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Study on Anti-collision Technique for RFID System with Multiple Tags

조선대학교 대학원

첨단부품소재공학과(정밀기계설계공학전공)

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Advisor: Prof. Suk-seung Hwang, PhD

This Thesis is submitted to the Graduate School of Chosun University in partial fulfillment of the requirements for a Master's degree

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조선대학교 대학원

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카드카 그리슈마의 석사학위논문을 인준함

위원장 조선대학교 교 수 유 영 태 (인)

위 원 조선대학교 교 수 심 재 기 (인)

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조선대학교 대학원

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ACRONYMS

RFID	Radio Frequency Identification
EPC	Electronic Product Code
TD	Time Division
AWGN	Additive White Gaussian Noise
RCS	Radar Cross Section
SNR	Signal to Noise Ration
FER	Frame Error Rate
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
IEEE	Institute of Electrical and Electronics Engineers
MAC	Medium Access Control

ABSTRACT (Korean)

다수 태그 RFID 시스템을 위한 신호 충돌방지 기법 연구

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RFID 는 물류와 자산을 효율적으로 추적 또는 식별하기 위해 개발된 기술이다. 무선통신 기술과 이동 계산 환경이 발전해 나갈수록 RFID 는 더욱더 유비쿼터스 계산의 필수적인 중요 요소로 평가되고 있다. RFID 는 전자기 에너지를 이용해 임의적인 간섭 또는 잡음 환경에서 판독기에게 태그의 데이터를 전송한다. 최근 이 기술에 관심이 집중되고 있는 이유는 적은 비용과 신속한 절차, 그리고 독특한 식별 기능 때문이다. 그러나 태그는 속성 상 무선으로 식별 데이터를 전송하는 자원 제한적인 장치이기에 보안적 RFID 식별 시스템을 개발하는 것이 가장 큰 과제다. 여러 RFID 태그가 한 판독기에게 동시에 반응할 시 각 태그의 신호가 그 외 다른 태크와 판독기의 통신을 방해해 신뢰성과 효율성을 저하시킨다.

본 논문은 위에서 언급한 문제점들을 해결하기 위한 몇가지 알고리즘을 제안한다. 첫째로, 판독기가 하나의 태그로부터만 신호를 받을 수 있도록

밀집된 구역에 있는 태그들 중 특정 태그에게 특정한 시간대를 배정하는 시분할(TD, Time Division) 기법을 제안한다. 이 기법은 우수한 간섭제거 성능을 가지지만, 주위에 많은 태그들이 존재 할 시 간섭제거 성능이 급격히 낮아지게 된다. 이러한 문제점 해결을 위해 확산/역확산 기법을 사용하는 골드코드를 RFID 통신시스템에 적용하였다. 이 방식은 많은 수의 태그들에 대해 우수한 간섭제거 성능을 가지지만, 태그들의 수가 골드코드의 길이에 비해 많아지면 급격하게 간섭제거 성능이 하락하고, 골드코드의 길이를 증가시키면 시스템이 복잡해 지게된다. 이러한 문제점을 해결하기 위해서 본 논문에서는 시분할 기법과 골드코드 기법을 혼용하여 사용하는 방식을 제안한다. 이 시분할 및 골드코드 혼합시스템은, 처음 제시된 두 기법에 비해 더 많은 태그들에 대한 간섭을 제거 할 수 있는 우수한 간섭제거 성능을 가진다. 컴퓨터 시뮬레이션을 통해 본 논문에서 제시된 모든 방식들에 대한 간섭제거 성능을 확인한다.

ABSTRACT (English)

다수 태그 RFID 시스템을 위한 신호 충돌방지 기법 연구

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Radio frequency identification (RFID) is a technology aimed at efficiently identifying and tracking goods and assets. Due to the development in wireless communication technologies and mobile computing environment, RFID is becoming an important and essential component of ubiquitous computing. It utilizes the electromagnetic energy for data transmission from a tag to a reader, in the presence of arbitrary interference and noise. Recently, increasing attention has been given to this technology because of its low cost, fast handling and uniquely identifying capability. However, since tags are resource-constrained devices sending identification data wirelessly, designing secure RFID identification protocols is a challenging task. When numerous RFID tags try to respond to the single reader at the same time, the signal from each tag may interfere in communicating between

other tags and a reader, resulting in the reduction of the reliability and efficiency of the RFID system.

The present dissertation contributes to the design of algorithms aimed at dealing with the issues explained above. First, we proposed algorithm employing the Time Division (TD) technique where tags in the interrogation zone are assigned a specific time slot so that at one point in time the reader communicates with just a single tag. Moreover, we present an application of Gold code for RFID communication system, which uses spread spectrum techniques. In this RFID system, data bits are spreaded in each tags with the unique Gold code and the spreaded data bits are despreaded in the reader with the same Gold code. Finally, in order to make the system more efficient, we proposed a new combine primary digital transmission technique (TD/CDMA) tags anti-collision algorithm which helps in eliminating noise and interference between different tags.

I. INTRODUCTION

A. Motivation

Ubiquitous computing components such as radio frequency identification (RFID) is a tracking technology that enables immediate automatic object identification and quick data sharing. By using radio wave for data transmission from the tag to the reader, it can be used for a wide variety of modern applications. RFID is a contactless, non line-of-sight, low power and low-cost wireless communication technology that allows readers to read the identification of inexpensive electronics tags from a distance, without the use of battery power. With the remarkable progress in microelectronics and low-power semiconductor technologies, inexpensive RFID tags have moved from obscurity into mainstream application. RFID is significantly smarter than the well known ubiquitous bar code or the unified product code, mostly due to automated, wireless-readable sensory-based identification method and network. Embedding RFID tags in an object could eliminate the need for manual inspection and identification of objects. Nowadays, several RFID systems are deployed worldwide on a massive scale, namely for asset tracking, supply chain management, manufacturing, retailing, payments and for other applications such as security, access control, and object identification in construction technology.

The RFID technology has the capability of identifying a large number of human centric applications including healthcare, human-computer interactions, as well as it is widely used in positioning system. RFID systems do not continually track a moving object, but RFID readers located at different waypoints, create trajectories by identifying tags passing through those points.

However, all these potential benefits have been partially overshadowed by the RFID collision problem which is caused by interference from neighboring tags and readers. Collisions are classified into a reader-reader collision problem, reader-tag, and tag-tag collisions [1-5]. Reader to reader collision occurs when one reader can not know the status of the other readers, because they do not exchange their informations with each other in a dense RFID environment. Similarly, a tag-tag collision occurs when multiple signals arrive concurrently to the reader, preventing reliable detection of all tags in its interrogation zone. Due to the lack of information exchange among the different RFID readers and tags cause signal interference, and can reduce the efficiency and reliability of the RFID system which ultimately results in misreading, unsuccessful reading of RFID tag [6].

Several efforts have been made in designing collision free RFID systems. An increasing number of articles are being written on RFID anti-collision based on deterministic and probabilistic approach. All these efforts contribute to the establishment of a technology that help to reduce the collision issues in RFID technology.

We finally focus on mitigating the collision issues that may arise from RFID tags caused by interference from neighboring tag. Analyzing the interference problem in an RFID system, we propose our algorithm for efficient identification of RFID tags in a dense environment.

B. Contribution

The main contributions of this dissertation are the following:

1. Efficient RFID Tag Identification using Time Division (TD) Method:

In order to suppress a signal interference from multiple neighboring tags, the proposed algorithm uses a time division (TD) technique where tags in the interrogation zone are assigned a specific time slot so that at one point in time the reader communicates with just a single tag. We allocate specific time slots and the fixed number of data bits for the preamble data and main data. This helps to provide accurate detection, and at the same time significantly reduce communication overheads.

2. Performance Analysis of RFID Interference Suppression System based on the Gold Code:

This thesis presents the implementation of the CDMA Gold code technique to suppress the interference signal from the neighboring tags. The Gold code provides high flexibility in code length and is relatively simple to implement. It is capable of accommodating a large number of RFID tags, in comparison to the existing anti-collision protocols.

3. Combined TD/CDMA Operation RFID Anti-Collision systems:

After a successful performance evaluation of TD method and Gold code method, finally this thesis presents a combine TD/CDMA technique which helps to increase the tag-to-reader communication by reducing the tag-to-tag interference. In the combined TD/CDMA technology, TD helps to reduce tags interference, whereas CDMA communication network takes the advantage by increasing effective communication between tags and reader.

4. Threshold Detection of Passive RFID tag for Efficient Communication:

In order to secure the reliability of the transferred data, we propose an effective signal decision algorithm based on Signal-to-interference and noise ratio (SINR). SINR value is compared with a minimum threshold value. Those tags which SINR value is greater than the minimum threshold value are allowed to transfer their main data, whereas tags with smallest SINR value compared to the minimum threshold are not allowed to transfer their main data.

C. Organization of the Dissertation

The structure of this thesis is as follows. In section II, we present the background, collision issue, and works related to RFID anti-collision technology. In section III, we present the anti-collision Time Division RFID system for tag collision scenarios to improve the tag to tag collision in an RFID system. Theoretical analysis and comprehensive simulation results using TD method can provide accurate detection, and at the same time substantially reduce communication overheads unlike conventional systems. The implementation of the Gold code technique to evaluate the performance analysis of RFID interference suppression is discussed in section IV. In section V, we used the combined TD/CDMA technique. Similarly, in section VI presents the data efficiency and reliability of the RFID system based on the measured signal to interference and noise ratio (SINR). It helps in determining the minimum threshold value at different data reliability rates. Finally, the conclusion of this study is summarized in section VII.

II. BACKGROUND

A. RFID Technology

An RFID system has two main categories of components-- readers and tags.

1. Reader

The RFID reader (see example in Figure II.1) [7] or transceivers are responsible for reading the tags that are present within its readable-field. It creates an electromagnetic signal, which is transmitted to the RFID tags through one or more antennas. The function of the antenna is to both transmit and receive electromagnetic signal between the tags and the reader. An effective electromagnetic field from which the antenna transmits in RFID terms, known as the interrogation zone.

2. Tags

RFID tags (see examples in Figure II.2) [8] or transponders are responsible for permanently storing identity information, and relaying that information to the reader. Tags contain three basic parts which include a electronic integrated circuit, miniature antenna and a substrate to hold the integrated circuit and the antenna. Depending on the power, tags are also classified into passive, active and, semi-passive.

Passive tags are powerless, and requires close proximity to the reader and antenna in order to obtain sufficient power to transmit a signal. Passive tags transmit data by reflecting power from the interrogator whereas active tags contain an onboard power source. As a result, the range of active tags is generally far superior to that of passive tags.

In order to communicate with a reader, passive tags, uses near field (inductive coupling) and far field (backscatter reflection) communication. Near field is used by the RFID system operating in LF and HF frequency bands whereas far field is used in UHF and microwave systems.

Figure II.1 RFID Reader

Figure II.2 RFID Tags

B. Collision Issues in RFID Identification

Interference of tag signals is a common issue in RFID systems. Simultaneous transmission from multiple tags leads to collision, as the readers and the tags normally use the same channel.

1. Reader-Reader Collision

A reader-reader collision (see examples in Figure II.3) occurs when neighboring readers simultaneously interrogate the specific tag in the same frequency band. Furthermore, reader-to-reader collision may occur when the tag is within the readable range of one reader and interference range of the other reader. Thus, the signal from the latter reader may interfere with the return signal from the tag[1, 2]. The reader-reader collision is discussed in colorwave [9].

2. Reader-Tag Collision

A reader-tag collision (also called tag interference shown in Figure II.4) occurs when a tag receives multiple concurrent queries from the different readers. This problem has been studied in the EPC-Global Class1 Gen1 and Gen2 standards for UHF readers [[10].

