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Performance Analysis of ACO Based Routing Protocols-EMCBR, AntChain, IACR, ACO-EAMRA for Wireless Sensor Networks (WSNs)

Anand Nayyar[1*] and Rajeshwar Singh[2]

[1]Research Scholar, Department of Computer Science, Desh Bhagat University, Mandi Gobindgarh, India.
[2]Doaba Group of Colleges, Nawanshahr, Punjab, India.

Authors' contributions

This work was carried out in collaboration between both the authors. Author AN designed the study, literature review, selection of Ant Colony Based Routing Protocols for Wireless Sensor Networks to be used for performance comparison, analyzed the various simulation parameters, programmed the protocols in NS-2 simulator and performed simulation on various WSN based performance parameters. Author RS analyzed the results and observed the best protocol among all the protocols being compared and validated the results outcome. Both the authors read and approved the final manuscript.

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Study Protocol

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Abstract

This research paper is study of ACO based routing protocols proposed for Wireless Sensor Networks by various researchers. The protocols comprehensively compared via this research paper are: Ant Colony Based Energy Aware Multipath Routing Algorithm for Wireless Sensor Networks (ACO-EAMRA), Improvised Ant Colony Routing (IACR), Efficient Minimum Cost Bandwidth Constrained Routing in Wireless Sensor Networks (EMCBR) and AntChain Protocol. Extensive study on simulations are made on different scenarios and simulation time on Random Way Point Mobility Model for all protocols. The results show that overall IACR is best among all the other protocols to the extent about 30-40% better in terms of Packet Delivery, Energy Efficiency and maintaining overall robustness and scalability of Wireless Sensor Networks.

**Corresponding author: E-mail: anand_nayyar@yahoo.co.in;*

Keywords: Wireless Sensor Networks; Swarm Intelligence; Ant Colony Optimization; ACO Routing Protocols; EMCBR; AntChain; IACR; ACO-EAMRA; AntNet; Basic ACO; Simulation; NS-2; Energy Efficiency.

1 Introduction

In 21st Century, MEMS (Micro-Electro-Mechanical Systems), Wireless Communications and Smart Sensor Networks [1] are coming up with spectacular advancements which has led to the design and incorporation of low-cost, power-efficient and multi-purpose wireless sensor nodes capable of communicating data at short distances with Quality of Service. Sensor nodes are highly efficient in data sensing, processing and communicating. Sensor networks are deployed in diverse real-time applications like Civilian, Military, Environmental monitoring, Industrial production and control. These days, traditional sensors are completely replaced with Smart sensor nodes which are low power consuming devices and equipped with one or more varied sensors, processor, memory control unit, power supply, radio transmitter and actuator. Wireless Sensor Networks [2,3] technology provides unique advantages and have significant edge over conventional networking solutions and Mobile Adhoc Networks (MANETS) [4,5] in terms of low pricing, reliability, scalability, efficiency, flexibility, easy deployment and faster computational capabilities. In Sensor Network, there lies beneath the capabilities of Wireless Adhoc-Network, in which every sensor is capable of supporting multi-hop routing algorithm and every node act as packet relaying agent to transmit the sensed data back to sink/base node in the network. The potential of Wireless Sensor Networks applications is therefore, making WSN network a growing market worth trillions of dollars, but WSN requires major progress and improvements considering the standards, topologies, issues to support new applications deployment.

The primary responsibilities of Sensor Network [6] is Self-Management i.e. Self-organization, Self-Healing, Self-Optimization, Self-Protecting and Self-Diagnosing. Wireless Sensor Networks have little or in some situations no infrastructure.

WSNs are of two categories: Structured and Unstructured Network [7]. A Structured WSN network is one where node location is predefined and all the nodes are scattered in environment as per proper planning. An Unstructured network is one with dense collection of sensor nodes and deployed in ad-hoc manner having dynamic topology.

Wireless Sensor Networks face lots of constraints in terms of Dynamic Routing Topology, Resource-Constraint, Multi-Hopping, Energy Efficiency. Among all these shortcoming, Routing is regarded as the most challenging activity to manage in terms of Quality of Service, rapidly changing topology, security and above all Energy Efficiency. Considering all these challenges, researchers working in this area have come up with lots of novel and improvised routing protocols based on Genetics, Fuzzy Logics, Neural Computing and Swarm Intelligence, but it becomes really mind-challenging task to decide which one is best and which one to choose depending on the real-time monitoring applications. Studies and results have shown that Swarm Intelligence is one of the most utilized area and concentrated area by researchers to develop novel routing protocols. In Swarm Intelligence Computational techniques, the most widely suitable techniques for Wireless Sensor Networks are Ant Colony Optimization and Bee Colony. Thorough this paper, we throw light on four Ant Colony Optimization based routing protocols which are proposed by researchers for optimal routing keeping in mind various parameters like Packet Delivery Fraction, Throughput, Routing Overhead, End-to-End Delay and Energy efficiency. The paper will highlight comparative results of Ant Colony-Based Energy Aware Multipath Routing Algorithm (ACO-EAMRA), Improved Ant Colony Routing (IACR) Routing Algorithm, Efficient Minimum-Cost Bandwidth Constrained Routing (EMCBR) Protocol and Ant Chain routing protocol for Wireless Sensor Networks using NS-2 simulator. The results shown via graphs are done by considering Modified AODV and Basic ACO based routing protocol at Static Mobility Speed and Random Way point Mobility model.

