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Re:	Call for Contributions on Project 802.16m System Description Document (SDD) - IEEE 802.16m-07/047, specifically, changes to the 802.16m reference model.
Abstract	This contribution describes the rational for Rx BF and proposes to include 4 antenna receiver BF at the BS as mandatory feature in 802.16m SDD document.
Purpose	To incorporate the requirement of placing of at least 4 Rx antennas at the BS.
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Interference Mitigation Performance with 4 antenna BS

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1. Introduction

Receive beamforming (Rx BF) has become on of the prominent method for interference mitigation in communications systems. The concepts underlying Rx BF originate from the field of phased array systems in RADAR theory. In phased array techniques it is long known that an adequate complex weighting of an antenna array results in an equivalent directional antenna. Similarly, complex weighting of an antenna array may lead to the formation of spatial nulls, suppressing the radiation from a certain direction. This may be viewed as spatial filtering.

In communications systems, the receiver is usually aiming at the amplification of desired information sources and the suppression of interfering sources. When the desired sources and interferers are spatially separated, it is possible to apply beamforming techniques to enhance the communication link.

In OFDMA, weight vectors are usually applied independently to small frequency bands (smaller than the coherence bandwidth of the channel) as done with PUSC without Subchannel rotation in the UL. Thus, the standard Rx BF methods do not apply to ranging signals that spread about the whole bandwidth. This means that a different BF procedure is invoked for Ranging.

In this document we compare the performance of Rx BF on PUSC without Subchannel rotation UL with that of standard MRC. Moreover, we give the performance of Rx BF applied to Ranging signals. The simulations reveal the significant robustness of Rx beamforming algorithms when the BS is endowed with (at least) 4 Rx antennas.

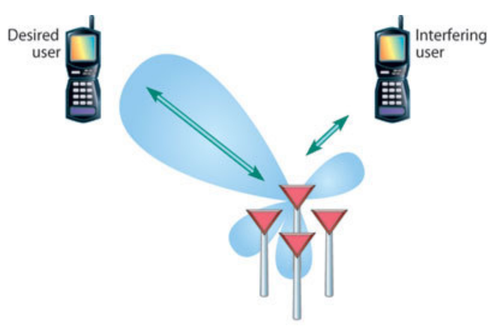


Fig. 1: Typical scenario of Rx beamforming. The BS constructs a beam aiming at the desired user while trying to eliminate the contribution from the interfering user (spatial nulls).

2. Preliminaries

2.1 PUSC UL Tile Structure

We consider hereafter PUSC w/o Subchannel rotation UL transmission. This transmission format is applied here since it allows a large density of pilots in a relatively small frequency band. This allows the generation of a weight vector designed for a band as small as 4 SCs.

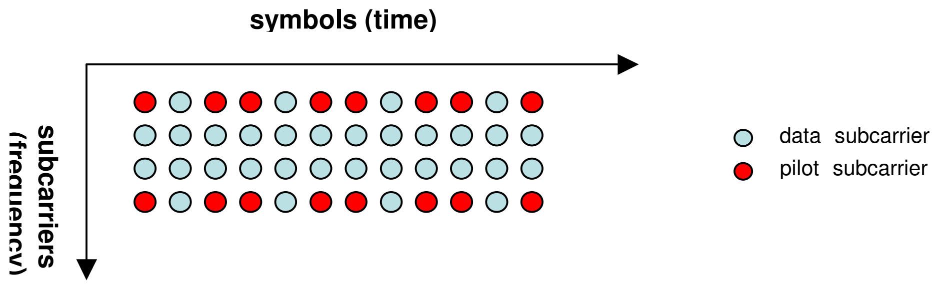


Fig. 2: UL PUSC frame structure

2.2 Mathematical Model and Definitions

We consider a case where the BS is endowed with M Rx antennas. Denote by $\mathbf{h}_0 = (h_{01,} ..., h_{0M})$ is the channel from the desirable source and by s_0 the signal from the desirable source. We also assume the presence of N sources of interference s_i. Thus, the mathematical model for the received signal $\mathbf{y}$ (for OFDMA on a subcarrier level) is

$$\mathbf{y} = \mathbf{h}_0 s_0 + \sum_{i=1}^{N} \mathbf{h}_i s_i + \rho \mathbf{n}, \quad (1)$$

where $\mathbf{h}_i$ is the channel of the i-th interference source and $\mathbf{n}$ is an additive white Gaussian noise (AWGN) with unit power.

