Cairo University

SMART ROUTING ALGORITHM FOR APPLICATIONS WITH DEADLINE IN WIRELESS SENSOR NETWORKS

By

Marwa Mohamed Mostafa Hassan Elnashal

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Computer Engineering

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Under the Supervision of

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FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis:

Smart Routing Algorithm for Applications with Deadline in Wireless Sensor Networks

Key Words:
Wireless sensor network; real-time applications; deadline; swarm intelligence; ant colony optimization

Summary:

Many wireless sensor network (WSN) applications require real-time communications in which bounded delay requirements need to be satisfied. WSN lossy links and limited resources of sensor nodes pose great challenges for supporting real-time applications in WSN. Many WSN routing algorithms focus on being energy efficient to extend the network lifetime while delay was not the main concern. However, these algorithms are unable to deal with real-time applications in which data packets need to be delivered to the sink node within a predefined deadline. Therefore, there is a need of a routing algorithm that achieves a balance between energy efficiency, and reliability while being suitable for real-time applications as well. In this thesis, an energy efficient, and reliable routing algorithm for real-time applications in WSNs based on Swarm intelligence is introduced which selects the paths that can deliver a data packet within its deadline and considers the relay speed when selecting the next relay to minimize the number of packets that miss their deadline. In addition, link quality and buffer size is considered to reduce the delay as a result of retransmissions reduction. Finally, energy consumption minimization among sensor nodes is considered to extend the network lifetime. Simulation results show that the proposed approach enhances network performance in terms of average end-to-end delay, packets delivery rate, energy balancing as well as network lifetime.

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Dedication

I dedicate this thesis to my precious daughters, Marwa and Salma.

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Nomenclature

ACO	Ant Colony Optimization
ACO_QoSR	Ant Colony Optimization Based Quality of Service Routing
ADC	Analog to Digital Converter
BIOSARP	Biological Inspired Self-organized Secure Autonomous Routing Protocol
BS	Base Station
CBRR	Contention-based Beaconless Real-time Routing Protocol
CO	Combinatorial Problems
EBiO4SeL	Biologically-inspired Optimization for Sensor Lifetime
EIF	Energy Imbalance Factor
GPS	Global Positioning System
HRT	Hard Real-Time
IoT	Internet of Things
MAC	Medium Access Control
MANETs	Mobile Ad Hoc Networks
MEMS	Micro Electronic Mechanical Systems
NFL	Neighborhood Feedback Loop
OF	Optimal Forwarding value
PDR	Packet Delivery Rate
PRR	Packet Reception Ratio
QEMPAR	QoS and Energy Aware Multi-Path Routing Algorithm for Real-Time Applications
QoS	Quality of Service
Qos_Aco	QoS based on Ant Colony Routing
Rc	Gradient Overall Path Resource Cost
RPAR	Real-time Power-Aware Routing
RREP	Route Reply message
RREQ	Route Request message
RTEA	Real-Time and Energy Aware Routing
RT-GRACE	Real-Time Gradient Cost Establishment
RTLD	Real-Time Routing Protocol with Load Distribution
RTR	Request To Route
SI	Swarm Intelligence
SNGF	Stateless Non-deterministic Geographic Forwarding
SRT	Soft Real-Time
Tc	Gradient Overall Path Temporal Cost
THVR	Two-Hop Velocity-based Routing
THVRG	Two-Hop Velocity-based Gradient Routing
WBANs	Wireless Body Area Networks
WSN	Wireless Sensor Network

Abstract

Wireless sensor network (WSN) is a fast growing technology which attracts a large number of researchers in the recent years. WSN is made of a dense number of small size, low cost, battery operated sensor nodes which, in most cases, scattered randomly in the monitored area. Sensors gather data from the sensing area and transfer it to one or more sink nodes or base station in a multi-hop fashion over a wireless shared medium.

