TSG-RAN Working Group 1 meeting No. 15 **TSG R1-00-1057**
August 22– 25, Berlin, Germany

Agenda item:	**AH24**
Source:	**Lucent Technologies**
Title:	**Enhancements for HSDPA using multiple antennas**
Document for:	**Discussion**

1. INTRODUCTION

A work item on High Speed Downlink Packet Access (HSDPA) was proposed by Motorola in [1] followed by additional presentations [2,3,4,5,6]. In this contribution, we consider enhancing the HSDPA system using multiple antennas at both the base station and terminal. Using multiple antennas with novel transmission and detection techniques, one can exploit the spatial dimension and increase the spectral efficiency of fading wireless channels significantly compared to conventional single antenna links. In particular, we hope to accomplish the following two goals using the multiple antenna techniques:

- To reduce the Eb/No requirements for achieving data rates associated with higher order constellations (8PSK, 16QAM, 64QAM) described in [2].
- To expand the number of rate options for adaptive modulation and coding (AMC) and to increase the maximum rate.

2. BACKGROUND ON MULTIPLE ANTENNA TECHNIQUES

It is well-known that using multiple base station transmit antennas that are spaced sufficiently far apart (or cross polarized) can provide multiple decorrelated paths to the mobile terminal, enabling transmit diversity techniques. For CDMA systems, space-time transmit diversity (STTD) is a simple technique based on [7] for achieving transmit diversity of order two without sacrificing bandwidth, code, or power resources. The simplicity and effectiveness of this technique is highlighted by its adaptation in both the IS2000 and UMTS standards.

At the terminal, multiple antennas can provide additional link improvements through diversity and coherent antenna combining. The gains from coherent combining are essential for providing high data rate services to multiple users over a large area. Recent antenna technology advances have made it possible to support multiple antennas in the terminal, and in particular for large size data terminals such as laptops, it is possible to have up to four integrated antennas with sufficient spacing so that the correlation of the transmitted/received signals across the antennas is small.

Using multiple antennas at the transmitter and receiver for diversity and coherent combining, one can achieve significant gains over conventional single antenna systems. In this case it can be shown that the Shannon capacity (defined as the theoretical limiting rate of information that can be transmitted and reliably decoded at a receiver, as measured in bits per second per Hertz) grows logarithmically with the number of receive antennas.

Recent information theoretic results show that if one exploits more than just diversity from the spatial dimension, the capacity has the potential to increase *linearly* with the number of antennas. We recapitulate the key results from [8] to stress this point. Consider a point-to-point link with *M* transmit and *N* receive antennas. When there is sufficient scattering in the environment, the *MN* channels between the transmitter and the receiver can be modeled as independent, identically distributed complex Gaussian random variables. Denote the $M \times N$ matrix channel by $\mathbf{H}$. Then the Shannon capacity of the link at any given signal-to-noise ratio (*SNR*) is given by [8]

$$C = \log_2 \det\left(\mathbf{I} + \frac{SNR}{M}\mathbf{H}\mathbf{H}^H\right)$$

(where the *H* superscript denotes the hermitian transpose, and **I** is the *M*-by-*M* identity matrix). Asymptotically as the number of transmit and receive antennas tend to infinity (and $N \geq M$), the capacity grows linearly with the number of transmit antennas : $C \sim M \log_2(1 + SNR)$.

The Shannon capacities given above require impractical codes with infinitely long block lengths. Our goal then is to approach these limits using practical space-time transmission and processing techniques. As mentioned earlier, one space-time transmission technique is the Alamouti space-time block code which achieves transmit diversity without using additional bandwidth or power resources compared to a single antenna transmission [7]. Unfortunately this technique is applicable only for two transmit antennas when complex data constellations are used.

Another technique is AT&T space-time trellis coding [9] which is designed to maximize diversity order and coding gain. The capacity of this technique is limited to $\log_2 G$ bps/Hz (where *G* is the constellation size), independent of the number of transmit antennas. In systems such as HSDPA where there is already significant diversity from the multiuser scheduling, it may be more beneficial to trade off less diversity for higher throughput.

A third space-time technique, Bell Labs Layered Space-Time (BLAST) [10], can be viewed as one such space-time coding technique that makes this tradeoff. In contrast to diversity systems where the same data is sent through multiple antennas, BLAST transmits multiple parallel data streams through the antennas. In addition to increased throughput, space-time interleaving and/or coding could be used to provide diversity gains as well. The transmitted signals share the same frequency band, but they can be resolved at the receiver by using multiple antennas and by relying on the distinct spatial signatures induced by the fading channel in a rich scattering environment. In general, the terminal must have at least as many antennas as the transmitter for efficient detection. Because antenna spacing of a half wavelength (about 7.5cm at 2GHz) is sufficient for signal decorrelation, the back of a laptop screen would provide ample area for four antennas. In the context of a CDMA system such as HSDPA, the multiple parallel data streams would share the same spreading code. Hence this technique can also be called *code re-use* since each code could modulate up to *M* data streams.

3. SPACE-TIME TECHNIQUES FOR HSDPA

In this section we describe a practical implementation for code re-use in a HSDPA system. Introducing code re-use as a transmission option increases the number of modulation coding schemes (MCSs) and increases the maximum throughput. For example, using code re-use with M = 4 transmit antennas, the maximum data rate achievable is 4 times the current maximum-rate MCS..

