Performance of Multiple-Antennas in ISO 18000-7 Standard with Using Limited Feedback Schemes

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Abstract—**Radio Frequency Identification (RFID) is a pervasive wireless technology to automatically identify, track, and locate objects or people. RFID technology falls into three categories with respect to tags' energy source: passive, semi-passive and active. Active RFID tags are preferred in many applications for their advantages: Visibility, security, quality and high distance communication. Active RFID systems present a couple of challenges that are vital and should be overcome before enjoying their benefits. One of the most important new challenges is energy-efficient data gathering. ISO/IEC 18000-7, operating at 433 MHz, is one of the active RFID standards. We realize that a tag consumes too much energy source to perform a satisfactory communication compliance with the standard in Rayleigh fading channel. Motivated by this need, in this paper, we aim to ameliorate a RFID system performance from the perspective of better communication and energy efficiency. Detailed and extensively simulations show that using multiple antennas with limited feedback schemes significantly diminish the frame error rates and increase the battery lifetime. Moreover, we have evaluated the performance of the limited feedback schemes when the wireless channels are correlated and multiple antennas are present at the reader.**

***Index terms: e*nergy efficiency, ISO 18000-7 standard, limited feedback schemes, multiple antennas, RFID**

I. INTRODUCTION

Radio Frequency Identification (RFID) has become very popular in wireless technologies. RFID technology uses radio signals to automatically identify, track, and locate objects or people. RFID has achieved widespread success in various technical and application areas, ranging from animal identification, asset tracking highway toll collection, smart home appliances, and supply chain management, to mobile payment systems. A typical RFID system basically consists of a tag (transponder), a reader (interrogator) and a back-end system (server). A tag contains an antenna and a microchip that stores data. A reader interrogates RFID tags with its modulated radio signals, acquires data in tag and transfers it to the server. An RFID server that keeps some information about RF tags and processes data in tag. Furthermore, RFID systems can also be grouped into three basic ranges by their using operating frequency: Low frequency (LF, 30-300 KHz), high frequency (HF 3-30MHz) and ultra high frequency (300MHz-3GHz) / microwave (>3 GHz) [7].

RFID tags can also be categorized in three groups by using energy source such as passive, semi-passive and active (battery assisted) tags. Passive RFID tags do not have own internal energy source. Instead, they use the radio energy transmitted by the reader. Semi-passive and active RFID tags have their own energy source. The difference between them is that semi-passive tags do not talk first and they are powered up by the reader's request. The energy source is used after the request. Active tags might talk to RFID reader first or answer its first request. An active tag can transmit its data at great range by using its internal source. In general, active tags have larger size and contain much more information than the passive ones. The advantages of active RFID over semi-passive RFID are lower reader costs, longer reading range and more robust performance in real environments, dense reader mode, lower radiated power and longer battery life [1].

Active RFID tags might be used to increase transmission distance in many applications for long range distance such as health-care systems, container identification and location estimation. However, the battery life is decreased by the active parts of the tag. Hence, it causes a trade-off between communication distance and power consumption. In addition to this, the increased transmission distance might also cause interference problem because a large number of tags or multiple-reader multiple-tag environment within the range of a reader grounds communication difficulties. The frames are also corrupted by fading because RFID systems at UHF and microwave frequency band are exposed to fading [3] and [13]. Coding schemes or multiple-antenna techniques can be solutions to overcome these troubles (see Figure 1).

Griffin et al. model forward channel and backscatter channel as a cascaded channel for passive RFID systems [10]. They also show that these channels can be modeled by Rayleigh

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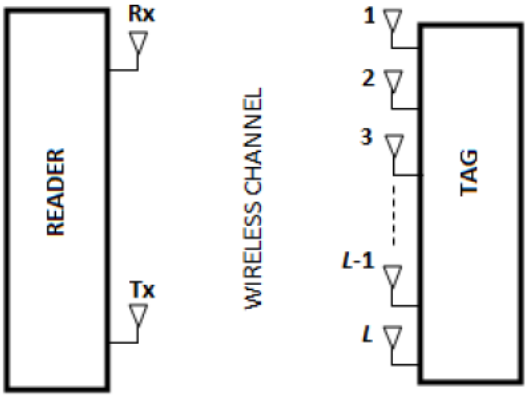

