Reader Scheduling for Tag Access in RFID Systems

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***Abstract*—"Reader" and "Tag" type devices are utilized in the Radio-Frequency IDentification technology for identification and tracking of objects. A tag can be "read" by a reader when the tag is within the reader's sensing range. However, when tags are present in the intersection area of the sensing ranges of two or more readers, simultaneous activation of the readers may cause "reader collision". In order to ensure collision-free reading, a scheduling scheme is needed to read tags in the shortest possible time. We study this scheduling problem in a stationary setting and the reader minimization problem in a mobile setting. We show that the optimal schedule construction problem is NP-complete and provide an approximation algorithm and techniques that we evaluate through simulation.**

***Keywords*—RFID Radio Frequency IDentification ; reader anticollision problem ; ressource allocation scheduling ; distributed algorithms**

I. Introduction

Radio Frequency Identification (RFID) systems, comprising of *readers* and *tags*, are used extensively for identification of objects with unique identifiers. In order to support complex needs of RFID dependent business sectors, such as Supply Chain Management and Transportation, a RFID system is expected to allow readers fast and accurate access to tags available in the environment. However, simultaneous transmissions by multiple readers and tags in close proximity may cause signal interference and hinder accurate reading. Such interference can be divided into three classes : *tag-to-tag*, *reader-to-tag*, and *reader-to-reader*. To overcome these hindrances and achieve interference-free operation, development of conflict resolution techniques are essential. Accordingly, several conflict resolution techniques have been developed. However, most of these techniques are developed for resolving tag-to-tag collision, instead of reader-to-reader collision.

In this paper we study the optimal schedule construction problem to avoid reader-to-reader collision. We formalize the optimal schedule construction problem for RFID readers as computation of *interval chromatic number* [1] of a RFID-conflict graph (a generalized version of Unit Disk Graphs), and prove that the problem is NP-complete. We provide a centralized and a distributed approximation algorithm for the problem with a guaranteed performance bound.

The rest of the paper is organized as follows: In Section II we outline the related work in this domain. In Section III we show that the scheduling problem is NP-complete and provide centralized and distributed approximation algorithms for the problem. In Section IV we present the results of our experiments, and finally Section V concludes the paper.

II. Related Work

Reader-reader anti-collision protocols from the literature are of several kinds. Some, like HiQ-learning [2] use a hierarchical architecture to provide an online learning of collision patterns of readers and assign frequencies to the readers over time. Others, such as [3], [4] apply a carrier sense multiple access (CSMA) based algorithms to detect collisions. Centralized solutions [5] use an iterative procedure. A reader is allocated a color in an order determined by the number of neighboring readers already colored, choosing at each step, the color with the smallest index. In Distributed Color Selection (DCS) [6], each reader randomly selects a time slot in a frame for transmission. The Variable-Maximum DCS (VDCS, or colorwave) [7] allows adjustment of the maximum number of colors. In [8], mobile readers communicate with a centralized server which grants service to readers for tag identification on a first-come-first-served basis. [9] proposed an Adaptive Color based Reader Anti-collision Scheduling algorithm for 13.56 MHz RFID technology where every reader is assigned a set of colors that allows it to read tags during a specific time slot within a time frame. [10] also studied the slotted access model to improve the read throughput of a multi-reader RFID system by extending a centralized algorithm to a distributed one that operates without location information of other readers.
Our model differs from the slotted access model as we assume a reader can read only one tag per time unit. Also, a reader fails to read any nearby tags if there is a reader collision, i.e. a tag is present in the sensing range of two active readers.

III. Scheduling Problem

Hardware requirements dictate that even in a collision-free environment, if there is no tag collision, a reader requires $t \times N_{tag}$ seconds to read a set of N_{tag} tags in its sensing range where t is the minimum amount of time needed to read one tag (t is set to 5ms for 13.56 MHz tags [11]). Consequently, to ensure that every tag available in a reader's sensing range is detected, the reader has to be turned ON during at least $t \times N_{tag}$ *consecutive* seconds in order to let the underlying tag-tag anti-collisions schemes to perform correctly and identify all tags in its sensing range.

