GRIDS: Geographically Repulsive Insomnious Distributed Sensors – An efficient node selection mechanism using Passive Clustering

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Abstract— Due to the limited capacity of the sensors’ batteries, energy is a critical resource in wireless sensors networks. Sleep mode operation is an effective approach to prolong the life time of the network. How to determine insomnious (wakeup) node is a critical component of this approach. There are a number of selection methodologies in the literature but all of them except randomized sleeping require local or global residual energy information exchanges among sensors. This can be very expensive especially in a densely deployed sensor network. In this paper, we propose to use Passive Clustering (PC) as a selection method and we further increase the service time of a sensor network by introducing an energy-aware selection mechanism. This mechanism allows balanced energy consumption among the sensor nodes. Each sensor determines being insomnious or not based on its residual energy and the number of neighbouring insomnious nodes and their energy level. An efficient flooding during each wake up period determines insomnious nodes in the network. GRIDS selects insomnious nodes well distributed in the sensor deployed area. The simulation results show that the selection mechanism distributes “evenly” the duty cycles among sensor nodes and thus considerably increase the network’s lifespan as the result.

Keywords— cluster, balancing energy, lifespan, sensor network, sleep node selection

I. INTRODUCTION

Flooding is frequently used in wireless ad hoc networks and wireless sensor networks (WSNs) to discover and/or to advertise network topology [1]. It is oftentimes used as a method of information deliveries as well. Flooding generates unnecessary duplicates in dense networks and it speeds up the energy consumption of ad hoc/sensor nodes. Several solutions were proposed to reduce the overhead of the flooding. In general, these solutions improve the efficiency of flooding by selecting a subset of nodes (critical nodes), and by allowing only the subset of nodes participate in flooding. These approaches are also applicable for reducing the power consumption of sensor networks when the sensors’ radio can operate in a sleep mode and the non-critical nodes may shut down their radio when communication is not needed.

Topology based efficient flooding including MPR (multi-point-relay) [2, 3] requires at least 2 hop neighbor information to apply set-cover heuristics. Probabilistic approaches do not require additional overheads such as topology information; unfortunately, these overhead-free approaches do not guarantee flooding coverage. Structure based efficient flooding includes cluster based efficient flooding [2]. In cluster based efficient flooding, the traffic is handled by a limited number of nodes: Cluster Heads (CHs) and gateways (GWs).

When we organize sensor networks with limited number of critical nodes, the overall energy consumption as well as the number of unnecessary flooding duplicates are reduced; unfortunately, it also greatly increases the energy consumption of those critical nodes. The most important/critical nodes consume their batteries fast and stop functioning early, which may cause disconnections of the network.

There have been extensive efforts to reduce the consumption of energy and to improve the lifespan of WSN in recent years. A common technique is to put some sensors in the sleep mode and put the others in the active mode for the sensing and communication tasks [5]. For example, the authors in [6] present a new energy saving method by dividing the sensor nodes into disjoined sets so that each unit covers each target to be controlled. Energy can be saved with this method by activating only one set of nodes at a time.
The techniques used to reduce the total energy consumption of a network do not necessarily increase the lifespan of the network. Indeed, the lifespan of the network is defined [7] in WSNs according to three criteria: (1) The first node breaks down; (2) A fraction of the nodes breaks down; and (3) Loss of the coverage/connectivity. Figure 1 shows a sensor network where red nodes run out of energy (e.g., battery capacity is 500mW); even though black nodes have still residual energy, they cannot communicate (i.e., black nodes in the left cannot communicate with black nodes in the right) since no feasible path exists. Thus, the key to increase the life span of the network is to balance the consumption of energy among the network nodes while still aiming at reducing the total energy consumption. Indeed, ideally all the network nodes should die at almost the same time.

