Proceedings of the Federated Conference on
Computer Science and Information Systems pp. 813–820

ISBN 978-83-60810-51-4

Modeling and Simulation of MISO Diversity for UHF RFID Communication

Grzegorz Smietanka[1] and Jürgen Götze[2]
Information Processing Lab
Department of Electrical Engineering and Information Technology,
TU Dortmund University
Email[1]: grzegorz.smietanka@udo.edu, Email[2]:juergen.goetze@udo.edu

***Abstract*—Radio Frequency Identification (RFID) is used in high scattering environments where deep fading exists. This makes diversity particularly interesting for this communication scenario. In this paper the potential of using multiple tag antennas for RFID-communication is shown. The bit error rate (BER) and packet error rate (PER) is presented, which include the backscattering answer of a RFID-Tag according to the EPC Class-1 Gen-2 protocol. The rates are regarded in combination with the relevant fading channel models for RFID communication such as the Rician- and the Dyadic Backscatter Channel. It is shown that the possible diversity gain from the signal according to EPC Class-1 Gen-2 protocol is several dB regarding the error rates. It is also shown that this diversity gain increases with the correlation of the forward and backward link and decreases with the usage of a more robust encoding scheme and a correlation between the several transmission paths. Additionally the performance of Multiple Input Single Output (MISO) system with different spatial and forward/backward correlation situations is regarded to have a detailed view on a correlated RFID transmission system using diversity. The performance of this model is verified, using simulations of this propagation system.**

***Index Terms*—RFID, Communication, Diversity Methods, Numerical Simulation, Rician-, Dyadic Backscatter Channel**

I. Introduction

In RFID technology the communication is done by backscattering [1], where a continuous wave (CW) is sent out to a tag and reflected by its transmitter. The reflection can be driven by the receive power of the transmitter. This makes the technology very cheap as the tags can be produced in large quantities and with small dimensions because of the inexistent power source. Furthermore it can provide non line of sight communication over a couple of meters.

The primary field of research for passive RFID tags is aiming at the improvement of reading accuracy and operating range. To model the RFID propagation a environment with a fading channel is necessary. In this scenario a fading channel with a Rician distribution can be used. But for a backscatter link this model can only provide a rough modeling accuracy. Therefore a Dyadic Backscatter Channel was introduced in [2], where the characteristic of RFID communication with forward and backward link is considered. This implies deeper fades which decrease the performance of the system significantly. It is shown in [3] that for certain constellations the read rate is very poor even if the range between the reader and the tag is not very large. The EPCglobal communication system [4] does not support any forward error correction (FEC). This becomes a serious problem when the system operates in noisy fading channels. A common method to raise the performance in a fading channel without using FEC is the usage of multiple antennas. In [5] a diversity scheme is presented, where the usage of multiple antennas clearly increases the performance of the system. In this paper the performance of the EPCglobal transmission protocol in case of using two tag antennas is investigated. It is shown that due to the disadvantageous channel constellation in RFID communication the possible diversity gains for the signal according to EPCglobal protocol is several dB regarding the bit- or packet error rate. It will be also shown that the diversity gain is still significant when the spatial correlation during a MISO transmission is high.

In section II the basics for RFID communication including the en- and decoding of the backscatter signal are presented. The relevant channel models are introduced in section III. In section IV a transmit diversity scheme according to [5] is described. Simulation results using this combination scheme for MISO transmission and are shown for different channel constellations in section V.

II. RFID communication system

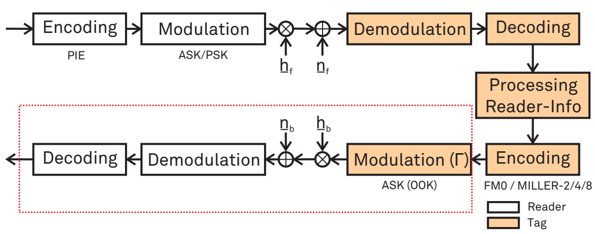

Fig. 1. RFID schematic transmission link

The communication system, which is considered in this work, is based upon the EPCglobal standard [4] for UHF RFID transmission. During a transmission the reader emits a continous wave. On this wave the information for a population of tags is pulse interval encoded (PIE) and modulated via amplitude- (ASK) or phase shift keying (PSK).

Any tag in the read range of the reader will send back his information by reflecting the incoming CW using a FM0 or Miller subcarrier encoding and an ASK modulation. For a more detailed description of UHF RFID communication we refer to the EPCglobal standard [4]. Subsequently only the backscattering answer of the tag to the reader is considered because of their higher sensitivity to noise. Nevertheless the forward and backward fading value are taken into account because of their dependence during the transmission. In figure 1 this implies the marked area. The en- and decoding of the tag information is examined in the following subsection.

A. En- / Decoding

The EPCglobal standard contains two specifications for the encoding of the backscatter data. For both encoding types one bit is spread into a chip sequence which is defined as a sequence of several one/zero combinations, where more chips implies a more robust but also more time costly code. The most simple transmission method is the FM0 encoding. It is distinguished by one edge on the boundery of two symbols and an edge change in the middle of a symbol which describes a zero bit. As a result one bit can be FM0-encoded with two chip values. Figure 2 shows the state diagram for this encoding scheme.