3. Tag-Tag Collision

A tag-tag collision (see examples in Figure II.5) occurs when multiple signals arrive concurrently to the reader, preventing reliable detection of all tags in its interrogation zone.

This situation is shown in Figure II.5 where tags Tag1, Tag2, Tag3, and Tag4 simultaneously send signals to a single reader which prevents the reader from recognizing tags accurately. Without an anti-collision protocol, the data from these tags would collide at the reader and degrade identification. Besides, it also causes bandwidth and energy waste[11].

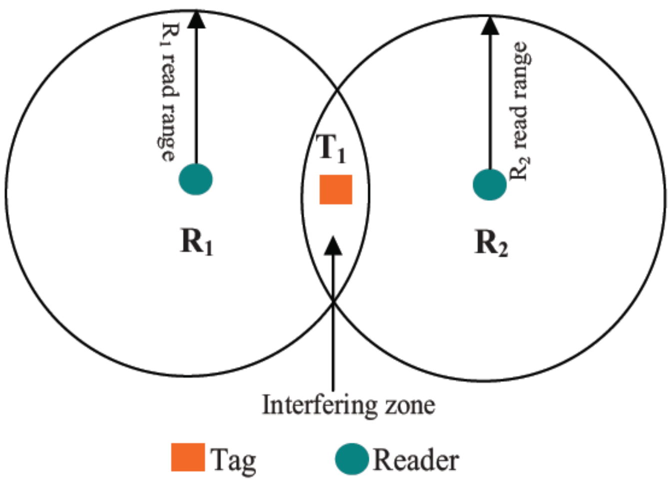

Figure II.3 Reader Reader Collision

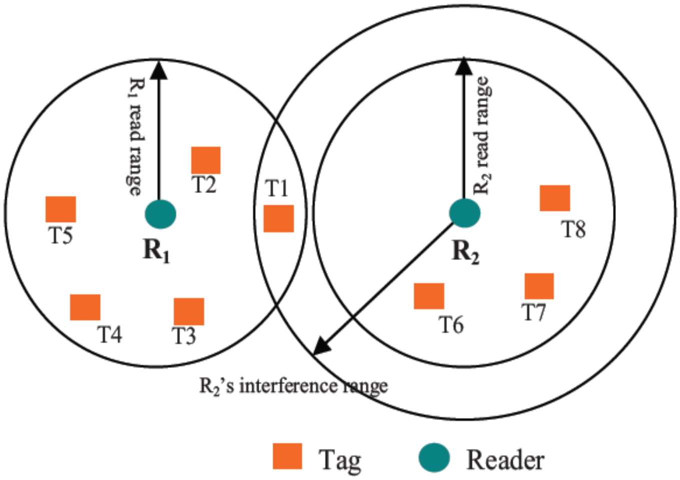

Figure II.4 Reader-Tag Collision

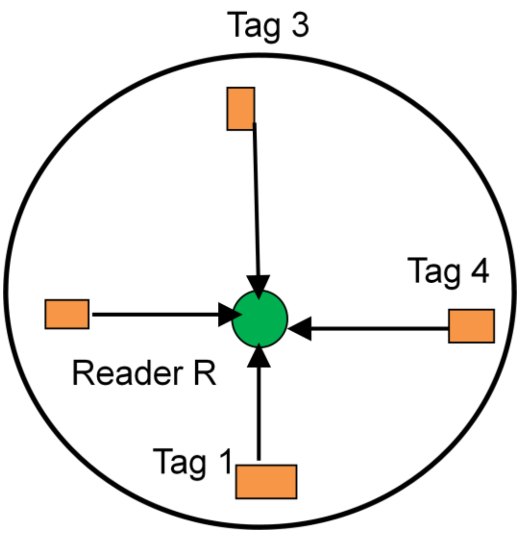

Figure II.5 Tag-Tag Collision

C. Some Works on Collision Problem

In this thesis, we specifically address the problem of a single reader in the environment with multiple tags. Further, we focus on practical application of RFID technology in the construction industry. Typically, in a construction site, there are a massive number of tagged objects. Thus, it is extremely important to improve object identification and at the same time minimize operation costs. There are two basic anti-collision techniques that use deterministic or probabilistic approaches. A variety of multiple access technologies have been used in recent RFID systems: space division multiple access (SDMA), frequency-domain multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA), also known as the spread-spectrum[12, 13]

SDMA reuses certain resources (channel capacity) in spatial slots. SDMA protocols separate the channel using electronically controlled directional antennas or multiple readers to identify the tags. The drawback of this approach is its high implementation cost, the need to design a complicated antenna system, and its limitation to only a few specialized applications. On the other hand, FDMA uses different frequency ranges for data transfer from and to the transponders. Thus, FDMA requires the complex receiver at the reader end (since a dedicated receiver must be provided for every reception channel). Lastly, CDMA requires tags to multiply their IDs by a pseudo-random sequence (PN) before the transmission. This result shows that CDMA is very expensive and power consuming.

TDMA is the most popular RFID tag anti-collision scheme, which can easily incorporate into other multiple access technologies. In the TDMA based anti-collision, the entire available channel capacity is divided among the participants chronologically. TDMA protocol is classified as synchronous and reader-driven, where all steps are simultaneously controlled by the reader. At any particular time interval, an individual tag is first selected from a group of tags after which fast data communication is made between the selected tag and reader, which we call reader-talk-first (RTF). In a tag –driven protocol, which is considered as asynchronous, a tag announces its itself to the reader by transmitting its ID in the presence of a reader which we called tag-talk-first (TTF). TTF is relatively slow and inflexible to RTF[12, 14] .

Most of the standards for the UHF RFID system references the binary tree search, which is based on an anti-collision algorithm as deterministic schemes, since each roof-to-leaf path denotes a unique tag ID and all IDs can be retrieved once all branches are completely searched. On the other hand, aloha-based anti-collision algorithms are probabilistic because each tag ID has a chance to be retrieved successfully. However, there is a possibility that some tags may not be accessed because of a recurrent collision [15].

In aloha anti-collision algorithms, the duration of transmission of data for each tag is a small fraction of the repetition time, causing long pauses between transmissions from the same tag occurs. Each tag randomly transmits its data to the reader, depending on the amount of data. Thus, communication between the reader and the tags is not continuous and in case of low throughput rate, there is a high probability of collision between the tags.

In a slotted aloha RFID system, the duration of the channel is divided into uniform slots, and the transmission of tag IDs involves synchronization between the tag and the reader. In contrast to simple aloha, the throughput rate increases from 18.4 to 36.8 per cent, but the system is unstable and has low efficiency.

In FSA algorithm, the entire timeline is divided into a number of frames, each frame consisting of several slots. Since the tag can choose only a single slot in the frame and send its data only once during the frame length, the probability of collision is lower than with slotted aloha. Due to the fixed frame size, however, the probability of collisions greatly increases as the tags population grows. On the other hand, with small tag population, the number of wasted slots increases.

To overcome the drawbacks of the FSA algorithm, the DFSA algorithm was introduced. With this algorithm the frame size is dynamically adjusted according to the estimated number of tags[16, 17].

Tree-based anti-collision algorithms use a virtual tree to read all tags by iterative querying a subset of tags at different levels and tag IDs are distributed based on their prefixes. The root is the set of tags to be identified, intermediate nodes represent the group of colliding tags, while leaves represent individual tag responses[18]. Tree-based algorithms are further classified into tree splitting (TS), query tree (QT), binary search (BS), and bitwise arbitration [13].

In binary tree (BT) algorithms, the reader uses a slotted identification procedure and recursively examines the virtual tree from root to leaves. In each slot, a tag transmits its ID if and only if the value of its counter equals to 0. For each slot, the reader assigns a status, whether it's idle, single, or collision.

As, BT is reader driven, the reader claims the idle, single, or collide condition of slots, According to reader reports, tag changes its counter. If a collision occurs in the previous slot, tags involved in collision randomly select 0 or 1, and add the number to the counter. Tags, which are not involved in the collision, simply increase their counter by 1. In a non-collide slot, all tags decrease their counter by 1. The tags, which have been already identified, keep silent throughout the entire identification process, until the process is finished[19].

III. ANTI-COLLISION TIME DIVISION RFID SYSTEM FOR TAG COLLISION SCENARIOS

A. Introduction

Recent advancements in digital electronics, signal processing, and wireless communications have given a rise to low-cost and low-power, automatic, wireless sensor systems, which allow non-contact out of visibility reads out of data by the means of electromagnetic signals. RFID has become the key technology that spans across a wide range of applications such as asset management, supply chains, medicine, inventory and material management, construction, and so on. RFID system consists of a reader (interrogator), a tag (transponder), and middleware software, which helps in data processing from the tag to the reader using RF signals[20]. Tags can be passive, semi-passive, and active depending on functionality.

A passive tag is not equipped with a power source and therefore, requires energy from the reader to back scattered the re-modulated signal containing its ID information to the reader [6].

RFID tags used in the construction industry for materials management suffers a lot from interference from their neighbors which ultimately results in tag-to-tag collision problem. In order to suppress collision from neighboring tags, we propose an anti-collision algorithm based on time division technique. In this technique, a data frame is divided into several timeslots assigned to individual tags, and the reader can read all tags concurrently [10]. Furthermore, we consider using preamble data that can help in channel estimation, signal-to-noise ratio (SNR) estimation, and synchronization etc.

B. Received Signal Model

The received signal vector $r(k)$ at sample index k can be modeled as

$$r(k) = x_1(k) + x_2(k) + x_3(k) + \cdots + x_L(k) + n(k) \qquad (1.1)$$

which can be summarized as

$$r(k) = \sum_{l=1}^{L} x_l(k) + n(k) \qquad (1.2)$$

where l represents the l^{th} tag, L is the total number of tags transmitting the signal to the reader, $x_l(k)$ is the signal received from each tag, and $n(k)$ is the additive white Gaussian noise (AWGN) with independent and identically distributed components, each with zero mean and variance σ^2.

The distance relation is calculated using Friis free space equation where the transmitted power from the reader P_r and the power received by the antenna of the tag P_{tag} is given by

$$P_{tag} = P_r G_r G_{tag} \left(\frac{\lambda}{4\pi r}\right)^2 \qquad (1.3)$$

where G_r and G_{tag} are the transmitter and receiver antenna gain, respectively. λ is the wavelength in meters, and r is the distance between the transmitter and the receiver antenna[21, 22].

From equation 1.3, the indoor environment path loss model is given by

$$P_{loss}(dB) = P_{loss}(d_0) + 10nlog\left(\frac{d}{d_0}\right) \qquad (1.4)$$

where d_0 is the reference distance, and n is the value that depends on the surrounding and building type: the more hostile the environment is, the higher is n value, and the path loss, accordingly, is higher for the same distance as compared to the environment with lower value of n, and d is the separation distance between two antennae[23, 24].

The signal received by RFID reader is the sum of desired Modulated backscattered signals, noise, and interfering signals. The amount of power available to the RF tag for operation is given by

$$P_{tag} = P_r + G_r + G_{tag} + 10log_{10}\left(\frac{\sigma}{4\pi}\right) - 20log_{10}\left(\frac{4\pi}{\lambda}\right) - 40log_{10}(r) \qquad (1.5)$$

where σ is the radar cross section (RCS) of the RF tag which have a vital role in the system level efficiency and reliability [25-27].

