A Self-Optimized Multipath Routing Protocol for Wireless Sensor Networks

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***Abstract*— Wireless sensor networks (WSNs) is becoming a progressively important and a challenging research area. Advancements in WSN enable a wide range of environmental monitoring and object tracking applications. Moreover, multihop routing in WSN is affected by new nodes constantly entering or leaving the network. Therefore, the self-optimized and self-aware mechanism is required to handle the problems arise very frequently in WSNs. The ant colony optimization has shown excellent results in discovering routes for WSN. In this paper, the model of self-optimized multipath routing algorithm for WSN and its results are presented. Certain parameters like energy level, delay and velocity are considered. These decisions will come up with the optimal and organized route for WSN. In addition, the stated algorithm is enhanced with the multipath capability to avoid congestion state in WSN. Eventually, the enhanced feature helps WSN in maximizing the data throughput rate and minimizing the data loss**

***Keywords*— ant colony optimization, multipath, routing protocol, self-optimization, wireless sensor network**

I. INTRODUCTION

Wireless communication plays valuable role in the sector of telecommunication and got huge importance for the future research. Some of infrastructure less networks like wireless sensor networks (WSNs) serves an imperative task in monitoring. Due to the development of wireless sensing systems, monitoring becomes much simpler. With the passage of time new gadgets and software advancements are getting available in WSN very frequently to the end-user. The stated fast growth and huge number of devices in the network make WSN more and more complex. The deployment area for WSNs is mostly out of the human reach. Many protocols and algorithms, like DSR and AODV, have been proposed for traditional wireless ad hoc networks. But they are not well suited for the unique features and application requirements of WSNs [1].Above mentioned challenges as growing complexity and unreachable maintenance need new mechanisms. The new self-organized mechanism can maintain the features of 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 adaptability problems. 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)[2- 5]. WSN routing algorithms based on ACO have been presented in last few years, such as [6], Sensor-driven Cost aware Ant Routing (SC), the Flooded Forward Ant Routing (FF) algorithm, and the Flooded Piggybacked Ant Routing (FP) algorithm [7], Adaptive ant-based Dynamic Routing (ADR) [8], Adaptive Routing (AR) algorithm and Improved Adaptive Routing (IAR) algorithm [9], E&D ANTS [10]. The problem of the previous approaches is, the selected shortest path might not be a minimum energy cost route. Some other works concentrate on decreasing the energy consumption by replacing the hop-count routing with minimum energy routing. They compute a minimum-energy path for packet delivery in a multi-hop wireless network. However, the nodes on this path will get depleted soon [11].

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

Furthermore, due to the extremely tiny size, the sensors tend to have storage space, energy supply and communication and width so limited that every possible means of reducing the usage of these resources is aggressively required [1]. For example, a sensor typically has 8-120KB of code memory and 512-4096 bytes of data memory. The transmission bandwidth ranges from 10kbps to 115kbps [1]. Due to these network constraints the huge packet loss and congestion originates in WSN [12]. Node level congestion and link level congestion are the two types which can occur in WSNs [13]. Therefore, to avoid these problems we enhance our routing algorithm with multipath capability. This enhancement helps WSN in maximizing the data throughput rate and minimizing the packet loss.

The next section reviews the related research for optimal route discovery through ACO and also the multipath routing mechanisms. Section 3 shows the methodology of our routing protocol. Section 4 describes the implementation. The results are given under section 5 and conclusion is declared under section 6.

II. RELATED RESEARCH

A. ACO based Routing Protocols

Dorigo et al [6] proposed the first ant colony algorithms 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. Whereas 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 metaheuristic 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 [14] and their performance have greatly matched many well studied stochastic optimization algorithms, for example, genetic algorithm, pattern search, GPASP, and annealing

B. Overview of ACO based routing algorithms in WSN

Zhang et al. [7] 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. [8]. The authors used a delay parameter in the queues to estimate reinforcement learning factor.

In [15] proposed a novel approach for WSN routing operations. Through this approach the network life time is maintained in maximum, for 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 [9] 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.

[10] 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.

