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Abstract—Wireless Sensor Networks, have witnessed significant amount of improvement in research across various areas like Routing, Security, Localization, Deployment and above all Energy Efficiency. Congestion is a problem of importance in resource constrained Wireless Sensor Networks, especially for large networks, where the traffic loads exceed the available capacity of the resources. Sensor nodes are prone to failure and the misbehaviour of these faulty nodes creates further congestion. The resulting effect is a degradation in network performance, additional computation and increased energy consumption, which in turn decreases network lifetime. Hence, the data packet routing algorithm should consider congestion as one of the parameters, in addition to the role of the faulty nodes and not merely energy efficient protocols. Nowadays, the main central point of attraction is the concept of Swarm Intelligence based techniques integration in WSN. Swarm Intelligence based Computational Swarm Intelligence Techniques have improved WSN in terms of efficiency, performance, robustness and scalability. The main objective of this research paper is to propose congestion aware, energy efficient, routing approach that utilizes Ant Colony Optimization, in which faulty nodes are isolated by means of the concept of trust further we compare the performance of various existing routing protocols like AODV, DSDV and DSR routing protocols, ACO Based Routing Protocol with Trust Based Congestion aware ACO Based Routing in terms of End to End Delay, Packet Delivery Rate, Routing Overhead, Throughput and Energy Efficiency. Simulation based results and data analysis shows that overall TBC-ACO is 150% more efficient in terms of overall performance as compared to other existing routing protocols for Wireless Sensor Networks.

Keywords—Wireless Sensor Networks, Swarm Intelligence, Ant Colony Optimization (ACO), AODV, DSDV, DSR, Trust BasedCongestion-ACO, Performance.

I. INTRODUCTION

In 21st Century, Wireless Sensor Networks [1] has gained huge amount of attention of researchers across the world with regard to tons of theoretical, practical and implementation challenges. The research progress in Wireless Sensor Networks has explored diverse novel applications enabled by large-scale networks comprising of thousands of sensor nodes capable of sensing environmental information, processing it in efficient manner and transmitting the information back to base locations for further analysis. Wireless Sensor Networks comprise of large number of low-cost, low power and multi-functional capable wireless sensor nodes [2, 3] for sensing different information’s, equipped with wireless communication transmission mediums and computational capabilities. In sensor nodes, different types of sensors in form of mechanical, biological, chemical, optical can be attached to acquire real-time data from environment and transmit it back after processing. The sensor nodes forming Wireless Sensor Networks [4, 5] have limitation in terms of low memory, less processing speeds. A radio is integrated on nodes to transmit the information back to sink node. The nodes are powered using battery to act as main power source. As the batteries are the only and primary power source, it becomes difficult to replace and charge the batteries once nodes are deployed which remains the foremost challenge in front of researchers to enhance the Energy Efficiency of sensor nodes. The characteristics of Wireless Sensor Network [1, 6, 3] are Deployment of sensor nodes; Less power; less computation capability; Limited memory; Unreliability. Therefore, the characteristics open wide range of challenges for the development and real-time implementations of wireless sensor network in the world. Sensor nodes once deployed in the real world are grouped into clusters, and each cluster has a node named as “Cluster Head”. All the nodes in the cluster forward their sensed data to the cluster head and it is the duty of Cluster Head to route the information back to Sink Node (termed as “Base Station”) via multi-hop wireless communication as shown in Fig. 1. With regard to various limitations cum shortcomings, Wireless Sensor Networks requires a collection of network protocols for implementing network control and other managerial functions in terms of synchronization, localization, security, routing, clustering etc. Various routing protocols proposed till date for routing the packets among nodes suffer from energy-constraints. Researchers [2, 5] have combined various allied field like Neuro-computing, evolutionary computing, fuzzy logic computing, reinforcement learning and swarm intelligence based techniques in WSN. The ultimate goal is to improvise the Routing Efficiency in Wireless Sensor Networks. Researchers have successfully deployed Swarm Intelligence based techniques to address varied challenges existing in area of Wireless Sensor Networks and able to successfully deploy WSN in varied applications. The aim of this research paper is to explore various challenges surrounding WSN, which gives wide open doors for researchers with novel ideas and practical initiatives. In addition to this, ACO based routing protocol is simulated and compared with other routing protocols of Wireless Sensor Networks on various performance parameters.
II. SWARM INTELLIGENCE

