Performance of a MAC Protocol for Multicell Cellular Systems with Space Time Processing *

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ABSTRACT

A smart antenna's ability to combat both cochannel interference(CCI) and inter-symbol interference(ISI) makes it an important candidate for enhancing system performance in a high speed cellular network. However, the randomness and dynamics implied by a packet switched wireless data network makes the MAC design a very difficult issue. In this paper, we present a reservation based MAC protocol for multi-cell cellular systems with space time processing capabilities. We study the protocol's performance in frequency selective fading channels. Different receiver structures and different system design parameters are compared, providing guidelines for system design. Throughput results compared to the case of flat fading show the degree to which the system performance is degraded by ISI. Training overhead needed for providing channel estimation in the protocol is also given in terms of the receiver tap numbers.

1 INTRODUCTION

Bandwidth demanding applications such as Internet access and multimedia services require high date rates, and digital transmission at high rates faces the challenge posed by multipath induced inter-symbol interference(ISI). In general, several methods can be used to combat ISI: spread spectrum, multicarrier modulation, and channel equalization. For example ETSI HIPERLAN-1, bases its air interface on single carrier GMSK modulation combined with channel equalization. In fact, techniques such as adaptive decision feedback equalization has been demonstrated to be essential for solving the problem of ISI for digital transmission over multipath channels at high symbol rate [1, 2].

In addition to ISI, cellular frequency reuse causes cochannel interference(CCI), and further limits the communication quality and the system capacity. Spread spectrum and directional antennas are commonly used by system designers to combat CCI. In spread spectrum communications, the processing gain offers protection on the desired users' signal from the cochannel interfering users. With multiple antennas, the desired users' signal will have spatial signatures distinct from the signals of the cochannel users, and this difference is exploited to reduce the CCI.

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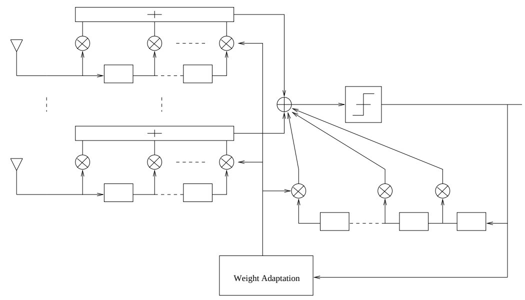

Figure 1: Space Time DFE

Abatement of ISI with channel equalization and abatement of CCI with multiple antennas could be incorporated into space time processing. Space time processing has the advantage of enhanced array gain, increased diversity gain as well as the ability to suppress ISI and CCI simultaneously, and thus provide capacity enhancement, extended coverage or improved service quality [5]. In addition, a software radio architecture can be implemented more conveniently exploiting both spatial and temporal signal processing [3, 4]. The optimum spatial and temporal receiver requires a Viterbi detector, which will not be considered in this paper due to its high degree of complexity. However, good results could be achieved by combining an adaptive decision feedback equalizer(DFE) with smart antennas.

In this paper, we present a reservation based MAC protocol for a cellular system equipped with space time processor as shown in Figure 1, and then study its performance in a typical multiple cell environment. The MAC protocol enables dynamic assignment of bandwidth to bursty mobile terminals, and also provide means to allow rapid array acquisition in a random environment. With this protocol, we exploit the smart antenna's ability to resolve multiple users at the same time.

In a realistic wireless system, factors such as flat or frequency selective fading, shadowing, path loss, base station assignment and number of users in a cell affect the system performance in various ways. With smart antenna at the base station, the system performance is also determined by the receiver structure used, and depends on the training overheads provided by the MAC protocol. In this paper, we focus our attention on some of the major factors that govern the system performance including the effect of long delay spread, the influence of various numbers of antenna elements, the comparison of different receiver structures, particularly, the comparison of different size of the ST-DFE receiver, and the effect of different training overhead.

A quasi-analytical approach that combines both reasonable efficiency and good modelling accuracy is taken. Simulation results under a realistic cellular environment are obtained to demonstrate the impact of the above mentioned parameters on the performance of the system, and their implications on system design are discussed. Typical results show that although severe ISI together with CCI causes degradation in system performance compared to the case of flat fading, we are able to ensure satisfactory SINR performance and thus desirable throughput performance under full frequency reuse by choosing the right configuration of antenna numbers and the right receiver structure at the base station . On the other hand, admission rules for a specific system configuration can be derived from the obtained results to control the number of users admitted, so that each admitted user is guaranteed to have a certain throughput level.

The paper is organized as follows: In section 2, the MAC protocol is described. And then the space time processing algorithm is presented in section 3. In section 4, we will give the simulation model. Simulation results for the MAC protocol are presented in section 5, and finally, we conclude the paper with section 6.

