A Novel and Efficient Anti-Collision Protocol for RFID Tag Identification

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***Abstract*—Radio frequency identification (RFID) is prominent technology for fast object identification and tracking. In RFID systems, reader-to-reader or tag-to-tag collisions are common. Majority of probabilistic and deterministic anti-collisions methods are inefficient in channel distribution and improving the performance. In this work, simulation annealing based anti-collision protocol is proposed where there is uniform distribution of channels among readers. In addition, preference is given to tag state parameters over fixed scheduling in order to increase the performance. The tag state parameters named energy efficiency, distance from selected reader and distance from obstacles are considered. The simulation results show that the proposed approach is an effective mechanism where there is a minimum improvement of 16.7% for 100 readers and maximum of 32.7% for 1000 readers in tag identification ratio, and a minimum improvement of 23% for 1000 readers and maximum of 75.3% for 100 readers in total successful interrogation cycles. Further, total time cycles, total IDLE cycles, total number of collisions, delay, and total number of packets sent and received are reduced compared to state-of-art protocols. It is observed that the proposed simulation annealing based protocol is contiguous channels allocation algorithm with zero collision.**

***Keywords*—RFID; anti-collision; simulated annealing; performance; tag-to-tag collisions; reader-to-reader collisions**

I. INTRODUCTION

Radio frequency identification (RFID) is preferred over bar code because of its long range of interrogation, fast speed, low cost, penetration through obstacles, multiple reading capacity, source battery source etc. RFID tags, readers and backend system are the indistinguishable components of RFID system[1][2]. RFID tag stores the product information, RFID reader reads product information from tag and sends it to backend system. Backend system securely stores the necessary information. There are various applications [3] of RFID networks like healthcare, agri-food, fruit temperature monitoring, food chain tracking, defense and security, smart university, construction and waste management etc. In RFID network, tags are distributed in some geographical area and the presence of multiple tags creates a dense network. In dense network, multiple readers are read by each reader from specified geographical location. Both RFID reader and tag have one transmitter and receiver unit, thus one reader can communicate with one tag at a time. If a reader has to read multiple readers at same time then there is need of identification and scheduling mechanism that uniquely identifies the tags. On the other hand, multiple tags will contend to be read by reader, thus these tags will produce their uniquely identification numbers for fast, secure and timely identification. In presence of multiple tags per reader or single tag for multiple readers, chances of collisions are higher and proportionately decrease the performance of network. Thus, anti-collision protocols are designed for collision free identification which aim to increase the performance of the network.

To measure the performance of anti-collision protocols, various parameters used are as followed.

- *Tag Identification Ratio (TIR):* The ratio of the number of identifiable tags to the total number of tags.
- *Total time cycles*: An efficient anti-collision protocol should identify maximum tags in minimum number of time cycles.
- *Total IDLE cycles*: In anti-collision protocol, a reader goes into IDLE time cycle, whenever (i) it could not identify any tag due to prefix mismatch, (ii) collision found in previous round, (iii) time required for pre-computation etc. An anti-collision protocol should target to minimize total number of IDLE cycles while identifying tags.
- *Total successful interrogation cycles*: A successful interrogation cycle is a cycle in which a reader interrogates tags without collision. An efficient anti-collision protocol should maximize the successful interrogation cycles while identifying tags.
- *Total collisions:* An anti-collision protocol should identify maximum tags with minimum number of collisions.
- *Total Delay:* If chances of collision increase then delay in identification also increased. Hence, anti-collision protocol should be designed in a way that maximum tags are identified within minimum duration.
- *Total number of messages received and sent by reader or interrogator:* In anti-collision protocols, reader may take one or more rounds per tag for its proper identification. Hence, the number of messages exchanged between a reader and each tag increases the communication and computational cost of network with increase in number of rounds.

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- *Order of tag identification:* An order in which tags are identified is relevant for some application. For example, in traffic management, if multiple routes exist between source and destination then, to measure the traffic on specific route, all readers on road site unit of that specific route should interrogate all tags attached to vehicles and send data in required time. Tag identification from source to destination helps in estimating the time taken to reach the destination.

