Genetic-Based Approach for Efficient RFID Reader Antenna Positioning

Nazish Irfan, Mustapha C. E. Yagoub, and Khelifa Hettak

***Abstract*—Radio Frequency Identification (RFID) systems, due to recent technological advances, have been used for various advantages in industries like production facilities, supply chain management etc. Read accuracy and coverage achieved by readers are some of the critical factors to be considered in the adoption of any RFID system. For passive tags, these parameters depend not only on the volume of region that receives sufficient power from the reader but also on the relative orientation of reader and tag antennas as well as their polarization. In this work, we used Genetic Algorithm to optimize the directional antenna beam direction including down tilt to maximize the reader coverage and accuracy. This work can be used as an effective tool in warehouse management and logistics.**

***Index Terms*—RIFD, antenna, optimization, genetic algorithm.**

I. Introduction

Radio Frequency Identification (RFID) is based on radio communication for tagging and identifying an object [1]. It consists of two blocks namely, RFID transceivers (readers) and RFID transponders (tags). Over the last few years, RFID has drawn a great deal of attention and it is now widely believed that RFID can bring revolutionary changes [2]. Some of the major retailers have already invested significantly in RFID and mandated their manufacturers to place tags on cases and pallets, which resulted in mass production of inexpensive RFID tags [3].

In recent years, more efforts have been made to implement RFID applications in inventory control and logistics management. RFID-based system leads to significant reduction on processing time and labor as inventory in warehouses can be tracked more accurately in a simple, timely and more efficient manner. More importantly RFID-based system provides complete visibility of accurate inventory data, from manufacturer's warehouse, shop floors and brings opportunities for improvement and transformation in various process of the entire supply chain [4]. Applications like inventory detection and automated product receiving in supply chain management require RFID readers to read tags anywhere within a large geographic area. Since the range of reader to tag communication is very limited, readers must be deployed in high densities over the entire area [5]. Therefore, the deployment of RFID system has generated the RFID network planning problem that needs to be solved for large scale deployment. However, RFID network planning is one of the most challenging problems since it has to meet many requirements for efficient operation of RFID system [6]. RFID network planning results in a reasonable reader antenna position so that the wireless network between the reader and tag is established to maximize the coverage, performance and minimize the equipment cost.

In this work, we optimized the antenna beam orientation position to maximize the reader coverage. Two degrees of antenna freedom have been considered i.e. tilt (when reader is mounted at a certain height to tags) and orientation angle (when reader and tags are placed at the same level). Fig. 1 illustrates these two degrees of freedom, reader-1 can optimize the coverage by adjusting its tilt angle and similarly reader-2 can optimize coverage by adjusting its orientation angle. Genetic Algorithm is used to optimize the antenna beam angle. This work can be used in warehouse and logistics applications to achieve maximum coverage by optimizing the RFID reader antenna beam angle position.
The remainder of this paper is organized as follows: Section 2 briefly presents the related work. Section 3 introduces the theory of radio propagation we used in the present work. Section 5 presents results and discussions and finally, Section 6 concludes the proposed work.

II. Related Work

In any RFID network the cost and complexity depends upon the number of readers (antennas) required to achieve the desired objective. Minimizing the number of readers required will increase the Quality of Service (QoS) especially by reducing the interference between readers [7]. Typically the reader location and reader antenna beam orientation are determined by trial and error and adhoc techniques used by design engineers [8]. RFID network planning is fundamentally similar to the antenna positioning problem in cellular networks. However, RF tags are low functionality devices and use backscatter signal to communicate with the reader, therefore some assumption of wireless communication in cellular networks are not applicable to RFID network planning. Moreover, RFID systems are generally operate in indoor environment therefore multipath fading affects the communication between a reader and a tag. The problem of network planning of RFID network generally involves selection of sites for reader and configuration of different antenna parameters like azimuth and tilt [7].

Antenna tilt is an important design parameter for network planning when considering coverage vs. capacity for cell planning as well as tuning network. An antenna tilting of base station is very common technique for improving cell isolation

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Nazish Irfan and Mustapha C. E. Yagoub are with the School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa, ON, Canada (e-mail: nirfan@site.uottawa.ca, myagoub@eecs.uottawa.ca).

Khelifa Hettak is with Communication Research Center, Ottawa, ON, Canada (e-mail: khelifa.hettak@crc.gc.ca)

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and/or increasing covers in cellular networks. Tilt angle optimization can be achieved electrically, mechanically or by a combination of both [9]. It is reported that both coverage and quality performances are very sensitive to antenna tilt variations [10].