2 The Reservation MAC Protocol

Intended for bursty data traffic, a MAC protocol seeks to insure an orderly sequencing of packets from the various users onto the shared channel, with a minimum of time lost to collisions. The MAC delivers bandwidth-on-demand, meaning that a user having a greater volume of packets to send contends for the channel more frequently than one having less to send.

When applied to cellular radio systems, a MAC protocol must also cope with the various impairments suffered on the radio link (multi-path fading, shadowing, co-channel interference from other users). This is especially troublesome since not all receivers will hear all transmissions with the same intensity, making access cooperation among the users more difficult to achieve. In addition, the upstream/downstream traffic may be both highly dynamic and highly asymmetric, implying that the full bandwidth channel must be shared by the base station and all remote units within the cell.

We consider Time Duplex Division (TDD) systems with slow fading, where the time between a receive and a transmit is small compared to the channel coherence time, thus the reciprocity principle holds. Also, TDD flexibly enables instantaneous and asymmetrical division of the radio spectrum between the uplink and downlink directions as may be needed to support multimedia applications.

The frame structure for the MAC protocol is shown in Figure 2. It consists of three parts: reservation and grant period, uplink period and downlink period.

The uplink period and downlink period are composed of multiple slots. In each slot, a number of users will transmit their information to the base station simultaneously or receive information from the base station simultaneously. Since packet switching essentially requires the space time processor at the base station to be tuned slot by slot, as the set of users transmitting in a given slot is dynamically depending on the random traffic, the information transmissions are always preceded by training sequences, enabling the base station to acquire the proper combining weight for the space time processor with a fast algorithm.

The training field here provides the base station with the information of the interference environment that the user will experience during this slot. we assume that synchronization is achieved between neighboring cells within some small guard time, so that the training field will contain all interference and the interference situation will not change in the duration of one slot. The training sequences also serve the function of distinguish the desired user from the interfering users.

The base station needs to know which training sequence it should use to get the correct weight. In our scheme, the users make reservations before-hand and thus the base station knows when to expect each user. For every active user, there is one reservation and grant(RG) slot reserved for it in the reservation and grant period to send request to the base station and get channel assignment information from the base station. Reservation slot could be used exclusively for some streaming type users, since the users are generating packets at a variable rate, they have to inform the base station of the current number of packets in their queue or the variation since last request. The information transmission slots in both the uplink and downlink direction are assigned to a user according to its demand. Upon completion of the call or a long burst, the user send a termination indicator in the reservation slot to release the resources.Unnecessary contentions are avoided by using RG slots.

3 Space Time Processing

A Key enabler of a meaningful study is a detailed model of the system. A thorough characterization of it(including frequency selective fading, shadowing, path loss, best station assignment, matched filtering and coding) results in computationally intensive efforts. It is very important to find accurate analytical approximations to provide a faster way to do physical layer numerical analysis. We take a pseudo-analytical approach which couples reasonable efficiency with good modelling accuracy. A time discrete model in the equivalent low-pass domain is considered. It is assumed that burst synchronization is achieved. We use the following notations in the paper:

- $\mathbf{A}$, bold face denotes matrix
- $\underline{A}$, underline denotes vector
- $(.)^*, (.)^T$ designates the complex conjugation and transposition respectively
- $(.)^H$ designates the complex conjugation and transposition

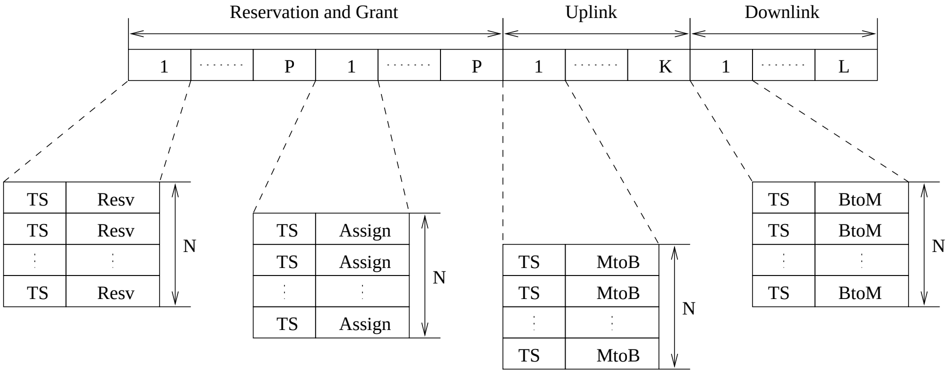

Figure 2: MAC Frame

The channel impulse response for each user can be expressed in the form of the following matrix:

$$\mathbf{H} = \begin{pmatrix} h_{11} & \cdots & h_{1N_{ds}} \\ \vdots & \vdots & \vdots \\ h_{l1} & \cdots & h_{lN_{ds}} \end{pmatrix}$$

l is the number of antennas at the receiver and N_{ds} is the channel length in symbol periods. $\mathbf{H}$ captures the effects of the array response, path fading, and path loss. It is assumed to be time invariant during the time slot we are considering.