C. Routing Techniques with Multipath Feature

Currently, lots of work is going on congestion control for WSNs. Scenarios with multipath routing are not considered. It is not clear whether they can be directly applied to WSNs with multipath routing enabled. Moreover, most of the protocols deal with homogeneous traffic [12].

Earlier routing schemes for sensor networks involve direct communication protocols which facilitate direct communication between the source node and the base station [16]. Therefore, for scenarios where the base station is quite a distance away from the source node, there is excessive usage of energy resources, ultimately resulting in a complete drainage of power on a certain path.

Recently, in [12] have presented an efficient scheme to perform multipath congestion control for heterogeneous traffic which avoids packet loss and thus enhances the probability of achieving the desired throughput of heterogeneous traffic. The congestion detection mechanism is chosen based on packet service ratio and congestion notification. In the proposed protocol they have assumed three points: 1. Every sensor node in the network has equal number and same types of sensors, 2: Multiple routes have been established by any multipath routing protocol, 3: While establishing the route the sink dynamically assigns individual priority for the heterogeneous application data. Each sensor node can transmit route data of its children nodes as well as its originating data. They have calculated the average packet service time at MAC layer by using Exponential Weighted Moving Average (EWMA) formula.

[13] proposed a node priority based control mechanism PCCP for WSN. It introduces an efficient congestion detection technique addressing both node and link level for detecting congestion. PCCP prioritizes both source and transit traffic but here the limitation of handling multiple sensed data within a node also remains.

III. METHODOLOGY

System design deals mainly with the development of state machine and flow chart diagram of the sections as routing, security and energy management as shown in Fig. 1. Routing management will be dependent mostly on forwarding metrics calculation. If any error occurred in this state, generated error will be handled by the routing problem handler as elaborated in Fig. 2.

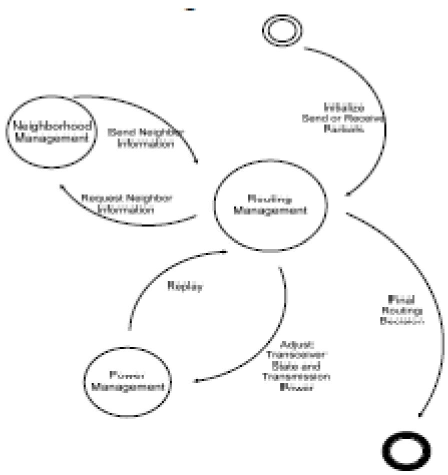

Figure 1. System Diagram

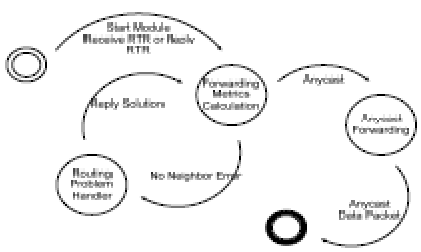

Figure 2. Routing Management

Further onwards the most important state in this routing mechanism is neighbor management. New or a better neighbor will be managed through this state. Common function in neighbor management state is neighbor table maintenance, neighbor discovery, insert new neighbor, neighbor replacement, etc as exposed in Fig. 3.

Our proposed self-organized system mainly based on routing section. The optimal route discovery is tackled by ACO. Routing decision will achieved through probabilistic decision rule described in [15]. The decision will depend on the used metrics as, velocity, PRR and remaining power mechanism as given in Table I. The probabilistic decision rule can be expressed mathematically by

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

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

TABLE I.
ROUTING METRICS

	Packet Receiving Rate	**Energy**	**Delay**
Node 1	α^1	$\gamma 1$	β^1
Node 2	α^2	$\gamma 2$	β^2
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
Node n	α^n	γ^n	β^n

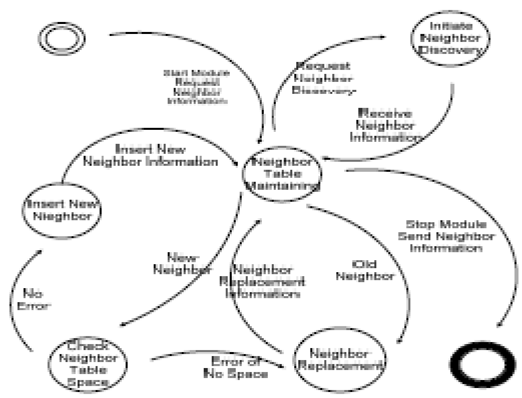

Figure 3. Neighbor Management

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. In order to achieve high gains in the overall performance of WSN, cross-layer interaction is used in the design of routing algorithm.