In this work, a novel and efficient simulation annealing based anti-collision protocol [4] is extended for performance improvement through linear ordering and simulation annealing processes. As compared to state-of-art protocols, the proposed protocol gives better performance in terms of total time cycles, total IDLE cycles, total successful interrogation cycles, total collisions, total delay, total number of messages received or sent and order of tag identification. In total time cycles, a minimum improvement of 56.8% for 500 readers and maximum improvement of 94.0% for 1000 readers are observed compared to other approaches[5]-[10]. In total IDLE cycles, a minimum improvement of 82.7% for 400 readers and maximum improvement of 95% for 100 readers are observed compared to other approaches[5]-[10]. In total successful interrogation cycles, a minimum improvement of 23% for 1000 readers and maximum of 75.3% for 100 readers are observed compared to other approaches[5]-[10]. The total number of collisions are reduced to almost zero in proposed mechanism compared to other approaches [5]-[10]. In total number of messages sent, a minimum improvement of 28.5% for 300 readers and a maximum improvement of 67.8% for 200 readers are observed compared to other approaches[5]-[10]. In total number of messages received, a minimum improvement of 28.3% for 100 readers and a maximum improvement of 80.8% for 400 readers are observed compared to other approaches[5]-[10].

The rest of the paper is organized as follows. Section II describes the state-of-art anti-collision protocols for tag identifications. Section III describes the proposed simulation annealing based anti-collision protocols for multiple tag identification. Section IV describes the experimental setup, performance analysis of proposed algorithm, verification and validation of results. Finally, conclusion is drawn in section V.

II. RELATED WORK

RFID anti collision protocols deals with tag-to-tag or reader-to-reader collisions [11]. Deterministic and probabilistic algorithms are broad classification of anti-collision protocols. The protocols in each of these categories are as follows.

A. Deterministic Algorithms

Protocols in this category are based on multiple access methods like SDMA, TDMA, FDMA and CDMA. Multiple access methods either give synchronous or asynchronous identification. In synchronous identification, methods like polling, I-code, contact-less, tree splitting, query tree [11][12] etc. distinguish tags using prefixes. These methods perform bit by bit matching for tag identification. Readers send interrogation request and tags respond with demanded prefix. In asynchronous identification, readers interrogate in fixed cycles. Here, readers send an interrogation request and tags respond with complete identification rather than a prefix. For example, CSMA protocol, CSMA protocol with soft reservation etc. Majority of deterministic algorithm are proposed for tag related collisions [11].

B. Probabilitistic Algorithms

The probabilistic algorithms are mainly proposed for reader related collisions. Source of the probabilistic algorithms are graph coloring, heuristic, neural network, simulated annealing, genetic algorithm etc. [11][13]. In these probabilistic algorithms, the main objective is to increase the performance of the network by estimating the chances of reader’s interrogation. These methods are designed especially for dense networks. In dense networks, number of readers per unit area is high, thus chances of collisions are also high. The probabilistic algorithms provide better performance in these scenarios.

Both deterministic and probabilistic algorithms does not provide collision free network. Further, reader state are also not taken into consideration while interrogation. Reader state is important to get specific gains like performance improvement, energy efficiency, scheduling etc. In Simulation annealing algorithms [5]-[9][14], both collision free network and reader state properties are taken into consideration while designing an anti-collision protocol. For example, Lin *et al.* [5] proposes a simulated annealing based anti-collision protocol which uses energy efficiency for reader selection. However, if there is no uniform distribution of channels then collisions can not be avoided among same energy readers. Hung *et al.* [6] proposed a uniform distribution scheme which uses reader’s temperature parameter for selection of the interrogator. In this scheme constant temperature, Geman-Geman rule and Kirkpatrick et al temperature control schemes are tested for reducing collisions. It is observed that simulated annealing schemes with temperature control mechanisms reduce collisions at much higher rate compared to random selection or heuristic algorithms. Although there is uniform distribution of resources in this scheme,it is observed that the problem of multiple nearby readers having same temperature still causes collisions. Further, in this scheme, the selection of readers is tag dependent, which is not realistic. Both readers and tags are free to move randomly and independently. Tian *et al.* [7] proposes a realistic solution to anti-collision protocol with chaos neural network based on annealing strategy which improves the reliability and efficiency of network. However, the use of coloring and scheduling approach for colliding readers does not avoid collisions completely. Further, if maximum number of nodes has the same color then tag identification ratio decreases drastically. Similarly, if maximum number of readers has different colors but differ from the current color of interrogator then also performance decreases with time. In [8], a location search using simulated annealing and error reduction using a gradient descent method is proposed for density computation. Although location of readers give clarity to selection but presence of multiple readers in dense network does not ensure collision free environment. In an another attempt to location and density based anti-collision protocol, Li *et al.* [14] proposes a RFID reader-to-reader collision avoidance model with multiple-density tag distribution. In this protocol, number of querying tags in artificial immune network is taken as annealing parameter for proposing the reader selection mechanism. Also, this approach is tag dependent, which is unrealistic. Next, the particle swarm optimization algorithms are easy to fall into local optimum in highly dense network, thus do not provide global optimum solution. Tao *et al.* [9] proposes an improved simulation annealing-particle swarm algorithm, with restriction to position change, for accelerating the convergence speed of the algorithm. Restricting the position change is unrealistic and load balancing by estimating the signal interference does not allow multiple nearby readers to interrogate simultaneously. Moreover, there is no uniform distribution of channels among readers. It gives preference to continuous interfering readers but these readers may not aim to interrogate. Alonso *et al.* [10] observed that channels can be uniformly distributed among readers using a scheduler. It uses a centralized server for collecting the requests and then distributing the channels and slots. However, this protocol does not take reader state into consideration. A reader may send a request for interrogation initially but its state does not allow him to interrogate during its time and slot. Similarly, many protocols [11] are proposed in state-of-art that ensure performance improvement but does not provide collision free environment. Thus, there is need of a protocol which restricts the interrogation for improving performance rather than movements and also there should be uniform and contiguous allocation of channels among readers.