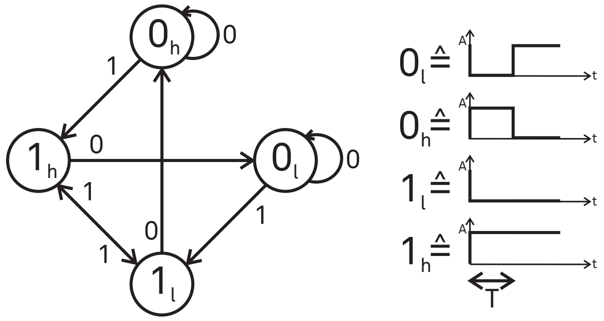

Fig. 2. FM0 encoding state diagramm

For the Miller-M subcarrier encoding one phase shift is done on the boundary of two zero symbols and there is also a phase shift in the middle of one symbol [4]. In this case a phase shift implies that the signal amplitude does not change form one period to another. This concept is shown in figure 3, where subcarriers are not considered. In practice M represent the number of cycles used for the encoding of one bit, where every symbol needs $t = 2M \cdot T$ with $M \in \{2, 4, 8\}$ to be transmitted. T is the time period of one chip. In this case $M = 8$ stands for the most robust but also for the most time consuming transmission mode. For the transmission of the encoded values the data is sampled with one value per chip duration T.

The decoding is done via correlation of the noisy bit stream with the possible symbols [6]. For this calculation the received ASK signal is shifted, so the high and the low amplitude level have the same absolut value and different signs. The possible symbols, which are used for the correlation correspond to that scheme. Additionally the threshold A_t is introduced, where

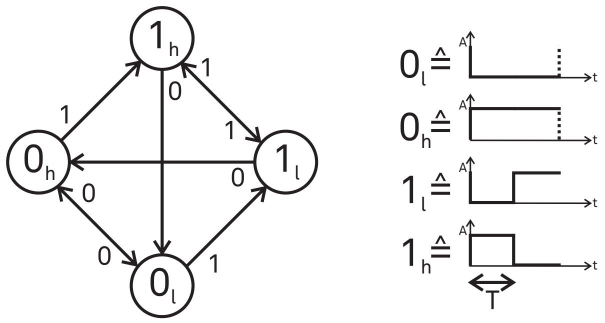

Fig. 3. Miller encoding state diagramm

every received chip value larger than the threshold is set to this threshold:

$$|A| = |A_t| \text{ for } |A| > A_t \tag{1}$$

This threshold is established for a couple of chips which reach very high amplitudes because of very deep fades. Deep fades are equivalent with high noise, which changes the amplitude of the transmitted sysmbol drastically. This have a slight negative impact on the performance of the system. Subsequently it is assumed that $A_t = A_h$. Note that without this threshold the coding gain for some of the used encoding schemes is several dB lower.

III. Channel models

The channel can be modeled by a weighting of the tranmitted symbol with a specific fading coefficient with normalized power. This value is sent over a common Additive-White-Gaussian-Noise (AWGN) channel. Both channel types use the following channel equation:

$$\underline{r} = \underline{h} \cdot s + a \cdot \underline{n} \tag{2}$$

The transmitted signal s is multiplied with a complex channel factor $\underline{h}$ and transmitted over a complex AWGN channel. The real and imaginary part of $\underline{n}$ are both random Gaussian numbers, where n_r and n_i are uncorrelated:

$$n_r \sim \mathcal{N}(0, \frac{\sigma^2}{2});\; n_i \sim \mathcal{N}(0, \frac{\sigma^2}{2}) \tag{3}$$

where σ^2 represents the variance / power of the complex Gaussian noise [7], a is a factor representing the Signal to Noise Ratio (SNR)

$$a = \sqrt{\frac{P}{10^{\frac{SNR_{dB}}{10}}}}, \tag{4}$$

P stands for the mean signal power and SNR_{dB} is the SNR in dB. The fading of the channel is considered in $\underline{h}$. This coefficent can be seen as a factor which in- or decreases the AWGN noise. Note that the successive approach can be easily transformed to a system with any number of transmit-, receive- or tag-antennas as shown in [2].

A. Rician Channel

The RFID communication is done in a rich scattering environment where a line of sight (LOS) path is often available. To consider the performance for such a constellation a Rician channel model is used. The channel factor $\underline{h}$ for this model has two components. The real valued line of sight (LOS) component and the complex none line of sight (NLOS) component which represents the scattering part of the signal. This part is represented by a complex Gaussian random number $\underline{h}_{ray}$ with the same characteristic as the random number of the Gaussian noise with zero mean and normalized power. The relationship between both components is

$$\underline{h} = \sqrt{P_{LOS}} + \sqrt{P_{NLOS}} \cdot \underline{h}_{ray} \tag{5}$$

where $P_{LOS} = \frac{K}{K+1}$ and $P_{NLOS} = \frac{1}{K+1}$ can be describe by the Rician factor $K = \frac{P_{LOS}}{P_{NLOS}}$, which characterizes the relationship between the power of the LOS and the power of the NLOS components. According to the sum of P_{LOS} and P_{NLOS} and the normalized power of $\underline{h}_{ray}$, the power of $\underline{h}$ is unity, so this factor does not influence the SNR characteristic of the channel.

