Energy Efficiency Sensor Scheduling To Ensure Quality of Sensing in Multi-task WSNs

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Abstract—The recent development of information and communication technologies has realized the significance of Software-Defined Sensor Networks (SDSNs), which has the ability to adapt to any underlying application requirements together efficiently utilizing the resources of WSNs. A sensor node in SDSN can perform multiple tasks with different sensing targets simultaneously. A given sensing task involves multiple sensors to achieve a certain quality-of-sensing. Subsequently, this necessitates an energy-efficient sensor scheduling and management strategy that in turn will guarantee quality-of-sensing for all tasks. The paper addresses three issues with relevance to quality-of sensing; sensor activation; task mapping; sensing scheduling. The proposed sensor scheduling and management strategy effectively decides the subset of sensor nodes that shall be activated; the task that each sensor node shall be assigned and the sampling rate on a sensor for a target. The problem is addressed with mixed-integer linear programming (MILP) thereby overcoming the computation complexity. Further, an online algorithm has been proposed which attempts to deal with sensor node participation and departure, during communication in SDSN. Simulation results prove that the proposed online algorithm performs better in terms of network energy efficiency and rescheduling time.

Index Terms—Software-defined Sensor Network, Sensor Activation, Task Mapping, Sensing Rate Scheduling, Energy Efficiency, Rescheduling time.

1 Introduction

Wireless sensor networks (WSNs) can be used in a wide variety of applications. Some of the potential area are physiological monitoring, environment monitoring, condition based maintenance, smart spaces, military, precision agriculture, transportation, factory instruction, and inventory tracking. WSNs are generally comprised of a large number of tiny sensors (devices) that are battery powered. Sensor device usually has four parts: a processer, sensor, transceiver, and battery. Each device is a low-power, low-cost, multi-functional, small embedded system. A wide variety of sensors (e.g., thermal, mechanical, optical, biological, and magnetic sensors) may be included in the device to measure properties of the environment. These sensors are capable of sensing, processing and gathering information from environment, and they transmit the sensed data, which will be acquired through some local decision process to the user (Base Station).

Software Defined Sensor Network (SDSNs) is now-a-days widely adopted in information and communication technologies. SDSN is becoming highly essential since WSN is prone to high deployment cost, low service reutilization, and complex hardware recycling. SDSN consists of number of sensor nodes that can perform software reconfiguration on individual sensor nodes to alter their functionality at runtime without human inference by injecting different programs [1].

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In SDSNs, each node equipped with different types of sensor is able to perform different sensing tasks according to the programs loaded and activated. Fig. 1, shows the sample concept of SDSNs with three type of sensing targets, which consists of a sensor control server and number of sensor node of SDSNs. Assuming that each sensor node is equipped with different kind of sensors for e.g. ultrasonic sensor, photoelectric sensor, infrared sensor and etc., each of which is held accountable for particular sensing task for a corresponding group of targets in its sensing area. At each time instance, a sensor can exactly sense one target. The targets are categorized by the sensing task as depicted by different notations in Fig. 1.

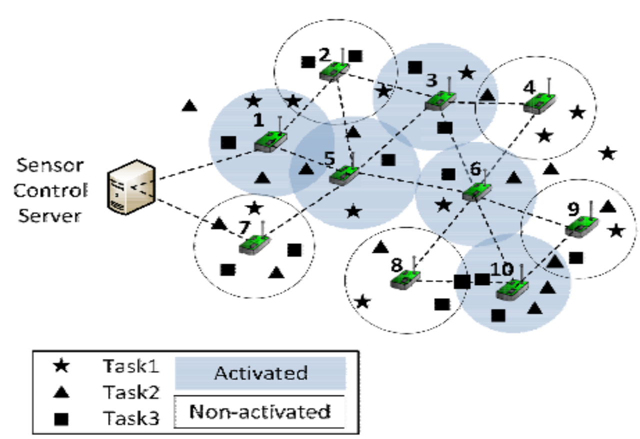

Fig. 1. Sample concepts of SDSNs with three types of sensing targets

Energy Efficiency which is essential to maximize the network lifetime seems to be a primary challenge in WSNs, due to limited battery resources. Existing medium access control (MAC) protocols for WSNs have been designed mainly for energy savings. In general, network lifetime can be prolonged by adopting sleep awake protocol across the sensor network. Mechanisms that conserve energy resources are highly desirable, as they have a direct impact on network lifetime, communication delay, data loss. Intuitively, lesser the sensors are activated, lesser the energy is consumed. Our work takes the coverage requirements to address the minimum-energy sensor activation problem. In SDSNs, each sensing task achieves certain quality of sensing e.g. minimum coverage ratio that means portion of targets covered by multiple sensors [2].