III. PROPOSED ANTI-COLLISION PROTOCOL

In this section, an anti-collision protocol for tag identification using simulation annealing is proposed. This protocol takes help of server to draw the geographical locations of readers, tags and obstacles. The geographical locations are plotted using polar coordinate system in polar graphs[15][16][17]. The simulation annealing approach results in an optimized solution for reader and tag selection. The proposed protocol works for both stationary and mobile readers and tags. In the proposed scheme, a server either draws an obstacle free or fixed cells network structure. It draws a obstacle free network structure if geographical area under observation is having obstacles for mobile readers or tags (case-1) otherwise fixed cells network structure (case-2). Fixed cells network structure is same as structures in cellular network where tags are identified by drawing a fixed structure cells repeatedly. After drawing obstacle free or fixed cells network structure, the server decides appropriate reader for interrogating tags using linear ordering algorithm with simulation annealing for maximizing the gain.

A. Draw Polar Graphs

RFID devices use radio waves for identifying the objects. Radio wave penetrates through obstacles but if the frequency of radio wave is increased then they start behaving like a light [3]. Thus, they can not penetrate through objects and bounce back. Now, a geographical area may or may not contain obstacles. If it does not contain obstacles then there is no need of drawing polar graphs for estimating the location but if it contains obstacles then drawing polar graph is essential for estimating the locations of mobile readers or tags. Devices in geographical area containing obstacles use radio waves that may or may not penetrate through these obstacles. Using orizontal and vertical polar graphs, it is easier to model topological placement of devices [17]. Further, polar graphs are preferred over other coordinate systems because it plots distance radially from any point on the surface of the globe to any other point in terms of polar coordinated which is essential for proper tag location identification in proposed system [15][16]. In location identification, using polar graphs, it is easier to locate tags with respect to omnidirectional signal of concentric circles intersected by radial lines through the position of reader as shown in fig. 1. The radical line and the angle θ provides the proper tag location for interrogation. For example, the location of tag in fig. 1 is (3, π/2).

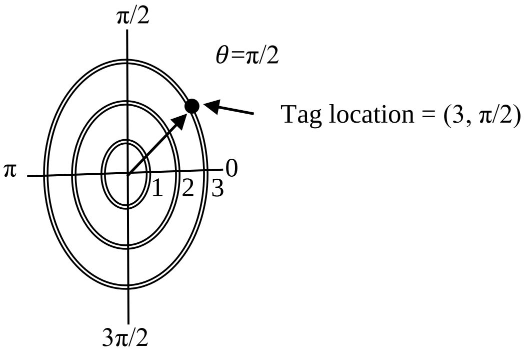

Figure 1: Location identification using polar coordinates

Case 1: If *radio waves do not penetrate through objects* then drawing a network structure with heterogeneous areas of squares and rectangles is appropriate for polar graphs. For example, fig. 2 shows an area under consideration containing obstacles and fig. 3 shows the network structure of the same area. In fig. 3, network structure of heterogeneous areas of squares and rectangles is drawn in a way that all obstacles lay on boundaries of squares or rectangles. Fig. 4 shows the polar graphs of this network structure. Polar graph is drawn on both vertical and horizontal sides of an area. In order to draw a polar graph, each square or rectangle area is numbered. For example, there are 14- obstacle free areas numbered from 1 to 14 in network structure of given area. Every obstacle free area has multiple exit points. For example, obstacle free area 1 has 1-1 and 1-2 exit points. These exits points with timestamp help in drawing vertical and horizontal polar graphs for tacking the movements of readers. For example, movements of reader 1 tracked using 2-1(T1-R1), 4-2(T2-R1) and 5-2(T3-R1) exit points and reader 2 are tracked using 1-1(T1-R2), 4-1(T2-R2), 7-1(T3-R2) and 10-2(T4-R2) exit points as shown in fig. 4. Vertical and horizontal polar graphs with timestamp of both readers are also shown in fig. 4. As a result, reader 1 is present in obstacle free areas 2, 4, 5 and 8 at time before T1-R1, T1-R1 to T2-R1, T2-R1 to T3-R1 and after T3-R1 respectively. Similarly, reader 2 is present in obstacle free areas 1, 4, 7, 12 and 13 at time before T1-R2, T1-R2 to T2-R2, T2-R2 to T3-R2, T3-R2 to T4-R2 and after T6-R2 respectively.

