Enhanced Ant Colony Algorithm for Self-Optimized Data Assured Routing in Wireless Sensor Networks

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Abstract—Wireless sensor network (WSN) deploys tiny wireless sensor nodes to communicate with each other with limited processing speed, power and security measures. A recent WSN routing protocol defined as Secure Real-Time Load Distribution (SRTLD) has been developed to provide real-time transfer, high delivery ratio, and longer sensor node lifetime. SRTLD has been compared with LQER, MMSpeed, RTPC and RPAR. However, SRTLD uses broadcast packets to perform neighbour discovery for every packet transfer every hop, thus consume high energy. A novel Biological inspired self-organized Secure Autonomous Routing Protocol (BIOSARP) to enhance SRTLD with self-optimized and autonomous secure routing mechanism. The BIOSARP routing protocol depends on the optimal forwarding decision obtained by Ant Colony Optimization (ACO). The pheromone value in ACO is computed based on end-to-end delay, remaining battery power, and packet reception rate metrics similar to SRTLD. The proposed BIOSARP has been designed to reduce overhead broadcast packet in order to minimize the delay, packet loss and power consumption in WSN. In this paper we have presented the improved ACO algorithm that has been utilized in BIOSARP to perform self-optimized routing in WSN. BIOSARP has been studied and verified through simulation in network simulator 2 (NS-2). In simulation study BIOSARP normalized overhead is 12.1% less as compare to E&D ANTS and achieves 14% higher delivery ratio with 9% less power consumption when compared to SRTLD. Hence, the results confirm that BIOSARP offers better performance and can be practically implemented in WSN applications as structural and environmental monitoring, battlefield surveillance.

Keywords-Ant Colony Optimization; Assurance; Autonomous; Biological Inspired; Intelligent Routing; Wireless Sensor Network

I. INTRODUCTION

Networks and telecommunication systems are becoming increasingly complex, because of the size and heterogeneity of networks, as well as the complex interaction among network elements. In telecommunication system, wireless networks have witnessed tremendous development and exponential growth due to the development of heterogeneous devices and applications [1]. Today, there is an immense increase in convergence and integration of different heterogeneous wireless networks that guarantees efficient and effective communication. Primarily these technologies includes: wireless wide area networks (WWANs), wireless local area networks (WLANs) and wireless personal area networks (WPANs). For example, the Bluetooth, wireless sensor network (WSN) and Ultra Wide Bands (UWB) are classified as WPANs. Cellular networks such as GSM are categorized as WWAN, and finally there is High Performance Radio Local Area Networks (HiperLANs).

The recent high-tech advancement, digital electronics and micro-electro-mechanical systems (MEMS), has directed towards low-power, multifunctional, low-cost wireless sensor nodes development [2]. Wireless sensor nodes consist of communicating components, sensing, and data processing. These miniaturized devices named as wireless sensor nodes transfer information within short distances [2]. The enormous wireless sensor nodes communicate with each other in adhoc multipath routing to form a system named as wireless sensor network (WSN) depends on IEEE802.15.4 standard [3]. WSN facilitates a user to productively sense and monitor from a distance [4]. The single wireless sensor node can be very small in size and accordingly the cost of WSN devices also varies. Cost restrictions and size in addition to the computational speed, memory, energy and bandwidth are the constraints that increase complexity of WSN [3].

The WSN challenges like power consumption, additional delay, and packet loss need new mechanism. The autonomous mechanism is capable to overcome the above mentioned adaptability issues specially energy efficiency in wireless sensor network. In order to address autonomous capability, we have proposed BIOlogical inspired self-organized Secure Autonomous Routing Protocol (BIOSARP) [5] that depends on ant colony optimization (ACO). BIOSARP is an extension of prior work done by [6]. Recent routing protocol SRTLD [6] for WSN has improved performance as compared to LQER, MMSpeed, RTPC and RPAR in [6]. In this paper we have presented the design and details of our improved ACO algorithm that has been utilized in BIOSARP to perform self-optimized routing in WSN. The next section reviews the recent related literature. Section 3 shows the design of improved ACO algorithm. Section 4 explains the simulation implementation. Under section 5 comparisons are presented and conclusion is narrated under section 6.
II. RELATED WORK

Under related work the most recent literature on ACO based routing protocols and the recent WSN routing protocol SRTLD has been presented.

