Joint Beamforming and Transmit Diversity for WCDMA
(Unclassified)

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Abstract

The current work develops an efficient scheme to be used for the downlink of a WCDMA network, using transmitter diversity and beamforming. The performances of space-time transmit diversity (STTD) in combination with selective transmit diversity (STD), beamforming (BF) and beam selective transmit diversity (BSTD) which is a composite scheme of STD and BF, have been studied at the system level using the capacity as performance index. Both fading and interference are jointly considered in the multipath propagation environment. The main constraint was the implementation problem. It considers the use of an array with eight antenna elements spaced half wavelength per 120° sector to implement dynamically the several proposed techniques based on the environment. It was found that the comparison is strongly related to the availability of path diversity. The system capacity is maximized by the BF in the presence of multipath diversity and high multiple access interference. Otherwise it is the BSTD that achieves the best overall capacity performance. For higher data rates and small number of users the system that gives the best capacity performance is STTD+STD.

Keywords - Space-time transmit diversity, selective transmit diversity, beamforming, system capacity, downlink of DS-CDMA, fading, Multiple Access Interference

1 – Introduction

Battle Force communications should use DS-CDMA technology due to its high data rates, network capacity and flexibility to allow a variety of services as Internet, multimedia, data base access, video-conference, etc. It is expected that it will become more and more asynchronous with higher rhythms of transmission in the downlink than in the uplink. This is necessary for services like Internet, Data Base Access, Multimedia, etc. The downlink capacity is limited by both fast fading and multiple access interference (MAI). To improve the received signal quality at the mobile station (MS), various techniques as Multi-user Detectors (MUD) [1], transmit diversity (TD) or pre-distortion schemes have been proposed to mitigate the performance degradation due to fast fading. In [2] Alamouti has presented a new diversity scheme known as STTD. This technique is based on Space-Time Coding [3][4] and belongs to an open loop TD class, being the one that better performs for the typical urban environments. As a representative of the closed loop, STD selects the antenna with the best instantaneous channel state for signal transmission and has a reverse link to inform the transmitter about the Channel State Information (CSI) [5][6][7][8]. It is expected that STTD has a superior performance when in the presence of a multipath fading channel (urban, hilly terrain and rural scenarios), even in the presence of inter-symbol interference [5]. STD should outperform STTD for the single path fading environment (sub-urban scenario) with low signal-to-noise per symbol rate [5]. In the present work it was considered a combination of both techniques (STTD+STD). Both transmit diversity schemes require low correlation between the antennas, which can be achieved by adequate separation between the antennas. On the other hand, the received signal at the MS is also corrupted by the MAI. Making use of the spatial isolation of different users, signals by beamforming (BF) is an effective solution to solve this problem. If the radio channel has a high degree of multipath diversity, it can be beneficial (depending upon the number of active users) to employ relatively few antenna diversity branches.
In CDMA systems there are typically many interferers and there are not enough degrees of freedom in the array to cancel them all. CDMA systems usually use the proposed beamforming or multibeam antennas [9].

In this case, the RAKE receiver already provides multipath diversity when in the presence of a several paths channel. For this reason, and because beamforming antennas will provide most of the gain in the area of MAI reduction it is generally suggested that beamforming directed towards the desired users, using algorithms such as Maximum Likelihood Sequence Estimator (MMSE) or Minimum Variance (MV) [10], should be considered for CDMA systems. To make the comparison more sufficient, another beam selective transmit diversity (BSTD) scheme is also proposed as an opponent to STTD+STD and BF. Actually, BSTD can be regarded to be a composite scheme of BF and STD, and all the array elements in BSTD are equally divided into several groups to form several sub-beamforming arrays whose antenna elements spacing is half wavelength, while the distance between adjacent sub-beamforming arrays is large enough to keep them uncorrelated. The performances are compared at the system level with capacity as performance index, and both fading and interference are jointly studied in the single path and multipath multi-user environments.
The rest of the paper is organized as follows. The system and signal model for BSTD is introduced in Section 2. With low modifications, the same model can also be applicable to STD, STTD+STD and BF, since all of them are almost the extreme cases of BSTD. In Section 3, the expression of the received signal to interference plus noise ratio (SINR) is presented and the statistics of the parameters in the SINR expression are studied as well. The system outage probability calculation is elaborated in Section 4, as well as capacity calculations, and corresponding numerical results are presented in Section 5. Finally, conclusions are drawn in Section 6.

2 – System and Signal Models

In this section, a baseband system model is presented for the analysis of the proposed beam selective transmit diversity (BSTD) scheme, in which several sub-beamforming arrays are equipped at the same BS and they are combined to implement the selective transmit diversity technique. BSTD scheme can be viewed as a composite of the beamforming (BF) scheme and the selective transmit diversity (STD) scheme and, with low modifications, can also be viewed as the proposed STTD+STD. The performance comparison of STTD+STD, BSTD and BF in later sections will be based on this model.