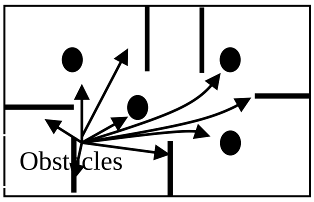

Figure 2: An area under observation containing obstacles

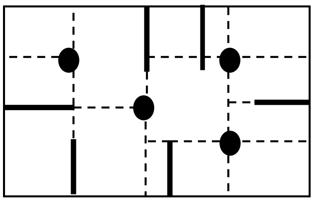

Figure 3: An area under observation depicting network structure of uneven squares and rectangles

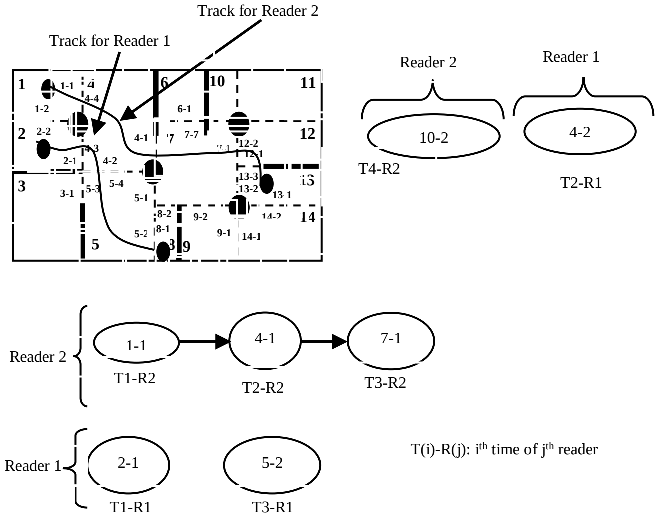

Figure 4: Polar graphs of network structure when radio waves can not penetrate through obstacles (case-1)

Case-2: If *radio waves penetrate through objects or there are no obstacles* then drawing a cell structure with homogenous areas of squares or rectangles is appropriate for polar graphs. For example, fig. 5(a) and 5(b) show the network structure of area shown in fig. 2 using rectangles and squares respectively. Fig. 6 shows a counter example of polar graphs of area shown in fig. 2. In this example, reader 1 moves from 1-1 and 2-2 exits at time T1-R1 and T2-R2 respectively. Thus, reader 1 is present in cell 1, cell 2 and cell 3 at time before T1-R1, T1-R1 to T2-R1 and after T2-R1 respectively.

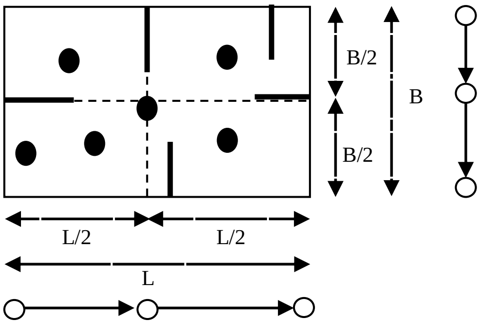

Figure 5(a): Polar graphs with rectangles

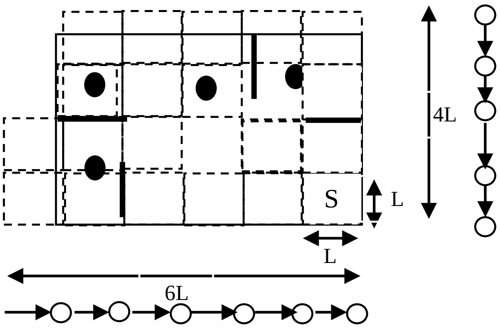

Figure 5(b): Polar graphs with squares

Figure 5: Polar graphs of network structure when radio waves can penetrate through obstacles (case-2)