Assuming that the signals have unit power, we define the signal to interference ratio (SIR), the signal to noise ratio and the signal to interference and noise ratio (SINR) as follows:

$$\mathbf{SIR} = \frac{P_D}{\sum_{i=1}^{N} P_i}, \quad \mathbf{SNR} = \frac{P_D}{\rho^2}, \quad \mathbf{SINR} = \frac{P_D}{\sum_{i=1}^{N} P_i + \rho^2}, \quad (2)$$

where P_D is the channel power of the desirable user , P_i is the channel power of i-th interferer and ρ is the noise intensity.

2.3 Ranging

Ranging codes are transmitted from the user to the BS in order to obtain information on the network set-up and synchronize the link. In particular, ranging is used to obtain the information about the user presence (user RNG sequence detection) and also for the time synchronization (user timing offset calculation).

The fundamental mechanism of ranging involves the user transmitting a randomly selected code division multiple access (CDMA) code in a specified ranging channel, on a randomly selected ranging slot. The BS receives this code and determines the required information. One ranging channel usually contains 144 subcarriers.

3. Simulation Results

3.1 Simulations parameters

We used the ITU benchmark Pedestrian B 3 km/h and Vehicular A 60km/h channels. The correlation between user's channels is 0.5 or zero (the correlation is assumed real valued). The interference channels are assumed uncorrelated with the desirable user channels. We also assume that the BS utilizes all its antennas.

Other simulation parameters are: Convolutional Turbo Coding, FEC block size=480 bits, QPSK1/2, Carrier frequency=2.5GHz.

3.2 Simulations results

a) **Ranging**

We start with the analysis of the ranging process in presence of a strong interference. We examine this scenario with variable number of Rx antennas at the BS. We show that increasing the number of Rx antennas at the BS significantly improves the quality of the ranging process. It turns out that the ranging process in a BS endowed with 4 antennas works well in the presence of interference up to –20dB for various channel models. We assume that there are 6 active users with orthogonal RNG sequences in the system. The graphs below show the empirical probability of incorrect ranging. Correct ranging is defined here as the event of successful detection of the code and timing offset estimation with accuracy of 5 samples. In the following figures, the SNR, SIR, and SINR values refer to the ranging signals (not the data).

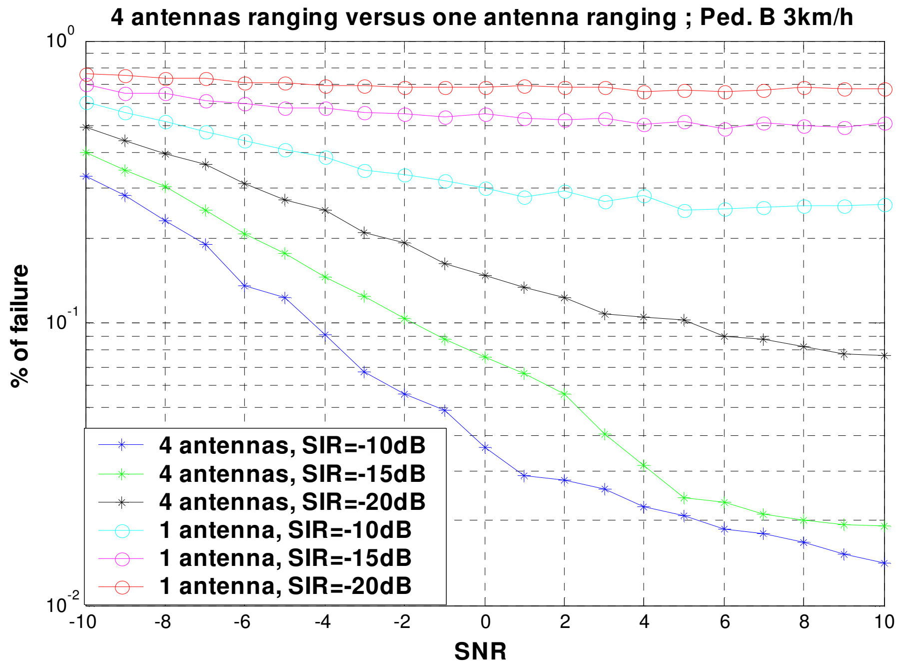


Fig. 3: Number of Rx antennas effect, Ped. B 3km/h;
No correlation.

