ARTICLE IN PRESS

Computers in Human Behavior xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Analyzing ant colony optimization based routing protocol against the hole problem for enhancing user's connectivity experience

Kashif Saleem [a,*], Abdelouahid Derhab [a], Jalal Al-Muhtadi [b], Mehmet A. Orgun [c]

[a] Center of Excellence in Information Assurance (CoEIA), King Saud University (KSU), Riyadh, Saudi Arabia
[b] Center of Excellence in Information Assurance (CoEIA), College of Computer and Information Sciences (CCIS), King Saud University (KSU), Riyadh, Saudi Arabia
[c] Intelligent Systems Group (ISG), Department of Computing, Macquarie University, NSW 2109, Australia

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Autonomous
Energy distribution
Fault tolerant
Holes problem
Ubiquitous computing
Wireless Sensor Networks

ABSTRACT

This paper investigates the ant colony optimization (ACO) based routing protocol against holes (or voids) to address user's connectivity via Pervasive Wireless Sensor Networks (PWSNs). A hole is an area that has no active sensors, which makes a connection between one side of the network and the other side impossible. To avoid such holes, prior works detected them only when packets reached nodes near the hole, called dead-ends. In this case, the packets need to be rerouted, which results in additional communication cost. The ant colony optimization (ACO) approach is known to be suitable for dynamic environments, which makes it a good choice to deal with the hole problem. We study the capability of an ACO-based routing protocol, called the biologically inspired secure autonomous routing protocol (BIOSARP), for resolving this issue. Because of its routing criteria, BIOSARP does not try to detect the holes after their appearance, but rather avoids them. Network simulator 2 (ns-2) is utilized to perform an analysis by adopting a flag-based feedback mechanism in BIOSARP and is further compared with on-demand routing with the void avoidance (ODVA) protocol in terms of the delivery ratio and energy consumption. Findings clearly demonstrate that BIOSARP can efficiently maintain the network prior to any possible hole problems, by switching data forwarding to the most optimal neighboring node. Thus, it can self-adapt to faults appearing in PWSN and efficiently maintains the network communication.

1. Introduction

The development of different devices and applications has led to an exponential growth in wireless communication (Alwagait & Shahzad, 2014; Kumar et al., 2008; Paradiso et al., 2010; Shahzad & Alwagait, 2013; Shahzad & Mathkour, 2009). This development subsequently increases the complexity of the wireless network. Some of these networks are independent and work intelligently such as Pervasive Wireless Sensor Networks (PWSNs), which are mostly deployed in areas that are out of human reach. PWSNs provide an extremely valuable service in ubiquitous systems (Belghith, Koubaa, & Shakshuki, 2011).

Generally, most low-power wireless networks usually have unreliable links with limited bandwidth, and their link quality can be heavily influenced by environmental factors (Cerpa, Wong, Kuang, Potkonjak, & Estrin, 2005). The research challenges in PWSNs are diverse and vast. In a PWSN, the holes caused by limited power and limited network lifetime are among the most common and critical problems that causes major problems in user's connectivity, which is the main aim of knowledge management (KM) (Chatti, Jarke, & Frosch-Wilke, 2007). A region affected by the hole problem is a set of nodes or an area that prevents data from being transferred from one part of the network to another. The most common types of holes problems are coverage holes, routing holes, jamming holes, and sink/black holes/worm holes (Ahmed, Kanhere, & Jha, 2005). The hole problem appears due to inactivity periods, vulnerability to destruction, battery power depletion, link quality, network attacks, physical disasters, etc. (Ahmed et al., 2005; He et al., 2003). Because of the hole problem, a sink node may not receive important information, which affects the overall communication of a network. In some cases, the whole network goes offline, which results in huge losses (Singh & Sharma, 2012).

* Corresponding author.
E-mail addresses: ksaleem@ksu.edu.sa (K. Saleem), abderhab@ksu.edu.sa (A. Derhab), jalal@ccis.edu.sa (J. Al-Muhtadi), mehmet@science.mq.edu.au (M.A. Orgun).

http://dx.doi.org/10.1016/j.chb.2014.11.030
0747-5632/

Please cite this article in press as: Saleem, K., et al. Analyzing ant colony optimization based routing protocol against the hole problem for enhancing user's connectivity experience. *Computers in Human Behavior* (2014), http://dx.doi.org/10.1016/j.chb.2014.11.030

Lightweight multi-agent systems are required for PWSNs (Patouni, Kypriadis, & Alonistioti, 2012) to provide highly distributed, robust, self-organizing, and autonomous systems to tackle the aforementioned hole problem in a PWSN. In addition, a group-based multi-agent solution helps to reduce the communication cost, especially the energy consumption, and enhances network communication. Routing protocols designed for PWSNs should intelligently manage the energy over the network to provide the maximum lifetime with efficient network performance (Ahmed et al., 2005; Mathkour et al., 2011; Shahzad & Afzal, 2006; Shahzad & Alwagait, 2012; Wang et al., 2012). Ant colony optimization (ACO) algorithms have been used successfully to addresses the hole problem in PWSNs while leading to efficient network performance.