Swarm Intelligence [6-9], another novel branch of Artificial Intelligence, has attracted several researchers to apply SI based optimization techniques in solving varied problems of Robotics, Networking, Wireless Communications, Drones, Electronics, Information Theory and other diverse areas. Swarm Intelligence concept was first introduced by Gerardo Beni and Jing Wang [10] in 1989 with relation to cellular robotic systems. In general terms, Swarm Intelligence is modelling of collective behaviors of simple agents interacting locally among themselves, and their environment, which leads to the evolution of a coherent functional global pattern. These models are inspired by social behavior of insects and other animals. Talking in terms of computation, Swarm Intelligence models are computing algorithm models used for undertaking and solving complex distributed optimization problems. In Swarm Intelligence, the most significant concept is “Swarm”. Swarm is used to refer any restrained collection of interacting agents or individuals. Communication among these swarms in distributed manner without any requirement of centralized control mechanism makes these models highly realistic and robust to be implemented in diverse applications. The concept of Swarm Intelligence was started by two main Algorithms: Ant Colony Optimization (ACO) being developed by Dorigo and Stutzle in 2004 and Particle Swarm Optimization (PSO) being developed by Kennedy and Elberhart in 2001. With time, various other algorithms have come up and make the Swarm Intelligence more rich and implementable in different applications like Fish Swarm, Monkey Swarm, Glow worms, Bee Colony, Artificial Immune System, Firefly Algorithm and many more. Swarm Intelligence primarily works on two found ing principles: 1. Self Organization 2. Stigmergy Self-Organization: The concept of Self Organization was defined by Bonabeau et al [11,12] in 1999 as “Self Organization is a set of Dynamic Mechanisms whereby structures appear at the global level of a system from interactions of its lower-level components”. Self organization lays the foundation of three important characteristics: Structure, Multi-Stability and State Transition.Structure: It is founded from a homogeneous start-up state. E.g. Ant Foraging trails. Multi-Stability: Co-existence of many stable states. E.g. Behavior of ants to search for food random in field. State Transitions: Change of System Behavior. Example: Location of new food source after finishing the entire food transmit from source to nest. Stigmergy: The word “Stigmergy” is mix of two words: Stigma= Work and Ergon=Work which means Simulation by work. It is based on the principle that the main area to operate for swarms in environment and work is not dependent on specific agents. It can be summarized as, “Coordination, Cooperation and Regulation of tasks doesn’t depend on workers directly, but on construction themselves”. The worker is properly guided rather than directed to perform the work. It is also a special form of stimulation called Stigmergy. Stigmergy can be of following types:

For modelling the behaviors of Swarms, Millonas [13] laid the following 4 Principles as follows:

1. Proximity Principle of Swarm: Swarms should be highly capable to perform simple computations with respect to the environment existing around them in terms of time and space. E.g. Search for living place and building nest in coordination.
2. Quality Principle of Swarm: Swarms should be highly respondent to environmental quality factors like food, safety and other stuff.
3. Diverse Response Principle of Swarm: The swarm should not allocate all of its resources along excessively narrow channels and it should distribute resources into many nodes.
4. Stability and Adaptability Principle of Swarm: Swarms are expected to adapt environmental fluctuations without rapidly changing modes since mode changing involves tremendous amounts of energy.

III. ANT COLONY OPTIMIZATION

A. Introduction to Ant Colony Optimization

Ant Colony Optimization (ACO) [14-16] 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 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.

### B. Ant Colony Optimization-Definition

Ant Colony Optimization technique is based on ants i.e. how ant colonies find the efficient path between nest and food source. In search of food, ants roam randomly in the environment. On location of the food source, ant’s first return back to their nest by laying a trail of chemical substance called “Pheromone” in their path. Pheromone lays the foundation for communication medium for other ants to follow the way and go to the food source. When other ants follow the path, the quantity of pheromone increases on that particular path. The rich the quantity of pheromone along the path, the more likely is that other ants will detect and follow the path. In other words, ants follow that path which is marked by strongest pheromone quantity. As pheromone evaporates over time, which in turn reduces its attractive strength. The longer the time taken by ant to travel the path from food source to nest, the quicker the pheromone will evaporate. So, the path should be shorter so that the active strength of pheromone is maintained and ants can easily transfer the food from source to nest. So, in turn of this policy the shortest path will naturally emerge.

