparisons with MPR and MPR-CDS are established. The results confirm that an amount of dominants may be removed with connectivity guarantee. The new approach is more efficient for dense networks that are composed by hundreds or even thousands nodes.

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