The envelope of the random variable $\underline{h}$ follows the Rician distribution and can be defined as a function of K [8]:

$$\begin{aligned} f(|\underline{h}|) =& 2|\underline{h}| \cdot (1+K) \cdot \exp(-|\underline{h}|^2 \cdot (1+K) - K) \\ & \cdot I_0(2|\underline{h}| \cdot \sqrt{K(K+1)}) \end{aligned} \tag{6}$$

where I_0 is the modified Bessel function of the first kind and zeroth order. For $K = 0$ the Rician distribution results in a Rayleigh distribution and for $K \to \infty$ the distribution becomes a dirac at $|\underline{h}| = 1$ which is equivalent to an AWGN channel. The behavior of this distribution for varying K is shown in figure 4.

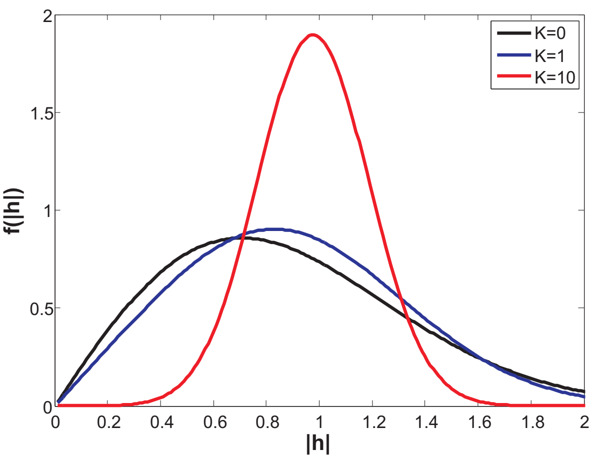

Fig. 4. Envelope for a Rician distributed number $|h|$ with different K

B. Dyadic Backscatter Channel

The Rician channel is an adequate model for LOS fading channels but it is restricted to one way channels. As the RFID communication from the tag is done via backscattering there is a forward and a backward link available. In this case a Rican channel can only be considered as a rough model for RFID communication. For a more precise description a Dyadic Backscatter Channel should be analysed. This model was first described in the context of RFID communication in [2].

The channel can be describe as a two way channel with a forward and a backward link. These fading coefficients are $\underline{h}_f$ and $\underline{h}_b$. For the overall fading per link both components can be multiplied to

$$\underline{h} = \underline{h}_f \cdot \underline{h}_b \tag{7}$$

The fading of the forward and the backward channel can be generated as described in the previous section. To consider the statistical dependence of the forward and the backward link the link correlation $0 \leq \rho \leq 1$ is introduced, where $\rho = 0$ represents a statistical independent forward- / backward fading and $\rho = 1$ a fully correlated forward- / backward link, which is equivalent with $\underline{h}_f = \underline{h}_b$. For a channel characteristic with a link correlation $0 < \rho < 1$ $\underline{h}_{f,ray}$ and $\underline{h}_{b,ray}$ can be obtained by two uncorrelated Rayleigh fading coefficients $\underline{h}_{U1}$ and $\underline{h}_{U2}$ with zero mean and equal variance $\sigma_{U1}^2 = \sigma_{U2}^2$ in the following way:

$$\underline{h}_{f,ray} = \underline{h}_{U1} \tag{8}$$

$$\underline{h}_{b,ray} = \rho \cdot \underline{h}_{U1} + \sqrt{1-\rho^2} \cdot \underline{h}_{U2} \tag{9}$$

The relation between ρ and the fading value is given as follows:

$$\begin{aligned} \rho =& \frac{2\,Cov(Re(\underline{h}_{f,ray}), Re(\underline{h}_{b,ray}))}{\sigma_f \cdot \sigma_b} \\ =& \frac{2\,Cov(Im(\underline{h}_{f,ray}), Im(\underline{h}_{b,ray}))}{\sigma_f \cdot \sigma_b} \end{aligned} \tag{10}$$

where $Cov(\cdot,\cdot)$ is the covariance operator and σ_f and σ_b are the standard deviations of the fading values. In the following $\sigma_f = \sigma_b = 1$ is valid. Also Rician fading coefficents are generated with this assumption. In this case the Rayleigh numbers are calculated first and then transformed into Rician numbers [9] with formular (5). Additionally to the forward/backward correlation a spatial correlation ρ_{spa} as generally described in [10] is considered during the transmission with two tag antennas. ρ_{spa} is defined in the same way as ρ. Considering a MISO transmission with one reader and two tag antennas over a dyadic backscatter channel, the fading coefficients for one transmission period are describe in the following way.

$$\underline{h}_{f1,ray} = \underline{h}_{U1} \tag{11}$$

$$\underline{h}_{b1,ray} = \rho \cdot \underline{h}_{U1} + \sqrt{1-\rho^2} \cdot \underline{h}_{U2} \tag{12}$$

$$\underline{h}_{f2,ray} = \rho_{spa}\underline{h}_{f1,ray} + \sqrt{1-\rho_{spa}^2} \cdot \underline{h}_{U3} \tag{13}$$

$$\begin{aligned} \underline{h}_{b2,ray} =& \rho \underline{h}_{f2,ray} + \sqrt{1-\rho^2} \cdot \\ & \left(\rho_{spa}\underline{h}_{b1,ray} + \sqrt{1-\rho_{spa}^2} \cdot \underline{h}_{U4}\right) \end{aligned} \tag{14}$$

where $\underline{h}_{U1}, \ldots, \underline{h}_{U4}$ represent uncorrelated fading coefficents. An alternatively calculation of $\underline{h}_{b2,ray}$, where $\underline{h}_{f2,ray}$

and ρ are switched with $\underline{h}_{b1,ray}$ and ρ_{spa} is also possible. For correlated links in a one way channel (like a MISO propagation in a Rician channel), $\underline{h}_{b1}$ and $\underline{h}_{b2}$ are not considered during the calculation.