Now we demonsrate that the ranging process for 4 antennas BS works well in SIR=-20dB.

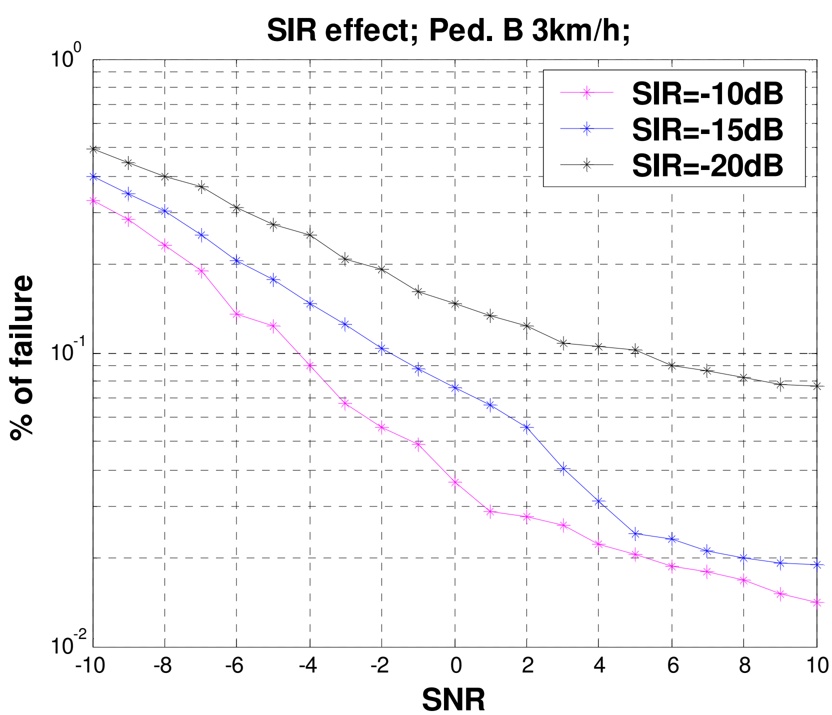


Fig. 4: SIR effect; Ped. B 3km/h; no correlation

It turns out that the ranging performed by 4 antennas BS shows good results in the case when the users' channels are correlated.

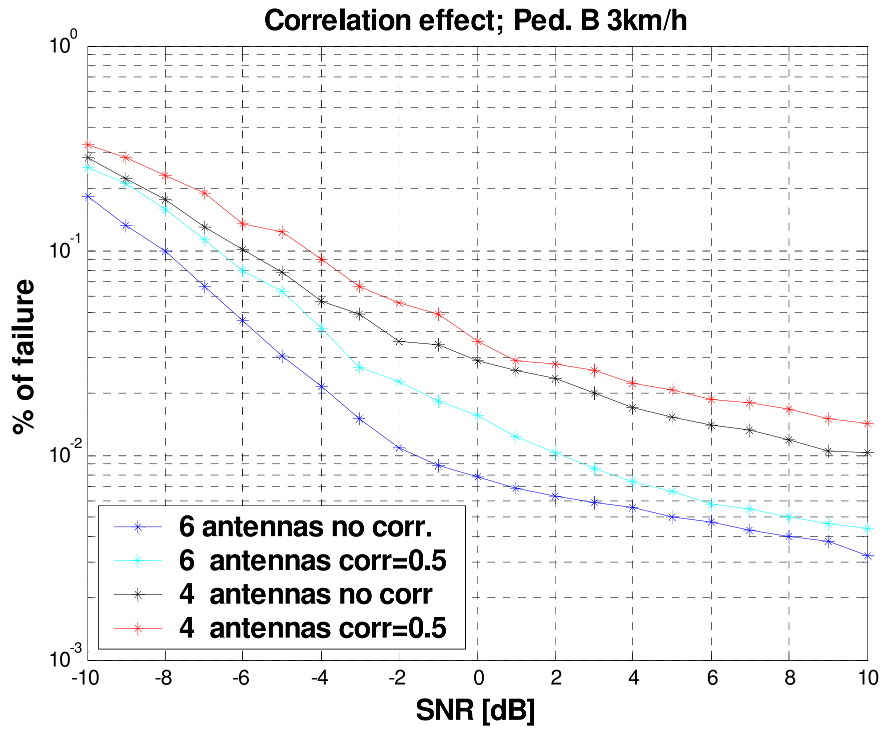


Fig. 5: Correlation effect; SIR=-10dB, Ped. B 3km/h;

Finally, the comparison of 4 antennas BS ranging process for various channels is presented.