Fig. 1. A basic RFID system with multiple-antenna tag

the performance effects of using multiple antennas at both reader and tag sides [9]. Using multiple antennas at the tag side or both tag and reader sides would ameliorate the system bit error rate (BER) performance without space-time coding is shown in [10] and [9]. He and Wang derive a close-form BER expression of non-coherent frequency shift keying (FSK) for passive RFID systems with using multiple antennas at the tag side in double Rayleigh Channel [11]. They show that RFID systems with multiple tag antennas causes a vital BER performance improvement without using space-time coding. Their simulation and analytical results present that almost 6 dB improvement in BER performance is provided by using two tag antennas.

We reformulate that using limited feedback in active RFID technology with multiple antennas at not only tag side but also at reader side will improve the whole system performance, quality and battery lifetime. High energy efficiency and effective communication in Rayleigh fading wireless channels can be reach by using limited feedback with multiple antennas at both tag and reader side. Motivated by this need, we show the performance of active RFID tags with multiple antennas for ISO/IEC 18000-7 standard and make a detail comparison of different limited feedback schemes. Although some parts of this work were presented in [19], the correlation of the wireless channels and multiple antennas at the reader has been newly investigated in this work.

The remainder of this paper is organized as follows. In Section 2, we briefly describe the system models. In Section 3, we explain ISO/IEC 18000-7 standard. In Section 4, we talk about the limited feedback schemes. In Section 5, we show the simulation results and evaluate the system performance. Section 6, we conclude the paper.

II. SYSTEM MODELS

A. Multiple-Input Single-Output Model

The RFID system model is similar to the He and Wang's fading in a non-line-of-sight (NLOS) environment and analyze model where the reader has one transmitting and one receiving antenna and the tag is equipped with L transmit antennas [11]. We can assume that all channels are frequency flat Rayleigh fading channel where channel gains are circularly complex Gaussian random variables and statistically independent from each other. The parameter h_i is the channel coefficient from the ith antenna of the tag to the reader receiving antenna where $i=1, 2,\ldots, L$.

We also assume that the channels are quasi-static. That is to say, the fading coefficients remain constant over the duration of one frame. The reader is assumed to have perfect knowledge of its own channels with using a Protocol ID (see in Table 1) section of the tag response. The noise can be modeled as additive white Gaussian whose components are circular complex random variable with zero-mean and variance σ^2. The tag transmits data bits with using frequency shift keying (FSK) modulation.

B. Multiple-Input Multiple-Output Model

The multiple-input multiple-output (MIMO) system model is similar MIMO system model except the number of receive antennas at the reader and the receiver complexity. In MIMO system, the reader is equipped with R receive antennas and to diminish receiver complexity at reader, the reader applies receive antenna selection [16].

III. ISO 18000-7 STANDARD

There are four available international standards for building active RFID systems: ISO/IEC 18000-7, IEEE 802.15.3 (or UWB), IEEE 802.11 (or WLAN or Wi-Fi), IEEE 802.15.4 (or WPAN, related to Zigbee). The ISO 18000-7 standard [12] is based on the Savi active RFID protocol, which was the first commercial active RFID system employed by the US military in the early 1990s [1].

ISO/IEC 18000 consists of 7 parts. The series from part-2 to part-7 is related to air interface communication parameters for different frequency bands. ISO/IEC 18000-7 standard was prepared by committee of ISO/IEC JTC-1 to address the air interface for an active RF tags at operating 433 MHz band in item management application. Later on, it is revised and the third edition cancels and replaces the second edition in 2008 [12]. An RF tag in this standard has its own on-board source. Hence, the communication may be started by tag or reader. The carrier frequency (fc) is 433,92 MHz with ±50kHz deviation. The transmitted signal is modulated by using FSK method. Data between two parties is transmitted in packet format by using Manchester coding. The data from reader-to-tag is sent by choosing one of two formats depending on the type of the message (frame or packet). The reader-to-tag message format is described in Table 1 and Table 2. There are two possible message response formats from the tag-to-reader. In the first response shown in Table 3, tags response to the reader's broadcast command within its reading range. The second one, shown in Table 4, is the response message format to the reader's point-to-point command.

