An Implementation Case Study on Ant based Energy Efficient Routing in WSNs

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Abstract. The earlier era of Wireless Sensor Networks (WSNs) is extending its hands towards Internet-of-Things (IoT) and Cyber Physical Systems (CPS). Emergence of new technologies using WSNs lead to dire need of real-time implementations to be utilized in typical applications like health care, agriculture, industries, and many more. These sensors are generally characterized by several limitations such as limited energy availability, low memory and reduced processing power. Routing in WSNs is a well studied research domain leaving several holes for further research. A large number of network routing algorithms have been developed to effectively pass the sensor data from individual nodes to base station. This paper presents an implementation case study using Ant Colony Optimization (ACO) heuristic for an energy efficient routing in WSNs. The real-time experiments were carried out using iSense proprietary hardware and software platform for WSNs. Many practical challenges like neighbor detection failure, Packet loss, interference from external objects were taken into consideration and ACO algorithm was modified accordingly to successfully solve those problems. The results achieved are reported in this paper.

Keywords: Wireless Sensor Networks; Ant Colony Optimization; Energy Efficiency; Routing; Implementation; Internet-of-Things; Cyber Physical Systems

1 Introduction

Wireless Sensor Networks (WSN) [1] have captured the attention of researchers over the past decade because of the diverse applications they support and the flexibility of network deployment options they provide. These advantages, along with the remarkable advances in sensor technology towards Internet of Things (IoT) and Cyber Physical Systems (CPS), make them a favorite option for many tracking and monitoring applications. In such applications, sensors nodes can collaboratively monitor the network environment and report real-time information about the monitored phenomenon. With the advent of miniaturization and improved capabilities in microprocessors, sensors and transceivers, several new set of applications appeared around WSNs. These WSNs are highly useful in typical applications like battlefiled, natural calamity monitoring, volcano monitoring, forest fire monitoring, agriculture, healthcare, etc. By nature, the WSNs are hypersensitive and vulnerable to energy. The limited energy is the key issue influencing WSNs. So, routing algorithms have to be designed to maximize the life of WSNs. A family of Ant Colony Optimization (ACO) [2] algorithms have been tested in past for checking their efficiency in routing data in WSNs. The efficiency found was comparatively high to other routing algorithms. Through this paper, ACO for energy efficient routing has been implemented using special parameters to maximize the life time of WSNs.

This paper presents a case study on implementation of energy efficient routing in WSNs using ACO. The rest of the paper is organized as follows. The recent literature survey is covered in Section 2 and Section 3 introduces the utilization of ACO for energy efficient routing in WSNs. The next section, Section 4, presents the experimental setup, the parameters used for experiments, methodology of experiments and results achieved during the implementation of the work. The last section, Section 5, concludes the paper.

2 Related Work

Several techniques are proposed in the literature to address the routing problem in sensor networks in an energy efficient [3] [4] [5] [6] [7] [8] manner. Some of the recent studies are presented in this paper to understand the way with which routing problem is addressed using ACO.

