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A Self-organized QoS-aware RED-ACO Routing Protocol for Wireless Sensor Networks

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Abstract: The open nature of wireless sensor networks (WSNs) recently attracted significant research attention. With the growing demand for quality of service (QoS) based routing protocol in sensor network has emerged as an interesting research topic. A wireless sensor network is composed of huge sensors that dynamically self-organized themselves into a wireless network. But sensors are very constrained in memory capabilities, processing power and batteries. WSNs still face problems in selecting the best path with efficient energy consumption and successful delivery of the packets with minimum delay. QoS based routing metric combined with Ant colony optimization (ACO) technique have been proposed to solve the routing problem and trying to deal with these constrains. The problem of providing QoS routing is formulated as link-based and path-based metrics. In the proposed protocol Reliability, Energy and Delay with Ant Colony Optimization (RED-ACO), the search range for an ant to select its next-hop sensor is limited to a subset of the set of the neighbors of the current sensor based on the required metric values. The probability transition rules for an ant to select its next-hop sensor are defined. Simulation results show that our routing protocol can perform better in many scenarios compared with different existing routing protocols.

Key words: Wireless sensor networks · Ant colony optimization · RED-ACO · Quality of service · Reliability · Energy · Delay

INTRODUCTION

Wireless sensor networks (WSNs) consist of an emergent technology deployed for a large range of solutions, civilian, environmental, spanning military and commercial applications. They consist of a huge tiny sensor of low cost sensing devices that dynamically self-organize themselves into a wireless network without the utilization of any preexisting infrastructure and spread throughout the large geographical area [1]. Although WSNs have deployed in various applications with different phenomenon like detecting fire, volcanic eruptions, gas leakage, vehicle tracking, battlefield surveillance, rescue operation and unmanned missions. Wireless sensors are composed of motes or sensors, transceiver, battery and the processor for performing local processing. These sensors are capable of sensing at least one phenomenon in the environment equipped with wireless communication, computation and detecting capabilities. It is tightly constrained with limited energy, limited analytical and computational ability, limited memory storage and also have low data rate as well as short range for wireless radio transmission. The sensors have to perform tasks for gathering requisite information and forward this information to sink. The reporting between sensor and sink consumes energy based on the type of communication protocol, communication path or paths and number of hops between sensor and sink [2]. This requires finding out optimal path between sensor to sink which will be useful in efficiently forwarding data, reducing power consumption and communication overhead in WSN. In sensor networks, minimization of end-to-end delay and energy consumption is considered to be a major performance criterion, in order to provide maximum reliability and network lifetime.

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Table I: Comparison among different QoS based routing protocols

Routing Protocol	SAR	SPEED	MMSPEED	ReInForM	DAST
QoS	Yes	Yes	Yes	Yes	Yes
Energy aware	Yes	No	No	No	Yes
Mobility	No	No	No	No	No
Data Aggregtion	Yes	No	No	No	Yes
Position awareness	No	No	No	No	No
Query based	Yes	Yes	Yes	No	No
Multipath	No	Yes	Yes	Yes	No

The remainder of this paper is organized as follows. Section II provides a brief overview of the related work on QoS routing and ACO based routing in WSNs. Section III introduces the network environment and assumptions used in it as well as presenting the formulation of the QoS routing problem. The proposed protocol RED-ACO is descried in Section IV. The simulation results are presented in Section V. Finally, the conclusion of this work is provided in Section VI.

Related Work

Routing Protocols for Wireless Sensor Networks: Unlike other networks, WSN are designed for specific applications which differ in features and requirements so, the routing protocols designed for WSN should consider the goal, technology associated with architecture and application area of the network. The design of QoS based routing protocols is influenced by many challenging factors caused by the nature of the WSNs. These factors must be overcome before efficient communication can be achieved in WSNs. For the performance and efficiency of the WSN to reveals the important issues that to be taken into consideration while designing the WSN routing protocol. Also, there are several optimization goals and design principles that should be taken into account for developing and implementing a WSN [3].