A number of recent cluster-based systems propose techniques to balance the energy consumption of the network nodes; these techniques consist mainly of rotating the CHs in a randomized fashion [8, 9]. Usually, these cluster-based systems combine active/sleep technique with randomized rotation; further their limitations (e.g., require signaling protocols to build the cluster structure) compared to passive clustering [10], they have stringent requirements to implement the active/sleep techniques; examples include [8, 9]: sensors have synchronized clocks; sensors have global knowledge (e.g., energy of other sensors), localization information, etc. A good survey on these systems can be found in [5].

In this paper, we propose an improved version of Passive Clustering (PC) [10], called GRIDS, which extends the lifespan of the network by using an efficient selection mechanism of critical (or not) nodes. GRIDS enables balanced energy consumption among the network nodes without requiring additional overheads including additional signaling, time synchronization, global information, etc. Active nodes are well distributed and density is well adapted. The simulation results show that GRIDS balances the energy consumption among the network nodes and thus increases the lifetime of the network.

The main contribution of the paper consists of the proposed selection mechanism that, when combined with PC, allows extending considerably the lifespan of the network. The key innovations of this mechanism, compared to existing approaches, is that it (1) does not have any stringent requirements (e.g., clock synchronization and global knowledge); and (2) does not generate considerable extra control traffic to exchange energy information among nodes. Furthermore, the proposed mechanism can be easily adapted/used with other clustering protocols; in this paper, we selected PC since it has the best performance of all clustering protocols, especially, in highly mobile dense networks [10].

The remainder of this paper is organized as follows. Section II describes the efficient flooding mechanism with passive clustering. Section 3 presents the selection mechanism, called GRIDS. Section 4 demonstrates the effectiveness of the proposed mechanism via simulations. Finally, Section 5 gives concluding remarks and directions for future work.

II. PASSIVE CLUSTERING

There are two approaches to construct the cluster platform: active clustering and passive clustering. Active clustering requires signalling protocols to exchange information among neighbouring nodes to select CHs and GWs; it generates considerable overhead (especially in the case of high node density.)

Passive clustering (PC) [10] is an “on demand” protocol which constructs and maintains the cluster architecture only when there are on-going data packets. Each node collects neighbour information through promiscuous packet receptions. In PC, there are four possible cluster states and 1 internal state; Initial, Cluster Head (CH), Ordinary Node (ON), GateWay (GW) and CH Ready (CH_ready - internal.) Nodes piggyback their cluster states in packets.

If a node receives a packet from a CH or a GW, it adds this information to its CH list and the GW list. The node’s state is determined by the number of CHs and GWs based on Gateway Selection Heuristics ‘GSH’. This heuristics provides a procedure to elect the minimal number of gateways (including distributed gateways) required to maintain the connectivity in a distributed manner. All nodes maintain the list of CHs and GWs that they can overhear. The list is a soft-state, i.e., each entry of the list has a timer which keeps the most recent reception history and the entry is removed when the timer expires. A node assumes that some nodes are out of locality if they have not sent any data longer than timeout duration. With reasonable offered load, a node can catch dynamic topology changes.

A node cannot be a CH if it is in the territory (Tx range) of another CH, i.e., it has received a packet from one or more CHs. This guarantees that the distance among any CHs is at least 2 hops. This implements First Declaration Wins rule ‘FDW’ which allowed a node that first claims (sends packets) to be a cluster head and then it ’rules’ the rest of nodes in its cluster (radio coverage).

There is no waiting period (to make sure all the neighbors have been checked) unlike that in all the weight-driven clustering mechanisms [12] [13]. Figure 2 illustrates an example of clustering - the black nodes are CHs, white nodes are GWs and grey nodes are ordinary nodes (ON). Only CHs and GWs relay data packets. ONs receive packets but do not take part in the re-broadcasting, which consequently limits the number of collisions, reduces the overheads, and avoids channel saturation.
The Passive Clustering [10] procedure is simple, easy to implement and most importantly, overhead free. At the beginning or when there are no network activities for a long time, all nodes are in the 'initial' state. This state does not change as long as a node does not receive a packet. When a node receives a packet and if the state of a sender is not CH, the receiver's state switches to CH_ready. A node in CH_ready state will change to CH if it transmits successively outgoing packets before receiving a packet from another CH.