Schurgers *et al.* [9] presented an approach in two fold to improve the life time of the sensor nodes. First, it aims at aggregating the streams of packets by optimal traffic scheduling and the second, to achieve the uniform resource utilization with the help of network shaping. The approach used is gradient based routing with spreading for balancing the traffic flow and data combining entities that act like cluster heads to aggregate the data received from the sensors. Several simulation studies are done to showcase the work presented by the authors. As rightly indicated by the authors the approach may fail if the nodes are critical in network connectivity. Yet another method to improve the life time of the sensor nodes is developed by Kalantari *et al.* [10]. This paper presented a method based on partial differential equations to find shortest paths to cluster head from the source node. Gui *et al.* [11] has made an extensive study of literature survey on application of swarm intelligence for routing in WSNs. Farzana *et al.* [12] presented a method to assess the link quality and link delay parameters based on packet reception rate, received signal strength, and link quality index. The link quality and link delay parameters are used for choosing a reliable path between source and destination. This research is based on several simulations. But some of the results indicated a weakness of poor delivery of the packets. Ghosh *et al.* [13] presented a dominant set based modified LEACH protocol with the application of ACO to construct a cluster and select a cluster head based on remaining energy level at the current node. However the entire study is based on static and homogeneous nodes. A similar effort is done by the same authors in [14] by using PEGASIS to improve the life time of the sensors and reduce the redundancy and latency in the communications. Both these methods are simulation based approaches.. Gupta *et al.* [15] considered different packet sizes as a parameter to enhance the energy component of the sensor nodes within the cluster and outside the cluster. Several studies are made to assess the energy for both cluster and non-cluster environments. Yao *et al.* [16] developed an energy efficient, delay-aware model based on ACO to improve the life time and balance the data collection in WSNs. The model is uses status gossiping and route construction methods for optimization. In this approach, ants will choose the nodes with highest remaining energy for routing the packets and further route construction process. Unlike many other researchers, the authors considered the heterogeneous nodes instead of homogeneous nodes for the study. This paper has done several simulation studies apart from implementation of the system with a testbed of several motes and a workstation to study the performance analysis of the model presented in their work. Zhong *et al.* [17] focused on the issue of depleting energy at mobile sinks due to large traffic load. To address the problem, they used ACO to mobile sink to optimize the traffic movement and maximize the life time of the nodes. The paper is based on simulations considering the factors like forbidden regions and maximum movement distance of the sink in the optimization procedure. Liu *et al.* [18] developed a model that allows network to be energy balanced and energy efficient by limiting the local transmission distance to be optimal using ant colony algorithm.

Though considerable research is reported in WSNs, there is little research reported with real-time implementations and performance analysis while applying ACO for energy efficient routing. Keeping this fact in mind, our paper attempts to implement a energy efficient routing for WSNs by applying ACO. Several experiments are carried out to analyze the established test bed. The results are reported.

3 Ant Colony Optimization (ACO)

ACO [2] is based on the behavior of ants that hunt for food by depositing pheromone on their path. Among large number of random paths available, the path that leads to food source will be having high probability because of collective behavior of ants that deposit large amounts of pheromone along those paths. In this process, ACO denotes query packets as forward ants and response packets as backward ants. The concentration of pheromone is in inverse proportion to the distance to the destination node and directly proportional to the average of remaining amount of energy level of the nodes on the path. In route maintenance process, the sensor nodes send a certain number of forward ants to the destination node periodically to monitor the quality. In this paper, we have adapted primary principles of ACO from [19]. In this approach, each ant attempts to find the optimal path in terms of shortest and energy efficient path. In their journey from source node to destination node, ants move from node i to a neighboring node j with a transition probability [19]

$$P_{ij}[k] = \frac{\tau_{ij}^{\alpha}\eta_{ij}^{\beta}}{\sum_{l \in N_i[k]} \tau_{il}^{\alpha}\eta_{il}^{\beta}}, j \in N_i[k] \tag{1}$$

Where $P_{ij}[k]$ is the probability for ant k to move from node i to node j, η_{ij} is the pheromone value deposited on link (i,j), η_{ij} a heuristic value assigned to the link, and (α, β) are weights used to control the importance given to the pheromone and the heuristic values, respectively. Here, $N_{ij}[k]$ is the list of neighbors of node i visited by ant k. The pheromone value $\tau_{ij}[k]$ on a given link depends on the likelihood that the ants pass by the link while constructing the solutions. The heuristic value η_{ij} on the other hand, depends on the calculated cost of the link. The initial pheromone value is usually set to be equal for all links. The heuristic value of the link (i,j) is the inverse of the link cost, C_{ij}. The heuristic variable is calculated as follows.

$$\eta_{ij}(t) = \frac{e_j(t)}{\sum_{S_l \in C(i)} e_l(t)} \tag{2}$$

where $e_j(t)$ is the remaining amount of energy of neighbor j for node i. The denominator is the sum of remaining energy levels of all neighbors for node i. When the forward ant gets to the destination node, the destination node generates a backward ant, and sends it back along the reverse path. The backward ant in each visited node release a certain amount of pheromone $\Delta\tau$ and it is given by

$$\Delta\tau = c.(Hop_{max} - Hop_{count}).Eavg_n \tag{3}$$

where c is the variable parameter, Hop_{max} represents the maximum allowed number of hops for forward ants; Hop_{count} represents the number of hops forward ant has taken to reach the destination node.

