
Agenda item:

Source: Lucent Technologies

Title: Throughput Simulations for MIMO and transmit diversity enhancements to HSDPA

Document for: Discussion

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1. INTRODUCTION

A work item on High Speed Downlink Packet Access (HSDPA) was proposed by Motorola in [1]. MIMO transmission was proposed by Lucent to enhance the performance of HSDPA [2]. Link level simulations results were presented showing potential gains for different coding and modulation schemes achieving data rates of up to 21.6 Mbps [3]. While the link simulations showed significant gains mostly for the higher data rates the impact of the MIMO technology at the system level in terms of metrics such as the average system throughput is of interest. This is especially the case since most of the link gains shown in [3] were for the high data rates which will typically only be feasible for terminals relatively close to the base station. In this contribution, we present average sector throughput results as a function of the number of base and terminal antennas available. Previous contributions on system simulation methodology do not address how system simulations can be performed when multiple antennas are considered. We describe here how the simulation methodology of [4] for single antenna set up can be generalized to multiple antennas and thus can be adopted for system throughput simulations for MIMO and diversity transmission techniques. Because many high speed applications for the HSDPA are more tolerant to packet delays than voice applications, a judicious scheduling algorithm can improve the system performance significantly. We evaluate the throughput as a function of the number of users for three different scheduling algorithms, namely max carrier-to-interference (C/I) [4], round robin and proportional fair scheduling. We illustrate through the simulation results, the interaction of transmit diversity and multi-user diversity from scheduling for the different scheduling algorithms.

The details of the simulation assumptions are presented in the next section. We emphasize that the simulation results reported here do make several simplifying assumptions. All packets are assumed to be single slot transmissions and hybrid ARQ is not considered. Error in C/I estimation at the terminal or the feedback delay and errors in reporting the C/I are not included in the simulations. Fast cell-site selection is limited to choosing the best base station at the time the terminals are placed in the sector. Only single path Rayleigh fading, independent across all antennas is considered. Nevertheless, relative comparison of performance achieved by the different antenna configurations would indicate potential gains from use of multiple antennas.

2. SYSTEM SIMULATION DESCRIPTION

2.1 Overview

The system simulation incorporates placement of base stations in a hexagonal grid, placement of terminals within each sector, determining the pathloss and shadow fading from each base to each of the terminals, choosing the best base station for service based on path loss and shadow fading, and also Rayleigh fading from the central base station to each of the terminals it serves. The system simulation is dynamic in that the Rayleigh fading simulated for each user evolves in discrete time steps of 0.667 ms corresponding to a single slot. All of the base station power excluding the overhead for pilots etc is assumed to be available for data. The pathloss, shadow fading and Rayleigh fading are combined to determine the Ec/Nt at the terminals. The determination of this Ec/Nt is by averaging the 5 samples in a 3.333 ms HSDPA frame and is in line with the description in [4] for single antenna terminals. We describe the method for multiple antennas in the next section. Once the Ec/Nt is determined, then AWGN (static) channel FER Vs Ec/Nt curves for the different coding and modulation schemes are used to determine the FER for each data rate. This FER then determines the successful over the air delivery of the packet. Different scheduling algorithms are considered in this throughput study.

2.2 Link Level Parameters and Method

Link level simulations for AWGN channel is performed for each data rate, coding and modulation. The system simulation generates 5 Ec/Nt samples per HSDPA frame. These 5 values are averaged to determine a frame metric which is then used with the appropriate static curve to determine if the frame is erased. This method is in line with what is suggested in [4]. The Ec/Nt at each time step t is determined by

$$\left(\frac{E_c}{N_t}\right)(t) = \left(\frac{E_c}{N_t}\right)_{loc} |\, h(t)\, |^2$$

where $h(t)$ is the instantaneous Rayleigh fading from the base station to the terminal and the location Ec/Nt is given by

$$\left(\frac{E_c}{N_t}\right)_{loc} = \frac{g_1 G_1 A(q_1)}{\sum_{k=2}^{19} g_k G_k A(q_k)} \frac{E_c}{I_{or}}$$

where $\frac{E_c}{I_{or}}$ is the power fraction of the central base station power devoted to this terminal and $g_{k,} G_{k,} A(q_k)$ are, respectively the shadow loss, path loss and the antenna gain from the k^{th} base station to the terminal under consideration. Note that the cells are three sectored, but the antenna pattern is assumed to be ideal outside the sector.