A. Problem Formulation

The inputs for the RFID scheduling problem are the locations of the readers and the tags in the deployment area. Suppose that there are n readers located in points $\{p_1, \ldots, p_n\}$ and m tags located in points $\{q_1, \ldots, q_m\}$. If the deployment area is a two dimensional space, then each point p_i (or q_i) is specified by its x, y co-ordinates (x_i, y_i). We formulate the RFID scheduling problem as computation of the *Interval Chromatic Number* of a *RFID Graph*.

Definition: *Interval Chromatic Number (ICN):* An interval coloring of a weighted graph maps each node v to an interval of size $w(v)$ such that intervals of adjacent nodes do not intersect. The size of a coloring is the size of the union of these intervals. The minimum possible size of an interval coloring of a given weighted graph is its interval chromatic number [1].

We draw a circle of radius r, with each point $p_i, 1 \leq i \leq n$ as the center, where r is the sensing range of the readers. Corresponding to every point p_i in the problem instance, we create a node v_i in the graph $G = (V, E)$, and two nodes share an edge if the intersection area of the sensing circles of the corresponding points p_i and p_j covers at least one tag. Since G is constructed from an instance of the RFID problem, we will refer to it as a *RFID Graph (RFIDG)*. It can be seen that RFIDGs are a generalization of the UDG (when $r = 1$).

As a reader needs to be turned on for $t \times N_{tag}$ *consecutive* time units to ensure that all tags in its sensing range is read, for each node $v_i \in V$ we assign a *weight* $w_i = t \times N_i$, where N_i is the number of tags available in the reader's sensing range. This way of assigning weights may be considered somewhat inefficient as the tags that belong to the intersection area of the sensing range of multiple readers will be read by multiple readers. However, such duplication can be avoided if the readers have sophisticated electronics to determine which tag is being read by which reader, this is currently unavailable in today's commodity RFID readers. Accordingly, we use this weight assignment rule to ensure that no tag is left unread.

We can now view the optimal schedule construction problem for the RFID problem as the Interval Coloring problem of the corresponding RFID graph. We associate colors to readers as communication tokens. A single color stands for a unit of time. To ensure that every reader i successfully accesses all tags in its sensing range, i has to be allocated N_i colors.

Incompatibility rule: Two readers are *incompatible* if there is a tag in the intersection area of their sensing range.

Optimal Schedule Construction Problem (OSCP):

GIVEN: Two sets of points $P = \{p_1, \ldots, p_n\}$ (locations of readers) and $Q = \{q_1, \ldots, q_m\}$ (locations of tags), the sensing range r, from which the RFID Graph $G = (V, E)$ can be constructed, where V is the set of nodes corresponding to the set of readers, and for every pair of nodes $\{u, v\} \in V$ there exists an edge $(u, v) \in E$ if the readers represented by the nodes (u, v) are *incompatible*.

QUESTION: Is it possible to assign an interval $I(v_i)$ of size $|I(v_i)| = w_i$ to each node v_i in V, such that the total span of all the intervals does not exceed some predefined value B ($\cup_i |I_i| < B$), and $\forall i, j I_i \cap I_j = \emptyset$? A schedule is said to be "optimal" if the total span all the intervals is the smallest.

From our discussion, Optimal Schedule Construction Problem (OSCP) for a RFID system is equivalent to the ICN computation problem of the corresponding RFID graph.

B. Algorithms and Analysis

We first prove that the OSCP is NP-complete. We then provide an approximation algorithm and analyze it to establish a performance bound. Finally, we provide a distributed implementation of our algorithm. As the solution to the OSCP is equivalent to the computation of ICN of a RFID graph, our algorithm essentially computes the ICN of a RFIDG. Note that UDG is a special case of RFIDG. We prove that the result produced by this algorithm will be bounded by a factor of $\mathtt{max}(3, 2 + k)$ of the optimal solution for UDG, and $\mathtt{max}(3\alpha, 2 + k)$ of the optimal solution for RFIDG, where k and α are parameters determined by reader and tag density respectively. For our application we expect $k \leq 5$ and $\alpha \leq 5$, and later in this section we explain why we expect the two parameters to satisfy these two bounds.

