MMSE Frequency-domain Equalization Combined with Space-time Transmit Diversity and Antenna Receive Diversity for DS-CDMA

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***Abstract*—DS-CDMA transmission performance can be improved with minimum mean square error frequency-domain equalization (MMSE-FDE) compared to the use of coherent rake combining. In this paper, to achieve a further performance improvement, combined use of space-time transmit diversity (STTD) and antenna receive diversity is applied. The bit error rate (BER) performances of DS-CDMA downlink and uplink are evaluated by computer simulation. It is confirmed that the use of STTD and antenna receive diversity combined with MMSE-FDE is very effective to improve the BER performance. When STTD/receive diversity is used at both base and mobile stations, both uplink and downlink have almost the same BER performance for small number *U* of users. As *U* increases, the uplink performance degrades and exhibits BER floors due to large multiuser interference (MUI). However, the uplink BER floor when *U*=16 can be reduced to around 2x10^{-3} when the spreading factor of *SF*=64 is used.**

Keywords-DS-CDMA, MMSE-FDE, STTD

I. INTRODUCTION

Wireless channel is composed of many propagation paths with different time delays, producing frequency-selective multipath fading [1]. In a frequency-selective fading channel, the bit error rate (BER) performance of single-carrier (SC) transmission significantly degrades due to severe inter-symbol-inference (ISI). Direct-sequence code division multiple access (DS-CDMA) can exploit the channel frequency-selectivity by the use of rake receiver that resolves the propagation paths having different time delays and coherently combines them to achieve the path diversity effect [2]. Wideband DS-CDMA has been adopted as a wireless access technique in the 3rd generation mobile communications systems, known as IMT-2000 systems, for data transmissions of up to a few Mbps [3]. However, in the case of broadband wireless data transmissions of more than a few Mbps using DS-CDMA, the transmission performance may significantly degrade due to large inter-path interference (IPI) even if coherent rake combining is used.

Recently, multi-carrier (MC)-CDMA which attains the frequency diversity effect by one-tap frequency-domain equalization (FDE) has been attracting much attention for broadband wireless data transmissions in a severe frequency-selective channel [4~6]. However, MC-CDMA has the problem of large peak-to-average power ratio (PAPR). Recently, it was suggested [7] that minimum mean square error (MMSE)-FDE can be successfully applied to the DS-CDMA signal reception in order to improve its BER performance in a frequency-selective fading channel and that MMSE-FDE provides a better BER performance than coherent rake combining. Recently, we have shown that the additional use of antenna receive diversity can significantly improve the BER performance of DS-CDMA using MMSE-FDE [8, 9]. Another promising diversity technique is the transmit antenna diversity [10]. A combined use of MMSE-FDE, antenna receive diversity, and space-time transmit diversity (STTD) [11] can further improve the BER performance of DS-CDMA. In this paper, MMSE-FDE combined with STTD and antenna receive diversity is presented. Remainder of this paper is organized as follows. Section 2 presents space-time encoding and decoding combined with MMSE-FDE. In Section 3, the achievable BER performance in a frequency-selective Rayleigh fading channel is evaluated by computer simulation. The BER performances of DS-CDMA uplink and downlink are compared. Section 4 offers some conclusions.

II. MMSE-FDE COMBINED WITH STTD AND ANTENNA RECEIVE DIVERSITY

The base station and mobile station of a DS-CDMA system using MMSE-FDE combined with STTD and antenna receive diversity are illustrated in Fig.1. At the transmitter, the *u*-th user's data-modulated symbol sequence $\{d^{(u)}(n)\}$ is spread by multiplying it with a spreading sequence $\{c^{(u)}(t)\}$ having a spreading factor of *SF*. The *U* users' chip sequences are added and then multiplied by a common scramble sequence. The resulting chip sequence is divided into a sequence of blocks, each with N_c chips. The even and odd chip blocks, $\{s_e^{(u)}(t)\}$ and $\{s_o^{(u)}(t)\}$, are STTD-encoded as shown in Fig. 2 [12]. After insertion of guard interval (GI), the STTD encoded chip blocks are transmitted simultaneously from two transmit antennas during the time interval of two consecutive (even and odd) chip blocks. The STTD-encoded chip blocks transmitted from a base (mobile) station over a frequency-selective fading channel are received by two diversity antennas at a mobile (base) station receiver. After removal of GI, the STTD-encoded even and odd chip blocks received on the *m*-th antenna (*m*=0, 1) and perturbed by additive white Gaussian noise (AWGN) are decomposed by N_c-point FFT into N_c subcarrier components $\{R_{e,m}(k);\ k=0\sim N_c-1\}$ and $\{R_{o,m}(k);\ k=0\sim N_c-1\}$, respectively (the terminology "subcarrier" is used although subcarrier modulation is not used). $R_{e,m}(k)$ and $R_{o,m}(k)$ for uplink can be written as

