Poster Abstract: Energy Efficient Area Coverage in Arbitrary Sensor Networks

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ABSTRACT
Arbitrary sensor networks comprise randomly deployed sensors that may have different capabilities and capacities and are fully autonomous. This paper deals with static nodes in synchronized networks that have different sensing and communication capabilities and different energy capacities. The paper describes our first results towards a fully localized solution for energy efficient area coverage of arbitrary sensor networks that comprise autonomous nodes. According to the proposed solution a node sleeps when (a) it is not needed for preserving system's connectivity and (b) its sensing area is covered. This solution works very efficiently for nodes with different sensing and communication abilities, relaxing many of the limitations and assumptions made in other proposals.

Keywords
Sensor networks, area coverage, energy efficiency.

1. INTRODUCTION
Aiming at deploying fully autonomous sensor nodes in hostile and inaccessible terrains so as to report data to a single server station, we deal with arbitrary sensor networks' self-organization capabilities. Arbitrary sensor networks have a random topology and comprise fully autonomous sensors with differing capabilities and capacities. In this paper we deal with static nodes in synchronized networks that have different sensing and communication capabilities. Therefore, each sensor has communication (CR) and sensing (SR) radii that may differ among themselves (i.e. $CR_I \neq SR_I$ for the node I) as well as between different sensors (i.e. given two nodes I and J, in the general case it holds that $CR_I \neq CR_j$, $SR_I \neq SR_j$ $SR_I \neq CR_j$ and $CR_I \neq SR_j$). Furthermore, the energy capacity of each sensor may differ from the capacity of other nodes in the network.

The aim of this paper is to provide the results of a fully localized solution towards prolonging the lifetime of arbitrary sensor networks whose objective is to monitor a geographic area and report data to a single station. The paper contributes towards relaxing limitations, assumptions and constraints that hold in other approaches as far as the topology and nodes' abilities are concerned, ensuring full area coverage, system's connectivity and node's autonomy. Approaches that aim to provide a fully localized solution in energy efficient area coverage [2], either do not ensure full area coverage, they compute a large percentage of active nodes [3], or the nodes that cover an area are not ensured to be connected [1]. A very recent approach [4] aims at reducing communication overhead and preserve connectivity, but assumes that all the nodes have the same communication and the same sensing radii at any time point– which is not realistic in cases where nodes' capabilities are affected by the energy they consume.

This paper examines an enhancement of the method proposed by Tian and Georganas (TG) [1]. The proposed method allows dealing with arbitrary networks where node's communication abilities affect systems' connectivity and node's sensing abilities affect area coverage. To test the proposed solution we simulated arbitrary networks comprising of Medusa MK2 - like nodes [5] that have to report to a single sink server. For simulation reasons we assume that initially all sensors have the same sensing and communication abilities: This changes at later time points as sensors consume energy independently from each other. Generally, at any specific time point during systems' lifetime, the sensing and communication radii of different nodes are different.

2. PROBLEM STATEMENT
Let G be an arbitrary network of neighboring sensors S. G has a random topology characterized by its density d. Each sensor I in S is static and has communication and sensing abilities. Specifically, at every time point t during network's lifetime a sensor is specified by $<I, PR^t_I, CR^t_I, SR^t_I, ST^t_I, BL^t_I, CM_I>$. I is the identification number of each sensor and is unique for every node. PR^t_I is the priority of each node, which is specified to be a function of node's remaining battery. CR^t_I is the communication range of each node and SR^t_I is its sensing range. ST^t_I is the state of the node and can be either "active" or "sleeping". BL^t_I is the remaining battery level of the node at time t in mA. Finally, CM_I is a consumption matrix that specifies the consumption rate of each sensor component in active and in static states. Figure 1 shows a dialog box of our simulation software where one may specify CM. The default figures (except for the sensor component) are those of the Medusa MK2 node. It must be noticed that all the characteristics of a node, except I and CM_I, change during systems' life time as a function of BL^t_I.

The neighboring sensors N(I) of a sensor I at time t are those whose distance from I is less that CR^t_I. N(I) may change between different time points due to the changing CR_I.