The clustering state of a non-CH node is determined by the number of CH and the number of GW in its list. When the number of CHs is greater or equal to the number of GWs, the node becomes a GW (the details of the Gateway Selection Heuristic (GSH) can be found in [10]). Otherwise, the node becomes an ON.

When we use original PC, CHs and GWs work more. These nodes drain their power quickly and die faster (see Figure 1). To avoid the “early die” problem of critical nodes, we propose to improve Passive Clustering by a new node selection mechanism called GRIDS (Geographically Repulsive Insomnious Distributed Sensors).

III GRIDS

In this section, we present the details of GRIDS. The main novelty is that GRIDS implements balanced energy consumption among network nodes without introducing additional line overhead. As a result, the lifespan of the network is significantly increased.

A. GRIDS mechanism

GRIDS is an energy-aware cluster formation protocol based on the following principles:

- Passive clustering and its two modified principles: Energy-aware FDW ‘eFDW’ and Energy-aware ‘eGSH’.
- An energy model which delivers node’s residual/remaining energy level in real time. This information is piggybacked in the nodes packet header.
- Periodic polling.
- Geographical repulsion.
- Insomnious principal.

GRIDS inherits PC for constructing and maintaining clusters: The main differentiator is that a set of nodes in a cluster with higher energy levels have higher probability to become critical nodes, i.e., CH or GW. In PC, CHs keep their cluster status until there is a CH collision, i.e. the hop distance between two CHs becomes 1, and one of them resigns from CH. In GRIDS, an energy abundant node can challenge CH and usurps the role. Even if there is a CH declaration, nodes can challenge when their energy levels are higher than the one of CH. These nodes keep their cluster status even if they receive packets from the current CH.

Energy-aware GSH (eGSH) enforces the energy level comparison when a node counts the number of neighbouring GHs. Only the GHs with higher energy level contribute to the number of GHs. As a consequence, an ON (i.e., Ordinary Node) with higher energy level becomes a GW and a GW with lower energy level becomes an ON (see Figure 3). In this way, GRIDS selects critical nodes among energy rich nodes. eFDW and eGSH are the basic ideas of GRIDS.

In a new duty cycle, every node wakes up and runs GRIDS. We assume there is a data sink which collects sensor data and the data sink starts “initialization” flooding on every duty cycle. The “initialization” flooding is an efficient way of establishing reverse paths from all the insomnious nodes to the data sink. All sensor nodes execute GRIDS for efficient flooding and at the same time insomnia node selection. Once the flooding is done, CHs and GWs have higher residual energy levels than ordinary nodes. CHs are evenly distributed over the sensor area because CHs cannot be neighbours. CHs are geographically repulsive by the nature of GRIDS operation. GWs will fill the gab among CHs.

GRIDS regulates the energy consumption among sensor nodes and prolongs the network lifetime without using any extra communication. GRIDS enables an efficient flooding

Figure 2. Cluster Structure with Passive Clustering (PC)

Figure 3: GRIDS automata
even for the very first flooding; it improves scalability and provides density adaptability.

The decision made by a node to be insomnious or not is completely distributed. Each node compares its residual energy level with the residual energy level of insomnious nodes in its neighbourhood.

B. Operational Description

In GRIDS, when a source node sends the first data packet, all of the nodes in its radio range become CH_ready. The first node that succeeds forwarding the packet becomes a CH. All nodes in the cluster will add 1 to #CH only if the residual energy level of the CH is higher than its own energy level. Comparing #CH with higher energy level and #GW, non-CH nodes determines the clustering status (Figure 4).