$$\begin{cases} R_{e,m}(k)=\sum_{u=0}^{U-1}H_{0,m}^{(u)}(k)S_e^{(u)}(k)+\sum_{u=0}^{U-1}H_{1,m}^{(u)}(k)S_o^{(u)}(k)+N_{e,m}(k) \\ R_{o,m}(k)=-\sum_{u=0}^{U-1}H_{0,m}^{(u)}(k)S_o^{(u)*}(k)+\sum_{u=0}^{U-1}H_{1,m}^{(u)}(k)S_e^{(u)*}(k)+N_{o,m}(k) \end{cases} \qquad .(1)$$

where $S_e(k)$ and $S_o(k)$ are the subcarrier components of the even and odd chip blocks, respectively, and $H_{n,m}^{(u)}(k)$ represents the channel gain at the kth subcarrier for a propagation channel between the n-th transmit antenna and the m-th receive antenna of the u-th user (n and m=0 or 1). $N_{e,m}(k)$ and $N_{o,m}(k)$ respectively represent the Fourier transforms of noise processes due to additive white Gaussian noise (AWGN). Note that for the downlink case, all users' spread signals go through the same propagation channel, hence, $H_m^{(u)}(k)=H_m(k)$ for all u. The block diagram of MMSE-FDE combined with STTD decoding and receive antenna diversity is shown in Fig. 3.

It is assumed that the u-th user's data is to be detected. Subcarrier-by-subcarrier one-tap MMSE-FDE is carried out jointly with STTD decoding and receive antenna diversity to obtain $\tilde{S}_e^{(u)}(k)$ and $\tilde{S}_o^{(u)}(k)$:

$$\begin{cases} \tilde{S}_e^{(u)}(k)=\sum_{m=0}^{N_r-1}\left\{w_{0,m}^{(u)*}(k)R_{e,m}(k)+w_{1,m}^{(u)}(k)R_{o,m}^{*}(k)\right\} \\ \tilde{S}_o^{(u)}(k)=\sum_{m=0}^{N_r-1}\left\{w_{1,m}^{(u)*}(k)R_{e,m}(k)-w_{0,m}^{(u)}(k)R_{o,m}^{*}(k)\right\} \end{cases} \qquad (2)$$

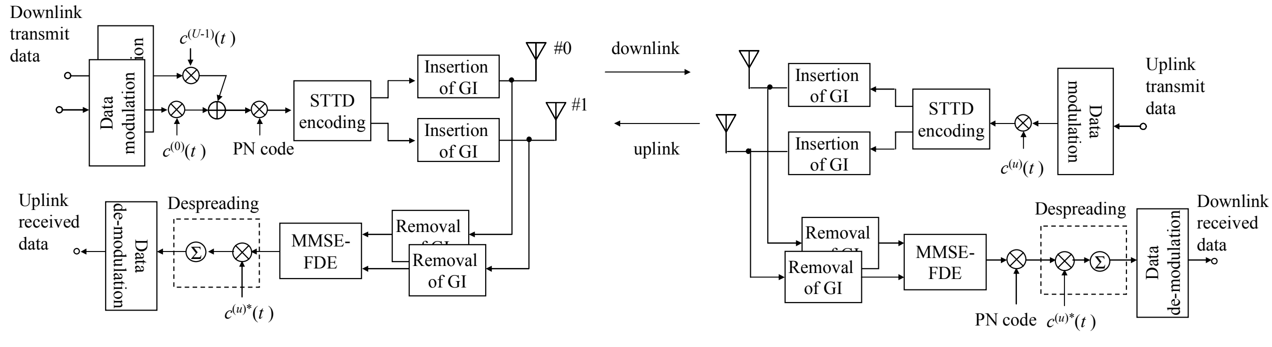
for k=0~N_c-1, where $w_{0,m}^{(u)}(k)$ and $w_{1,m}^{(u)}(k)$ are the MMSE weights and are given by [12]

