Journal of Computer Science

Review

Ant Colony Optimization Approaches in Wireless Sensor Network: Performance Evaluation

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Article history
Received: 18-02-2017
Revised: 25-04-2017
Accepted: 23-06-2017

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Abstract: Wireless Sensor Network (WSN) has been widely implemented in large sectors such as military, habitat, business, industrial, health and environment. WSN is part of a distributed system where elements such as routing, load balancing, energy efficiency, node localization, time synchronization, data aggregation and security need to be addressed to improve its efficiency, robustness, extendibility, applicability and reliability. Despite multiple approaches proposed to improve all these aspects, there is still room for improvement in order to enhance the capability of WSN in terms of routing and energy efficiency. Ant Colony Optimization (ACO) is one of the approaches used to extend WSN capabilities because its heuristic nature is very suitable with distributed and dynamic environments. This study covers the common WSN aspects and performance evaluation criteria in addition to the list of previous studies that have used ACO approaches in WSN.

Keywords: Wireless Sensor Network, Network Aspects, Performance Evaluation, Ant Colony Optimization

Introduction

A computer network can be established by wired and wireless connection (Kaur and Monga, 2014). Through high connection speed and bandwidth, users can share data and communicate using a computer network. In a wired network, several software and hardware are combined by series of cables to establish a computer network (Srividya and Vijayarani, 2015). However, wired network applications are inflexible and ineffective because they are limited to a fixed area, can only support limited connections and require high installation cost. Due to these facts, wireless network is introduced in order to allow multiple areas to be connected, increase the number of connections, as well as reduce installation and maintenance costs.

A wireless network is established by using the Internet that consists of various resources that can be accessed and connected from different geographic locations. The main objectives of the wireless network are to support the Internet and mobility services while reducing the installation cost. Wireless Sensor Network (WSN) is introduced to further improve the service of the wireless network in terms of reducing deployment and maintenance costs and at the same time, trying to increase the network lifetime and security of the system. WSN consists of sensor nodes with limited energy power that are responsible to sense and obtain the information from the environment (Okdem and Karaboga, 2009). However, WSN also have different requirements and constraints compared to the traditional wireless network.

This brief survey covers several important aspects in WSN, as well as summarizes briefly the list of previous studies that used ACO approaches in WSN. Section 2 describes the research methodology used for the review while brief explanations on each WSN aspect are presented in section 3. Performance evaluation criteria that are used in validating the performance of the WSN system are explained further in section 4 and brief overview of the ACO algorithm is described in section 5. A list of recent studies that used ACO approaches in WSN is presented in section 6. Advantages and disadvantages of ACO algorithm in WSN are explained in section 7 while section 8 concludes this survey in addition to a brief explanation on future work.

Research Methodology

The review was conducted as a Systematic Literature Review (SLR) based on methodological framework proposed by Kitchenham *et al*. (2009). The framework consists of a set of steps to be carried out from defining research questions, hypotheses and systematic reviews to finding answers or supporting information. This research methodology is divided into three mains stages which are research question, search process and inclusion criteria.

Research Question

Research questions are defined in order to explore specific research topic in WSN which includes important elements of WSN, performance evaluation, use of Ant Colony Optimization (ACO) algorithm to solve WSN problems and performance measurement. The following research questions are used to systematically define the scope of this article:

RQ1: What are the important elements in WSN and how they work?
RQ2: How to evaluate the performance of the WSN system?
RQ3: What is ACO and how does it work in WSN?
RQ4: What are the problems of WSN that can be solved by ACO?
RQ5: How to measure the performance of the ACO algorithm in WSN?

Search Process

In the search process, several academic materials such as journal articles, research reports, dissertations and books are searched for the review purpose. Important keywords, terms and procedures that are relevant in answering the research questions are pre-defined. In addition to that, the following criteria are set to refine the searching process:

- Research works that are published in established computer science basis
- Research works that are published from 2006 until 2017
- Only works that are written in English

The theme for this review article is defined from the extracted data that have been processed. The articles that align with defined research questions will be used in the next stage.