The RFID tag cross-section area can be written as

$$\sigma_{tag} = \frac{|\tau|^2 G_{tag}{}^2 \lambda^2}{4\pi} \qquad (1.6)$$

Substituting the value of σ_{tag} into equation 1.5, The amount of modulated power from the RF tag to the tag reader becomes:

$$P_{tag} = P_r + G_r + G_{tag} + 20\log_{10}(\tau) - 40\log_{10}\left(\frac{4\pi}{\lambda}\right) - 40\log_{10}(r) \qquad (1.7)$$

C. Anti-Collision based on TD for RFID

In this section, we suggest an anti-collision algorithm for a single reader receiving signals from multiple tags simultaneously.

In the conventional method, a tag simultaneously sends its data packet to the reader that results in a reduced network throughput because of the interference between the tags and presence of channel noises. To leverage this interference and noise, we suggest a collision-free TD method that distributes tag information on a specific time slot.

The reader transmits a carrier signal to all tags located within their interrogation zone. All tags in the coverage area of the reader transmit their identification to the reader using synchronized unique time slots. This provides better communication performance by reducing power consumption as individual tags only transmit once within a certain time period and don't attempt repeating transmissions.

BPSK signal modulation scheme is shown in Figure III.1. A signal with constant amplitude is sent by the reader to wake-up all tags within its interrogation zone[28].

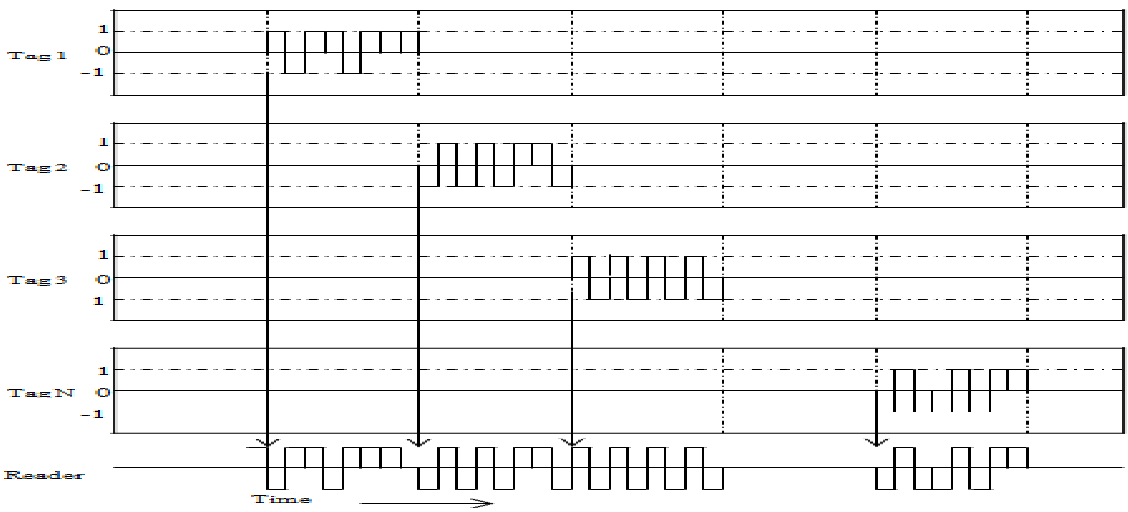

Figure III.1 Received tag IDs at the reader using BPSK signals

D. RFID Data Architecture for RFID Anti-Collision based on Time Division (TD)

We propose the efficient data architecture for RFID anti-collision based on TD. Here, we allocate specific time slots and the fixed number of data bits for the preamble data and main data. The reader reads the tag with fixed data bits in a particular time interval, and time intervals are reserved for each specific tag, preventing a collision between the tags in the reader interrogation zone.

The function of the preamble and main data are summarized as follows:

Preamble: Data for channel estimation, signal-to-noise ratio (SNR) estimation, synchronization, etc.

Main data: Tag information (ID, electronic product code (EPC) number and main information).

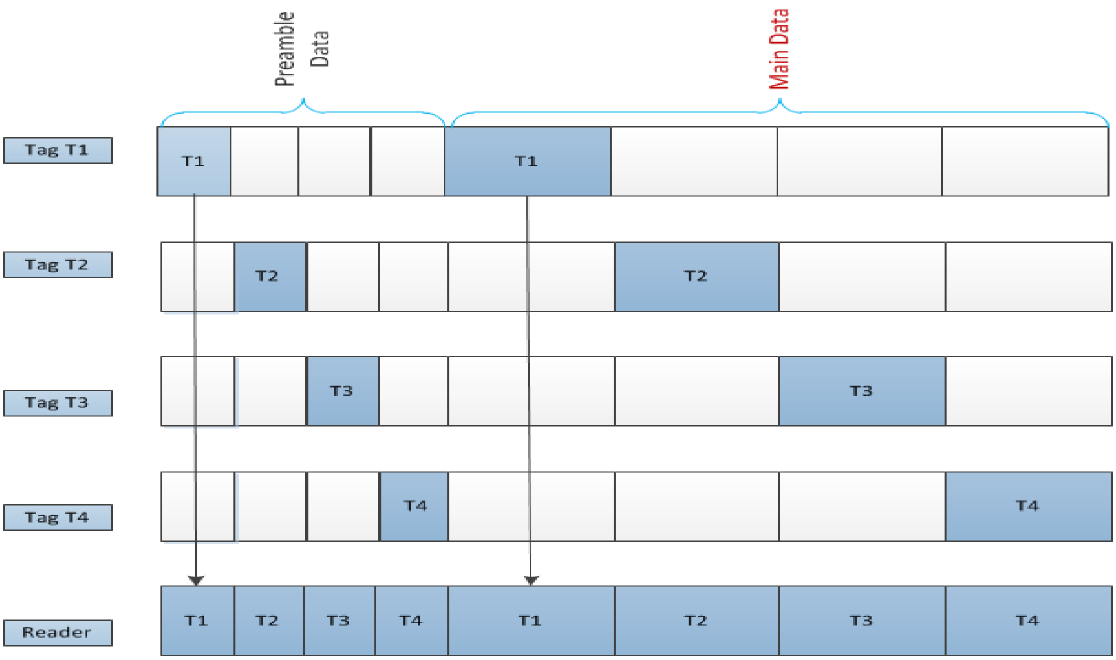

Figure III.2 Data architecture for suggested anti-collision protocol

In this communication system, when the reader sends the wake-up signal to the tags, tags begin transmitting the preamble data using a specific time interval as shown in Figure III.2. Using the proposed data architecture, when the specific tag transmits the data to a reader, other tags do not transmit any data. Therefore, there is no interference signal for communicating between multi tags and a reader at the same time. While the anti-collision architecture based on TD for RFID in Figure III.2 considers four tags and a reader, it might be extended for more tags.

E. Computer Simulation

In this section, we present the results of the analysis of the suggested protocol using computer simulation to illustrate the method performance and interference suppression capabilities.

For simulation, we consider two cases:

Case 1: Transmitting signals of four RFID tags located at the same distance within the reader interrogation zone.

Case 2: Transmitting signals of four RFID tags located at different distances within the reader interrogation zone.

We assume that the frequency of RFID signal is 900 MHz for passive tags (T1, T2, T3, and T4), and the transmitted power of the tag is fixed for distance of 2m with minimum loss in bits.

Figure III.3 shows the bit error rate (BER) for the first case (same distance). From Figure III.3, one can see that the BER of the proposed system is much lower than with conventional methods. Figure III.4 shows the BER for the second case (different distances from 1.8 through 2.4m). One can see that the BER is lower when the distance between the tag and the reader is shorter and is always better than conventional system.

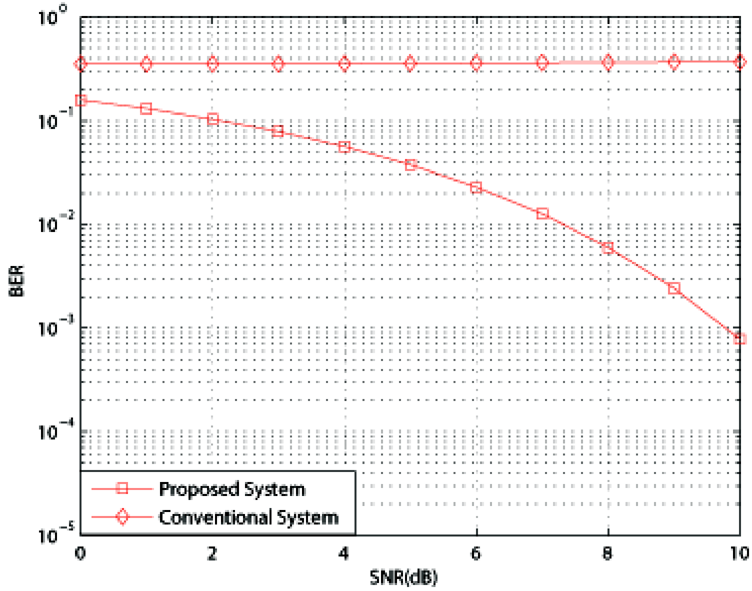

Figure III.3 BER performance for the proposed TD and conventional system for the first case

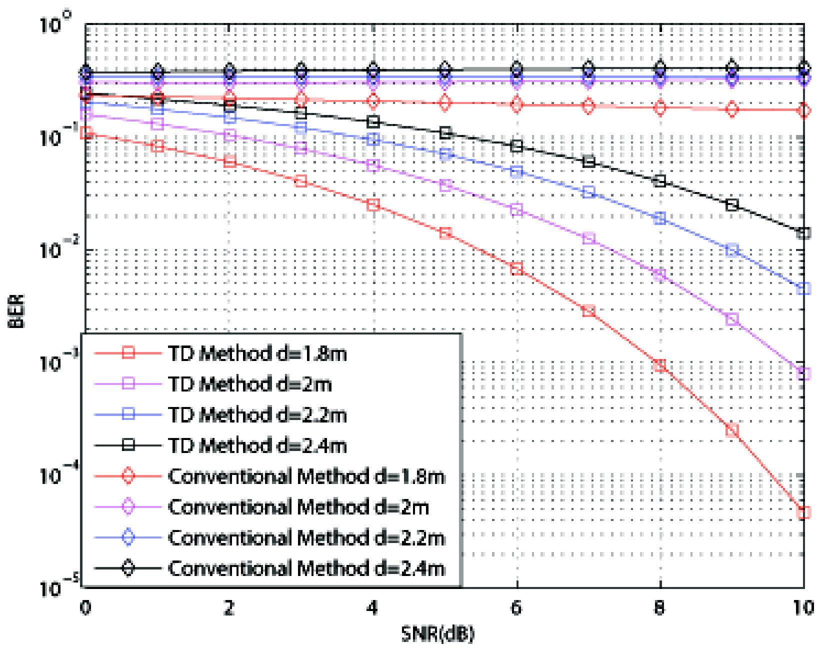

Figure III.4 BER performance of the proposed TD and conventional system for the second case

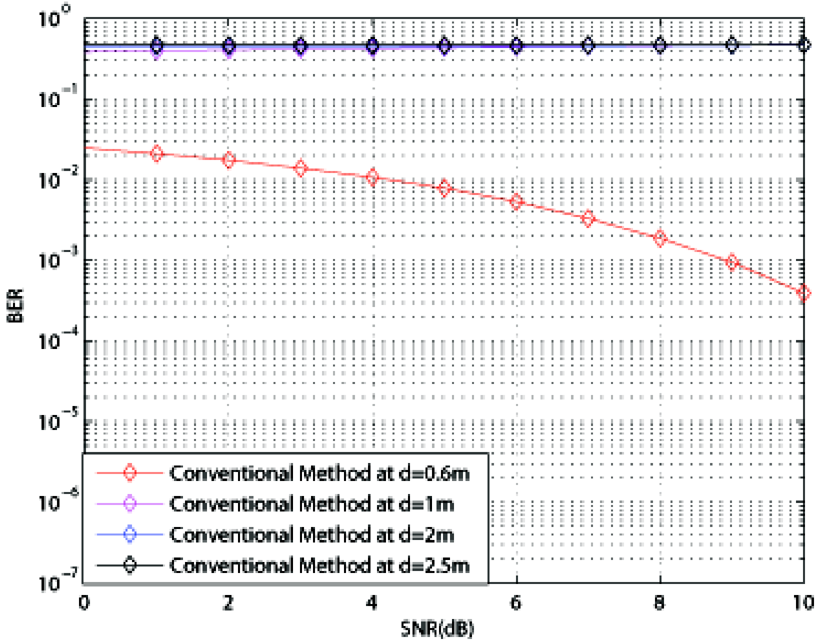

Figure III.5 BER performance of the conventional system

Figure III.5 shows the bit error rate (BER) performance for conventional systems at different distances. One can see that only a small number of tag messages can be recovered up to the distance of 0.6m whereas above it, maximum number of data bits will be lost due to the presence of neighboring tag interference and noise. Thus, conventional system limits up to a distance of 0.6m with minimum loss in bits.