When multiple antennas are used and diversity mode transmission is employed the same static FER vs Ec/Nt curves are used to determine the successful transmission of the packet. However, now the system simulation simulates the Rayleigh fading coefficient, $h_{i,j}(t)$, from each transmit antenna to each receive antenna for each terminal and the Ec/Nt sample value is now computed as

$$\left(\frac{E_c}{N_t}\right)(t) = \left(\frac{E_c}{N_t}\right)_{loc} \frac{1}{M} \sum_{i=1}^{M} \sum_{j=1}^{N} |\, h_{i,j}\, |^2$$

where M is the number of transmit antennas ($M = 1, 2, or\ 4$) and N ($N = 1, 2, or\ 4$) is the number of receive antennas. Note that the above Ec/Nt is what is achieved when $M = 2$ and space-time transmit diversity (STTD) is employed at the transmitter and maximal ratio combining (MRC) is done at the receiver. For $M = 4$, since there is no known technique that achieves the full fourth order diversity without any loss in SNR, the above Ec/Nt value should be viewed as an upper bound and the throughput results obtained for the 4 transmit antenna case in the diversity mode will also be an upper bound to the actual throughput in practice.

We consider the following data rates shown in Table 1 below for the 1 transmit 1 receive, 2 transmit 1 receive, and 4 transmit 1 receive cases. Figure 1 shows the static link simulation results for each of these data rates from [5]. For multiple transmit and receive antenna scenarios, additional rates can be defined based on the idea of code reuse as explained in [2,3]. Table 2 indicates the rate set used for the system simulation in this contribution for 4 transmit and 4 receive antenna case.

Data Rate (Mbps)	Code Rate	Modulation	Mode
2.4	½	QPSK	STTD/MRC
3.6	¾	QPSK	STTD/MRC
4.8	½	16 QAM	STTD/MRC
7.2	¾	16 QAM	STTD/MRC
10.8	½	64 QAM	STTD/MRC

Table 1. Data rates for diversity modes

Data Rate (Mbps)	Code Rate	Modulation	Mode
2.4	½	QPSK	TD/MRC
3.6	¾	QPSK	TD/MRC
4.8	½	16 QAM	TD/MRC
7.2	¾	16 QAM	TD/MRC
10.8	~ ½	QPSK 4 streams	MIMO
14.4	¾	QPSK 4 streams	MIMO
21.6	¾	8 PSK 4 streams	MIMO

Table 2. Data rates for MIMO transmission for 4 Tx, 4 Rx

When multiple transmit and receive antennas are available at the both the base station and the terminals and MIMO transmission as described in [2] is employed, then the above method of determining frame erasures from frame metric based on Ec/Nt is not possible since a single Ec/Nt cannot be defined for MIMO transmission. Hence we propose to use the Shannon bound as the metric. The simulation results shown in Figure 2 indicate that this metric can be used to determine the best transmission rate based on the location Ec/Nt and also the channel matrix **H.** The log-det metric is given by

$$C\left(\left(\frac{E_c}{N_t}\right)_{loc},\mathbf{H}\right)=\operatorname{logdet}\left(\mathbf{I}_M+\frac{1}{M}\left(\frac{E_c}{N_t}\right)_{loc} l\,\mathbf{H}\mathbf{H}^h\right)$$

where $\mathbf{H}$ is the instantaneous matrix channel between the base station antennas and the terminal antennas for any given user and l is the spreading gain. As before the 5 metric sample values during a frame are averaged to obtain the frame metric which is then used to determine the frame error rate. Figure 2 shows the FER plotted against the log-det metric defined above. The plot is obtained by simulating 100 channel matrices for each of 5 different values of location Ec/Nt. For each of the channel matrices and Ec/Nt values the FER is obtained from link simulations over a large number of frames. The FER is then plotted against the log-det metric value for the corresponding channel and Ec/Nt value. It is clear that it is possible to set metric thresholds above which the FER can be guaranteed to be less than 0.1 %. For example for the 10.8Mbps data rate a metric value greater than 8 guarantees this.

2.3 System Simulation Parameters and Method

The list of some relevant system level simulation parameters is given in Table 3 below. Data-only terminals is only considered. All terminals are assigned the same speed of 3 Km/hr. All signals are assumed to be Rayleigh fading and independent across the antennas. No traffic model is considered in this simulation. Instead, all users are assumed have infinite amount of data to be sent. Three scheduling algorithms are considered. All of these scheduling algorithms transmit to a single user in a given HSDPA frame. The algorithms provide various degrees of fairness:

- Proportional Fair scheduler (PF): The scheduler maintains an average rate R_avg transmitted to each user over the last 1000 frames and examines the ratio of the instantaneous to the average channel conditions experienced by different users and chooses the user with the maximum ratio, i.e. max(R(t)/R_avg) [6]. This scheduler tries to maximize the average sector throughput while maintaining some degree of fairness.

