DYNAMIC PARTNER SELECTION AND GROUPING FOR HIGH-SPEED USERS IN A COOPERATIVE WIRELESS COMMUNICATION SYSTEM

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***Abstract*– This work investigates the impact of utilizing a dynamic partner selection strategy on the BER performance of a DS-CDMA uplink in a wireless communication system, where multi-user cooperation is employed. For the cooperative environment introduced in this work – where users might be moving at any speed and direction – we consider the issue of selecting the best partner(s), with which the source user will cooperate. Cooperation is provided in the form of partners relaying the source signal to its destination using the decode-and-forward (DF) scheme. The mobile users grouping and partner selection strategy used in this work will be *dynamic*. Dynamicity will be based on a group of bounds defined, by the source user, to set the performance and operation criteria in choosing the best partners to cooperate with. At first we assume a flat fading channel, then we extended our work to study the impact a doubly selective channel has on the behavior of our proposed strategy. We take advantage of the inherited diversity offered by a doubly selective channel, with the aid of the well known Time-Frequency (TF) RAKE receiver structure. Simulation results reveal the improvements offered by the proposed strategy and its immunity to the harmful effect of Doppler spreading caused by mobility.**

Keywords*– *Cooperative diversity, partner selection, decode-and-forward, TF RAKE.

I. INTRODUCTION

Nowadays, the demands on high performance and high throughput wireless networking, such as the 3G and 4G networks, are rapidly growing. As a general fact, increasing the transmitted signal bit rates tends to make the communication channel into a frequency selective one. Frequency selectivity usually manifests itself in the form of inter-symbol interference that results from the generated multipath effect [1].

It is readily well known that using multiple-input multiple-output (MIMO) systems in wireless networks enhances the overall system performance and capacity. This is achieved by introducing spatial diversity, which in its turn fights multipath fading caused by the channel frequency selectivity. However, since it is far from practical to insert multiple antennas into mobile terminals, a recent solution was to introduce virtual MIMO systems. This works on the basis of letting nearby mobile terminals use each other's antenna in order to create spatial diversity. This is called user cooperative diversity [2][3].

In the case of fast moving mobile terminals, a new effect is introduced into the channel, namely the Doppler spreading. Doppler spread is usually considered as a source of performance degradation in conventional wireless systems; because it causes rapid fluctuations in the received signal strength. However, with the proper design of the receiver, it can be used as another source of diversity [4], [5].

For the cooperative environment introduced in this work we tackle the problem of selecting the best partners, with which the source user will cooperate. Cooperation is provided in the form of partners relaying the source signal to its destination using the decode-and-forward (DF) scheme. Unlike previous related work [6], [7], [8] and [13], in this work, mobile users are considered to be moving freely at any possible direction and speed, for instance at one moment a mobile user could be moving slowly at a given direction and at the next moment he starts moving fast in a different direction.

Therefore, and for such consideration, we developed a dynamic mobile user grouping and partner selection strategy. Dynamicity will be based on a group of bounds and policies defined by the source user to set the performance and operation criteria in choosing the best partners to cooperate with. By following this, we will have two major improvements:

1. More reliable end-to-end channels are achieved, relying on instantaneous channel measurements for choosing best partners.
2. Relative speeds between the source user and best partners are expected to be low enough, which tends to reduce the interfering influence of Doppler spreading.

Also, a TF RAKE will be implemented at the receiver side, which is considered to acquire a satisfactory performance in a doubly selective channel, since it exploit the inherited diversity in such channel via appropriate signal processing [4][5][9].

This paper is organized as follows. In Section II, we discuss the overall system model. Section III introduces our partner selection strategy. In Section IV, computer simulation results are presented as an evaluation of the whole system performance. Finally, this paper is concluded in Section V.

II. SYSTEM MODEL

A. Flat-Fading Time-Selective Channel

We are considering a synchronous direct-sequence code-division multiple access (DS-CDMA) cellular uplink of an infrastructure-based wireless communication system with a total of k wireless users, each of which is given an *orthogonal* spreading code.