**Algorithm: Ant Colony Optimization**

1. Initialize Parameters
2. Initialize pheromone trails
3. Create ants
4. Update pheromone trails
5. Allow Daemon Actions

### C. Suitability of Ant Colony Optimization Routing Algorithm towards Wireless Sensor Networks

Ant Colony Optimization Routing Algorithm mentioned above is highly suitable and performs well in Wireless Sensor Networks because of the following reasons:
1. Provide traffic adaptive and multipath routing.
2. Rely on both passive and active information monitoring and gathering.
4. Don’t allow local estimates to have global impact.
5. Setup paths in a less selfish way than in pure shortest path schemes favoring load balancing.
6. Showing limited sensitivity to parameter settings

### D. Basic Ant Routing Algorithm [17]

Let $G=(V, E)$ be a connected graph with $n = |V|$ nodes. The simple ant colony algorithm can be used to find the shortest path between a source node $v_s$ and a destination node $v_d$ on the graph $G$. The path length is given by the number of nodes on the path. Each edge $e (i, j) \in E$ of the graph connecting the nodes $v_i$ and $v_j$ has a variable $\chi_{i,j}$ (artificial pheromone), which is modified by the ants when they visit the node. The pheromone concentration $\chi_{i,j}$, is an indication of the usage of this edge.

$$\text{delay}(\text{path}(i,j)) = \sum_{e \in \text{path}(i,j)} \text{delay}(e) + \sum_{n \in \text{path}(i,j)} \text{delay}(n)$$

An ant located in node $v_i$ uses pheromone $\chi_{i,j}$, of node $v_j \in N$ to compute the probability of node $v_j$ as next hop. $N$ is the set of one-step neighbours of node $i$.

$$P_{ij} = \frac{\chi_{ij}}{\sum_{j \in N_i} \chi_{ij}} \text{ if } j \in N_i$$

$$P_{ij} = 0 \text{ if } j \notin N_i$$

The transition probabilities $p_t$, of a node $v_i$ full fill the constraint:

$$\sum_{j \in N_i} P_t = 1, \text{ } i \in [1,N]$$

In the simple ant colony algorithm, the ants deposit a constant amount of pheromone. An ant changes the amount $\Delta \phi$ of pheromone of the edge $(i, j)$ when moving from node $v_i$ to node $v_j$ as follows:

$$\chi_{ij} := \chi_{ij} + \Delta \phi$$

Artificial pheromone concentration decreases with time to inhibit a fast convergence of pheromone on the edges.

### E. Basic Ant Colony Routing Algorithm- Working

Basic Ant Colony Routing [17] comprise of three main stages: Route Discovery, Route Maintenance and Route Error/Failure Handling.
1. Route Discovery: In this phase, the new routes discovery takes place and leads to the creation of a forward ant (F\text{ant}) and a backward ant (B\text{ant}). A F\text{ant} is an agent which establishes the pheromone track to the source node. In contrast, a B\text{ant} establishes the pheromone track to the destination node. The F\text{ant} is a small packet with a unique sequence number. Nodes are able to distinguish duplicate packets on basis of the sequence number and the source address of the F\text{ant}. A forward ant is broadcasted by the sender and will be relayed by the neighbors of the sender. A node receiving the F\text{ant} for the first time, creates a record in its routing table.

A record in the routing table is a triple and consists of (destination address, next hop, pheromone value). The node interprets the source address of the F\text{ant} as destination address, the address of the previous node as the next hop, and computes the pheromone value depending on the number of relays the F\text{ant} to its neighbours. Duplicate F\text{ant} is identified through the unique sequence number and destroyed by the nodes. When the F\text{ant} reaches the destination node, it is processed in a special way. The destination node extracts the information of the F\text{ant} and destroys it. Subsequently, it creates a B\text{ant} and sends it to the source node. The B\text{ant} has the same task as the F\text{ant}, i.e. establishing a track to this node.

When the sender receives the B\text{ant} from the destination node, the path is established and data packets can be sent.

2. Route Maintenance: After establishing the pheromone levels by F\text{ant} and B\text{ant}, data packets are used to maintain the routing path.

3. Handling Route Failure: The last stage of Basic Ant Routing is Handling Route Failure which is caused by node mobility and occurs in Wireless Sensor Nodes. It recognizes via acknowledgement missing and searches for alternative link to send packet via that path. If the packet sent, doesn’t reach the destination, the source node performs the duty to discover new routing path to transmit the packets.