TABLE 1

INTERROGATOR-TO-TAG COMMAND FORMAT (BROADCAST)

Protocol ID	Frame Options	Frame Length	Session ID	Command Code	Command Arguments	CRC
1 Byte	1 Byte	1 Byte	2 Bytes	1 Byte	*N* Bytes	2 Bytes

TABLE 2

INTERROGATOR-TO-TAG COMMAND FORMAT (POINT-TO-POINT)

Protocol ID	Frame Options	Frame Length	Tag Man. ID	Tag Serial No.	Session ID	Command Code	Command Arguments	CRC
1 Byte	1 Byte	1 Byte	2 Bytes	1 Byte	2 Bytes	1 Byte	*N* Bytes	2 Bytes

TABLE 3

TAG-TO-READER BROADCAST RESPONSE MESSAGE FORMAT

Protocol ID	Tag Status	Frame Length	Session ID	Tag Man. ID	Tag Serial No.	Command Code	Data	CRC
1 Byte	2 Bytes	1 Byte	2 Bytes	2 Bytes	4 Bytes	1 Byte	*N* Bytes	2 Bytes

TABLE 4

TAG-TO-READER RESPONSE MESSAGE FORMAT (POINT-TO-POINT)

Protocol ID	Tag Status	Frame Length	Session ID	Tag Man. ID	Tag Serial No.	Command Code	Data	CRC
1 Byte	2 Bytes	1 Byte	2 Bytes	2 Bytes	4 Bytes	1 Byte	*N* Bytes	2 Bytes

For broadcasting, the length of the reader message is $8+N$. It is $13+N$ for point-to-point communication, where N denotes the length of the command arguments in bytes. Arguments are defined for some specific command. A command is not able to require a command argument. Hence, the minimum length of the frame in reader side is 8 bytes and the maximum length can possibly reach to 255 bytes. On the other hand, tag can use a tag can use a frame within a range from 20 bytes to 255 bytes as a response. Tags can prefer a different frame length but the length never exceeds the maximum frame length. In addition to this, the length of the frame determines the performance of an RFID system. When the length of a frame is increased, the frame error rate (FER) curves become worse. Hence, a healthy communication cannot be provided and the system consumes the battery for another transmission.

In the study of wireless communications, path loss (or path attenuation) is one type of the large-scale fading effects [17]. This term is a decreasing the intensity of an electromagnetic wave while it propagates through space. The amplitude of a transmitted signal in a wireless channel over a short period time might be rapidly fluctuated [18]. This is called 'small-scale fading effect' of the channel. The transmitter transmits the signal but the signal might reach to the receiver in more than one path because of the channel characteristics. Hence, the receiver obtains the superposition of the multiple copies of the signal. These reflections are called multipath waves. Each multipath wave is exposed attenuation, phase shift and delay.

The theoretical bit error rate (BER) of single transmitting antenna at the tag and single receiving antenna at the reader (1Tx:1Rx) RFID systems for coherent FSK in Rayleigh channels is shown in Equation 1. The Equation 2 formulates the FER with respect to the length of the frame, which is Mx8 is the length of the frame, where M represents the number of bytes sent in the frame. This formula says that the length of the frame is increased; the FER values become worse shown in Table 5.

$$Pe = \frac{1}{2} erfc\left(\sqrt{SNR}\right) \qquad (1)$$

$$Pe_{FER} = 1 - \left(1 - Pe\right)^{Mx8} \qquad (2)$$

In (1Tx:1Rx) RFID systems, the required Signal-Noise Ratio (SNR) for various FER values can be found in Table 5.

