International Journal of Communication Networks and Information Security (IJCNIS) Vol. 1, No. 2, August 2009

Ant based Self-organized Routing Protocol for Wireless Sensor Networks

K.Saleem[1], N.Fisal[2], S.Hafizah[3], S.Kamilah[4] and Rozeha A. RAshid[5]

[12345]Faculty of Electrical Engineering, Universiti Teknologi Malaysia,
81310-Skudai, Johor, Malaysia
[1]*kashnet@hotmail.com*, [2]*sheila@fke.utm.my*

Abstract: The field of wireless sensor networks (WSNs) is an important and challenging research area today. Advancements in sensor networks enable a wide range of environmental monitoring and object tracking applications. Moreover, multihop routing in WSN is affected by new nodes constantly entering/leaving the system. Therefore, biologically inspired algorithms are reviewed and enhanced to tackle problems arise in WSN. Ant routing has shown an excellent performance for sensor networks. Certain parameters like energy level, link quality, lose rate are considered while making decisions. These decisions will come up with the optimal route. In this paper, the design and result of ant based autonomous routing algorithm for the sensor networks is presented. The proposed bio-inspired self-organized algorithm will also meet the enhanced sensor network requirements, including energy consumption, success rate and time.

Keywords: ANT Colony, Self-Organization, Wireless Sensor Network, Multihop Communication, Anycast Forwarding.

1. Introduction

Wireless communication plays an important role these days in the sector of telecommunication and has huge importance for future research. There has been an exponential growth in wireless communication due to development of different devices and applications. This development subsequently increases the complexity of the network. Also some of infrastructure less wireless sensor networks deployment area is out of human reach. The wireless sensor network serves an extremely valuable position in sensing and monitoring systems. In sensing and monitoring systems new gadgets and software advancement are very frequently available to the end-user. The above mentioned challenges like growing complexity, unreachable maintenance and unsecure communication need new mechanisms.

The new mechanism can maintain the features of wireless sensor networks (WSNs) such as multihop routing and dynamically environmental changes in a complete autonomous mode. In order to address autonomous capability for multihop WSNs, it has been visualize that self-organized network application can understand the network operational objectives. Additionally, probabilistic methods that provide scalability and preventability can be found in nature and adapted to technology.

Towards this vision, it is observed that various biological principles are capable to overcome the above adaptability issue. The area of bio-inspired network engineering has the most well known approaches which are swarm intelligence (ANT Colony, Particle swarm), AIS and intercellular information exchange (Molecular biology)[1-4]. WSN routing algorithms based on ACO have been presented in last few years, such as [5], Sensor-driven Cost-aware Ant Routing (SC), the Flooded Forward Ant Routing (FF) algorithm, and the Flooded Piggybacked Ant Routing (FP) algorithm [6], Adaptive ant-based Dynamic Routing (ADR) [7], Adaptive Routing (AR) algorithm and Improved Adaptive Routing (IAR) algorithm [8], E&D ANTS [9]. The author of [4] propose misbehavior detection in nature inspired MANET protocol, BeeAdHoc.

This paper present a novel architecture by implementing the most well known and successful approaches. ANT Colony Optimization (ACO) method is utilized for the optimum route discovery in multihop WSN. These techniques will be accomplished by assigning each procedure to the group of agents. The agents will work in a decentralized way to collect data and/or detect an event on individual nodes and carry data to required destination through multihop communication.

The next section reviews the related research for optimum route discovery through ACO. Section 3 shows the methodology of our mechanism. Section 4 describes the implementation and preliminary results. The conclusion and future work are stated under section 5.

2. Related Research

2.1 Overview of Ant Routing in WSN

Ant colony algorithms were first proposed by Dorigo et al [5] as a multi-agent approach to difficult combinatorial optimization problems like the traveling salesman problem (TSP) and the quadratic assignment problem (QAP), and later introduced the ACO meta-heuristic.