A. ACO based Routing Protocol for WSN

Dorigo et al [7] first proposed the multi-agent ant colony mechanism to solve difficult combinatorial optimization problems such as the ACO meta-heuristic, the quadratic assignment problem (QAP) and the traveling salesman problem (TSP) [7]. “ACO algorithms are a class of constructive meta-heuristic algorithms that mimic the cooperative behaviour of real ants to achieve complex computations and have been proven to be very efficient to many different discrete optimization problems” [7]. In ACO algorithms two types of ants are normally employed, forward ant and backward ant. Forward ants, explore and collect information of the paths from the source nodes to the destination node. Due to nature inspired characteristics of the algorithms, such as collaborate cooperation, distributed computation and stochastic search [8], Ant Colony Optimization is particularly suitable for large scale self-organize system and exceeds the traditional metrics in three aspects: scalability, robustness and suitability for dynamic environment.

In [9], the authors propose two adaptive routing algorithms based on ant colony algorithm, the Adaptive Routing (AR) algorithm and the Improved Adaptive Routing (IAR) algorithm. To check the appropriateness of ADR algorithm in the case of WSN, the author modified the ADR algorithm (removing the queue parameters) by involving reinforcement-learning concept and named it as AR algorithm. The AR algorithm did not result in optimum solution. In IAR algorithm by adding a coefficient, the cost between the neighbour node and the destination node, they further improve the AR algorithm. Both AR and IAR algorithms are consuming energy in the initialization phase by broadcasting through every node.

[10] proposed a dynamic adaptive ant algorithm (E&D ANTS) based on Energy and Delay metrics for routing operations. Their main objective is to preserve network lifetime in extreme and minimize the propagation delay by using a novel variation of reinforcement learning (RL). The E&D ANTS results are evaluated with AntNet and AntChain schemes.

B. Review on SRTLD

SRTLD [6] is a real time load routing protocol that provides optimal next hop decision of selecting the forwarding nodes. In order to achieve high gains in the overall performance of WSN, cross-layer interaction was used in the design of SRTLD [6]. The routing management computes the optimal forwarding choice of next hop nodes. The optimization is done using exhaustive search techniques. The optimal forwarding (OF) is computed as follows:

$$\text{OF} = \max (\lambda_1 \cdot \text{PRL} + \lambda_2 \cdot V_{\text{t}} + \lambda_3 \cdot V_{\text{m}} + \lambda_4 \cdot V_{\text{m}})$$ (1)

The network process optimizes the optimal forwarding decision based on the physical parameters that includes signal strength for PRR, remaining battery power using Vbatt and timestamp for end-to-end delay. The optimal forwarding is invoked after discovering neighbouring nodes at every hop. The power management determines the state of transceiver power. Neighbourhood management discovers neighbouring nodes and maintain neighbour table.

III. DESIGN OF IMPROVED ACO ALGORITHM

WSN using standard ACO routing algorithm may experience heavy traffic and overhead which causes the battery to exhaust very fast [10] like, AntNet, AntHocNet, etc. architectures are used for wired and wireless without considering the energy factor. The challenge is to design an ACO routing algorithm for WSN that ensure QoS in terms of throughput, minimize delay and strengthen the network lifetime (battery usage).

In BIOSARP, the routing process is activated only when there is data to be transferred. This concept is known as on-demand routing [10]. Therefore, whenever data D is to be transferred from source to destination the routing process is activated. The routing process in BIOSARP generates optimal decision. To avoid the huge traffic overhead the proposed ACO functions with only two ant agents, which are, Search Ant (SA\(_i\)) and Data Ant (DA\(_i\)) agents, where c is current, n is next, s is source and d is the destination node as given in “Figure 1”. The routing process using proposed ACO is elaborated by flow chart in “Figure 2”. BIOSARP behaviour is explained more clearly and systematically as follows:

- The Data Ant (DA\(_i\)) is called to transfer the traffic, when the data packets D are generated as in “Figure 2”. The Data Ant (DA\(_i\)) checks neighbour table \(R^k\) for pheromone value \(p_{cv} (t)\) where c is current node, v is neighbouring node and k is neighbouring node ID.

- While checking the neighbour table \(R^k\) as in “Figure 2”, if Data Ant (DA\(_i\)) does not found any neighbouring node \(v_k\) entry, it invokes Search Ant (SA\(_i\)).

- Search Ant (SA\(_i\)) searches the neighbouring nodes \(v_k\) and fills up the neighbour table \(R^k\) with new record/records, if any.

- Pheromone value \(p_{cv} (t)\) depends on the neighbouring nodes \(v_k\) characteristics (end-to-end delay, energy and velocity) stored in neighbour table \(R^k\). If Data Ant (DA\(_i\)) could not found pheromone value \(p_{cv} (t)\) in the neighbour table \(R^k\), it calculates the pheromone value \(p_{cv} (t)\) based on the characteristics of the neighbouring node \(v_k\) as mentioned above. The computed pheromone value \(p_{cv} (t)\) is then stored in neighbour table \(R^k\) against the respective neighbouring node \(v_k\).