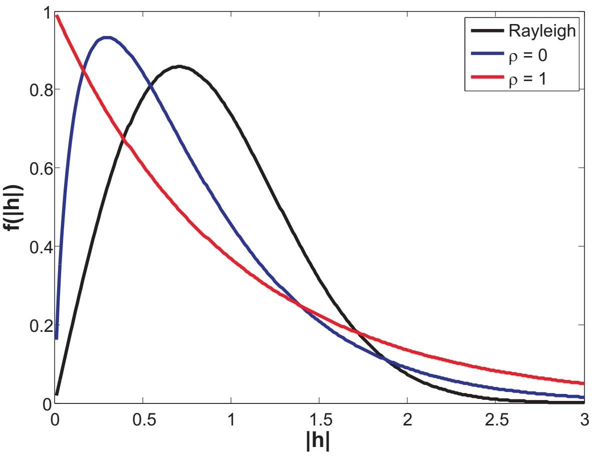

Fig. 5. Envelope of the Dyadic Backscatter distribution with Rayleigh random numbers compared to a normal Rayleigh distribution

To distinguish the differences between the Dyadic Backscattter and a one way channel the probability density functions (PDF's) of channels between one reader and a tag antenna for $\rho = 0$ and $\rho = 1$ respectively, are described. In this case both links in the backscatter channel have a Rayleigh distributed fading, which results in [2]:

$$f(|\underline{h}|) = |\underline{h}|^{\frac{1}{\rho+1}} \cdot \left(\frac{2}{(\rho+1)\sigma_f\sigma_b}\right)^{\frac{\rho+2}{\rho+1}} \cdot \frac{2^{\frac{\rho}{\rho+1}}}{\Gamma(\frac{1}{\rho+1})} \cdot K_{\frac{\rho}{\rho+1}}\left(\frac{2|\underline{h}|}{(\rho+1)\sigma_f\sigma_b}\right) \quad (15)$$

where $\Gamma(\cdot)$ is the Gamma function and $K_{\frac{\rho}{\rho+1}}(\cdot)$ is the modified bessel function of the second kind and $\rho/(\rho+1)$ order.

The PDF's are shown in figure 5 and (15). The random numbers of the backscatter signal tend to have smaller values ($|\underline{h}| < 1$) which is equivalent to more destructive fading during the transmission. Futhermore the deep fading is more distinctive for a high correlation of forward and backward channel.

IV. Transmit Diversity Technique

To achieve a transmit diversity the Alamouti-scheme is applied for two transmit antennas as described in [5] and shown in figure 6.

The encoding scheme for this transmission is shown in table I where two arbitrary symbols are send over two antennas in one timing period t. In the next period $t + T$ the symbols switch on the antennas and additionally both symbols are conjugated and the first symbol is inverted. With this approach a combination of both symbols can be accomplished in the receiver.

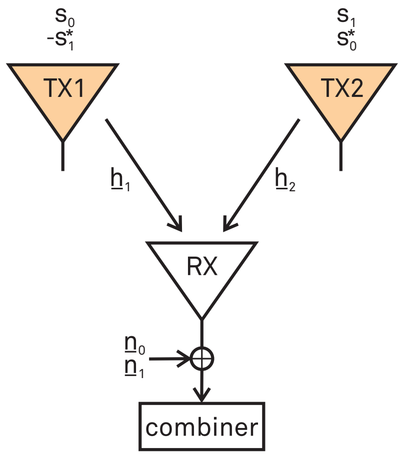

Fig. 6. Alamouti transmission scheme with two transmitters and one receiver

TABLE I
Encoding scheme for transmit diversity

	TX1	TX2
t	s_0	s_1
$t+T$	$-s_1^*$	s_0^*

For the combination scheme it is assumed that the fading is constant over two timing periods.

$$\begin{aligned}\underline{h}_1(t) &= \underline{h}_1(t+T)\\ \underline{h}_2(t) &= \underline{h}_2(t+T)\end{aligned} \quad (16)$$

This assumption and the encoding in table I leads to the following received signals

$$\begin{aligned}\underline{r}_0 &= \underline{r}(t) = \underline{h}_1 \cdot s_0 + \underline{h}_2 \cdot s_1 + \underline{n}_0\\ \underline{r}_1 &= \underline{r}(t+T) = -\underline{h}_1 \cdot s_1^* + \underline{h}_2 \cdot s_0^* + \underline{n}_1\end{aligned} \quad (17)$$

To combine both signals, $\underline{r}_0$ and $\underline{r}_1$ are weighted with the fading coefficients and then added.

$$\begin{aligned}\tilde{\underline{s}}_0 &= \underline{h}_1^* \cdot \underline{r}_0 + \underline{h}_2 \cdot \underline{r}_1^*\\ \tilde{\underline{s}}_1 &= \underline{h}_2^* \cdot \underline{r}_0 - \underline{h}_1 \cdot \underline{r}_1^*\end{aligned} \quad (18)$$