We assume the scenario of having a single source user with multiple "best" cooperating partners, which are chosen using the partner selection strategy proposed in this work. Now, let $\mathcal{K}$ be the set of all users in the system, such that the set size equals the number of users, i.e., $|\mathcal{K}| = K$. Let $\mathcal{B} \subset \mathcal{K}$ be the set representing the best cooperating users, with a size equal to $|\mathcal{B}| = B$. The continuous-time BPSK baseband signal sent by the $k'th$ user is expressed as follows:

$$x_k(t) = b_k[i] q_k(t - iT), \qquad iT \le t < (i+1)T \qquad (1)$$

where $b_k[i]$ is the $i'th$ transmitted bit from the $k'th$ user, such that, $b_k \in \{\pm 1\}$, and $q_k(t)$ is the normalized spreading waveform, given for $0 < t < T$ and $1 < k < K$, by:

$$q_k(t) = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} c_k(m) \psi(t - mT_c) \qquad (2)$$

where M is the processing gain, c_k is signature sequence assigned to the $k'th$ user with values in the set $\{\pm 1\}$, $\psi(t)$ is the normalized chip waveform, such that $\int |\psi(t)|^2 = 1$, $T_c = T/M$ is the chip duration and T is the symbol interval.
As illustrated in Figure 1, the best cooperating partners apply DF for relaying the source user data to the destination base station (BS), with no error correction codes applied. It is, also, worthwhile clarifying that the cooperating users have no data of their own to transmit. The instantaneous CSI of the Source-Partner (S-P) link is assumed to be known at the cooperating partner. Also, the CSI of the Source-Destination (S-D) and P-D links are assumed as well known at the BS.
The channels are assumed to be independent and identically distributed (i.i.d.) Rayleigh flat fading channels, where fading could be either slow or fast, depending on the amount of Doppler spreading caused by the relative speed between any two nodes in the system. Negligible inter-symbol interference is assumed ($T_m \ll T$), where T_m is the delay spread.

Since we are using orthogonal spreading codes and ignoring the effect of the near-far problem, multiple access interference (MAI) is considered to be negligible in this work. We should emphasis that dealing with MAI is out of the scope of this work.

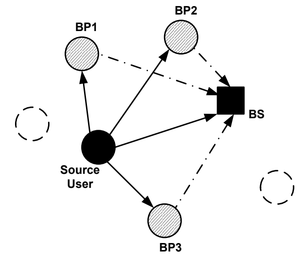


Figure 1: Source user broadcasts data, and the best cooperating partners (BP's) relay them to the BS

The reader is referred to [10], where the authors dealt with the MAI problem in a similar system model.
The cooperation process proceeds in two orthogonal time phases, as shown in Figure 2, such that:

- In the first phase, the source user broadcasts its own data to be relayed by the chosen best partners, as shown in Figure 2 (a). The received signal in the interval $iT \le t \le (i+1)T$ at any of the best cooperating partners is given by:

$$r_{su,bp}(t) = h_{su,bp} x_{su}(t - iT) + z_{bp}(t) \qquad (3)$$

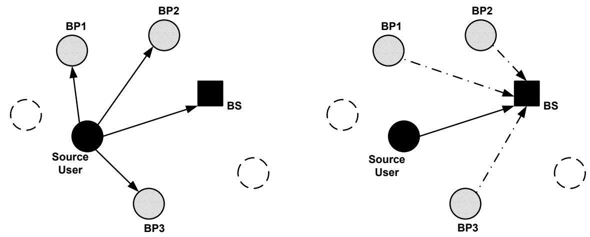
  where $x_{su}(t)$ is the source user transmitted signal, $h_{su,bp}$ is the fading coefficient of the channel between the source user and the best partner, $h_{su,bp}$ is a zero mean, complex Gaussian random variable with variance σ^2, and $z_{bp}(t)$ is the AWGN, added at the best partner receiver, with zero mean, variance σ_n^2 and a PSD of $N_o = 2\sigma_n^2$.

- In the second phase, the best partners relay the decoded signal received from the source user to the BS (see Figure 2(b)). By considering a total of $U = B + 1$ users in cooperation, where U includes the source user and the best cooperating partners, we may express the received signal at the destination BS in the interval $(i+1)T \le t \le (i+2)T$ as:

$$r_d(t) = \sum_{u=1}^{U} h_{u,d} x_u(t - iT) + z_d(t) \qquad (4)$$

  where $x_u(t)$ is the $u'th$ cooperating user transmitted signal, $h_{u,d}$ is the fading coefficient of the channel between the $u'th$ cooperating user and the destination, $h_{u,d}$ is a zero mean, complex Gaussian random variable with σ^2 variance and $z_d(t)$ is the AWGN, added at the destination, with zero mean, σ_n^2 variance and a PSD of $N_o = 2\sigma_n^2$.