There are two types of ants applied in the algorithms, forward ants and backward ants. Forward ants, whose main actions are exploring the path and collecting the information from the source nodes to destination node, have the same number as the source nodes. The paths that forward ants travel will construct a tree when they merge into each other or reach the destination and data is transmitted along the tree paths. There are two key factors that conduct the movement of the forward ants: one is pheromone trails that are deposited along the edges, and the other is the nodes potential which provides an estimate of how far an ant will have to travel from any the node to either reach the destination d or to aggregate data with another node. While the backward ants, traveling back from destination node to source nodes contrary to the forward ants, perform their uppermost function of updating the information of their pass-by nodes.

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 to many different discrete optimization problems. Many theoretical analyses related to ACO show that this optimization can converge to the global optima with non-zero probability in the solution space [10] and their performance have greatly matched many well-studied stochastic optimization algorithms, for example, genetic algorithm, pattern search, GPASP, and annealing simulations [5].

Sanjoy Das et al have given an on-line ACO algorithm using AntNet techniques for MSDC [11] which has been formalized to be a typically Minimum Steiner Tree problems. Improved algorithm proposed by adding another type of ants, random ants, just like the newspaper deliverer, whose main task is to dissipate information gathered at the nodes among other neighboring nodes. Simulation results also show that their algorithms are significantly better than address-centric routing. In these proposed algorithms the forward ants normally spend a long time. There is a bug of dead lock in their algorithms. In their improved algorithm, a large amount of random ants are needed.

In [5] the authors propose a new idea of keeping the information by all sensor nodes of their own. By this even in the absence of global processing the nodes still can work on their own information. In this research still have a drawback of broadcasting while initialization phase which consumes lot of energy at the beginning of the network deployment.

Zhang et al. [6] proposed three ant-routing algorithms for sensor networks. The SC algorithm is energy efficient but suffers from a low success rate. The FF algorithm has shorter time delays; however, the algorithm creates a significant amount of traffic. Despite high success rate shown by the FP algorithm that it is not energy efficient.

An Adaptive ant-based Dynamic Routing (ADR) algorithm using a novel variation of reinforcement learning was proposed by Lu et al. [7]. The authors used a delay parameter in the queues to estimate reinforcement learning factor.

In [12] proposed a novel approach for WSN routing operations. Through this approach the network life time is maintained in maximum while discovering the shortest paths from the source nodes to the base node using an evolutionary optimization technique. The research has also been implemented on microchip PIC® series hardware, called PIC12F683.

In [8] 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 suitability of ADR algorithm in the case of sensor networks, they modified the ADR algorithm (removing the queue parameters) and used their reinforcement learning concept and named it the AR algorithm. The AR algorithm did not result in optimum solution. In IAR algorithm by adding a coefficient, the cost between the neighbor node and the destination node, they further improve the AR algorithm.

[9] proposed a dynamic adaptive ant algorithm (E&D ANTS) based on Energy and Delay metrics for routing operations. Their main goal is to maintain network lifetime in maximum and propagation delay in minimum by using a novel variation of reinforcement learning (RL). E&D ANTS results was evaluated with AntNet and AntChain schemes.

2.2 Comparison of the most recent ANT based Routing in WSN

Comparison of the most recent ANT based routing in WSN: SC and [12] depends on the energy metric while FF based on delay. IA and IAR is the modification of ADR which used a delay parameter in the queues to estimate reinforcement learning factor. In FP they combine the forward ant and data ant to enhance the success rate. E&D ANT based on energy and delay metrics for routing operations. In our proposed algorithm, the best values of velocity, PRR and remaining power mechanism [13] are used to select forwarding node because velocity alone does not provide the information about link quality. The best link quality usually provides low packet loss and energy efficient [14]. Another novel feature of proposed algorithm is, it utilizes the remaining power parameter to select the forwarding candidate node.

The remaining power assists the source node or intermediate node to distribute the forwarding load to all available forwarding candidates and hence avoid the routing holes problem.