The overall signal plus interference and noise model at the receiver antenna array can be written as:

$$\begin{aligned} \underline{x}_k &= \mathbf{H} \cdot \underline{\mathbf{S}}_\mathbf{k} + \sum_{\mathbf{q=1}}^{\mathbf{Q}} \mathbf{H^q} \cdot \underline{\mathbf{S}}^\mathbf{q}_\mathbf{k} + \underline{\mathbf{n}}_\mathbf{k} \qquad (1) \\ &= \underline{r}_k + \sum_{q=1}^{Q} \underline{r}_k^q + \underline{n}_k \end{aligned}$$

where Q is the number of both inter-cell and intra-cell interference users, $\mathbf{H}$ and $\mathbf{H^q}$ are the channel impulse response matrices for the desired user and the q_{th} interference user respectively, and $\underline{n_k}$ is the sampled vector of additive noise. And $\underline{S_k}$ and $\underline{S_k^q}$ are vectors of N_{ds} consecutive symbols of the transmitted sequence of the desired user and the q_{th} interference user, and is defined as:

$$\underline{S}_k = \begin{pmatrix} s_k & \cdots & s_{k-N_{ds}+1} \end{pmatrix}^T$$

The s_k's are given by the following expression

$$\begin{aligned} s_k &= \underline{G}^T \times \underline{d}_k \\ &= \underline{G}^T \times \begin{pmatrix} d_{k+N_{ISI}} \\ \vdots \\ d_k \\ \vdots \\ d_{k-N_{ISI}} \end{pmatrix} \end{aligned}$$

where d_k's are the data sent by the user and $\underline{G}$ is the shaping filter coefficients, N_{ISI} is the truncation length of the shaping filter.

$$\underline{G}^T = \begin{pmatrix} g_{-N_{ISI}} & \cdots & g_0 & \cdots & g_{N_{ISI}} \end{pmatrix}$$

Note that Equation 1 suggests that signal and interference are baud synchronous. However, this constraint can be relaxed and the time offsets can be absorbed into the channel response matrices.

All the received signals that the space time processor will operate on can be expressed by the following vector:

$$\begin{aligned} \underline{R} &= \underbrace{\begin{pmatrix} \underline{r}_{1+N_{ff}} \\ \vdots \\ \underline{r}_1 \\ d_0 \\ d_{-1} \\ \vdots \\ d_{-Nfb+1} \end{pmatrix}}_{\underline{R}^0} + \sum_{q=1}^{Q} \underbrace{\begin{pmatrix} \underline{r}^q_{1+N_{ff}} \\ \vdots \\ \underline{r}^q_1 \\ 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix}}_{\underline{R}^q} + \underbrace{\begin{pmatrix} \underline{n}_{1+N_{ff}} \\ \vdots \\ \underline{n}_1 \\ 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix}}_{\underline{N}} \\ &= \underline{R}^0 + \sum_{q=1}^{Q} \underline{R}^q + \underline{N} \end{aligned}$$

where N_{ff} and N_{fb} are the lengths of the feedforward part and feedback part. In the feedforward part, each vector contains l elements, and l is the number of antennas as aforementioned. The space time processor chooses the weights to achieve the minimum mean square error:

$$\arg\min_{\underline{W}} E \left\| \underline{W} \cdot \underline{R} - d_1 \right\|$$

And by the projection theorem, the solution to this problem is [5, 6]:

$$\begin{aligned} \underline{W} &= \{E\{\underline{R} \cdot \underline{R}^H\}\}^{-1} \cdot E\{\underline{R} \cdot d_1^*\} \\ &= \mathbf{R_{xx}^{-1}} \cdot \underline{\mathbf{Rd}} \qquad (2) \end{aligned}$$

Assuming that the signals transmitted by different users are independent and they are independent of the noise, then we will have:

$$\begin{aligned} \mathbf{R_{xx}} &= E\{\underline{R}^0 \cdot (\underline{R}^0)^H\} + \sum_{q=1}^{Q} E\{\underline{R}^q \cdot (\underline{R}^q)^H\} + E\{\underline{N} \cdot \underline{N}^H\} \\ &= \mathbf{R} + \sum_{\mathbf{q=1}}^{\mathbf{Q}} \mathbf{R^q} + \mathbf{R_n} \qquad (3) \end{aligned}$$

$\mathbf{R}$ is the contribution from the desired user, and $\mathbf{R^q}$ is the contribution from the q_{th} interference user, and $\mathbf{R_n}$ is the noise autocorrelation matrix.Note that we have $\mathbf{R^H} = \mathbf{R}$.