- Maximum C/I scheduler (max C/I): The scheduler chooses the users with the highest instantaneous carrier-to-interference(C/I) ratio [4]. It achieves the maximum network throughout but ignores the user fairness.

- Round Robin (RR): This scheduler allocates equal time to all users independent of the channel conditions thus achieving fair sharing of resources.

For all three schedulers it is necessary to determine the data rate at which to transmit to the terminal chosen during a particular frame. This data rate is determined by picking the rate that maximizes the throughput, which is defined as

$$Throughput=(datarate)*\left(1-FER\left(\frac{E_c}{N_t},\mathbf{H}\right)\right)$$

The FER, which is a function of the frame averaged Ec/Nt, is obtained from the static link simulations as explained in Section 2.2 for diversity mode transmission. For the MIMO schemes, the FER is obtained from the log-det metric value. Since the FER is very sensitive to the log-det metric value we set the FER to be 10^-3 above a threshold value and 1 below the threshold. The thresholds for the different rates are determined from Figure 2.

The simulation proceeds as follows. A given number of terminals are dropped in a 120 degree sector of the central base station of a hexagonal grid of base stations. Time varying Rayleigh fading is simulated for each user. The data rate, coding and modulation scheme that achieves the maximum rate is computed for each user for each frame. The scheduling algorithm that is being simulated then determines the user to which that frame should be assigned. Based on the FER a uniform random variable is used to determine if that frame was successfully transmitted or not. Simulation proceeds for 60 seconds (18000 frames) after which the terminals are relocated randomly within the sector and the simulation is repeated. After 30 minutes of such simulation, the average sector throughput which is the total number of successful bits transmitted to all terminals divided by the total time is computed. Simulation is repeated for different number of users and different antenna configurations.

PARAMETER	VALUE	COMMENTS
Number of cells (3 sectored)	19	2 rings of interferers
Log-normal Shadowing	8.9 dB	No correlation
Propagation Model	28.3+35log10(d) dB	Interference limited simulation
Fast cell-site selection	Once per drop only	Helps combat slow fading only
Speed	3 Km/hr	Jakes Model
Delay Spread	Single ray Rayleigh	Flat fading
Site-to-site distance	Irrelevant	Interference limited scenario
Carrier frequency	1.9 Ghz	
Antenna Horizontal Pattern	70 deg (-3 dB)	
Overhead Channel Power	20 %	

Table 3: System Simulation Assumptions

3. SIMULATION RESULTS

The cumulative distribution function of the geometry obtained according to simulation parameters described in Table 3 is shown in Figure 3 for reference. The average sector throughput as function of the number of terminals (“users” in the figure) in the sector for the different antenna configurations is shown for the PF scheduling in Figure 4, for the max C/I scheduling in Figure 5 and RR scheduling in Figure 6. For the PF and max C/I schedulers we see that the throughput increases with increasing number of terminals as expected due to multi-user diversity gains.

In Figure 4 we see that when there is only one user, transmit diversity (STTD) outperforms conventional single antenna transmission since transmit diversity improves the average link quality. As the number of users increases, we observe the surprising result that the single antenna transmitter outperforms the transmit diversity system. While the average (C/I) is the same for the conventional and transmit diversity systems, the variance of the conventional system is higher. Because the scheduler services a user when its channel is relatively good, in these situations the instantaneous (C/I) of the conventional system is often higher than that of transmit diversity. Hence the single antenna throughput is higher than the STTD throughput. We see a similar phenomenon for the max C/I scheduler in Figure 5, but the loss from transmit diversity is much less marked in this case. This is due to the fact that the max C/I scheduler, for several instances of the terminal locations may transmit to only a single user always and hence variance of the C/I due to fast fading affects the max C/I to lesser extent than the PF. The RR result in Figure 6 is as expected where transmit diversity gives a small improvement in throughput.

Figure 4, 5, and 6 show the advantage of doing MIMO transmission in the 4 Tx, 4 Rx and 2 Tx, 2 Rx cases over 1 Tx, 1 Rx receive case. The gains are clearly significant for the scenario simulated. The fraction of time each of the available data rates is used is shown in Figure 7 for the 4 Tx, 4 Rx PF case. A natural question to ask is what the gain of 4 Tx, 4Rx MIMO transmission is relative to a scheme based on transmit diversity and maximal ratio combining at the receiver also with for 4 Tx, 4Rx. This is illustrated in Figure 8 for the PF scheduler. The gain for the 4Tx, 4Rx case is still significant. However, note that the 4 Tx, 4 Rx diversity curve remains flat for more than 8 users while the MIMO case continues to increase with increasing number of users. This suggests that the gap between MIMO technique and the diversity case may be reduced if power control is also employed whenever the highest rate is used.

