Application of channel models to indoor off-body wireless MIMO communication with textile antennas

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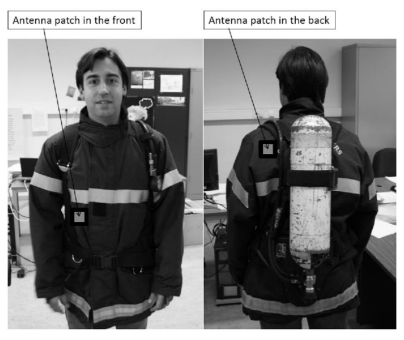
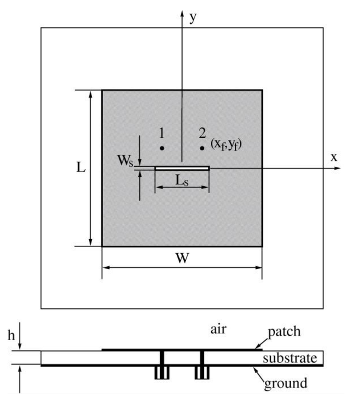
I. Introduction



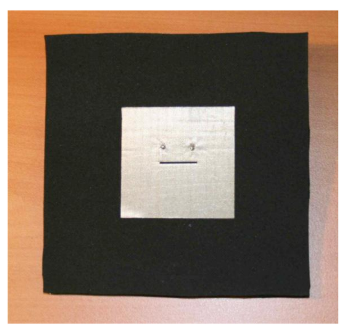
Fireman equipped with textile antennas

•Two dual-polarized textile antennas are integrated in the fireman's garment, allowing the simultaneous transmission of four signals.
•The base station uses two such antennas resulting in four receiving channels.

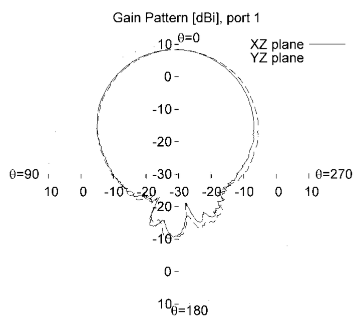
Antenna design



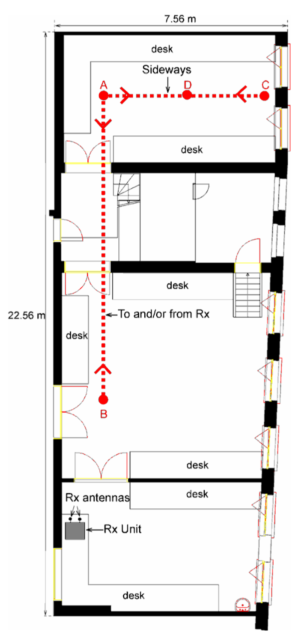
Prototype



Radiation pattern



Floor plan



Measurement of a 4x4 MIMO wireless off-body link.

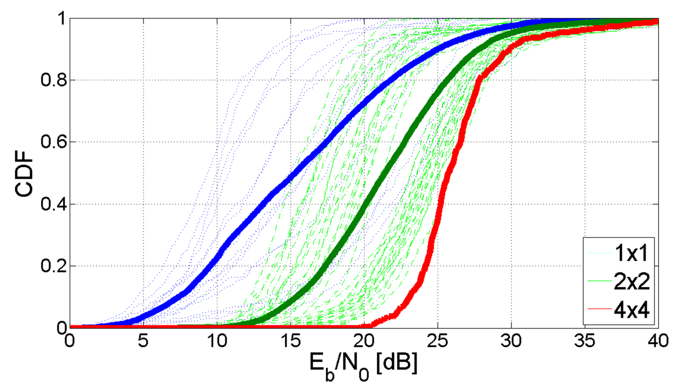
•Fireman walks in indoor environment with small-scale fading caused by multipath propagation.
•Measurements discussed here were performed along non line-of-sight path marked "sideways" in floor plan.
•Receiver situated in left bottom corner of floor plan.
•Orthogonal space-time code used for transmission with fourth order diversity.
•Total transmitted power is 1mW for bit rate of 1.5 Mbits/s.