Theorem 1. *The OSCP is NP-complete.*

Proof: If we consider a case of the OSCP where weight $w(v_i)$ of every node v_i is 1, and the intersection area of every pair of circles associated with the readers has a tag, OSCP becomes equivalent to the computation of the Chromatic Number of a Unit Disk Graph, a known NP-complete problem [12]. ∎

Notations:

$N(v_k)$: Set of v_k's neighbors, ie nodes sharing an edge in G with v_k.
$N^l(v_k)$ (resp. $N^r(v_k)$) : Left (resp. right) neighbors of v_k : $v_i \in N(v_k)$ s.t. $x_i < x_k$ (resp $(x_i > x_k)$).
$|I(v_i)| = w_i$: Length of $I(v_i)$, where w_i is the weight of v_i
$L(I(v_i))$: Left end point of $I(v_i)$ on the Interval Line.
$R(I(v_i))$: Right end point of $I(v_i)$ on the Interval Line.

Definition: *Lexicographic Ordering:* The Lexicographic Ordering of a set of points in a plane is the ordering induced by their (x, y) coordinates. The points are ordered by the increasing values of their x coordinates and in case of a tie, are ordered by the increasing values of their y coordinates [12].

Definition: *Least Indexed Coloring (LIC):* LIC scheme assigns an interval $I(v_i)$ to each node v_i, such that $L(I(v_i))$ is as small as possible, without violating any stated constraint.

Our interval coloring uses the LIC scheme on lexicographic ordering of the nodes. Centralized and distributed algorithms for computation of ICN are summed up in Algo. 1 and 2 resp.

Algorithm 1 Centralized ICN Algorithm for RFIDG/UDG

Arrange the nodes (readers) in Lexicographic Ordering
Sequentially apply LIC on the nodes till each node is assigned an interval of size equal to its weight with no overlap with intervals of adjacent nodes.

Algorithm 2 Distributed ICN Algorithm for RFIDG/UDG (executed independently by each node v_i in the graph)

v_i broadcasts x_i, y_i and N_i
while v_i is not assigned color **do**
  if Every node in $N^l(v_i)$ has assigned colors **then**
    v_i chooses $I(v_i)$ such that $|I(v_i)| = N_i$, $\forall v_j \in N^l(v_i)$, $I(v_i) \cap I(v_j) = \emptyset$ and $L(I(v_i))$ is the smallest.
    v_i broadcasts $I(v_i)$
  end if
end while

For the distributed version of the coloring algorithm we assume that the readers are aware of their own position as well as the positions of its neighbors and the location of the tags in its sensing range. As discussed earlier, each reader v_i must be assigned a set of w_i consecutive colors to ensure that every tag is read. To do so, we rely on [12] which proposes a 3-approximated lexicographic order coloring. To illustrate it, let us consider the conflict graph represented on Fig. 1(b). Nodes represent readers with the number of colors they should have. Each reader v_i collects the position of its neighbors and their colors. As readers are aware of their own position and positions of their neighbors in the deployment area, they can determine the "lexicographic order" (i.e. F, H, E, I, A, G, D, C and B in Fig. 1(b)). Each reader will assign a set of colors to itself, only after all its *left* neighbors have assigned colors to themselves. In Fig. 1(b), reader G will wait till readers I and A are colored. Reader B waits for D, G and C, but H and E chooses independently as soon as F is colored as they do not share an edge. F has no left neighbors, thus it chooses first and takes the smallest set of 5 colors, i.e. colors 1, 2, 3, 4, 5 (as shown on Fig.1(c)). Readers H and E follow by respectively assigning colors 6-8 and 6-11, and so on. B cannot take colors between 2-14, nor 21-28 as they have already been selected by readers G, C and D. Although colors 14-21 are available in the left neighborhood of reader B, it cannot utilize these colors as it requires 9 consecutive colors. It thus assigns colors 28-37. Finally, G assigns itself colors 2-6 as reader I is already using colors 0-2. It may be noted that in this example, the centralized and distributed algorithms provide the same solution.

