3GPP TSG RAN WG1 *TSGR1#19 R1-01-0259*
Las Vegas, U.S.A., 27.2-2.3, 2001

Agenda Item:

Source: Nokia[1]

Title: METRA project results: Link-level simulation results for standard-friendly MIMO techniques in the TDD mode of UTRA

Document for: Discussion

---

1. Introduction

This document presents TDD link-level simulation results evaluating several techniques that employ multiple antennas at the transmitter and receiver. These MIMO (multiple input and multiple output) techniques, such beamforming, are fully compliant with the current specifications of the TDD mode of UTRA. The presented results have been obtained in the context of the METRA project [1]. The MIMO channel used in the simulations follows a delay distribution according to the ITU description, and a spatial (angular) and Doppler distribution derived after an extensive MIMO channel sounding campaign (see [2,3] for further details on the Doppler-spatial channel characterization).

2. Signal and Channel Model

The simulated setting consisted on 8 intra-cell users and 2 inter-cell users uniformly distributed within [-60...60] degrees. All UE and Node B's were equipped with an array of 4 uniformly spaced antennas with an inter-element separation respectively fixed to 0.4?? and 1.5?, where ? denotes the wavelength corresponding to a transmitting frequency of 1.910GHz. The users' speed was set to 3Km/h (Jake's Doppler Spectrum) and the power delay profiles were generated following the Indoor A+B and Pedestrian A+B shapes [4]. The MIMO channel was simulated according to the statistical spatial model in [3], where the envelope correlation coefficients between antennas were

$$?_{UE} ? \begin{bmatrix} 1 & 0.3394 & 0.0856 & 0.1615 \\ 0.3394 & 1 & 0.2947 & 0.1379 \\ 0.0856 & 0.2947 & 1 & 0.2499 \\ 0.1615 & 0.1379 & 0.2490 & 1 \end{bmatrix} \quad ?_{Node?B} ? \begin{bmatrix} 1 & 0.2628 & 0.2550 & 0.1216 \\ 0.2628 & 1 & 0.2417 & 0.2143 \\ 0.2550 & 0.2417 & 1 & 0.2896 \\ 0.1216 & 0.2143 & 0.2896 & 1 \end{bmatrix} \qquad (1)$$

Each user was transmitted using a single spreading code. The background reception noise limited the maximum Es/No (Symbol energy to Noise Spectral Density) to Es/No=20dB.

Concerning the slot configuration, a single-switching-point setting was considered, so that the separation between links of a single communication was fixed to 8 slots (no DTX assumed). The power control (PC) delay (defined as the delay between measurement and correction instants) was assumed equal to a frame length (15 slots), and a slot format 0 was assumed for both uplink and downlink communications (midamble of 512 chips, spreading factor 16 and 244 bits/slot). The imperfections of the power control were simulated with an additive Gaussian-distributed estimation noise plus a multiplicative log-uniformly distributed noise accounting for the PC step uncertainty.

Table 1 summarizes the parameters used in the simulations.

---

[1] In cooperation with the Signal Processing Group of the Universitat Politècnica de Catalunya (UPC) in Barcelona, Spain, within the framework of the European IST (Information Society Technologies) METRA (Multiple Element Transmit/Receive Antennas) project [1].

Table 1. Simulation parameters

Chip rate	3.84 Mchip/s
Slot format	0
Frame structure	8 consecutive slots downlink + 7 consecutive slots uplink (no DTX)
Bits/slot	244 (122+122)
Midamble length	512 chips
Spreading factor	16
Channel coding	Not simulated
Power control	3dB step
Channel and covariance estimation	From Midamble
Channel modeling	PedA+B channel, 3 km/h IndA+B channel, 3 km/h
Carrier to Noise ratio	8dB
G (CIR)	Variable
Number of intracell users	8 (spreading factor 16)
Number of intercell users	2 (spreading factor 16 in uplink, Gaussian noise in downlink)
Log-normal fading (inter-cell users)	10-12 dB
Directions of Arrival	Uniformly distributed within [-60,60] degrees
Number of antennas	1 or 4 (for both UE and Node B)
Transmit beamforming design	From channel measurements in the reciprocal link

3. Algorithms under Study

3.1 Transmission

At the transmitting side, single antenna and beamforming transmission techniques were compared. Assuming a space-time channel estimate **H** obtained at the reciprocal link, the beaforming was designed as the maximum eigenvalue eigenvector of the matrix $\mathbf{H}\,\mathbf{H}^H$, where superindex H indicates conjugate transpose. This is a generalization of a beamforming that points towards the direction of arrival of the desired user for spatially distributed sources.

3.2 Reception

At the receiving side, different strategies were considered for uplink and downlink communications. Here we only give a brief description of the algorithms under study. The reader is referred to [5] for a deeper treatment.