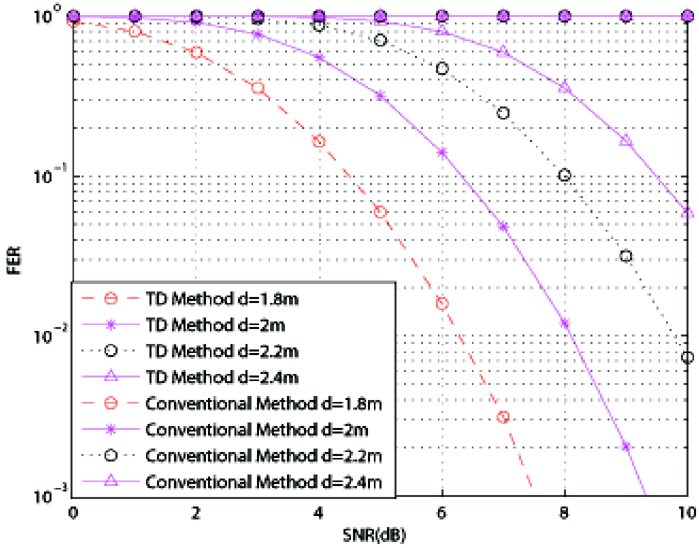

Figure III.6 FER performance of the proposed TD method with frame size equal to 64 bits

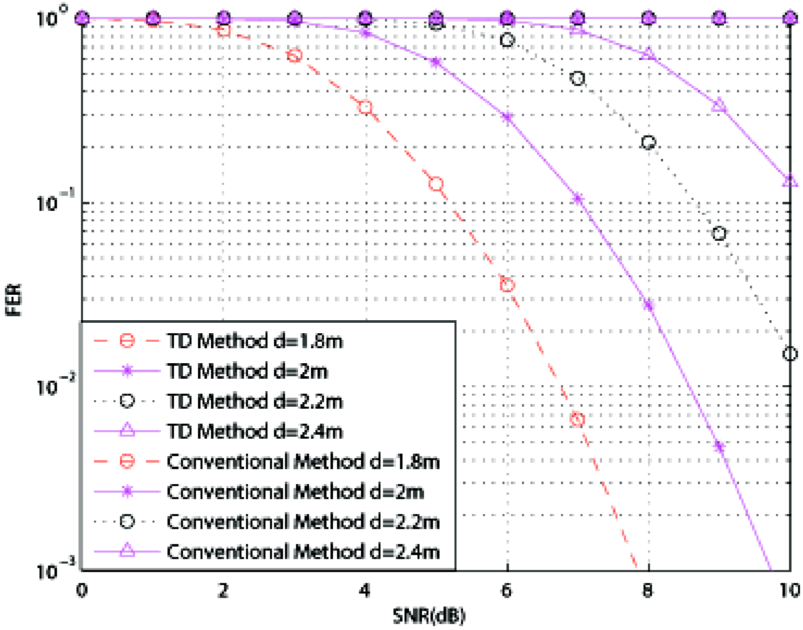

Figure III.7 FER performance of the proposed TD method with frame size 144 bits

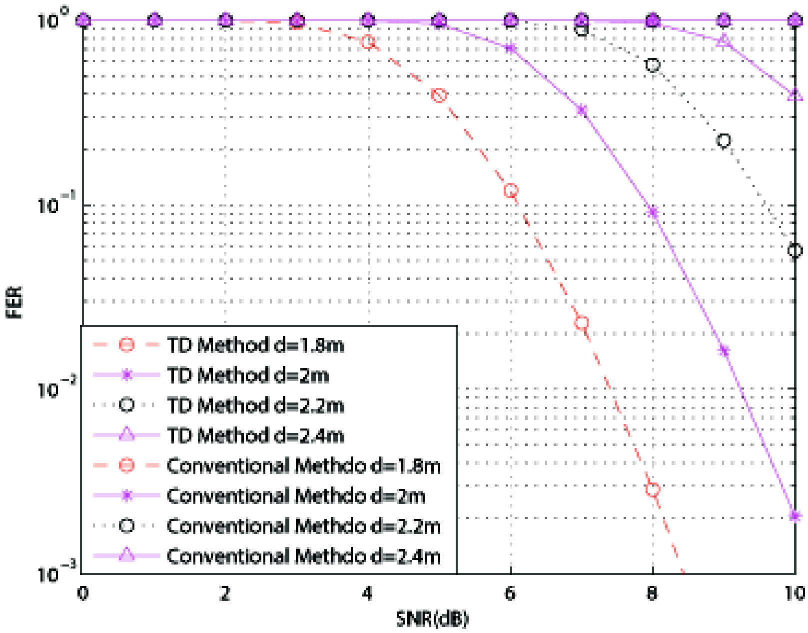

Figure III.8 FER performance of the proposed TD method with frame size 512 bits

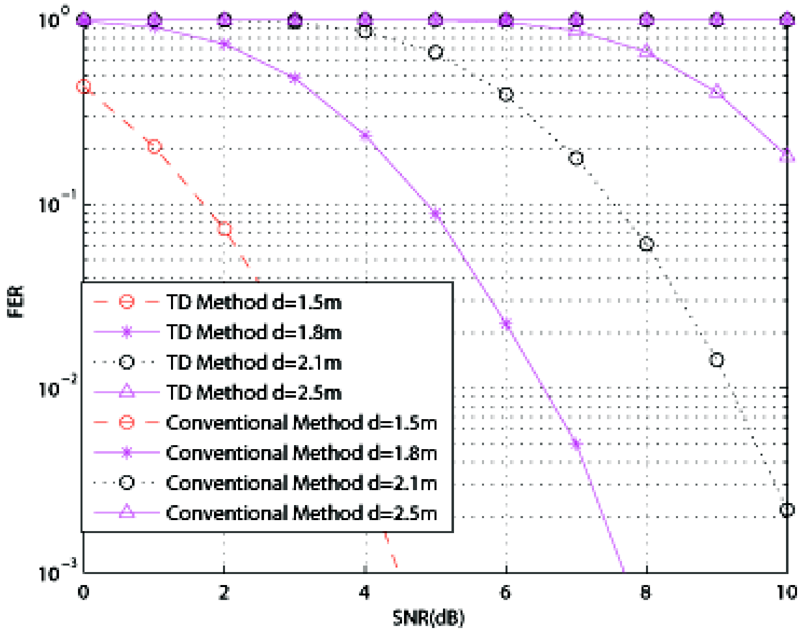

Figure III.9 FER performance of the proposed TD method with frame size 64 bits

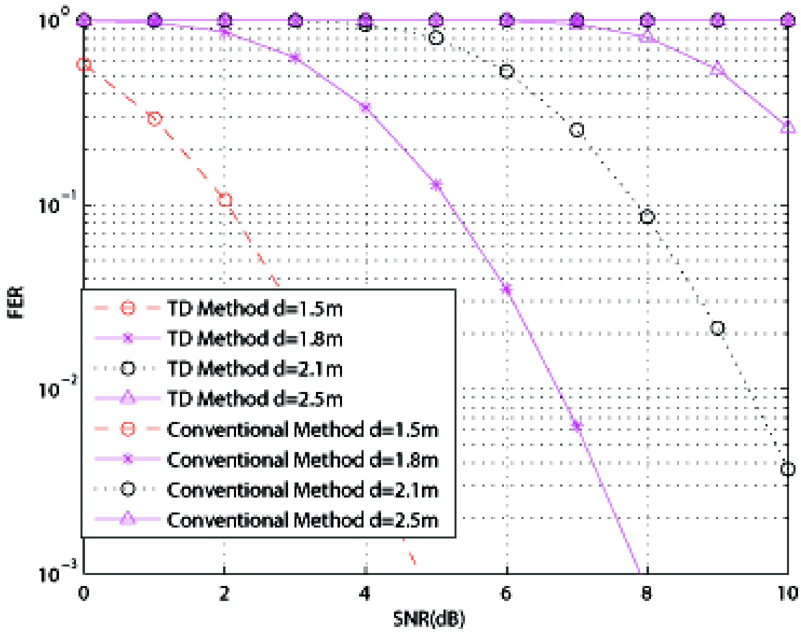

Figure III.10 FER performance of the proposed TD method with frame size 144 bits

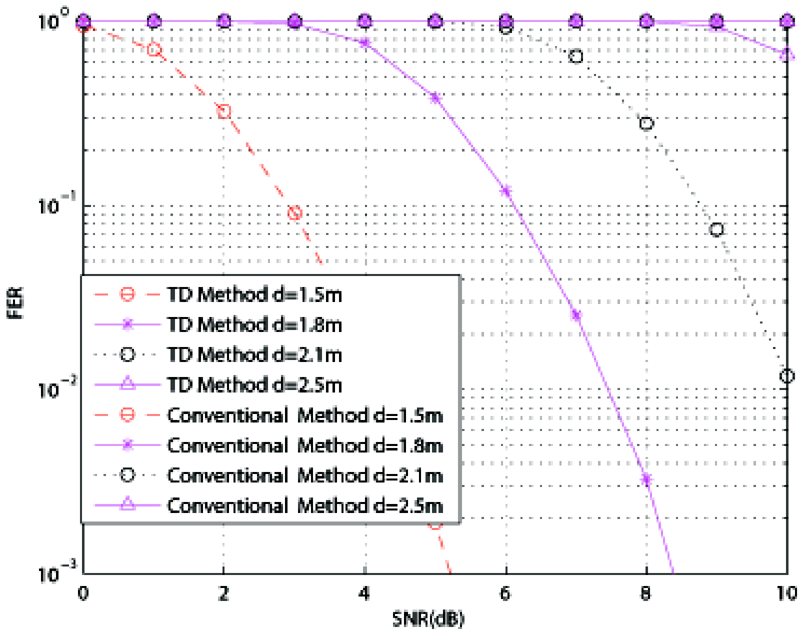

Figure III.11 FER performance of the proposed TD method with frame size 512 bits

The simulated output FER for the proposed system at frame lengths equal to 64, 144, and 512 bits are shown in Figures III.6, III.7, and III.8 respectively. In all cases, four RFID tags were placed at different distances (1.8, 2, 2.2, and 2.4m). From the above figures, one can see that FER is lower when the distance between the tag and the reader is shorter, and FER for smaller frame length results in lower probability of frame error. The same result is also shown in Figures III.9, III.10, and III.11 at different distances (1.5, 1.8, 2.1, and 2.5m). One can also observe that using the proposed system, the reader can receive tag information even at longer distances with minimum frame losses as compared to conventional systems.