To obtain $\mathbf{R}$, we first need to know

$$\underline{r}_i * \underline{r}_j^H = E\left\{\mathbf{H} * \mathbf{R(i,j)} * \mathbf{H^H}\right\}$$

where $\mathbf{R(i,j)}$ is a N_{ds} by N_{ds} matrix with the (k,l) element given as:

$$\begin{aligned}\mathbf{R(i,j)_{kl}} &= E\left\{\underline{d}^T_{i-(k-1)} * \underline{G} * \underline{G}^H * \underline{d}^*_{j-(l-1)}\right\} \\ &= sum\left\{E\left[\underline{d}_{i-(k-1)} * \underline{d}^H_{j-(l-1)}\right] .* \left(\underline{G} * \underline{G}^H\right)\right\}\end{aligned}$$

".*" here means multiply element by element. Notice that $\mathbf{R(i,j)} = (\mathbf{R(i-j)}$ is only determined by $i-j$. And

$$\begin{aligned}&E\left[\underline{d}_{i-(k-1)} * \underline{d}^H_{j-(l-1)}\right] \\ &= \begin{cases}\mathbf{Diag(1,m)_{(2N_{ISI}+1)\times(2N_{ISI}+1)}}, \\ \quad (i-k)-(j-l) = m \; and \; |m| \leq N_{ISI} \\ \\ \mathbf{0_{(2N_{ISI}+1)\times(2N_{ISI}+1)}}, \\ \quad Otherwise\end{cases}\end{aligned}$$

where $\mathbf{diag(1,m)}$ is a matrix with 1 on the m_{th} diagonal and 0 at all other places.When $m = 0$, it is the main diagonal, when $m < 0$, it is the diagonal above the main diagonal, and when $m > 0$, it is the diagonal below the main diagonal.

We also need

$$\begin{aligned}&E\left\{\underline{r}_i \begin{pmatrix} d^*_0 & \cdots & d^*_{-N_{fb}+1}\end{pmatrix}\right\} \\ &= E\left\{\mathbf{H}\begin{pmatrix}\underline{d}^T_i\underline{G} \\ \vdots \\ \underline{d}^T_{i-N_{ds}+1}\underline{G}\end{pmatrix}\begin{pmatrix} d^*_0 & \cdots & d^*_{-N_{fb}+1}\end{pmatrix}\right\} \\ &= \mathbf{H}\underbrace{E\left\{\begin{pmatrix}\underline{d}^T_i\underline{G} \\ \vdots \\ \underline{d}^T_{i-N_{ds}+1}\underline{G}\end{pmatrix}\begin{pmatrix} d^*_0 & \cdots & d^*_{-N_{fb}+1}\end{pmatrix}\right\}}_{\mathbf{RF_i}}\end{aligned}$$

where

$$\begin{aligned}&(\mathbf{RF_i})_{\mathbf{kl}} \\ &= E\left\{\underline{d}^T_{i-(k-1)}\underline{G}d^*_{-(l-1)}\right\} \\ &= E\left\{\underline{d}^T_{i-(k-1)} \cdot d^*_{-(l-1)}\right\}\underline{G} \\ &= Sum\left\{E\left\{\underline{d}^T_{i-(k-1)} \cdot d^*_{-(l-1)}\right\} .* \underline{G}\right\}\end{aligned}$$

The first term in the above formula is given by

$$\begin{aligned}&E\left\{\underline{d}^T_{i-(k-1)} \cdot d^*_{-(l-1)}\right\} \\ &= \begin{cases}\underline{e}_{N_{ISI}+1+m}, \\ \quad i-k-l = m \; and \; |m| \leq N_{ISI} \\ \\ \underline{0}_{(2N_{ISI}+1)\times 1}, \\ \quad Otherwise\end{cases}\end{aligned}$$

where $\underline{e}_i$ is the unit vector in which the i_{th} element is 1 and all others are zeros, and $\underline{0}$ is the all zero vector.