Consider the following space-time signal model:

$$\mathbf{x} = \mathbf{Hs} + \mathbf{n} \qquad (2)$$

where vector $\mathbf{x}$ contains *M* received snapshots from *P* different antennas stacked on top of one another, matrix $\mathbf{H}$ represents the convolution of the spreading codes and the intra-cell channel impulse responses, $\mathbf{s}$ contains the transmitted symbols from the intra-cell users and $\mathbf{n}$ the intra-cell interference plus background noise, with covariance

$$\mathbf{C}_n = E\{\mathbf{nn}^H\} \qquad (3)$$

In the uplink, two different linear detectors were simulated, namely

- A Multi-user Denoised Matched Filter (DMF), which nulls out the inter-cell interference and applies a matched filter to each of the intra-cell users:

$$\mathbf{F}_{DMF}^{MU} = \mathbf{C}_n^{-1}\mathbf{H} \tag{4}$$

- A Multi-user linear Minimum Mean Squared Error (MMSE) detector, which nulls out the inter-cell contribution and jointly detects the intra-cell users:

$$\mathbf{F}_{MMSE}^{MU} = \left(\mathbf{H}\mathbf{H}^{H} + \mathbf{C}_n\right)^{-1}\mathbf{H} \tag{5}$$

In both cases, the estimated symbols are obtained as $\hat{\mathbf{s}} = \mathbf{F}^{H}\mathbf{x}$.

For the downlink, consider the following modification of the received signal model:

$$\mathbf{x} = \mathbf{H}_1\mathbf{s}_1 + \mathbf{n}_1 \tag{6}$$

Now $\mathbf{H}_1$ contains the channel plus spreading impulse response corresponding to a single intra-cell user, while the contribution from noise, intra-cell and inter-cell interference is lumped together in $\mathbf{n}_1$, now with covariance $\mathbf{C}_{n1} = E\left\{\mathbf{n}_1\mathbf{n}_1^{H}\right\}$. Three different receive algorithms were simulated:

- A Single-user Denoised Matched Filter (DMF), which nulls out the inter+intra-cell interference and applies a matched filter to user of interest:

$$\mathbf{F}_{DMF}^{SU} = \mathbf{C}_{n1}^{-1}\mathbf{H}_1 \tag{7}$$

- A Single-user linear Minimum Mean Squared Error (MMSE) detector, which nulls out the inter+intra-cell contribution and applies a linear MMSE equalizer to the user of interest:

$$\mathbf{F}_{MMSE}^{SU} = \left(\mathbf{H}_1\mathbf{H}_1^{H} + \mathbf{C}_{n1}\right)^{-1}\mathbf{H}_1 \tag{8}$$

- A Multi-user linear Minimum Mean Squared Error (MMSE) detector, which nulls out the inter-cell contribution and jointly detects the intra-cell users:

$$\mathbf{F}_{MMSE}^{MU} = \left(\mathbf{H}\mathbf{H}^{H} + \mathbf{C}_n\right)^{-1}\mathbf{H} \tag{9}$$

In the latter case, it is assumed that the UE knows the training and spreading sequences used by all the intra-cell users.

4. Simulation Results (uplink)

Figure 1 represents the uncoded Bit Error Rate (BER) as a function of the carrier to interference ratio (CIR) for the Pedestrian and Indoor environments, where here the interference term contains the contribution from inter-cell users exclusively.

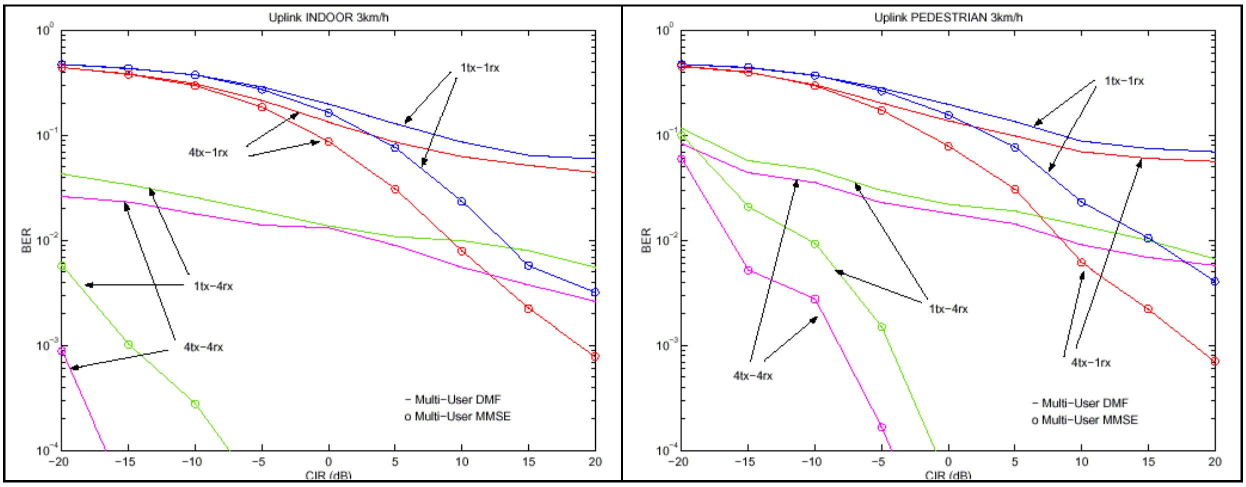

Figure 1.Link-level simulation results for Indoor (left) and Pedestrian (right) channel models.