The concept of multipath feature is towards distributing the traffic load among two or more routes. Load distribution is to avoid the congestion problems in the network and to increase data throughput rate. The proposed system uses both single-path routing and multi-path routing in order to select the route with the best maximum data throughput rate as shown in Fig. 4.

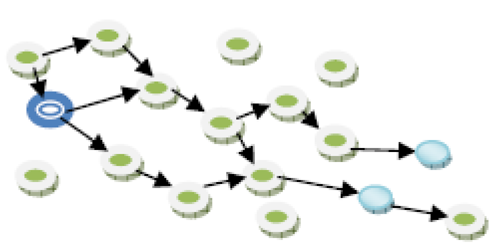

Figure 4. Multipath Routing.

The self-optimized routing mechanism works at the network layer and optimize the decision based on the physical parameters translated as forwarding metrics. The physical parameters are the PRR and remaining power. The forwarding metrics is used to get an optimal decision. The forwarding metrics are requested only during neighbor discovery and network initialization phase.

IV. SIMULATION

The scenario was simulated using network simulator 2 (NS2) [17] based on the network topology. 25 wireless sensor nodes were deployed onto 50 x 50 m2 grid as shown in Fig. 5. The self-optimized multipath routing algorithm is implemented under NS2. Program is written in C++ and OTcl programming language

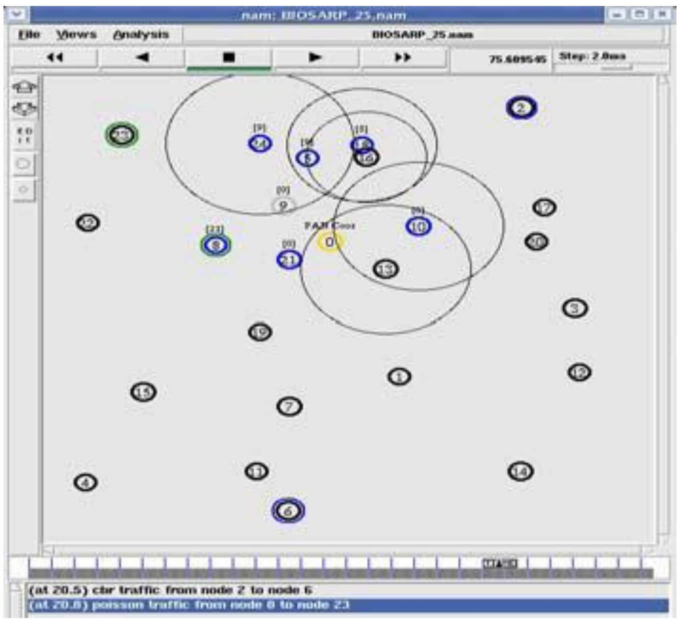

Figure 5. Graphical Representation of Network Topology.

Each link is bidirectional and the weighting value of the link depends on the power consumption (nJ/bit), ant's moving time delay (ms) and packet reception rate (PRR). After the source nodes produce a quantity of artificial ants, 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 II. In order to avoid routing cycles we initialize $\tau 0$ as in [18].

TABLE II.
SYSTEM PROPERTIES

Parameters	Values
Reinforcement factor	0.05
Propagation Model	Two Ray Ground
phyType	Phy/WirelessPhy/802_15_4
macType	Mac/802_15_4
CSThresh_	8.54570e-07 (15m)
RXThresh_	8.54570e-07 (15m)
frequency	2.4e+9
Traffic	FTP,CBR, POISSON

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 [19] where the parameters (c, a, a', ε, h, t) were set to (2, 10, 9, 0.25, 0.04, 0.5).