  Now, each of the cooperating users transmits and receives at the same time on different spreading codes (channels) during phase 1.



(a) Phase1 (b) Phase 2

Figure 2: Transmission phases

The problem of self-interference caused by transmitting and receiving at the same time can be reduced by using co-located antennas and/or multiple spreading codes [10]. At the destination node maximum ratio combining (MRC) is applied to combine the signal received from the source user and the best cooperating partners.

B. Doubly selective fading channel

For the same communication system mentioned in part A, we extend the work to include the scenario of a doubly selective channel. In [4][9], the inherited diversity in the time-frequency shifts were exploited using appropriate signal processing, specifically called canonical channel decomposition. We will use this method to express the received signals model at the two phases of the cooperation process.

- In the first phase, the received signal in the interval $iT \le t \le (i+1)T$ at any of the best cooperating partners is given by [4]:

$$y_{bp}(t) = \frac{T_c}{T} \sum_{n=0}^{N} \sum_{l=-L}^{L} H_{l,n}^{su,bp} u_{l,n}^{su}(t) + n_{bp}(t) \quad (5)$$

where n represents the multipath diversity components, with $N = T_m / T_c \approx T_m B$, l represents the Doppler diversity components with $L = B_d T$, $B = 1/T_c$ is the signal bandwidth, $H_{l,n}^{su,bp}$ are the time-frequency (TF) channel coefficients between the source user and the best partner, $u_{l,n}^{su}(t)$ is the basis signal of the source user. $n_{bp}(t)$ is the AWGN, added at the best partner, with zero mean, σ_n^2 variance and a PSD of $N_o = 2\sigma_n^2$.

For any user j we define the basis signal $u_{l,n}^{j}(t)$ as

$$u_{l,n}^{j}(t) = b_j[i] q_j(t - nT_c) e^{j\frac{2\pi l t}{T}} \quad (6)$$

where $b_j[i] \in \{\pm 1\}$ and $q_j(t)$ is the $j'th$ user normalized spreading waveform.

- In the second phase, we may express the received signal at the destination BS in the interval $(i+1) \le t < (i+2)T$ as:

$$y_d(t) = \frac{T_c}{T} \underbrace{\sum^{U} \sum^{N} \sum^{L} H_{l,n}^{u,d} u_{l,n}^{u}(t)}_{Cooperating\ \ users} + n_d(t) \quad (7)$$

where $H_{l,n}^{u,d}$ are the TF channel coefficients between the $u'th$ cooperating partner and the destination, $u_{l,n}^{u}(t)$ is the basis signal of the $u'th$ cooperating user and $n_d(t)$ is the AWGN, added at the destination, with a zero mean, a σ_n^2 variance and a PSD of $N_o = 2\sigma_n^2$.

Due to the assumption of negligible ISI it is possible to utilize a one-shot (symbol-by-symbol) detector at the receiver. As mentioned before, a TF rake is used at the receiver, for both the cooperating partners and the BS. The TF rake in [4] and [5] can be modeled as a bank of conventional rake receivers [1], with the difference of inserting a frequency shift at each rake to exploit the power in the Doppler components- caused by mobility - of the signal.

III. DYNAMIC PARTNER SELECTION (DPS) STRATEGY

A. DPS Algorithm

This section, with the aid of the flow diagram shown in Figure 3, gives a detailed description on how the algorithm actually works.

When a source user i is having problems in communicating with the BS, the SNR between the source user and the destination (SNR_i) is below a given threshold S_1. In such a case, it will start searching for partners to cooperate with, in an attempt to improve the quality of the link through exploiting the spatial diversity gain offered by cooperation. The cooperation process proceeds as follows:

1. User i starts by selecting a group of K users, with the following characteristics:
   - They are willing to cooperate with user i.
   - The normalized Doppler frequency shifts of their received signals at user i do not exceed the predetermined bound f_b, such that [11], [12]:

$$f_b = |f_m| = |f_d| T_s = \frac{|v_{t,r}|}{\lambda} T_s = \left| \frac{v_t \cos(\theta_t) + v_r \cos(\theta_r)}{\lambda} \right| T_s \quad (8)$$