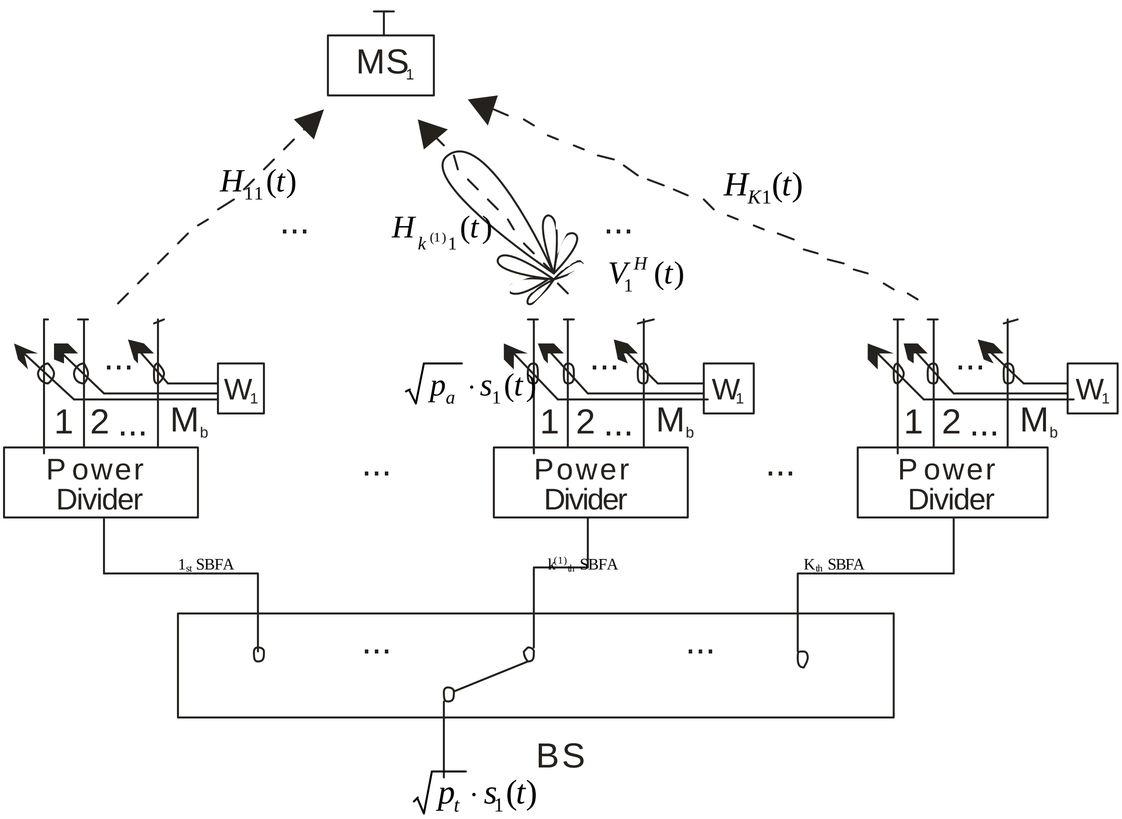

Fig. 1 – Base station configuration for BSTD

There is a total of N Mobile Stations (MS) randomly distributed along the arc boundary of a 120º cell sector, and the nth MS is denoted to be MS_n for n=1,…,N. The BS configuration for BSTD is shown in Fig.1. There are K sub-beamforming arrays (SBFA) equipped at the Base Stations (BS) for this cell sector. Each SBFA has an antenna elements spacing of half wavelength, while the distance between adjacent SBFAs is large enough to keep them uncorrelated. The array element number in each SBFA is M_b and thus the total element number of the K SBFAs is $M=M_b x K$.
Without loss of generality, we will describe the multipath channel model for the 1st and the same model is also applicable to other N-1 users. It is assumed that the $k^{(1)}_{th}$ SBFA results in the best channel state for the 1st user and thus is selected to form a beam toward the desired MS_1 as shown in Fig.1. Here, $k^{(1)}$ represents the index of the SBFA selected by the 1st user. The impulse response of the multipath channel between the $k^{(1)}_{th}$ SBFA and the MS_1 can be modeled as:

$$H_{k^{(1)}1}(t)=\sum_{l=1}^{L} a^{l}_{k^{(1)}1}\cdot\Lambda(q_1)\cdot d\left(t-t^{l}_{k^{(1)}1}\right), \qquad (1)$$

$$\sum_{l=1}^{L}\left[\left|a^{l}_{k^{(1)}1}\right|^2\right]=\sum_{l=1}^{L} g/L=g \qquad (2)$$

$$\Lambda(q_1)=\left[1,e^{jp\sin q_1},\ldots,e^{j(M_b-1)p\sin q_1}\right]^T . \qquad (3)$$