1.1 Organization of paper

The remainder of paper is organized as follows: Section II reports overview of Ant Colony Optimization and related work regarding routing protocols compared in this research paper- ACO-EAMRA, IACR, EMCBR and Ant Chain Protocol. Section III, presents the simulation platform used for simulation, Simulation model/parameters used for comparison, comprehensive analysis of data values generated regarding simulation results and graphical analysis. Finally, Section V includes conclusion and future scope.

2 Routing Protocols Based on Ant Colony Optimization for Wireless Sensor Networks

2.1 Objectives of routing protocols for wireless sensor networks

The main objective of routing protocols for Sensor networks is assurance of timely delivery of data packets between source and destination nodes. In addition to timely delivery, various other parameters have to be considered in order to maintain overall efficiency, performance and reliability in Wireless Sensor Networks like Data Aggregation, Security, Quality of Service, Deployment and above all Energy Efficiency [8-11].

1. Packet Delivery/Message Delivery: The routing protocols should provide proper assurance of message packets delivery between source to destination which means that it is the prime responsibility of routing protocol to find optimal route between the communicating nodes and performance should be evaluated using Message Delivery Ratio.
2. Energy Utilization: The main objective of any routing protocol is to maintain energy efficiency in overall network. As sensor nodes have limited power, and considering the application runtime, the protocol should aim to balance the energy consumption equally among the sensor nodes considering their residual energy level.
3. Routing Overhead: In order to determine the route, broadcasting is regarded as efficient method, but the routing overhead associated with broadcasting is quite large. Routing Protocols should not incur large routing overhead and generate various issues like re-transmissions, contentions and collisions. Routing Overhead reduction is highly crucial for determining the efficient route between nodes and delivering the data in specified amount of time.
4. Throughput: Throughput is regarded as maximum rate of processing something. It is regarded as the rate of successful packet delivery over a communication medium. The routing protocols should be best in overall throughput to maintain consistency and scalability in network.
5. End-To-End Delay: End-To-End delay is regarded as time taken for a packet to be transmitted across a network from source to destination. Routing protocols should be highly efficient to maintain the overall speed in network by reducing collisions, maintaining Quality of Service (QoS) and Reliability in network.

2.2 Routing protocols for wireless sensor networks based on Ant Colony Optimization

2.2.1 Concept of ant colony optimization

Ant Colony Optimization (ACO) [12-17] was discovered and introduced by M. Dorigo and colleagues as a Nature-Inspired meta-heuristic for providing optimal solutions to hard combinatorial optimization (CO) problems. A Meta heuristic is regarded as set of algorithms that can be used to elaborate heuristic method applicable to wide range of problems. It is regarded as general purpose framework to different optimization problems with few modifications. “Marco Dorigo” in his Ph.D Thesis “Optimization, Learning and Natural Algorithms”, in which he elaborated the way to solve problems using behavior being used by real ants, presents the first algorithm defining the framework in 1991. Real Ants are highly sophisticated and intelligent swarms are used to find the shortest path from food source to nest by depositing pheromone on the ground and laying the trails so that other ants can follow. The most important component of ACO Algorithms is the combination of a priori information regarding the structure with a posteriori information about the structure of previously obtained optimal solutions.

In order to determine the shortest path, a moving ant lay the pheromone which acts as base for other ants to follow and deciding the high probability to follow it. As a result, it leads to the emergence of collective behavior and forms a positive feedback loop system through which other ants can follow the path and makes the pheromone more stable and best path for transferring the food back to nest.

```
input: An instance P of a CO problem model 𝒫 = (𝒮, f, Ω).
InitializePheromoneValues(𝒯)
𝔰bs ← NULL
while termination conditions not met do
  𝔖iter ← ∅
  for j = 1, . . . , na do
    𝔰 ← ConstructSolution(𝒯)
    if 𝔰 is a valid solution then
      𝔰 ← LocalSearch(𝔰)        {optional}
      if (f(𝔰) < f(𝔰bs)) or (𝔰bs = NULL) then 𝔰bs ← 𝔰
      𝔖iter ← 𝔖iter ∪ {𝔰}
    end if
  end for
  ApplyPheromoneUpdate(𝒯,𝔖iter,𝔰bs)
end while
output: The best-so-far solution 𝔰bs
```