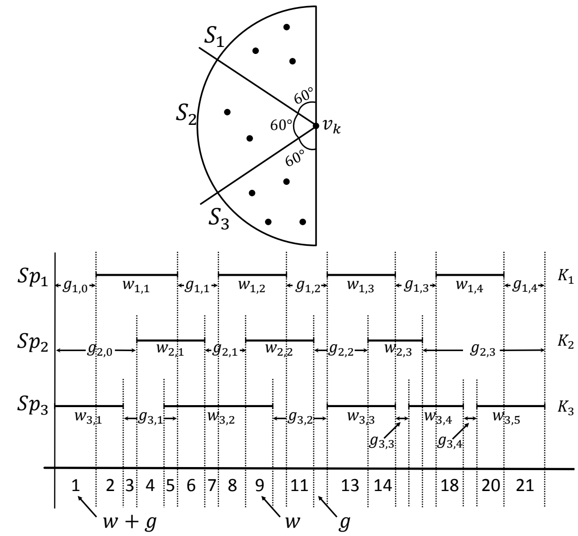
1) Analysis of Algorithm: The input of both algorithms, are the locations of the readers (nodes) and the weights assigned to the nodes. In the following sections, we first analyze the performance of our algorithms for a special case of RFID graphs, known as Unit Disk Graphs (UDG). In UDGs every pair of readers has at least one tag present in the intersection area of the circles associated with the nodes.

Part I: Analysis of Algorithm for Unit Disk Graphs

Our interval coloring algorithm uses the LIC scheme on lexicographic ordering of the nodes.If $R(I(v_i)) \geq R(I(v_j)) \forall 1 \leq j \leq n$ then the node v_i is called a *critical node*. Suppose that v_k is a critical node when algorithm $\mathcal{A}$ is applied on an instance of the RFID scheduling problem. In this case, $R_{\mathcal{A}}(I(v_k))$ is the solution to the instance of the interval coloring problem using algorithm $\mathcal{A}$. We will refer to $R_{\mathcal{A}}(I(v_k))$ as *Approximate Interval Chromatic Number* and denote it by $AICN$. As per the interval layout shown in Fig. 1(c), the critical node is $v_k = B$.

Intervals $I(v_1), I(v_2), \ldots, I(v_{k-1})$ associated with nodes $v_1, v_2, \ldots, v_{k-1}$ are mapped on the Interval Line before the interval $I(v_k)$. For this reason, $L_{\mathcal{A}}(I(v_k))$ may be greater than zero as some of the nodes in the set $\{v_1, v_2, \ldots, v_{k-1}\}$ may be adjacent to v_k in G and the intervals associated with these sets of nodes cannot overlap with the interval $I(v_k)$.

If v_l and v_r are two nodes in $N(v_k)$, such that $L_{\mathcal{A}}(I(v_l)) \leq L_{\mathcal{A}}(I(v_j))$, and $R_{\mathcal{A}}(I(v_r)) \geq R_{\mathcal{A}}(I(v_j))$, , the interval between $L_{\mathcal{A}}(I(v_l))$ and $R_{\mathcal{A}}(I(v_r))$ will be referred to as the *span* of $N(v_k)$ with algorithm $\mathcal{A}$, and will be denoted by $Sp_{\mathcal{A}}(N(v_k))$. The *length* of the span is the difference between $L_{\mathcal{A}}(I(v_l))$ and $R_{\mathcal{A}}(I(v_r))$ and is denoted by $|Sp_{\mathcal{A}}(N(v_k))|$. In Fig. 1(c) $Sp_{\mathcal{A}}(N(v_k))$ is from 2 to 28, of length of the span $|Sp_{\mathcal{A}}(N(v_k))| = 26$.