Space–time code

	TX Antenna nr.			
time slot	0	1	2	3
t	$s1$	$s2$	$s3$	0
t+T	$-s2^*$	$s1^*$	0	$s3$
t+2T	$s3^*$	0	$-s1^*$	$s2$
t+3T	0	$s3^*$	$-s2^*$	$-s1$

II. Measurement results

CDF of signal levels



Statistical distribution of signal levels

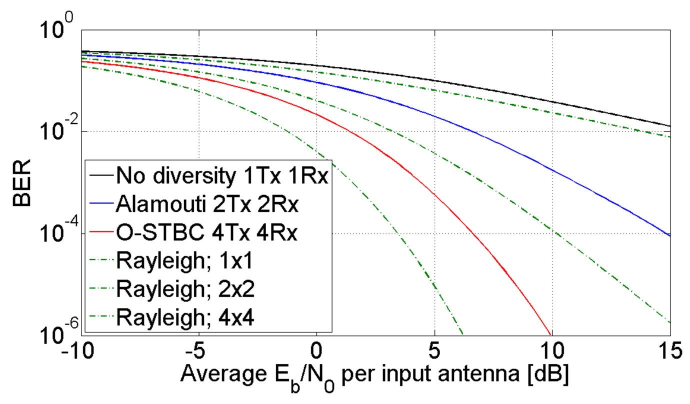
•Received signal strength varies dramatically for all 16 channels present in 4x4 MIMO link.
•Cumulative Distribution Functions are compared for 1x1, 2x2 and 4x4 links.
•Substantial gain is obtained by increasing the diversity order.

The gain can be expressed numerically by comparing the 10% probability levels.
•The 2x2 system performs 8 dB better than the average 1x1 case.
•The 4x4 system performs15.7 dB better than the average 1x1 case.

Bit error characteristics for diversity and array gain

•Based on the distribution of the signal levels, the bit error characteristics are calculated for diversity links of varying order.
•Bit error rates as a function of the average E_b/N_0 per antenna display diversity gain and array gain.
•Characteristics for measured link are compared to the theoretical curves for Rayleigh fading with diversity.

Diversity gain and array gain



Error probability as a function of SNR at detector after combining

$$P_{b1} = \frac{1}{2N}\sum_{i=1}^{N} erfc\left(\sqrt{SNR_D\left(i\right)}\right)$$

Energy per bit at detector for MxM case

$$E_b = \frac{1}{2 \cdot M^2 \cdot N}\sum_{i=1}^{N}\sum_{t=1}^{M}\sum_{r=1}^{M}|h_{t,r}(i)|^2$$

III. Channel models

The performance of a practical MIMO link is limited by signal correlation and unequal average channel gain. For this reason the bit error rate characteristics are not as good as predicted by the theory for equal gain uncorrelated Rayleigh fading channels. Two channel models are applied to capture the channel properties, including correlation and unequal gain.

The Kronecker model

The Kronecker model assumes the full correlation matrix between the channels can be expressed as the Kronecker product of a transmit and a receive correlation matrix.

$$\mathbf{R}_H = \frac{1}{tr\left\{\mathbf{R}_{RX}\right\}}\mathbf{R}_{TX} \otimes \mathbf{R}_{RX}$$

With G a matrix of i.i.d. random zero-mean complex-normal distributed values, a channel realization can then be generated by the model as

$$\tilde{\mathbf{H}} = \frac{1}{\sqrt{tr\left\{\mathbf{R}_{RX}\right\}}}\mathbf{R}_{RX}^{1/2}\mathbf{G}\left(\mathbf{R}_{TX}^{1/2}\right)^T$$

The eigenbeam model

The eigenbeam (Weichselberger) model treats the influence of the antennas and environment by means of eigenbases and a coupling matrix.
With U_A and U_B the eigenbases of the unparameterized one-sided correlation matrices of sides A and B of the link, a channel realization is generated as

$$\tilde{\mathbf{H}} = \mathbf{U}_A\left(\tilde{\mathbf{\Omega}} \odot \mathbf{G}\right)\mathbf{U}_B^T$$