   Where, f_m is the normalized Doppler frequency shift, f_d is the Doppler frequency shift, T_s is the symbol period, $v_{t,r}$ is the relative velocity between the transmitter and receiver in m/s, $\lambda = f_c/c$ is the wave length of the transmitted signal, where $c \simeq 3 \times 10^8\ m/s$ is the speed of light, (v_t, v_r) are the velocities of the transmitter and receiver, respectively, in m/s, and (θ_t, θ_r) are the angles between the direction of movement and the line-of-sight between transmitter and receiver.

We will refer to the process of grouping the 'willing to cooperate' users -based on a relative speed upper bound- as *velocity grouping*. Relative speed will be represented in the form of normalized Doppler shifts. Velocity grouping aims at reducing the relative speed between the source user and cooperating partners, which in effect lowers the unwanted influence of Doppler spreading.

2. From users in group K, we will apply one of the two following policies, [13], to determine the best relaying partners to cooperate with and place them in group M.

   Policy1: represents choosing the user's bottleneck channel.

$$h_r = \min\left(\left|h_{su,r}\right|^2, \left|h_{r,d}\right|^2\right) \tag{9}$$

   where $h_{su,r}$ and $h_{r,d}$ are the source-relay and relay-destination instantaneous channel fading coefficients, respectively.

   Policy2: represents choosing the harmonic mean of the two channels of the user.

$$\mathbb{h}_r = \frac{2}{1/\left|h_{su,r}\right|^2 + 1/\left|h_{r,d}\right|^2} \tag{10}$$

   The best partners at a given instance are those with maximum $\mathbb{h}_r$, given an upper bound on the number of partners.

3. Users in M will be arranged in a descending order according to the coefficients $\mathbb{h}_{rj}$, where $\mathbb{h}_{rj}$ is the policy coefficient of the $j'th$ user in group M.
4. The first W users from group M will be chosen and placed in group B as best partners, such that $W \leq W_{max}$, where W_{max} is a pre-specified maximum number of possible best cooperating partners.
5. Now, the size of group B will be compared to zero to find out whether there are any best partners in B or not.
6. If the result of step 5 is true, then:
   - There exists at least one best partner in B. Hence, user i will start cooperating with user(s) in B for a preset period of time T', where T' is a single frame period.
   - After T' seconds, if user i still has the need for cooperation - $SNR_i < S_1$- then another search for best partners is started, otherwise the process terminates.
7. If the result of step 5 is false, user i checks the need for cooperation, if there is a need, another search for best partners is started; otherwise the search for best partners to cooperate with is terminated.

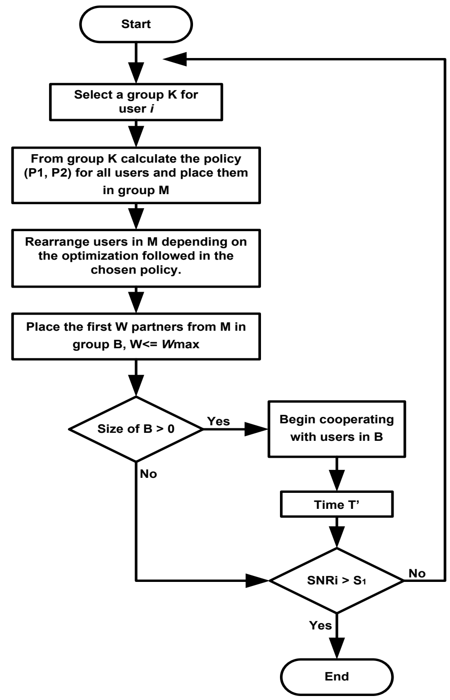


Figure 3: Flow diagram of the proposed dynamic partner selection strategy

It is important to mention that, in this work we are going to assume that the source user is always in need for cooperation (i.e. $SNR_i < S_1$).