The following fig.3 elaborates the Workflow of Basic Ant Colony Routing Algorithm as mentioned above in form of flow chart.
In trust based ant colony routing we present a congestion aware energy efficient trusted routing scheme for WSN in which ACO algorithm is utilized to maximize the network lifetime.

A. Stage 1
In stage 1 trust value detects the misbehaviour of sensor nodes. The trust congestion metric is generated for the trusted nodes (also called valid nodes), for the data packet routing algorithm which is implemented in the next stage. The malicious nodes having trust value below the threshold level are not considered for data packet routing due to which the congestion metric is not computed for such nodes. This causes a reduction in the computation overhead and thereby enhances battery life time.

1) Trust Computation: The trust value of node i upon node j is calculated based on trust metrics namely, remaining node energy (N_\text{rem}), packet transmission ratio (P_{TR}) and packet latency ratio (P_L). All the parameters are normalized so that the values belong to the range: [0,1]. P_{TR} is defined as the ratio of the number of acknowledgement received from node j to the total number of packets sent from node i to node j. P_L is the ratio of the latency (time it takes for the packet to reach the destination). N_\text{rem} is defined as the average energy of the node i and node j. If E_i and E_j are the existing energy value of node i and node j respectively, then

\[ N_\text{rem} = (E_i + E_j) / 2. \]

The energy of a sensor node should be greater than or equal to the threshold value of Eth for transmitting data packets to its one hop neighbor in the radio communication range.

Trust of node upon node j is calculated by the following equation

\[ T_{ij} = w1*N\text{\text{rem}} + W2*P_{TR} + W3*P_L \]

\[ = \frac{\text{w1} + \text{w2} + \text{w3}}{W1 + W2 + W3} \]

where \text{w1}, \text{w2}, \text{w3} are the corresponding weights used for N_\text{rem}, P_{TR}, P_L such that \text{w1}, \text{w2}, \text{w3} \in [0,1]. A predefined trust threshold value (T_{TH}) is set on the basis of the application of the sensor networks [18]. If T_{ij} > T_{TH}, the link between the node i and j is called a trustworthy link. Similarly if, T_{ij} < T_{TH} the link is termed as an untrusted link. The nodes having no trustworthy link are called malicious nodes and those with at least one trusted link are called trusted nodes (valid nodes) that can take part in data packet routing.

2) Estimation of Network Node Congestion: The congestion level of a valid node is estimated with the help of the parameter known as the Congestion Index. Each node maintains a queue for storing data packets in its buffer. As packets are transmitted from a particular node towards the next node, buffer space is cleared and the packets waiting in the queue go to the empty buffer space of the node. When the packet received rate of the node is greater than the packet transmission rate, queue length increases, buffer overflows, congestion level of the node increases. If a node is not able to clear the data packet in its queue, then it waits for a certain number of pre-defined cycles and holds the packets in each cycle until the packets are finally dropped.

The Congestion Index of the mth node is calculated by the equation

\[ CI_m = \frac{r_{\text{in}}^{m} + \sum_{i=1}^{n-1} (N_{ia})}{n-1} - r_{\text{out}}^{m} \]

\[ = \frac{r_{\text{in}}^{m} + Q^{n}(n-1)}{W1 + W2 + W3} \]

\[ \text{where} \quad Q^{n}(n-1) \text{is the empty space left in the queue of the mth node till (n-1)th cycle. The parameters} \]

\[ r_{\text{in}}^{m}, r_{\text{out}}^{m} \text{is defined as} \]

\[ = \sum_{i=1}^{n-1} (N_{ia}) \]

\[ n-1 \]

\[ = \sum_{i=1}^{n-1} (N_{i\text{out}}) \]

\[ n-1 \]

\[ \text{N_{in}} = \text{Number of packets forwarded to n}^{\text{th}} \text{node in i}^{\text{th}} \text{cycle} \]

\[ \text{N_{out}} = \text{Number of packets forwarded o}^{\text{th}} \text{nodes to other nodes in i}^{\text{th}} \text{cycle} \]

The congestion index of each trusted node, which is calculated by using equation (2), represents the node level congestion of the WSN. It is calculated dynamically at regular intervals, depending upon the application of the network.