The paper addresses the minimum-energy sensor activation problem with task mapping while guaranteed quality-of-sensing in multi-task WSNS. We first derive the effective sensing rate that can be achieved by collaborating sensing in closed-form, based on minimum-energy sensor activation problem as Mixed-Integer Quadratic constraints Programming (MIQP) addressing the constraints such as coverage ratio, schedulabilty and storage [3]. Subsequently, reformulation of MIQP to Mixed-Integer Linear Programming (MILP) [4] complements for linearization. An online algorithm using local optimization based on MILP facilitates dynamic events in SDSNs further complementing towards energy conservation with lower rescheduling time.

2 Relted Work

Table I
RELATED WORK

S. No	Existing Technique	Energy Efficiency	Quality of Sensing	Lesser Delay
1	Biologically Inspired Node Scheduling Control for Wireless Sensor Networks [10]	✓	✗	✓
2	An Energy-Balanced Heuristic for Mobile Sink Scheduling in Hybrid WSNs [11]	✓	✗	✗
3	Optimal and Maximized Configurable Power Saving Protocols for Corona-Based Wireless Sensor Networks [12]	✓	✗	✓
4	A Mobile Data Gathering Framework for Wireless Rechargeable Sensor Networks with Vehicle Movement Costs and Capacity Constraints [13]	✓	✗	✗
5	Cellular Automata based Node Scheduling Control for Wireless Sensor Networks [14]	✓	✓	✗
6	Joint Scheduling of Tasks and Messages for Energy Minimization in Interference –aware Real- time Sensor Networks [15]	✓	✗	✗

The earlier literature emphasizes much on the Energy Efficiency and Latency with a least focus on Quality of Sensing which decides the accuracy of sensor network operations. Consequently the paper attempts to focus on Quality of Sensing which seems to be highly essential in real time environments.

3 SDSN Model

A software defined sensor node can perform multiple tasks, each of which is explicitly specified a set of sensing target with different sensing range and endure loss of quality-of-sensing [2]. Each task needs to attain specific sensing targets within its coverage ratio. We assume that both sensor nodes and the sensing targets are randomly distributed in the network area. Target of a task is monitored by sensor only if residing within the sensing range of sensor. Notice a point, a sensor node may have different sensing ranges for different tasks. In SDSNs, only the sensor node loaded with a program for task can sense targets. Different programs are with different program sizes. Consequently, program size of task is normalized.

To ensure the sensing accuracy to a target, it is essential that the minimum sensing rate requirement is guaranteed. For each task requires the minimum sensing rate and sensing duration to its target. Only the Minimum sensing rate to a target needs to be satisfied for the target to be effectively covered by a sensor. Multiple tasks need to be handled by an SDSN at the run time. Only subset of sensors in network shall be activated for these tasks. It's widely proved that careful scheduling on the sensor activation is a promising way to conserve the energy consumption [6]-[9]. Each sensor is loaded with multiple programs for different task. Consequently, we are focused in which sensors will be activated and which tasks will be assigned to each of them to minimize the sensing power consumption while guaranteeing the quality-of-sensing for each task [5].