IV. LIMITED FEEDBACK SCHEMES

There are several well-known limited feedback schemes in MIMO systems. One of the schemes is transmit antenna selection (TAS) which is an effective way to obtain good system performance with low complexity [15]. Using TAS, a single antenna or a subset of the antenna array is optimally selected for the transmitter. In [8], space-time block coding with optimal antenna selection scheme which is called transmit antenna selection with Alamouti's scheme has been proposed. The transmit antenna selection with Alamouti's scheme selects highest channel gain pair out of L transmit antennas and transmits Alamouti's code. The mobile user needs $L(L-1)/2$ feedback bits ($L \geq 3$). In the transmit antenna selection, the best of the transmit antennas is selected based on the channel state information (CSI) at the base station in order to minimize the instantaneous error probability. The mobile user needs ceil($log_2 L$) feedback bits ($L \geq 2$) where the operator ceil {.} rounds to the smallest integer greater than or equal to its argument. In [5,6], the extended balanced space-time block codes (EBSTBCs) scheme has been proposed. In the EBSTBCs, an arbitrary numbers of codes can be generated for improved coding gain. In the EBSTBC scheme, all available transmit antennas are employed to achieve full diversity and to maximize the coding gain. Another limited feedback method is an improved transmit scheme (ITS) which has been proposed in [4]. In the ITS, one out of L transmit antennas does not transmit and one out of L transmit antennas which maximizes the received SNR at the receiver doubles the power of the antenna. The performance of the ITS approaches less than 1 dB to the ideal beamforming performance [4].

TABLE 5

FRAME ERROR RATE PERFORMANCE WHEN SINGLE ANTENNA PRESENTS AT THE TAG

FER	Frame Length (20 Bytes)	Frame Length (255 Bytes)
FER=10^{-1}	25.8 dB	36.86 dB
FER=10^{-2}	36 dB	47.07 dB
FER=10^{-3}	46 dB	57.07 dB

Beamforming (BF) needs ideal CSI at the base station and it requires unlimited feedback from the mobile user [2].

However, the bandwidth of the feedback channel is limited. In this case, the mobile user should quantize the CSI in the form of transmit beamforming vector and informs the base station through a low-rate, limited bandwidth feedback channel [14].

V. PERFORMANCE EVALUATIONS

The frame error rates of the EBSTBC, the ITS, the transmit antenna selection (TAS *L*:1), and the transmit antenna selection with Alamouti (TAS *L*:2) are evaluated for FSK modulation by computer simulations. The wireless channel is already explained in Section 2. The frame length is either 20 bytes or 255 bytes. The reader checks cyclic redundancy check (CRC) of the frame and discards the frame if the received CRC in the frame does not match the calculated CRC. For comparison, FER curves of the Alamouti's code (2Tx:1Rx), single antenna at the tag (1Tx:1Rx) and ideal beamforming (Ideal BF) are also included in Figures 2-5.

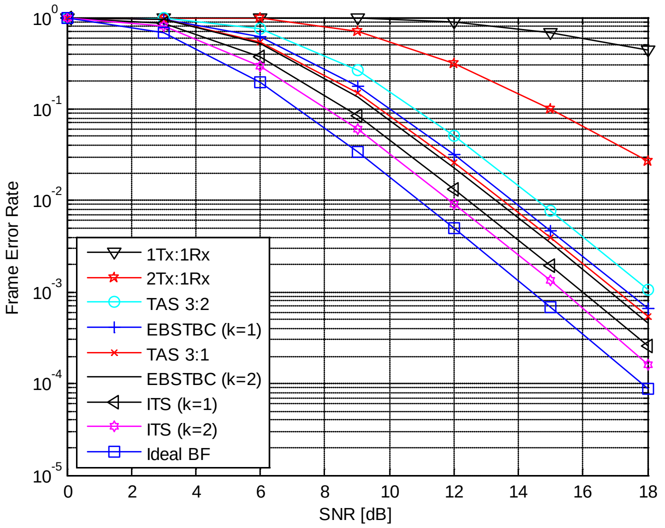

Fig. 2. FER for three antennas at the tag and frame length is 20 bytes

Figure 2 presents frame error rates of the ITS with one bit extension of feedback (ITS (*k*=1)), the ITS with two bit extension of feedback (ITS (*k* =2)), the EBSTBC with one bit extension of feedback (EBSTBC (*k* =1)), the EBSTBC with two bit extension of feedback (EBSTBC (*k* =2)), the transmit antenna selection (TAS 3:1), the transmit antenna selection with Alamouti (TAS 3:2) when tag transmitted frame length is equal to 20 bytes and the tag is equipped with three transmit antennas. When 18 dB SNR is available, FER performances of the single antenna at the RFID tag (1Tx:1Rx), the Alamouti's code (2Tx:1Rx) and the transmit antenna selection with Alamouti (TAS 3:2) yield 0.4352, 2.72×10^{-2} and 1.04×10^{-3}, respectively. For a FER value of 1×10^{-3}, the required SNR values can be found in Table 6. Compared to the single antenna at the tag (1Tx:1Rx), the ITS with two bit extension of feedback (ITS (*k*=2)) provides approximately 30.58 dB better performance. It decreases battery conservation while diminishing interference at the wireless environment.