- Once ant agents (Data Ant (DA\(_i\)) and Search Ant (SA\(_i\))) are generated, they behave in a fully autonomous way. They communicate in an stigmergic
way, through the information they locally read from and write to the nodes.

- At each visited node \( v_k \) and arriving from neighbour \( v_j \) the Data Ant \((DA'_{s→d})\) updates the local routing information in the route from \( s \) to \( d \). In particular, the following data structures are updated: neighbouring nodes \( v_k \) characteristics and the pheromone values \( p_{cv}^k(t) \) used by the ants. Once the ant agents \((DA'_{s→d})\) and \((SA'_{c→n})\) have returned to their destination nodes, the agent is removed from the network.

- At last, the data packets \( D \) are forwarded as presented by “Figure 2”, with the help of Data Ant \((DA'_{s→d})\) according to the best pheromone value

\[ \text{Best} \rightarrow p_{cv}^k(t) \] stored in the routing table \( R^{v_k} \).

Finally, routing management invokes the forwarding mechanism. In the design of BIOSARP, the link quality \( \omega_{cv} \) and energy factors \( \eta_{cv} \) are considered in order to improve the delivery ratio and energy efficiency respectively. The link quality \( \omega_{cv} \) is measured based on PRR to reflect the diverse link qualities within the transmission range. The second heuristic \( \omega_{cv} \) is the link quality value, which is added in probabilistic rule (2) to determine the link quality of neighbouring nodes. Decision based on more parameters helps in attaining better QoS [11, 12]. The probabilistic rule is expressed mathematically as:

\[
p_{cv}^k(t) = \frac{[\tau_{cv}(t)]^\alpha \cdot [\eta_{cv}(t)]^\beta \cdot [\omega_{cv}(t)]^\gamma}{\sum_h [\tau_{cv}(t)]^\alpha \cdot [\eta_{cv}(t)]^\beta \cdot [\omega_{cv}(t)]^\gamma}
\]  

(2)

Where \( p_{cv}^k(t) \) is the main entry required by Data Ant \((DA'_{s→d})\) agent to move from current node \( c \) to neighbouring node \( v \) and with the help of \( k \) which is neighbouring node ID. \( \tau_{cv} \) depends on the end to end delay parameter. \( \eta_{cv} \) is a heuristic evaluation of neighbouring node remaining power. \( \omega_{cv} \) is the second heuristic evaluation of neighbouring node link quality. \( \alpha, \beta \) and \( \gamma \) are parameters weights that controls the priority according to the application needs.

\[
\tau_{cv} = \frac{V}{v_m}, \quad \eta_{cv} = \frac{V_{mbat}}{v_m}\text{batt}, \quad \omega_{cv} = \text{PRR}
\]

Where \( V_m \) is the maximum velocity of the RF signal that is equal to the speed of light. \( V_{mbat} \) is the maximum battery voltage for sensor nodes and is equal to 3.6 volts [6]. The determination of PRR, battery voltage \( (V_{mbat}) \) and packet velocity \( (V) \) is elaborated in the following sections. The routing management is additionally described through flow chart as shown in “Figure 4”. If the neighbour table does not have any neighbouring node information, -1 is assigned to optimal choice. As soon as the algorithm find optimal choice is equal to -1, neighbour discovery process is initiated. Otherwise, the pheromone value is checked as shown via “Figure 4” that should be in between 0.0 and less or equal to 1.0. The pheromone value calculation is performed and then the value is stored in neighbour table, if the value does not falls in the given range. as elaborated in “Figure 4”. This cycle continues until last neighbour table entry. Finally, if the optimal choice contains neighbouring node ID else then -1, the routing management forward the data towards chosen neighbouring node.

The design of the proposed self-optimized secure routing algorithm (BIOSARP) based on Ant Colony Optimization (ACO) as shown in “Figure 3”. The pseudo code of the complete algorithm is given in “Figure 5".
VALUES INITIALIZATION:
Best pheromone value = 0
Optimal Choice = -1
Product of all three parameters Submission of all Entries = 0
Neighbor Table Entry Position = -1

If pheromone value > 0.0 & < 1.0
Best pheromone value = pheromone value
Optimal Choice = Node ID

If Best pheromone value < pheromone value & flag = 1
Best pheromone value = pheromone value
Next optimal node is equal to current node ID