Title of the Mechanism	Velocity or Deadline	Remaining Power	Link Quality	Types of Forwarding
SC		Energy Efficient		Multicast (one-to-many) and Converge-cast (many-to-one)
FF			network layer estimation	Multicast and Converge-cast
FP	Forward Agent + Data Agent		network layer estimation	Multicast and Converge-cast
AR	Heuristic Correction Factor			Broadcast, Unicast & Multicast
IAR	Heuristic Correction Factor			Geographic Routing
Okdem	Path costing	Energy Level		Broadcast, Unicast & Multicast
E&D ANTS		Energy	Network Layer Estimation	Broadcast, Unicast & Multicast

Table 1. Comparison of most recent ant based protocols for WSN.

3. Methodology

System design deals mainly with the development of state machine diagrams the routing management, neighborhood management and energy management as shown in Figure 1. Routing management will be dependent mostly on forwarding metrics calculation. While establishing the forwarding procedure, the routing management will look for the next best node towards the destination through the routing table, available at every node. By acquiring the optimal route from the routing table, routing management will finalize the forwarding process. Otherwise, if it could not find next node towards destination, then routing management will call the process of neighbor discovery under neighborhood management as shown in Figure 1.

The neighborhood management will then search for the best neighboring node by calling method. Calling method take place through broadcasting hello massages. The node which broadcast will receive replies from the neighboring nodes along with their characteristics. On the base of these replays it provides the final solution back to the routing management state. According to this solution the routing management state will update the routing table on current node.

The key role of power management state is to check the remaining power and inform accordingly to the higher state. The power management state also can adjust the power for the transceiver according to the environmental conditions. Under this state the energy parameter is imported from the physical layer into the network layer. In wireless sensor node there are 5 levels of power transmission. At the time of forwarding the first level is utilized, but if node is out of reach then the power level is increased in stages. Helping neighborhood management state in the energy aware route discovery and power level management is controlled by the power management state.

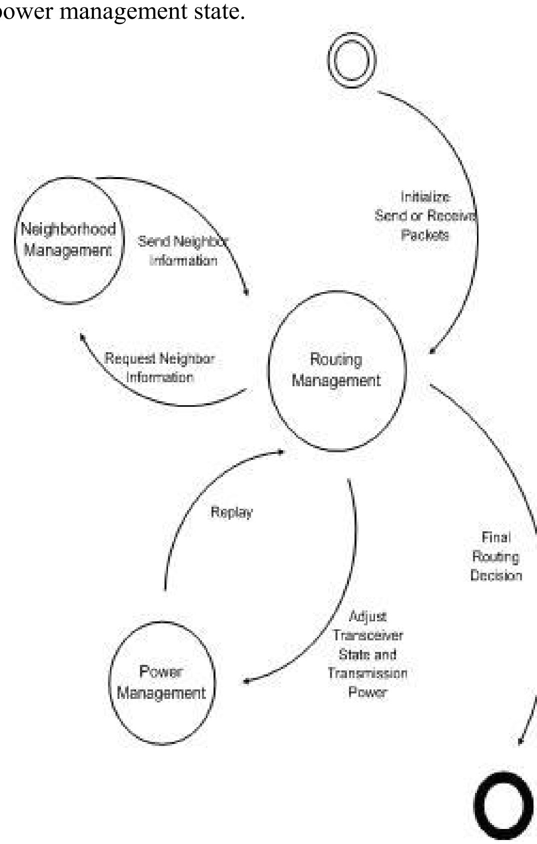

Figure 1. System Diagram.

Inside routing management the forwarding metrics calculation takes place as shown is Figure 2. The forwarding metrics as given in Table 2 are calculated to get the optimal route decision towards the destination. If the error occurred while processing this state, it will be control by routing problem handler as elaborated in Figure 2. The error can be like required neighbor not present or the best neighboring node is lost or the required parameter is not there. Otherwise, if there is no error while forwarding calculation then the anycast state will be called to forward the required packets.