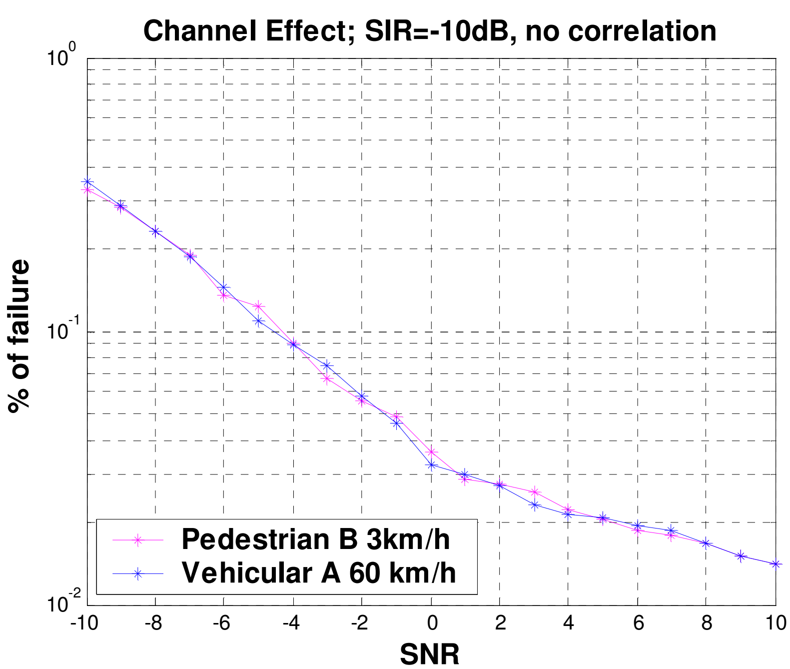


Fig. 6: Channel effect; SIR=-10dB, no correlation

b) **Rx BF on UL Data**

In the next two graphs the performance of Rx BF versus the performance (BER and PER) of the standard MRC 1X4 scheme is presented for SIR=-10dB. The users' channels are assumed to be uncorrelated. The graphs show that the MRC has a error floor at BER=0.3, while the Rx BF provides much better performance.