From the results we obtained so far and by applying the fact $\mathbf{H} = \mathbf{H^H}$, we could construct the entire $\mathbf{R}$ matrix . The $\mathbf{R^q}$'s in Equation 3 can be obtained in a similar way. We still need $\underline{Rd}$ in Equation 2 to calculate the correct combining weight.

$$\underline{Rd} = \begin{pmatrix}\underline{Rd}_i & \cdots & \underline{Rd}_1 & 0 & \cdots & 0\end{pmatrix}^T$$

where

$$\begin{aligned}\underline{Rd}_i &= E(\underline{r}_i \cdot d^*_1) \\ &= E\left\{\mathbf{H} \cdot \begin{pmatrix}\underline{d}^T_i\underline{G} \\ \vdots \\ \underline{d}^T_{i-N_{ds}+1}\underline{G}\end{pmatrix} \cdot \mathbf{d}^*_1\right\} \\ &= \mathbf{H}\underbrace{E\left\{\begin{pmatrix}\underline{d}^T_i\underline{G} \\ \vdots \\ \underline{d}^T_{i-N_{ds}+1}\underline{G}\end{pmatrix} \cdot d^*_1\right\}}_{\mathbf{RS_i}}\end{aligned}$$

where $\underline{RS_i}$ can be calculated similarly as $\underline{RF_i}$

$$\begin{aligned}&(\underline{RS_i})_k \\ &= E\left\{\underline{d}^T_{i-(k-1)}\underline{G}d^*_1\right\} \\ &= E\left\{\underline{d}^T_{i-(k-1)} \cdot d^*_1\right\}\underline{G} \\ &= Sum\left\{E\left\{\underline{d}^T_{i-(k-1)} \cdot d^*_1\right\} .* \underline{G}\right\}\end{aligned}$$

where

$$\begin{aligned}&E\left\{\underline{d}^T_{i-(k-1)} \cdot d^*_1\right\} \\ &= \begin{cases}\underline{e}_{N_{ISI}+1+m}, \\ \quad i-k = m \; and \; |m| \leq N_{ISI} \\ \\ \underline{0}_{(2N_{ISI}+1)\times 1}, \\ \quad Otherwise\end{cases}\end{aligned}$$

To implement the system described, it is worthwhile to note that the complexity of the receiver is directly in proportion to the number of taps. Since higher bit rates are required, we have to employ a sufficiently small number of taps to keep the computational cost tractable and yet the system performance acceptable. Note that there are all together $l(N_{ff}+1)$ taps in the feedforward chain and N_{fb} taps in the feedback chain.

In an actual system, a training sequence of Nt know symbols will be transmitted to initialize the coefficients. Since the wireless channel is time variant, a decision directed mode could be used to track the channel thereafter. In our simulations, we consider the variance of the channel is slow enough so that it can be viewed as static over the time slot considered and thus the tracking is not necessary.

The simple, fast and robust Recursive Least Square(RLS) algorithm could be used to adaptively to update the coefficients involved in the scheme. The RLS algorithm uses the training sequences to adjust the filter weights of the ST-DFE, following the procedures listed below [7]: Suppose at time $t-1$ we have the combining weight $\underline{W}(t-1)$, and the newly received signal component at time t is $\underline{r}(t)$. Then the estimate error is

$$e(t) = d(t) - \underline{W}^H(t-1) \cdot \underline{r}(t)$$

and the Kalman gain vector is given by:

$$\underline{K}(t) = \frac{\mathbf{P(t-1)} \cdot \underline{\mathbf{r}}(\mathbf{t})}{\lambda + \underline{r}^H(t) \cdot \mathbf{P(t-1)} \cdot \underline{\mathbf{r}}(\mathbf{t})}$$

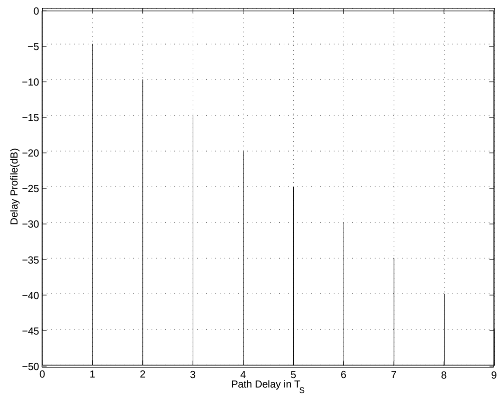

Figure 3: Delay Spread Profile

where

$$\mathbf{P(t)} = \frac{\mathbf{1}}{\lambda}\left[\mathbf{P(t-1)} - \underline{\mathbf{K}}\mathbf{(t)} \cdot \underline{\mathbf{r}}^{\mathbf{H}}\mathbf{(t)} \cdot \mathbf{P(t-1)}\right]$$

Then the coefficients can be updated by:

$$\underline{W}(t) = \underline{W}(t-1) + \mathbf{P(t)} \cdot \underline{\mathbf{r}}\mathbf{(t)} \cdot \mathbf{e^*(t)}$$