Inclusion Criteria

The purpose of inclusion criteria stage is to limit the number of articles found during the search process (Farias *et al.*, 2016). Only high quality works that are related to the research question will be selected based on the following steps:

- The abstract of each paper will be analyzed, so that only papers that have information related to WSN in their abstract will be selected and further process in the next step
- In this step, the contents of each selected article from the previous step will be evaluated to check whether the abstract and contents are related. Articles that do not have sufficient or significant information will be filtered out from the list while qualified articles will undergo quality screening process in later step
- The selected articles will go through a quality screening process to check whether their framework, methodology, protocol, simulation or experiment fulfill the requirements to support this review article

Important Elements in Wireless Sensor Network

All submitted packets and available sensor nodes need to be managed properly in order to maximize the energy efficiency and network lifetime of the WSN system. There are various network elements, such as routing, load balancing, energy efficiency, nodes localization, time synchronization, data aggregation and security (Gupta and Younis, 2003; Krishnamachari, 2005; Hu and Cao, 2010), which are important to be further explored in order to improve the WSN applications. The following section explains briefly all these aspects.

Routing

Routing packets by sensor nodes in WSN are complicated due to the characteristics of each packet and also the capacity of each sensor node (Luo and Li, 2012). The matching process between the packets and sensor nodes is considered very important in WSN because the forwarding packets must be matched with the available sensor nodes in terms of packet characteristics such as packet length and packet priority and also sensor node capacity such as residual energy and current load of each sensor node. Without this matching, the distribution of packets may not be fair in all available sensor nodes. A good routing algorithm should be able to find one or more optimal paths in forwarding submitted packets from source node to destination node with minimum forwarding time and minimum energy.

Load Balancing

Load balancing is also a critical aspect in the WSN system because an effective load balancing algorithm can reduce the energy consumption of each sensor node and at the same time, can extend the network lifetime of the WSN system (Wajgi and Thakur, 2012). In order to improve this aspect, all forwarding packets need to be distributed fairly among the available sensor nodes. A good load balancing algorithm must be capable of balancing the entire

DOI: 10.3844/jcssp.2017.153.164

sensor nodes through a fair distribution of the entire packets across available sensor nodes by considering packet characteristics and sensor node capacity in order to gain optimal node utilization. The hotspot problem where certain sensor nodes are under heavy traffic load can be solved while considering the load balancing aspect (Naghibzadeh *et al*., 2014).

Energy Efficiency

The main functions of sensor nodes are to sense any changes in WSN and communicate between the available sensor nodes to forward packets from source node to destination node (Xia *et al*., 2009; Sutar and Bodhe, 2010). However, the available sensor nodes in WSN have limited energy and computational power. The routing algorithm in WSN should consider this limitation in order to select the optimal sensor nodes to forward the packets to the destination node to ensure that all packets arrive in the minimum time possible. In addition to that, the packet loss problem may occur due to the depletion of sensor nodes and it could affect the energy consumption of each sensor node, which will eventually reduce network lifetime.

Node Localization

Node localization is another important aspect that has a direct influence on the coverage and performance in WSN. In a typical WSN system, sensor nodes are deployed randomly without considering whether they are distributed far or too close from each other (Ahmad, 2014). Random deployment may cause overlapping, coverage holes, connectivity failure and at the same time, will potentially reduce the performance and connectivity of the sensor nodes (Sahoo and Liao, 2015). A good node localization WSN application should have low power and low cost multifunctional sensor nodes that can communicate through wireless links in a short distance.

Time Synchronization

Time synchronization is an important aspect that needs to be considered in the WSN system. The local clock of available sensor nodes should be synchronized in order to attain the accurate time of each sensed data (Ranganathan and Nygard. 2010). The mobile object tracking scenario is the best example of time synchronization, where sensor nodes are deployed to monitor passing objects (Song *et al*., 2007). In this situation, whenever an object appears, the sensing nodes will record the detecting location and time before sending the information to the aggregation node. The aggregation node is responsible to estimate the moving route of the object. Time synchronization is important in ensuring that the estimated route of the object is similar to the actual one.

