Agenda item:	AH24 : High Speed Downlink Packet Data Access
Source:	Lucent Technologies
Title:	Link level results for HSDPA using multiple antennas in correlated and measured channels
Document for:	Discussion

1. INTRODUCTION

In previous contributions [1][2], link level results for high speed downlink packet access (HSDPA) demonstrated the gains of multi-input/multi-output (MIMO) techniques in spatially correlated channels compared to conventional single antenna techniques.

In this contribution, we present link level performance results based on the following channel environments:

1. A microcell environment suggested by Siemens during offline discussions following the previous RAN1 meeting.
2. Actual channels measured in a dense urban environment (midtown Manhattan).

In addition, we present results for a maximum likelihood detector which further improves the MIMO performance.

2. TRANSMISSION TECHNIQUES

The table below gives the transmission techniques considered in this contribution. Details are given in [1]. We use the notation (*M*, *N*) to denote a MIMO system with *M* transmitters and *N* receivers.

# transmitters	Tx technique	Code rate	Modulation	Data rate per substream	# substreams	Total data rate
1	Conventional	¾	64QAM	540Kbps	20	10.8Mbps
2	MIMO	¾	8PSK	270Kbps	40	10.8Mbps
2	MIMO	¾	16QAM	360Kbps	40	14.4Mbps
4	MIMO	~½	QPSK	135Kbps	80	10.8Mbps
4	MIMO	¾	QPSK	180Kbps	80	14.4Mbps

Table 1. Antenna architectures

3. CHANNEL MODEL

For both channel cases, we assume a flat fading channel model with spatial correlation between the antenna array elements at both the base station and terminal. In the first case, assumptions about the channel parameters result in a channel correlation matrix which is used to generate spatially correlated channel matrices over which simulations are run. In the second and case, the procedure is similar except that channel correlation matrix is drawn from empirical measurements.

The spatially correlated channel suggested by Siemens (known here as “channel C” (channels A and B were described in [2])) is a microcellular environment which is parameterized by the channel model given in [3]. The base station antennas are arranged in a linear array with 0.7 wavelength separation, and the UE antennas are arranged in a linear array with 0.5 wavelength separation. The angular spreads about the base station and UE are, respectively, 45 and 360 degrees.

Channel measurements were taken in a dense urban environment using a 16 element transmitter array and a 16 element receiver array. The transmitter array was installed on a 38th floor balcony of the New Yorker Hotel in midtown Manhattan. At this height, some of the surrounding buildings are lower and some are higher. The receiver array was placed on the side of a van at a height of about 2m, and the van was driven along various streets and avenues within a 1.5 Km radius of the transmitter. A single channel matrix measurement, consisting of 256 complex channel coefficients, was taken each 1.5 ms. In total, over 4 million matrices were measured. To guarantee sufficient accuracy of these estimates, only those with measured signal-to-noise ratio (SNR) over 20dB. Given the collection of measured channel matrices, the Shannon capacity was computed for each realization at a fixed SNR of 20dB. For a (4,4) system, the median measured capacity is approximately 94% of the median capacity obtained in an ideal, spatially uncorrelated channel. In other words, there is sufficient channel scattering in this urban environment for the MIMO system to achieve a significant fraction of the capacity predicted by Shannon theory.

The transmitter consists of a horizontal linear array of 16 patch antennas with two polarizations co-located. For our numerical results, a subarray of two elements corresponds to two co-located antennas, and a subarray of four elements corresponds to two sets of dual-polarized antennas spaced 10 wavelengths apart. The carrier frequency is 2.11GHz, so that this distance is 1.42m. A four element transmitter is shown in Figure 1. An individual antenna element has a half power beamwidth of about 70 degrees, and gain of about 4 dBi. Each antenna transmits a different continuous tone, and the tones are separated by 2KHz so the total transmitted bandwidth is 30KHz. The transmit power per antenna is 23dBm.

The receiver consists of 16 antennas arranged in a 4-by-4 pattern with adjacent antennas having alternating horizontal and vertical polarizations. A 2 element subarray consists of two adjacent antennas with different polarizations, equivalent to the left or right pair of Figure 1. The distance between the active elements is less than ½ wavelength (7.1cm); however, because of the electrical isolation (over 30dB), the effective distance is much larger. The dimensions of this 2 element subarray are about 13cm -by- 8cm. A 4 element subarray, shown in Figure 2, consists of 2 rows of 2 antennas whose overall dimensions are 13cm -by- 15cm. The distance between active elements with the same polarization is 7.5cm, or 0.54 wavelengths. Each antenna is followed by a homodyne demodulator, and the signals are sampled at a rate of 78125 Ksamples/sec. The time series data is converted to a set of complex amplitudes using a 120-point Fast Fourier Transform. Because there are 16 transmitters and 16 receivers, a single channel realization is characterized by a total of 256 complex amplitudes. A realization is obtained once every 1.5 ms, and at 20 miles per hour, this time corresponds to a distance of 1/8th wavelength.