When a GW with a higher energy level sends a data packet, each recipient add 1 to #GW and some nodes with lower energy level becomes ONs. When there is another data sink and if the initialization flooding is initiated at the same time from a different region, the insomnious node selection can be expedited and the resulting insomnious node selection might be more efficient, i.e., smaller number of insomnious sensors. When a node has lower energy level compared with ones of neighbouring nodes, it is most likely that its cluster status becomes ON and the node will sleep for this duty cycle. When a node reaches its lower energy level, GRIDS allows it to finish its transaction and declares it dead. By this way, GRIDS balances energy consumption by network nodes.

Table 2 presents a pseudo-code that shows the operation details of GRIDS.

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Table 1: GRIDS pseudo-code

III. SIMULATIONS

Simulations were carried out with GloMoSim [13]. The simulation parameters are as follows: the roaming space is 600X600 m square, the radio propagation range for each node is 150 m and channel capacity is 2 Mb/s. The battery capacity is equal to 500 mW and when a node consumes 500 mW it is considered dead. The random waypoint model is used for node mobility. Simulations are done using 100 nodes; distributed randomly in the roaming area; supporting 10 sessions (10 sources and 10 destinations). The node’s maximum speed is 6m/s. The MAC Protocol used is IEEE 802.11. Duration of a single simulation is 6 minutes. The traffic model used is constant bit rate (CBR). Packet length is 566 bytes. Each node sends 100 packets with inter-arrival time of 0.2 second.

The radio power consumption rates in our simulations are: during transmission and reception the radio uses 18mW/second while during the idle period it uses 5mW/second. AODV [14] is the routing protocol of our choice for this study; PC (original/improved) is used in the flooding phase of AODV (route-request flooding).```
The objective of the simulations is to show that GRIDS allows balanced energy consumption among the network nodes and thus increases the lifespan of the network.

Figures 4-5 show the distribution of energy consumption of nodes using GRIDS and PC. When using GRIDS (Figure 4), 23% of nodes consume between 39% and 40% of their energy, 23% consume between 42% and 44%, 28% consume between 45% and 46% and 26% consume between 46% and 48% of their energy. The maximum difference of energy levels of the network nodes is 9%. This value is far smaller than the maximum difference of energy levels of the network nodes, when using PC (Figure 5), which is equal 46%. Thus, GRIDS considerably outperforms PC in terms of balancing energy consumption of the network nodes.

Figure 6 shows the number of dead nodes, over time, in the network using GRIDS and PC. Let us note that the deaths in the X-axis represents cumulative deaths (e.g., deaths during [250,300] include all the deaths starting from time 0). Figure 6 shows that until time 150s, no node is dead using GRIDS. We record less than 1% death during [150, 200] and less than 2% (cumulative) deaths during the time interval [200s, 250s]. This means that during this time period, GRIDS keeps most of nodes alive (i.e., they have still residual energy). During this time period, 75% of nodes are dead using PC. The delay between the first deaths using PC and using GRIDS is 100s. This represents a considerable increase in the lifespan of the network when using GRIDS. Indeed, the network with GRIDS functions normally and longer than in the case of original PC (see Figure 7).

IV. CONCLUSION

In this paper we propose a node selection mechanism that increases the network life time via energy consumption...
balancing among the network nodes. GRIDS uses passive clustering and allows a coordinated sleep node selection which does not require any protocol dependent control packet. It promotes energy efficiency by reducing communication and effective sleep mode operation. By examining remaining power level, low powered sensor nodes can go to sleep for the next round of operation period. GRIDS inherits many advantages from Passive Clustering. Well distributed insomniac nodes are guaranteed in any density of sensor networks. GRIDS is especially useful when there is a data sink which polls sensor information periodically. It does not have stringent requirements in terms, for example, of synchronization and does not generate extra traffic to exchange energy information among nodes. The proposed selection method can be used (or easily adapted) in cluster-based adhoc/sensor networking as well as active node selection.

REFERENCES