Fig. 1. ACO routing algorithm

The following algorithm explains Ant Colony Optimization in brief:

Initialize Parameters
Initialize pheromone trails
Create ants
While stopping criteria is not reached, **do**
  Let all ants construct their solution
  Update pheromone trails
  Allow Daemon Actions
End while

2.2.2 Routing protocols for wireless sensor networks- AntNet, ACO-EAMRA, IACR, EMCBR and ant chain

2.2.2.1 Basic ant colony optimization (ACO) routing protocol

Swarm Intelligence [18] is regarded as modelling of collective behaviors of simple agents interacting locally among themselves, and their environment, which leads to the emergence of a coherent functional global pattern. Swarm Intelligence is emerged with collective intelligence of groups of simple agents and this approach stresses on various characteristics like distributedness, flexibility, robustness and direct or indirect communication among simple agents.

The basic concept of Ant Colony Optimization (ACO) surrounds around the behavior of ants moving randomly in the nearby environment searching for food laying pheromone trail from nest to food source to lay optimal paths for other ants to follow.

Ant Agents are categorized into following two types:

1. Forward Ants (FANT)
2. Backward Ants (BANT)

The main objective of this categorization is to support Backward Ants to make use of the information collected by forward ants on their way from nest to food source. Based on this methodology, no routing information updation is performed by Forward Ant, whose main work is to report network delays to Backward Ants.

Routing information is passed as follows:

- Forward ant is being launched by network nodes at defined time intervals.
- Ants determine a path to food source on the basis of information in routing tables.
- The Forward Ant creates a stack which contains the information of nodes which is being used to reach the final node.
- When Forward ant reaches the destination, the Backward ant fetches all the information.
- After getting all the information, the Backward ant pops the stack and follows the reverse path from destination (Food Source) to Nest.
- The routing table is updated based on Trips.

AntNet Protocol

AntNet [19-22] routing protocol was proposed by Marco Dorigo and Gambardella in 1997. The concept of AntNet is based on Real Ants. In AntNet, every artificial ant builds an optimal path from nest to food source. While building its path, it collects explicit information regarding time length of path components and implicit information about the load status of the network. The information is forwarded back to another ant moving in opposite direction and is used to modify the overall routing tables of nodes visited. AntNet protocol when compared with Adaptive Vector-Distance and Link-State Shortest Path routing algorithms have shown best performance in terms of reliability, scalability and robustness.

AntNet Algorithm

- At regular intervals, and concurrently with the data traffic, from each network node mobile agents are asynchronously launched towards randomly selected destination nodes.
- Agents act concurrently and independently, and communicate in an indirect way, through the information they read and write locally to the nodes.
- Each agent searches for a minimum cost path joining its source and destination nodes.
- Each agent moves step-by-step towards its destination node. At each intermediate node, a greedy stochastic policy is applied to choose the next node to move to. The policy makes use of (i) local agent-generated and maintained information, (ii) local problem-dependent heuristic information, and (iii) agent-private information.
- While moving, the agents collect information about the time length, the congestion status and the node identifiers of the followed path.
- Once they have arrived at the destination, the agents go back to their source nodes by moving along the same path as before but in the opposite direction.

- During this backward travel, local models of the network status and the local routing table of each visited node are modified by the agents as a function of the path they followed and of its goodness.
- Once they have returned to their source node, the agents die.

BEGIN

{ Routing Tables Set-Up: For each node k the routing tables are initialized with a uniform distribution:

$$P_{ji} = \frac{1}{n_k}\ , \quad \forall i \in N_k .$$

DO always (in parallel)

{ STEP 1: In regular time intervals, each node s launches an $F_{s\rightarrow d}$ ant to a randomly chosen destination d.

/*During its trip to d, when $F_{s\rightarrow d}$ reach a node k, ($k \neq d$), it does step 2*/

DO (in parallel, for each $F_{s\rightarrow d}$

{ STEP 2: $F_{s\rightarrow d}$ pushes in its *stack* $S_{s\rightarrow d}(k)$ the node k identifier and the time elapsed between its launching from s to its arriving to k.

$F_{s\rightarrow d}$ selects the next node to visit in two possible ways:

(a) It draws between i nodes, $i \in N_k$, where each node i has a P_{ik} probability (in the k routing table) to be selected.

IF the node selected in (a) was already visited

(b) It draws again, but with the same probability for all neighbor nodes i, $i \in N_k$. $F_{s\rightarrow d}$ jumps to chosen node.

IF the selected node was already visited

STEP 3: A cycle is detected and $F_{s\rightarrow d}$ pops from its *stack* all data related to the cycle nodes, since the optimal path must not have any cycle. $F_{s\rightarrow d}$ comes back to step 2 (a).

END IF

END IF

}**WHILE** jumping node$\neq d$

STEP 4: $F_{s\rightarrow d}$ generates another ant, called backward ant $B_{s\rightarrow d}$. $F_{s\rightarrow d}$ transfers to $B_{s\rightarrow d}$ its *stack* $S_{s\rightarrow d}$ and then dies.