4 Simulation Model

A cellular system is considered, the base stations are located at the center of an hexagonal cell. There is an space time processor at each base station. A frequency reuse factor of unity is considered. The modelled propagation characteristics include path loss(following an inverse fourth power decay with distance), log-normal shadowing with a standard deviation of 6dB, and Rayleigh multipath fading, following the wide-sense stationary uncorrelated scattering model. The delay spread is assumed to comprise multiple channel symbols, so that the fading process is frequency selective.We use the delay profile shown in Figure 3, where the power decreases exponentially with delay, and the maximum delay spread is up to 10 symbols. Finally, all propagation characteristics remain constant on a time scale larger than the time scale on which connections are established and torn down. Accordingly, all propagation parameters, including the multipath impulse response, are random but fixed in time.

There are multiple active users in each cell. Users are dispersed in the system randomly and assigned to a base station based on best long-term channel conditions accounting for path loss and log-normal shadowing. This assignment strategy reduces the interference throughout the system. On the uplink, user signals are power controlled so that the received power at the base station will be a constant when averaged over multipath fading.

For a certain user, there are two sources of cochannel interferences: the intracell interference from the users in the same cell and the intercell interference from the users in the adjacent cells. For the intercell interferences, we account for the interferences from the six closest cells.

As shown in the MAC protocol, up to M users per cell are allowed to transmit in each slot. When the load of the system is heavy, where all users have data to transmit all the time, there will be exactly M transmissions in each cell in every slot. All the results presented here are for the uplink direction, where the MAC protocol is of more importance.

5 Numerical Results

From the point view of protocol analysis, the packet loss rate is of great significance. In the environment under consideration, where the propagation conditions are assumed invariant during a time slot, there is a one-to-one correspondence between SINR and error probabilities. A packet is assumed to be correctly received if the SINR it experiences exceeds a certain threshold, chosen according to some minimum BER requirement. If such a threshold is not met, the packet is assumed to be incorrect. We will presents mostly the SINR statistics for all the users in the simulated system. When needed, the error probabilities could be obtained using their relationship to the SINR statistics.

Figure 4 shows how the SINR statistics changes with the number of antennas for the cases of 2-3 users per cell. The feedforward filter length and the feedback filter length are set to 2 and 9 respectively. The plots give the the 90 percentiles to 99 percentiles of the output SINR. For example, in Figure 4(b), when there are 12 antennas, 95 percent of the time, the users are having a SINR greater than 10dB, or equivalently, 95 percent of the users are experiencing SINR greater than 10 dB any time. From the plots, we can see that if the number of antennas is fixed, the SINR get worse when the number of users increase, which is natural since there are more interferers. If the number of users are not changing, but the number of antennas are increased, the SINR also gets better significantly. It can also be noted that when we increase the antenna numbers from 4 to 8, there is a more significant increase in the system performance than if we increase the number of antennas from 16 to 20. This can be explained by the fact that on average there is a certain number of dominant interferers in the system. When the number of antennas is small, adding more elements will help to suppress more dominant interferers which leads to much better performance. While when the number of antennas is large enough to cancel out all the dominant interferers, adding more elements still helps, but not as effective as when the antenna number is small.

Given the SINR statistics, we can easily compute the average number of successes per slot, and the throughput for the cases with different number of antennas are plotted in Figure 5. Here we assume that a transmission is successful when the SINR is greater than 10dB. When the number of antennas is large enough to combat the interferences, increasing the number of users per cell gives more throughput. But note from the plots that allowing more users to transmit in a cell is not always desirable, even if multiple successful transmissions are possible. The throughput first increases as the number of users increases up to a certain point, and then it decreases as more users are allowed. Because large number of simultaneous transmissions will cause excessive interferences and thus be detrimental to the overall throughput. Comparing with the throughput plot under the same SNR for flat fading case in Figure 6, we can see that there is a significant degrade in throughput. Taking into account that the receiver structure here is much more complex than that in the flat fading case, the penalty paid for the frequency selective fading is costly. But the good side is that we are able to achieve satisfactory throughput performance with more complex receiver and increased antenna numbers.

Figure 7 shows how the SINR statistics changes with the length of feedforward filter for the case of 2 users in each cell. The number of antennas is fixed to 8, and the length of feedback filter is fixed to 9. We can see that as we increase the length of the feedforward filter length, which essentially increase the capability of the space time processor, the system performance can be improved. In the plot, $N_{ff} = 0$ corresponds to the case, where only a beamformer is used in the feedforward part, hence the space time processor reduces to the BF-DFE structure . From the results, we can see that ST-DFE out performs BF-DFE by a significant margin.