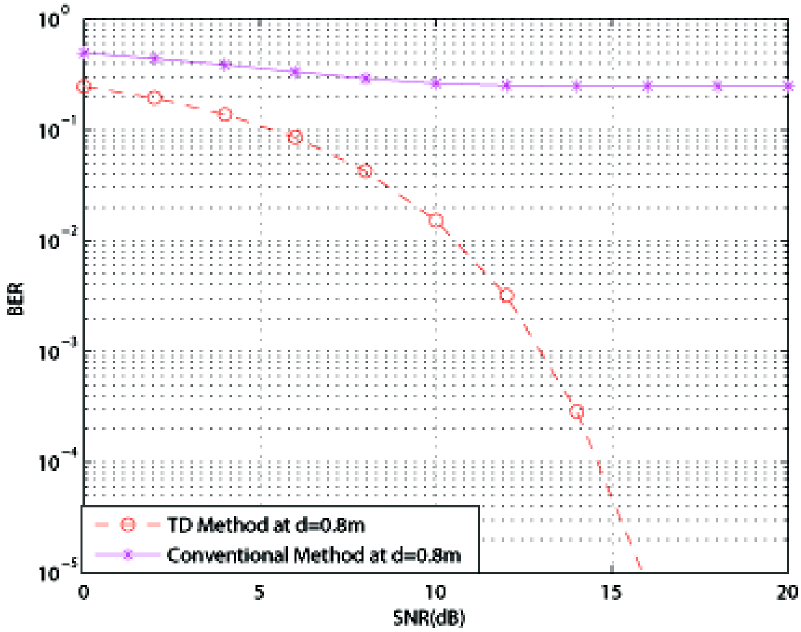

Figure III.12 BER performance of the proposed TD method at distances 0.8m.

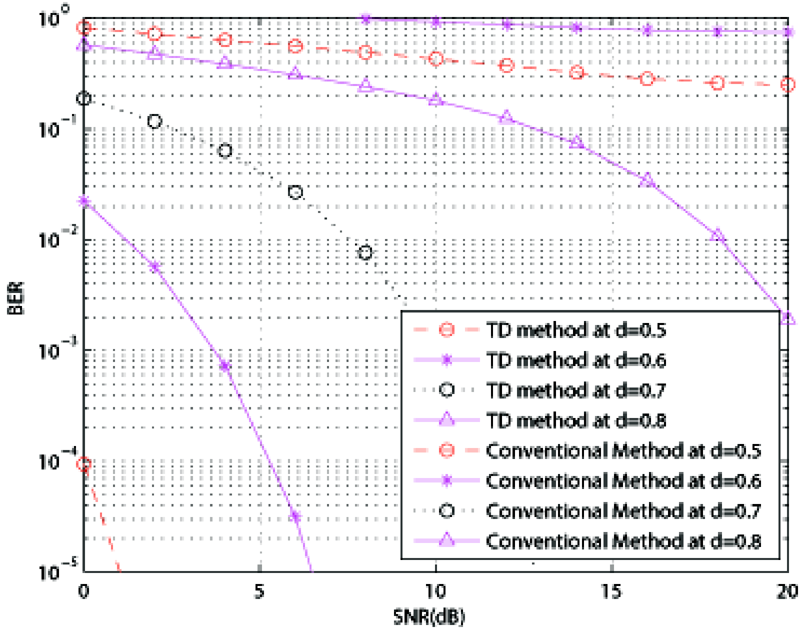

Figure III.13 BER performance of the proposed TD method at random distances from 0.5, 0.6, 0.7, and 0.8m in the presence of 510 interference tags.

Figure III.12 shows the BER performance of the conventional system and the proposed system at 0.8m distance in the presence of more than 250 interference tags. Similarly, we performed our simulation in different scenarios which are shown in Figures III.13 and III.14. In Figure III.13, we simulate in the presence of more than 500 interference tags at different distances (60 interference tags at a distance of 1.5m to 4m, 150 interference tags at a distance of 7m to 4m, and 300 interference tags at a distance of 10m to 7m). Similarly, In Figure III.14, more than 250 interference tags are placed at different distances (30 interference tags at a distance of 1.5m to 4m, 90 interference tags at a distance of 7m to 4m, and 150 interference tags at a distance of 10m to 7m). From the above simulation, we can see that, BER increase as the distance between reader and tags increases and our system can perform efficiently even in the presence of a huge number of interference tags when compared to conventional system.

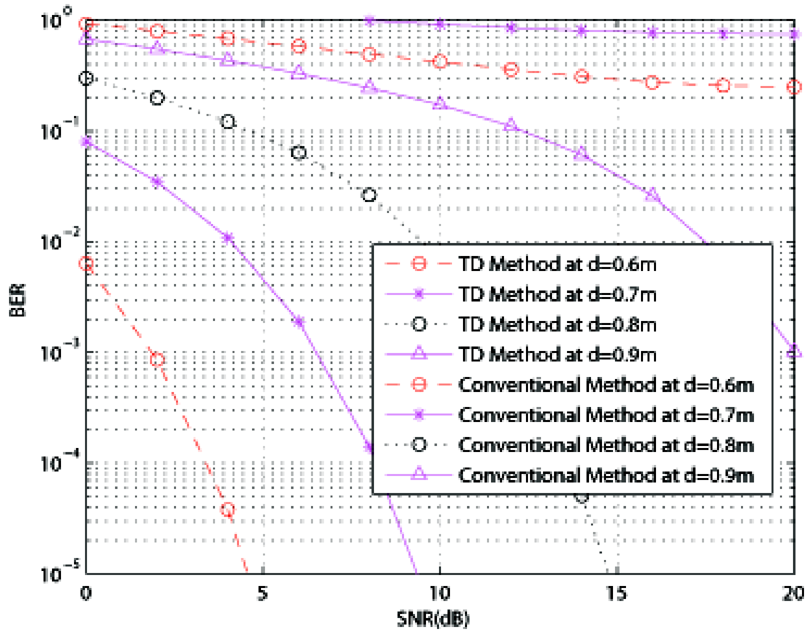

Figure III.14 BER performance of the proposed TD method at distances 0.6m, 0.7m, 0.8m, and 0.9m in the presence of 270 interference tag.

F. Conclusion

In order to minimize tag-to-tag collision, we propose an anti-collision method and data structure for RFID systems using time division technique. Theoretical analysis and comprehensive simulation results show that TD method can provide accurate detection, and at the same time significantly reduce communication overheads as compared to conventional systems. Since only specific tags transmit the data to the reader within a specific time slot, no collision occurs. The proposed RFID architecture improves data reliability,efficiency, and performance by identifying the information for the specific objects or materials that can be upgraded in the environment with multiple tags and the single reader when it is employed in the construction workplace.

IV. PERFORMANCE ANALYSIS OF RFID INTERFERENCE SUPPRESSION SYSTEM BASED ON THE GOLD CODE

A. Introduction

In order to design an efficient anti-collision protocol for interference cancellation, we present the implementation of CDMA (code division multiple access) Gold code technique [29], which is capable of accommodating a huge number of RFID tags [30] then the existing anti-collision protocols due to its inherent immunity to interference [31].

For efficient communication between multiple low-cost passive RFID tags and a single reader, employing Gold code in the RFID system can be a good solution, because, it supplies a number of codes with a good balance between auto and cross correlation with high flexibility in code length. It is also relatively easy to implement, requires only a shift register to generate all the codes [32].

In this thesis, we compare the BER performance of the RFID system based on the Gold code with the conventional system without an anti-collision technique system and the RFID system based on the time division (TD) technique which uses the specific time slots and the fixed number of data bits for the preamble and main data[33].

B. Received Signal Model

For the received signal, we consider L tags which individually transmit spread spectrum signals at the same time. In order to spread a signal spectrum in the transmitter, the data bit for the i^{th} tag $b_i(k)$, is directly multiplied by the element of the cyclostationary Gold code with length N for the i^{th} tag, $g(k)$ written as

$$x_i(k) = g_i(k)b_i(k) \tag{1.8}$$

The received signal vector $r(k)$ at sample index k can be modeled as

$$r(k) = \sum_{i=1}^{L} g_i(k)b_i(k) + n(k) \tag{1.9}$$

where $n(k)$ is the additive white Gaussian noise (AWGN) with independent and identically distributed components, each with zero mean and variance σ^2. In equation 2, $b_i(k)$ remains constant over the length of one cycle of the Gold code.

The gold code for the i^{th} tag g, is defined as

$$\boldsymbol{g}_i = [\boldsymbol{g}_i(k), \boldsymbol{g}_i(k+1), \boldsymbol{g}_i(k+2) \ldots \boldsymbol{g}_i\,(K+N-1)]^T \tag{1.10}$$

where N is the length of the Gold code.

Using the Friss free space equation, the distance relation is calculated where the transmitted power from the reader P_r, and the power received by the antenna of the tag P_{tag} is given by equation (1.3) Where the transmitter and receiver antenna gain are represented by G_r and G_{tag} respectively. λ is the wavelength in meters, and r is the distance between transmitter and receiver antenna[21].

C. RFID Anti-Collision based on Gold Code

In this section, we present Gold code technology for interference cancellation in RFID for receiving information from multiple tags to a single reader. For this system, we allocate the fixed number of unique Gold code to each tag. The transmitted signal is spread over each tag and the received signal is disproved in the reader with each unique Gold code to detect the desired data.

1. Spreading of the Transmitted Signal

During transmission, in order to provide the unique Gold code to each tag and to spread the signal spectrum the data bit for the i^{th} tag, $b_i(k)$ is directly multiplied by the element of Gold code for the i^{th} tag, $g_i(k)$, which is independent of $b_i(k)$.

2. Despreading of the Received Signal

In a receiver, the multiplexed signal from all tags and the noise are received and multiplied again by the same Gold code, g_i for i^{th} tag to detect the desired data for the i^{th} tag and to suppress the interference signal from other tags. Since $g_i^T g_i = N$ and $g_i^T g_i = -1,\ i \neq l$, the despreaded signal with i^{th} Gold code is given by

$$r^T(n)g_i = [r(k), \dots, r(K+N-1)] \begin{bmatrix} g_i(k) \\ \vdots \\ g_i(k+N-1) \end{bmatrix} \quad (1.11)$$

where $b_i(n) = [b_i(k), \dots, b_i(K+N-1)]g_i$ and $n(n) = [n(k, \dots, n(K+N-1)]Tgi$

The despreader output includes the signal of the interested tag, additive Gaussian noise (AWGN), and residual interference signals with the low-power, because the power of the signal for the desired i^{th} tag is increased and the interference signals from other tags are suppressed, after dispreading. It helps to minimize the interference signals from other tags while communicating from multiple tags and a reader by employing this method.

D. Computer Simulation

In this section, we analyze the considered RFID system through computer simulation to illustrate the performance of the interference suppression. For the simulation, we assume that the received signal consists of four RFID tag signals and AWGN with zero mean and variance, the frequency of RFID signal is 900MHz, all RFID tags are passive, the transmitted power of the tag is fixed for distance of 2m with minimum loss in bits, and the length of Gold code, N is 15. For the simulation, we consider two cases as follows.

Case 1: Four RFID tags transmit each signal, which are located in the reader interrogation zone at the same distance of 2m.

Case 2: Four RFID tags transmit each signal, which are located in the reader interrogation zone with different distances of 1.5m, 2m, 2.5m and 3m.

Figure IV.1 and IV.2 shows the bit error rate (BER) curves for the first case at the same

distance and the BER curves in the second case with varying distance, respectively. From Figure IV.1, we observe that BER of the Gold code system is much lower than that of the time division (TD) and conventional RFID system. In Figure IV.2, BERs of the Gold code and RFID system are lower than that of the TD system and BERs are low when the distance between tags and a reader is short for both systems.