Data Aggregation

Sensor nodes in WSN have very limited abilities in terms of energy, memory, computational power and communication capacity (Sendra *et al*., 2011; Khan *et al*., 2013). In order to preserve the energy, the data aggregation technique is introduced. There are three types of sensor nodes in the data aggregation technique, which are regular nodes, aggregator node and destination node (Maraiya *et al*., 2011). Regular nodes are responsible in sensing packets from the environment and sending them to the aggregator node. The aggregator node will collect the data from multiple regular nodes and aggregate the data packets by using the aggregation function before sending them to the destination node. The objectives of the data aggregation technique are to prevent redundant data transmission, to reduce energy consumption and also to increase the WSN lifetime.

Figure 1 illustrates the non-data aggregation model, where all Regular Nodes (RN) need to send the data directly to the Destination Node (DN). This model will consume a lot of energy and influence the depletion of sensor nodes.

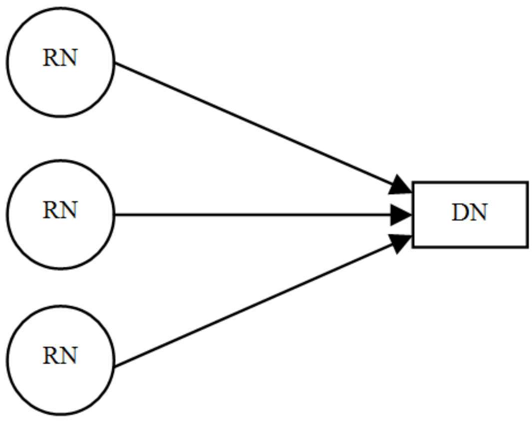

Fig. 1. Non-data aggregation model

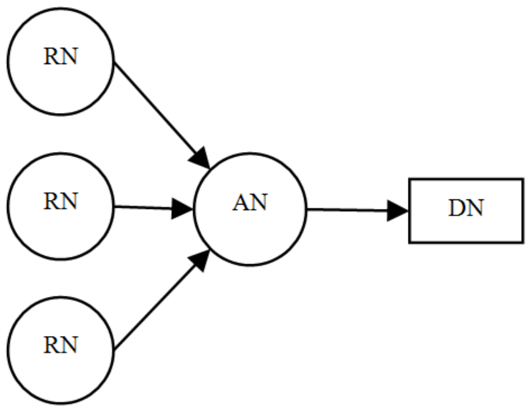

Fig. 2. Data aggregation model

Figure 2 shows the data aggregation model, where the Aggregation Node (AN) will collect all data from the regular nodes and send the collected data in one batch transmission to the destination node. This will reduce the energy consumption of nodes.

Security

The security aspect in WSN is also important as more WSN applications are deployed and connected wirelessly to the central system. It is a fact that wireless networks are more exposed to security threats compared to wired networks because of the effect on unguided transmission medium. For example, eavesdropping can easily happen during message transmission in a wireless communication. There are several attacks in WSN such as sybil attack, denial of service, attacks on information in transit, hello flood attack, sinkhole/blackhole attack and wormhole attack (Pathan *et al*., 2006). Despite many security solutions available, it is impossible to have a completely secured WSN system as new threats are continuously emerging with new exploitation methods. However, it still possible to reduce the possibility of security threats by applying proper security protocols, such as TinySec (Karlof *et al*., 2004), Lightweight Security Protocol (LISP) (Ojha and Jain, 2015) and Link Layer Security Protocol (LLSP) (Ren *et al*., 2005).

Performance Evaluation Criteria

There are several performance evaluation criteria used in evaluating the performance of the WSN system, such as throughput, delay, number of dead nodes, number of alive nodes, energy consumption, energy efficiency, network lifetime, packet loss and path length. Each of these performance evaluation criteria are described as follow.

Throughput

Throughput is measured by a number of successful packets per second that arrive from source node to destination node (Saha *et al*., 2015). The throughput value will be influenced by the number of available sensor nodes, where a large number of sensor nodes will increase the throughput value due to the multiple optimal routes that can be constructed from source node to destination node.

Delay

Delay is an average time taken by the packets to be submitted from source node to destination node. In order to get an accurate delay value, propagation delay and queuing time need to be considered (Alazzawi and Elkateeb, 2008). Low delay indicates high quality routing process, while high delay indicates otherwise.