Because of (18) it is assumed that we have a perfect channel estimation at the receiver. Therefore the result of the calculation can be written as

$$\begin{aligned}\tilde{\underline{s}}_0 &= \gamma s_0 + \underline{h}_1^* \cdot \underline{n}_0 + \underline{h}_2 \cdot \underline{n}_1^*\\ \tilde{\underline{s}}_1 &= \gamma s_1 - \underline{h}_1 \cdot \underline{n}_1^* + \underline{h}_2^* \cdot \underline{n}_0\end{aligned} \quad (19)$$

where γ is a scaling factor which is proportional to the magnitude of the fading coefficients. After the combination it is obvious that the data pair can be extracted. During this work the diversity scheme is used before the signal is modulated, so the encoding of the symbols on both antennas is done on chip level. After the combination of the signals at the receiver the decoding of the bits is done as describe in section II. Note that for this combination scheme a perfect synchronization of the transmit antennas is assumed. This holds true for one tag with several antennas. But these tags are not used in commercial systems. The usage of multiple commercial tags to achieve transmit diversity is more complicated because of the limitations in hardware and the required synchronization between several separated tags.

V. RFID Propagation Modeling

The modeling of the RFID propagation is done according to the EPCglobal protocol. In this work only the backscatter transmission from a tag to the reader is considered, because of the higher sensitivity to noise compared to the forward link. For a backscatter transmission the data is encoded with a spreading sequence as described in section II. The spreaded data is then ASK modulated and afterwards transmitted over the channel. As an extension to this protocol the transmit diversity technique, described in section IV, is implemented before the data is modulated in case of a transmission with two tag antennas. Subsequently the channel correlation is calculated as describe in (11)-(14). To the best of our knowledge, different transmit diversity situations with the BER for a RFID transmission using the EPCglobal protocol were not investigated so far.

For a comparison of the diversity gain the BER is shown over the SNR for certain channels. The SNR is the ratio between the energy of one transmitted and modulated symbol E_s and the noise power spectral density N_0. Also the number of chips per symbol should be taken into account but as an ASK modulation for all following results is used, there is one chip mapped on one modulation symbol and the SNR does not change in this case. As we use a spreading sequence for the encoding looking at the BER and PER over the ratio of the bit energy E_b per N_0 would also make sense. But as this paper observes the transmit diversity and not the performance of the codes both SNR definitions can be used. If E_b/N_0 is utilized the curves in the upcoming figures move $3, 6, 9$ and $12\ dB$ to the right for the FM0, Miller-2, Miller-4 and Miller-8 codes respectively. It is to mention that a transmission gain of $3\ dB$ is considered in the communication with two antennas. Therefore, half of the power is utilized on each antenna during the MISO transmission. For a fair comparism of the used diversity a channel coefficient $\underline{h}$ should also be constant for two transmission symbols when no diversity is used. It will be shown in section VI that channel coefficients with different durations have a huge influence on the performance of the encoded bit sequences (but no influence on a sequence which is not encoded). The functionality of the channels was additionally verified with the results of [2], [11] and [12]. For the PER it is assumed that the maximal number of backscatter bits is transmitted according to EPCglobal. This implies the RN16 with 16 Bits and the EPC with 528 Bits with two preambles in front of these sequences with 18 or 22 bits for FM0 or Miller subcarrier encoding respectively. It is also assumed that a packet can be detected correctly if at least 95% of the preamble is accurately detected. An erroneous detection for one information bit is equal to a packet error.

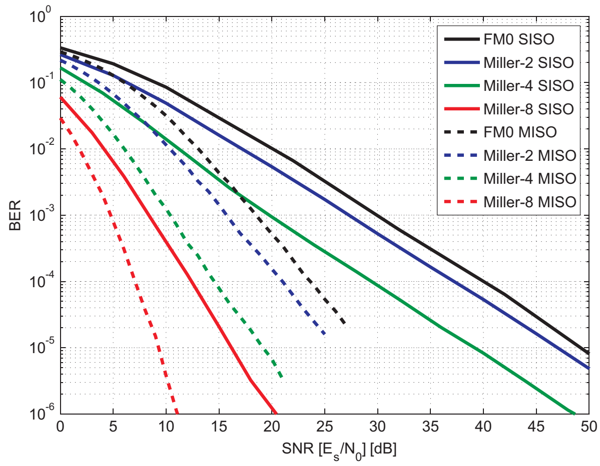

Fig. 7. Bit error rate for different backscatter encoding schemes and transmission with one (SISO) or two (MISO) tag antennas and one reader antenna in a Rayleigh fading channel.

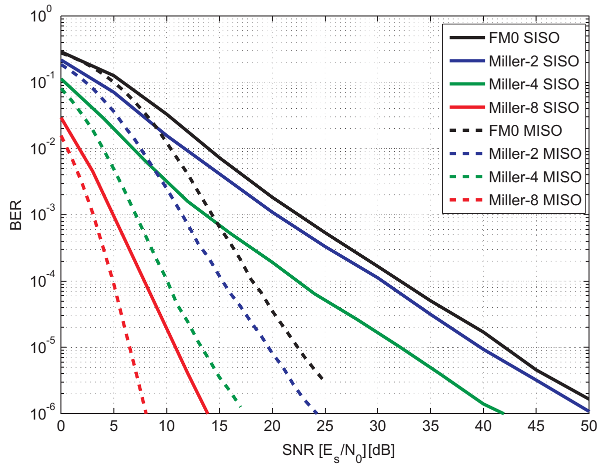

Fig. 8. Bit error rate for different backscatter encoding schemes and transmission with one (SISO) or two (MISO) tag antennas and one reader antenna in a Rician fading channel with Rican Faktor $K = 3$.