It is assumed that $H_{k^{(1)}1}(t)$ contains L independently faded multipath components. The zero mean complex Gaussian random variable $a^{l}_{k^{(1)}1}$ represents the complex fading amplitude of the l_{th} signal path in $H_{k^{(1)}1}(t)$. If uniform power delay profile is considered, the average path strength $E\left[\left|a^{l}_{k^{(1)}1}\right|^2\right]$ will be equal to g/L for each signal path as shown in (2), where the factor g represents the average channel gain and is equal to the sum of all the L signal paths average strengths. The matrix $\Lambda(q_1)$ only introduce a phase shift, although, there exist beamforming algorithms that can also introduce an amplitude attenuation component. The $d(t)$ in (1) is the delta function and the discrete path delays $t^{l}_{k^{(1)}1}, l=1,\ldots,L$, are supposed to be separated more than one chip duration from one another, and thus the L paths can be resolved by the mobile Rake receiver in the delay domain.

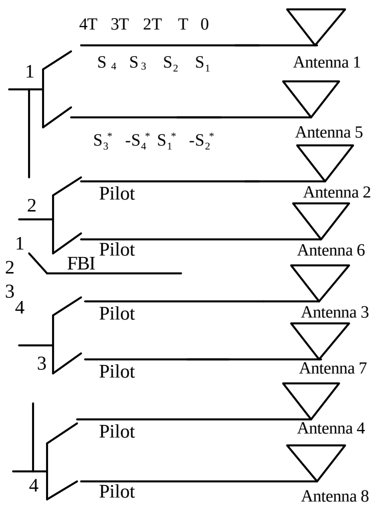

Fig. 2 – Configuration of STTD+STD

Fig.2 shows the proposed configuration of STTD+STD, which is a hybrid scheme that employs the Alamouti scheme (open loop class) with Feedback Indication (FBI) about the state of the Rayleigh fading channel (close loop class). Within this scheme, only the two 'best' antennas transmit information and signalling data while the others antennas only transmit signalling data at a lower bit rate (e.g., an overhead of 10%).
The total received signal at the MS_1 can be expressed as:

$$r_1(t) = d_{11}(t) + \sum_{n=2}^{N} i_{n1}(t) + n_1(t) \qquad (4)$$

$$= \sum_{l=1}^{L} a^{l}_{k^{(1)}1} . \sqrt{p_t . M_b} . s_1(t - t^{l}_{k^{(1)}1}) + \sum_{n=2}^{N} \sum_{l=1}^{L} a^{l}_{k^{(n)}1} . \sqrt{p_t . M_b x_{n1}} . s_n(t - t^{l}_{k^{(n)}1}) + n_1(t) \qquad (5)$$

where $n_1(t)$ represents the complex white Gaussian noise of the receiver.

3 – Expression and Statistics of the SINR Expression

In most DS-CDMA system, orthogonal Walsh code is adopted for the downlink transmission. However, in the multipath rich environment with path delay separation with more than one chip duration, the orthogonality of the Walsh code would be difficult to be maintained and the performance should be close to that of the random code. Since the number of orthogonal codes is limited, the use of non-orthogonal codes can also be a choice for the 3G WCDMA systems. For the reasons mentioned above, the random spreading code is assumed in this analysis. Moreover, the Rake receiver with maximum ratio combining (MRC) is supposed to be employed at each MS, and the expression of the total signal received by the Rake receiver at the MS_1 is given by (5). If the self-interference in each Rake finger is ignored, the SINR at the Rake combiner output can be shown as:

$$\Gamma_1 = \frac{\sum_{l=1}^{L} \left| a_{k^{(1)}1}^{\,l} \right|^2 .p_t.M_b}{\frac{1}{G'} \cdot \sum_{n=2}^{N} x_{n1} \sum_{l=1}^{L} \left| a_{k^{(n)}1}^{\,l} \right|^2 .p_t.M_b + s_n^2} \tag{6}$$

$$= \frac{\sum_{l=1}^{L} \left| a_{k^{(1)}1}^{\,l} \right|^2 .\frac{p_t.M_b}{s_n^2}}{\frac{1}{G'} \cdot \sum_{n=2}^{N} x_{n1} \sum_{l=1}^{L} \left| a_{k^{(n)}1}^{\,l} \right|^2 .\frac{p_t.M_b}{s_n^2} + 1} = \frac{\Psi_1}{\frac{1}{G'} \cdot \sum_{n=2}^{N} x_{n1}.\Phi_n + 1}$$

where s_n^2 denotes the noise power per Rake finger, and the pseudo processing gain G' is defined as G'=1.06G=1.06 T_s/T_c ,T_s and T_c are the data symbol duration and the chip duration respectively, while G represents the system processing gain and the factor 1.06 is due to raised cosine pulse shape with roll-off factor 0.22 [1].

When M_b>1, the beam pattern can be generated and the $?_{n1}$ can be modeled as a function of the angle difference$\left| q_n - q_1 \right|$. The beamwidth BW and the side lobe level SLL are used to model the 3 dB beamwidth of the main beam and the effect of the side lobe, respectively. In such "key hole" array gain pattern, the gain is assumed to be unitary when the MS_1 falls in the angular range of $\left[q_n - BW/2, q_n + BW/2 \right]$, otherwise it is approximated to be SLL.