There are many papers [9], [11]-[13], which have studied the effect of antenna tilt control on radio network planning and cellular network. Authors have shown that significant reductions in path-loss delay spread, transmitted power and system interference can be achieved when suitable height and antenna tilt are selected. It is reported that in a dense network, the importance of antenna down tilt becomes more significant. Wireless communication in cellular network is different than communication between readers to tag in indoor environment therefore these papers highlights the importance of antenna tilting but not directly related to RFID application.

In RFID applications, there are many papers [6], [7], [14]-[20] in which authors have presented different techniques to optimize RFID networks (i.e. RFID network planning) using different optimization techniques or by eliminating redundant readers from the RFID networks.

In [14]-[16], authors have used redundant reader elimination techniques to optimize the RFID network. The idea was to remove readers with no or minimal coverage so as to minimize the number of readers used in the network. Coverage of a reader was computed by considering the power received by a tag of an omni-directional reader antenna. The authors in these papers used free space models for communication between readers and tags, which is not a realistic model. In fact, the read range of a reader in indoor environment is effected by multi path fading therefore simple free space model is not practical [21]. Moreover, in [22], the authors mentioned that antennas having an omni-directional radiation pattern should be avoided and wherever possible directional antennas should be used because directional antennas have advantages of less disturbance to the radiation pattern and to the return loss.

On the other side, network planning for RFID network has been widely investigated using many optimization techniques [6], [7], [18]-[20]. Similar to redundant reader elimination techniques, most authors used omni-directional antennas for their approaches [6], [19], [20]. Omni-directional antennas have short range and no particular advantage in terms of signal to noise ratio (SNR). Also, even if in [18], authors used directional antennas, they did not consider reader antenna tilt for optimization purpose. Authors in [7], used directional antenna, tilt and other parameters for RFID network planning. However, the data of incidence angle between reader and tags are pre-computed for a discrete RFID network; therefore tilt angle for each reader was fixed and not varied. Since tilt angle was not varied for a reader, this approach cannot be used as a generic approach.

In the present work, we took a general approach based on genetic algorithms (GA) to optimize the antenna beam orientation position in order to maximize the coverage. For this aim, Fig. 1 shows a typical topology of a box of items containing RFID tags; here, reader-1 presents one degree of freedom along x axis, which relates to tilt angle optimization for reader-1, while reader-2 presents a degree of freedom over both x or y directions. Antenna beam can be positioned in +x/y or − x/y direction based on the concentration of RFID tags.

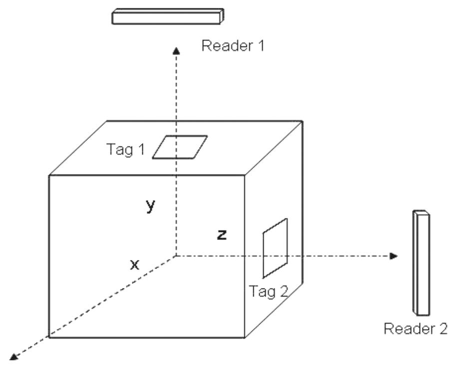

Fig. 1. Typical topology of a box with RFID tags in warehouse.

III. Genetic Algorithm

Genetic algorithm is an optimization and search technique based on the principles of genetics and natural selection. The method was developed by John Holland [23].

Initially the population is generated randomly. The fitness values of all chromosomes are evaluated by calculating the objective function in a decoded form (phenotype). From the population, a particular group of chromosomes (parents) are selected to generate the offspring by the defined genetic operations. The fitness of the offspring is evaluated in a similar fashion to their parents. Based on certain replacement strategy, the chromosomes in the current population are replaced by their offspring. The above GA cycle is repeated until a desired termination criterion is reached. Finally, the best chromosomes in the final population can become a highly evolved solution of the population. There are various techniques that are employed in the GA process for encoding, fitness evaluation, parent selection, genetic operation and replacement.

A. Encoding Scheme

In GA algorithm, encoding scheme is one of the key issues because it can severely limit the window of information that is observed from the system. In general, the GA evolves a multi-set of chromosomes and each chromosome x_i (i = 1, 2, $\cdots N$) represents a trial solution to the problem setting. The chromosome is usually expressed in a string of variables, each element of which is called a gene. The variable can be represented by a binary real number of other forms and its range is usually defined by the problem specified.