QoS based Routing Protocols for WSN: Last few years many researchers have explored QoS based routing protocols in WSN from different perspective depends on their application [4]. So, a careful approach is needed while designing a QoS based routing protocol for WSNs based on their metrics such as lowest delay, maximum throughput, least energy consumption or the best link quality whose primary aim is to establish a best path between sources and sink [5]. To provide a comprehensive analysis of the most recently proposed some of the QoS based routing protocols for WSNs are discussed below in the Table I [6]. It provides a fast overview of the main motivations behind their design and the methods used to achieve the desired goals.

Ant Colony Optimization (ACO): Successful applications coming from biologically inspired algorithm like Ant Colony Optimization (ACO) based on artificial swarm intelligence which is inspired by the collective behavior of social insects. ACO has been inspired from natural ants system, their behavior, team coordination, synchronization for the searching of optimal solution and also maintains information of each ant. At present, ACO has emerged as a leading metaheuristic technique for the solution of combinatorial optimization problems which can be used to find shortest path through construction graph developed by Marco Dorigo and his co-researchers at the beginning of the 1990's [7] which is inspired upon stigmergic communication [8].

In dynamic system, the ant colony algorithm works in graphs with different topologies. A graph G is a pair G = (V, E), where V consists of two nodes, namely v_s representing the anthill and v_d representing the food source. Furthermore, E consists of two links, namely e_1 and e_2, between v_s and v_d. To e_1, to assign a length of l_1 and e_2 a length of l_2 such that $l_2 > l_1$, that is e_1 represents the short path and e_2 represents the long path between v_s and v_d. To introduce an artificial pheromone value τ_i for each of the two edges e_i, i = 1, 2. Such a value indicates the strength of the pheromone trail on the corresponding path. Each ant, starting from anthill (v_s), an ant chooses with probability between path e_1 and e_2 for reaching the food source (v_d). Obviously, if $\tau_1 > \tau_2$, the probability of choosing e_1 is higher and vice versa [9]. For returning from v_d to v_s, an ant uses the same way and it changes the artificial pheromone value τ_i associated to the used path as follows

$$\tau_i = \tau_i + \frac{Q}{l_i}$$

where Q is a positive constant parameter of the model. In other words, the amount of artificial pheromone that is added depends on the length of the chosen path (shorter path). Ants deposit pheromone on the paths on which they move. Thus, the chemical pheromone trails are modeled as follows

$$p_i = \frac{\tau_i}{\tau_1 + \tau_2} \quad where\ i = 1, 2$$

In nature the deposited pheromone is subject to evaporation over time. Moreover, ACO deals with a process in which decreasing in amount of pheromone deposited on every path by the time is known as *trail pheromone evaporation*. To simulate this pheromone evaporation in the artificial model is

$$\tau_i = (1-p).\tau_i$$

where i = 1, 2 and the parameter *p* □ (0, 1] that regulates the pheromone evaporation. Finally, all ants conduct their return trip and reinforce their chosen path.

ACO based routing protocol for WSN: Recently nature inspired algorithms have been explored as means of finding an efficient solution for routing problem such as ACO. It is a technique used for solving complex computational problems, such as finding optimal routes in networks and trying to deal with these constrains [10]. It can help us in dynamically changing environment for setting communication paths in WSN and having characteristic like achieving global optimization through local interaction and high degree of self-organization. The ACO technique has been successfully applied to take optimal routing decisions in WSN. ACO based routing algorithm is creating artificial ants or agents in the form of data packets which are moving around in the network from one node to the other, updating routing tables (called pheromone table) of the nodes that they visit with what they have learned in their traversal so far. Afterwards agents selecting optimal shortest communication path from updated pheromone table. On the other words, ACO is iterative algorithm, a number of artificial ants are generated at each time and build a solution to the considered optimization problem and exchange the quality information of these solutions via communication scheme. A distributed heuristic solution like ACO routing algorithm shows many features that makes it particularly suitable for sensor network [11].

- Algorithm is fully distributed that mean there is no single point of failure.
- The operations done in every node are simple.
- Autonomous interaction of ants and the algorithm based on agents' synchronous.
- It is self-organizing, thus robust and fault tolerant. There is no need to define path recovery algorithm.
- Intrinsically adapts to traffic without requiring complex and yet inflexible metrics.
- It inherently adapts to all kinds of variations in topology and traffic demand, which are difficult to be taken into account by deterministic approaches [12-14].