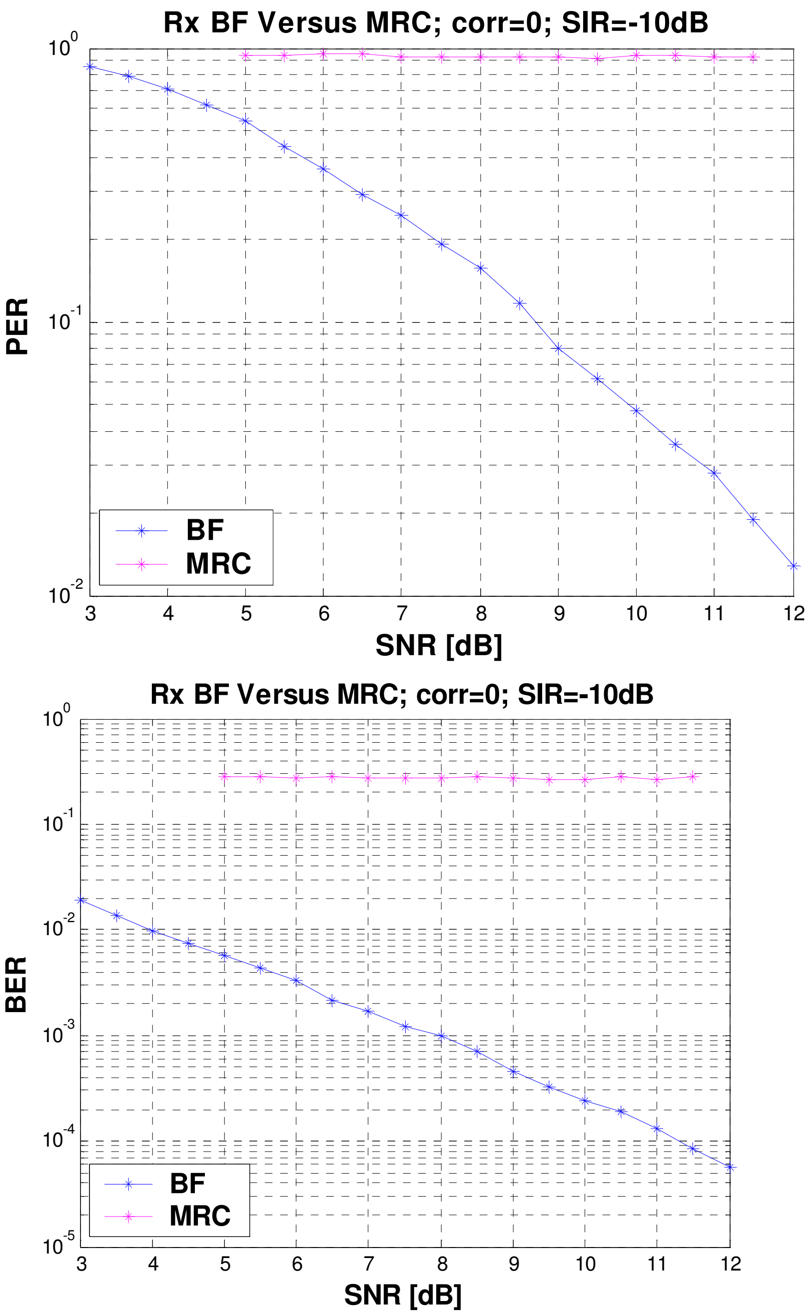
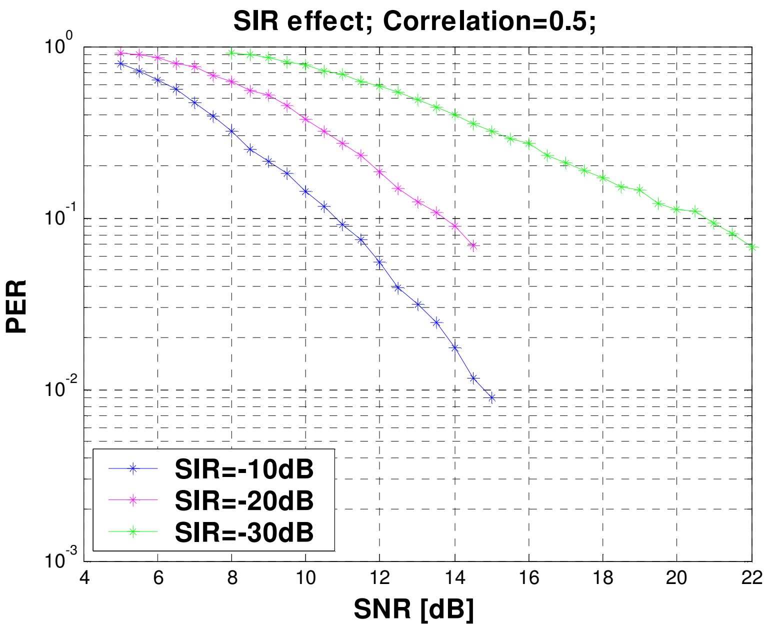


Fig. 7: MRC 1X4 versus Rx BF, SIR=-10dB, zero correlation, Ped. B 3km/h.

Next, we demonstrate that Rx BF works well also for SIR=-30dB.



