Novel Two-Level Randomized Sector-based Routing to Maintain Source Location Privacy in WSN for IoT

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Abstract

WSN is the major component for information transfer in IoT environments. Source Location Privacy (SLP) has attracted attention in WSN environments. Effective SLP can avoid adversaries to backtrack and capture source nodes. This work presents a Two-Level Randomized Sector-based Routing (TLRSR) model to ensure SLP in wireless environments. Sector creation is the initial process, where the nodes in the network are grouped into defined sectors. The first level routing process identifies sector-based route to the destination node, which is performed by Ant Colony Optimization (ACO). The second level performs route extraction, which identifies the actual nodes for transmission. The route extraction is randomized and is performed using Simulated Annealing. This process is distributed between the nodes, hence ensures even charge depletion across the network. Randomized node selection process ensures SLP and also avoids depletion of certain specific nodes, resulting in increased network lifetime. Experiments and comparisons indicate faster route detection and optimal paths by the TLRSR model.

Keywords: *RandomizedRouting; WSN; IoT; ACO; Simulated Annealing*

1. Introduction

Internet of Things (IoT) is the process of interconnecting several physical devices to formulate a network that performed seamless data transmission. IoT devices are both transmitters and receivers. IoT environments vary drastically based on the applications and configurations. They usually require a varied number of devices in varied configurations. Hence IoT networks are often designed as Wireless Sensor Networks (WSN). Flexibility to adapt to complex applications has made WSN models a good choice for implementing IoT based networks. Each device in IoT is considered as a sensor and possess limited computing capacity. IoT has several applications ranging from home automation to industrial monitoring, patient monitoring to building small cities [1, 2].

Several applications have made WSN models a frequent target for adversaries [3]. Several security challenges exist in WSN environments, of which Source Location Privacy (SLP) is most notable. If an adversary captures a packet, the nodes traversed can be identified by backtracking based on the routing model, and the adversary can reach the source node [4]. This leads to a vulnerable source node, resulting in a breach of security. Source nodes are data generating nodes, and will be closely connected to the deployed environments. Any modification in the source node can make the deployed environment vulnerable. Security, and inability to backtrack to sources are some of the vital components in WSN designed for IoT [5].

Designing a robust routing model incorporated with randomization mechanisms can enhance SLP to a vast extent [6]. General, highly secure routing mechanisms cannot be used in WSN environments due to their power and resource constrained nature [7, 8]. Hence, designing routing models that are highly secure and less power-hungry is mandatory. Such algorithms must tackle the major limitations of IoT devices which include low processing capacity and low memory. The devices exhibit uneven distributions in the environments. Further, each device might operate at varied configurations, resulting in the issue of resource throttle. The routing models should be designed to be operated on devices with the least configurations. This work presents a randomized two-level routing model that enable SLP for WSN environments. The devices are grouped into sectors and a two-level routing is performed. The model has low computational requirements, and randomization in the second level of

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routing provides SLP, hence resulting in a secure routing model.

2. Related works

Wireless Sensor Networks are being very prevalent in the current interconnected scenario. Hence the domain has gained huge prominence with several researchers working to identify and solve issues relating to security and energy awareness in WSN.

A Taylor-based hybrid optimization algorithm designed mainly for energy efficiency was proposed by Vinitha et al. [9]. The multi-hop routing model has been designed using Taylor based Cat Salp Swarm Algorithm (Taylor C-SSA), which is a modified form of C-SSA algorithm. The model follows a two-stage process, which includes a cluster head selection and data transmission. A trust-based routing algorithm, Trust-Aware Routing Framework (TARF) proposed by Zhan et al. [10] focusses on energy efficiency and also node trust. Routing is performed by identifying the reliability of the neighboring nodes. Routes are created using reliable nodes with high trust. All the other unreliable nodes are ignored from creating routes. An algorithm to compute node reliability was proposed by Zahariadis et al. [11]. It is a distributed algorithm operating based on Ambient Trust Sensor Routing (ATSR). Every node in the model monitors its neighbors, and calculates and maintains the trust value. Other similar energy-efficient routing models are green routing protocol by Cengiz et al. [12], fuzzy logic and clustering based model by Purkait et al. [13] and delay constrained multihop routing model by Selvi et al. [14].

