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WSN in cyber physical systems: Enhanced energy management routing approach using software agents

Elhadi M. Shakshuki [a,b,*], Haroon Malik [c], Tarek Sheltami [d]

[a] Jodrey School of Computer Science, Acadia University, Wolfville, NS, Canada
[b] King Faisal University, Saudi Arabia
[c] School of Computing, Queen's University, Kingston, ON, Canada
[d] Department of Computer Engineering, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

HIGHLIGHTS

- An agent based routing approach for WSN to reduce the battery consumption is proposed.
- The approach increases the network lifetime using Dijkstra's algorithm and agents.
- The approach saves 20% more energy as compared to Directed Diffusion (DD).
- The approach also decreases the network latency up to 50% as compared to DD.

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ABSTRACT

Recently, the cyber physical system has emerged as a promising direction to enrich the interactions between physical and virtual worlds. Meanwhile, a lot of research is dedicated to wireless sensor networks as an integral part of cyber physical systems. A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices that use sensors to monitor physical or environmental conditions. These autonomous devices, or nodes, combine with routers and a gateway to create a typical WSN system. Shrinking size and increasing deployment density of wireless sensor nodes implies the smaller equipped battery size. This means emerging wireless sensor nodes must compete for efficient energy utilization to increase the WSN lifetime. The network lifetime is defined as the time duration until the first sensor node in a network fails due to battery depletion. One solution for enhancing the lifetime of WSN is to utilize mobile agents. In this paper, we propose an agent-based approach that performs data processing and data aggregation decisions locally i.e., at nodes rather than bringing data back to a central processor (sink). Our proposed approach increases the network lifetime by generating an optimal routing path for mobile agents to transverse the network. The proposed approach consists of two phases. In the first phase, Dijkstra's algorithm is used to generate a complete graph to connect all source nodes in a WSN. In the second phase, a genetic algorithm is used to generate the best-approximated route for mobile agents in a radio harsh environment to route the sensory data to the base-station. To demonstrate the feasibility of our approach, a formal analysis and experimental results are presented.

1. Introduction

Recent advances in wireless communications, networking, and embedded system technologies have led to a growing interest in developing Cyber Physical Systems (CPSs) for various purposes. In recent years, the CPS has emerged as a promising technology that can support the human-to-human, human-to-object, and object-to-object interactions in the physical and virtual worlds.

A CPS is the integration of abstract computations and physical processes [1–3], where sensors, actuators, and embedded devices are networked to sense, monitor, and control the physical world. A typical CPS application is to connect appliances embedded with sensor nodes (which are responsible for information collection from the physical world as the source of CPS inputs) to some real-time decision making system (which represents the virtual world). Upon receiving the inputs from sensor nodes, the CPS will make a corresponding decision based on the inputs and computational processing to the actuators in the physical world by a sequence of control processes.

These CPS applications can be roughly classified into smart space, healthcare, emergency real-time system, environmental monitoring and control as well as smart transportation. For all

* Corresponding author at: Jodrey School of Computer Science, Acadia University, Wolfville, NS, Canada.
E-mail addresses: eshakshuki@kfu.edu.sa, elhadi.shakshuki@acadiau.ca (E.M. Shakshuki).

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the aforementioned applications, Wireless Sensor Network (WSN) technology is an integral component of CPS designs. For example, a healthcare application could acquire vital signs by medical sensors worn by patients or elders. In the case of environmental monitoring and control applications, sensor nodes can be deployed in the outdoor environments to monitor soil moisture, air quality, and so forth. Similarly, Smart transportation is one of the most important CPS applications. Sensor nodes (such as accelerometer and GPS receiver) could be embedded in vehicles to improve the traffic safety and efficiency.

For all the aforementioned applications, Wireless Sensor Network (WSN) technology is an integral component of CPS designs. If WSN technology is not used in the development of CPSs, the real-time decision making system might have difficulty in acquiring available CPS inputs and making timely decisions.

1.1. Wireless Sensor Network (WSN)

Wireless sensor network is a collection of tiny disposable devices called motes [4] with micro sensors embedded in them, a CPU to perform computation, small amount of memory to store program code and data, and a radio transceiver for wireless communication [5]. These motes collaborate and work together to sense, gather and process large volume of data [6,7]. The base-station is a node in a WSN that has a dedicated power supply and more resources (CPU, memory, storage, etc.) than a mote. The mote that can identify the user requested i.e., attributes of interest is called source node. The source nodes report back the data to the sink either directly or by relaying it via other sensor motes in WSN.