WSNs can be part of a tremendous number of applications. Many wireless sensor networks applications require real-time communications in which the sensed data is assumed to be delivered from the source node to the sink node within a predefined deadline decided by the application. Data delivery within its deadline ensures taking appropriate actions in-time, while late delivery of data has a negative influence on the effectiveness of the taken action.

WSNs lossy links and limited resources of sensor nodes (e.g., memory and power) pose great challenges for supporting real-time applications in WSNs. In addition, many WSN routing algorithms focus on being energy efficient but delay was not the main concern. Thus new routing protocols which are reliable and energy efficient while being suitable for real-time applications are highly required in WSNs.

The proposed algorithm is a real-time routing algorithm suitable for delay sensitive applications in WSNs. It can provide reliable and energy efficient communications while being able to deliver data in-time as well. It achieves this by choosing the candidate neighbors that can deliver the packet within its deadline (if any) as the eligible ones to take part in the routing process. In addition, it computes the relay speed for each eligible candidate relay to reduce the selected paths delay. Furthermore, it considers link quality, hop count, and available buffer size of the selected relays which lead to end-to-end delay reduction and minimizes the energy consumption as well. Finally, it considers the node's energy consumption rate when selecting the next forwarder to extend network lifetime. A swarm intelligence approach is used to select the next relay node. The probability of choosing a candidate relay node as the next relay is computed using important parameters such as relay speed, link quality, buffer size, hop count, and energy consumption rate along with the pheromone value.

The performance of the proposed algorithm is compared to previous work in terms of average end-to-end delay, packet delivery rate (PDR), network lifetime , and energy balancing under different values of average traffic rate and different numbers of nodes for both homogeneous and heterogeneous networks.

Experimental results show improvement in the performance compared to the best results of previous works as follows:

First, varying the average traffic rate values results in (i) average reduction in the average end-to-end delay equals 42% for homogenous networks and 43% for heterogeneous networks. (ii) average enhancement in the PDR equals 59% for homogeneous networks and 60% for heterogeneous networks. (iii) average improvement in the network lifetime equals 121% for homogeneous networks and 89% for heterogeneous networks.

Second, varying the number of nodes results in (i) average reduction in the average end-to-end delay equals 25% for homogenous networks and 25% for heterogeneous networks. (ii) average enhancement in the PDR equals 21% for homogeneous networks and 21% for heterogeneous networks. (iii) average improvement in the network lifetime equals 109% for homogeneous networks and 90% for heterogeneous networks.

Chapter 1 : Introduction

1.1. Wireless Sensor Network Overview

The progress in wireless communication systems and micro-electronic-mechanical systems (MEMS) gives great opportunity in achieving low cost, smart sensor nodes that can be used in a tremendous number of applications. WSNs have unique characteristics that introduce many challenges in its development and applications. A lot of researche has been conducted to solve many design and application problems and these researche gained significant results in the development of WSNs. There is no doubt that in the near future WSNs will be part of many civilian and military applications and will have a great effect on the way we live and work [1].

WSNs are composed of small size, low cost, battery-powered devices called sensors; its main goal is data delivery. In most cases, sensors are deployed randomly in the monitored area and send the gathered data to one or more sink nodes or base station (BS) wirelessly possibly in a multi-hop fashion. The sink node may send the data to a user to take the appropriate actions via the internet or a satellite as depicted in Fig. 1.1 [2].