Therefore, when node receives the backward ant from the destination node by the n_{th} neighbor node, the node will update the pheromone concentration $\tau_{n,d}$ given by

$$\tau_{n,d} = (1-\rho).\tau_{n,d} + \Delta\tau \tag{4}$$

where ρ is the pheromone evaporation coefficient, 1- ρ is the pheromone residue factor. The range of pheromone is from $[0, 1]$. The proposed algorithm considers both energy and distance. In order to take into account the movement of destination node the above formula is slightly modified as

$$\tau_{n,d} = (1-\rho).\tau_{n,d} + \frac{\Delta\tau}{\omega.Hop_{count}} \tag{5}$$

where ω is a control factor for controlling the influence of number of hops over pheromone update rule and Hop_{count} is the number of hops traveled by the backward ant. In order to limit the maximum and minimum values of pheromone values to the range between 0 and 1 the minimum amount of pheromone for a particular neighbor is 0.005 and the maximum value is 0.9.

In this paper, temperature data has been used as the phenomenon that is being monitored by WSNs. The data and forward ants have been sent at specific intervals and entire network is made to operate at a single synchronized time for coordination between forward ants and data packets by using time synchronization protocol provided in isenseSDK[1] .

4 Implementation and Results

In this paper, we have attempted to implement the ACO algorithm applied to WSNs to optimize the route in an energy efficiency manner. Several experiments are conducted on a practical test bed set up in the lab with actual motes, base station and laptop. The following sections present the details of experimental setup and results achieved during the experiments.

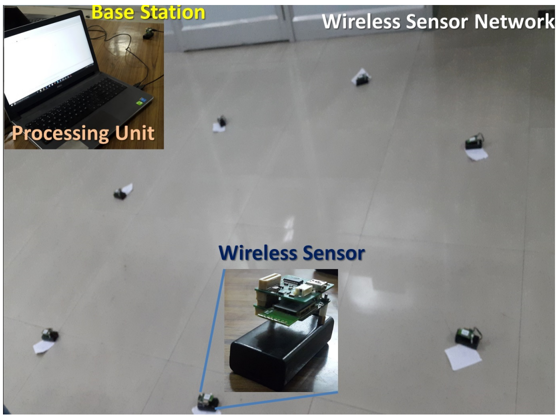

Fig. 1. Wireless Network Experimental Setup.

4.1 Experimental Setup

Fig. 1 shows the experimental test bed setup at out laboratory which include a maximum of 10 motes connected wireless to a base station. The base station is

[1] `http://www.coalesenses.de/index.php/products/solutions/isense-devices/` - last access May 2016

connected to a laptop used for collecting the routing information and processing it for performance analysis. The sensors kit available in the lab is procured from Coalesenses[2], a German based company. These modules are prefixed with a C++ based proprietary iSense software. All motes were coded with the energy efficient routing protocol using ACO. For successful implementation of ACO in WSNs, a time frame was proposed as shown in Table 1 for route discovery process and route maintenance process using ACO. The variation of energy of the network with time was observed in real time. Also the variation of total of number of forward ants that are required for the entire network to get converged to their optimal paths from nodes to destination was observed. The network was subjected to various disturbances like switching off nodes in the network dynamically (in order to create a case of node fault), hindrance from other objects which lead to variation in the signal strengths between nodes. Table 2 lists the several important parameters used during the experiments in implementation phase.