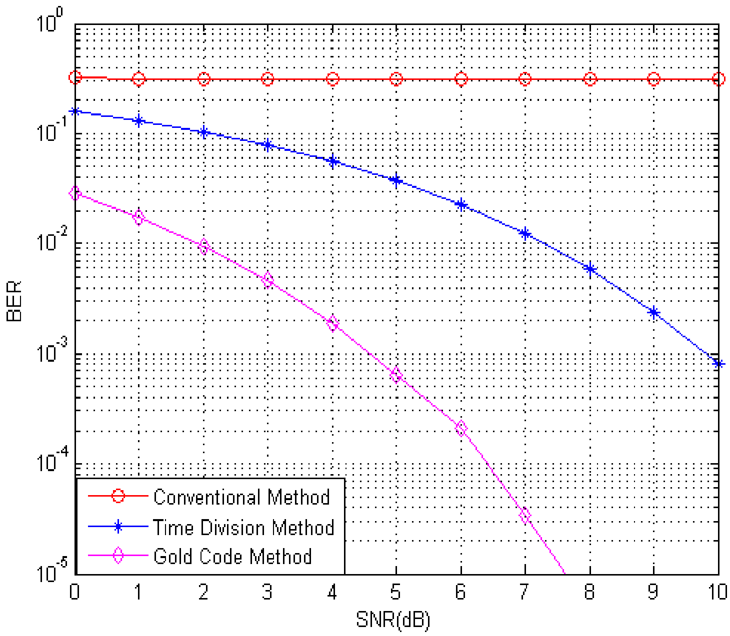

Figure IV.1 BER performance of the Gold code, TD and conventional RFID system for the first case

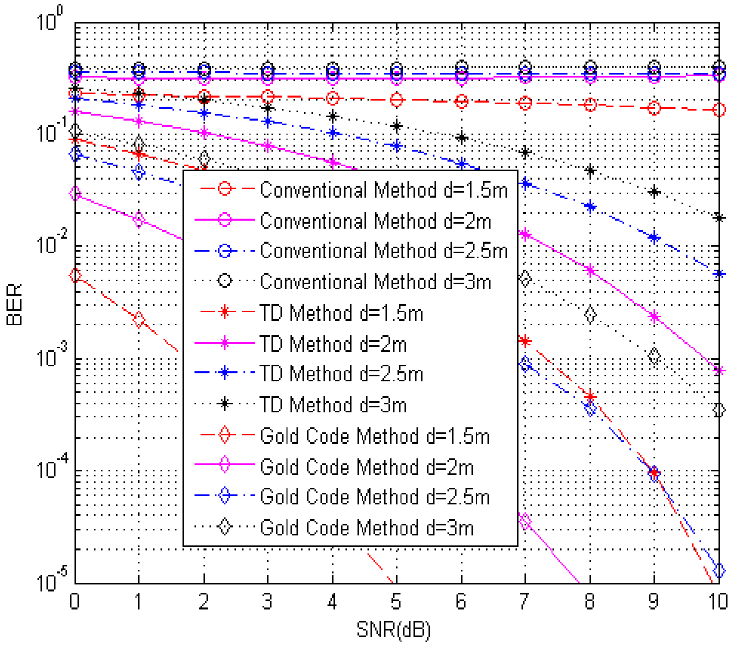

Figure IV.2 BER performance of the Gold code, TD and conventional RFID system for the second case

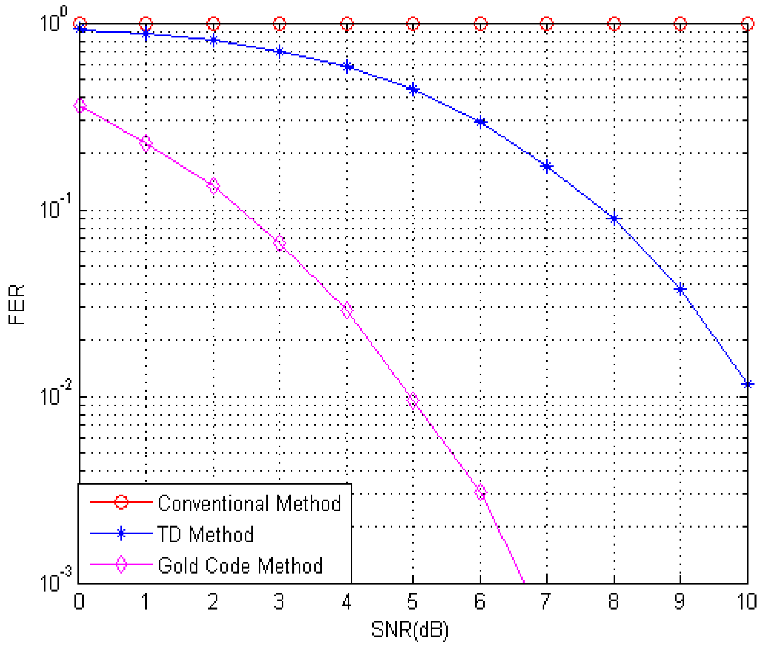

Figure IV.3 FER Performance of the Gold Code, TD and Conventional RFID system for the first case

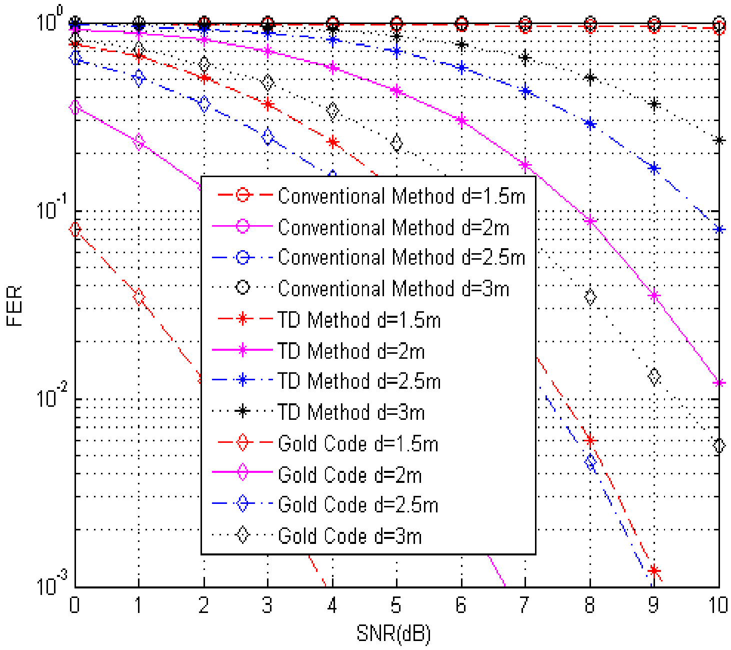

Figure IV.4 FER performance of the Gold code, TD and conventional RFID system for the second case

The simulated frame error rate (FER) curves for the first case of the Gold code, TD, and conventional RFID systems are shown in Figure IV.3. For this simulation, we assume that the length of the data frame is 64bits. From the figure, we observe that the Gold code system is more efficient for receiving the transmitted data from the RFID tag than the TD and conventional systems. Note that the conventional RFID system without considering anti-collision technique does not work for RFID data transmission, especially when there exists serious interference signals from adjacent tags. Figure IV.4 shows the FER performance in the second case with different distances. In this case, we also observe that the Gold code system has better performance than other systems and the RFID systems has performed better for the shortest distance between a tag and a reader for all cases.

Note that the considered Gold code, RFID system has better performance of the interference suppression than the TD system and the conventional RFID system without anti-collision function.

E. Conclusion

RFID with various applications is one of the core technologies for managing and identifying multiple objects. The data transmission from a tag to a reader suffers from the interference signals from adjacent tags, because we generally use many tags and single reader in an interrogation zone. In this thesis, we presented and evaluated an anti-collision method based on spread spectrum technique using Gold code to suppress the interference signals from neighboring tags in RFID computing environments. Since the implementation of the Gold code for the RFID technique plays an important role to solving the interference problem, it may improve simultaneous reading of multiple tags by a single reader. The considered RFID architecture has better performance compared to the TD and conventional RFID systems and it helps to improve the data reliability and the efficiency. The interference suppression performance of this RFID technique was analyzed through computer simulation examples with two cases.

V. Combined TD/CDMA RFID Anti-Collision System

A. Introduction

In an RFID system, interference from external source and internal interference, including tag to-tag, tag-reader and reader to- reader collision from different radio signals with the same frequency, leads to the distortion of the original signals [34]. Collision of signals results in a waste of bandwidth, and energy as well as an increase in identification delays. Various works based on probabilistic and deterministic approach have been performed to reduce the collision problem. Multiple access techniques such as space division multiple access (SDMA), frequency-domain multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA) are widely used in RFID anti-collision [13].

In contrast to other multiple access systems like FDMA, the current standard for TDMA offered three times the capacity of FDMA, and it was computed that CDMA offered six times the capacity[35]. Thus, in a combined TD/CDMA technology, TD helps to reduce tags interference, whereas the CDMA communication network can take the advantage in increasing effective communication between tags and reader.

This paper combines the TD technique which uses the specific time slots and fixed number of data bits and Gold code technique [36] for accommodating multiple RFID tags to reduce tag-to-tag interference, thereby increasing the tag-to-reader communication.

B. Received Signal Model

In TD/CDMA method the specific tag group is only transmitted in a precise time interval. Let us consider, L is the total number of tags contain in each tag group and M is the total number of data bits in each tag. The tag group obtained in a fixed time interval is spread using CDMA process. In order to spread data sequence of each Tag group, each tag data bits is directly multiplied by the element of the cyclostationary gold code with length N. Here, we allocate the unique gold code to each tag contained in a Tag group. The received signal vector $r(k)$ after spreading can be written as

$$r_i(k) = \sum_{i=1}^{M} b_{i,j}(k) g_j(k) + n(k) \quad where\ i = 1, \dots, L \tag{1.12}$$

where $g_j(k)$ is the cyclostationary gold code with length N for the i^{th} tag, $n(k)$ is the additive white Gaussian noise (AWGN) with independent and identically distributed components, each with zero mean and variance σ^2. In a receiver, the multiplexed signal from all tags of a particular Tag group and the noise are received and multiplied again by the same gold code. Since $g_i^T g_i = N$ and $g_i^T g_l \neq N$, the despreaded signal with i^{th} gold code is given by

$$r_i^T(n) g_i = [r_i(k), r_i(k+1), \dots, r_i(k+N-1)] \begin{bmatrix} g_i(k) \\ \vdots \\ g_i(k+N-1) \end{bmatrix}$$

$$= -b_1(n) - b_2(n) - \cdots + N b_i(n) + \cdots - b_L(n) + n(n) \tag{1.13}$$

Where

$$b_{i,j}(n) = \left[b_{i,j}(k), \dots, b_{,ji}(K+N-1)\right] g_i \tag{1.14}$$

and

$$n(n) = [n(k, \dots, n(K+N-1)]^T g_i$$

C. RFID Anti-Collision based on Combined Time Division (TD) and CDMA Method

Many researchers have proposed schemes to minimize tag anti-collision problem at the physical layer. However, transmitting tag data efficiently to the reader is still challenging. To avoid interference due to neighboring tags, we present TD/CDMA method for receiving information from multiple tags to a single reader. A combined TD/CDMA method helps in providing a simultaneous access of a communication channel and also helps in eliminating the effects of multiple access interference, which degrades and limits the BER performance within the system [2].

1. Data Architecture for RFID Anti-Collision based on TD/CDMA Method

In order to implement our system, we propose the efficient data architecture for RFID anti-collision based on TD/CDMA method. Here, we divide TD/CDMA method, it into two phases.