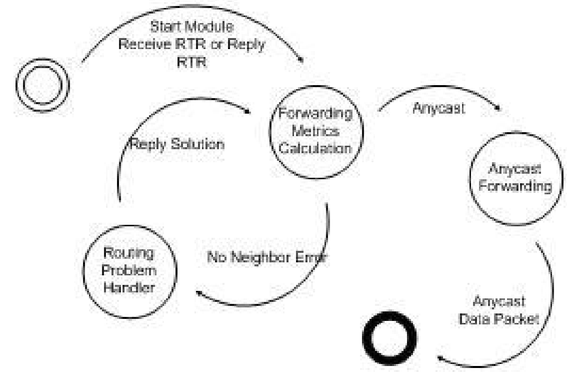

Figure 2. Routing Management

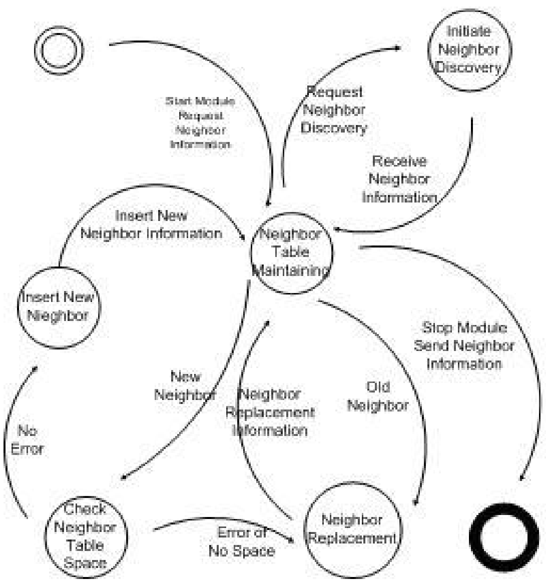

Figure 3. Neighbor Manageent.

Common functions under neighbor management state are neighbor table maintenance, neighbor discovery, insert new neighbor, neighbor replacement, etc as exposed in Figure 3. Main and most important thing the routing table is maintained via this state. If the best node towards the destination could not be found, the child state neighbor discovery is initiated. The explored new nodes will be checked with the old records by neighbor replacement process. While inserting a new record, the routing table space is first checked by neighbor table space state according to the wireless sensor node memory. Finally, the new record is inserted in routing table through insert new neighbor state.

Our proposed self-organized system mainly based on routing section. The optimal route discovery is tackled by ant colony optimization. Routing decision will achieved through probabilistic decision rule described in [12]. The probabilistic decision rule can be expressed mathematically by

$$p_{ij}^{k}(t) = \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}{\sum_{h \in J_i^k}[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}} \qquad (1)$$

- $p_{ij}^{k}(t)$ overall desirability for ant *k located in city i to choose to move to city j*.
- T*ij is a value stored in a pheromone table.*
- η*ij* is an heuristic evaluation of edge (*i,j*).

The decision will depend on the used metrics as, velocity, PRR and remaining power mechanism as given in Table 2.

	Packet Receiving Rate	Energy	Delay
Node 1	α^1	γ^1	β^1
Node 2	α^2	γ^2	β^2
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
Node n	α^n	γ^n	β^n

Table 2. Routing Metrics

The algorithm for each component in the designed system has been written and relations between the system models are established. Energy management is evolved to maintain the energy consumption of every sensor node in WSN.

4. Logical Implementation

To evaluate the above analysis, we use network simulator 2 (NS2) to construct the network topology graph as given in Figure 4. The topology is described as a randomly deployed 12-node sensor network. For the Bio-inspired routing algorithm implementation, the program is written in NesC programming language.