B. Best Partner Selection Protocol.

A demonstration of the protocol that could be possibly used for selecting the best cooperating partners, is presented as follows:

1. Let us say that at some moment source user A, happens to be in a need for cooperation.
2. User A sends a Request to Cooperate packet (RTC) to the BS. This packet solicits the BS to broadcast a Clear to Cooperate (CTC) packet, and announces to the nearby users that it is in a need for cooperation.
3. Users who have overheard the RTC packet, and are willing to cooperate, standby to hear the CTC packet from the BS.
4. The willing to cooperate users, then, use the CTC packet to measure the SNR in the downlink channel, and then each one of them broadcasts a Willing to Cooperate (WTC) packet containing its own address along with the measured SNR, Figure 4.
5. Suppose that users D, E and F are willing to cooperate, and they show that by broadcasting, WTC_D, WTC_E and WTC_F, respectively, containing their addresses along with the measured SNRs (SNR_D, SNR_E and SNR_F).

6. Each WTC packet contains at its beginning a sequence of bits used as a pilot. This pilot is used at the source user A for two purposes:
   - To measure the SNR corresponding to each of the willing to cooperate users, hence, we have $SNR_{A,D}$, $SNR_{A,E}$ and $SNR_{A,F}$.
   - To measure the Doppler frequency shift due to their mobility. Hence, we have $f_{d_{A,D}}$, $f_{d_{A,E}}$ and $f_{d_{A,F}}$.
7. Depending on the measured $SNRs$ and Doppler frequency shifts, the source user A can employ the DPS algorithm to select the best partners to cooperate with.

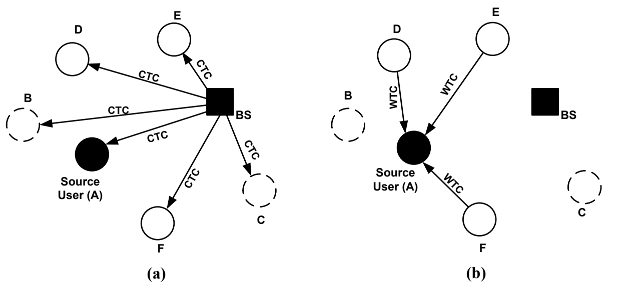


Figure 4: (a) the BS broadcasts a CTC packet. (b) users D, E and F who are willing to cooperate send a WTC packet to the source user

8. Suppose that user A has selected users E and F as best partners. At this point, user A broadcasts a short duration flag packet informing that the cooperation process will involve only users E and F.
9. After the reception of the flag packet, the first phase starts where users E and F begin receiving user's A data, Figure 5. All other willing to cooperate who had heard the flag packet, are free to cooperate with any other user.

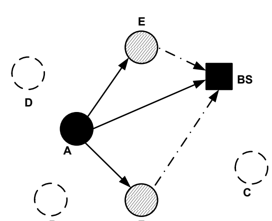


Figure 5: Cooperation process between user A and best partners E and F

10. The second phase proceeds with users E and F decode and forward user's A data to the BS.

11. The cooperation process with the best partners lasts for T', after which, another search for best partners is lunched, if needed - $SNR_A < S_1$.

IV. SIMULATION RESULTS

For the orthogonal DS-CDMA communication system under consideration, we have the simulation setup illustrated in Table I.

TABLE I. SIMULATION SETUP

Parameter	Value
Number of mobile users	30
Max. number of best cooperating partners	5
Speed-range of mobile users†	0 to 250 km/h
Number of multipath diversity components	2 (N = 1), with a power of $(0, -15)_{dB}$
Number of Doppler diversity components	3 (L = 1), with a power of $(E[\alpha_{-1}^2], E[\alpha_0^2], E[\alpha_{+1}^2])$‡

† The direction is represented in the form of the angle between the direction of movement and the line of sight with the source user, and it takes a value from the range[0,360)°.
‡ α is the Rayleigh distributed channel coefficient magnitude.

Figure 6 aims at clarifying the improvement offered by the velocity grouping, which is a part of the DPS strategy. It is observable that the introduction of velocity grouping provides a satisfactory improvement, which is a reflection of the slower fading in the inner channels; between the source user and cooperating partners.