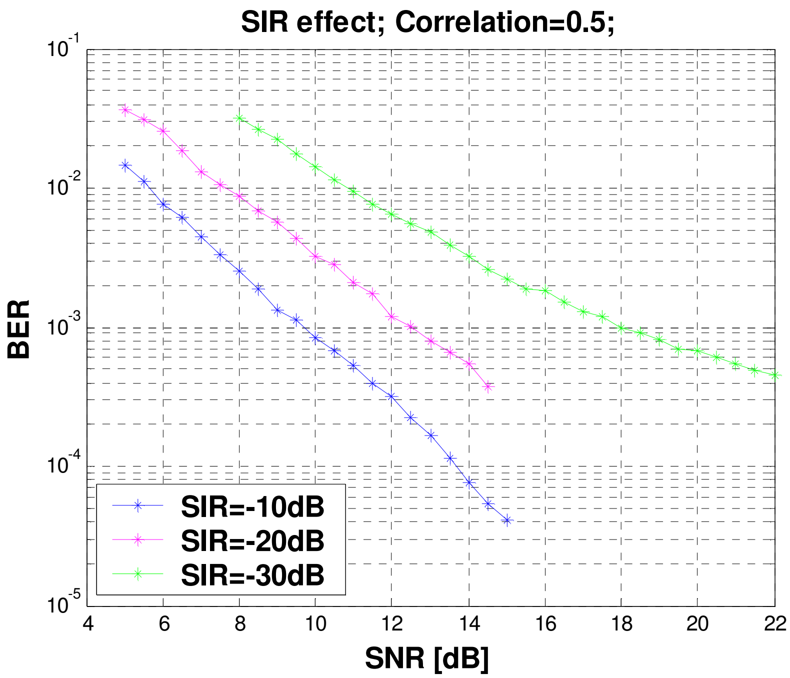
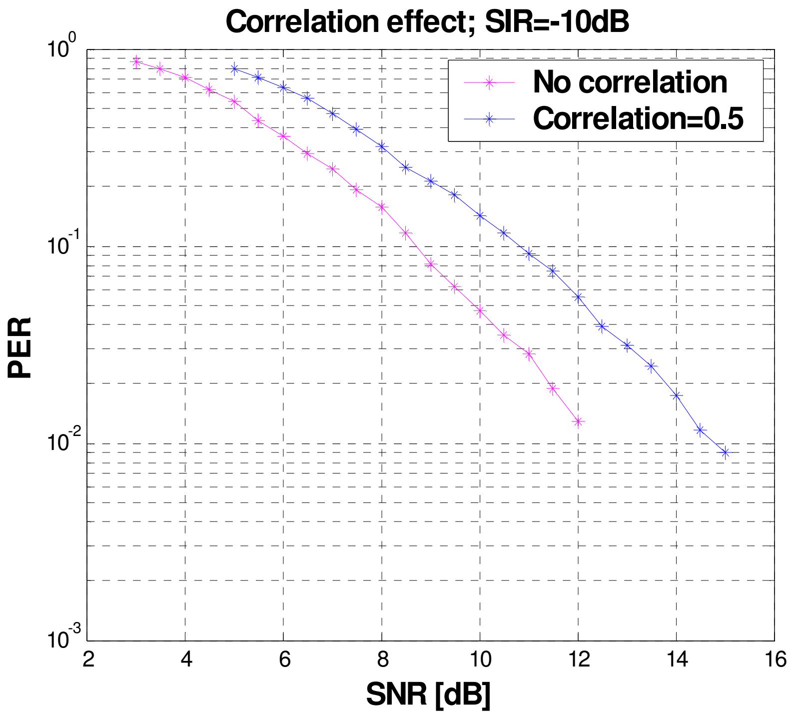


Fig. 8: SIR effect; Correlation=0.5, Pedestrian B 3km/h.

In the next two graphs we present the performance (BER and PER) of the Rx BF for different correlation between user's channels.