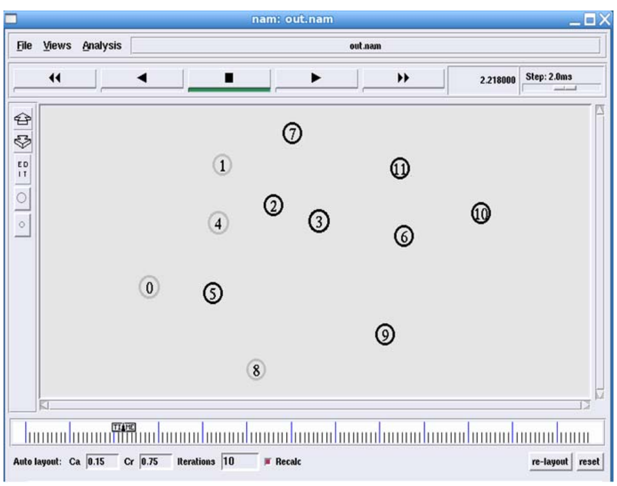

Figure 4. Network Topology

In Figure 4, each link is bidirectional and the weighting value of the link depends on the power consumption (nJ/bit) and ant's moving time delay (ms). After the source nodes produce a quantity of artificial ants or packets conforming to the Poisson distribution, the destination nodes are randomly chosen by average probability. When one packet passes through a node by a certain speed, the node takes the first step to gather all the ant agents into buffer storage and then selects the optimal path from its routing table to transfer packets.

In this way all the ants disperse in as many paths as possible to achieve the balance of the load. A fixed size of one packet is considered in our simulation. The experimental parameters used to configure the system according to WSN are listed in Table 3. In order to avoid cycles and the routing table's freezing, we need to initialize τ_0 as in [15].

Parameters	Values
Reinforcement factor	0.05
Propagation Model	Shadowing
path loss exponent	2.5
shadowing deviation (dB)	4.0
reference distance (m)	1.0
phyType	Phy/WirelessPhy/802_15_4
macType	Mac/802_15_4
CSThresh_	1.10765e-11
RXThresh_	1.10765e-11
frequency	2.4e+9
Traffic	CBR

Table 3. System Properties

In this case, ant agents can adjust to the more efficient path when the network traffic loads change and the congestion fades away. Simulation methods for the AntNet were attempted in [16] where the parameters (c, a, a', ε, h, t) were set to (2, 10, 9, 0.25, 0.04, 0.5).

Initial result through this implementation is the pheromone table on each node. As an example pheromone table at node 0 is shown in Table 4. Table at each node contains the pheromone value for the next node towards the required destination. While the network is online, the routing table is directly built up through pheromone table exponential transformation.

dest	next	phvalue	dest	next	phvalue
1	4	0.4809	6	1	0.5024
1	1	0.5190	7	4	0.4990
2	4	0.4881	7	1	0.5009
2	1	0.5118	8	4	0.5118
3	4	0.4970	8	1	0.4881
3	1	0.5029	9	4	0.5113
4	4	0.5239	10	4	0.5044
4	1	0.4760	10	1	0.4955
5	4	0.5059	11	4	0.5024
5	1	0.4940	11	1	0.4975
6	4	0.4975			

Table 4. Phermone Table at Node0

5. Conclusion

In this paper, we have proposed an enhanced ant colony inspired self-organized routing mechanism for WSNs. Our specified mechanism is based is based on delay, energy and velocity. The adopted factors help WSN in improving the overall data throughput; especially in case of real time traffic while minimizing the energy consumption. The algorithm is also capable to avoid permanent loops which promotes dead lock problem in the running networks.

The dead lock problem is cured by assigning unique sequence ID to every forward ANT and also to search ANT. Simulation results clearly demonstrate the protocol efficiency and also verify that the protocol is more practicable. Furthermore, this algorithm is also enhanced with reinforcement learning (RL) feature to get superior optimal decision. Finally, this autonomic routing mechanism will come up with better success rate, time and energy consumption.

Our immediate future work involves the building and testing of given self-organize protocol in the real WSN test bed. Onwards, other ant colony variants will also be considered.

6. Acknowledgment

I wish to express my sincere appreciation, sincerest gratitude to Ministry of Higher Education Malaysia for their full support and Research Management Center, Universiti Teknologi Malaysia (UTM) for their partial and special thanks to researchers in Telematic Research Group, UTM.