Figure 8 shows how the SINR statistics changes with the length of feedback filter. The number of antennas is fixed to 8, and the length of the feedforward filter is fixed to 2. The effects of increasing the feedback filter length is different under different occasions. When the number of users in each cell is small, e.g. Figure 8(a), the system performance improves with longer feedback filter length. But when the number of users in each cell is large, e.g. Figure 8(b), there is almost not much improvement by increasing the length of the feedback filter. This could be attributed to the fact that when the number of users are large, the co-channel interference is the dominant factor in system performance. Since feedback filter only helps to suppress residual inter-symbol interference, increasing its length will not be of much use when the CCI is dominant.

Figure 9 shows how the SINR statistics changes with the length of training sequences when the RLS algorithm is used. The number of antennas is 8, and the length of the feedforward and feedback filter are 2 and 9 respectively. There are one active user in each cell. The output SINR is plotted again the training sequence length, and the 95 to 99 percentiles of the output SINR are shown. The training length is expressed as integer multiplications of the number of taps. For example, 99 percent of the users experience SINR more than 11.3dB when the training sequence length is 4 times the number of taps. It is clear from the plots that a training sequence length of 4 to 8 times the number of taps are enough to get near the asymptotic performance. Not much performance gain can be obtained by increasing the training length even more.

6 Conclusion

A ST-DFE can be formed by combining the power of smart antennas and decision feedback equalizer. In this paper, suitable MAC protocol has been designed to exploit the space-time processing power provided by such receiver, and the performance of the protocol in a heavily loaded cellular system is studied, taking into account both the ISI and the CCI. The power of the space time processing to improve the system performance under appropriate MAC protocol is demonstrated again. And it is shown that the feedforward part play a significant role in STP especially when the CCI is severe. We also show that a training length of 4-8 times the number of taps are needed to get near the best possible performance. Compared with the throughput for flat fading case, there is a degradation in performance when the system is suffering frequency selective fading. But with increased antenna numbers and more complex receiver such as ST-DFE, satisfactory throughput performance can be achieved.

When examined over a time window much smaller than the reciprocal of its Doppler frequency, the impulse response of the radio channel is identical in both directions. In other words, the information obtained from the wireless channel by probing in it one direction is also valid in the opposite direction provided that the channel can be assumed stationary during this time interval. This fact has been conveniently exploited to propose an asymmetric system configuration that perform both the uplink and downlink related operations at the BS [1, 8]. The mobiles are thus relieved from the complexity associated with these tasks.

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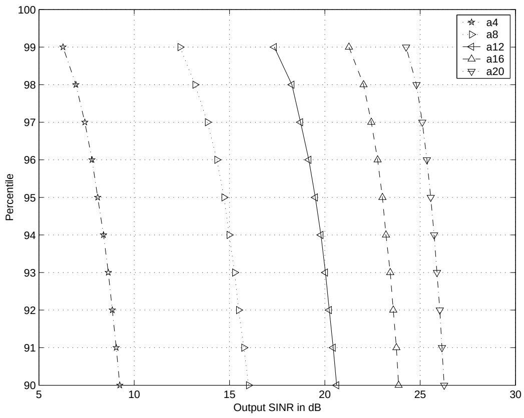
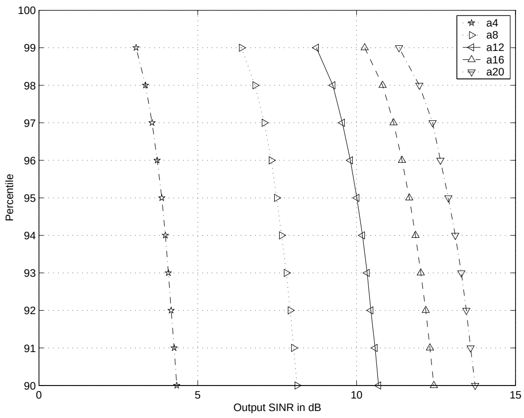
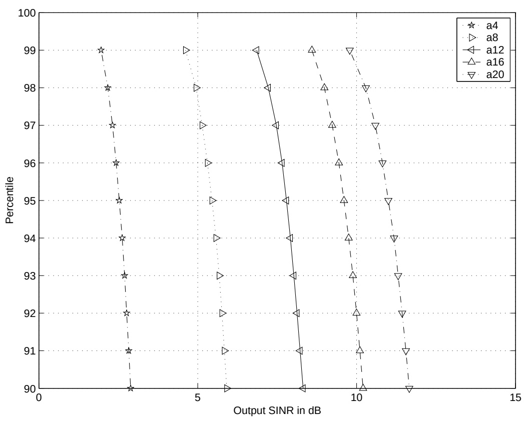