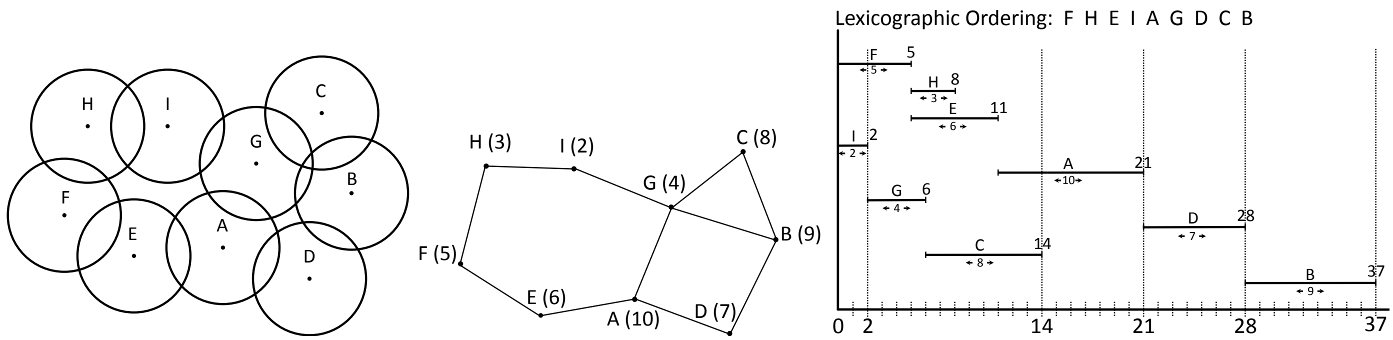


(b)

Fig. 2: (a) Left side neighbors of the critical node v_k, (b) Span of the three segments associated with the critical node v_k

It may be recalled that as our graph is a UDG, the nodes $v_1, \ldots, v_n$ correspond to points $p_i, \ldots, p_n$ on a two dimensional plane. Suppose that we draw a semi-circle of unit radius around the point p_k corresponding to the node v_k (as shown in Fig. 2(a)), and divide the semi-circle into three 60 degree segments, $S_1, \ldots, S_3$, as shown in Fig. 2(a). We denote by $N^i(v_k)$ the subset of $N(v_k)$, comprised of nodes corresponding to points in $S_i, \forall 1 \leq i \leq 3$. Due to the construction rule of a UDG, the nodes corresponding to the points that belong to segment $S_i, 1 \leq i \leq 3$ form a clique with the node v_k in $G = (V, E)$. As such, $AICN \geq |Sp(N^i(v_k), \mathcal{A})|, \forall i, 1 \leq i \leq 3$. Although $Sp(N^i(v_k), \mathcal{A})$ and $Sp(N^j(v_k), \mathcal{A}), j \neq i$, need not be non-overlapping, in the worst case scenario $|Sp_{\mathcal{A}}(N(v_k))|$ may be as large as $\sum_{i=1}^{3} |Sp_{\mathcal{A}}(N^i(v_k))|$. The maximum value of $|Sp_{\mathcal{A}}(N(v_k))|$, denoted by $Max\_Sp_{\mathcal{A}}(N(v_k))$, can be $\sum_{i=1}^{3} |Sp_{\mathcal{A}}(N^i(v_k))|$. As points (nodes) that belong to segment $S_i, 1 \leq i \leq 3$ form a clique with the node v_k in G, the minimum value of $|Sp_{\mathcal{A}}(N(v_k))|$, denoted by $Min\_Sp_{\mathcal{A}}(N(v_k))$, has to be at least $\max_{1 \leq i \leq 3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right]$.

It may be recalled that $\{v_1, v_2, \ldots, v_{k-1}\}$ were assigned intervals on the Interval Line before the critical node v_k. We will denote the set $\{v_1, v_2, \ldots, v_{k-1}\}$ by V_{k-1}. Thus, the set of nodes in V_{k-1} that are not adjacent to the node v_k is given by (called *non-neighbors of* v_k, $NN(v_k)$), $NN(v_k) = V_{k-1} \setminus N(v_k)$. In the example of Fig. 1(a), the set $NN(v_k) = \{A, E, F, H, I\}$, where $v_k = B$. When the nodes in the set $NN(v_k)$ are assigned intervals on the Interval Line by the algorithm $\mathcal{A}$, some of these intervals may have overlap with the interval span of the neighbors of v_k, i.e., $Sp(N(v_k), \mathcal{A})$. However, there may be some nodes in $NN(v_k)$ whose assigned intervals may not have any overlap with the $Sp(N(v_k), \mathcal{A})$. We will refer to this subset of $NN(v_k)$ as *non-overlapping non-neighbor* of v_k and denote it by $NO\_NN(v_k)$. In the example of Fig. 1(a), the set $NO\_NN(v_k) = \{I\}$. The span of non-overlapping non-neighbors of v_k, $Sp(NO\_NN(v_k), \mathcal{A})$ can be at most $|I(v_k)|$, as otherwise $I(v_k)$ can be assigned space in the interval line covered by the $Sp(NO\_NN(v_k), \mathcal{A})$, as such an assignment will not violate the *non-overlapping*