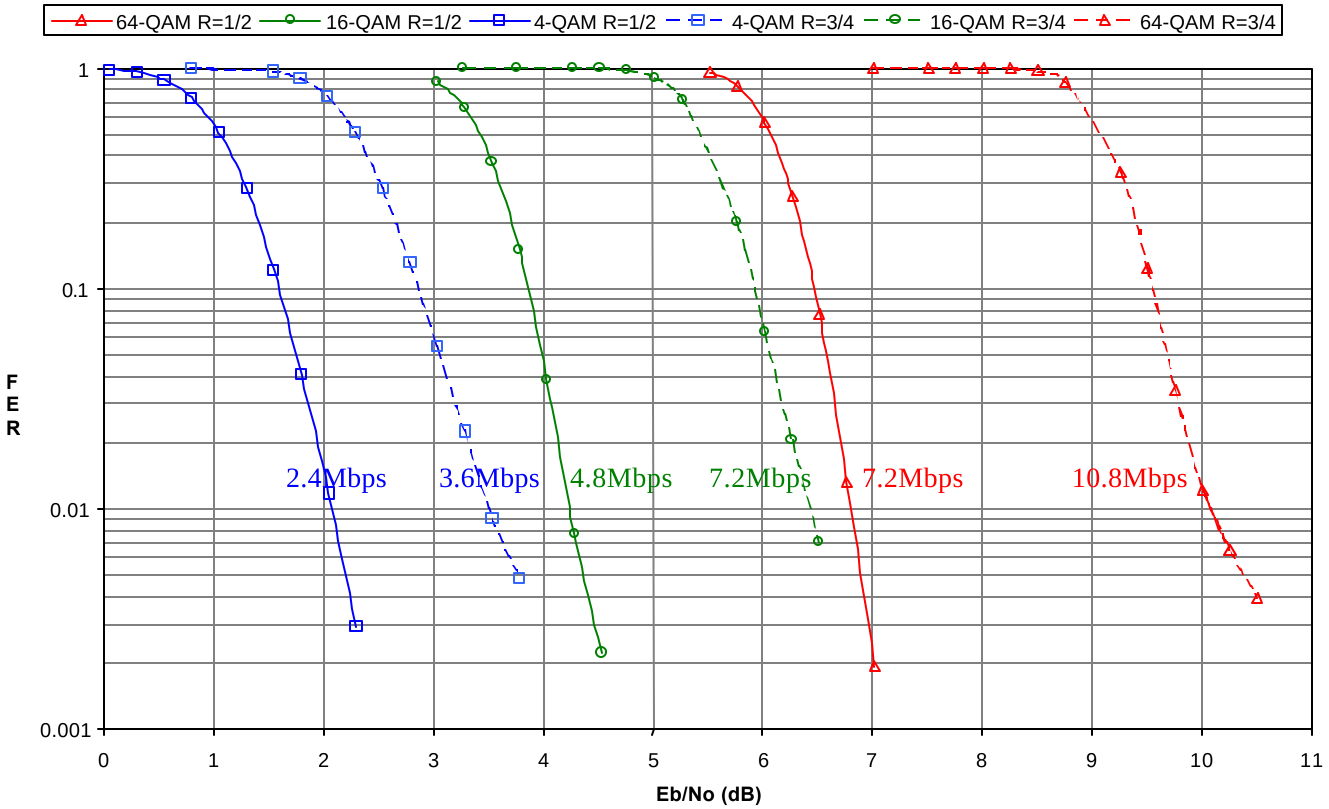

Figure 1. Static Link Level Curves

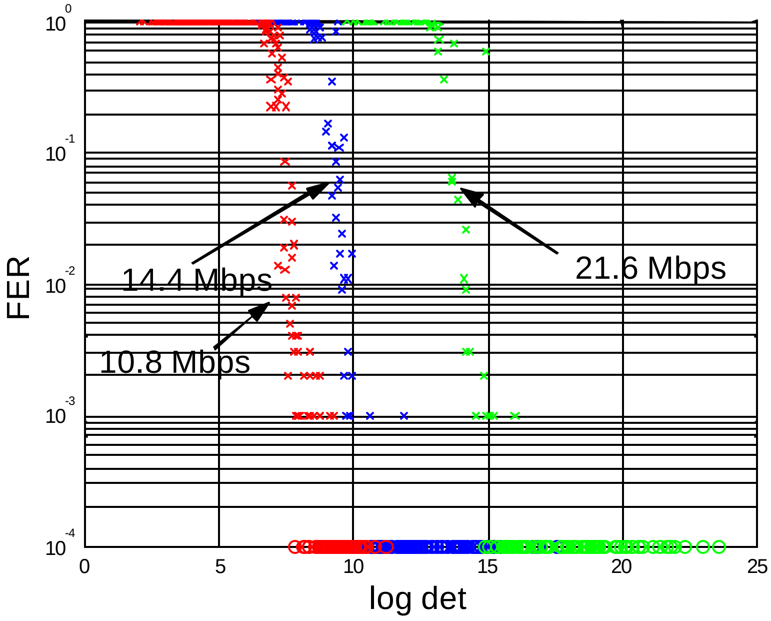

Figure 2. Frame error rate as a function of the metric $C\left(\left(E_c / N_t\right)_{loc}, \mathbf{H}\right)$