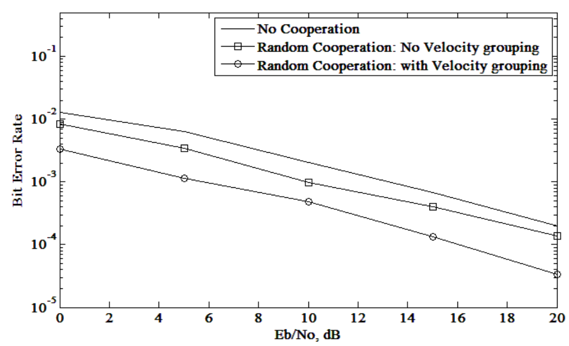


Figure 6: Impact of velocity grouping

Figure 7 explores the effect of the chosen relative speed upper bound on the BER performance. The relative speed upper bound is expressed in terms of Doppler frequency shift (f_d) using relation (8).

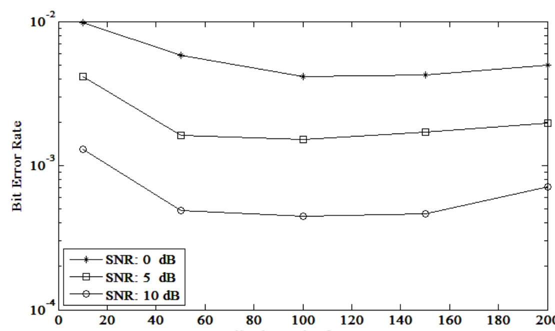


Figure 7: Effect of relative speed bound on the BER performance

Under the current simulation setup, the best performance is achieved when an upper bound of 120 km/h ($f_d = 100\,Hz$) is chosen. Even though the Doppler frequency is growing in the [0,100] Hz range, it is considered to be small enough. As the Doppler frequency bound increases toward 100 Hz the applicable number of cooperating users also grows, which in turn improves the spatial diversity gain. As the relative speed increases, and even though the applicable number of users that apply might be larger, the channel variation becomes much more rapid and the BER performance degrades.

Figure 8 presents a comparison between the performances of the best cooperation (DPS strategy), random cooperation and no-cooperation cases, such that no velocity grouping is adopted in the case of random cooperation. Obviously, cooperating with best partners offers a considerable improvement over the two other cases. Note that there is no big difference between the policy 1 and policy 2 in terms of BER performance.

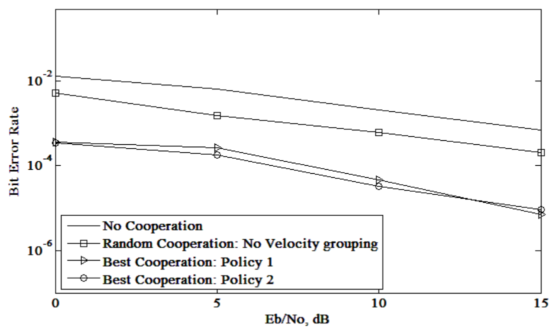


Figure 8: BER performance enhancement when cooperating with the best partners

In Figure 9, we clarify the improvement in BER performance when the TF rake receiver is introduced into the system model, over the cases of no-cooperation and best cooperation (DPS strategy). It is observable that if the velocity grouping part is omitted from the DPS Strategy, degradation in performance occurs, and this case is similar to the work presented in [13].

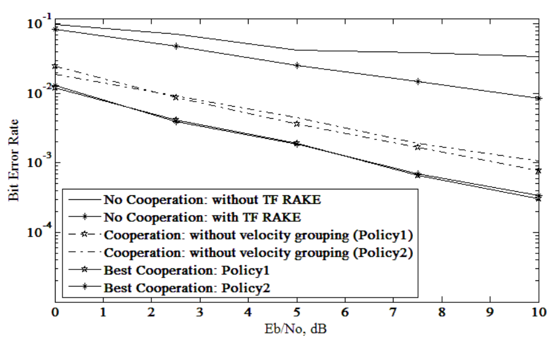


Figure 9: BER performance of a TF RAKE on the cases of no-cooperation and best cooperation

V. CONCLUSION

In this work, we have studied user cooperation with the best possible relaying partners in the uplink of a DS-CDMA wireless communication system. Users are assumed to be moving at different speeds –fast, slow or static- and in any possible direction. Simulation results showed clearly that velocity grouping used as a part of the proposed partner selection strategy enhances the overall BER performance. Also, combining velocity grouping with one of the two policies -used for selecting the best end-to-end link- in our strategy, offers a noticeable improvement.

Furthermore, it was shown that a doubly selective channel degraded the BER performance severely, and how the use of a TF rake at both the best cooperating partners and the destination receivers made it less sever.

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