/*$B_{s\rightarrow d}$, will follow the same path used by $F_{s\rightarrow d}$, but in the opposing direction, that is, from d to s*/

DO (in parallel, for each $B_{s\rightarrow d}$ ant)

{ /*When $B_{s\rightarrow d}$ arrives from a node f, $f \in N_k$ to a k, it does step 5*/

STEP 5: $B_{s\rightarrow d}$ updates the k routing table and list of trips, for the entries regarding to nodes k' between k and d inclusive, according to the data carried in $S_{s\rightarrow d}(k')$.

IF $k \neq s$

$B_{s\rightarrow d}$ will jump from k to a node with identifier given by $S_{s\rightarrow d}(k\text{-}1)$

END IF

}**WHILE** ($k \neq s$)

}

}

END

Fig. 2. Ant Net Algorithm

2.2.2.2 ACO-EAMRA- Ant colony based energy aware multipath routing algorithm

ACO-EAMRA (Ant Colony Based Energy Aware Multipath Routing Algorithm) is proposed by Xia and Wu [23] in 2009. In this algorithm, the authors optimized state transition rule and global pheromone update rule. Two parameters q and q_o were added in the algorithm to improve the state transition rule and ants possibility to find optimal path to avoid local optimization.

Algorithm:

Step 1: Initialization of Pheromone: In the beginning, during initialization phase, ants are placed on different source nodes and the value is initialized and routing table is generated, a small positive constant for pheromone intensity of each edge is also generated.

Step 2: Selection of Path: Ants determine the path from source node to sink node. As per state transition rule, the ants choose the next hop node from set of neighboring nodes.

Step 3: Updation of Local Pheromone: When the ants arrive at mid node, the ants first determine whether the node is closer to sink node and how far it is from source node than former node. If true, the ant modifies the pheromone of edge as per local pheromone update rule. If No, the ant terminates the search.

Step 4: Complete Routing: The algorithm repeats Step 2 and Step 3 till the ants finishes the complete process of search.

Step 5: Updation of Global Pheromone: The system determines the optimal path of each search and modifies the pheromone of each edge as per Global Pheromone update rule.

Step 6: Multipath Routing: The Algorithm will repeat Step 2, 3, 4 N number of times to get optimal global routing path.

Simulation:

To test the novelty of Algorithm, the Authors compared the algorithm with Directed Diffusion (DD) on two parameters: Energy Consumption and Network Lifetime.

Simulation Parameters:

Energy Consumption: Simulation Environment: 200x200 m area, Communication Radium: 40m, Random Way Point=10 seconds, Length of Frame rate=256 bits, Node Initial Energy=40J, No of Nodes= 50, 150, 200, 300, 500. Results showed that ACO-EAMRA is highly Energy Efficient as compared to DD and also highly efficient in balancing the energy among the nodes in entire network.

Network Lifetime: Simulation Environment: No of Nodes=100 and Rest same as above.

Simulation Results:

The results showed that overall network kept running for 89 hours 42 minutes and 7 seconds as compared to DD which ran for 54 hours 21 minutes and 41 seconds. So, overall ACO-EAMRA is efficient in Network Lifetime.

2.2.2.3 IACR- An adaptive quality of service (QoS) energy aware routing algorithm

IACR (An Adaptive Quality of Service Energy Aware Routing Algorithm) [24] is proposed by Peng et al. in 2008. The authors has basically improvised the Basic Ant Colony Routing Algorithm in terms of QoS along with Energy Efficiency to improve overall Lifetime of the network.

IACR is composed of following two main components:

1. Route Discovery
2. Route Maintenance

Route Discovery: The Route Discovery Methodology consists of series of following six steps:

a. When the sink nodes gets interests such as Vehicles Network or Highways, it first of all determines the routes from the cache. If no routes are found, it broadcasts forward ants and the process is almost same as spreading the ants to all directions in environment in search for food.
b. The task of Forward ant is to search for destination by going hop by hop as per Link Probability distribution function and creating the pheromone trail in routing table. All the links visited have equal probability and every visited node is saved into memory. The selection probability is trade-off between visibility and actual pheromone concentration.
c. On moving ahead, every forward ant records list of nodes being visited and tries to avoid those nodes visiting again making the route loop-free.
d. When Forward Ant reaches destination, it changes itself to Backward Ant and starts moving backward in the same links as visited before to reach the destination.
e. During journey backward, the pheromone is distributed in the path among all the nodes after considering all the parameters of Minimum Energy, Travelled Distance and Optimized Route Path.
f. In the next route exploration, the link probability distribution of each node acting as intermediate will be updated as per pheromone concentration. By doing this again and again in iterative manner, every node will determine the best neighbor and maintains the optimal path.