B. Fitness Techniques

In GA, the status of each chromosome is evaluated using an objective function. The objective function taking chromosome as input produces a list of numbers as a measure to the performance of the chromosome. The fitness function is needed to map the objective value to a fitness value to maintain uniformity over various problem domains. Some of the commonly used fitness techniques are given as follows:

- Linear normalization: In this technique, the chromosomes are ranked in ascending or descending order of objective value based on the objective function to be minimized or maximized. If f_{best} is the best chromosome then the fitness of the j^{th} chromosome in the ordered list is conducted by the following linear function

$$f_j = f_{best} - (j-1)\cdot d \quad (1)$$

- Roulette wheel weighting: In this technique, the probabilities assigned to the chromosomes in the mating pool are inversely proportionally to their cost. A chromosome with the lower cost has the greater probability of mating, while the chromosome with the highest cost has the lower probability of mating. A random number determines which chromosome is selected. There are two weighting techniques namely, the rank weighting and the cost weighting. The rank weighting approach is problem independent and finds the probability from the rank n, of the chromosome by

$$P_n = \frac{N_{keep} - n + 1}{\sum_{n=1}^{N_{keep}} n} \quad (2)$$

where N_{keep} is the number of chromosomes that are kept in each generation out of total population N_{pop}.
In the cost weighting approach, the probability of selection is calculated from the cost of the chromosome rather than its rank in the population. Probability P_n is calculated as

$$P_n = \left| \frac{C_n}{\sum_{m=1}^{N_{keep}} C_m} \right| \quad (3)$$

where C_n is the normalized cost of each chromosome.
- Tournament selection: This approach involves running several "tournaments" among a few individuals chosen at random from the population. The chromosome with best fitness i.e. the winner of each tournament is selected from crossover. Tournament selection works best for larger population sizes because sorting becomes time-consuming for large population.

C. Genetic Operations

Genetic operations include:
- Crossover: This operation combines subparts of two parent chromosomes to produce offspring that contain some parts of both parents genetic material. There are mainly two types of crossover, i.e. single and multipoint.
- Mutation: This is an operator that introduces variations into the chromosome. This variation can be global or local.

IV. Radio Propagation of RFID Deployment

A radio propagation model is required to determine the signal quality received at each tag from the reader. This helps predicting the propagation loss of a electromagnetic field between a reader and a tag in a RFID network. In a RFID system, the passive tag is activated by the reader's activate power and the reader is much more powerful than tag. Therefore, forward link i.e. reader to tag link is the principal issue in the deployment of a RFID network [24].

The simplest way to determine the power receive by the tag from the reader in free space path loss environment can be given by the Friis equation [25].

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2 \quad (4)$$

where P_r is the power received by tag, P_t the transmitted power from reader, G_t the transmitter antenna gain, G_r the receiver antenna gain, and d the length of the direct path between the transmitter and receiver antenna. The factor $(\lambda/4\pi d)^2$ determines the free space path loss.

Practical deployment of RFID systems in indoor line of sight environment involves the in-building path loss. In this work, we used the indoor propagation model given by [7].

$$L(dB) = 10\log\left[\frac{1}{G_t G_r} \left(\frac{4\pi}{\lambda} \right)^2 d^n \right] + \alpha(dB) \quad (5)$$

where n is the path loss exponent that depends on surroundings and building types and α is 10dB in worst case.

V. Simulation Setups and Results

To evaluate the performance of the proposed optimization technique, we implemented two experimental setups. Both experimental setups, as shown in Fig. 2 and Fig. 5, have an area of 20 × 20m, 5 readers and 75 tags. First setup was used to maximize the coverage of each reader at a specific optimized tilt angle. Similarly, second setup was used to optimize the antenna beam orientation angle to maximize the coverage of each reader. As the test device, the Intermec RFID reader IA33A circularly polarized panel was adopted and the Intermac UHF tag was used [26].