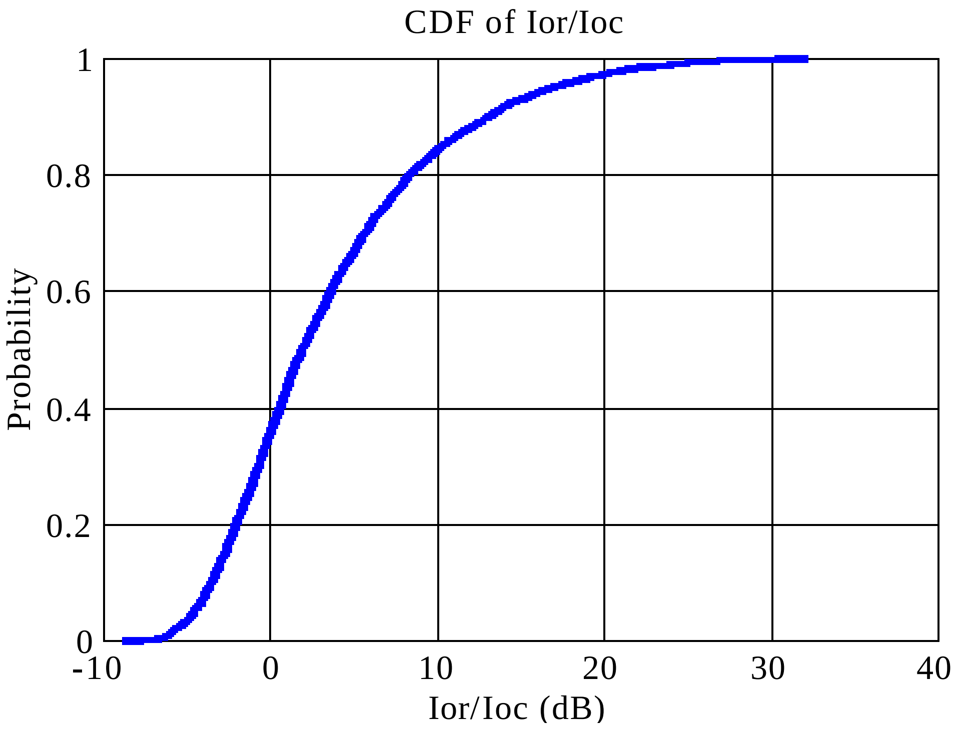

Figure 3: CDF of Geometry

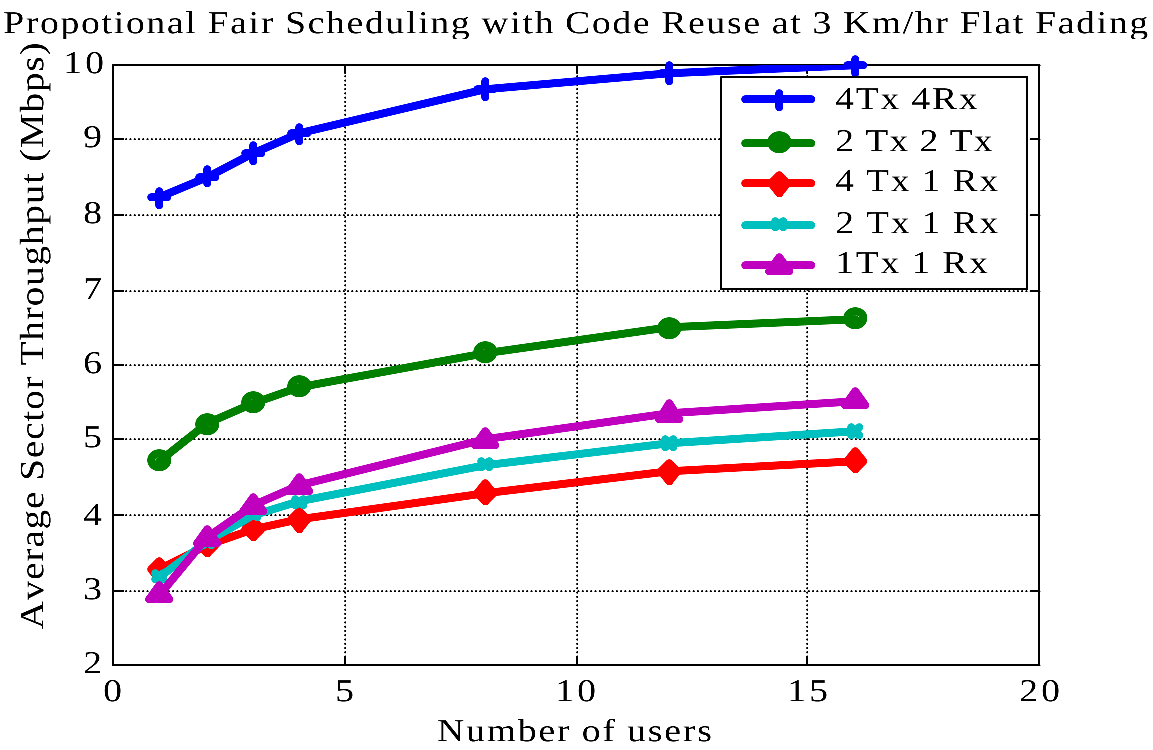

Figure 4. Average Throughput for PF scheduling at 3 Km/hr

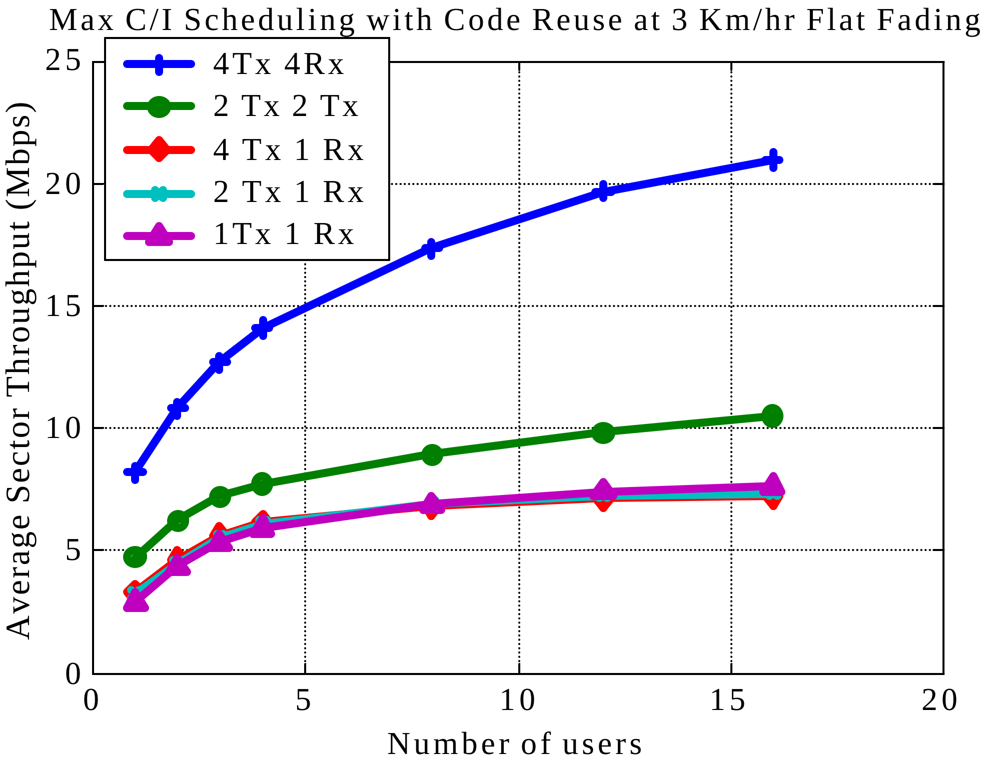

Figure 5. Average Throughput for Max C/I scheduling at 3Km/hr

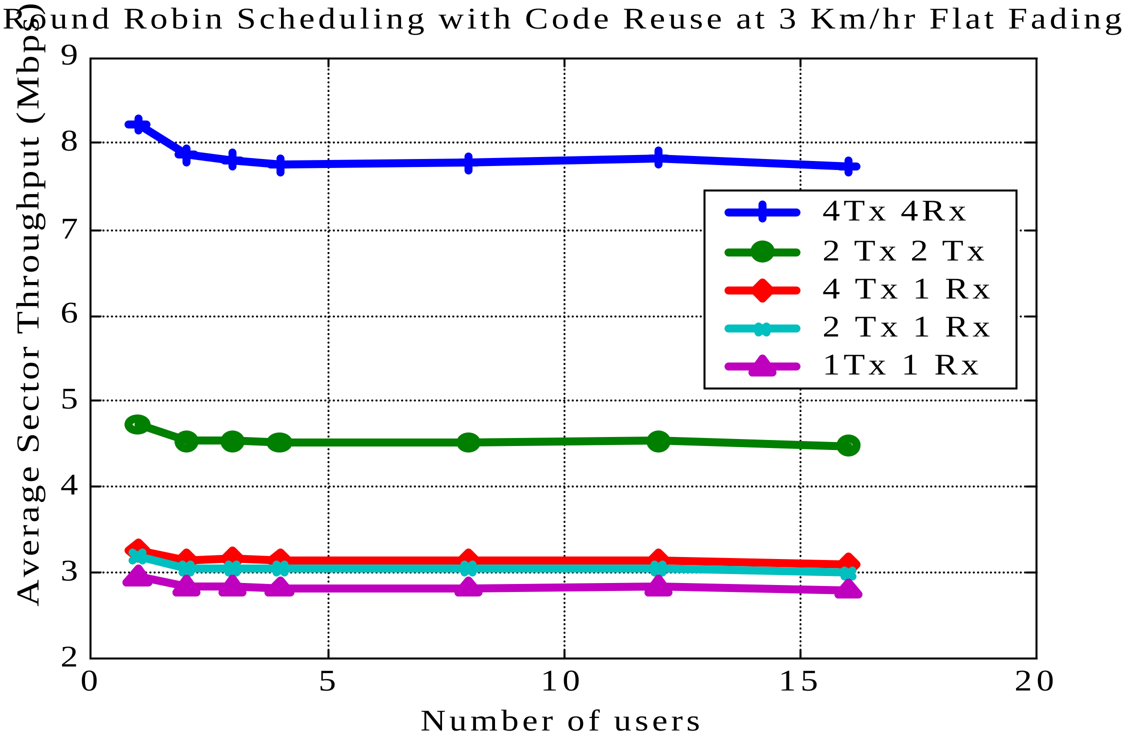

Figure 6. Average Throughput for RR scheduling at 3 Km/hr

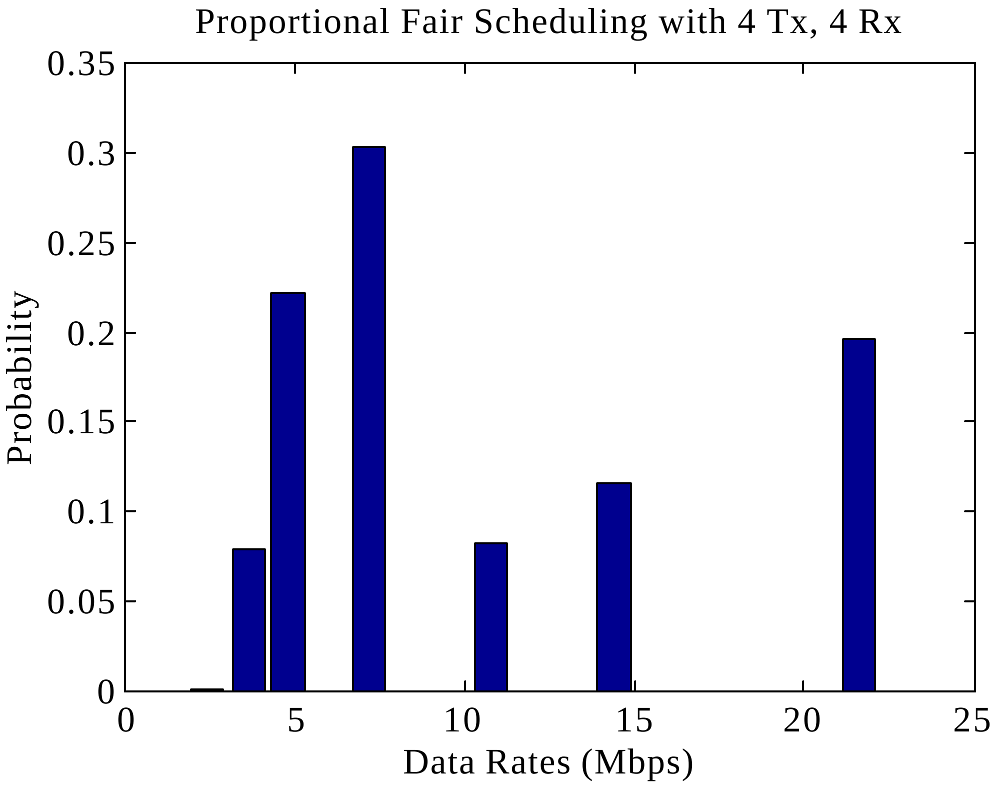

Figure 7: Histogram of rates for PF scheduler

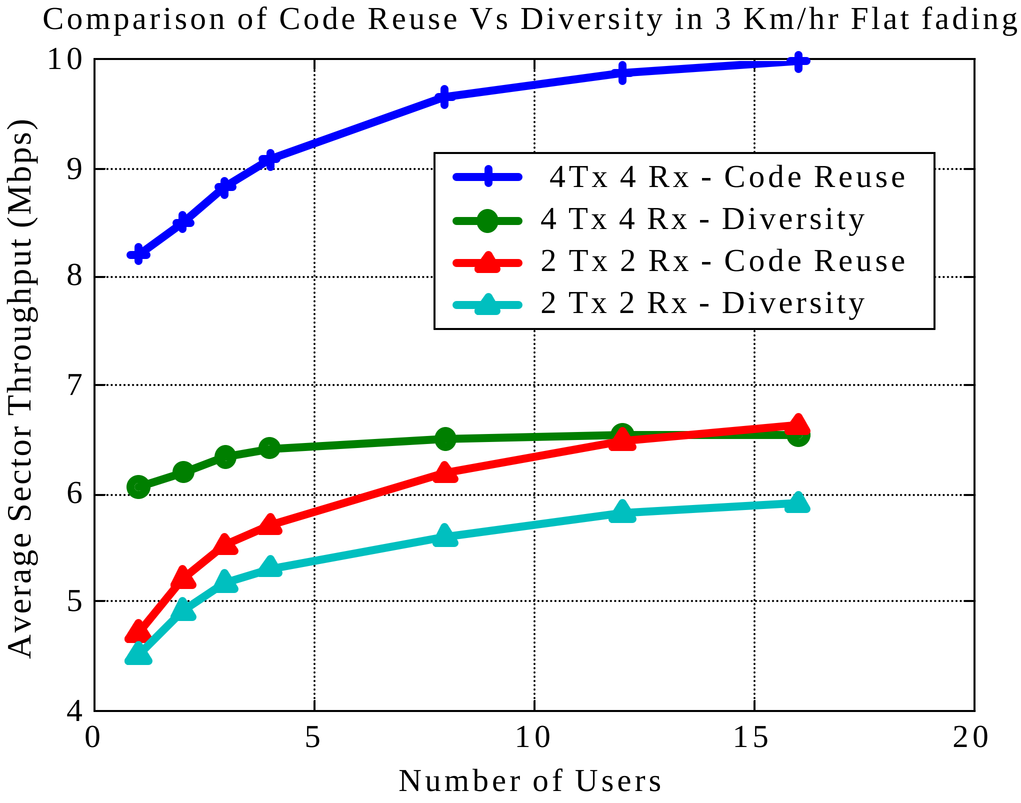