3) Computation of Trust based Congestion Metric (TBCM): The Trust based Congestion Metric (TBCM) of each trusted nodes, also called as the valid node, is computed by the equation:

\[ TBCM_{ij} = \alpha * CI_j * (1 - \alpha)T_{ij} \]

\[ = \sum_{i=1}^{n} CI_i \]

\[ \text{where node i and node j are considered as the source node and the destination node, respectively. CI_i is the Congestion Index of the destination node and T_{ij} is the trust value of source node i upon the destination node j. The constant} \]

\[ \alpha \]

\[ \text{is denoted as Trust Congestion Coefficient which belongs to [0,1].} \]

The proposed TC-ACO algorithm stage 2 implements the data routing protocol using Ant Colony Optimization [6] - [8]. The probability P_{ij} for transmission of data packets in optimal route from node i in level L to node j in level (L+1) is given by equation (6).
\[ P_{ij} = \frac{(TBC_{ij})^{\beta_1} \cdot (1/d_{ij})^{\beta_2} \cdot (T_{ij})^{\beta_3}}{\sum_{k} (TBC_{ik})^{\beta_1} \cdot (1/d_{ik})^{\beta_2} \cdot (T_{ik})^{\beta_3}} \quad \ldots \quad (6) \]

where 'k' represents all the valid nodes in level (L+1). We consider random deployment of sensor nodes in the entire sensor field at the various levels as depicted in Fig. 1, denoted by level 0, 1, 2 . . . level L, (L+1) . . . level (r-1), level r respectively. The source node is considered as a level 0 node. All nodes within the one hop neighbor of the source node in the radio communication range are denoted as the level 1 nodes. Similarly, all nodes within the one hop neighbor of the level 1 in the radio communication range are called the level 2 nodes and so on. At the end of the cycle c, \( T_{ij} \) is updated as

\[ T_{ij} = (1-p) \cdot T_{ij}(n-1) + N_{ij}/d_{ij} \quad \ldots \quad (7) \]

The data packet routing algorithm used in the proposed TBC-ACO as

For each node i in the Lth level

do

Step1: Find all the valid node k in level (L+1). The node satisfying the condition \( T_{ij} > T_{TH} \) are valid nodes

Step 2: Compute the probability of packet transmission from node i to node j defined as \( P_{ij} \)

Step 3: Arrange the nodes in descending order based on value of \( p_{ij} \) and store in the matrix

Step4: Initialize \( p=1 \)

while (\( E_i \geq E_{th} \) && \( p \leq \text{size}(x) \))

if (Queue(x(p)th node is full OR \( E_{x(p)} < E_{TH} \))

\( p = p+1 \)

end if

end while

done


<table>
<thead>
<tr>
<th>Number of Rounds</th>
<th>protocols</th>
<th>Percentage of Dead Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AODV</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>DSR</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>DS DV</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>ANT</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>TCB-ACO</td>
<td>27</td>
</tr>
</tbody>
</table>

Number of Rounds VS Percentage of Dead Nodes(Initial Energy=1.0 j/Node)

Fig. 4. Bar graph Analysis with Initial Energy 1.0 Joule/Node
V. COMPARISON OF TBC-ACO ROUTING PROTOCOL WITH EXISTING ROUTING PROTOCOLS OF WIRELESS SENSOR NETWORKS

In this part, trust based congestion aware Ant Colony Optimization Routing Protocol is compared with existing protocols of Wireless Sensor Networks. In order to prove the improvement in Routing provided by ACO based routing protocol, the results are compared with AODV [19], DSDV [20] and DSR Routing [21] and Antnet protocol on the basis of Probability of Packet Delivery Rate, Throughput, Routing Overhead, Energy Consumption, End-to-End Delay. Metrics used for Simulation:

1. Packet Delivery Rate : 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.
2. Overhead is determined on the above mentioned Simulation Scenario on varied time intervals

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

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Probability of packet Delivery Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DSDV</td>
</tr>
<tr>
<td>100</td>
<td>0.867545</td>
</tr>
<tr>
<td>200</td>
<td>0.845675</td>
</tr>
<tr>
<td>300</td>
<td>0.781754</td>
</tr>
<tr>
<td>400</td>
<td>0.767545</td>
</tr>
<tr>
<td>500</td>
<td>0.736752</td>
</tr>
<tr>
<td>600</td>
<td>0.745633</td>
</tr>
</tbody>
</table>
Analysis show significant improvement by ACO in Packet Delivery which is near to about 90% as compared to other existing protocols for wireless sensor networks.