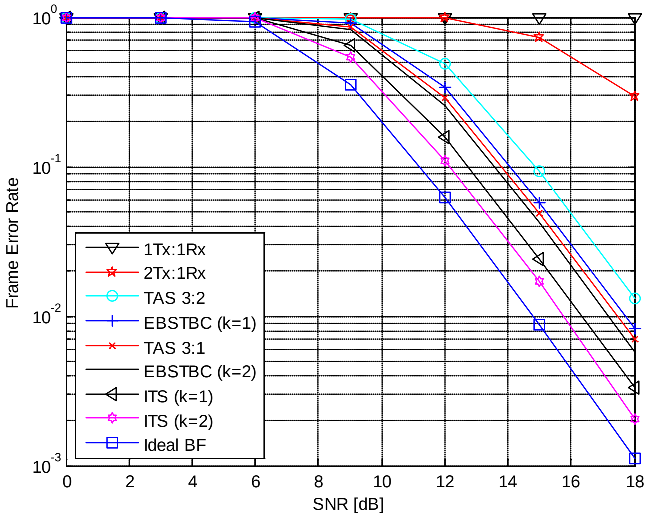

Fig. 3. FER for three antennas at the tag and frame length is 255 bytes

Figure 3 shows frame error rates of several limited feedback schemes when tag transmitted frame length is equal to 255 bytes and the tag is equipped with three transmit antennas. When 18 dB SNR is available FER performances of the single antenna at the RFID tag (1Tx:1Rx), the Alamouti's code (2Tx:1Rx) and the transmit antenna selection with Alamouti (TAS 3:2) yield 0.9994, 0.2968 and 1.32×10^{-2}, respectively. For a FER value of 1×10^{-2}, the required SNR values can be found in Table 6. Compared to the single antenna at the tag (1Tx:1Rx), the ITS with two bit extension of feedback (ITS (*k*=2)) provides approximately 31.31 dB better performance.

TABLE 6
FRAME ERROR RATE PERFORMANCE WHEN THREE ANTENNAS PRESENT AT THE TAG

Limited Feedback Schemes	Frame Length=20 Bytes, FER=10^{-3}	Frame Length=255 Bytes, FER=10^{-2}
EBSTBC (*k*=1)	17.35 dB	17.71 dB
TAS 3:1	17.08 dB	17.44 dB
EBSTBC (*k*=2)	16.82 dB	17.17 dB
ITS (*k*=1)	15.98 dB	16.33 dB
ITS (*k*=2)	15.42 dB	15.76 dB
Ideal BF	14.44 dB	14.80 dB