References

[1] S. Balasubramaniam, D. Botvich, W. Donnelly, M. Foghluh, and J. Strassner, "Biologically Inspired Self-Governance and Self-Organisation for Autonomic Networks," in *IEEE*, 2006.

[2] S. Balasubramaniam, W. Donnelly, D. Botvich, N. Agoulmine, and J. Strassner, "Towards integrating principles of Molecular Biology for Autonomic Network Management," in *Hewlett Packard university Association (HPOVUA) conference*, Nice, France., 2006.

[3] P. Boonma and J. Suzuki, "MONSOON: A Coevolutionary Multiobjective Adaptation Framework for Dynamic Wireless Sensor Networks," in *In Proc. of the 41st Hawaii International Conference on System Sciences (HICSS)* Big Island, HI, 2008.

[4] N. Mazhar and M. Farooq, "BeeAIS: Artificial Immune System Security for Nature Inspired, MANET Routing Protocol, BeeAdHoc," *Springer-Verlag Berlin Heidelberg,* vol. LNCS 4628, pp. 370–381, 2007.

[5] G. Chen, T.-D. Guo, W.-G. Yang, and T. Zhao, "An improved ant-based routing protocol in Wireless Sensor Networks," in *Collaborative Computing: International Conference on Networking, Applications and Worksharing, 2006. CollaborateCom 2006.*, Nov. 2006, pp. 1-7.

[6] Y. Zhang, L. D. Kuhn, and M. P. J. Fromherz, "Improvements on Ant Routing for Sensor Networks," *M. Dorigo et al. (Eds.): ANTS 2004, Springer-Verlag Berlin Heidelberg 2004,* vol. LNCS 3172, pp. 154-165, 2004.

[7] Y. Lu, G. Zhao, and F. Su, "Adaptive Ant-based Dynamic Routing Algorithm," in *In Proceedings of the 5th World Congress on Intelligent Control and Automation*, Hangzhuo, China, June 2004, pp. 2694-2697.

[8] R. G. Aghaei, M. A. Rahman, W. Gueaieb, and A. E. Saddik, "Ant Colony-Based Reinforcement Learning Algorithm for Routing in Wireless Sensor Networks," in *Instrumentation and Measurement Technology Conference - IMTC* Warsaw, Poland: IEEE, 2007.

[9] Y.-f. WEN, Y.-q. CHEN, and M. PAN, "Adaptive ant-based routing in wireless sensor networks using Energy*Delay metrics," *Journal of Zhejiang University SCIENCE A* vol. 9, pp. 531-538, 2008.

[10] T. Stuetzle and M. Dorigo, "A short convergence proof for a class of ACO algorithms," *IEEE Transactions on Evolutionary Computation,* pp. 358-365, 2002.

[11] G. Singh, S. Das, S. Pujar, and S. Gosavi, "Ant Colony Algorithms for Steiner Trees: An application to Routing in Sensor Networks," IGI press, 2004.

[12] D. Karaboga, "Routing in Wireless Sensor Networks Using Ant Colony Optimization" in *Proceedings of the First NASA/ESA Conference on Adaptive Hardware and Systems (AHS'06)*, 2006.

[13] L. A. L. A. Ali, M.A. Sarijari, N. Fisal, "Real-time Routing in Wireless Sensor Networks," in *The 28th International Conference on Distributed Computing Systems Workshops*, Beijing, China, 2008.

[14] J. Zhao and R. Govindan, "Understanding Packet Delivery Performance in Dense Wireless Sensor Networks," in *Proceedings of the 1st international conference on Embedded networked sensor systems*, USA, 2003.

[15] B. Barin and R. Sosa, "A New approach for AntNet routing," in *Ninth International Conference on Computer Communications and Networks, 2000. Proceedings*, Las Vegas, NV, USA, 2000, pp. 303-308.

[16] G. D. Caro, F. Ducatelle, and L. M. Gambardella, "AntHocNet: An adaptive nature-inspired algorithm for routing in mobile ad hoc networks," *European Transactions on Telecommunications,* vol. 16, pp. 443-455, 2005.