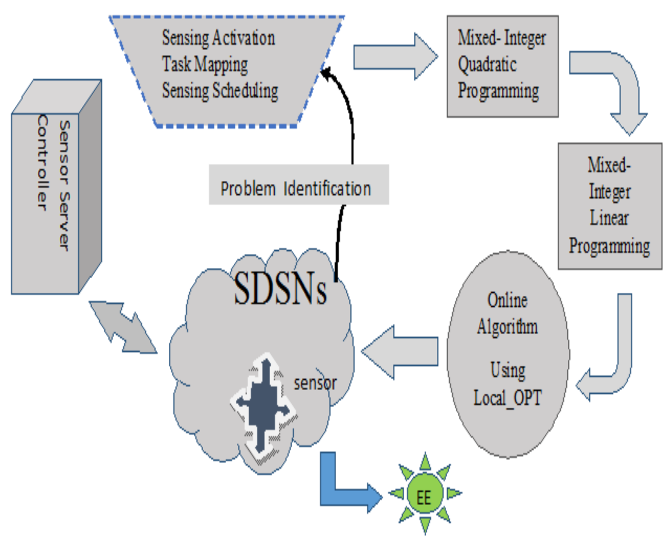

Fig. 2. Block Diagram of Proposed System

3.1. Problem Formulation

With relevance to SDSN, the issues of Sensor Activation, Task mapping, and Sensing scheduling are formulated with MILP, as illustrated in the Pseudocode the follows.

Pseudocode for problem formulation on SDSNs

Coverage ratio constraints
for each sensor → perform multi-task within its different sensing range at a time
initialization Minimum sensing rate , sensing duration, sensing range;
do multiple sensors → sense one target of task cooperatively
for a task → need minimum sensing rate (ft-threshold) and sensing duration (d)
do for a sensor → sensed that target of task with certain sensing rate 'fs' with 'd'
if multiple sensor exceeds minimum sensing rate
effective sensing rate 'e' = sum of 'fs' and its divided by (1+ d * summing rates)
if e ≥ ft , then counted that no. of sensors to covered a target
if coverage ratio ≤ no. of sensors to covered target of task / set of targets of task
if coverage ratio constraints satisfied, that subset of sensors are activated for a task
Schedulability Constraints
for each sensor →scheduled for multiple targets to sense
for each target → need certain sensing rate and sensing duration
do for each sensor → sum of ('d' and 'fs') of all task ≤ 1
Then a sensor ensure the multi-task schedulability
Storage Constraints
for each sensor → perform multi-task at a time
initialization program size;
for each task → need program→ store on a sensor.
if total capacity for all tasks mapped onto a sensor will not exceed its storage capacity
Then all sensors are follows storage constraints
Mixed Integer Constraints Quadratic Programming
To minimize the total sensing power consumption 'p'
do for all activated sensors
p = sum of power consumption of activated sensors
while summation of all the constraints
Mixed Integer Linear Programming
To minimize the total sensing power consumption 'p'
do if MIQP→ solve NP-hardness **then,** non-linear to linear constraints
do for all activated sensors → p = sum of power consumption of activated sensors
while summation of all the constraints and linear constraints

4. ONLINE ALGORITHM

An online algorithm deals with network dynamic events (Sensor node dynamics) such as sensor node participation and departure during SDSN operations. In WSNs, sensors are powered by batteries with limited capacity, and usually they cannot be recharged. Consequently, new nodes will be deployed to compensate the portion of sensors that have exhausted their batteries. Let us consider a dynamic network where existing nodes will depart because of power depletion, and new nodes will be deployed periodically. Spontaneously, to deal with network dynamic is to apply the global optimization. But global optimization has some weakness such as high computational complexity, large power consumption and delay more[1]. The rescheduling time is used to reschedule the sensor node dynamic events per time units. Local optimization requires much lower rescheduling time compared to global Optimization. Assume that rescheduling time for each dynamic event along 500 time units. We notice that it is unnecessary to always apply global optimization on the whole network. Consequently, our proposed online algorithm requires only local network information (local optimization) with low complexity than the global optimization.