$$\begin{cases} w_{0,m}^{(u)}(k)=\dfrac{H_{0,m}(k)}{\sum_{n=0}^{1}\sum_{m=0}^{N_r-1}|H_{n,m}(k)|^2+\left(\dfrac{U}{2}\dfrac{E_c}{N_0}\right)^{-1}} \\ w_{1,m}^{(u)}(k)=\dfrac{H_{1,m}(k)}{\sum_{n=0}^{1}\sum_{m=0}^{N_r-1}|H_{n,m}(k)|^2+\left(\dfrac{U}{2}\dfrac{E_c}{N_0}\right)^{-1}} \end{cases} \text{, for downlink}$$

$$\begin{cases} w_{0,m}^{(u)}(k)=\dfrac{H_{0,m}^{(u)}(k)}{\sum_{n=0}^{1}\sum_{m=0}^{N_r-1}|H_{n,m}^{(u)}(k)|^2+\left(\dfrac{1}{2}\dfrac{E_c}{N_0}+U\right)^{-1}} \\ w_{1,m}^{(u)}(k)=\dfrac{H_{1,m}^{(u)}(k)}{\sum_{n=0}^{1}\sum_{m=0}^{N_r-1}|H_{n,m}^{(u)}(k)|^2+\left(\dfrac{1}{2}\dfrac{E_c}{N_0}+U\right)^{-1}} \end{cases} \text{, for uplink} \qquad .(3)$$

where E_c/N_0 is the average chip energy-to-AWGN power spectrum density ratio per receive antenna.

IFFT is applied to obtain the equalized and diversity combined time-domain chip blocks, $\tilde{s}_e^{(u)}(t)$ and $\tilde{s}_o^{(u)}(t)$, for despreading and data demodulation.



(a) Base station

(b) Mobile station (the u-th user)

Figure 1. Transceiver structures of base and mobile stations.

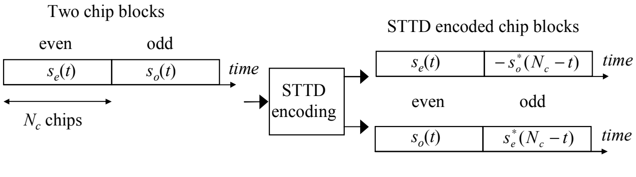


Figure 2. STTD encoding process.

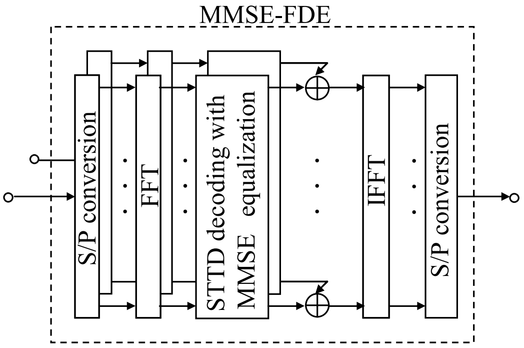


Figure 3. MMSE-FDE combined with STTD decoding and antenna receive diversity.

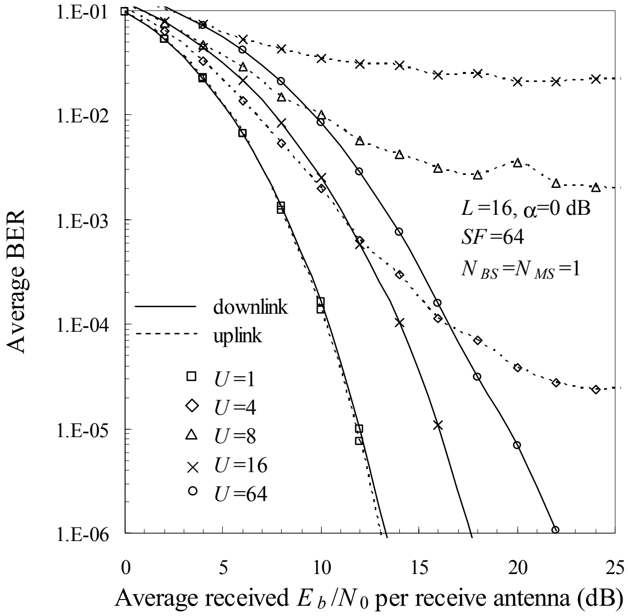
III. COMPUTER SIMULATION

The simulation parameters are summarized in Table 1. Quaternary phase shift keying (QPSK) data modulation, N_c=256, N_g=32, *SF*=64, and an *L*=16-path frequency-selective Rayleigh fading channel having an exponentially decaying power delay profile with decay factor α dB are assumed. Ideal sampling timing and ideal channel estimation are assumed at the receiver.