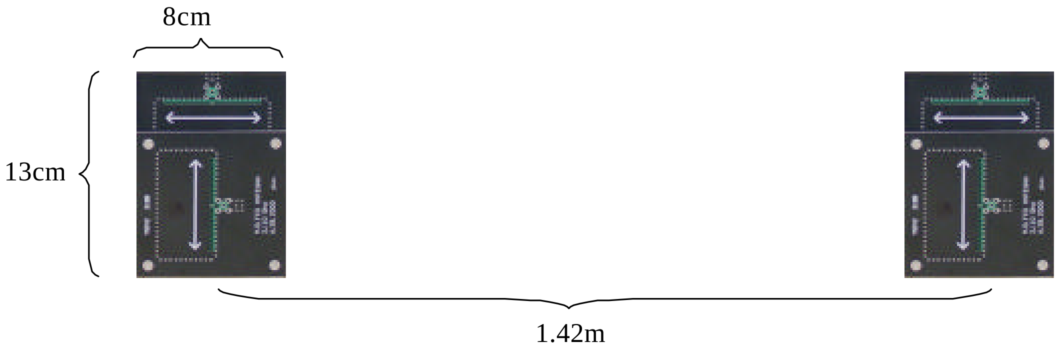

Figure 1. Node B 4-antenna transmit array

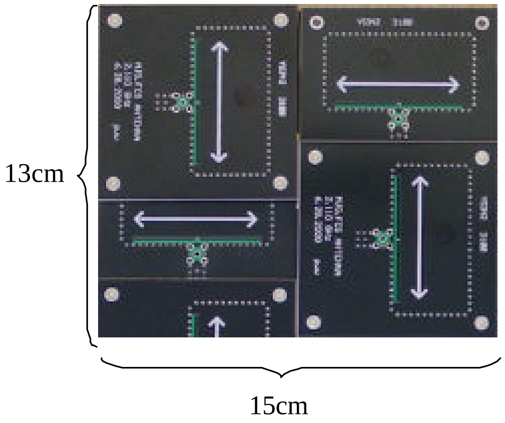

Figure 2. UE 4-antenna receive array

From the collection of channel measurements, we arbitrarily pick a series of 68 consecutive channel realizations (taken over a window of 102ms = 68 x 1.5ms) which correspond to the median measured capacity value. Covariances among the channel amplitudes are obtained as follows. Letting h_{mp} be the complex channel coefficient between transmitter *m* (*m* = 1 … *M*) and receiver *p* (*p* = 1 … *P*), the normalized covariance between two coefficients is given by

$$r(h_{m_1p_1}h_{m_2p_2}) \triangleq \frac{E\left[h_{m_1p_1}h^*_{m_2p_2}\right]}{\sqrt{E\left[h_{m_1p_1}h^*_{m_1p_1}\right]E\left[h_{m_2p_2}h^*_{m_2p_2}\right]}}.$$

For a (2,2) system, we define the channel vector $\mathbf{h} \triangleq \left[h_{11}\ h_{21}\ h_{12}\ h_{22}\right]^T$ (*T* denotes the matrix transpose) and the correlation matrix

$$\mathbf{R} \triangleq \begin{bmatrix} r\left(h_{11},h_{11}\right) & r\left(h_{11},h_{21}\right) & r\left(h_{11},h_{12}\right) & r\left(h_{11},h_{22}\right) \\ r\left(h_{21},h_{11}\right) & r\left(h_{21},h_{21}\right) & r\left(h_{21},h_{12}\right) & r\left(h_{21},h_{22}\right) \\ r\left(h_{12},h_{11}\right) & r\left(h_{12},h_{21}\right) & r\left(h_{12},h_{12}\right) & r\left(h_{12},h_{22}\right) \\ r\left(h_{22},h_{11}\right) & r\left(h_{22},h_{21}\right) & r\left(h_{22},h_{12}\right) & r\left(h_{22},h_{22}\right) \end{bmatrix}.$$

For an uncorrelated channels, **R** is given by the identity matrix. For correlated channels, given the correlation matrix **R**, the correlated channel coefficients $\mathbf{h}_{corr}$ is given by $\mathbf{h}_{corr} = \mathbf{R}^{1/2}\mathbf{h}_{uncorr}$ where $\mathbf{R}^{1/2}$ is the matrix square root of **R**, and $\mathbf{h}_{uncorr}$ is the vector of uncorrelated channel coefficients. In the simulations, the components of $\mathbf{h}_{uncorr}$ are independent zero-mean, complex Gaussian random variables with unit energy whose time variations are governed by a Jakes fading process. This procedure can be generalized for (2,4) and (4,4) systems.