Metaheuristics have become a popular choice for routing due to their ability to include multiple objectives into the model at ease. A multi-objective energy-aware routing protocol based on fractional particle lion algorithm was proposed by Bhardwaj et al. [15]. The model uses distance, delay, energy, cluster density and traffic level as parameters to design the fitness function. Energy awareness is provided by the lion algorithm. A hybrid particle swarm optimization-based algorithm to detect events was proposed by Mohanasundaram et al. [16]. The model also integrates FCM clustering to identify thepositions of the storage nodes in the cluster. Other similar approaches include the artificial bee colony algorithm based routing model by Kumar et al. [17], bird mating algorithm by Faheem et al. [18] and PSO based model by Upendran et al. [19].

WSN model aimed at load-balanced routing was presented by Yarinezhad et al. [20]. The load balancing issue is handled by the approximation algorithm which exhibits an approximation ratio of 1.1. The model is based on creating equally dense clusters during the sensor node grouping process. Other approximation-based models for load balancing clustering problems are works by Low et al. [21] and Kuila et al. [22]. Metaheuristics is also used for solving this issue. Some of the works under this domain includes Genetic algorithm-based models by Kuila et al. [23], Gupta et al. [24], PSO based models by Kuila et al. [25], Azharuddin et al. [26], Bee Colony based model by Mann et al. [27].

3. Network Model

Consider the WSN is composed of N sensor nodes. Each node is separated by large and short distances based on the reachability levels of the node. Reachability is defined by the radio range. The distances of separation are not uniform and vary between nodes. Communication is wireless and is set within the recommended radio range limits. Transmission occurs between nodes and also to the base station. The proposed model considers both nodes and base station as standard nodes and does not exhibit any difference during transmission. Nodes are grouped into sectors. Exemplar nodes are defined in each sector and they act as representatives for the sectors. Sectors are defined by density and not by shape. Hence a varied number of nodes can be found in sectors. Sectors are also in varied shapes. Every node in the sector maintains certain attributes like, its location, charge remaining in the node, Boolean indicator representing its exemplar status and average charge details. Average charge represents the average charge of all the nodes in the sector. The average charge details are maintained only by the exemplar nodes. During the network construction, the average charge is set to zero. It is updated after the sectors are defined and the exemplars are updated.

4. Two-Level Randomized Sector based Routing (TLRSR)

Security in routing is a major requirement due to the unmanned nature of such networks. This work presents a location-based randomized routing process that performs routing in two levels for secure routing. The model is based on sector based routing, where the sector routes are identified in the first level and node based routes are identified in the second level. The process of routing is performed in phases; sector creation, graph creation, ACO based sector route identification and Simulated Annealing based route expansion.

4.1 Affinity Propagation based Sector Creation

The initial phase of the model is to group sensor nodes into defined sectors. Sectors are identified based on the Affinity Propagation (AP) model. The AP model groups nodes by performing a pair-wise comparison of nodes. Grouping is based on the location of deployment of the node, i.e. the x and y coordinate of the node is used as the base for the grouping process. The major advantage of AP model is that it has the capability to create unevenly sized sectors, which do not follow any specific geometrical structure. Deployment nature of sensors requires flexible grouping, as some locations contain dense distribution of sensors, while others are sparse. Another major advantage of the AP model is that the number of sectors need not be defined initially. Based on the reachability, sectors are automatically created.

AP model functions by initializing the similarity matrix. Similarity matrix is an *NXN* matrix that maintains the similarity levels between nodes. Similarity levels are identified by Euclidean distance, and is given by

$$sim(i,j) = -\left(\left\|x_i - x_j\right\|^2 + \left\|y_i - y_j\right\|^2\right)$$

Where $x_i$and $y_i$are the location coordinates of node i and $x_j$and $y_j$are the location coordinates of node j. Diagonal values in the matrix present the likelihood of the node becoming an exemplar. Exemplar is a representative sample of a sector. Along with the similarity matrix, the responsibility and availability matrices are also maintained for grouping.

The responsibility matrix, R is composed of data, that represents the suitability of a node in operating as an exemplar. Value r_{ik} in matrix R presents the suitability of k to serve as an exemplar for i. Similarly, the value a(i, k) in availability matrix A represents how appropriate it is for node i to pick node k as its exemplar. Values for R and A are initially set to zero and are updated for every iteration.