VI. Simulation Results

A. Diversity Behavior

Figure 7 shows the BER for a transmission over a one way Rayleigh channel which is used as a reference to the other BER plots. The diversity gain exists for every encoding scheme and increases as the spreading of the codes decreases. This leads to a diversity gain of $16.5\ dB$ for a BER$= 10^{-4}$ and even $7\ dB$ for a BER$=\ 10^{-2}$. This gain decrease with a more robust encoding sequence. So, for the most solid Miller-8 encoding a diversity gain of $5.3\ dB$ and $2.3\ dB$ for a BER=10^{-4} and 10^{-2} is achieved, respectively. The good performance considering the diversity of the weaker spreading sequences is because of the low coding performance during the SISO transmission. In this case the potential for diversity is much larger for more fragile spreading sequences. Note that in a usual UHF-RFID transmission FM0 and Miller-2 codes are the most common spreading sequences in virtue of a faster transmission [4]. For a one way channel with LOS path (Rice channel with $K = 3$ in fig. 8) the diversity gain decreases by 1 to 2.5 dB compared to fig. 7.

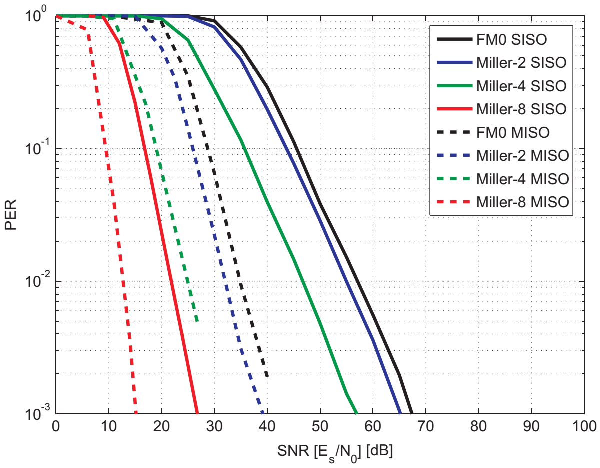

Fig. 9. Packet error rate for a EPC length of 528 bits, different backscatter encoding schemes and transmission with one (SISO) or two (MISO) tag antennas and one reader antenna in a Dyadic Backscatter Channel with an uncorrelated forward and backward link. Both links have a Rician distribution with $K = 0.5$.

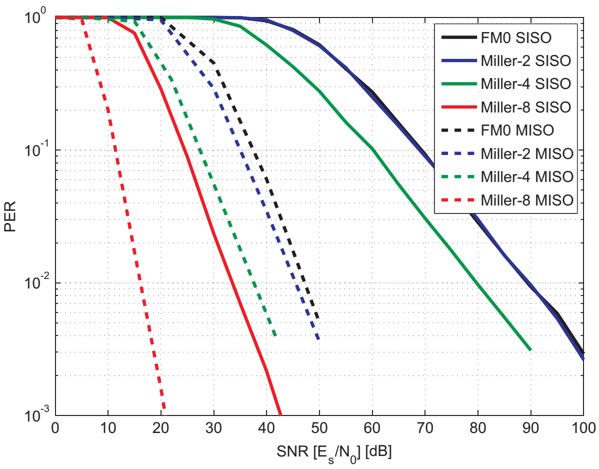

Fig. 10. Packet error rate for a EPC length of 528 bits, different backscatter encoding schemes and transmission with one (SISO) or two (MISO) tag antennas and one reader antenna in a Dyadic Backscatter Channel with a fully correlated forward and backward link. Both links have a Rician distribution with $K = 0.5$.

Looking at the results in a fully uncorrelated ($\rho = \rho_{spa} = 0$) Dyadic Backscatter Channel in figure 9 the diversity gain increases compared to an one way channel. This is also the case when the BER's are compared. The potential of diversity transmission for RFID communication becomes clear because of the loss caused by the deeper fades compared to a one way channel. The gain also increases for a fully correlated forward and backward link ($\rho = 1$) and a uncorreated spatial link ($\rho_{spa} = 0$) as shown in figure 10. It is very likely that the correlation in a real RFID transmission is high if the reader antenna serves as a transmitter and a receiver.

Note that the performance of the encoding schemes varies with the temporal characteristic of the channel coefficient. Regarding the BER for SISO transmission when the channel coefficient is not changed during two symbol periods compared to a change after one transmission symbol shows significant differences in the performance of the spreading sequences. Consider a Rician channel with $K = 3$ and a BER of 10^{-4} the performance with one channel coefficent $\underline{h}$ per symbol is up to 10 dB better compared to a transmission with one channel coefficient for two symbols when a Miller-4 encoding is assumed. Using the Miller-8 and Miller-2 codes a gain of 1.9 dB and 1.3 dB is achieved, respectively. The FM0 has even advantages (1 dB) when using one channel coefficient for two symbols. This behavior is similar for different channel parameters and increase as the general performance of the encoding scheme decrease. In a fully correlated dyadic backscatter channel the gain for a Miller-4 code and different transmission characteristic is nearly 30 dB. There is one main reason for this behavior. A channel coefficient which is valid for two transmission symbols makes a robust spreading sequence more fragile because of the higher influence of deeper fades (small channel values). The Miller-8 code is robust enough to reasonably compensate these disadvantages. The Miller-2 and FM0 codes are very fragile towards errors, so a change in the characteristic of the channel coefficient does not make a huge difference regarding the performance of the codes.