Route Maintenance:

To maintain the optimal path routing table and response towards dynamic topology change, IACR algorithm is highly efficient. In this algorithm, each sensor node exchange hello message among each other at regular intervals. On sharing the Hello Message, it includes geographic location, energy pending, available bandwidth, buffer size and pheromone concentration.

If any node receives Hello Message from new node, it updates the routing table and expects to get Hello Message at regular intervals. If Hello Message doesn’t come, the node will be removes. So, the nodes are always updated with their neighboring nodes along with their other additional information and keep the routing table always updated.

Simulation

Simulation Parameters:

Simulation of IACR Algorithm is done on OMNeT++ on following parameters: Area: 300x300/600x700m; Nodes: 10, 50; Node Placement: Uniform; Payload Size: 512 Bytes: MAC Protocol: 802. CSMA/CA; Radio Bandwidth: 1 Mbps.

Simulation Results:

The IACR Algorithm is compared with DD Algorithm and results showed: IACR has similar Packet Delivery Ratio as compared to DD and DD has high routing overhead as compared to IACR but QoS and Energy Efficiency is much better in IACR as compared to DD Algorithm.

Overall Evaluation:

IACR Algorithm is regarded as much better algorithm for WSN network in terms of Load Balancing, Energy Efficiency and Overall Network Lifetime.

2.2.2.4 EMCBR- Efficient minimum cost bandwidth constrained routing in wireless sensor networks

EMCBR (Efficient Minimum Cost Bandwidth Constrained Routing) in Wireless Sensor Networks protocol is proposed by Patel et al. [25] in 2004. The protocol is derived from Combinatorial Optimization Problem also known as Minimum Cost Flow Problem in operations. In this protocol, the author has made use of Polynomial Time Minimum-Cost Flow Algorithms to make it highly scalable and efficient for Wireless Sensor Networks.

In this protocol, route discovery is performed by resource rich base stations which reduce the overall flooding in the system to discover new routes and sensor nodes no longer require to maintain routing tables, topology-related information and state of traffic in overall network.

Simulation:

Simulation Parameters:

In order to test the novelty of EMCBR Algorithm it is compared with Maximum Lifetime Bandwidth Constrained Routing Protocol (MLBCR) on following parameters: Area: x100m; Transmission range of each sensor node: 25 mts; Transmission Range of each Base Station: 50 mts; Size of Data Packet: 500 bits; Size of Routing Packet: 200 bits; Link Capacity: 10 Kbps.

Simulation Results:

The Simulation Results that EMCBR is better as compared to MLBCR in terms of energy efficiency and scalability.

Overall Evaluation:

Overall the EMCBR algorithm is Simple, Fast, Scalable and Power Efficient and as compared to MLBCR routing protocol.

2.2.2.5 AntChain

AntChain Protocol was proposed by Ding and Xiaoping [26,27] in 2004 is regarded as Centralized Algorithm whose main task is to partition the roles of sensor nodes and sink node as per hardware resources and distances among them to maintain overall energy efficiency in WSN Network as well as removing transmission delays.

Algorithm

In AntChain Algorithm, the basic assumption is taken that every sensor node can communicate with all other sensor nodes and even with sink node. A node can be in any of the following four states: Sleep, Idle, Receiving and Transmitting.

After the nodes are physically deployed, the sensor nodes communicates at regular intervals to the base stations. The base station send a "Setup_Enable" signal to all nodes at the start the work. Sensor nodes on receiving the signal transmit their ID and Location to Base Station. If the Base Station already knows the location of the Sensor Node, sensor node just sends an Acknowledgement Signal to confirm regarding its alive. After getting all the information, AntChain Algorithm performs MMAS Algorithm and creates a chain of all sensor nodes in such a manner that it is optimal lowest cost chain.

The sensor node which is very near to Base Station is regarded as "Chain Tail" and sends the information to Base Station. The Head is the first node in Ant Chain and start the Data Gathering process by sending the information to next neighbor in first time slot. The sensor nodes in the middle of the network receive the data from preceding neighbor and perform data aggregation and send to right neighbor. All the sensor nodes are regular in contact with Base node for requirement of any re-configuration or new query. All the nodes works in Steady State under the end of Data Aggregation.

Simulation:

Simulation Parameters:

AntChain Protocol is tested on NS-2 Simulator and compared with LEACH and PEGASIS Algorithms. The parameters are- Area: 100x100m; No. of Nodes: 100; Initial Energy of Node: 0.5J.

Simulation Results:

Results Show that AntChain is highly efficient as compared to LEACH and PEGASIS by 8 times and 2 times respectively in simulation and is highly reliable and scalable as compared to these two protocols.

3 Simulation Model and Simulation Results

In this section, we describe the Simulation Model being used for Simulating the Four Protocols mentioned above and what Results in terms of Data and Graphs are being analyzed on different parameters for Wireless Sensor Networks.