In biological inspired autonomous systems "ACO algorithms are a class of constructive meta-heuristic algorithms that mimic the cooperative behavior of real ants to achieve complex computations and have been proven to be very efficient in many different discrete optimization problems" (Zhang, Wu, Lu, & Du, 2011). The recently improved ACO-based Biological Inspired Secure Autonomous Routing Protocol (BIOSARP) (Saleem & Fisal, 2012) for PWSNs can overcome the above-mentioned hole problem (Adnan, Razzaque, Ahmed, & Isnin, 2013). In BIOSARP, to acquire an optimal route decision, the authors utilize an improved ant colony optimization (IACO), and an artificial immune system (AIS) is involved to detect abnormalities. BIOSARP depends on probabilistic values called the pheromone values of the neighboring nodes stored in the routing table. The pheromone value is calculated based on the end-to-end delay, remaining battery power, and packet reception rate (PRR). These parameters are updated continuously, which results in maintaining the regional knowledge in the network.

BIOSARP has shown an improved performance compared to the recent MM-SPEED, LQER, RTPC, RPAR, and RTLD routing protocols (Saleem & Fisal, 2013). With respect to security, BIOSARP possesses less processing time, and provides more efficient security measures than those of TinyHash, TinySec-AE, TinySec-Auth, EBSS, TEA LBRS-Auth, SRTLD, and SPINS (Saleem, Khalil, Fisal, Ahmed, & Orgun, 2013). However, despite its promising performance, BIOSARP has not been studied in a scenario with hole problems. In addition, it is unknown how fairly BIOSARP distributes the energy consumption over the network to maximize its lifetime.

The main contributions of this paper are as follows:

1. To the best of our knowledge, this is the first study about the hole problem in ACO-based routing protocols.
2. We utilize the self-adaptation feature of the ACO routing protocol BIOSARP to avoid the hole problem, which results in conserving energy and minimizing packet loss.
3. We analyze the capabilities of two variants of BIOSARP at handling the hole problem, which are with feedback and without feedback mechanisms.
4. We compare BIOSARP without feedback and ODVA in terms of packet delivery and energy consumption. Simulation results show the superiority of BIOSARP.

These results demonstrate that BIOSARP without any additional support can effectively maintain the network prior to any possible holes problem. This is because the protocol selects the most optimal neighboring node to transfer the data packet toward its destination. Furthermore, the analysis shows that BIOSARP fairly distributes the energy consumption over the network.

The next section reviews the related literature and BIOSARP. Section 3 presents the approach to analyze BIOSARP. The implementation, results, and comparison are discussed in Section 4. Section 5 provides the detailed analysis and discussion. Section 6 states the conclusion and future work.

2. Related work

In this section, we first review the state of art routing protocols that can handle void regions and/or the hole problem. Then, we review the recent literature related to ant colony optimization (ACO)-based routing protocols, because of the self-adaptation feature of such protocols. Finally, we review one of the recent ACO-based routing protocols called BIOSARP, which has shown better performance in a WSN for routing data packets.

2.1. Routing protocols for hole/void avoidance in WSN

Traditionally, the routing protocols proposed specifically to tackle the hole problems are location dependent and categorized as geographical routing protocols. In an earlier work, (Intanagonwiwat, Govindan, & Estrin, 2000), the authors present an algorithm for sensor networks that enables the nodes to diffuse their interest in acquiring data to other nodes in the network.

Recently, in Aissani, Mellouk, Badache, and Boumaza (2010), the authors introduced three schemes based on a geographical routing approach for void-avoidance in a WSN. The first scheme prevents the dropping of packets by nodes that are on the boundary. The second one is used by the node that sends the data packets to launch rerouting that is near the void boundary. The third scheme protects the data packets from dropping at concave regions and the nodes beside void-boundaries. The given approach is location dependent and considers the locations of the sender, the center of the void region, and destination while making routing decisions. The authors assume that the location information is discovered by the network itself by using periodic beaconing. Then, while forwarding the packet, the sender marks the packet with the destination location. Complex mathematics is utilized to generate routing decisions based on angles, which requires extra processing time and consumes more battery power. In Aissani et al. (2010), the authors implemented the stateless protocol SPEED and three schemes (SPEED-0h, SPEED-nh, and SPEED-cv) on network simulator-2 (ns-2) to perform a comparison and evaluation in terms of the packet delivery ratio, average end-to-end delay, average path length, and control packet overhead. The results showed that their schemes give better performance than the SPEED protocol. In Aissani, Bouznad, Allia, and Hariza (2013), the authors proposed a three scheme-based approach called RV-SPEED and compared it with the Greedy Perimeter Stateless Routing (GPSR) protocol. The authors claim that their given approach can be used for a WSN, but in all of the conducted simulations, the MAC and physical layers were based on IEEE802.11.

In Preethi and Sumathi (2012), the authors proposed an on-demand routing with void avoidance (ODVA) routing protocol to prevent data packets from forwarding to the nodes at the boundary of a void region. The idea behind ODVA is to generate the neighbor table using the *x* and *y* locations of neighboring nodes. At the initialization phase, a node starts constructing the set of neighboring nodes, which involves 2D-Eculidean distance computation. After completing the neighbor information table, the node processes the out-degree and in-degree of the neighboring nodes. The out-degree of the current node is the number of downstream nodes that are closer to the sink node and is calculated by

Neighbor list information $N(v_i)$

$$N(v_i) = \{v_i \in N | \theta \leq 180^{\circ} | i \in (v_i), i \neq j\}$$

where $\theta = cos^{-1}(a_1a_2 + b_1b_2)/\sqrt{(a_1^2 + b_1^2)(a_2^2 + b_2^2)}$.

If $((V_i) \leqslant 180^{\circ})$, then V_i = out-degree

The current node generates the in-degree, which is the number of upstream nodes closer to the source node and calculated as