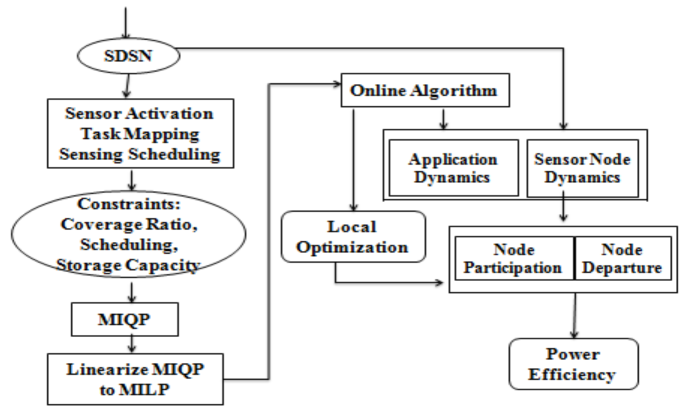

Fig. 3. Overall Process-stepping

4.1. Sensor Node Dynamics

Let as consider an example for participation events, two targets are sensed by two active sensor nodes A and B respectively. When a new node C is deployed and its sensing range is large enough to cover two targets, then deactivate nodes A and B. Then only one active sensor is initialized using online algorithm. And consider node departure events, if sensor node 10 is departure, four targets of Task 2 and Task 3 become uncovered after the departure of 10 Fig. 1. A subgraph consisting of nodes 6, 8 and 9 will be established. Via applying Local OPT to the subgraph, node 8 and 9 will be activated to ensure the coverage requirements.

Steps for Sensor Node Dynamics using Online Algorithm

Step 1: New node 'x' registers its information including the location, resource capacity, sensing units to server.

↓

Step 2: Server discovers potential targets within its range, then server derive a set of sensors to reach these targets.

↓

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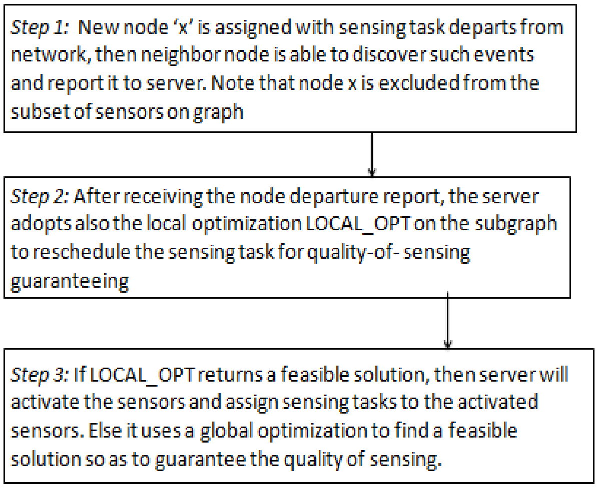
↓

Step 4: Server solves local optimization on the subgraph to reduce the no. of activated sensors while guaranteeing quality of sensing.

↓

Step 5: If node x needs to become active such that other two or more sensors can be deactivated. Else node x remains inactive.

Steps for Partipation



Steps for Departure

5 RESULTS

To improve the power efficiency on SDSNs using online algorithm, different parameters are varied such as the network size, the coverage ratio and the transmission range in Fig. 4, Fig. 5 and Fig. 6.

When the network size (number of sensors deployed) is small, more sensors cover more targets to satisfy the quality-of-sensing and thus less power will be consumed. If the network size is large enough to easily find the sensors that shall be activated for quality-of-sensing guaranteeing. Further increasing the network size does not benefit the power efficiency. Thus, the power consumption slightly increases based on the function of number of sensors in Fig. 4.