Packet Loss

The total number of packets that do not arrive at the destination node per all submitted packets from the source node is measured as packet loss. A small number of packet loss indicates the high quality of the transmission path, while a low quality of the transmission path is indicated by a high number of packet losses.

Number of Alive Node

Alive node is measured by the number of available sensor nodes after the successful packet transmission per all the number of available sensor nodes before the packet transmission. The ratio between the number of alive nodes before and after transmission can be used to evaluate network lifetime.

Number of Dead Node

Dead node is an opposite measurement of the alive node, where the number of missing or dead sensor nodes after the packet transmission per number of available sensor nodes before the packet transmission is measured. The lower number of dead nodes indicates that the higher quality of network lifetime.

Network Lifetime

The total time taken by the network from the first packet transmission until the first sensor node is measured as network lifetime (Saraswat and Kumar, 2013). A good routing algorithm can increase the network lifetime of WSN by reducing the delay, number of path length, energy consumption, packet loss and also by distributing the packets fairly among available sensor nodes.

Energy Consumption

Energy consumption is measured by the total energy used by the sensor nodes while transmitting and processing submitted packets in the WSN system (Duarte-Melo and Liu, 2002). The measurement of energy consumption is based on the energy used for communication, including idling, transmitting and receiving. Low energy consumption during each transmission ensures the network lifetime of the WSN system.

Path Length

Path length is measured based on the number of hops taken by the packets from source node to destination node (Yaacoub and Abu-Dayya, 2012). The multi-hop technique can potentially reduce energy consumption of each sensor node during the packet transmission because a shorter path requires low energy to fully transmit the packet as compared to a longer path.

Ant Colony Optimization Approach in Wireless Sensor Network

Swarm intelligence algorithms have been widely used in solving WSN issues (Kulkarni and Venayagamoorthy, 2011; Zungeru *et al*., 2012; Saleem *et al*., 2011). ACO is one of the swarm intelligence approaches that were inspired by the foraging behavior of ants that work together to find the shortest path between nest and food source (Singh *et al*., 2010). It uses the concept of chemical substances called pheromones, which are used for indirect communications between the ants to perform node selection (Lee *et al*., 2011). Swarm intelligence is a sub category of artificial intelligence that is motivated by the intelligent behavior of groups in natural ecological systems of social insects like bees, ants, wasps and termites (Jangra *et al*., 2013). The other examples of swarm intelligence are the artificial bee colony algorithm, which is based on the foraging behavior of honey bees and the particle swarm intelligence, which is based on the behavior of bird flocking and fish schooling (Zhao *et al*., 2010).

The ACO algorithm has been applied in WSN because it is easily adapted to solve both static (Acharya *et al*., 2009; Singh and Behal, 2013) and dynamic (Zhong and Zhang, 2012; Ye and Mohamadian, 2014) combinatorial optimization problems. Routing and load balancing are among the problems that can be solved by using ACO. In terms of routing, the ACO algorithm is often used to determine the optimal routes from source to destination through a metaheuristics approach. In addition to determining optimal routes, the stagnation problem where a majority of packets are assigned to the same sensor node that lead to the node having high workload can eventually be solved using the load balancing technique. This is because the optimal routes may change from time to time by using global and/or local pheromone updates. However, the performance of the ACO algorithm can still be further extended in order to obtain maximum throughput, minimum delay, minimum energy consumption of sensor nodes, minimum stagnation problem, to balance the entire sensor nodes and at the same time, to extend the network lifetime of the WSN network.

Table 1 contains the list of works that used ACO approaches in improving WSN performance such as routing, load balancing, energy efficiency, node localization, time synchronization, data aggregation and security. Furthermore, the list of performance evaluation criteria is also extended in order to provide further details on how the improvement on specific aspects is evaluated.