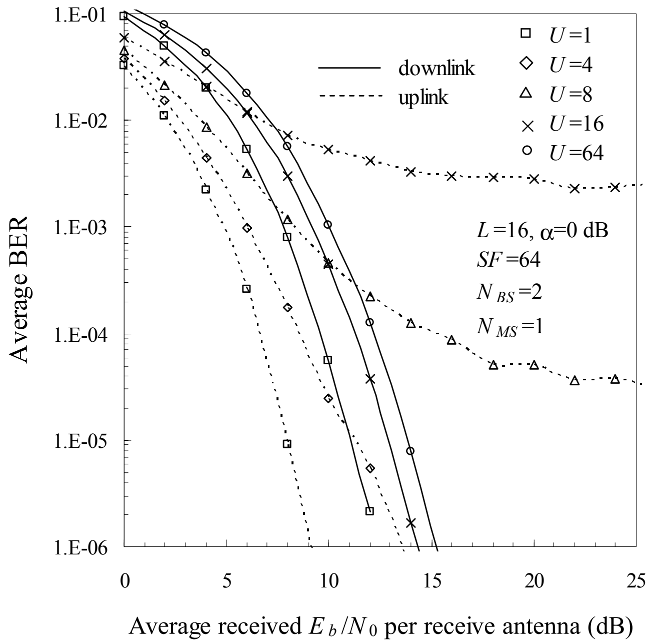
TABLE 1 SIMULATION PARAMETERS

Transmitter	Modulation	QPSK
	Number of FFT points	N_c=256
	Guard interval length	N_g=32(chip)
	Spreading Factor	*SF*=64
	Number of transmit antennas	N_t=1, 2
Channel	Fading	Frequency -selective block Rayleigh fading
	Power delay profile	*L*=16-path exponential power delay profile
		Decay factor α=0, 8 dB
Receiver	Number of receive antennas	N_r=1, 2
	Frequency-domain equalization	MMSE
	Channel estimation	Ideal

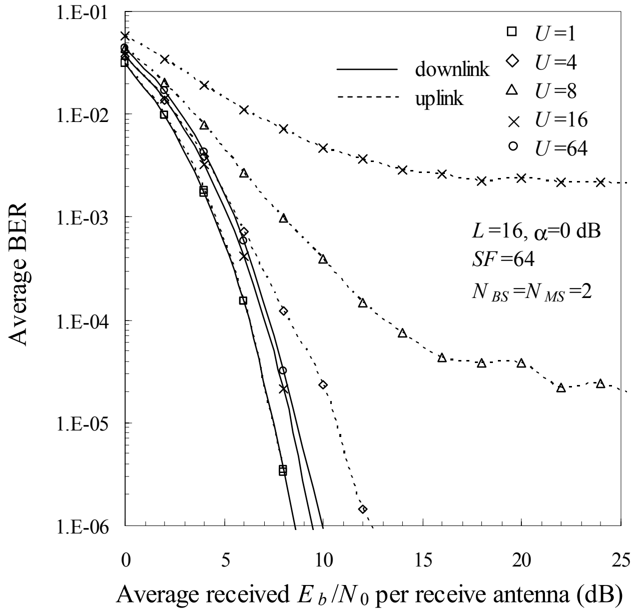
Figure 4 compares average BER performances of DS-CDMA downlink and uplink, with the number *U* of users as a parameter for different diversity antenna configurations. For comparison, the BER performances without antenna transmit/receive diversity (N_{BS}=N_{MS}=1) are plotted for uplink and downlink cases (see Fig. 4(a)). For the uplink case, since users' transmitting timings are asynchronous and, furthermore, different user's signal goes through a different propagation channel, a BER floor is produced even when *U*=4 due to a large multi-user-interference (MUI). However, no BER floor is produced in the downlink since all users' transmit signals are synchronous and go through the same propagation channel. It can be clearly seen that an additional use of STTD/receive diversity at a base station (N_{BS}=2, N_{MS}=1) significantly improves the BER performance (see Fig. 4(b)); however, a BER floor of around 5x10^{-3} is still produced on the uplink when *U*=16. In low E_b/N_0 regions, where errors are predominantly produced by AWGN rather than MUI, the uplink exhibits better BER performance than the downlink. This is because STTD used on the downlink is equivalent to the two-branch receive antenna diversity using maximal ratio combining (MRC), used on the uplink, but with 3 dB transmit power penalty. Further performance improvement can be attained by the use of STTD/receive diversity at the mobile station (N_{BS}=N_{MS}=2). It can be seen that both links can achieve almost the same BER performance for a small number *U* of users (see Fig. 4(c)). As *U* increases, however, the uplink performance degrades due to large MUI and exhibits a BER floors. But, the uplink BER floor for *U*=16 can be reduced to around BER=2x10^{-3}. On the other hand, receive antenna diversity at the mobile station is very effective and improves the downlink BER irrespective of the number *U* of users. When *U*=64, a combined STTD/receive diversity gain of 9.2dB is obtained at BER=10^{-4} compared to the case of N_{BS}=N_{MS}=1.