Figure 8: Comparison of MIMO with Diversity for PF scheduler

4. CONCLUSIONS

The interaction of multi-user diversity and transmit diversity was illustrated. Transmit diversity gains generally diminish with increasing number of terminals due to multi-user diversity gains for channel-aware scheduling schemes. Using proportional fair scheduler, transmit diversity actually hurts the system throughput performance for number of users greater than 2. The use of MIMO technique can potentially increase the system throughput significantly at least for flat fading channels with low mobility as shown by our simulation results. It should be pointed out that we used the same pilot power fraction for both the single antenna and multi-antenna scenarios, while in practice some additional pilot power will be required for the multiple antenna case since more channels have to be estimated. Also, it should be noted that the link simulations for MIMO were based on maximum likelihood detector and the gains may be reduced with less complex detectors.

5. 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.
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[3] Lucent. Preliminary link level results for HSDPA using multiple antennas. TSG_R WG1 document TSGR1#16(00)1218, 10-13th, October 2000, Pusan, Korea.
[4] Motorola, "Evaluation Methods for High Speed Downlink Packet Access", TSG R1#14(00) 909
[5] Motorola, " Link Evaluation Methods for HSDPA", TSGR1#14(00)910
[6] D. Tse, "Forward-Link Multiuser Diversity through Rate Adaptation and Scheduling", submitted to IEEE *Journal. on Select Areas in Communications.*