B. Spatial correlation

In the results of Figure 7-10 the two transmit channels for MISO communication are completely uncorrelated. This is usually not the case during the RFID communication because of the close spacing of the tag antennas [10]. The diversity gain decreases with a higher correlation of both transmit paths. For maximal correlated channels ($\rho_{spa} = 1$) no diversity gain could be achieved compared to a SISO transmission because both channels produce the same information. Fig.11 shows the effect for a correlated channel with correlated forward and backward links. Note, that the diversity gain decreases by several dB compared to an uncorrelated link. But a diversity gain can still be achieved as long as the channels are not fully correlated.

For existing spatial correlation the BER behavior during MISO transmission is shown in figures 12 and 13 are regarded. The general behavior is shown in figure 12 where BER for different correlation situation in a dyadic backscatter channel ($K = 0.5$) are shown for a FM0 encoded signal. Looking at a not fully correlated channel ($\rho, \rho_{spa} < 1$) a gain between $4 - 5$ dB can be achieved, comparing the BER of the (partially) uncorrelated channels and a (partially) correlation

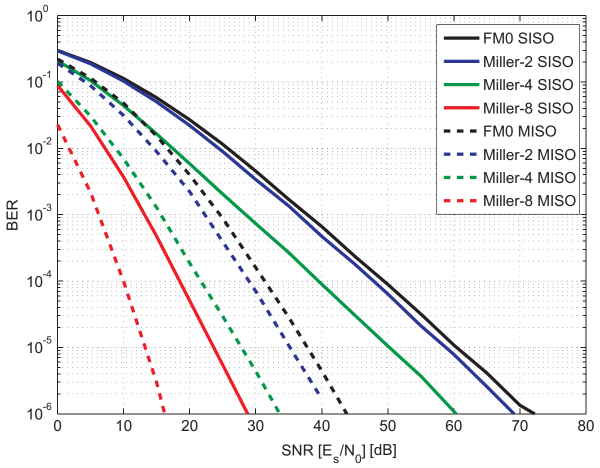

Fig. 11. Bit error rate for different backscatter encoding schemes and transmission with one (SISO) or two (MISO) tag antennas and one reader antenna in a Dyadic Backscatter Channel with a correlation of $\rho = 0.5$ for the forward and backward link. During the MISO transmission the two links are correlated with a factor of $\rho_{spa} = 0.5$. Both links have a Rician distribution with $K = 0.5$.

of $\rho, \rho_{spa} = 0.8$. It is remarkable that the gain between a high correlated and the fully correlated channel is clearly higher then between an uncorrelated and high correlated channel. Also it is noted that a variation of the spatial correlation achieves a lower gain than a variation of the forward/backward correlation. This leads to two results when regarding the correlation behavior. First, the influence of ρ is larger than the gain loss when the spatial correlation rho_{spa} increases. Second, the performance of the channel decrease with increasing spatial and forward/backward correlation, but the main leak of performance happens when one of the correlation values is very high $\rho, \rho_{spa} > 0.9$. So even when the spatial correlation is high a diversity gain could be achieved.

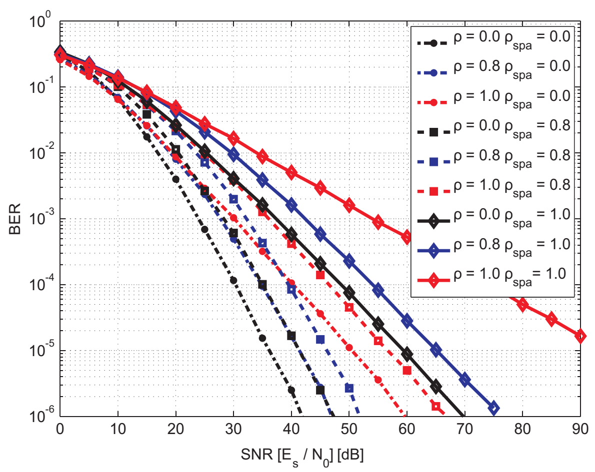

Fig. 12. Bit error rate for FM0 encoded signal in a Dyadic Backscatter channel with LOS component ($K = 0.5$), a transmission with two (MISO) tag antennas and different forward/backward and spatial correlations. A spatial correlation of $\rho_{spa} = 1$ is equivalent to a transmission with one (SISO) tag antenna.

In figure 13 the behavior of this correlation characteristic is analysed regarding the FM0 and the more robust Miller-8 code. In this figure the SNR for BER$= 10^{-4}$ is shown for different channel constellations over a dyadic backscatter channel ($K = 0.5$). The performance decreases as the correlation coefficients increase. For coefficients smaller 0.6 the changes of the SNR are relatively small and have a nearly linear behavior. The differences become larger when one of the correlation coefficients is getting high, but the largest performance loss occurs when one of the correlation parameters is equal to one. The performance of the Miller-8 encoded sequence has a similar behavior regarding the performance of the code. The differences in the gain are smaller and the step between a high and a fully correlated channel is not that large. The main reason is the more robust code compared to the FM0 encoded sequence.