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:

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Throughtput(Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DSDV</td>
</tr>
<tr>
<td>100</td>
<td>6.335</td>
</tr>
<tr>
<td>200</td>
<td>7.123</td>
</tr>
</tbody>
</table>

Figure 6. Performance Comparison of Routing Protocols on basis of Packet Delivery Ratio

Figure 7. Performance Comparison of Routing Protocols on basis of Throughput
Analysis shows significant improvement in terms of Network Throughput maintained by ACO Routing Protocol in entire network as compared to other protocols in Sensor networks scenarios.

3. Routing Overhead: Routing Overhead is the number of routing packets required for network communication. Routing Overhead is determined via awk scripts which processes the trace file and gives the result output.

Values:

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Routing Overhead(%)</th>
<th>DSDV</th>
<th>AODV</th>
<th>DSR</th>
<th>ACO</th>
<th>TBC-ACO</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td></td>
<td>9.541234</td>
<td>7.24432</td>
<td>5.039923</td>
<td>5.42321</td>
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<td>0.714981</td>
<td>6.523167</td>
<td>4.217894</td>
</tr>
</tbody>
</table>

Figure 8. Performance Comparison of Routing Protocols on basis of Routing Overhead

Analysis shows less amount of Routing overhead atleast 70% less amount of routing overhead is being determined in case of TBC-ACO as compared to ACO,DSDV, DSR and AODV routing protocol in sensor network scenarios.

4. 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 Spendon 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:

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>End to End Delay(ms)</th>
<th>DSDV</th>
<th>AODV</th>
<th>DSR</th>
<th>ACO</th>
<th>TBC-ACO</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td></td>
<td>7.28</td>
<td>5.94</td>
<td>7.21</td>
<td>4.23</td>
<td>2.18</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>8.01</td>
<td>6.11</td>
<td>7.56</td>
<td>3.89</td>
<td>3.02</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>8.86</td>
<td>6.94</td>
<td>8.15</td>
<td>3.67</td>
<td>3.56</td>
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<tr>
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<td>9.13</td>
<td>6.98</td>
<td>8.27</td>
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<td></td>
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<td>9.45</td>
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<td>5.76</td>
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<td></td>
<td>11.52</td>
<td>9.84</td>
<td>10.78</td>
<td>7.52</td>
<td>7.19</td>
</tr>
</tbody>
</table>
5. Energy Consumption: Energy Consumption is termed as the power utilized by sensor nodes in network for transmission of data packets. In this scenario, we have analyzed the energy efficiency of routing protocols in WSN and compared with TBC-ACO to see the efficiency in energy conservation.

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>DSDV</th>
<th>AODV</th>
<th>DSR</th>
<th>ACO</th>
<th>TBC-ACO</th>
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<td>95.46</td>
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<tr>
<td>100</td>
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<td>89.87</td>
<td>90.32</td>
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<tr>
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<tr>
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<td>80.98</td>
<td>85.23</td>
</tr>
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</table>

Figure 10. Performance Comparison of Routing Protocols on basis of Energy Consumption
REFERENCES

Analysis show that as compared to other routing protocols, ACO used almost 120% less amount of energy of sensor nodes for transmitting data among other nodes.

VI. CONCLUSIONS AND FUTURE SCOPE

Wireless Sensor Networks are regarded as highly dynamic, flexible and special type of networks which are gaining researchers attention in recent times. Wireless Sensor Networks are using multi-path routing instead of static networks infrastructure and are always making use of Dynamic topology in real-world implementations. Therefore, there are always new challenges are shortcomings in routing protocols of WSNs as traditional protocols are not getting replaced by latest protocols based on Swarm Intelligence based techniques like ACO, BEE Colony or PSO. Researchers are designing new protocols and are comparing the protocols with existing protocols in terms of suitability, stability and performance. This research paper is a novel attempt towards comprehensive evaluation of five main protocols-AODV, DSDV, DSR and ACO Based Routing Protocol, Trust Based Congestion-ACO Routing Protocol. In the past few years, new standards are implemented to enhance the performance of sensor nodes operating in WSN environment. In this paper, using the latest simulation environment NS-2.35, we have evaluated performance of five routing protocols on basis of Packet Delivery Rate, Throughput, End to End Delay, Routing Overhead and Energy Efficiency and the Data Values and Graphical Analysis shows that SI based TBC-ACO Routing Protocol overrun’s in terms of various parameters and further improves the overall performance of WSN network in real-world environments. In short, TBC-ACO Routing Protocol is all round performer as it has low end-to-end delay, less packet overhead, best throughput, less routing overhead and maintains energy efficiency in the network.