Table 1. Time line of the events defined for implementation

Step	Time Tick	Event Occurrence
1	0	Boot and Wait for time synchronization
2	6	It takes one second for getting synchronized. But time has been given for six seconds.
3	66	Start the route discovery process by flooding sample data to neighboring nodes. Neighboring nodes can then identify its neighbors
4	76	Send flooding data again in order to compensate for the lost flooded data initially
5	86	Send flooding data for one last time and then enter into the energy sending process
6	93	Send energy level of the node to the top four neighbors in terms of signal strength
7	99	Send energy levels again in order to compensate for the lost energy level data packet sent previously because of unpredictable environment conditions
8	110	Check whether the given node is in the immediate neighbor of base station. If it is, then no need to send the forward ant. Or else, send a forward ant.
9	116	Go to Step 3

[2] `http://www.coalesenses.de/` - last access May 2016

Table 2. Parameters Used for Implementation

Parameter		Value
α		1.0
β		2.0 - 3.0
ρ		0.5
ω		0.6
Default Pheromone		0.5
Number of motes		1 - 10
Sensors type		Temperature Sensors
Number of base stations		1
Number of processing units		1
Radio type		ZigBee
Transmission range of each node		600m
Internet protocol applied		IPv6 and 6LoWPAN
Transport protocol		UDP
Port number		8080
Identifiers Used	Energy Data	200
	Forward Ant	202
	Backward Ant	203

4.2 Results

In this work, several experiments were conducted to observe the impact of ACO on the experimental test bed setup as shown in Fig. 1 by varying the number of nodes in the network over number of ants and the behavior of network with the depleting battery power over a period of time. Fig. 2 shows a screen shot of the data collected of the routing information and energy values of the individual nodes at base station. Fig. 3 provides results of assessment on impact of total number of ants as the number of nodes increase. Since the growth is almost linear, we believe that the ACO model used for experiments is scalable to a larger network. Further analysis is done to verify the impact of ACO on energy factor of the sensors over a period of time as shown in Fig. 4. We can observe from the figure that the depletion rate is also almost linear. However, further optimization is required to enhance the sustainability of the energy for a longer periods. During the study, it is observed that there is an impact of total number of forward ants that are required for the entire network to get converged to their optimal paths from nodes to destination. It is also observed that several disturbances on the network lead to variation in the signal strengths between nodes and still the network got dynamically adjusted to the variations and optimal paths were recorded.
Overall, the experimental studies indicate that ACO is a suitable algorithm for WSNs for energy efficient routing, even in real-time scenarios.

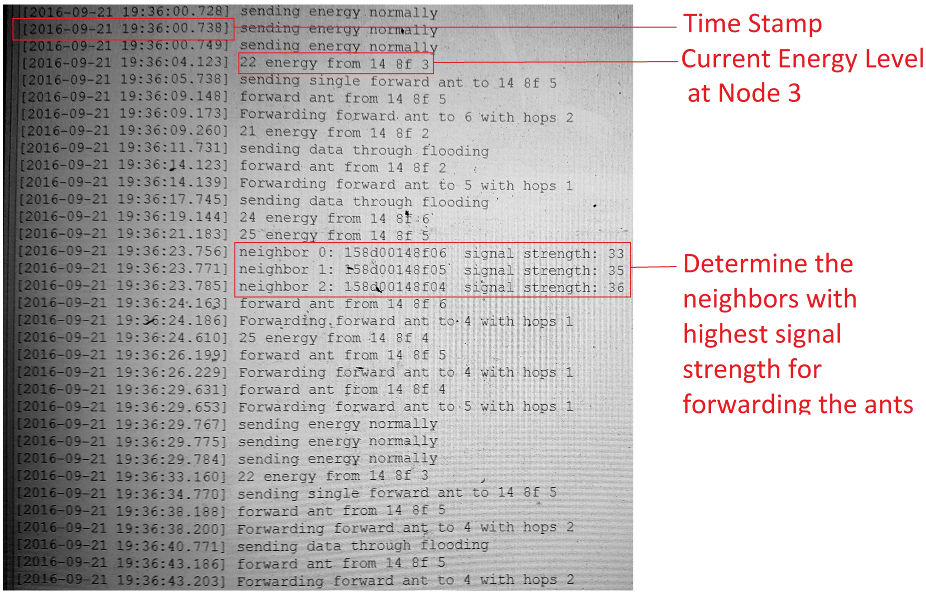

Fig. 2. Routing information and Energy Values captured during the experiments.