Unlike traditional IP-based networks, WSN operates on batteries. The deployment of WSNs is usually hard to reach in remote areas such as glaciers, battlefields and forests. Therefore, recharging or changing their batteries is difficult and sometimes impossible. Thus, increasing the lifetime of WSN is one of the fundamental concerns to many researchers. The lifetime of a WSN correspond to the operational time of WSN, before it is unable to report the quality attributes of interest to a base-station due to communication holes created in network. The communication holes results from motes with drained batteries. The motes in WSN sense the environment and report the data either directly to a base-station or indirectly by relaying the data through other motes in path of base-station as in multi-hop communication.

1.2. Energy waste in WSN

There are several causes of energy waste in WSNs. Firstly, in WSNs there is high density of mote deployment that needs to compete for same channel. Channel contention consumes some amount of battery power. Secondly, sensor motes are mostly deployed in ad hoc fashion rather than with careful pre-planning; thus, they self-organizing to form a communication network to draw quality data. There is sufficient amount of energy spent in maintaining the self-organizing network. Thirdly, the primary mode of communication in WSN is broadcast, which in some cases, results into fair amount of collision. Retransmitting a collided packet adds to the mote's energy consumption. Finally, due to the massive deployment of motes in WSN, a lot of redundant sensor traffic is produced. Routing of such redundant traffic to the base-station consumes a lot of battery power.

Among all the cause of energy losses in WSN, the routing of redundant sensory traffics to base-station accounts for the number one cause of energy consumption in WSN; hence, reduction in their lifetime. This is due to the reason that radio activities i.e., transmission and receiving consumes the most battery power of the mote [8]. Our proposed approach models the routing optimization problem i.e., generating the best approximate route for Mobile Agent (MA) to transverse the WSN, as Euclidean Traveling Salesman Problem (TSP) [4]. Compared to traditional TSP, the scalable and the dynamic topology of sensor networks can result in an incomplete graph. Incomplete graph results when a source node has no direct communication link with other source nodes in a WSN. To allow the source nodes to communicate with each other, generating a complete graph becomes a necessity. To achieve this objective, our proposed approach uses Dijkstra's algorithm. Genetic Algorithm (GA) uses this complete WSN graph to generate best approximate route to send the sensory data to the sink.

In addition, we introduce the concept of mobile agent that can autonomously visit the source nodes and save WSN energy by suppressing the redundant sensory data along the routing path generated by GA. To be specific, the agent is dispatched according to the routing path generated by GA at base-station. Then, the data is aggregated at each source node and is brought back to sink during every data-gathering round. This allows substantial gain towards the network lifetime.

1.3. Contributions and paper organization

The main contributions of this paper are: (1) the generation of an optimal routing path in WSN by the use of both Dijkstra and Genetic algorithm, and (2) a successful demonstration of mobile agents for suppressing the redundant sensory data that is the cause of energy waste.

The remainder of this paper is organized as follows: Section 2 describes the literature review about the related work based on energy-efficient routing in WSNs. Section 3 discusses our proposed intelligent routing approach. Section 4 provides the details of simulation. Section 5 lists the experimental results of our proposed approach. Finally, Section 6 concludes the paper and provides a few directions for the future work.

2. Related work

There have been several attempts by many researchers to propose several approaches to prolong node's lifetime [8–12] and to eliminate redundant sensory data [13–15]. Recently, software agent is used as a combined approach in wireless sensor networks [16–21]. Also, there have been attempts to reduce energy consumption based on mobile agents [22,16,23,24,5]. In wireless sensor network, mobile agent is an intelligent, autonomous program that periodically visits source nodes to collect and aggregate sensory data in a target region.

Due to the bandwidth constraints in WSN, the network's capacity may not satisfy the transmission of sensory data [25]. In order to handle the problem of overwhelming data traffic, Qi, et al. [26] proposed mobile agent-based distributed sensor network (MADSN) for multi-sensor data fusion. Their proposed approach, not only achieves data fusion, but also reduces energy expenditure. However, the application of this approach can only be applied on cluster-based topologies. Mobile agent-based directed diffusion (MADD) in [14] is also introduced an approach to deal with the same problem. The drawback of the approach presented in [27] is that it does not always guarantee the best sequence of nodes to be visited by a mobile agent for collecting sensory data from source nodes.

Currently, most energy-efficient proposed approaches [13,14,28] are focused on data-centric model, such as the directed diffusion [29]. By selecting good path to drain quality data from source nodes, directed diffusion approach can achieve substantial energy gain.

However, it still allows redundant sensory traffic to flow back to sink. The main advantage of MADD is to reduce the redundant sensory data. Through using mobile agent, data is aggregated at