2. Allocation of Time Slots for Different Tag Groups

In the first phase, we allocate the specific time slots for different tag groups where they all contain a certain number of tags as shown in Figure V.1. Here, all tags within a Tag group contain a fixed number of data bits for the main data. The function of main data helps in providing tag information (ID, electronic product code (EPC) number and main information). During communication, the reader sends a wake up signal to tags located at different distance within its interrogation zone, thus a fixed tag group starts transmitting of the main data in a specific time interval. This means a particular time interval is reserved for the specific group of tag, which prevents collision between the tags of a different group.

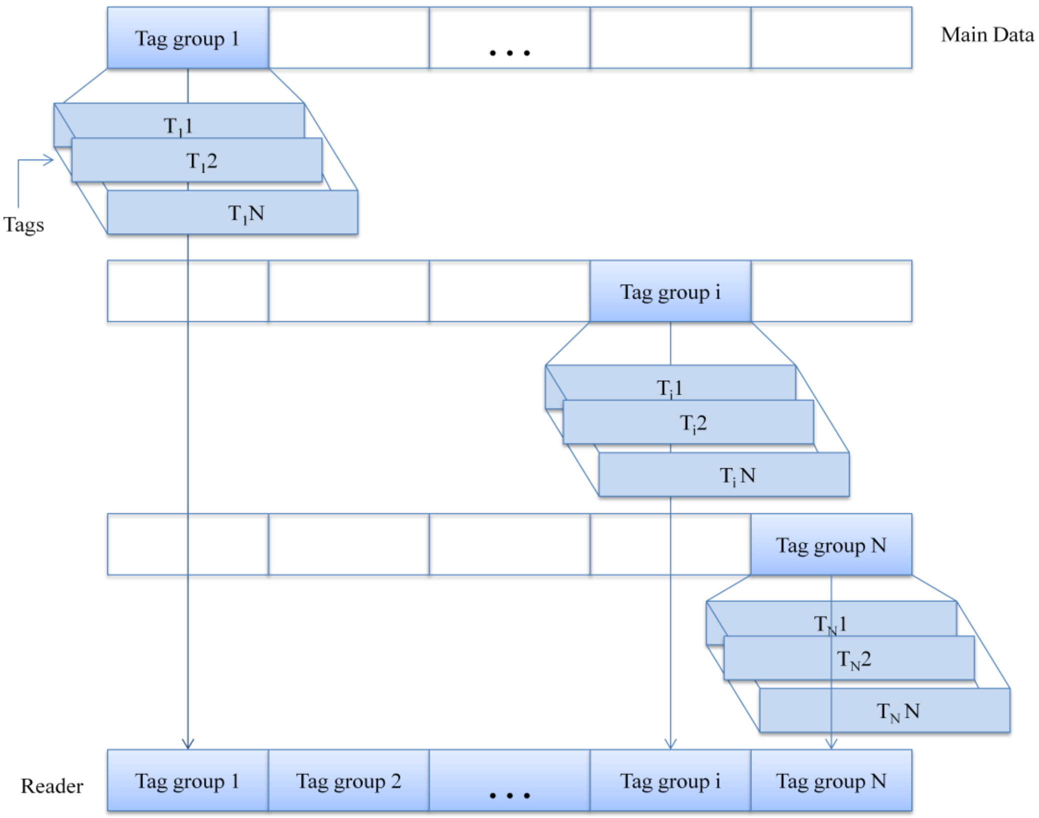

Figure V.1 Data Architecture of Proposed TD/CDMA method

3. Spreading and Despreading of Data Sequences of Each Tag Groups:

In the second phase, the spreading signal is generated by convolving a unique gold code sequence to each tag data bit of a fixed Tag group obtained at a specific time intervals. Figure V.2. Shows the allocation of gold cord to each data bits of a particular tag. The despreading is done at the receiver where the multiplexed signal from all tags within a specific Tag group, and the noise is received and multiplied again by the same gold code to detect the desired data and to suppress the interference signal from other tags as shown in Figure V.3.

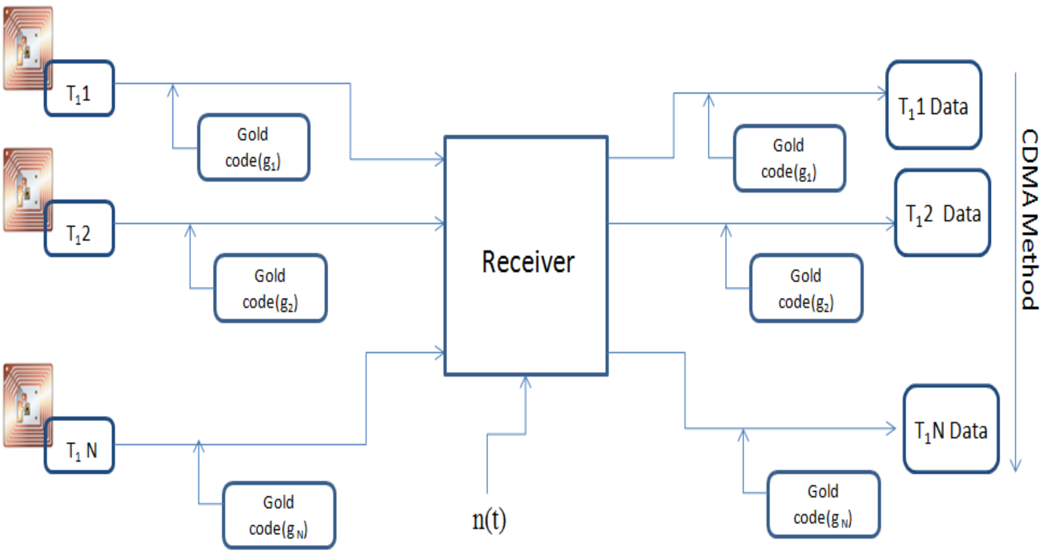

Figure V.2 Spreading and despreading of Gold code signal sequence

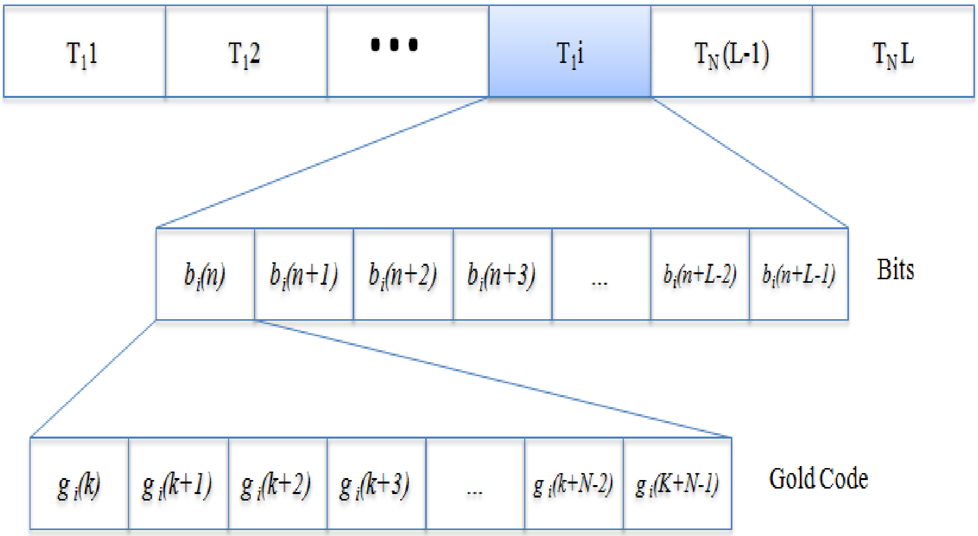

Figure V.3 Allocation of Gold code to each data bits of a particular tag.

D. Computer Simulation

The evaluation of combined TD/CDMA operation for RFID anti-collision was done using computer simulation to illustrate the performance of interference suppression. For the simulation, we assume a 900MHz frequency of RFID signal with seven passive tag signals and AWGN with zero mean and variance σ^2. Similarly, we assume that the transmitted power of the tag is fixed at the distance of 2m with minimum loss in bits, and the length of gold code is 15. Figure V.4. shows the BER performance of the system at different distances. We observe that using TD/CDMA we can lower the bit error rate for more tags.

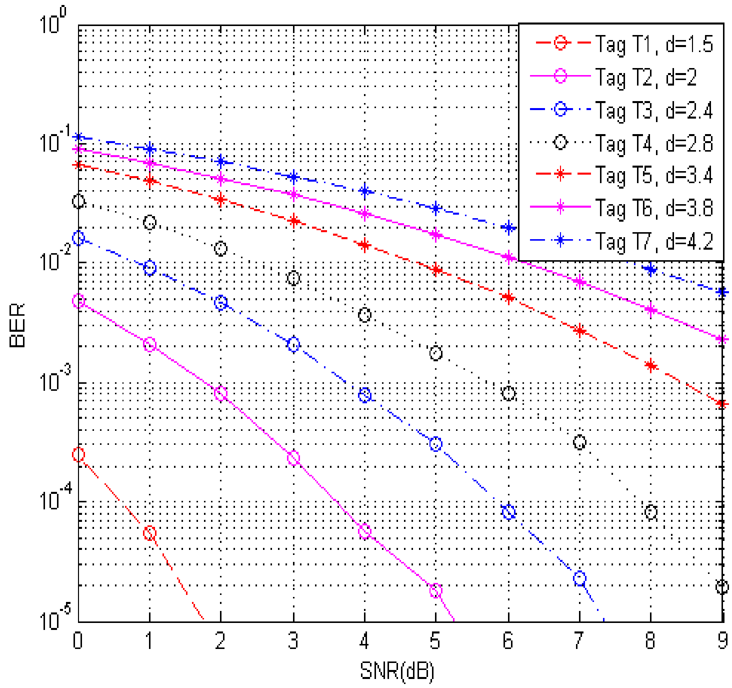

Figure V.4 BER performance of the proposed TD/CDMA system at different distances.

E. Conclusion

The data transmission from an RFID tag to the reader suffers the interference signals from adjacent tags. In order to solve this problem, we proposed an efficient and simple TD/CDMA interference rejection method. With this method, we can add more tags within the read range of the reader, which is considered to be the greatest achievement in RFID data architecture.

Therefore, the proposed RFID architecture improves the data reliability and efficiency throughout the system. The interference suppression performance of the proposed method at different distances was illustrated by a computer simulation.

VI. Threshold Detection of Passive RFID tag for Efficient Communication

A. Introduction

Radio-frequency identification (RFID) communication systems have the capability to eliminate the manual inspection of an object by automatic identification. It is significantly smarter than the bar code because it is conducted by a wireless sensor based identification method. In the RFID communication system, lack of information exchange between the RFID reader and tags causes signal interference, reducing the reliability and efficiency of the RFID system which results in misreading and unsuccessful reading of RFID tags. In this paper, we propose an effective signal decision algorithm based on the signal-to-interference and noise ratio (SINR) to secure the reliability of transferred data. Those tags which possess greater SINR value compared to a minimum threshold are activated and are allowed to transfer their main data, whereas tags with Smallest SINR value compared to the minimum threshold are not allowed to transfer their main data. We compared our SINR threshold value with data reliability rate at 95%, 97%, and 99%.

In passive RFID, tags reuse the power radiated by the reader, due to the limited coordination between the number of tags, which leads to the collision of signal. The transmission of the message signal from the tag to the reader is possible only if the reader is within the transmission range of its intended tag and outside the interference range of other tags. In order to address the interference more accurately, we proposed decision of data efficiency and reliability based on the measured signal-to-interference and noise ratio (SINR). A transmission is successful if the SINR is above the predefined threshold [37, 38]

B. Received Signal Model

The received signal vector $r(k)$ at sample index k can be modeled as

$$r(k) = x_1(k) + x_2(k) + x_3(k) + \cdots + x_T(k) + n(k) \quad (1)$$

which can be summarized as

$$r(k) = \sum_{l=1}^{T} x_l(k) + n(k) \quad (2)$$

where l represents the tag l^{th}, T is the total number of tags transmitting the signal to the reader, $x_1(k)$ is the received signal from each tag, and $n(k)$ is the additive white Gaussian noise (AWGN) with independent and identically distributed components, each with zero mean and variance σ^2 .