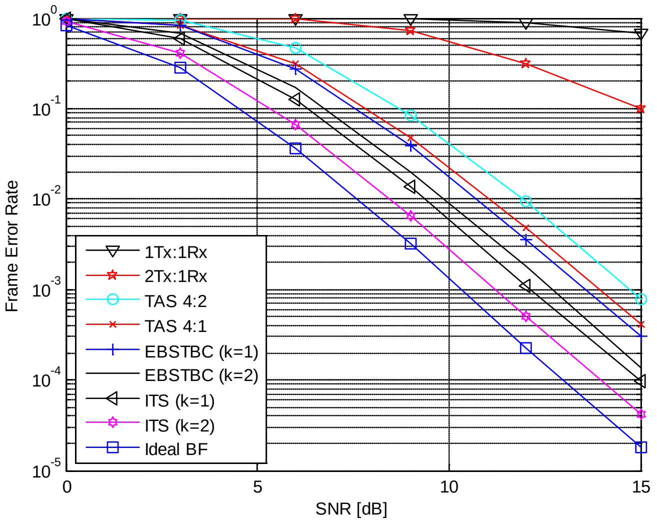

Fig. 4. FER for four antennas at the tag and frame length is 20 bytes

Figure 4 presents the frame error rates of the ITS with one bit extension of feedback (ITS (k =1)), the ITS with two bit extension of the feedback (ITS (k =2)), the EBSTBC with one bit extension of feedback (EBSTBC (k =1)), the EBSTBC with two bit extension of the feedback (EBSTBC (k =2)), the transmit antenna selection (TAS 4:1), the transmit antenna selection with Alamouti (TAS 4:2) when tag transmitted frame length is equal to 20 bytes and the tag is equipped with four transmit antennas. When 15 dB SNR is available, FER performances of the single antenna at the RFID tag (1Tx:1Rx) and the Alamouti's code (2Tx:1Rx) yield 0.6766 and $9.88\text{x}10^{-2}$, respectively. For a FER value of $1\text{x}10^{-3}$, the required SNR values can be found in Table 7. Compared to the single antenna at the tag (1Tx:1Rx), the ITS with two bit extension of feedback (ITS (k =2)) provides approximately 34.79 dB better performance.

Figure 5 depicts frame error rates of several limited feedback schemes when tag transmitted frame length is equal to 255 bytes and the tag is equipped with four transmit antennas. When 15 dB SNR is available, FER performances of the single antenna at the RFID tag (1Tx:1Rx) and the Alamouti's code (2Tx:1Rx) yield 1 and 0.7341, respectively. The tag and the reader do not communicate. For a FER value of $1\text{x}10^{-2}$, the required SNR values can be found in Table 7. Compared to the single antenna at the tag (1Tx:1Rx), the ITS with two bit extension of feedback (ITS (k=2)) provides approximately 35.59 dB better performance.

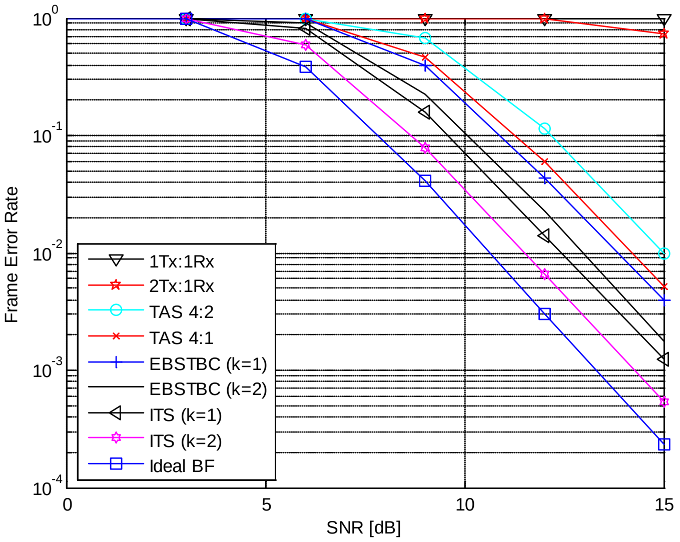

Fig. 5. FER for four antennas at the tag and frame length is 255 bytes

TABLE 7
FRAME ERROR RATE PERFORMANCE WHEN FOUR ANTENNAS PRESENT AT THE TAG

Limited Feedback Schemes	Frame Length=20 Bytes, FER=10^{-3}	Frame Length=255 Bytes, FER=10^{-2}
TAS 4:2	14.68 dB	14.97 dB
TAS 4:1	13.94 dB	14.22 dB
EBSTBC (k=1)	13.56 dB	13.85 dB
EBSTBC (k=2)	12.66 dB	12.92 dB
ITS (k=1)	12.13 dB	12.42 dB
ITS (k=2)	11.21 dB	11.48 dB
Ideal BF	10.33 dB	10.62 dB

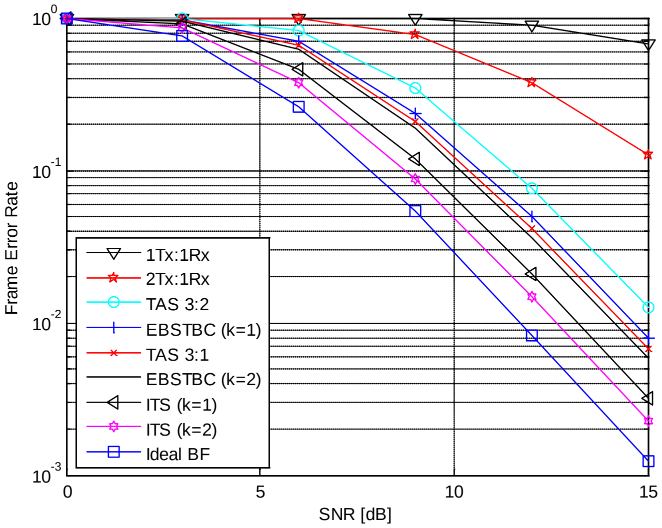

Fig. 6. FER for three antennas at the tag when the wireless channel correlation coefficient is equal to 0.5 and frame length is 20 bytes