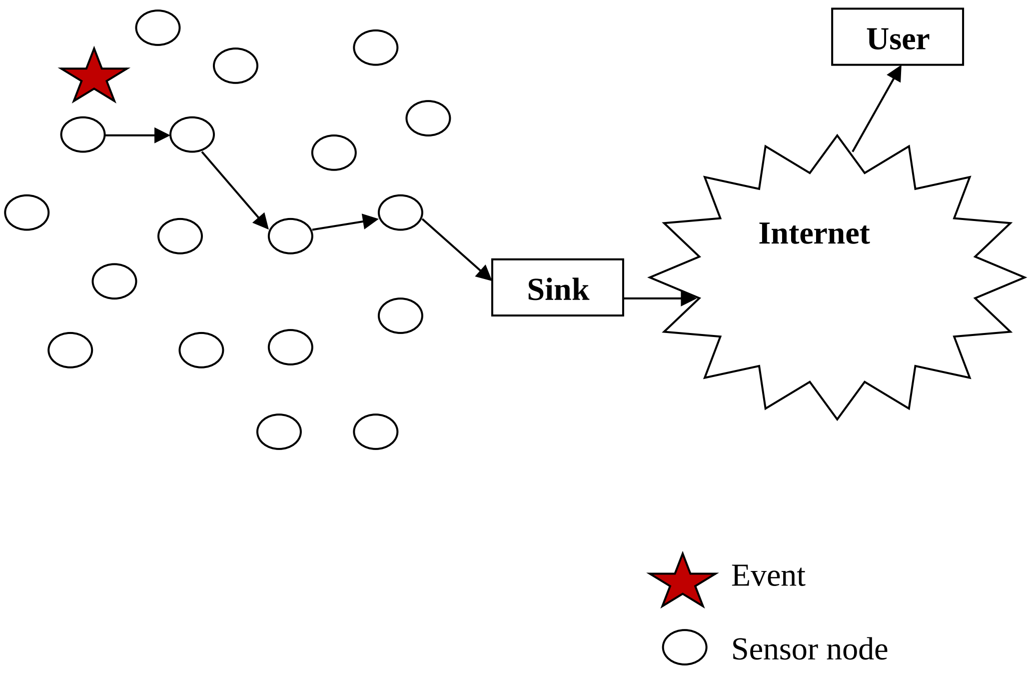

Fig. 1.1 Wireless sensor network [2]

1.1.1. Sensor Node Architecture [1]

The sensor node is considered as the building block of WSNs, on which the network depends to execute its mission. A sensor node consists of several parts which are: a sensing unit, a processing unit, a transceiver, and a power unit as shown in Fig. 1.2 [2]. Additional units may be used such as mobility and localization units.

- Sensing units consist of two parts: sensors and analog to digital converter (ADC). Sensors generate analog signals based on the observed phenomena and ADC converts these signals to a digital signal which are sent to the processing unit.

- The processing unit, also called the controller, is responsible for several important tasks such as managing the procedures that make the sensor node able to perform its sensing task, runs associated algorithms, and enables the coordination between the sensor node and other nodes to perform the required tasks. In other words, the processing unit is the core of a wireless sensor node.

- A transceiver unit is composed of a transmitter and a receiver used to connect the node to the network through which the sensor node performs its communication with other nodes. It is the unit that consumes the majority of the power of the node.

- The power unit provides all parts of the sensor node with their required energy. It is usually a low battery power unit; these batteries are difficult or impossible to be recharged. This is why minimizing the power consumption is a very important thing in WSNs. In some cases, power units can be supported by natural ways such as using solar cells.

- A mobility unit may be added to the sensor to move it when the mobility of sensors is required to be able to perform their tasks.

- Localization unit may be needed when it is necessary for the sensor nodes to know their locations to execute their tasks.

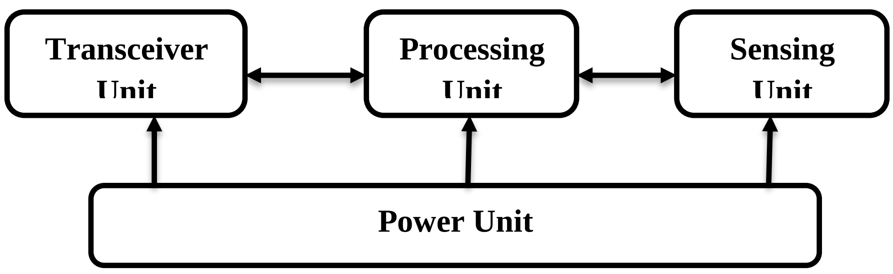

Fig. 1.2 Sensor node architecture [2]