Qos-based Routing Problem Formulation for Wireless Sensor Network Model

Network Environment and Assumptions: A WSN are modeled as an undirected graph G(V, E, W), where V denotes the set of vertices that represent the sensors, E denotes the set of edges representing wireless links between sensors and W is the weight set of all directed links (x,y). The weight e_{xy} of direct link is the energy consumption of communication between x and y and the distance between two sensors is ◎◎◎◎◎◎. A path is defined as a sequence of links from source to sink and ◎◎= {$path_1$, $path_2$,..., path ◎◎}is the set of ◎◎ available node-disjoint paths between source and sink.

In this paper, we assume that sensors are homogeneous; each sensor has same transmission radius, r and they consume equal energy to transmit a bit of data. Furthermore, we assume that the sensors are stationary, homogenous, location-aware, energy of sensors cannot be recharged, each sensor is able to compute its available energy level (◎◎$_{ava}$) as well as record the link performance between itself and its neighbor in terms of delay (◎◎$_{link}$) and reliability (◎◎$_{link}$), where ◎◎$_{link}$ is expressed in terms of signal-to-noise ratio. Additionally, each sensor is assumed to know its exact position, the position of sensors with in its range of communication, neighbor and of the sink using localization techniques.

Reliability Metric: The reliability of data transmission is an important key of QoS, calculated to measure the probability of transmission failures and can be expressed in terms of data delivery ratio. If all source sensors send total packets of P_{source} and the number of packets received by the sink is P_{sink}, then the data delivery ratio (DDR) can be written as

$$DDR = \frac{number\ of\ packets\ receied\ at\ the\ sink}{number\ of\ packet\ generated\ by\ source} = \frac{P_{sink}}{P_{source}}$$

In the case that the required QoS can be met using a single path to transmit data to sink from source and the reliability on a single path i is R_{pathi} is calculated as follows

$$R_{path_i} = \prod_{l=1}^{hop_i} R_{link_l}$$

However, when the sink decides to transmit data packet on n disjoint paths, the end-to-end reliability R_{e2e} and it is related to the number of used paths

$$R_{e2e} = 1 - \prod_{i=1}^{np} (1 - R_{path_i})$$

If R_{req} is an application-specific parameter which reflects the required end-to-end reliability for data transmission, only if the data reliability satisfies

R_{e2e}=R_{req}. The reliability objective function, f_R is to maximize the data transmission reliability $R_{e2e,}$ such that R_{e2e} = $R_{req.}$

Energy Consumption: The energy consumed for data transmission from source to sink on a single path, can be written as E_{pathi}

$$E_{path_i} = \sum_{l=1}^{hop_i} E_{con_l}$$

where hop_i is the hop count of path i, np ≥ i ≥ 1 and the energy consumption E_{conl} is expressed by

$$E_{con_l} = e_{trans} + e_{rece}$$

where e_{trans} is the energy consumption to transmit n bits of data

$$e_{trans} = (e_t + \varepsilon_{amp} \times r^2) \times n$$

and e_{rece} is the energy consumption to receive n bits of data between two sensors

$$e_{rece} = e_r \times n$$

where e_t and e_r are the energy consumption to transmit and receive one bit of data, respectively. $\square_{amp}$ is the energy consumption of the transmitting amplifier. When sensors have fixed communication radius r, sensors located randomly at any distance within the area of Πr^2. Then,

$$E_{con_l} = (e_t + e_r + \varepsilon_{amp} \times r^2) \times n$$

To transmit 'n' bits of data packet, the available energy at a sensor (E_{ava}) must be greater than or equal to the minimum energy threshold required to transmit the packet (E_{req}).

In multipath routing, the total end-to-end energy consumption (E_{e2e}) to transmit any data is measured as the addition of the energy consumption on all the used paths is given as

$$E_{e2e} = \sum_{i=1}^{np} E_{path_i}$$

where 'n' is the number of node-disjoint multipath used to route the data packet. Then, we present the energy objective function f_E that minimizes the total energy consumption on all used paths as

$$f_E = \min\{E_{e2e}\}$$

Delay Metric: Delay is the time elapsed from the departure of a data packet from source to sink. The delay metric between two sensors represented as D_{linkl} is the sum of transmission, propagation, processing and queuing delay.

$$D_{link_l} = d_{trans} + d_{propa} + d_{proces} + d_{queue}$$

where, transmission delay d_{trans} measures the time between the first bit leaving source and the last bit arriving at sink

$$d_{trans} = \frac{n\ bits}{b\ bits/sec}$$

Propagation delay d_{propa} measures the time required for a bit to travel from source to sink.

$$d_{propa} = \frac{d\ meters}{s\ meters/sec}$$

Queuing time is the time needed for each intermediate sensor to hold the message before it can be processed. The queuing time is not a fixed factor; it changes with the load imposed on the network. When there is heavy traffic on the network, the queuing time increases. Processing time is the time to select the next node to send the data packet.