The SINR experienced in deciding effective signal by tag due to a transmission of reader R, is given by

$$SINR = 10log_{10}\left(\frac{P_l}{N_p + \sum_{l=1}^{T-1} I_l}\right) \quad (3)$$

where P_l is the signal power of each tag, N_p is the noise power, and I_l is the interference power created by other contending tag.

C. System Model for Effective Signal Decision

In this section, we propose an effective signal decision algorithm. The single reader R and a set of n multiple tags denoted by $T = (1, \ldots, N)$ are employed as a system network scenario for communication. For effective communication between reader and tag is determined usually by different factors [39]:

1. A Possible distance where tag receives sufficient power for activation by the reader (down-link communication).

2. A possible distance where the reader has received the backscattered signal by the target tags (up-link communication).

In our system, we suppose that n tags are arbitrarily located at varying distances from the reader.

Each tag possesses a different power level as every tag has an arbitrarily chosen destination from where it sends its backscattered information to the reader.

A successful transmission is possible, if the SINR is above the minimum SINR threshold. If the measured SINR is greater than the minimum SINR threshold, then the transmission is received successfully by the reader. On the contrary, if the measured SINR is smaller than the minimum SINR threshold, then the transmitting signal is not effective and is not received successfully by the reader.

D. Effective Signal Decision Algorithms

A flow chart for the RFID effective signal communication between reader and tags is shown in figure VI.1. The active reader R at any given time activates the tags within its interrogation region. Those tags denoted by t_{active} which can capture sufficient power for its activation get activated but, only the limited number of tags denoted by $t_{correct}$ which receive the interrogation commands accurately from the interrogator (reader) can respond to the reader.

Only the tags which have received power from the reader and is greater than its minimum required power $P_{min,tag}$ can respond.. In order to maintain the data reliability rate and effective signal communication between reader and tag, we calculate the threshold value denoted by T_h. The SINR received from the reader is compared with a T_h. If the measured $SINR \geq T_h$ value which means that the transmitted signal is effective in transmitting its main data. On the contrary, if the measured $SINR \leq T_h$ which means that the transmitted signal is not effective in transmitting its main data. Whenever a tag is not correctly detected, the system request to decrease the distance between the reader and tag. The cooperative re-transmission of reader signal is repeated until all the tags are successfully identified.

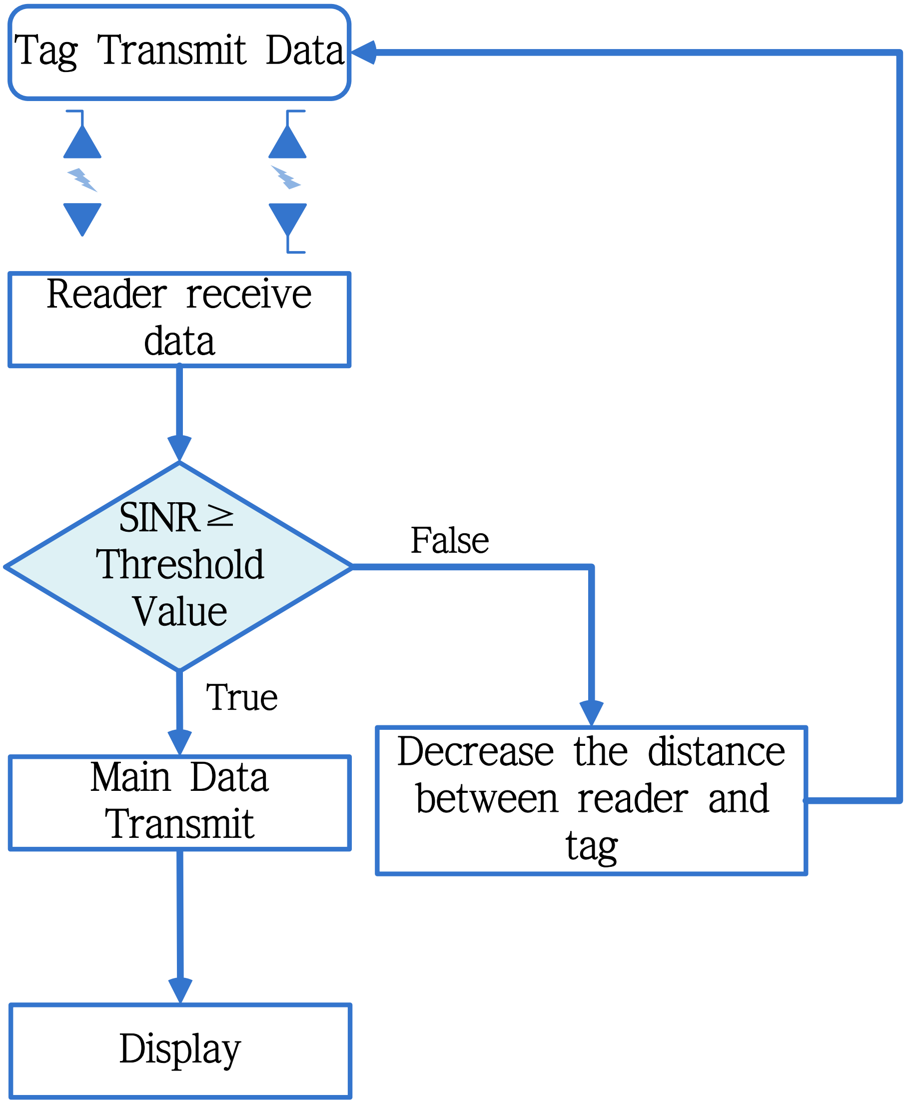

Figure VI.1 Flow chart for determining the effective signal in RFID communication

E. Computer Simulation

The performance of SINR threshold for an effective data decision method is shown using computer simulation. The data reliability rate with respect to SINR (dB) is shown in fig. 2. From the figure, one can see that the data reliability rate increases corresponding to rising SINR. In this thesis, we compare our SINR threshold value with the data reliability rate at 95%, 97%, and 99%. Fig. 2 shows that, The output SINR (dB) threshold value for data reliability rate 99%, 97%, and 95% are respectively 2, 3.372, and 5.211 dB respectively. The simulation results are summarized in Table 1.

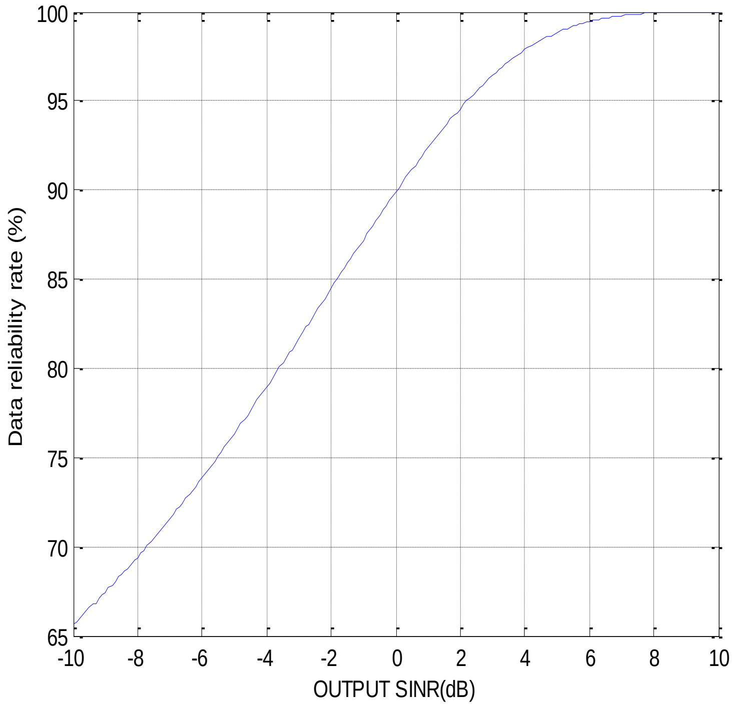

Figure VI.2 BER performance of the Gold code, TD and conventional RFID system for the second case

Table .1 SINR(dB) threshold values for three data reliability rates

Data Reliability Rate (%)	Threshold (T_h)
99%	5.211
97%	3.372
95%	2

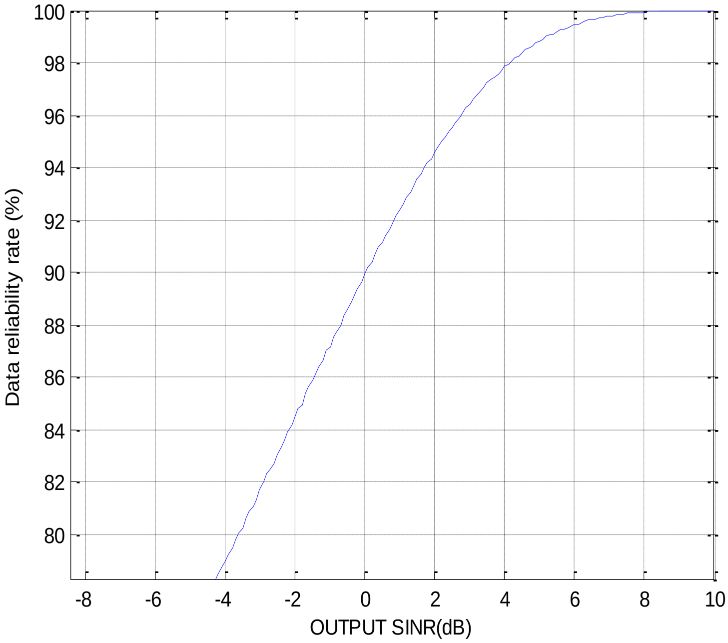

Figure VI.3 expanded data reliability rate for different SINR

F. Conclusion

Theoretical analysis and computer simulation results shows that the effective signal decision algorithm based on the signal-to-interference and noise ratio (SINR) improves the data reliability and efficiency of the RFID system. We are successful in determining the minimum threshold value at different (95%, 97%, and 99%) data reliability rates.

VII. CONCLUSION

This dissertation focused on interference suppression and anti-collision in RFID system for effective communication between tags and reader.

RFID tags suffers a lot from interference from their neighbors which ultimately results in collision problem. To overcome this collision problem, we proposed TD method in which a data frame is divided into several timeslots assigned to individual tags, and the reader can read all tags concurrently. TD method provides accurate detection, and at the same time significantly reduces communication overheads as compared to conventional systems.

Although, TD method has good performance and a low computational complexity compared with a conventional system, this method is not efficient for large number of tags. In order to make the system more efficient, we proposed implementation of gold code for interference suppression. Gold code supplies a number of codes with a good balance between auto and cross correlation with high flexibility in code length. It helps to improve the data reliability and the efficiency compared to TD and conventional systems.

Furthermore, in order to increase the system efficiency and to cover the dense RFID tags environment, we proposed a combined TD/CDMA technique. With this method, we can add more tags within the read range of the reader, which is considered to be the greatest achievement in RFID data architecture.

Finally, we proposed decision of data efficiency and reliability based on measured signal-to-interference and noise ratio (SINR) which helps in minimizing the interference from neighboring tags and also we are successful in determining the minimum threshold value at different (95%, 97%, and 99%) data reliability rates.

The performance of each proposed algorithm was illustrated by computer simulation examples.

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