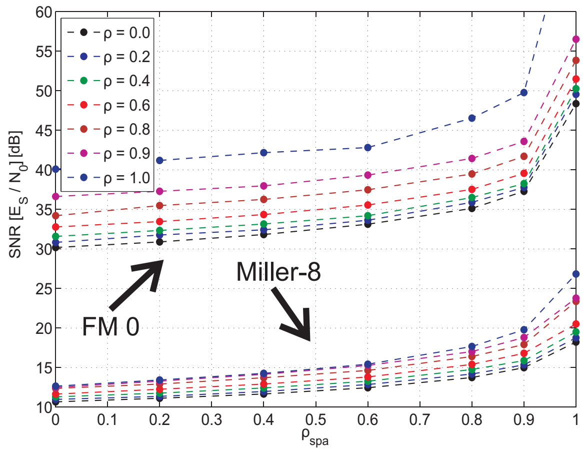

Fig. 13. SNR values at a BER$= 10^{-4}$ for a MISO transmission ploted over the spatial correlation ρ_{spa} for different encoding schemes. The transmission is done over a Dyadic Backscater channel with LOS component ($K = 0.5$).

VII. Conclusion

The potential of MISO UHF RFID backscattering transmission using the EPCglobal standard was investigated. It was shown that the diversity gain between a SISO and a MISO communication is at least $1\ dB$ for the most robust encoding scheme in an one way channel. The gain increases for a higher scattering of the channel. For a typical RFID communication with a two way channel the gain increases because of deeper fades in this channel scenario. The highest gain is achieved with a fully correlated forward and backward link where the diversity gain is over $40\ dB$ for a FM0 encoded set of data at a PER$= 10^{-2}$. As the typical RFID small scale fading link has the characteristic of a Dyadic Backscatter Channel and the correlation between the forward and backward link can be relatively high especially when the transmitter and receiver antenna of the reader is the same. For this case the high potential of tags with multiple antennas in RFID systems was demonstrated. But it is also to mention that the diversity gain decreases if the correlation of the multiple transmission paths increases. Nevertheless significant gains during a MISO transmission can be achieved when two transmission channels are not fully correlated, even when their correlation is relativly high.

ACKNOWLEDGMENT

The reported R+D work was carried out in the frame of the BMBF-Project smaRTI (Smart ReUsable Transport Items); the smaRTI project is carried out in the frame of the Efficiency Cluster Logistic Ruhr (part of the Leading-Edge Cluster - High-Tech Strategy for Germany). This particular research was supported by the BMBF (Bundesministerium fuer Bildung und Forschung) of Federal Republic of Germany under grant 01IC10L10H (Sichere, flexible Detektion und Lokalisierung von UHF RFID-Labeln in rauer Umgebung). The responsibility for this publication is held by the authors only. In particular we have to thank our industrial partners Infineon Technologies AG and Deutsche Post AG supporting us by the required information regarding the RFID test environment and tag data.The authors would also like to thank the R+D Coordinator of smaRTI Application Scenario POST Dr. W. John (SIL GmbH (iG)) for his ongoing support regarding the RFID challenges of the postal logistic chain and the related industrial R+D requirements.

INVENTED IN GERMANY

SPONSORED BY THE
Federal Ministry
of Education
and Research

REFERENCES

[1] H. Stockman, "Communication by means of reflected power", in *Proceedings of the IRE*, vol. 36, no. 10, pp. 1196-1204, Okt. 1948

[2] J.D. Griffin and G.D Durgin, "Link Envelop Correlation in the Backscatter Channel" in *IEEE Communications Letters*, vol. 11, pp. 735-737, Sep. 2007

[3] M. Buettner, D. Wetherall, "A Flexible Software Radio Transceiver for UHF RFID Experimentation", *UW CSE Technical Report*, 2009

[4] *EPC Radio-Frequency Identity Protocols, Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz- 960 MHz*, version 1.0.9, EPC Global Jan. 2005.

[5] S.M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications" in *IEEE Journal on Slected Areas in Communications*, vol. 16, nr. 8, pp. 1456-1467, July 1999

[6] The Comprehensive GNU Radio Archive Network [Online]. Available at https://www.cgran.org/wiki/Gen2. (accessed Nov. 2011)

[7] W. Zhang and M.J. Miller, "Baseband Equivalents in Digital Communication System Simulation" in *IEEE Transactions on Educations*, vol. 35, issue: 4, pp. 376-382, Nov. 1992

[8] H. Nuszkowski, *Digitale Signalübertragung im Mobilfunk*, 1st ed, Vogt Verlag, pp. 29-31, 2010.

[9] H. Taricco and G. Coluccia, "Optimum Receiver Design for Correlated Rician Fading MIMO Channels with Pilot-Aided Detection" in *IEEE Journal on Selected Areas in Communications*, vol. 25, issue 7, pp. 1311-1321, Sep. 2007

[10] K. Vanganuru and A. Annamalai, "Analysis of transmit diversity schemes: impact of fade distribution, spatial correlation and channel estimation errors " in *Wireless Communications and Networking*, vol. 1, pp. 247-251, May 2003

[11] Chen He and Z. Jane Wang, "Gains by a space-time-code based signaling scheme for multiple-antenna RFID tags " in *23rd Canadian Conference on Electrical and Computer Engineering (CCECE)*, pp. 1-4, Sep. 2010

[12] J.D. Griffin and G.D Durgin, "Gains For RF Tags Using Multiple Antennas" in *IEEE Transactions on Antennas and Propagation*, vol. 56, nr. 2, pp. 563-570, Feb. 2008