(a) N_{BS}=N_{MS}=1



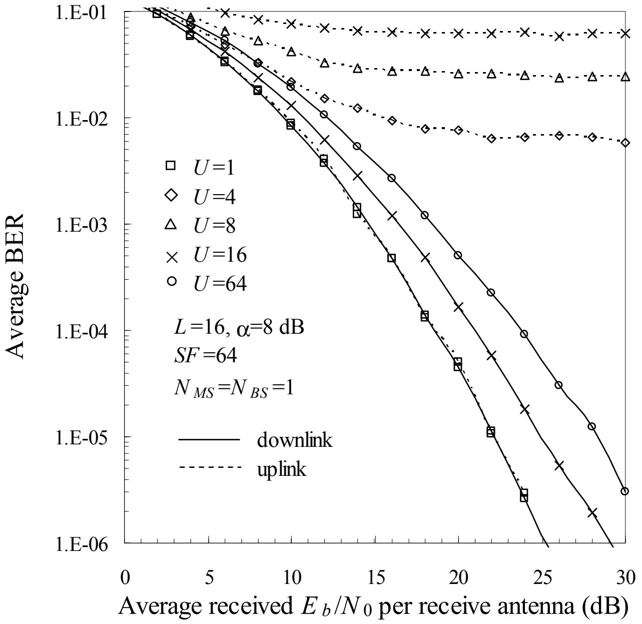
(b) N_{BS}=2 and N_{MS}=1



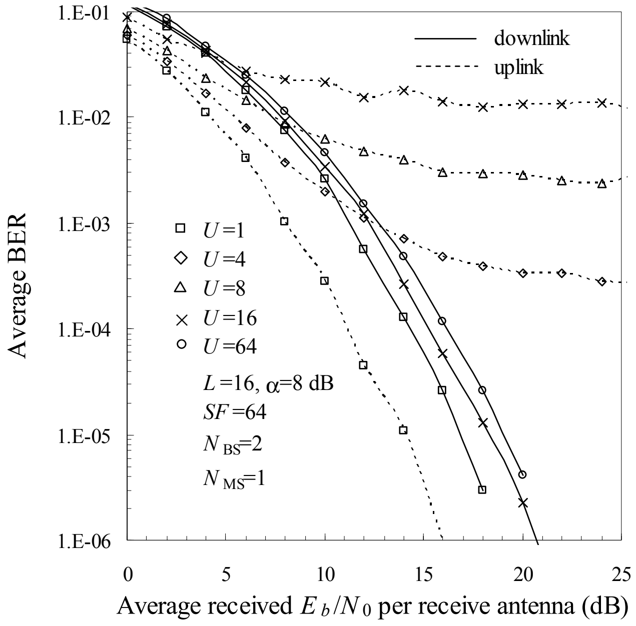
(c) N_{BS}=N_{MS}=2

Figure 4. Simulated BER performance of uplink and downlink DS-CDMA (α=0 dB).