3.1 Simulation model

The simulation is done on NS-Allinone Simulation version 2.35 on the basis of Simulation Parameters and Mathematical Model proposed by authors of protocols in varied research literature for wireless sensor networks.

3.2 Network simulator-2 (NS-2)

Network Simulator 2 (NS-2) [28-31] is regarded as discrete event simulation tool and has proved its worth in research of dynamic communication networks. NS-2 was developed in the year 1989 and since its inception various contributions are done that has brought various revolutions in the field of network research. The foundation of this simulator was based on REAL network simulator developed by University of California and Cornell University. Since 1995, DARPA also supported the NS-2 development via VINT (Virtual InterNetwork Testbed) and now National Science Foundation (NSF) is also contributing a lot to its development.

NS-2 is totally based on Object Oriented (OO) programming so it is also known as Object Oriented Discrete Event Simulator. It consists of two languages: C++ and Object oriented Tool Command Language (OTcl). C++ is primarily used for implementing various protocols and extending simulation libraries whereas OTcl scripts does the task of configuring simulator, network topology setting, creating network scenarios and displaying simulation results. C++ and OTcl are binded together using TclCL.

NS-2 comprise of 3,00,000 lines of code and is available free of cost and is used globally in academia. It can run on various operating systems like Linux, FreeBSD, MAC OS X, Solaris and even windows via use of third party software called Cygwin. The latest version is 2.36.

3.3 Simulation model

The following Table 1 enlists the Simulation parameters taken for comparing 4 Routing Protocols: ACO-EAMRA, IACR, EMCBR and AntChain.

Table 1. Simulation parameters

Simulation parameters	Values
Simulator used	Ns-allinone-2.35
Basic routing protocol	Modified AODV+ Basic ACO Routing Protocol
Area	1000 m x 1000 m
Simulation time	100 ms
Antenna type	Omni-Directional Antenna
Energy model	Energy Model (True)
Initial energy- All nodes	100 J
No. of nodes	100
Queue length	50
Data rate	Variable
Interface type	Wireless Physical Interface
Radio range for node	250 m
Mobility speed	Static
Mobility model	Random Way Point

3.4 Reasons for choosing ACO-EAMRA, IACR, EMCBR and AntChain routing protocol

- Protocols being novel, highly scalable and robust for Wireless Sensor Networks as compared to other standardized routing protocols based on Ant Colony Optimization for Wireless Sensor Networks.
- Highly Sophisticated in terms of Energy Efficiency, Packet Delivery and Throughput as required for proper packet flow in Wireless Sensor Networks.

3.5 Metrics used

3.5.1 Packet delivery overhead

It is the measure of the percentage of packets delivered successfully to the target nodes.

Packet Delivery Ratio: (No. of Packets Sent – Packet Loss) * 100/no. of packets sent.

Packet Delivery Overhead is determined on the above mentioned Simulation Scenario on varied time intervals and Data values generated under varied Simulation scenarios are as follows.

	Packet Delivery Fraction			
Simulation Time	ACEAMR	AntChain	EMCBR	IACR
25	87.76	84.51	90.40406	95.03
50	85.5	86.02	85.30188	96.94
75	82.7	83.31	89.32923	98.65
100	79.87	85.77	83.53518	99.13
125	77.73	87	87.49451	92.56
150	74.97	86.56	84.91605	91.26

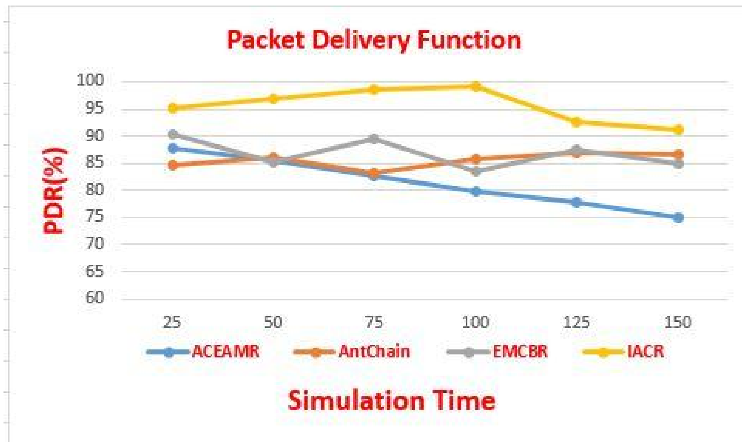

Fig. 3. Comparison of routing protocols on basis of Packet Delivery Fraction

Analysis show that IACR protocol is Better as compared to ACO-EAMRA, Ant Chain and EMCBR in Packet Delivery Fraction.

3.5.2 Throughput

Throughput is the amount of digital data per time unit delivered over a physical or logical link. It is measured in bits per second, occasionally in data packets per second or data packets per time slot.