Responsibility matrix is updated using the below equation

$$r(i,k) = s(i,k) - \max\{a(i,k') + s(i,k')\} \quad where\ k' \neq k$$

Availability matrix is updated next using the below equation

$$a(i,k) = min\left(0, r(k,k) + \sum_{i' \notin \{i,k\}} \max\left(0, r(i',k)\right)\right) for\ i \neq k$$

$$a(k,k) = \sum_{i' \notin \{i,k\}} \max\left(0, r(i',k)\right)\ for\ i = k$$

The process is repeated until sector boundaries and exemplars stabilize for a defined number of iterations. After the end of the sector creation process, exemplar status and the average sector charge are updated accordingly.

4.2 Graph Creation and Exemplar based Source and Destination Sector Identification

ACO [28, 29] is a graph-based optimization model. Hence the network graph is formulated prior to the route generation process. Graph is created based on the sectors, rather than nodes. Edges between sectors are defined based on the reachability of the exemplar. However, exemplars are mostly located at the center of the sector, and might not possibly reach some sectors. Hence a secondary edge creation mechanism is included, that checks for sector accessibility via nodes in the sector. If a sector is accessible via a node in another sector, they are considered to be connected, and an edge is created between them.

Transmission requirements arise from source nodes. The initial phase is to identify sector details of the source and the destination nodes. The source node is added to be a part of the constructed network graph, and becomes the start node. All other nodes are constructed based on the sector information. Exemplars are considered as the node values. This marks the end of the graph creation process. The created network graph is passed to ACO module for sector-based route identification.

4.3 ACO based Sector Route Generation

ACO is used as the algorithm of choice for sector based route identification. The process of route identification begins from source node and ends in the sector of the destination node. ACO operates based on the movement of intelligent agents known as ants. The ants follow the pheromone trail to reach the destination via the most optimal path. The probability of selecting a node is defined by the fitness of the node. Fitness for ACO is defined using pheromone trail and distance. The TLRSR model includes the average sector charge as an additional parameter in identifying the fitness of a solution. Fitness of a solution is given by

$$p_{ij}(t) = \frac{\left[\tau_{ij}(t)\right]^{\alpha}.\left[\eta_{ij}\right]^{\beta}[\varepsilon_j]}{\sum_{j=1}^{n}\left[\tau_{ij}(t)\right]^{\alpha}.\left[\eta_{ij}\right]^{\beta}.[\varepsilon_j]}$$

Where τ_{ij} is the pheromone trail between nodes, *i* and j, ε_j is the average sector charge contained in the exemplar node *j*and η_{ij} is the distance between the nodes, given by,

$$\eta_{ij} = \frac{1}{\sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}$$

The route identification process begins after the construction of the network graph. Ants are distributed in the source node and are directed to move towards the destination sector. The metaheuristic nature of the model incorporates randomness in the selection process. Fitness function determines the next node to be selected for movement. In this phase node corresponds to sectors. After every successful node selection,trail intensity between the nodes is updated by,

$$\tau_{ij}(t+1) = \rho.\tau_{ij}(t) + \Delta\tau_{ij}(t, t+1)$$

Where ρ is the evaporation parameter, *t*is the time and $\Delta\tau_{ij}$ is given by

$$\Delta\tau(i,j) = \begin{cases} (L_k)^{-1} & if\ (i,j)\ belongs\ to\ the\ global\ best\ tour \\ 0 & Otherwise \end{cases}$$

Where $L_k$is the total distance covered by the ant from the source to the destination.

Higher pheromone levels indicate preferred and optimal routes. The process of sector selection and addition to the route is performed until the destination node is reached.

The route obtained from this phase provides a skeletal framework of the traversal path. This path has been defined completely based on the exemplars. However, node details are required for the actual transmission to process, which is done by the route expansion phase.

4.4 Simulated Annealing based Route Expansion

Node based route expansion is performed by Simulated Annealing [30]. Every node (*n*) receiving a packet contains details about the next sector (NS) to which the transmission is to be performed. Details about the specific node to which the packet needs to be passed are identified in this phase. Nodes utilize the sector information to determine the best node for transmission. Randomness is introduced in the model by selecting a random set of nodes (RN) from the next sector. This ensures that nodes cannot backtrack to identify source details. It also facilitates uniform charge dissipation, as it avoids frequent selection of some nodes located at strategic points. Optimal node from the set of nodes in RN is selected by the Simulated Annealing technique.