Due to insufficient antenna space at the tag, the wireless channels could be correlated. In the Figure 6-8, we assumed that the wireless channels are correlated. Figure 6-8 show frame error rates several limited feedback schemes when wireless channel correlation coefficients are 0.5, 0.9, and 0.95, respectively and frame length is equal to 20 bytes, and the tag is equipped with three transmit antennas. It can be seen that the wireless channel correlation coefficient is increased, the performance of the limited feedback systems are sharply decreased.

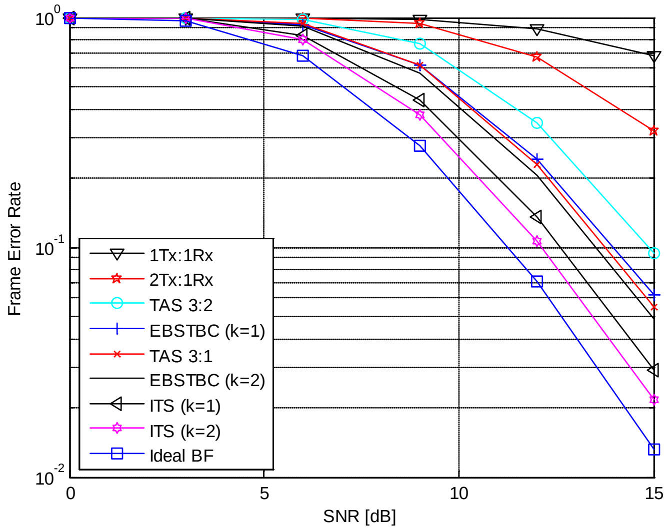

Fig. 7. FER for three antennas at the tag when the wireless channel correlation coefficient is equal to 0.9 and frame length is 20 bytes

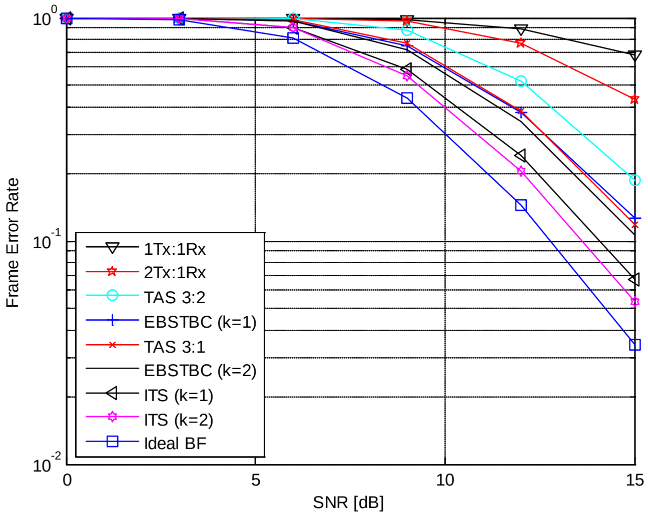

Fig. 8. FER for three antennas at the tag when the wireless channel correlation coefficient is equal to 0.95 and frame length is 20 bytes

Owing to insufficient antenna space and hardware limitations, the tag may not be equipped a higher number of transmit antennas. To improve the FER performance, the reader may be equipped more than one receive antenna. In the sequel, we assumed that the reader is equipped with two receive antennas. Figure 9-10 show frame error rates several limited feedback schemes when tag transmitted frame length is equal to 20 bytes and 255 bytes, respectively and the tag is equipped with three transmit antennas. For a FER value of 10^{-3}, the required SNR values can be found in Table 8. Compared to the single antenna at the tag and at the reader (1Tx:1Rx), the ITS with two bit extension of feedback (ITS (*k*=2)) provides approximately 36.83 dB and 45.8 dB better performance when frame length is equal to 20 bytes and 255 bytes, correspondingly.