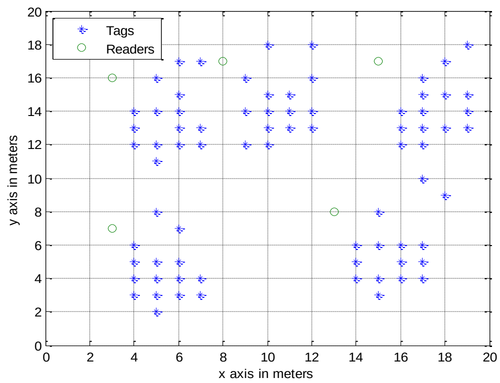

Fig. 2. RFID network topology of tilt angle optimization

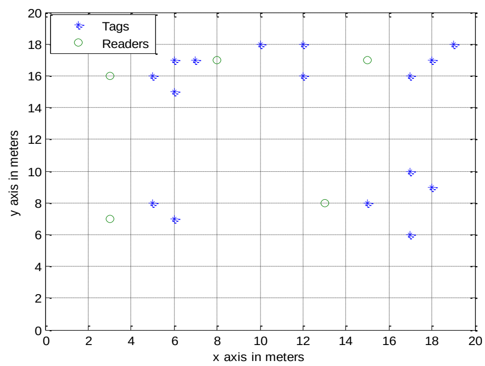

Fig. 3. Tags covered by reader with not tilt angle optimization

In this work, a continuous Genetic algorithm encoding scheme was adopted and the Roulette wheel fitness technique was used to evaluate the objective function. Such objective function was based on the radio propagation link budget between a reader and a tag. Genetic algorithm parameters used for optimization are mutation rate=0.2 and selection=0.5. In the first experimental setup, the reader tilt angle was optimized. Fig. 3 shows the number of tags covered by each reader when reader tilt angle is not optimized. It can be observed that out of 75 tags only 16 tags were covered by 5 readers. On the other hand, as shown in Fig. 4, after optimizing the reader tilt angle, 64 tags were covered by 5 readers.

Similar to the first experiment, in the second experiment the orientation angle of the antenna beam was optimized. Fig. 5 illustrates the typical RFID network topology considered for experiment. The number of tags (17) covered by all 5 readers without optimization of orientation angle of the RFID reader antenna is shown in Fig. 6. After optimization it can be easily observed that a total of 67 tags were covered by 5 readers as depicted in Fig. 7. Table I summarizes the results for both experiments.

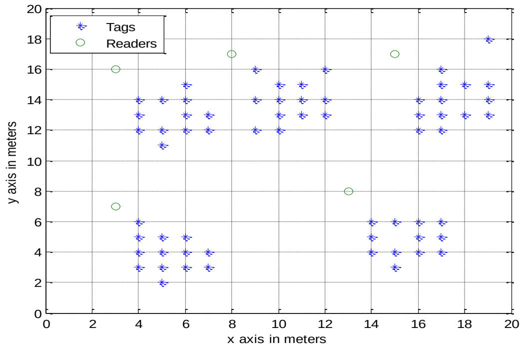

Fig. 4. Tags covered by readers with tilt angle optimization

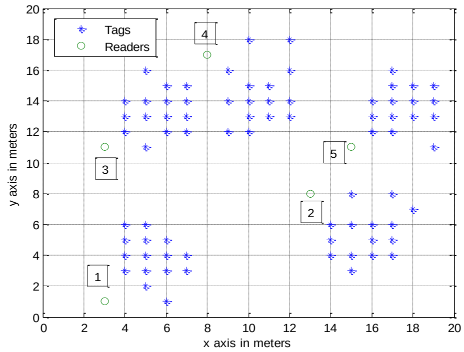

Fig. 5. RFID network topology for antenna beam angle optimization

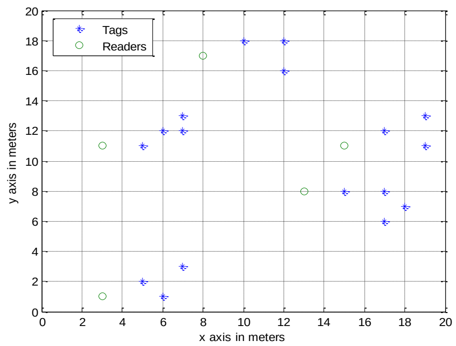

Fig. 6. Tags covered by reader with no antenna beam angle optimization

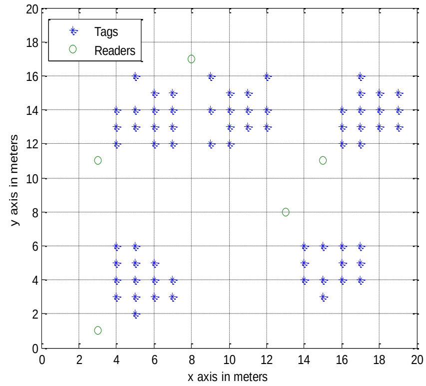

Fig. 7. Tags covered by reader with antenna beam angle optimization

These results prove that the optimal placement of the beam angle of a directional antenna can greatly increase the coverage. The optimization helps in deciding on the optimal number of reader placement thereby reducing the overall cost of the RFID system. This technique can be used in pre-planning of optimal number of reader placement with optimized antenna beam angle for warehouse and logistics applications.