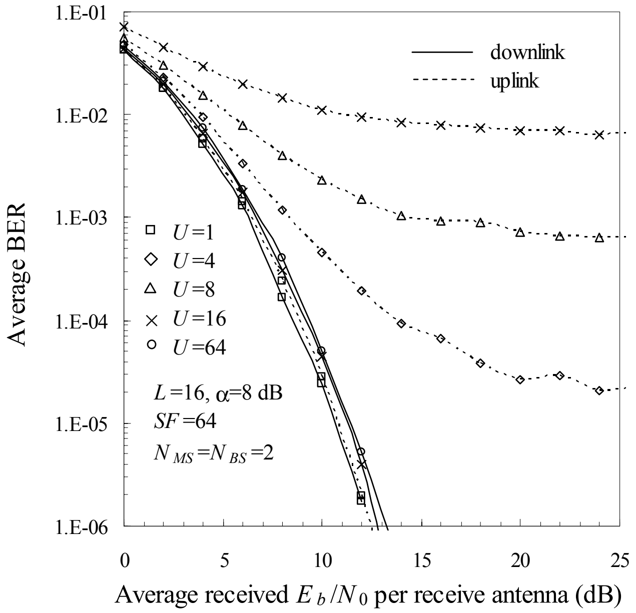
So far we have considered α=0 dB (the uniform power delay profile), which exhibits strong frequency-selectivity. The BER performance is sensitive to the channel frequency-selectivity. It is interesting to see the impact of the frequency-selectivity of the channel on the achievable BER performance. The average BER performance for the case of α=8 dB, which has a weak frequency-selectivity, is plotted in Figure. 5. In the case of α=8 dB, since the frequency diversity effect is less, the BER performance is worse than α=0 dB. In the uplink, a high BER floor of $6\text{x}10^{-3}$ is seen for U=4. In the downlink, however, the performance degradation due to weak frequency-selectivity is smaller in comparison with the uplink case. An addition of STTD/receive diversity at a base station (N_{BS}=2, N_{MS}=1) is effective to improve the BER performance as in the case of α=0 dB (see Fig. 5(b)). Even though the uplink BER floor for U=4 still exits, the use of receive antenna diversity can reduce the BER floor to BER=$3\text{x}10^{-4}$. The use of STTD also improves the BER performance for the downlink. An additional use of STTD/receive diversity at the mobile station (N_{BS}=N_{MS}=2) further improves the performance (see Fig. 5(c)) similar to the α=0 dB case. The STTD gain for the uplink when α=8dB is much larger than when α=0 dB. When α=8 dB, the STTD gain is lager since the frequency diversity effect is small. As a result, the uplink BER floor for U=4 can be reduced to around BER=$3\text{x}10^{-5}$. In the downlink, the use of STTD/receive antenna diversity is more effective than when α=0 dB. When U=64, a combined STTD/receive diversity gain of 14.4 dB, which is 9.2 dB when α=0 dB, is obtained at BER=10^{-4} compared with N_{BS}=N_{MS}=1 (see Fig. 5(a)). It is interesting to note that the downlink BER performance is almost insensitive to U (when α=0 dB, it is slightly sensitive to U).



(a) N_{BS}=N_{MS}=1



(b) N_{BS}=2 and N_{MS}=1



(c) N_{BS}=N_{MS}=2

Figure 5. Simulated BER performance of uplink and downlink DS-CDMA (α=8 dB).

IV. CONCLUSION

In this paper, a combined use of MMSE-FDE, receive antenna diversity, and STTD was applied to DS-CDMA and the BER performances of downlink and uplink were evaluated by computer simulation. It was found that a combination of STTD and receive antenna diversity used together with MMSE-FDE is effective to improve the BER performance of both uplink and downlink. Even though the uplink exhibits BER floors due to a large MUI, the uplink BER floor for U=16 can be reduced to around BER=2x10^{-3} compared to BER=2x10^{-2} of N_{BS}=N_{MS}=1 when α=0 dB. On the other hand, the BER performance for the downlink significantly improves irrespective of the frequency-selectivity of the channel. When U=64, a combined STTD/receive diversity gain of 9.2 (14.4) dB when α=0 (8) dB, is obtained at BER=10^{-4} compared to N_{BS}=N_{MS}=1. Furthermore, the downlink BER performance becomes almost insensitive to U.

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