Before studying the statistics of Ψ_1 and Φ_n, we firstly introduce a new random variable X_{k1} as:

$$X_{k1} = \sum_{l=1}^{L} \left| a_{k1}^{\,l} \right|^2 .\frac{p_t.M_b}{s_n^2}, \tag{7}$$

where $\sum_{l=1}^{L} \left| a_{k1}^{\,l} \right|^2$ denotes the sum of the L fading path gain in $H_{k1}(t)$, which is the channel between the MS_1 and the arbitrary k^th^ SBFA of the total K SBFAs in fig.1, and the factor $\frac{p_t.M_b}{s_n^2}$ can firstly be regarded as a constant. According to [11], the probability density function (pdf) of X_{k1} can be written as:

$$f_{X_{k1}}(X_{k1}) = \frac{X_{k1}{}^{L-1}.e^{-\frac{X_{k1}}{T}}}{T^L.(L-1)!}, \; (x_{k1} \ge 0), \tag{8}$$

$$T = E\left[\left| a_{k1}^{\,l} \right|^2 .\frac{p_t.M_b}{s_n^2} \right] = \frac{g}{L} \cdot \frac{p_t.M_b}{s_n^2} \tag{9}$$

Here, the average path strength $E\left[\left| a_{k1}^{\,l} \right|^2 \right]$ is equal to g/L for all l as defined in (2).

In the BSTD scheme, the SBFA selection is similar to the antenna selection in STD, and the SBFA resulting in the best channel state for the desired user is selected for signal transmission. Specifically, the sum of the L fading path gain of the selected channel $H_{k^{(1)}1}(t)$ in fig.1 should be the maximum among those of all the K candidate channels $\{H_{k1}(t), k = 1,...,K\}$. Here, the selection is assumed to be perfect and without delay and error. Therefore, the $?_1$ defined in (6) will also be the maximum of the set $\{X_{k1}(t), k = 1,...,K\}$:

$$\Psi_1 = \sum_{l=1}^{L} \left| a^{l}_{k^{(1)}1} \right|^2 \cdot \frac{p_t . M_b}{a_n^2} = \max\{X_{k1},\ k = 1,...,K\} \tag{10}$$

Since the channel states of different users are uncorrelated, the channel $H_{k^{(n)}1}(t)$ can be randomly selected from the set $\{H_{k1}(t),\ k = 1,...,K\}$ in fig.1 as seen from the MS_1, and thus the Φ_n defined in (6) will also be equivalent to the one randomly selected from the set $\{X_{k1}(t),\ k = 1,...,K\}$:

$$f_n = \sum_{l=1}^{L} \left| a^{l}_{k^{(n)}1} \right|^2 \cdot \frac{p_t \cdot M_b}{a_n^2} = rand\{X_{k1},\ k = 1,...,K\} \tag{11}$$

where $\sum_{l=1}^{L} \left| a^{l}_{k^{(n)}1} \right|^2$ denotes the sum of the L fading path gain in $H_{k^{(n)}1}(t)$. Moreover, it is assumed that the probability of being selected to be Φ_n is equal to $\frac{1}{K}$ (uniform distrib ution) for every X_{k1}.

4 – Expressions of Outage Probability

The outage probability is defined as the probability that the received SINR Γ_1 is lower than certain threshold h :

$$P\{\Gamma_1 \le h\} = \int_0^h f_{\Gamma_1}(g_1) \cdot dg_1, \tag{12}$$

where h is a positive number. With the Gaussian approximation for MAI the outage probability for N>>1 can be approximated as:

$$P\{\Gamma_1 \le h\} \cong \int_0^{+\infty} \frac{1}{2} \cdot erfc\left(\frac{\frac{1}{h} - E\left[\frac{1}{\Gamma_1} \mid \Psi_1\right]}{\sqrt{2 \cdot V\left[\frac{1}{\Gamma_1} \mid \Psi_1\right]}} \right) \cdot f_{\Psi_1}(y_1) \cdot dy_1, \quad (y_1 \ge 0), \tag{13}$$

where the specific $f_{\Psi_1}(y_1)$ is dependent on L, being for L=1:

$$f_{\Psi_1}(y_1) = \frac{dP(\Psi_1 \le y_1)}{dy_1} = \frac{K}{T} \cdot \left(1 - e^{-\frac{y_1}{T}}\right)^{K-1} \cdot e^{-\frac{y_1}{T}} \ (y_1 \ge 0). \tag{14}$$

and for L=2:

$$f_{\Psi_1}(y_1) = \frac{dP(\Psi_1 \le y_1)}{dy_1} = K \cdot \left\{1 - e^{-\frac{y_1}{T}} \cdot \left(1 + \frac{y_1}{T}\right)\right\}^{K-1} \cdot \frac{y_1}{T^2} \cdot e^{-\frac{y_1}{T}} \quad (y_1 \ge 0). \tag{15}$$

The expressions of $E\left[\frac{1}{\Gamma_1} | \Psi_1\right]$ and $V\left[\frac{1}{\Gamma_1} | \Psi_1\right]$ are also dependent on L.