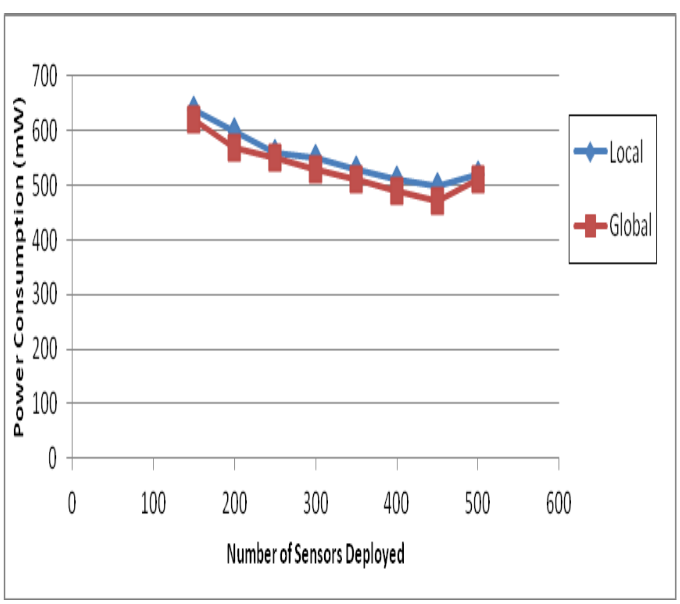


Fig. 4. Variation of power consumption with different number of Sensors Deployed

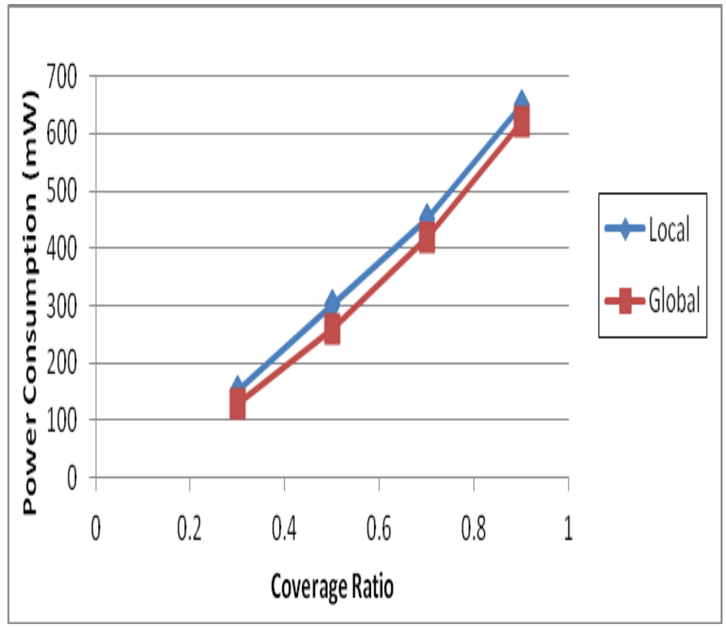


Fig. 4. Variation of power consumption with different Coverage Ratio

The quality of sensing (Coverage Ratio) also affects network power efficiency. When the coverage ratio is high, then high power is consumed on network and vice versa in Fig. 5.

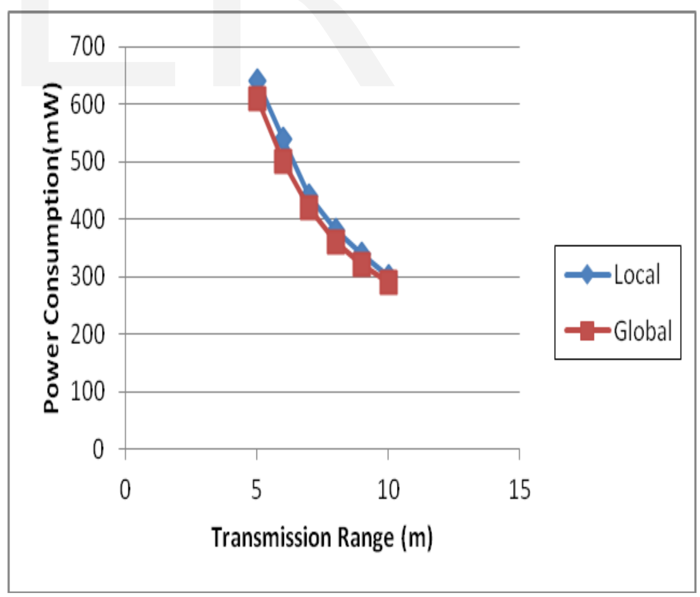


Fig. 6. Variation of power consumption with different transmission range

The sensing range, which determines the reachability of sensor nodes to the targets. The power consumption is a decreasing function of the sensing range. Thus, further increasing of sensing range does not take too much benefit to the power efficiency in Fig. 6.

6 Conclusion

The paper emphasizes minimum-energy sensor activation problem and scheduling problem in multitask WSNs with guaranteed quality-of-sensing. We first drive the effective sensing rate that can be achieved by collaborative sensing in closed-form. The minimum-power activation problem is addressed using MILP which in turn reduces computation complexity. The proposed online algorithm effectively deals with dynamic events during the SDSN runtime. The simulation results conform the efficiency of online algorithm to be very high. Ultimately, online algorithm indeed outperforms global optimization in terms of computation complexity.

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