The delay of a path D_{pathi} is the sum of all delays at all the intermediate sensors along the path

$$D_{path_i} = \sum_{l=1}^{hop_i} D_{link_l}$$

Therefore, the end-to-end delay to transmit the data packet to sink along the selected path or paths is given as

$$D_{e2e} = \sum_{i=1}^{np} D_{path_i}$$

The delay objective function, f_D is to ensure that the end-to-end delay on the selected paths is the minimum and/or D_{e2e} = D_{req}, where D_{req} is an application-specific parameter which reflects the required end-to-end delay for data delivery.

Proposed Red-aco Routing Protocol for Wireless Sensor Netowks: QoS based routing metric combined with ACO technique have been proposed to solve the routing problems. The proposed RED-ACO routing problem of providing QoS routing is formulated as link-based and path-based metrics. The link-based metrics are presented

Request ID	Source ID	Sender ID	D_{req}	R_{req}	Sink ID

(a) Request message format

Request ID	Sender ID	Source ID	R_{path}	E_{min}	D_{path}	Hop count	Sink ID

(b) Reply message format

Fig. 2: REQ and REP message format

in terms of reliability, energy, delay, distance to sink and hop count. The path–based metrics are partitioned in terms of end-to-end reliability, energy and delay.

Each sensor is assumed to update the local states of its neighbors by broadcasting a HELLO message in which the links conditions are reported in Fig. 2.

Each sensor maintains and updates its neighboring table information to record the link performance between itself and its direct neighbor in terms of required metric values. The cost of pheromone value (τ_i) is calculated as

$$\tau_i = \frac{E_{path_i}}{E_{min_i}} + \frac{D_{path_i}}{D_{req}} + \frac{R_{req}}{R_{path_i}}$$

In RED-ACO routing algorithm, is to find a set of available multidisjoint paths, P={ $path_1$, $path_2$,. .., path ◎◎} from the source to sink that satisfies the following objective function

$$f: \max(f_R), \min(f_E), \min(f_D)$$

This can be written as

$$\mathbb{Z}\sum_{p=1}^{np} f_p \times W$$

where W is the weight set for the QoS required by an application. The first term of the above function specifies the reliability of data transmission, the second term specifies the energy consumption of data packet transmission and the last term specifies the delay accrued in data transmission. Hence, the object function is to minimize data transmission power in order to extend the network lifespan, minimize the data transmission delay while maximize the data transmission reliability. This function is subject to the following constraints.

$$min\sum f_E$$

$$f_D \le D_{req}$$
$$f_R \ge R_{req}$$

Table II: Pheromone table

Neighbor ID	R_{path}	E_{path}	D_{path}	Hop count	Pheromone value
1	R_{path1}	E_{path1}	D_{path1}	hop_1	τ_1
2	R_{path2}	E_{path2}	D_{path2}	hop_2	τ_2
.	.	.	.	.	
.	.	.	.	.	
N	R_{pathn}	E_{pathn}	D_{pathn}	hop_n	τ_n

Table III: Protocol Parameters

Parameters	Values
Propagation Model	Two Ray Ground
MAC Type	Phy/WirelessPhy/802_15_4
Antenna	Omnidirectional
Simulation area	200X200m
Link bandwidth / Data rate	250kbps
Radio Frequency	2.4GHz
Number of nodes	100
Radius (r)	40m
Simulation time	1000s

The number of paths used to route data in RED-ACO protocol can be defined as the routing strategy (S) are presented as

$$S = \begin{cases} np & if\ T \ge np \ge 2, multipath\ routing \\ 1 & otherwise, sigle\ path\ routing \end{cases}$$

In the proposed protocol RED-ACO, the search range for an ant to select its next path is limited to a subset of the set of paths based on the threshold value.