(a) Deployment area (b) Unit Disk Graph (c) Interval assignment

Fig. 1: (a) Readers (points) in the deployment area and their sensing range, (b) UDG graph constructed from the problem instance in Fig. 1(a), (c) Interval assignment for the problem instance in Fig. 1(a)

requirement for adjacent nodes. The ICN will have three non-overlapping intervals on the Interval Line corresponding to $Sp(NO\_NN(v_k), \mathcal{A})$, $Sp(N(v_k), \mathcal{A})$ and $I(v_k)$. As such, we can conclude that $AICN \leq Max\_Sp(NO\_NN(v_k), \mathcal{A}) + Max\_Sp(N(v_k), \mathcal{A}) + |I(v_k)|$. As the maximum value of $Sp(N(v_k), \mathcal{A})$ is $\sum_{i=1}^{3} |Sp(N^i(v_k), \mathcal{A})|$ and the maximum value of $Sp(NO\_NN(v_k), \mathcal{A})$ is $|I(v_k)|$, it follows that:

$$AICN \leq \sum_{i=1}^{3} |Sp_{\mathcal{A}}(N^i(v_k))| + 2|I(v_k)| \tag{1}$$

As nodes in $N^i(v_k)$ form a clique with v_k, any optimal solution to the Interval Chromatic Number of UDG ($OICN$) must be at least as large as:

$$OICN \geq \max_{1 \leq i \leq 3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right] + |I(v_k)| \tag{2}$$

Next, we examine the relationship between $\sum_{i=1}^{3} |Sp(N^i(v_k), \mathcal{A})|$ and $\max_{1 \leq i \leq 3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right]$.

For any instance of the problem, the diagram of $Sp(N(v_k))$ will have the form shown in Fig. 2(b). Suppose the number of nodes in the segments S_1, S_2, S_3 are K_1, K_2, K_3. In that case Sp_1, Sp_2, Sp_3 will have K_1, K_2, K_3 intervals with possibly *gaps* between them as shown in Fig. 2(b). Suppose that the weights of nodes in $S_i, 1 \leq i \leq 3$ are $w_{i,1}, w_{i,2}, \ldots, w_{i,K_i}$. If we draw vertical lines through the left and right end points of every interval, the lines will intersect the Interval Line at most at $2\sum_{j=1}^{3} K_j$ points and divide the Interval Line into at most $2\sum_{j=1}^{3} K_i + 1$ *sub-intervals*. The sub-intervals are divided into three disjoint groups – *w-type*, *g-type* and *(w+g)-type*, depending on whether they include only w, g, or w and g type of parts from the spans Sp_i. Examples of *w-type*, *g-type* and *(w+g)-type* are shown in Fig. 2(b). The total space occupied on the Interval Line by w and *(w+g)* type sub-intervals is at most: $\sum_{i=1}^{3} \sum_{j=1}^{K_i} w_{i,j} = \sum_{i=1}^{3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right]$. The size of g-type sub-interval can be at most $|I(v_k)|$ as otherwise, the critical node interval $I(v_k)$ could have been inserted in the gap. The number of g-type sub-intervals can be at most half of the total number of sub-intervals on the Interval Line. As noted earlier, there could be at most $2K + 1$ sub-intervals and as such, the number of g-type sub-intervals can be at most $K' = \lceil (2K + 1)/2 \rceil = K + 1$. Consequently:

$$\sum_{i=1}^{3} |Sp_{\mathcal{A}}(N^i(v_k))| \leq \sum_{i=1}^{3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right] + (K+1)|I(v_k)|$$

Thus, from Equation (1), we have:

$$AICN \leq \sum_{i=1}^{3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right] + (K+1)|I(v_k)| + 2|I(v_k)|, \text{ or}$$

$$AICN \leq \sum_{i=1}^{3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right] + (K+3)|I(v_k)| \tag{3}$$

Using Equations (2) and (3), we have:

$$\frac{AICN}{OICN} \leq \frac{\sum_{i=1}^{3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right] + (K+3)|I(v_k)|}{\max_{1 \leq i \leq 3} \left[\sum_{u \in N^i(v_k)} |I(u)| \right] + |I(v_k)|}, \text{ or}$$

$$\frac{AICN}{OICN} \leq \max(3, (K+3)) \tag{4}$$

In the RFID application domain, it is unlikely that reader density will be high. If there are no more than five readers within a semi-circle of radius equal to the sensing range of a reader, then $K \leq 5$. In this case $\frac{AICN}{OICN} \leq 8$.