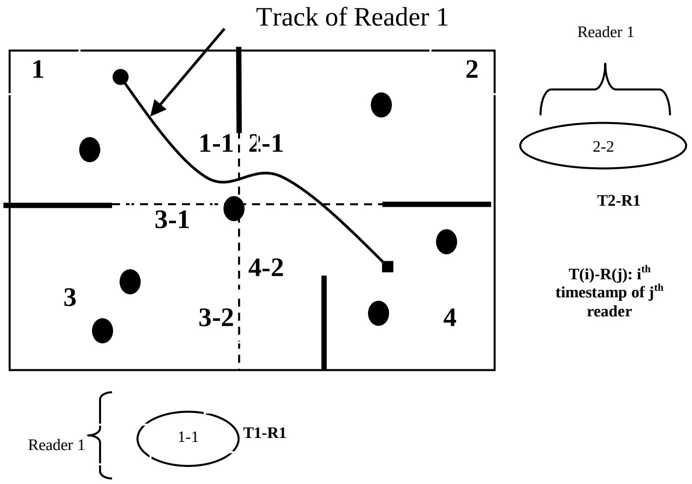

Figure 6: Counter example of polar graphs of network structure when radio waves can penetrate through obstacles (case-2)

B. Execute Linear Ordering Algorithm with Simulation Annealing

After estimating the locations of mobile readers and tags, the centralized server runs an anti-collision gain game for identifying the tags. Here, gain is the desired goal. Gain may be in form of maximizing the number of tags identification, efficient use of energy consumption, preference to those readers which are having maximum number of neighboring tags etc. The common steps followed for every type of gain in linear ordering algorithm with simulation annealing are as follows.

Step 1: Initialization – Start with a random point to draw a obstacle free or fixed cells network structure. Also, identify the current positions of all readers.

Step 2: Count the readers – In every obstacle free area or a cell, count the total number of readers.

Step 3: Calculate gain score – If it is first time that reader selection process executes then calculate the gain score else calculate the change in gain score with every change in count of readers in obstacle free area or cell.

Step 4: Select a reader per obstacle free area or cell – If it is first time that reader selection process executes then select a reader per obstacle free area or cell that provide maximum gain else depending on the change in gain score, accept or reject the previous selection of reader.

Step 5: Update– Update gain score regularly in a way that at least one reader per obstacle free area or cell must be selected for interrogation.

Step 6 Repeat– The process is repeated until all tags are identified.

In RFID network, collisions may occur among readers or tags. Algorithm 1 ensures that if multiple readers are active at a time in one obstacle free area or cell then exactly one reader should be selected for interrogation. Whereas, algorithm 2 ensures that if multiple tags respond at a time then selected reader interrogate tags in a sequence that improves the performance of network. In algorithm 1, process of reader selection starts with random selection of first reader as a seed value for saving the time and improving the performance. When seed reader interrogates then a process of computing the number of tags in obstacle free area or cell where readers are present, reader's energy efficiency, count of covering least number of obstacle free areas, distance covered by each reader and a random number selection is performed. These computations in algorithm ensure that if one or more readers are present per obstacle free area or cell, then exactly one reader should be active for interrogation using algorithm 1.

Algorithm 1: Linear Ordering with Simulated Annealing (for readers)

```
1.  $R$: Set of all readers
2.  $O$: Sequence of readers selection; ("initially empty")
3.  $IR_{r_i}$: interference range of i^th reader
4.  $D_{ij}$: distance between i^th and j^th readers
5.  Begin
6.      Seed:= Select seed reader
7.      O:=[Seed]
8.      R:=R-{Seed}
9.      Repeat
10.         For each reader $r_i \in R$ do
11.             Compute the gain for selecting reader $r_i$
12.             $gain_{r_i} := D_{ij} - IR_{r_{i-1}} - IR_{r_i}$
13.             If $gain_{r_i}$ is negative then
14.                 Select another $r_i$ and compute gain
15.         End for each
16.         Select the reader r with maximum gain
17.         If there is a tie then
18.             Select the reader which has maximum neighboring tags
19.             If there is a tie then
20.                 Select the reader that has the maximum energy efficiency
21.                 If there is a tie then
22.                     Select the reader that expect to cover least number of obstacle free areas or cells
23.                     If there is a tie then
24.                         Select the reader that cover least distance
25.                         If there is a tie then
26.                             Select the reader that has to read important/crucial information
27.                             If there is a tie then
28.                                 Select the reader with server priortization
29.                             Else
30.                                 Run the Slot_Allotment_Procedure for multiple readers
31.         O:=[r] (append r to the ordered sequence
32.         R:=R-{r}
33.     Until R=∅
34. End
```

In algorithm 1, preference is given to constrained readers thereafter channels are allocated uniformly among readers. In step 26th of algorithm 1, Slot_Allocation_Procedure() uniformly distributes these channels. Procedure 1 describes the algorithm for uniform channel allocation. In this procedure, the sever collects requests of slots from every reader with their priority. Server allocates channels in a linear ordering based on priority of each reader. If the number of channels is less than number of readers then remaining readers have to wait for Δ slots. This allocation procedure assigns channels based on priorities. Priorities of each reader are fulfilled one by one i.e. highest priority request from each reader is handled first followed by second highest priority from each reader and so on. This allocation procedure removes the collision problem in reader-to-reader interrogation cycles.