Simulated Annealing is a probabilistic technique to identify the approximate global optimal solution from a large search space. Fitness function defines the probability of selection of a node, and is formulated based on node charge. The process of optimal node selection is provided below.

1. *sn = randomly selected node from sector*
2. *For k = 0 to count(RN):*
   a. *T =charge contained in sn*
   b. *sn_{new} = select a random node from RN which is ≠ sn*
   c. *If P(E(sn), E(sn_{new}), T) ≥ random(0, 1):*
      i.sn ← sn_{new}
3. *snis reported as selected optimal node*

$$P(e, e', T) = \begin{cases} 1 & if\ e' > e \\ \exp\left(\frac{-(e'-e)}{T}\right) & Otherwise \end{cases}$$

Where, $e, e' anf\ T$ are the arguments passed to the function P.The packet is transmitted to the selected node. The selected node repeats this process to identify the next node for transmission. The process is repeated until the destination node is reached.

4.5. Routing Process

The above phases provides key operations performed in the TLRSR model. Operational sequence of the TLRSR model is provided below:

1. *Network is configured and sectors are created using the Affinity Propagation technique*
2. *Exemplars defined for each sector*
3. *If routing request arises from a source*
   a. *Packet preparations*
   b. *Source and destination sectors are identified*
   c. *Graph creation using source node and sectors*
   d. *Sector based route identification using ACO*
   e. *Source node identifies next sector (sec) from route*
   f. *Random nodes are selected from sec to form RN*
   g. *Optimal node (opt) identification from RN using Simulated Annealing*
   h. *Transmit packet to opt*
   i. *If opt is not destination*
      i. *Charge reduction in opt*
      ii. *Identify next sector sec using sector route*
      iii. *Goto step 3.f.*
   j. *If opt is destination, Terminate process*

5. Results and discussion

The simulation environment for the current experiment is composed of 30 sensor nodes. Each node maintains the node specific properties and it is assumed to have different charge levels to exhibit the varied nature of IoT devices. They are distributed in-random without following any specific criteria. The Affinity Propagation technique, the ACO based sector route creation model and Simulated Annealing based route expansion model are implemented using C#.Net. The transmission is set to motion from random nodes, with varied destinations for each iteration. The network was terminated after 100 varied transmissions, and the node and network properties were recorded.

Overhead incurred for the selection process has been timed and presented in Figure 1. Selection overhead comprises of the route creation, sector based route identification and route expansion processes. These are the additional components in the proposed work. Time incurred due to the addition of these components has been measured. A minimum of 6ms and a maximum of 19ms were observed to be the selection overhead. It is also to be noted that the route generation is included in this measurement. Because of the low overhead exhibited by the proposed TLRSR model, it can be concluded that the TLRSR model exhibits low overheads in terms of time.

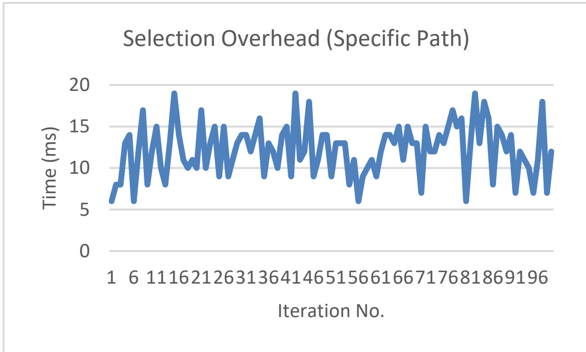

Figure 1: Selection Overhead for RSR

Distance covered by the TLRSR model during transmissions has been recorded and plotted in figure 2. Measurements were obtained for varied sources and destinations. The optimal distance requirement to cover the entire network is 423. It could be observed that the recorded path distances exhibit an average distance level of 200 and reach a maximum of 250, which is approximately half of the path length required to cover the entire network. The low distance requirements by the TLRST model shows that the model selects effective and optimal routes with low distance requirements.