	Channel C	Measured Urban
Node B antenna spacing	0.7 *l*	10 *l*
UE antenna spacing	0.5 *l*	0.54 *l*
Avg. cross-corr (2,2)	0.39	0.05
Max. cross-corr (2,2)	0.67	0.11
Avg cross-corr. (4,4)	0.20	0.17
Max cross-corr. (4,4)	0.67	0.77

Table 2. Channel parameters

4. RESULTS

We perform link level simulations and measure the frame error rate versus Ior/Ioc per receive antenna. We assume a flat fading channel where temporal variations are generated using Jake's time fading model at 3km/hr. At this velocity, the performance degradation due to channel estimation is negligible [1]; hence we assume perfect channel estimates.

Figure 3 gives the performance for the (2,2) system at 10.8Mbps using maximum likelihood (ML) detectors. As references, the red curve gives the performance of a conventional (1,1) system using 64QAM, and the green curve corresponds to a (2,2) system with uncorrelated channels. The performance in correlated channels is very robust. Under the measured urban channel, the performance degradation is negligible. With higher correlation in channel C, the performance loss is less than 2dB.

Figure 4 gives the performance of systems with four receive antennas at 10.8 Mbps. The red curve is the (1,1) reference, the dotted green curve is the performance of the (4,4) system in uncorrelated channels using a ML detector. This detector has an additional advantage of 2dB over suboptimal VBLAST detector [4] which has been used to generate previous link level results. The performance of the (4,4) system in uncorrealted channels using a VBLAST detector is shown by the solid green curve. The performance of the (4,4) VBLAST system is not as robust to correlated channels due to unfavorable eigenvalue distribution of the correlation matrix **R**. In other words, the low rank of the channel matrix results in poor performance of the detector. This problem can be solved by transmitting on fewer antennas to better match the rank of the channel, as described in [2]. We choose to transmit with two antennas so that the rates and transmission techniques in Table 1 can be used. One would expect that transmitting on the two outer antennas would lead to the best performance. However, as shown by the dashed lines in Figure 3, the performance is satisfactory even if we transmit from the *worst* antenna pair (worst in the sense of highest average cross-correlation). Hence *any* antenna selection algorithm, even a random one, would result in better performance. The resulting performance using the worst two transmit antennas, four receive antennas, and a ML detector is superior to the corresponding (4,4) systems using VBLAST. The performances are within 2dB of the dashed green curve showing the performance bound of a (2,4) system in uncorrelated channels. Compared to the (4,4) bound using ML detection in uncorrelated channels, the (2,4) performance is within 3dB.

Figure 4 gives the performance of the (4,4) system at 14.4 Mbps. As in the (4,4) 10.8Mbps case using VBLAST, the performance with four transmit antennas is sensitive to high channel correlations, but it can be significantly improved by transmitting with just two antennas. At 14.4 Mbps, both the (2,4) and (4,4) systems use VBLAST detection. The comparisons are done for VBLAST detectors only. The (4,4) ML performance in uncorrelated channels is shown as a reference of the best achievable performance regardless of complexity.

5. CONCLUSIONS

The performance results for the new correlated channel C are similar to those in the previous reference [2]. Namely, the (2,2) systems are minimally affected by channel correlations. The (4,4) systems are less robust, but significant performance improvements can be achieved by transmitting with two of the four antennas and using larger constellations. Initial performance results based on actual measured channel correlations in a dense urban environment are similar and indicate that MIMO performance will not be adversely affected by channel correlations. Additional channel measurements in urban and suburban environments have been taken. These measurements provide insights into the effects of sparser scattering, lower antennas, and the effects of the human body. While results will be presented in the near future, for the time being we simply state that MIMO performance does not deteriote significantly due to these factors.