Throughput = Number of packets send successfully / total time

Throughput is determined on the above mentioned Simulation Scenario and Data values generated at varied Simulation Time intervals are as follows:

	Throughput(Mbps)			
Simulation Time	ACEAMR	AntChain	EMCBR	IACR
25	198	182	175	190
50	223	213	187	182
75	217	212	205	207
100	189	187	185	213
125	193	188	185	184
150	178	188	210	204

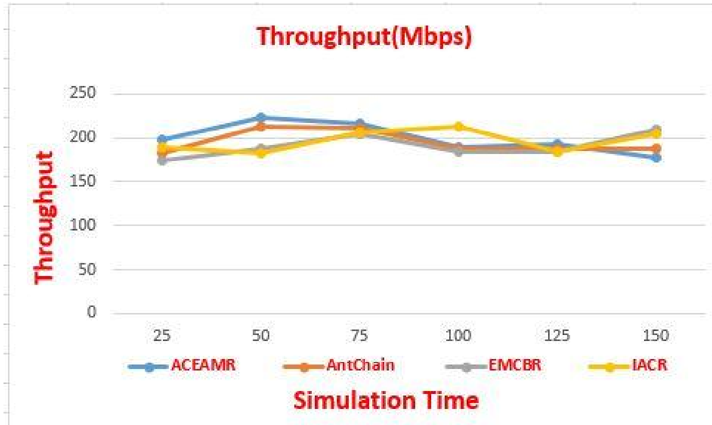

Fig. 4. Comparison of routing protocols on basis of Throughput

Analysis show that EMCBR gives better Throughput which is better as compared to IACR and AntChain and ACO-EAMRA routing protocols.

3.5.3 Probability routing overhead

Probability Routing Overhead is being determined on the above-mentioned Simulation Scenario and Data values generated at significant Simulation Time intervals are as follows:

	Probability Routing Overhead			
Simulation Time	ACEAMR	AntChain	EMCBR	IACR
25	0.68	0.81	0.62	0.59
50	0.66	0.78	0.89	0.62
75	0.65	0.79	0.67	0.62
100	0.67	0.78	0.67	0.57
125	0.67	0.79	0.63	0.66
150	0.63	0.78	0.65	0.63

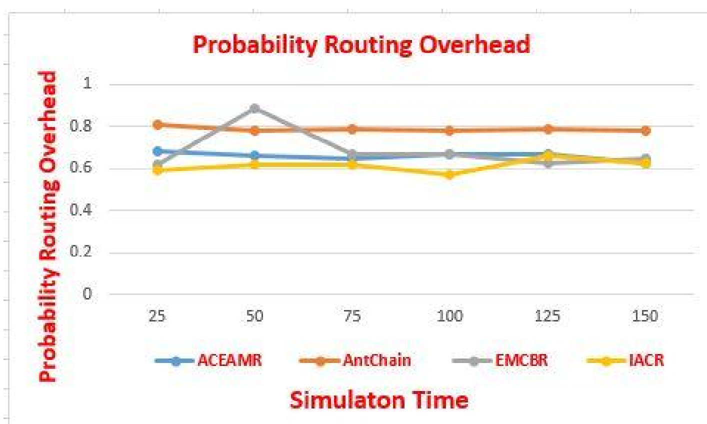

Fig. 5. Comparison of routing protocols on basis of Probability Routing Overhead

Analysis show that ACO-EAMRA and IACR shows less amount of Overhead as compared to AntChain and EMCBR routing protocols in Wireless Sensor Networks.

3.5.4 Energy consumption

Energy Consumption in Joules is being determined on the above mentioned Simulation Scenario and Data values generated at varied simulation intervals are as follows:

	Energy Consumption(Joules)			
Simulation time	ACEAMR	AntChain	EMCBR	IACR
25	98.21	98.2	98.81	99.42
50	97.23	97.25	97.785	98.32
75	85.05	86.335	86.9625	87.59
100	81.179	82.798	83.5495	84.301
125	77.308	79.261	80.1365	81.012
150	73.437	75.724	76.7235	77.723

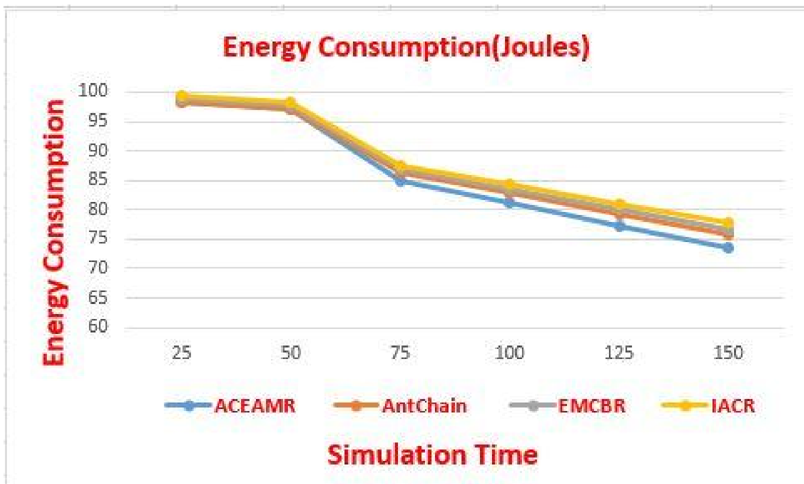

Fig. 6. Comparison of routing protocols on basis of Energy Consumption

Analysis show that IACR is the Best Protocol in Energy Conservation as compared to other routing protocols.