Simulation Environment: To evaluate the proposed optimal path selection algorithm, we have used network simulator ns-2 [15]. The following parameters and their values are chosen for illustrations which are as shown below in Table III.

RESULTS AND DISCUSSION

The impact of proposed RED-ACO on packet delivery ratio analysis in Fig. 3 indicate the packet delivery ratio of three routing algorithms for the case when the number of data packets generated in the network at each time step reliability is varied. For all the approaches, there is a decrease in packet delivery ratio and increase in packet loss ratio when the reliability increases. But proposed algorithm, the results indicate that there is an improvement in packet delivery ratio and packet loss ratio using RED-ACO compared with the other two routing algorithms AODV and AntSensNet.

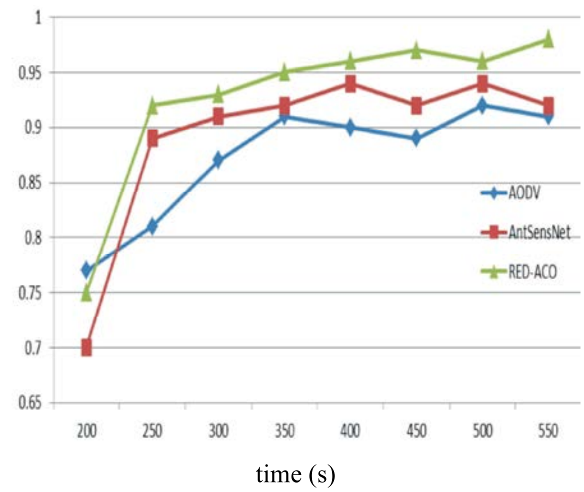

Fig. 3: Packet Delivery Ratio

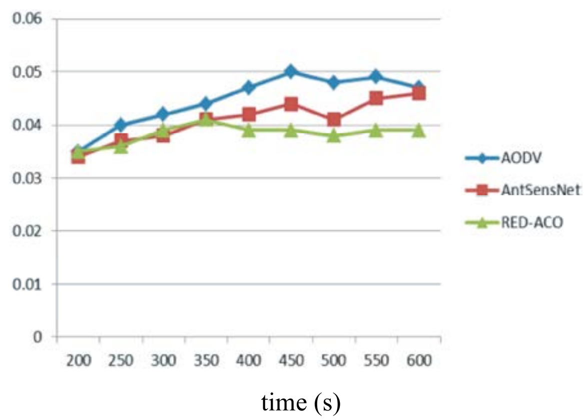

Fig. 4: End-to-end Delay

The impact of proposed RED-ACO on end-to-end delay is shown in Fig. 4. Initially the proposed algorithm may take some time compared to the AntSensNet algorithm but after some time the proposed algorithm stabilizes and has a constant end-to-end delay which reduces compared to AODV and AntSensNet. This is due to the fact that AODV and AntSensNet do not consider defined guided search criteria for ants to move in a particular direction. This metric guides the ants to select a random best path from the available paths. Hence there is reduction delay in the proposed algorithm.

Conclusion and Future Work: This paper presents an RED-ACO routing protocol for WSN, which can establish a route supporting multi-constrained QoS, increase network reliability and reduce energy consumption and delay by means of ant colony algorithm. The problem in this paper is considered both from network and user perspective with defined constraints. A cost effective function which is a combination of various metrics such as reliability, energy and delay is defined to select a base-case path or paths from subset of all disjoint path. Also in this processing time to build the pheromone table while simultaneously avoiding the generation of circle route. The approach searches for the optimal solution by always pursuing one more connected cover than the best-so-far solution. This way, the approach not only avoids building excessive subsets but also improves the search efficiency. Pheromone and heuristic information are also designed to accelerate the search process. A local search procedure is proposed to refine the best-so-far solution in the end of the each iteration. The performance of the proposed algorithm is evaluated with respect to the metrics such as end-to-end delay and packet delivery ratio. The results obtained show that proposed algorithm may take some time at initial stage but with increase in time it stabilizes the solution in terms of end-to-end delay. In the proposed algorithm, the experiments have been carried out for the homogeneous environment; further result can be improved for the heterogeneous environment with mobility.

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