6. REFERENCES

[1] Lucent. Further link level results for HSDPA using multiple antennas. TSG_R WG1 document TSGR1#17(00)1386, 21-24th, November 2000, Stockholm, Sweden.
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[3] Siemens. Channel model for TX diversity simulations using correlated antennas. TSG_R WG1 document TSG1#15(00)1067, 22-25th, August 2000, Berlin, Germany.
[4] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Physical Layer Aspects of UTRA High Speed Downlink Packet Access; (Release 2000), (3G Technical Report (TR) 25.848), TSG-RAN WG1; 27th February – 2nd March, 2001, Las Vegas, USA.

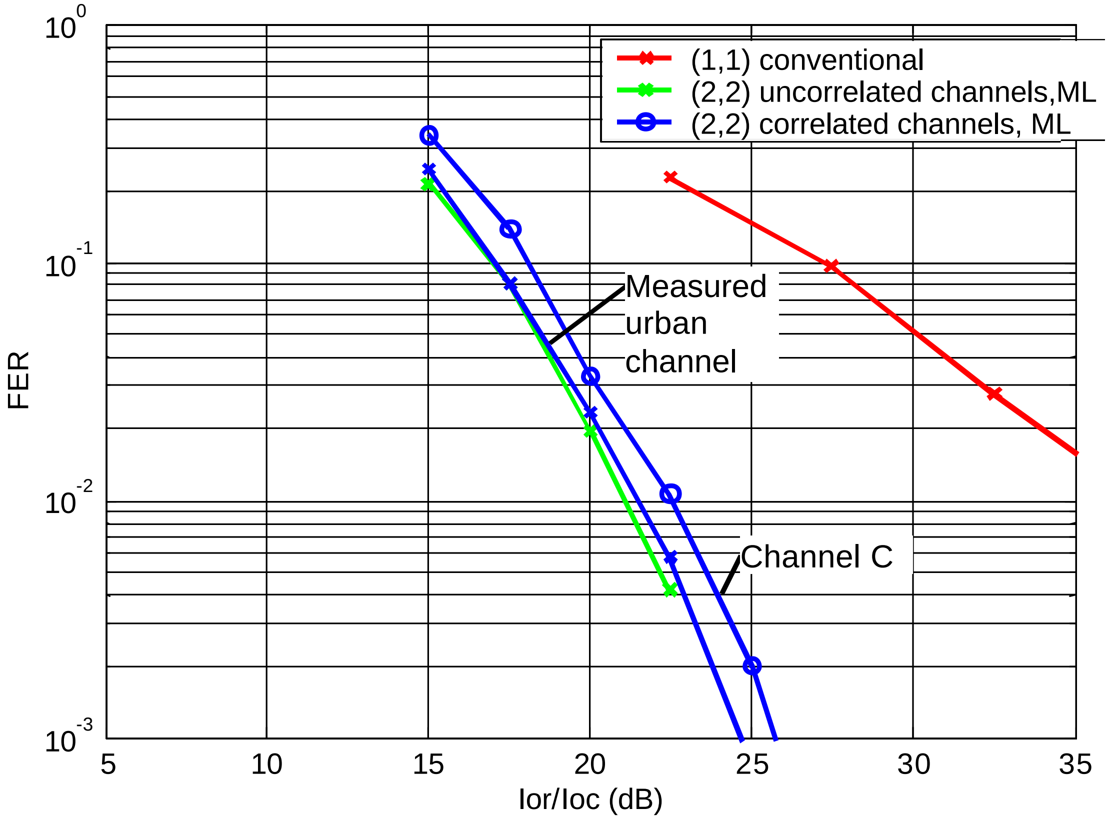

Figure 3. FER for (2,2) system, 10.8 Mbps, flat channel, 3km/hr

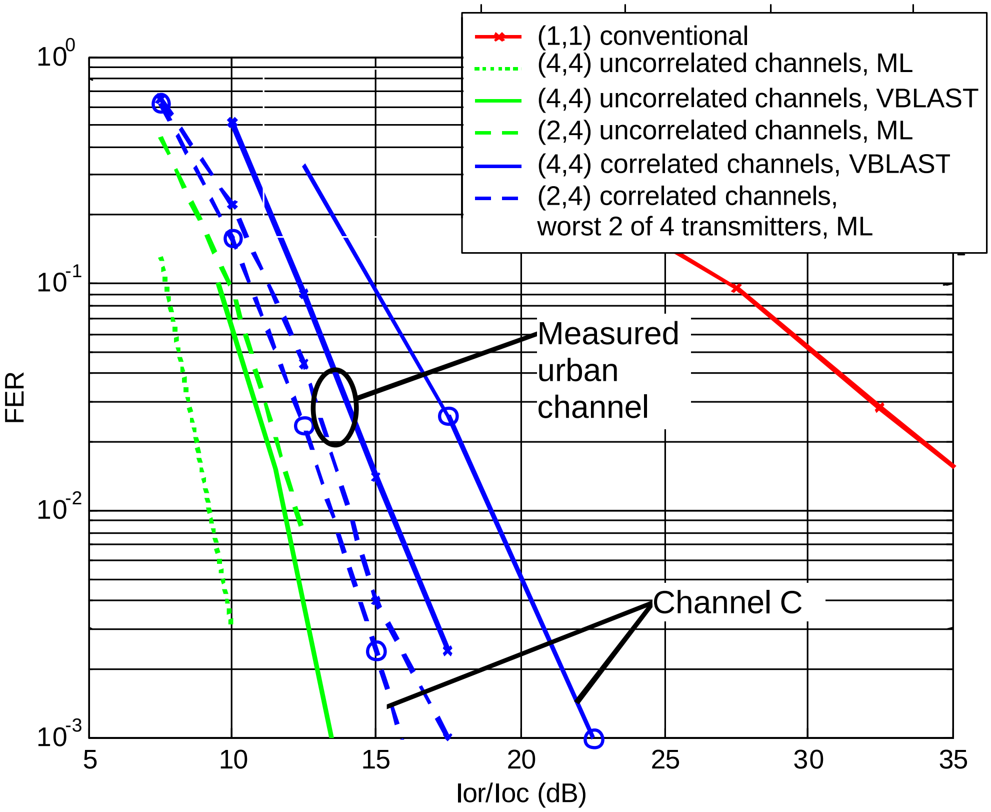

Figure 4. FER for 4 receive antenna system, 10.8 Mbps, flat channel, 3km/hr

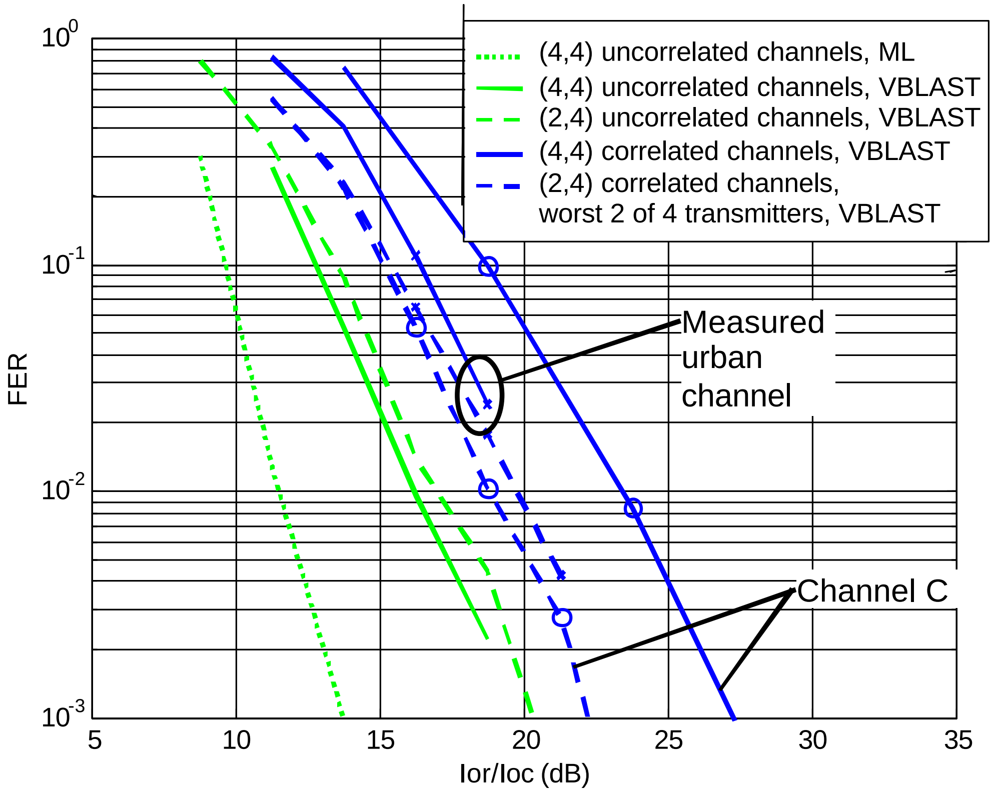

Figure 5. FER for 4 receive antenna system, 14.4 Mbps, flat channel, 3km/hr