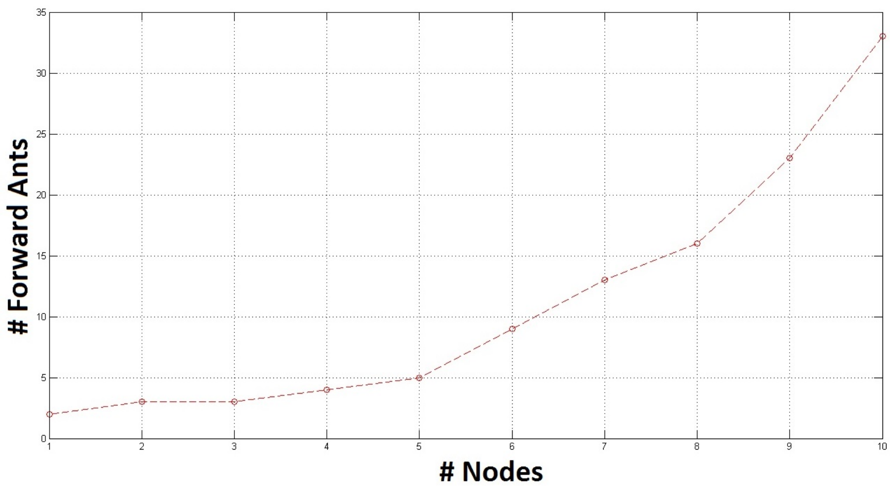

Fig. 3. Number of forward ants growing in the network as the number of nodes in the entire network increases.

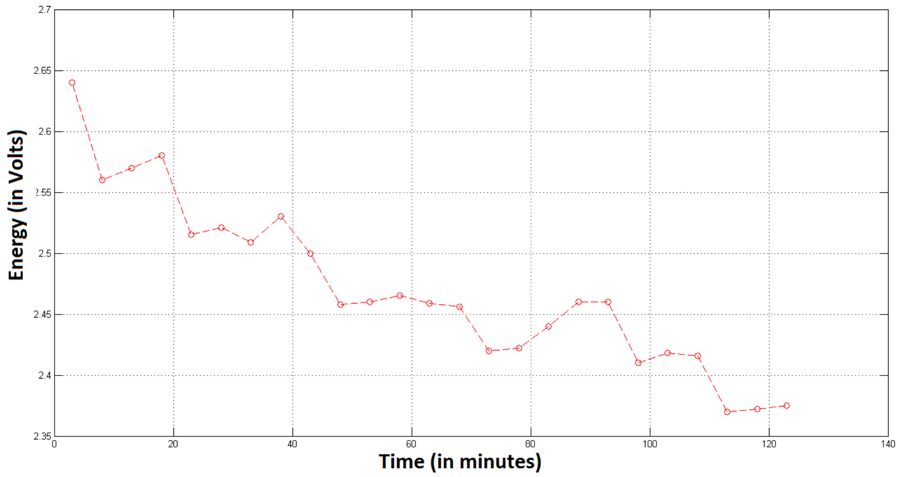

Fig. 4. Depletion of energy over a period of time

5 Conclusions

Through this work we have implemented ACO for Energy Efficient Routing and also minimum path distance in WSNs. We have proposed a new time frame for a better implementation of the above protocol in WSNs because of which the network could sustain many disturbances an converge to its optimal path. The future work could be to investigate ways in which the the total number of forward ants required to converge to optimal path for the entire network can be reduced.

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