VI. Conclusions

In this paper we used a Genetic algorithm to optimize the tilt angle and the beam orientation angle of a RFID reader directional antenna. Simulation results show that reader coverage can be greatly increased by optimizing the beam angle placement. This work can be used in pre-planning of warehouse and logistics applications to assess the number of RFID reader used with optimal position of directional antenna beam.

TABLE I: Number of Tags Covered Before and After Optimizing the Tilt Angle (Exp. #1) and the Orientation Angle (Exp. #2)

Reader	Experiment #1 (Tilt)			Experiment #2 (Orientation Angle)		
	Tags covered		*Optimum*	*Tags covered*		*Optimum*
	Before	*After*	*Value (°)*	*Before*	*After*	*Value (°)*
1	2	13	-21.74	3	14	23.38
2	4	12	-23.50	4	12	-23.50
3	4	12	-23.94	4	14	20.49
4	3	13	-23.73	3	13	-23.73
5	4	13	-23.33	3	14	20.49

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Nazish Irfan received his B.E. degree in Electrical from NIT Raipur, India in 1992 and his M.A.Sc. in Electrical Engineering from University of Ottawa, Canada, 2007. Presently he is a Ph.D. candidate in University of Ottawa, Canada. His research interests include RFID, reader/tag anti-collision protocols, optimization techniques, antenna and numerical electromagnetics.

Mustapha C. E. Yagoub received the Dipl.-Ing. degree in Electronics and the Magister degree in Telecommunications, both from the *École Nationale Polytechnique*, Algiers, Algeria, in 1979 and 1987 respectively, and the Ph.D. degree from the *Institut National Polytechnique*, Toulouse, France, in 1994.

After few years working in industry as a design engineer, he joined the Institute of Electronics, *Université des Sciences et de la Technologie Houari Boumédiene*, Algiers, Algeria, first as an Lecturer during 1983-1991 and then as an Assistant Professor during 1994-1999. From 1996 to 1999, he has been head of the communication department. From 1999 to 2001, he was a visiting scholar with the Department of Electronics, Carleton University, Ottawa, ON, Canada, working on neural networks applications in microwave areas. In 2001, he joined the School of Information Technology and Engineering (SITE), University of Ottawa, Ottawa, ON, Canada, where he is currently a Professor. His research interests include RF/microwave CAD, RFID design, neural networks for high frequency applications, planar antennas, and applied electromagnetics. He has authored or coauthored over 300 publications in these topics in international journals and referred conferences. He authored *Conception de circuits linéaires et non linéaires micro-ondes* (Cépadues, Toulouse, France, 2000), and co-authored *Computer Manipulation and Stock Price Trend Analysis* (Heilongjiang Education Press, Harbin, China, 2005).

Dr. Yagoub is a senior member of the IEEE Microwave Theory and Techniques Society, a member of the Professional Engineers of Ontario, Canada, and a member of the Ordre des ingénieurs du Québec, Canada.

Khelifa Hettak received the Dipl.-Ing. degree in telecommunications from the University of Algiers, Algiers, Algeria, in 1990, and the M.A.Sc. and Ph.D. degrees in signal processing and telecommunications from the University of Rennes 1, Rennes, France, in 1992 and 1996, respectively.

In 1997, he was with the Personal Communications Staff of the Institut National de la Recherche Scientifique (INRS)-Télécommunications.

In October 1998, he joined the Electrical Engineering Department, Laval University, where he was an Associate Researcher involved in RF aspects of smart antennas. Since August 1999, he has been with Terrestrial Wireless Systems Branch, Communications Research Centre (CRC) Canada, Ottawa, ON, Canada, as a Research Scientist, where he is involved in the development of MMICs at 60 GHz, low-temperature co-fired ceramic (LTCC) packaging, and RF microelectromechanical systems (MEMS) switches.