3.5.5 End-to-end delay

End-To-End delay refers to the time taken for a packet to be transmitted across a network from source to destination. Data transmission seldom occurs only between two adjacent nodes, but via a path which may include many intermediate nodes.

End-to-End delay is the sum of delays experienced at each hop from source to destination.

End-To-End Delay = Time Spend on Hop 1 + Time Spend on Hop 2 + …+ Time Spend on Hop n.

End to End Delay is determined on the above mentioned Simulation Scenario and Data values generated at varied time intervals are as follows:

	End To End Delay(seconds)			
Simulation Time	ACEAMR	AntChain	EMCBR	IACR
20	67.12273529	68.19306	48.28745	50.10035
40	66.890429	45.16161	57.5394	66.47537
60	38.82431975	60.82712	46.39518	44.24341
80	44.25852413	47.25135	39.43274	42.59242
100	67.55511056	64.98297	41.77738	66.52058
120	56.37658269	60.16414	43.03033	47.98582
140	64.67209385	52.00176	46.78287	67.75863

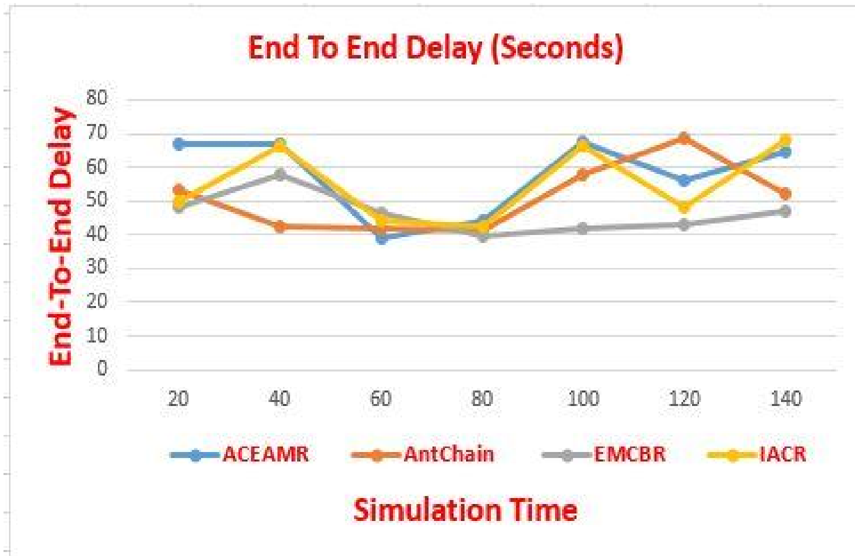

Fig. 7. Comparison of routing protocols on basis of End-To-End Delay

Analysis show that AntChain is the Best Protocol in End to End Delay as compared to other routing protocols.

3.6 Overall analysis and best protocol

Considering all the simulation scenarios and metrics used the following Table 2 states the Best Routing Protocols in varied metrics of Wireless Sensor Networks:

Table 2. Analysis of best protocol in varied network parameters after simulation based results

Network parameter	Best protocol
Packet Delivery	IACR
Throughput	EMCBR
Probability Routing Overhead	IACR, ACO-EAMRA
Energy Consumption	IACR
End to End Delay	AntChain

Overall, IACR is the Best Protocol among all other stated protocols for Wireless Sensor Networks.

4 Conclusion

In this paper, we presented a Comparative Analysis of Ant Colony Optimization Based Routing Protocols-ACO-EAMRA, EMCBR, IACR and AntChain Protocol. NS-2 Simulator is used to compare the performance of Routing Protocols and determination of results and graphs on basis of Packet Delivery Overhead, Throughput, Probability Routing Overhead, Energy Consumption and End to End Delay. Overall the results show that IACR is the best protocol in terms of Packet Delivery, Routing Overhead and Energy Efficiency as compared to other protocols almost 30-40% better.

5 Future Scope

In the near future, a Novel Routing Protocol will be proposed comparing all these protocols and will be better in terms of Packet Delivery, Energy Efficiency, Routing Overhead, Throughput and End-To-End delay. The proposed protocol will overall improvise WSN Network and turns WSN network into highly dynamic, robust and scalable wireless network.

Competing Interests

Authors have declared that no competing interests exist.

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