5 – Numerical Results

5.1 Parameters in the outage probability calculation

The results shown in the present paper were done considering two different classes of services and for each one, two different levels of multiple access interference (MAI) to allow different levels of QoS :

1. First, we consider the data service, where can be considered up to 7 users in each cell. In this situation we consider a data rate of 768 Kbps, and the required signal to noise ratio is E_b/N_o=1 dB with a processing gain of G=4. It is considered two different levels of MAI (or QoS) M_I=(N+I)/N, where N is the noise power (AWGN) and I is the interference power, namely M_I=3 dB and M_I=5 dB, leading to $E_b/(N_o+N_I)$=-2 dB and $E_b/(N_o+N_I)$=-4 dB (lower required QoS), respectively;

2. Second, we consider the voice service, where can exist up to 130 users in each cell. In this situation we consider a data rate of 12.2 Kb/s, and the required signal to noise ratio is E_b/N_o=5 dB with a processing gain of G=128. As in the case of data, it is also considered two different levels of QoS, which corresponds to M_I=3 dB and M_I=5 dB, leading to $E_b/(N_o+N_I)$=2 dB and $E_b/(N_o+N_I)$=0 dB.

5.2 Comparison of outage probability performance

The theoretical system outage probability was calculated for different user number N. In Fig.3, it is firstly assumed that the link SNR is equal to 1dB and only one fading path (L=1) exists in the channel defined in (1). Moreover, to make a fair comparison, the number of total array elements is kept as 8 for all the compared schemes. The KxM_b=1x8 BF represents a single beamforming array with 8 elements, while in the 2x4 BSTD, 2 sub-beamforming arrays with 4 elements in each are employed for spatial diversity. Since two-branch spatial diversity is the most common view in practical system, the number of sub-beamforming arrays is fixed to be two (K=2) for the BSTD in the following analysis. Finally, the 8 array elements are combined into 4 arrays with 2 elements widely separated to form a transmit diversity array in the 4x2 STTD+STD.

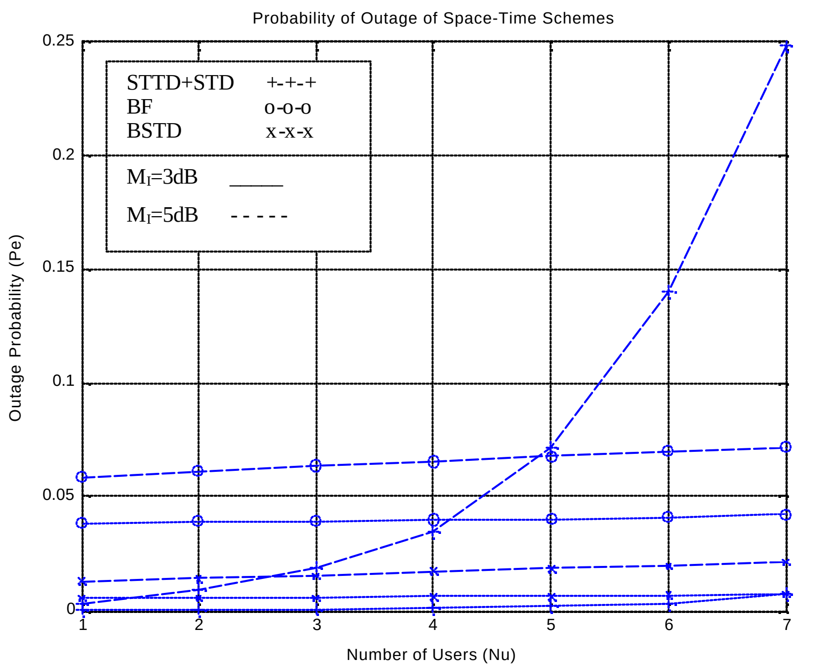

Fig. 3 – Outage Probability performance for the data service and single fading path per channel (L=1)

In fact, the Outage Probability (OP) is affected by both the fading and the interference in the DS-CDMA system. As show in Fig.3, the STTD+STD achieves the lowest OP among the 3 schemes when Nu<7 for M_I=3dB, and reducing the fading by the 8-order transmit diversity is the most effective way to decrease the OP for N=7. However, when we increase the M_I to 5dB, allowing higher interference levels, since no efforts are made to combat the MAI, the OP of the STTD+STD grows up rapidly with Nu. On the other hand, the OP of the BF increases much more gently with Nu. But without employing diversity to combat fading, the BF is hard to keep the OP lower than 10^{-2} even for the single user. Finally, the OP performance of BSTD seems to be a trade-off between those of the STTD+STD and the BF, and the OP increases at a compromise rate.