The simulation results for the pedestrian and indoor environments look almost identical. In both cases, the relative gain in terms of required CIR obtained from the use of multiple antennas at the transmitting side ranges from 5 to 10 dB depending on the receiving algorithm and the uncoded BER. Much higher gains are obtained when using multiple antennas at the receive side (note that our setting consisted of 2 inter-cell interferences, which can be easily null out with 4 receive antennas). It is worth stressing that the raw BER is represented against CIR, and not signal to noise plus interference ratio, which could be obtained as $SINR=(CIR^{-1}+SF\cdot Es/No^{-1})^{-1}$.

5. Simulation Results (downlink)

Figure 2 represents the link-level simulation results in terms of uncoded BER as a function of CIR (namely intra- to inter-cell interference ratio, also referred to as G factor). One can observe that the performance gain obtained from using an MMSE equalizer instead of a conventional matched filter is almost negligible for all the configurations. On the other hand, gains around 10dB in the required CIR are obtained with single user detectors in multi-antenna array settings at the UE. These gains turn out to be about two times higher if multi-user techniques are used.

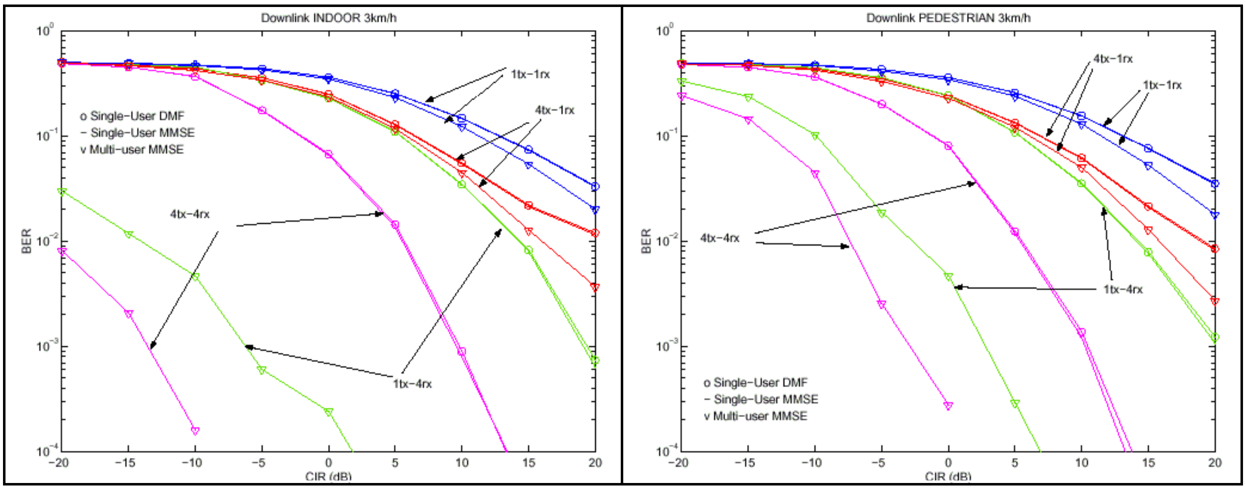

Figure 2.Link-level simulation results for Indoor (left) and Pedestrian (right) channel models.

6. Conclusions

This document has presented link-level simulation results for techniques that exploit the richness of MIMO configurations in the TDD mode of UTRA. Making use of the spatial channel characterization in [2-3], several standard-friendly transmit and receive techniques are evaluated. Results show that large gains can be obtained from using multiple antennas at Node B and UE in both uplink and downlink communication although a large number of antennas in UE may not be an attractive solution in complexity point of view. The gains could be utilized for higher data rates by using e.g. a higher order modulation or a weaker channel code.

5. References

[1] http://www.ist-metra.org

[2] Laurent Schumacher, Jean Philippe Kermoal, Frank Frederiksen, Klaus I. Pedersen, Albert Algans, Preben E. Mogensen, "MIMO Channel Characterisation", IST Project IST-1999-11729 METRA Deliverable 2, February 2001 (available at http://www.ist-metra.org).

[3] K.I. Pedersen, J.B. Andersen, J.P. Kermoal, and P.E. Mogensen, "A Stochastic Multiple-Input-Multiple-Output Radio Channel Model for Evaluation of Space-Time Coding Algorithms", *Proceedings of VTC 2000 Fall*, pp. 893-897, Boston, United States, September 2000.

[4] ETSI Tech. Report, "Selection procedures for the choice of radio transmission technologies of the UMTS", TR 101 112 v 3.2.0, 1998.

[5] "Review and Selection of Relevant Algorithms", IST Project IST-1999-11729 METRA Deliverable 3.2, June 2000 (available at http://www.ist-metra.org).