Advantages and Disadvantages of Ant Colony Optimization in WSN

Table 1 shows that ACO is commonly used in WSN to enhance routing, energy efficiency, energy consumption and delay. This is the result of ACO behavior that is able to construct optimal routing path from source node to destination node which eventually improves the energy efficiency, energy consumption and reduces delay. ACO algorithm is easily adapted to static, dynamic and mobile environments (Camilo *et al*., 2006). In static WSN environment, the source node and destination node are always in a fixed position while in mobile WSN environment, the destination node will move during simulation process to be allocated at the area that has high energy sensor nodes. Meanwhile, target tracking events to detect enemy, animal movement and moving vehicle are categorized as dynamic WSN where sensor node and destination node will randomly change their position during simulation process (Wu *et al*., 2016). ACO algorithm can also adapt to most topologies because ants have the capability to communicate between sensor nodes by using pheromone value to detect the location of the destination node. The optimal path constructed by ACO in WSN can change from time to time according to the conditions of each sensor node which is based on the remaining energy, distance and pheromone value.

Besides the top aspects explained earlier, ACO algorithm can also improve the submission of packet where packets will only be sent to destination node by using the optimal path. Ant will move and find the optimal path in WSN environment first before packet submission process (Jabbar *et al*., 2015). This approach can reduce packet loss rate and at the same time can prevent dead node problem where only sensor nodes with high capabilities are being utilized during routing determination process. ACO algorithm is also suitable in parallel situation whereby more than one ant will be released to observe the best routing path to submit a packet from source node to destination node (Zhu *et al*., 2010). This approach can increase the possibility to find alternative optimal path in short period of time should the current optimal path becomes less desirable.

Despite all the advantages, there are also disadvantages. The approach of ACO algorithm in finding the optimal path in WSN can also encourage stagnation and hotspot problem among sensor nodes (Parvatkar and Gore, 2014). This is because packets will be sent through the same path to the destination node that will lead to energy of certain sensor nodes depleting at faster rate. This situation will also lead to dead node that can minimize the network lifetime of WSN system. In order to solve this problem, local pheromone update is introduced in one of the most well-known ACO variant called Ant Colony System (ACS) to decrease the pheromone value on optimal sensor nodes and encourage the exploration to other potential path.

ACO algorithm also requires certain amount of memory to store the information of all routing elements such as sensor node ID, an ID, pheromone value, energy and path of each routing process. In large WSN environment where each ant needs to move long distance by using multi hop technique, sufficient memory is needed to store all information between hops. Since memory is very limited, Camilo *et al*. (2006) proposed an ant to only carry previous two visited nodes information while sensor nodes store pheromone value, energy and ID of each visited ants. This approach was proven to be able to preserve the routing path constructed by ant with very low memory utilization.