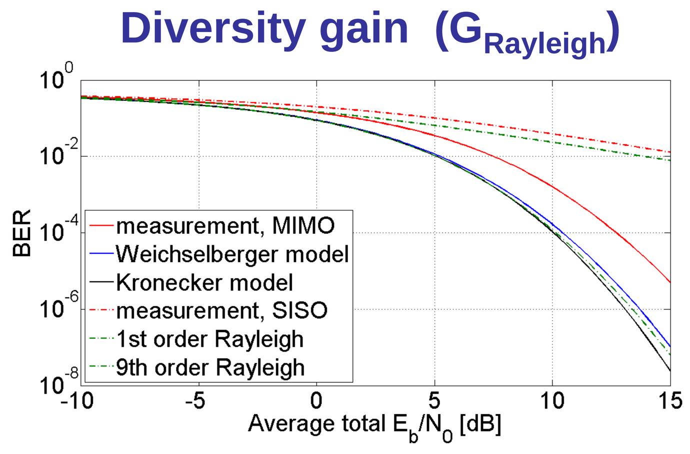
with $\odot$ the Hadamard product of G, which is a matrix of i.i.d. random zero-mean complex-normal distributed values, and a coupling matrix Ω.
The coefficients of Ω specify the mean amount of energy that is coupled from the *m*th eigenvector of side A to the *n*th eigenvector of side *B.*

Bit error rate characteristics for the modeled channels

Based on the channel realizations generated by the models, bit error rate characteristics are derived for these modeled channels and compared to the original measurement and the theoretical characteristics for Rayleigh fading.

IV. BER curves for the modeled channels

Diversity gain ($G_{Rayleigh}$)

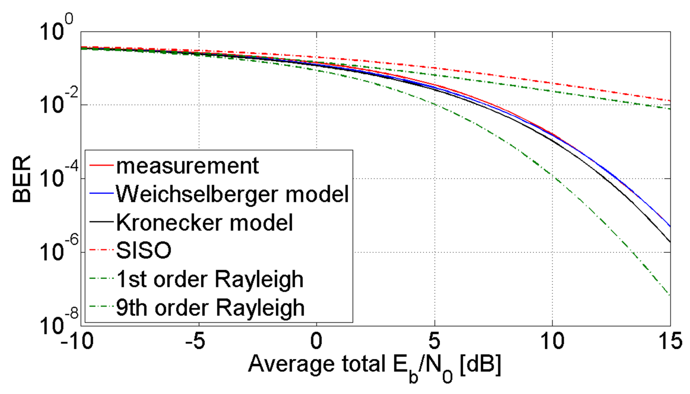


Bit error characteristics for diversity

•Bit error rates as a function of the average total E_b/N_0 at the detector display only the diversity gain.
•The modeled channels approximate the theoretical curves for Rayleigh fading with 9th order diversity, displaying the effective diversity obtained.

The curves for the modeled and measured channels have the same slope but do not overlap. The offset is caused by the distribution of the signal levels, which is exactly Rayleigh distributed for the modeled channels but only approximately for the measured channel. The model captures the unequal gain and correlation properties but not the distribution of signal levels.

Diversity gain (G_{alt})



•To account for the distribution of the measured signals an alternative G matrix is generated using i.i.d. random values with the same statistical distribution as these measured signals.
•The curves for measured and modeled channels now nearly overlap, indicating the validity of both models; of which the eigenbeam model provides the best match.

V. Conclusions

•The effective diversity gain of the MIMO system and channel can be reproduced by both the Kronecker and eigenbeam models, which indicates that the unequal gain and correlation is captured correctly by these models.
•When using the standard G matrix of Rayleigh distributed values for generating channel realizations, the measured and modeled characteristics are shifted by a few dB with respect to each other due to the distribution of the measured signals, which is nearly but not exactly Rayleigh distributed.
•Using an alternative G matrix of i.i.d. values having the same distribution as the measured signals removes this offset, making the characteristics of the measured and modeled channels virtually overlap.
•The curves for the eigenbeam modeled channel provide the best fit to the measurements.