V. RESULTS

The results presented in this paper, through the logical implementation of WSN, are the real time graphical network topology and graphs by the accumulated results. Graphical representation is through the network animator (nam) under NS2 as shown in Figure 5.

During the animation produced by nam we can examine the output of network. The cbr traffic is produced first from node 2 to node 6, then the Poisson traffic from node 8 to node 23. Each node contains a table with the pheromone value. This table contains information about the neighboring nodes towards the required destination. The routing table is automatically built up through a process of pheromone table exponential transformation. Secondly, presented the graphs generated by the Trace graph 2.05[20]. These graphs are depending on the results extracted from a trace file produced under NS2. Through parameters adjustment under trace graph we got the network information accordingly as given in Figure 6.

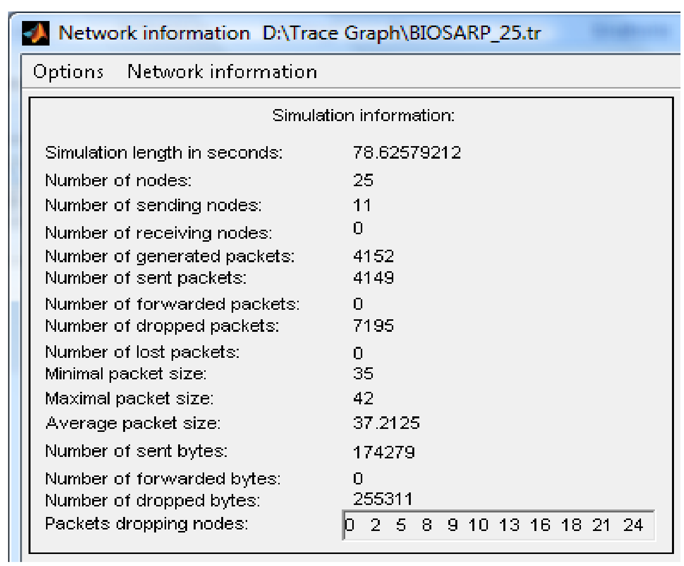

Figure 6. Network Information

In Fig. 7 the throughput of generated packets against the simulation time is exposed and in same Fig. 7 shows us the dropping of packets also. With the help of these results we can check the different states of network, like the sleep/wake state. By examining these states we can also improve our parameters to minimize the energy consumption.

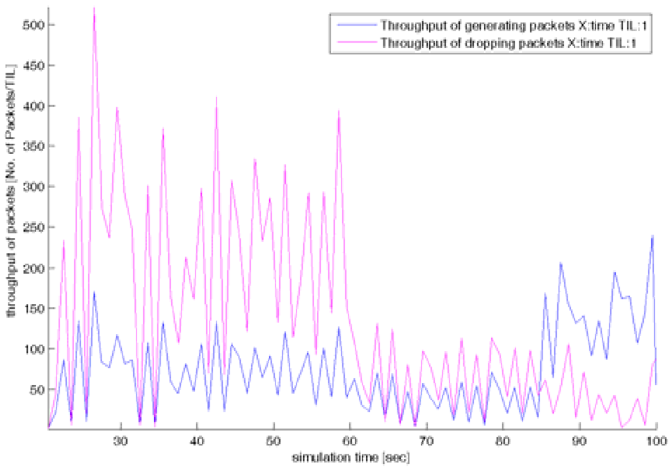

Figure 7. Throughput of Generated and Dropping Traffic.

VI. CONCLUSION

In this paper, we have proposed an enhanced ant colony inspired self-organized routing mechanism for WSNs. Our specified mechanism is based on delay, energy and velocity. The adopted factors and reinforcement learning (RL) feature help WSN in improving the overall data throughput; especially in case of real time traffic. 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 practicable. Furthermore, this algorithm is enhanced with the multipath feature to reduce congestion situations in WSN. Finally, this autonomic routing mechanism will come up with better data throughput rate while minimizing packet loss.

Our immediate future work involves the comparison of the presented algorithm with the most recent routing protocols for WSNs. After comparison we will apply our self-organized routing protocol in the real WSN test bed. Onwards, other ant colony variants will also be considered.

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