Table 1. ACO approaches in WSN in terms of aspects and performance criteria

	WSN Aspects							Performance Evaluation Criteria													
References	Routing	Load Balancing	Energy Efficiency	Node Localization	Time Synchronization	Data Aggregation	Security	Delay	Throughput	Packet loss	Alive Node	Dead node	Energy Consumption	Energy Efficiency	Network Lifetime	Overhead	Path Length	Position Error	Precision Error	Fitness Value	Convergence Rate
Camilo *et al*. (2006)	√		√											√							
Misra and Mandal (2006)	√		√			√								√							
Okdem and Karaboga (2006)	√							√													
Liao *et al*. (2007)	√		√			√							√								
Dhurandher *et al*. (2008)	√		√				√	√	√												
Liao *et al*. (2008)	√		√			√							√								
Salehpour *et al*. (2008)	√	√						√					√		√						
Wang *et al*. (2008)	√		√					√					√	√							
Xiu-Li *et al*. (2008)	√	√						√					√								
Acharya *et al*. (2009)	√	√										√									
Bing *et al*. (2009)				√													√				
Guifeng *et al*. (2009)	√		√								√		√								
Saleem *et al*. (2009)	√	√	√					√					√								
Yang *et al*. (2009)	√	√	√										√		√						
Domínguez-Medina and Cruz-Cortés (2010)	√		√					√					√	√			√				
Qi *et al*. (2010)					√													√			
Qin *et al*. (2010)				√													√				
Yang *et al* (2010)	√		√										√	√	√						
Yan *et al*. (2011)	√							√					√								
Al-Zurba *et al*. (2011)	√		√					√		√											
Fidanova and Marinov (2011)				√																√	
Li and Li (2011)				√														√			
Okazaki and Fröhlich (2011)									√	√						√					
Almshreqi *et al*. (2012)	√	√											√	√							
Bains and Sharma (2012)	√							√	√	√			√	√							
Kellner (2012)	√		√				√	√	√					√		√	√				
Lee and Lee (2012)	√		√								√				√						
Lin *et al*. (2012)	√		√			√			√				√	√	√						
Luo and Li (2012)	√							√		√		√									
Mourad *et al*. (2012)	√			√				√													
Qi *et al*. (2012)				√																	√
Saleem and Fisal (2012)	√		√				√	√	√				√			√					
Xi *et al*. (2012)	√		√				√	√	√												
Xiang and Yun (2012)	√												√								
Xie and Shi (2012)	√		√			√		√							√						
Xiang *et al*. (2012)	√		√										√		√						
Alrajeh *et al*. (2013)	√						√	√		√					√	√					
Anjali (2013)	√		√														√				
Fathima and Sindhanaiselvan (2013)	√		√						√					√							
Gurav and Nene (2013)	√																√				
Lee *et al*. (2013)					√								√								
Li and Shi (2013)	√	√						√			√										
Li *et al*. (2013)	√		√								√			√							
Li *et al*. (2013)	√		√										√		√						
Okafor and Fagbohunmi (2013)	√							√					√								
Singh and Behal (2013)	√								√				√	√	√						
Xue *et al*. (2013)	√		√										√								
Amiri *et al*. (2014)	√		√					√					√								
Arulanand and Fathima (2014)	√		√				√		√					√							
Geetha and Kannan (2014)	√		√				√		√												
Kadri *et al*. (2014)	√		√				√						√								
Kamal (2014)			√					√									√				
Khoshkangini *et al*. (2014)	√		√					√	√				√	√							
Kim *et al*. (2014)	√		√						√		√	√		√							
Lu and Zhang (2014)				√														√			
Parvatkar and Gore (2014)	√								√						√						
Rao and Rani (2015)	√													√							
Tewari and Vaisla (2014)	√	√							√						√						
Viji and Shankar (2014)	√						√	√	√								√				
Dhanalakshmi and Sathiya (2015)	√		√				√		√					√							
Gupta and Sharma (2015)	√		√								√		√		√						
Jabbar *et al*. (2015)	√								√				√								
Kaur and Sharma (2015)	√		√								√	√		√	√						
Raam and Rajkumar (2015)	√		√														√				
Tong *et al*. (2015)	√		√					√	√				√			√					
Velumani (2015)				√				√	√				√								
Ghosh *et al*. (2016)	√	√						√	√		√		√								
Kumar *et al*. (2017)	√								√		√			√							
Liu *et al*. (2016)	√											√	√								
Mondal *et al*. (2016)	√	√	√					√	√		√		√								
Wang *et al*. (2016)	√	√						√													√
Sun *et al*. (2017)	√											√	√		√						

Conclusion

A reliable WSN system should strongly consider routing, load balancing, energy efficiency, node localization, time synchronization, data aggregation and security. One of the approaches capable to cater all these aspects is the ACO algorithm because its heuristic nature is suitable with distributed and dynamic natures.

Further explorations and studies should be conducted not just using ACO approaches, but other swarm intelligence approaches such as Genetic Algorithm, Particle Swarm Optimization and Artificial Bee Colony Optimization, as well as non-bio inspired approaches in WSN to maximize energy efficiency, minimize submission time, maximize accuracy of each sensed data and increase the network lifetime of the WSN system. Furthermore, the packet priority aspect may also be considered because in a WSN system, there may be different types of sensor nodes and each of them may have different packet priorities. By assigning the priority, it may potentially lead to a more efficient routing process especially in a big scale implementation.

Funding Information

The authors wish to thank the Ministry of Higher Education Malaysia in funding this study under the Trans Disciplinary Research Grant Scheme (TRGS), S/O code 13164 and RMIC, Universiti Utara Malaysia, Kedah for the administration of this study.

Author's Contributions

All authors are equally contributed in this work and the article.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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