Procedure 1: Slot_Allotment_Procedure()

```
1.  C: Number of channels
2.  $A_i$: Allocation vector for i^th channel
3.  $P_i$ : Priority of i^th channel
4.  $N_R$ : total readers
5.  $D_{ij}$ : request vector for i^th reader with j^th priority
6.  Δ : Number of slots assigned to reader at stretch
7.  For each channel $c \in C$ do
8.      $A_c = 0$
9.  End For each
10. For each priority $p \in P$ do
11.     For each reader $r \in N_R$ do
12.         If $D_{ij}$ of r is 0 then
13.             Skip
14.         Else
15.             For each channel $c \in C$ do
16.                 If c is free then
17.                     Assign Δ slots to r on channel c
18.                     Increment $A_c = A_c + \Delta$
19.                     Decrement $D_{ij} = D_{ij} - \Delta$
20.                 Else if c is busy then
21.                     Choose another c
22.                 Else if all $c \in C$ are busy then
```

```
            Wait for Δ slots
        End for each
    Compute A_max = $Max_{c=1}^{C} A_c$
    End for each
End for each
```

Algorithm 2 is to generate linear ordering sequence of tags whenever multiple tags respond at same time to the selected reader request. Initially, a tag is randomly selected as seed value for saving time and improving the performance. When seed tag respond to reader then parallel processes for computing the time of each tag since it responded, energy efficiency, distance from selected reader, distance from obstacles and a random number selection are executed. These computations within algorithm ensure that if multiple tags respond to selected readers request, then selected reader should listen to exactly one tag at a time.

Algorithm 2: Linear Ordering with Simulated Annealing (for tags)

```
T: Set of all tags
O: Sequence of tags selection; (“initially empty”)
Begin
    Seed:= Select seed tag
    O:=[Seed]
    T:=T-{Seed}
    Repeat
        For each tag t ∈ T do
            Compute the gain for selecting tag t
            $gain_r$ := number of seconds spend when ‘t’ has not responded
        End for each
        Select the tag ‘t’ with maximum gain
        If there is a tie then
            Select the reader that has the maximum energy efficiency
            If there is a tie then
                Select the tag that has important/crucial information
                If there is a tie then
                    Select the tag that is nearer to obstacles
                    If there is a tie then
                        Select the tag that is nearer to minimum number of readers
                        If there is a tie then
                            Select the tag that has maximum distance from reader
                        Else
                            Randomly select one tag as desired
        O:=[t] (append ‘t’ to the ordered sequence)
        T:=T-{t}
    Until T=∅
End
```

IV. ANALYSIS OF RESULTS

Table 1 shows the simulation parameters used for analysis. In simulation, 100000 tags and 1000 readers are randomly distributed in an area of 1000m x 1000m. Fig. 7 shows the comparative TIR analysis of proposed protocol with Lin et. al. [5], Hung et. al. [6], Tian et. al. [7], Ko [8], Tao et. al. [9] and Alonso et. al. [10] protocols. Results show that the proposed protocol gives better TIR compared to selected state-of-art protocols. TIR increases with increase in number of readers because more readers are available for tag identification. Although there are no collisions among readers but achieving 100% TIR is impossible because waiting tags may or may not be identified.

TABLE I
SIMULATION PARAMETERS

Parameters	Value
Number of Readers	1000
Number of Tags	100000
Channel Type	WirelessChannel
Radio Propagation Model	TwoRayGround
Network Interface	WirelessPhy
MAC Type	802.11
Interface Queue	Priority Queue
Antenna	OmniAntenna
Max Packets in Queue	50
X dimension of the topography	1000 meters
Y dimension of the topography	1000 meters
Mobility Model	Random WayPoint
Data Rates	5 packets/second
Packet Size	512 bits
Simulator	ns-3[18], SUMO[19],
Simulation Time	1000sec
Number of slots assigned to reader at stretch (Δ)	1
Time of each slot	5 msec.