TABLE I. NETWORK PARAMETERS TO SIMULATE ROUTING MECHANISM

<table>
<thead>
<tr>
<th>Propagation Model</th>
<th>Shadowing</th>
</tr>
</thead>
<tbody>
<tr>
<td>path loss exponent</td>
<td>2.45</td>
</tr>
<tr>
<td>shadowing deviation (dB)</td>
<td>4.0</td>
</tr>
<tr>
<td>reference distance (m)</td>
<td>1.0</td>
</tr>
<tr>
<td>Low Rate WPAN</td>
<td>IEEE 802.15.4</td>
</tr>
<tr>
<td>phyType</td>
<td>Phy/WirelessPhy/802_15_4</td>
</tr>
<tr>
<td>macType</td>
<td>Mac/802_15_4</td>
</tr>
<tr>
<td>Operation mode</td>
<td>Non Beacon (unslotted)</td>
</tr>
<tr>
<td>Ack</td>
<td>Yes</td>
</tr>
<tr>
<td>CSThresh_</td>
<td>1.10765e-11 Watts</td>
</tr>
<tr>
<td>RXThresh_</td>
<td>1.10765e-11 Watts</td>
</tr>
<tr>
<td>freq</td>
<td>2.4e+9 Hz</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>3.3 Joule</td>
</tr>
<tr>
<td>Power transmission</td>
<td>1 mW</td>
</tr>
<tr>
<td>Transport layer</td>
<td>UDP</td>
</tr>
<tr>
<td>Traffic</td>
<td>CBR</td>
</tr>
</tbody>
</table>

The sourceaddr and seqno fields are used to fill the source address and the sequence number of transmitter. The originaddr and originseqno fields are used to fill the original source address and sequence number of the packet. The hopcount, batt_rem and deadline fields are used to store the number of hops between the source and the destination. In addition, the timestamp field is used to store the time of packet transmission in order to calculate one hop round trip delay. The performance of BIOSARP has been evaluated using equations as in [6].

Figure 6. Network Simulation Grid (Sink Node (Red), Source Node (Blue) and Sensor node (Green))
V. RESULTS AND COMPARISONS

A. Analysis of BIOSARP ACO Decision by considering Different Metrics

We have generated results by considering every performance metric individually. In this simulation, the end-to-end deadline and the simulation time are fixed at 250 ms and 300 sec respectively. The results of the experiments are shown in “Figure 7”, where (a) the delivery ratio, (b) the energy, and (c) the packet overhead are reported.

B. Comparison between BIOSARP and E&D ANTS

The results of E&D ANTS are taken and network topology to generate BIOSARP results is configured exactly as narrated in [10]. The topology is depicted as a randomly deployed 50-node sensor network in a field of 100m×100m. The bandwidth $B$ of each link is 250 kbps, the maximum is packet size 32 bytes and the traffic load is 5 packets per second.

“Figure 8” shows the routing overhead over the simulation time, where the routing load is the ratio of all the data packets received to the control packets generated. As expected, the normalized overhead is high in case of the E&D ANTS scheme. Because the actual data packets delivered by E&D ANTS are very less and the ratio of control overhead to data packets, like forward ants $F_k$ and backward ants $B_k$, is too high. The BIOSARP normalized overhead which is an average of 12.1% is less as compare to E&D ANTS.

C. Comparison between BIOSARP and SRTLD

“Figure 9” shows that the delivery ratio of BIOSARP is higher up to 14% as compared to the SRTLD routing protocols.

Delivery ratio is increased because the data packets are transferred without any discovery, calculation and processing from source to destination based on the pheromone value. Until and unless some problem occurs on the way, like low link quality, battery finish, etc., than neighbour discovery is invoked.
via neighbourhood management. In the state of problem, the node acts in an autonomous way with help of ACO and performs reselection or rediscovery to acquire other optimal node towards destination. As soon as it retains, the data packets are again start forwarding on the new path.

The utilization of resources is decreased by avoiding rediscoveries, replies, recalculations. As shown in “Figure 10”, BIOSARP consumes up to 9% less power when compared to SRTLD protocols. The reduced power consumption is due better load distributing throughout the sensor network.

![Figure 10. Comparison of BIOSARP and SRTLD in terms of Energy](image)

### VI. CONCLUSION

In this research article we have presented the design, process, flowchart and pseudo code of the improved Ant Colony Optimization (ACO) algorithm for self-optimized routing in Wireless Sensor Network (WSN). In BIOSARP, the routing process is activated only when there is need to transfer data. To avoid the huge traffic overhead the proposed ACO functions with only two ant agents, which are, Search Ant (SA) and Data Ant (DA) agents. The BIOSARP packet header format contains sequence number and deadline fields to avoid looping and to assure the delivery of required data. Analysis and effects of BIOSARP ACO routing decision by using different metrics with different Traffic Load in terms of delivery ratio, energy consumption and packet overhead has been presented. Onwards, BIOSARP has been compared with E&D ANTS and SRTLD. BIOSARP traffic overhead is less than 12.1% as compared E&D ANTS. While comparing to SRTLD the delivery ratio of BIOSARP is higher up to 14% with 9% less energy consumption. In the near future BIOSARP with enhanced AIS based self-security will be studied in real WSN testbed.

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**REFERENCES**