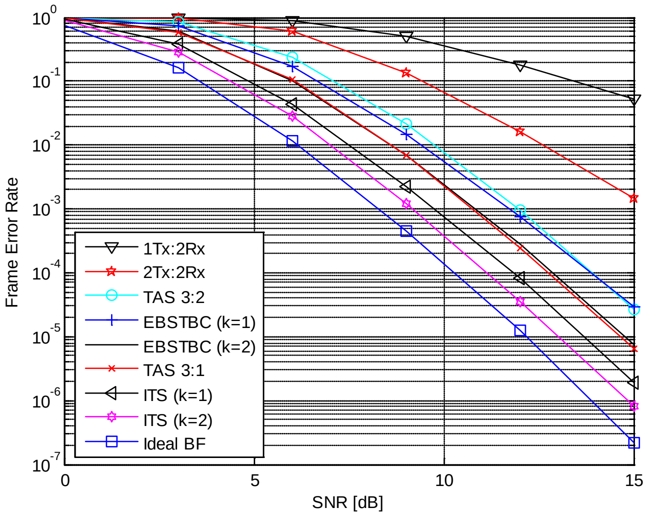

Fig. 9. FER for three antennas at the tag and two receive antennas at the reader and frame length is 20 bytes

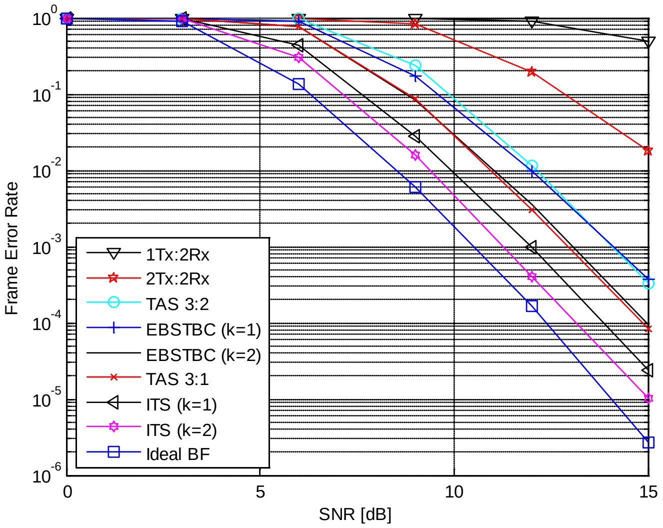

Fig. 10. FER for three antennas at the tag and two receive antennas at the reader and frame length is 255 bytes

VI. CONCLUSION

In this paper, we reformulate that the performance of an active RFID system compliance with ISO/IEC 18000-7

TABLE 8
FRAME ERROR RATE PERFORMANCE WHEN THREE ANTENNAS PRESENT AT THE TAG AND TWO RECEIVE ANTENNAS PRESENT AT THE READER

Limited Feedback Schemes	Frame Length=20 Bytes, FER=10^{-3}	Frame Length=255 Bytes, FER=10^{-3}
TAS 3:2	11.94 dB	14.06 dB
EBSTBC (*k*=1)	11.74 dB	14.09 dB
EBSTBC (*k*=2)	10.82 dB	13.04 dB
TAS 3:1	10.74 dB	12.93 dB
ITS (*k*=1)	9.73 dB	12.00 dB
ITS (*k*=2)	9.17 dB	11.27 dB

standard is improved by limited feedback methods. The tag is equipped with multiple-antennas and limited feedback is available from the reader to the tag. It can be seen from our detailed simulations that limited feedback schemes yields more than 30 dB better performance with respect to the single antenna case. In addition, we simulate performance of the MIMO-RFID system with using limited feedback schemes.

Compared to single transmit and receive antenna case, using multiple antennas at the tag and at the reader not only diminishes battery conservation at the tag side but also reduces interference at the wireless environment. Moreover, we assumed that channel gains are circularly complex Gaussian random variables and statistically independent from each other. Finally, due to the tag's size, the channel gains may be correlated with the each other. We evaluate the performance of the MIMO-RFID system with using limited feedback schemes in correlated channels. We show that the wireless channel correlation coefficient is increased, the performance of the limited feedback systems are sharply decreased.

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