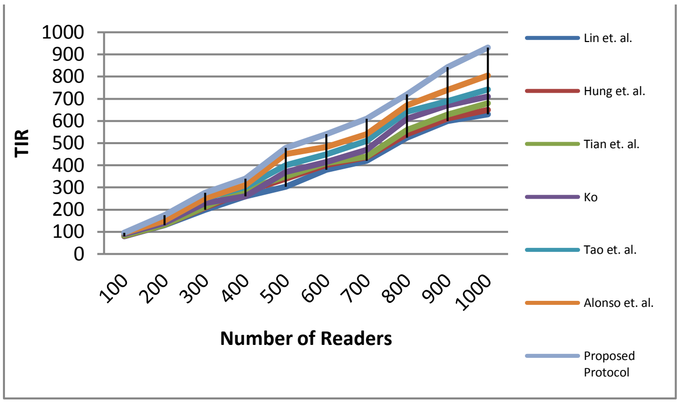

Figure 7: Comparative analysis of TIR

Fig. 8 shows the comparative analysis of number of cycles required for identifying 100000 tags. It is observed that the number of cycles required for identifying tags decreases with increase in the number of readers as more readers are available for identifying tags. It is also analyzed that the proposed scheme requires lesser number of cycles as compared to other protocols because contiguous allocation of channels uniformly distribute the channels slots among readers. The uniform distribution frequently gives chance to reader interrogation which in turn decreases the number of cycles required for interrogation. Fig. 9 shows the comparative analysis of number of IDLE cycles while identifying 100000 tags. The number of IDLE cycles increases with increase in the number of readers because more number of readers are available in same area which decreases the chances of reader interrogation. Thus, more readers sit IDLE and wait for their interrogation cycles. The proposed scheme uses contiguous allocation thus there are lesser chance of readers to be IDLE. In proposed scheme, readers go into IDLE state when all channels are busy. Since there is one waiting slot of 5 msec., thus readers frequently get chance of interrogation which reduces the number of IDLE cycles.

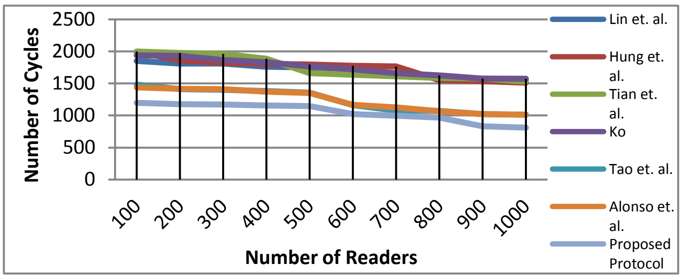

Figure 8: Comparative analysis of number of cycles required for 100000 tags identification

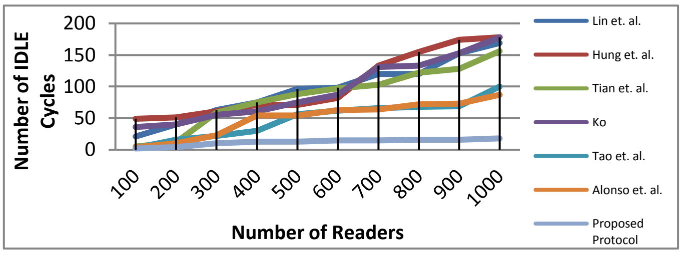

Figure 9: Comparative analysis of number of IDLE cycles while identifying 100000 tags

Fig. 10 shows the comparative analysis of number of successful interrogation cycles required for identifying 100000 tags. It is observed that the number of successful interrogation cycle increases with increase in number of readers because tags respond to their nearby readers for identification which increases the total successful interrogation. The proposed scheme is based on contiguous allocation with uniform channel distribution, thus there is maximum chance that every cycle should identify multiple tags even in dense area network.

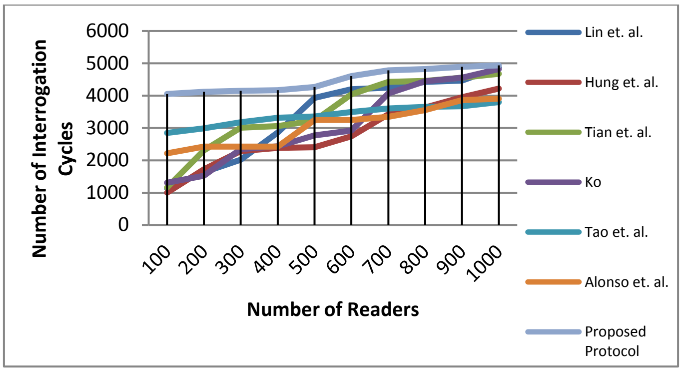

Figure 10: Comparative analysis of number of successful interrogation cycles for identifying 100000 tags

Fig. 11 shows comparative analysis of number of reader-to-reader collisions. Results show that the proposed scheme does not have any reader-to-reader collision at any stage because uniform allocation vector fairly distribute channels among readers which ensures no collision. Among other protocols, the number of reader-to-reader collisions decreases with increase in number of readers, because if a reader initially find a collision then it goes to an IDLE state, which in turn reduces the chances of collisions. Thus, increase in the number of readers increases the number of IDLE or interrogation cycles but reduces the number of collisions.