The OP performances for the voice service and single path Rayleigh fading (L=1) is show in Fig.4. Comparing Fig.4 with Fig.3, it is obvious that the OP increases dramatically for the STTD+STD, when we allow higher MAI levels (M_I=5dB). However, the STTD+STD achieves the lowest OP among the 3 schemes when Nu<80 for M_I=3dB. The OP performance is almost always the best for the BSTD in both cases of MAI levels. However, similar to that in Fig.3, the OP performance of the BF, in spite of increasing much more gently with Nu (due to action being taken to deal with the interference) the fading impairment predominates and the OP performance is the worst for low MAI levels (M_I=3dB).

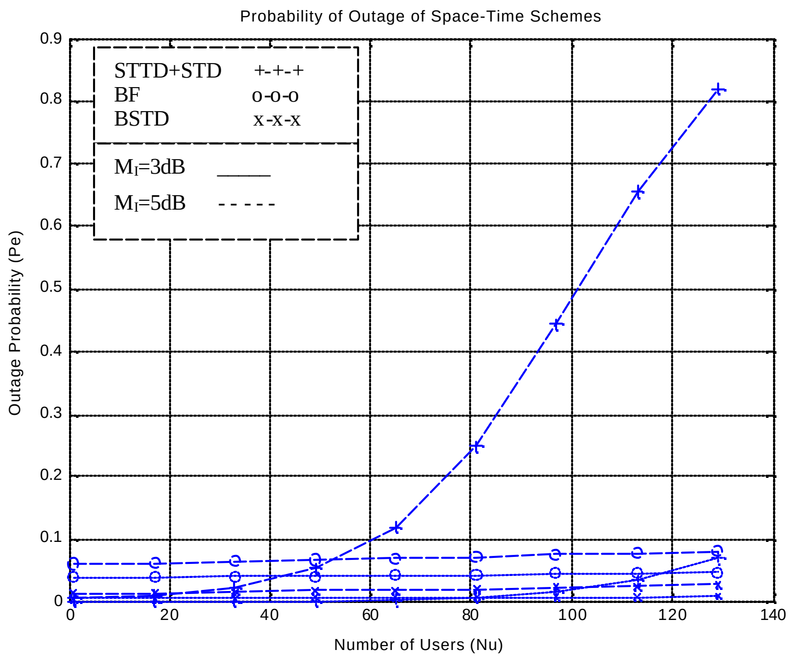

Fig. 4 – Outage Probability performance for the voice service and single fading path per channel (L=1)

In addition, we also resorted to computer simulations to check the accuracy of the outage probability calculation. The system and signal model in the simulations is the same as that introduced in Section 2. In case of 2x4 BSTD, two 4-element sub-beamforming arrays are employed at the BS and a certain number of users are randomly distributed along the cell sector boundary. For each user distribution, a large number of bits are successively transmitted to each user, the sub-beamforming array with better channel state is selected for current bit's transmission. Then, the SINR is measured and the outage is tested for each received bit at each MS. The outage probability for each given user number is counted over all the tested bits and is plotted along with the theoretical results. Good agreement between simulations and theory were observed for all the considered cases, and thus the accuracy of the analysis in both section 3 and 4 was confirmed.

5.3 Comparison of system capacity performance

We choose 10^{-2} as the outage probability threshold and corresponding number of users Nu is recorded as the system capacity. In fact, the capacity performance is jointly decided by many factors. In case of single path per channel (L=1) and for the data service, the three schemes system capacity as a function of MAI interference levels is plotted in Fig.5. As an example in Fig.5, the capacity of STTD+STD, BF and BSTD for M_i=4dB is 4, 0 and 2, respectively.

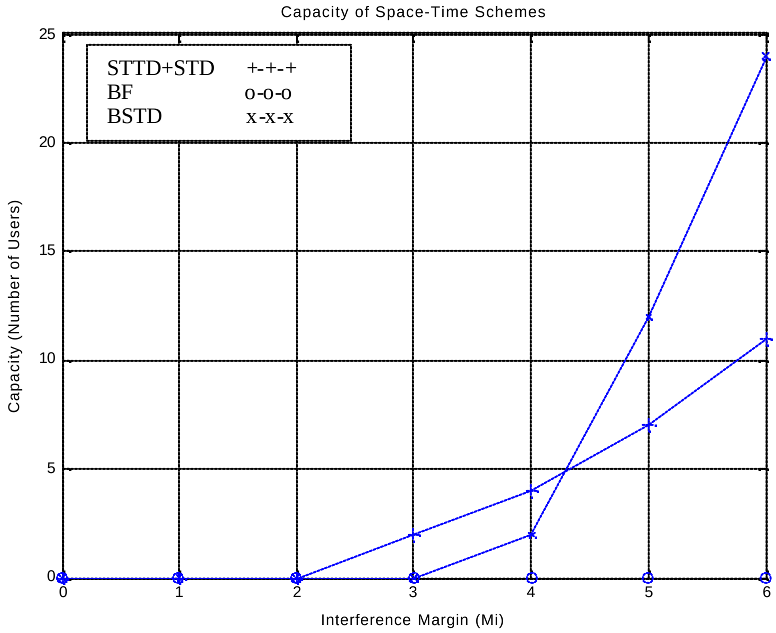

Fig. 5 – Capacity of the data service versus MAI level for single path per channel (L=1)