Let G be an arbitrary network of sensors whose task is to report monitoring data from an area to a single sink station BS. Let also L(G) be the lifetime of G in seconds. The problem addressed in this paper is to maximize L(G) subject to preserving the connectivity of the network at every time point t, 0≤t≤L(G). In other words, given t with 0≤t<L(G), and given that C_I[t, t+1] is the consumption of the node I in the interval [t,t+1], our aim is to minimize $K[t,t+1]=\sum_{I} C_I[t,t+1]$. Since at any unit interval [t,t+1] the set of nodes S can be partitioned to the set of active nodes A, and to the set of sleeping nodes S, $K[t,t+1]=\sum_{I\in A} C_I[t,t+1] + \sum_{I\in S} C_I[t,t+1]$.

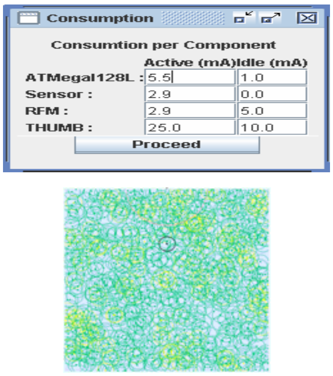


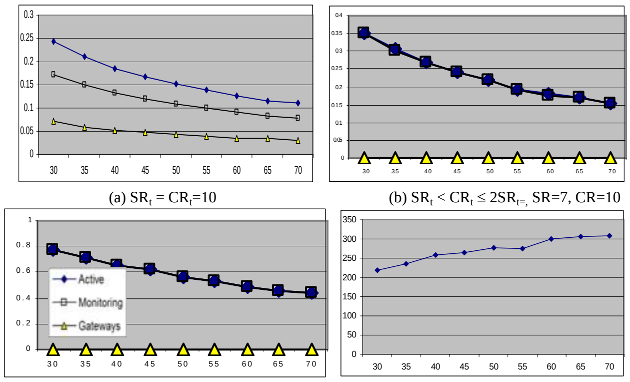
Figure 1. Consumption per component and a 1000 nodes system deployment in an 500x500 area (d=5).

Given the consumption specifications in Figure 1, any node I with ST^t_I = "active" consumes approximately 2.3 times more energy than if ST^t_I = "sleeping", given that the node sends a single message while being in any state. Therefore, the goal is to keep as many nodes as possible in the "sleeping" state and exchange the minimum number of messages between nodes during [t,t+1]. Nodes exchange messages so as (a) to be informed about the state of their neighboring nodes and decide about their own state, and (b) to send data to the sink server via a multi-hop route.

3. APPROACH and RESULTS

According to our approach, each node I that is determined to be non-active at a time point t –using the area coverage method proposed by Tian and Georganas (TG)- examines its covering neighbors to determine whether they are connected. It then waits for a time interval which is inversely proportional to its priority PR^t_I and examines the connectivity of its active neighbors. Its active neighbors contain its covering (monitoring) neighbors and any of its highest priority neighbors that have determined to be active (gateways).

Using this method nodes need to know only their one-hop neighbors: They exchange a "hello" message to learn their neighbors' sensing and communication radii and they may send/receive the state of their highest priority neighbors at any time t. Simulation results shown in Figure 2 are very encouraging, showing the potential of the method for arbitrary networks. Figure 2(d) shows the lifetime of networks in which $SR_I=CR_I$ versus their density (the pattern is the same for the other types of networks): The increase rate is low given that even sleeping nodes consume energy at a high rate.



(a) $SR_t = CR_t=10$ (b) $SR_t < CR_t \leq 2SR_t$, SR=7, CR=10

(c) $SR_t \leq CR_t$, SR=4, CR=10 (d) Duration versus density for $SR_I=CR_I$

Figure 2. Percentage of active nodes versus network density.

4. CONCLUSIONS

We have shown the potential of a method for prolonging the lifetime of an arbitrary sensor network subject to keeping it connected so as nodes to report to a single server. Future work concerns the enhancement of the method towards asynchronous networks and the study for further reduction of the number of messages by using enhancements of the TG method [6]. Furthermore, although redundancy is desirable for the reliability of the network, we need to compute and control the redundant nodes added.

5. REFERENCES

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