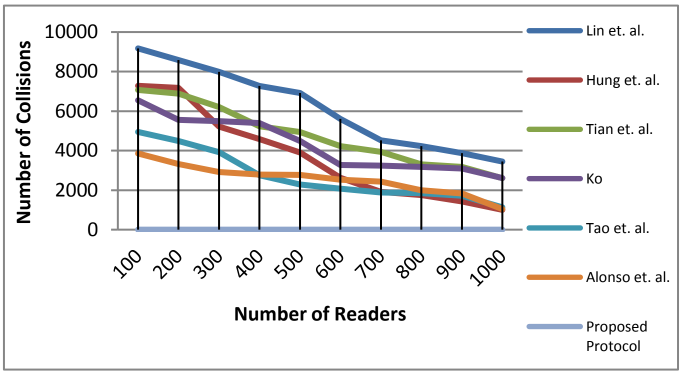

Figure 11: Comparative analysis of reader-to-reader collisions

Fig. 12 shows the comparative analysis of number of packets sent by readers. In proposed protocol, readers have lesser number of transmitted packets because contiguous allocations identify tags frequently, which prevent repeated requests to tags. Among other protocols, increase in IDLE cycles increases the chances of repeated requests after regular intervals which increases the number of packets sent.

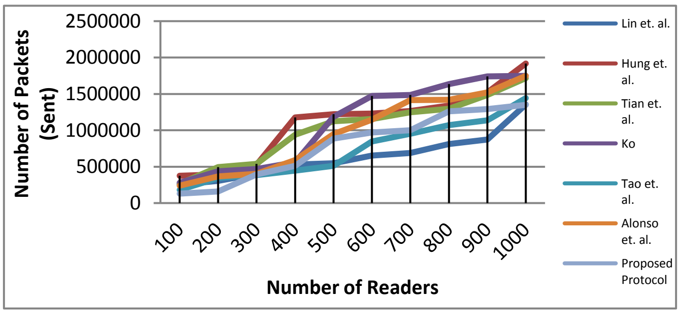

Figure 12: Comparative analysis of number of packets sent by readers

Fig. 13 shows the comparative analysis of the number of packets received by readers. Similar to number of packets sent by readers, there is increase in number of packets received with increase in number of readers because tags respond to reader's requests after IDLE cycles repeatedly. The number of packets received by readers is comparatively lesser and closes to number of identifiable tags for proposed scheme because there are no collisions. The increase in number of packets received with increase in readers is because of waiting time or IDLE states.

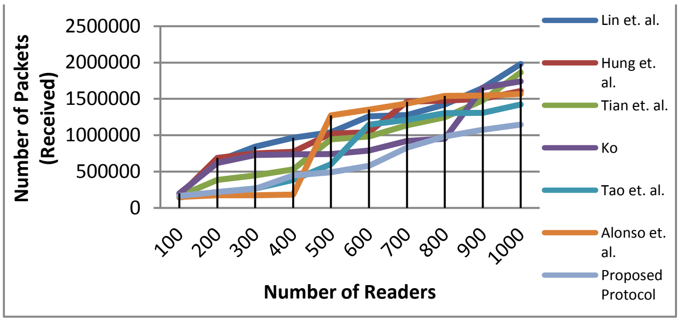

Figure 13: Comparative analysis of number of packets received by readers

V. CONCLUSION

In this work, the problems of RFID reader-to-reader and tag-to-tag collisions are resolved using simulation annealing with uniform distribution of channels. In the proposed reader-to-reader anti-collision protocol, various reader state parameters like number of tags in obstacle free area or cell where readers are present, reader's energy efficiency, count of covering least number of obstacle free areas and distance covered by each reader are considered for gain calculation, before contiguous channel allocation. Similarly, tag state parameters like time of each tag since it responded, energy efficiency, distance from selected reader and distance from obstacles are taken for tag-to-tag anti-collision protocol. Simulation results show that the performance of proposed protocol is better than current state-of-art protocols in terms of tag identification ratio, total successful interrogation cycles total time cycles, total IDLE cycles, total number of collisions, delay, and total number of packets sent and received. It is also observed that contiguous and uniform channel distribution reduce the reader-to-reader collisions to zero.

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