Part II: Analysis of Algorithm for RFID Graphs

In Part I, we established that $\frac{AICN}{OICN} \leq \max(3, (K+3))$ for Unit Disk graphs. In Part II, we extend that result to RFID graphs, a generalized version of the UDG. In a UDG, if the circles corresponding to points p_i and p_j intersect, then corresponding nodes v_i and v_j share an edge in G. In RFIDG, if the circles corresponding to points p_i and p_j intersect, then corresponding nodes v_i and v_j share an edge if and only if their sensing intersection area contains at least one tag. Unlike the UDG case, the nodes that belong to each $N^i(v_k)$, $1 \leq i \leq 3$ may no longer form a *clique* and we can no longer claim that Equation (2) holds true. However, if we assume that at least a fraction of the nodes in each $N^i(v_k)$, $1 \leq i \leq 3$ form a clique and the sum of the weights of the nodes in the clique is at least a fraction ($\frac{1}{\alpha}, \alpha > 1$), of the sum of the weights of all

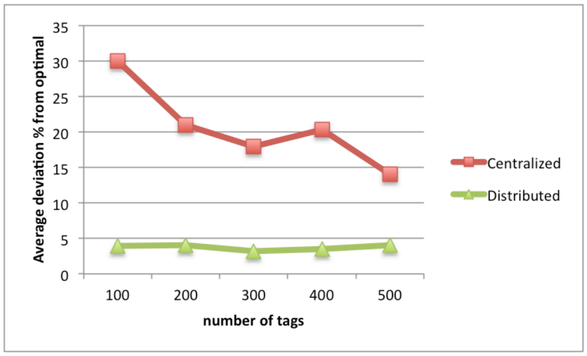


Fig. 3: Avg. % deviation of approx. schedule from the optimal.

nodes in each segment, we have:

$$OICN \geq \max_{1 \leq i \leq 3} \left[\sum_{u \in N^i(v_k)} \frac{|I(u)|}{\alpha} \right] + |I(v_k)| \qquad (5)$$

Thus, from Equations (3) and (5), it follows: $\frac{AICN}{OICN} \leq \max(3\alpha, (K+3))$.

In case of UDG we assume reader density determines that $K \leq 5$. In case of RFIDG, if we assume that the tag density is such that the sum of the weights of the nodes in segments S_1, S_2 and S_3 is at least 20% of the sum of the weights of all nodes in segments S_1, S_2 and S_3 respectively, (i.e. $\alpha \leq 5$), we have $\frac{AICN}{OICN} \leq 15$.

IV. Experimental Results

As primarily experiments, we implemented the distributed and centralized coloring algorithms and compared them to the optimal solution using WSNet [13], an event-driven simulator for large scale Wireless Sensor Networks. As to fairly evaluate the performance under various network scenarios, we considered a dense RFID system where 10 readers were randomly deployed with uniform distribution on a square network of dimension 100m $\times$ 100m. We set the reader-to-tag communication and sensing range to 10m, and set the reader-to-reader communication range to 20m. For each of the 100 simulations per scenario, we computed the optimal solution and recorded the difference between the optimal and our algorithm's result. Fig. 3 presents the average percentage deviation from the optimal solution for each scenario in terms of efficiency. As we can observe, the centralized protocol achieves performances close to the optimal and the more readers, the closer to the centralized approach our distributed solution is. These first results let us expect interesting behavior in terms of throughput and fairness (evaluation left for future work), especially in presence of high tag mobility.

V. Conclusion

In this paper we studied the scheduling for which we provided centralized and distributed approximation algorithms. Preliminary results are promising. For future work, we expect to combine this approach with an intercorrelated problem which is the reader minimization problem. In this environment, not only would one like to know the minimum number of mobile readers required to read all tags, but also the trajectories of the readers to get a complete RFID systems.

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