As we can see in Fig.5, the capacity performance of the STTD+STD and BSTD is strongly related to the MAI level. Specifically, successive zero capacity can be observed when the MAI level is zero dB, while the capacity increases rapidly. After the MAI level exceeds 5dB the BSTD capacity outperforms the STTD+STD. The successive zero capacity can be observed for the BF independently of the MAI level because of the predominance of the fading impairments. On the other hand, the fading can be smoothed sufficiently by the 8-order STTD+STD and certain number of users can still be supported by the STTD+STD even for small MAI levels. However, less capacity improvement can be achieved for the STTD+STD by increasing the MAI levels. Finally, the capacity performance of the BSTD seems to be the best compromise between those of the BF and the STTD+STD.

In Fig.6, the capacity versus MAI level is illustrated for the case of a Rayleigh fading with two paths per channel (L=2), for the data service. As an example in Fig.6, the capacity of STTD+STD, BF and BSTD for M_i=4dB is 2, 14 and 17, respectively. The BSTD supports the largest amount of users when the MAI level is between 0 dB and 5 dB. The overall capacity advantage of the BSTD and BF becomes more obvious for larger MAI levels and multipath fading (L=2).

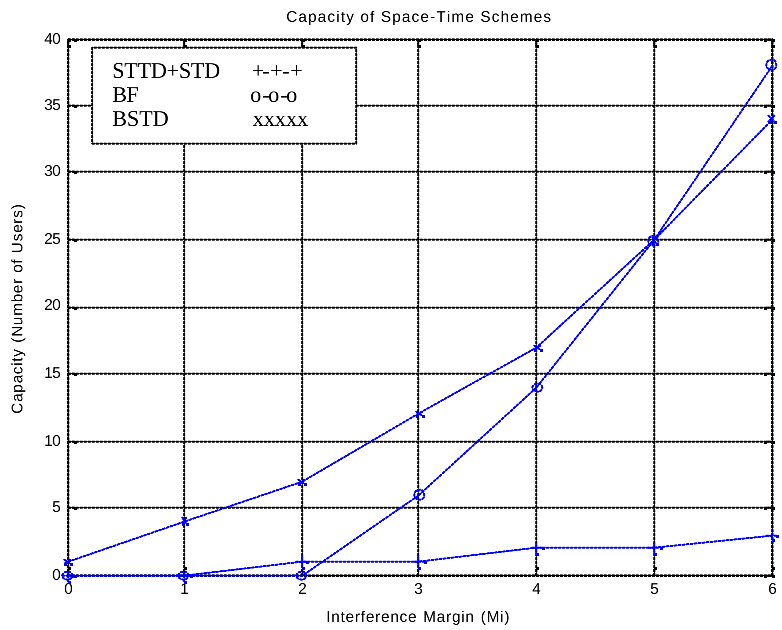

Fig. 6 – Capacity of the data service versus MAI level for Rayleigh fading with two paths per channel (L=2)

The capacity performance of the BSTD is only slightly inferior to that of the BF after the MAI level exceeds 5 dB. Due to the use of a MS Rake receiver in the multipath environment, utilizing all the array elements for beamforming would be preferable than splitting them for additional spatial diversity when the path diversity is exploitable.

Therefore, in case of single fading path per channel (L=1) or in the presence of two fading paths in each channel (L=2), the BSTD seems to be the most promising candidate to optimize the overall capacity performance.

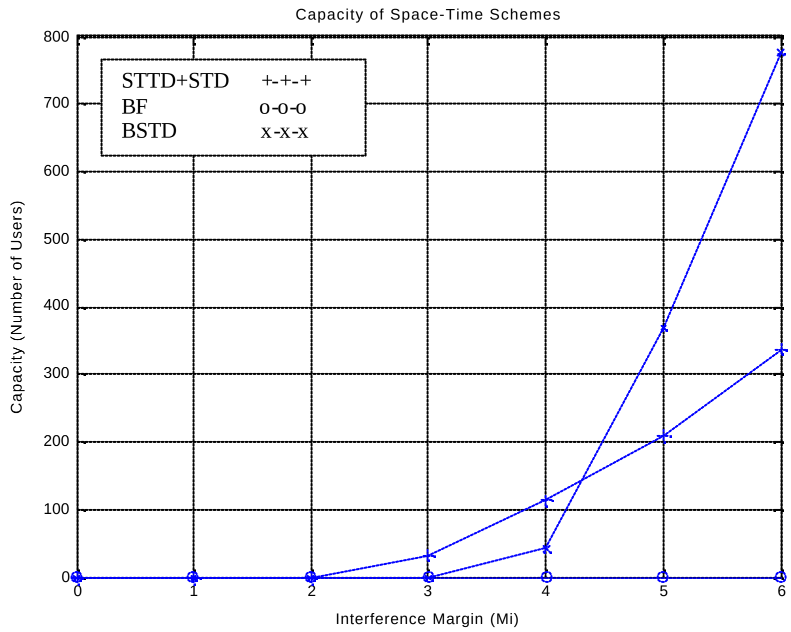

Fig. 7 – Capacity of the voice service versus MAI level for single path per channel (L=1)