Figure 1 shows the downlink physical layer block diagram for implementing code re-use with HSDPA. The data source is demultiplexed into M data streams (M is the number of transmit antennas), and each stream is separately encoded, rate matched, interleaved, and mapped to a complex data symbol. Each stream is further demultiplexed for multi-code spreading, added, and scrambled with a pseudonoise (PN) code. The same set of multi-codes is used for each stream. In a mixed traffic system where a portion of the code space is reserved for users not on the HSDPA link, the PN sequence may be the same among the streams in order to maintain orthogonality with voice streams spread with the same PN sequence. Otherwise if there are no users other than those using the HSDPA link, the PN sequence may be different among streams so there is less correlation among them. To improve performance, a space-time interleaver can be used in place of the M parallel interleavers, providing additional diversity gain with minimal cost.

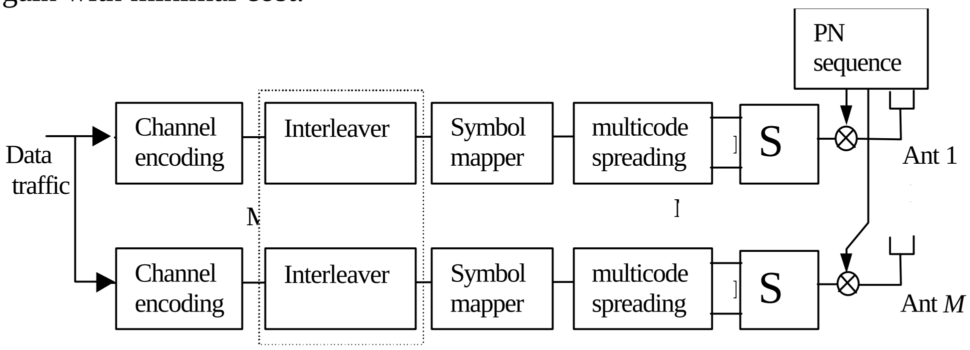

Figure 1. BLAST transmitter for downlink shared channel

Using multiple antennas with for HSDPA provides three advantages over conventional HSDPA. First, using multiple receive antennas, the gains from antenna combining reduces the required power for achieving a given rate. Alternatively, one can achieve higher rates using the same power, resulting in a higher overall cell throughput. Second, if multiple antennas are available at both the transmitter and receiver so that codes can be re-used, additional schemes can be defined that have throughputs larger than the highest rate scheme currently defined for HSDPA without going to higher order constellations. In principle the maximum achievable data rate with code re-use is M times the rate achievable with a single transmit antenna (where M is the number of transmit antennas). Higher peak throughputs imply not only better average throughputs but also better throughput-delay characteristics. Third, with code re-use, some intermediate data rates can be achieved with a combination of code re-use and small data constellations. Compared to single antenna transmission scheme with a larger constellation to achieve the same rate, the code re-use technique may have a smaller required Eb/No [11], resulting in overall improved system performance.

4. CONCLUSION

In summary, multiple receive antennas should be seriously considered for future data terminals. It would be difficult to meet the needs of future wireless data applications over large areas for a large number of users without significant improvements based on multiple terminal antennas. Furthermore, these antennas allow the possibility of code re-use which has the potential for efficiently achieving high throughput.

References

[1] Motorola. Work item description sheet for High Speed Downlink Packet Access. TSG-R document, TSGR#7(00)0032, 13-15th, March, 2000, Madrid, Spain, 3 pp.

[2] Motorola. Feasibility study of Advanced techniques for High Speed Downlink Packet Access. TSG-R WG1 document, TSGR1#12(00)0556, 10-13th, April, 2000, Seoul, Korea, 5 pp.

[3] Motorola. High speed downlink packet access. TSG-R WG1 document, TSGR1#13(00)0727, 22-25th, May, 2000, Tokyo, Japan, 58 pp.

[4] Ericsson. Some comments on High Speed Packet Data Access. TSG-R WG1 document, TSGR1#13(00)0764, 22-25th, May, 2000, Tokyo, Japan, 3 pp.

[5] Motorola. High speed downlink packet access. TSG-R WG2 document, TSGR2#13(00)1120, 22-26 May 2000, Oahu, HI, USA, 48 pp.

[6] Nokia. Considerations on High-Speed Downlink Packet Access. TSG-R WG1 document, TSGR1#14(00)0868, 4-7th, July, 2000, Oulu, Finland.

[7] S. M. Alamouti, A simple transmit diversity technique for wireless communications. *IEEE Trans. on Select Areas in Communications*, vol.16, p.1451-58, 1998.

[8] G. J. Foschini and M. J. Gans, On limits of wireless communication in a fading environment when using multiple antennas, *Wireless Personal Communications*, vol. 6, no. 3, pp 311-335, March 1998.

[9] V. Tarokh, N. Seshadri and A. R. Calderbank. Space-time codes for high data rate wireless communications: Performance analysis and code construction. *IEEE Trans on Info. Theory*, vol 44, no. 2, pp. 744-765, March 1998.

[10] G.J. Foschini, G.D. Golden, R.A. Valenzuela and P.W. Wolniansky, Simplified processing for high spectral efficiency wireless communication employing multi-element arrays. *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 11, pp 1841-1852, November 1999.

[11] H. Huang and H. Viswanathan, Multiple antennas and multiuser detection in high data rate CDMA systems. *Proceedings of the IEEE Vehicular Technology Conference*, Tokyo, Japan, May 2000.