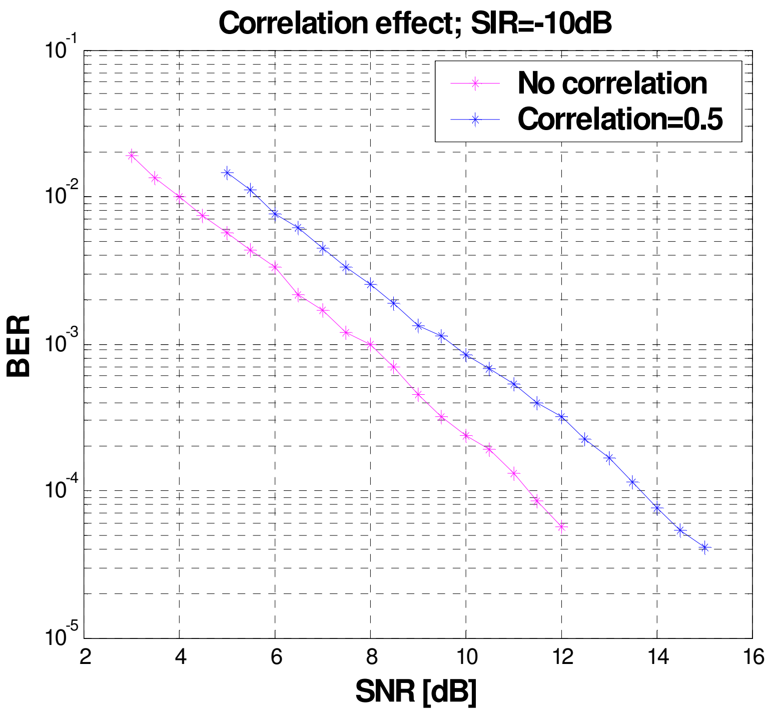


Fig. 9: Correlation effect; SIR=-10dB, Pedestrian B 3km/h.

Finally, we present the Rx BF performance (PER) for various channels models

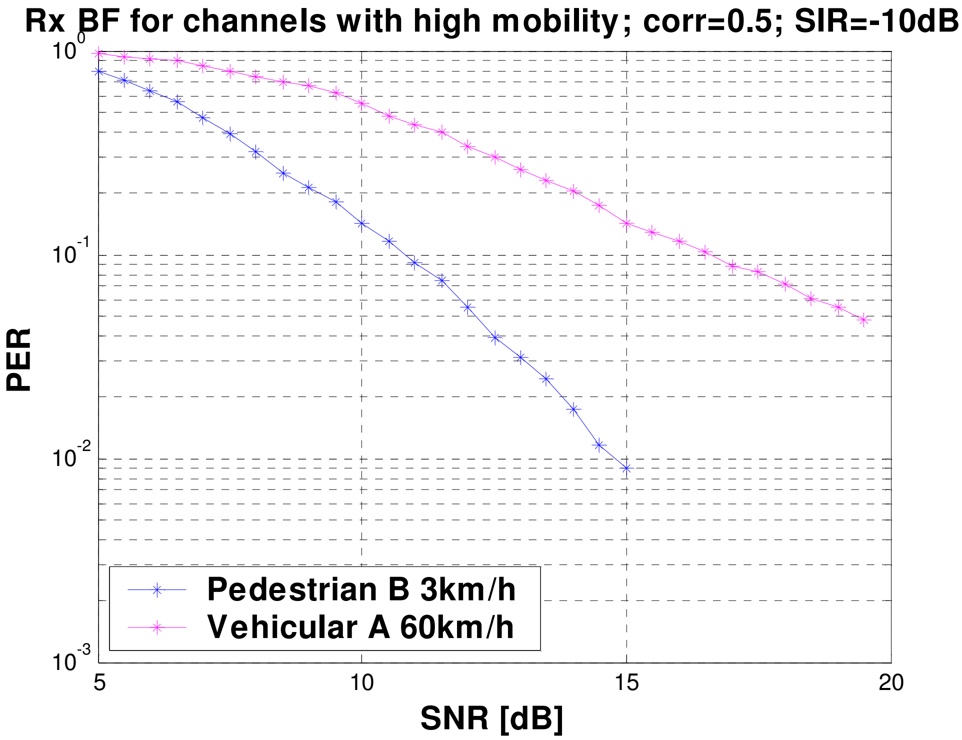


Fig. 10: Rx BF for various channel models; SIR=-10dB, correlation=0.5.

4. Conclusions

In this contribution we examined the performance of Rx BF algorithm employed at the BS. Two different BF algorithms where considered, one of the ranging signals and the other for UL data. In both cases, the BF algorithms provide significant performance gains in case of strong interference.

The scenarios of extremely strong interference where chosen to demonstrate the resilience of BF methods to interference in various transmission methods (not necessarily narrow band signals as PUSC w/o Subchannel rotation). Since in many of the deployment scenarios envisioned for 802.16m, the system performance is limited by interference (e.g. inter-cell interference), Rx BF techniques are likely to play a major. **Since Rx BF methods require larger number of antennas at the BS, we believe 4 antennas at the BS should be a starting point for the 16m**.

5. Proposed Changes

Include a Receiver Beamforming section in the SDD:

Receiver Beamforming

The system shall support receiver beamforming techniques at the BS. The minimum number of antennas for receiver beamforming at the BS shall be four.