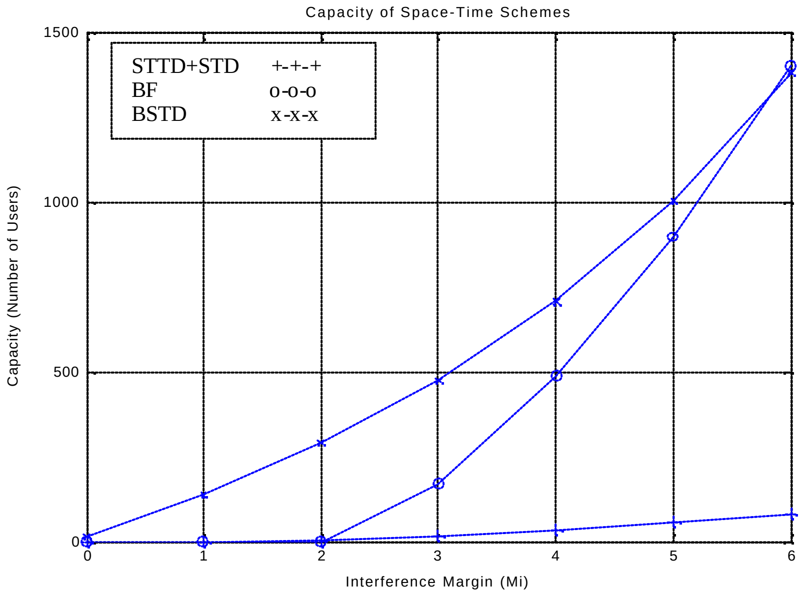

Fig. 8 – Capacity of the voice service versus MAI level for Rayleigh fading with two paths per channel (L=2)

Figs.7 and 8 correspond to Figs.5 and 6, for the capacity of the voice service, considering L=1 and L=2, respectively. Except for a scale factor all the conclusions drawn from the data service are valid for the voice service.

Based on the capacity performance comparison, it can be seen that the performance strongly depends on the number of fading paths in the channel and the multiple access interference levels allowed. In case of single fading path per channel (L=1), the BSTD is the most promising candidate to achieve the best overall capacity performance. When the path diversity is unavailable (sub-urban environment), spatial diversity provided by the two sub-beamforming arrays in the BSTD can indeed improve the capacity performance effectively, especially when the MAI level is not small. On the other hand, in the presence of two fading paths per channel (L=2), the 2-order path diversity is exploitable at the MS and the BF will become the optimum scheme to maximize the system capacity for increasing MAI. It can also be predicted that the advantage of the BF would be more evident in the multipath rich environment (urban, hilly terrain and rural environments), where the path number per channel is large and the fading can be further reduced by high order path diversity, with the use of the Rake receiver. Compared with both the BSTD and the BF, the STTD+STD has relatively poor capacity performance in multipath cases and only shows the advantage when the path number per channel L is one (sub-urban environment) and the MAI level is small (low number of users).

In [12] it will be presented the corresponding Bit Error Rate results for the several proposed configurations.

6 – Conclusions

In this document, a theoretical model has been presented to study the capacity performance of combined transmit diversity (STTD+STD) scheme, the beamforming (BF) scheme and the beam selection transmit diversity (BSTD) scheme. To make a fair comparison, we assume the total array element number is 8, the same for all schemes. For the single fading path channel model (sub-urban environment), the overall capacity performance of STTD+STD is the best for small levels of MAI; the BSTD seems to be better than those of the STTD+STD and the BF for medium to large interference levels. However, the BF achieves the best performance for the two fading path channel model (L=2) and large MAI, with the Rake receiver employed at the MS. In this case, utilizing all the array elements for beamforming can result in larger capacity than using them for transmit diversity. Therefore, the BF should be recommended for the downlink transmission, with high number of users, in the multipath rich environment (urban, hilly terrain and rural environments) when path diversity is exploitable at the MS. However, if only one path exists and path diversity is unavailable, the capacity performance of the BF will become quite small. If the conditions of the channels are difficult to predict, the BSTD should be a preferable choice to achieve good capacity performance for general mobile environments and interference levels. If those predictions can be accurately done, it should be preferable to employ an adaptive scheme where the employed technique can change depending upon the environment conditions.

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