(a) One user per cell



(b) Two users per cell



(c) Three Users per Cell

Figure 4: Different number of Antennas

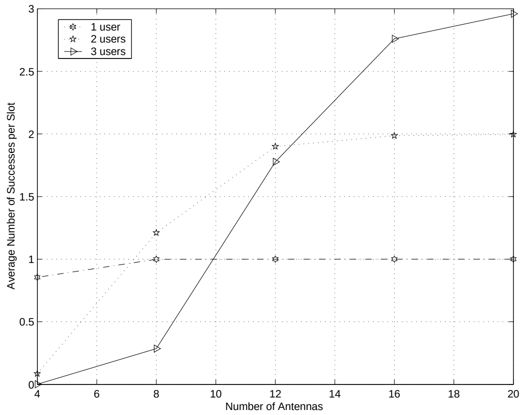


Figure 5: Throughput

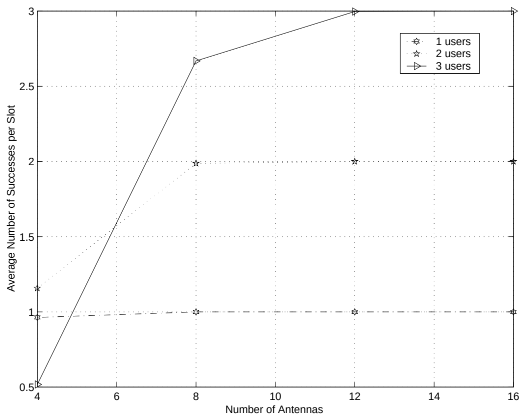


Figure 6: Throughput for Flat Fading Case

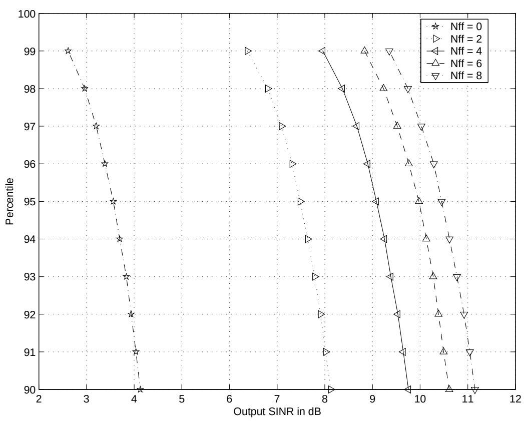
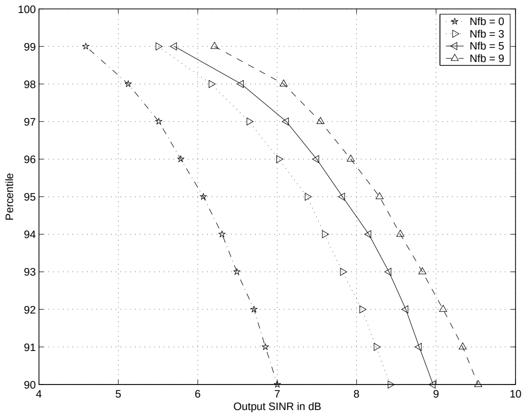
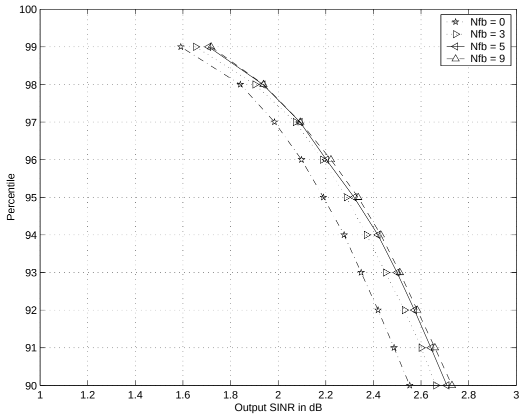


Figure 7: Different Feedforward Length



(a) One user per cell



(b) Three Users per Cell

Figure 8: Different Feedback Lengths

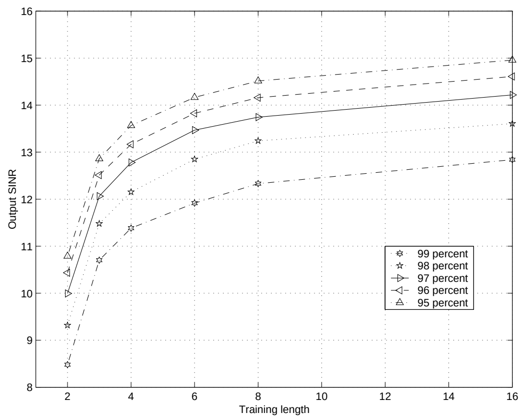


Figure 9: Different Training Lengths