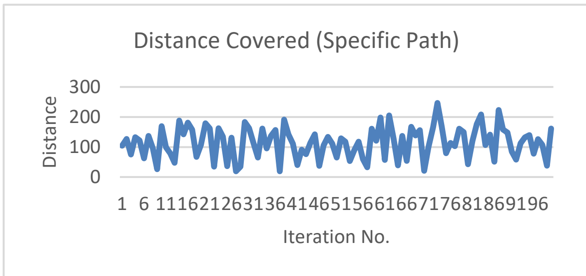

Figure 2: Distance Covered by TLRSR during Transmission

6. Comparative study

The obtained results from TLRSR are compared with the PSO-based routing model proposed by Upendran et al. [19].A comparison of the usage levels of nodes in the network is shown in figure 3. Node usage levels are measured by the level of depletion of charge in the node after transmissions. Measurements were done after 300 transmissions to ensure the balanced utility of nodes and to obtain a deeper view of the high and the low usage levels of nodes. It could be observed that a few nodes in the key points are utilized higher, while all the other nodes exhibit almost similar usage levels. Results from Upendran et al. also exhibits spikes in the same nodes showing that this spike in usage cannot be avoided. However, on analyzing the other nodes, it could be observed that the TLRSR model exhibits low deviation levels with the average utility level, while usage levels in Upendran et al. exhibits very low utility in several nodes showing that they are not used. This exhibits better load balancing by the TLRSR model.

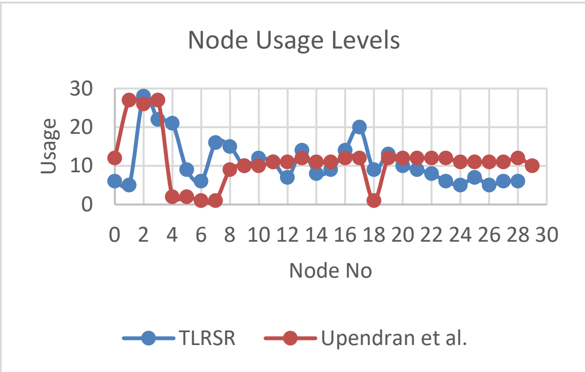

Figure 3: Node Usage Level Comparison

The average length of paths obtained by the TLRSR model and model proposed by Upendran et al. [19] has been compared and shown in figure 4. Lower distance exhibit optimal paths and also low utilization of nodes, resulting in lower charge depletion. Chart indicates that the TLRSR model exhibits lower path length, hence exhibiting lowered utility levels. This property also enables balanced utilization and hence ensures extended network lifetime.

Time and distance measures and comparisons indicate improved performances of the TLRSR model. This is contributed to the multi-level route detection and expansion mechanism using ACO and Simulated Annealing. Sector-based route creation and the randomized route expansion modules ensure equal load distribution, hence improving the network lifetime.

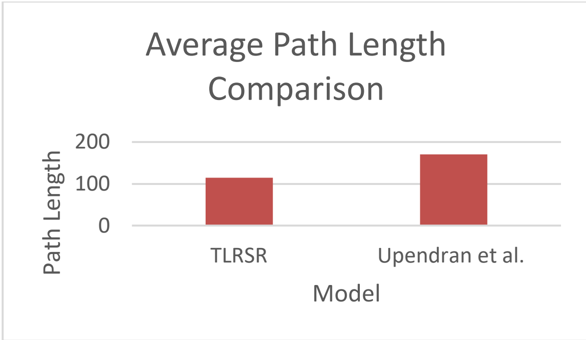

Figure 4: Average Path Length Comparison

7. Conclusion

Security is one of the major requirements of an interconnected system. WSN and WSN based IoT networks encounter a similar scenario. Source location privacy is one of the major challenges of WSN based models. The wireless nature of transmissions makes security huge a challenge. This work presents a two-level randomized sector-based model for routing, to ensure security during transmissions. Low storage and low computing capabilities are the major constraints for designing a routing model. The proposed TLRSR model has been designed to handle these constraints. The network has been initially divided into sectors. Initial level identifies sector based routes using ACO, while route expansion is performed by Simulated Annealing. The process of route expansion is randomized, resulting in balanced usage and source location privacy.

The major advantages of this model is that source node computes sector-based routes. It operates on sectors, which are limited, rather than operating on the entire network. The second level of expansion is performed on a per-node basis. A node computes to identify the next node, further resulting in a reduction of computations in nodes. The computations are also distributed, hence charge dissipation is even over the network. The limitation of this model is that the model does not analyze the status of a node prior to transmission. Future works will concentrate on integrating the trust factor into the node selection model to improve security.

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