Elimination of Inter-distract Downlink Interference Based on Autocorrelation Technique

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Abstract. In order to eliminate downlink interference and improve system performance, we proposed a method to eliminate inter-distract downlink interference based on the non-overlapping nature of the signal in autocorrelation domain. In this method, multi-antenna technology was used and spectrum resource was not additionally occupied, without requiring channel conditions. The simulation result showed that this method is suitable for the removal of strong downlink interference in the mobile station at the edge of the distract.

Keywords: Downlink interference · Autocorrelation · Mobile station

1 Introduction

The main purpose of signal processing is to identify and separate the useful signals and the interferences in the special transform domain. The typical transform domains are time domain, frequency domain, code domain, and spatial domain. There is an obvious advantage in the method of distinguishing signals based on the non-overlapping nature in the autocorrelation domain, i.e., the interfering signal may be eliminated no matter how strong it is, and the channel state information is not necessary to be supplied to the receiver. In this paper, the correlation function matching algorithm was applied to the downlink cellular system. The non-overlapping nature of the signal in the autocorrelation domain was achieved by preprocessing the autocorrelation function of signals that transmitted by the base station [1–7]. In the receiver, the inter-distract downlink Interference may be eliminated after passing through the autocorrelation matching filter.

2 Design of System

2.1 System Model

In this paper, each of the base stations is equipped with a single transmitting antenna, and each of the mobile stations is equipped with N_r receiving antennas, thus the downlink channel may be seen to be a SIMO channel model. The typical system model is given in Fig. 1.

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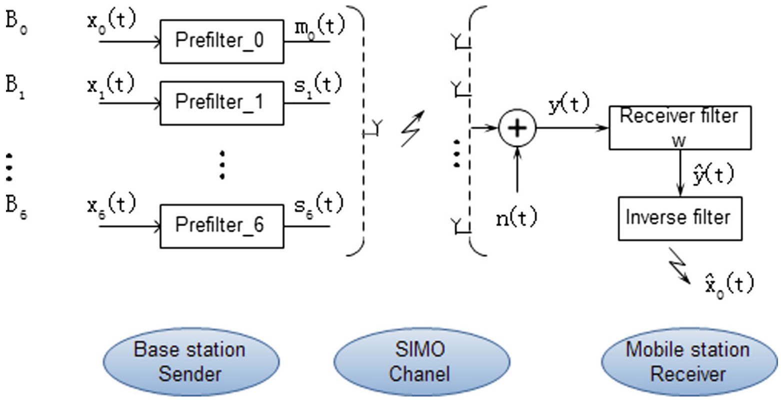

Fig. 1. System model

At the base station sender, the original signal to be transmitted is processed by a prefilter, so the autocorrelation function of the transmitted signal is linearly independent. At the mobile station receiver, the inter-distract downlink interference in the received signal was eliminated after passing through the receive filter W, and then the original signal was recovered by inverse filter. The receiver filter W was designed according to the autocorrelation function of the transmitted signal and the received signal. This is a blind algorithm, and the channel state information is not involved.

2.2 Signal Model

Both large scale fading and small scale fading are considered in the channel parameters. Assuming that the receiving antenna is properly placed, so that the large scale fading is of the same and the small scale fading is different between transmitting antenna and each receiving antenna of the base station. According to the system model of Fig. 1, the received signal of a mobile station in this distract B0 can be expressed to be,

$$\mathrm{y}(t) = \sqrt{P_0}\mathrm{h}_0\mathrm{m}_0(t) + \sum_{i=1}^{6} \sqrt{P_i}\mathrm{f}_i\mathrm{s}_i(t) + \mathrm{n}(t) \tag{1}$$

In formula (1),

P_0 is large scale fading power between the mobile station and the base station of this local distract;

P_i is large scale fading power between the mobile station in this local distract and the base station in adjacent distract;

h_0 is the N_r-dimensional small scale fading power vector between the mobile station and the base station in this local distract;

f_i is the N_r-dimensional small scale fading power vector between the mobile station in this local distract and the base station in adjacent distract;

$\mathrm{m}_0(t)$ is the L-dimensional transmitted signal vector of the base station in this local distract;

$s_i(t)$ is the L-dimensional transmitted signal vector of base station in the adjacent distract;
$n(t)$ is N_r-dimensional complex vector of white Gauss noise that obeys $N(0,1)$;

The sum on the right side of formula (1) represents the downlink interference received by the mobile station in this local distract.

Assume $\mathbf{F} = [\mathbf{f_1}, \cdots, \mathbf{f}_6]$; $\mathbf{P} = \mathrm{diag}[\sqrt{P_1}, \cdots, \sqrt{P_6}]$; $\mathbf{S}(t) = \mathrm{diag}[s_1(t), \cdots, s_6(t)]^T$, then the received signal in formula (1) can be expressed as,

$$y(t) = \sqrt{P_0}\mathbf{h}_0 m_0(t) + \mathbf{FPS}(t) + \mathbf{n}(t) \tag{2}$$

Assume the channel matrix $[\mathbf{h}_0 \quad \mathbf{F}]$ is a matrix of full column rank, then channel estimation is not needed for the receiver to obtain the channel parameters. At the receiver of the base station, based on the autocorrelation function of the transmitted signal and the received signal, the filter W, as a N_r-dimensional complex vector, was designed, in which the downlink interference may be eliminated. The output signal of the filter W is,

$$\hat{y}(t) = \sqrt{P_0}\mathbf{W}^*\mathbf{h}_0 m_0(t) + \mathbf{W}^*\mathbf{FPS}(t) + \mathbf{W}^*\mathbf{n}(t) \tag{3}$$

If the filter meets $\mathbf{W}^*\mathbf{F} = 0$, the inter-distract downlink interference may be completely eliminated.

2.3 Design of Transmitted Signal

In this paper, different autocorrelation functions were used to distinguish signals. If the N autocorrelation sequences are linearly independent, the N signals may not overlap in the autocorrelation domain, then they can be transmitted at the same time with the same frequency and the same spreading spectrum sequence, and they can not be confused. The original signals were processed through the prefilter in Fig. 1, so that the transmitted signal of the base station in this local distract and the signals from the adjacent distract are linearly independent. The following FIR filters are used as prefilter.

$$H(z) = 1 + z^{-\zeta} \tag{4}$$

In formula (4), $H(z)$ is the system function of the filter. Different ζ corresponds to different FIR filters. For the same filter, if the input signal is a white random signal, the output signal has the same autocorrelation sequence. If the mean value of the input signal is 0, the output signal has autocorrelation function values ($\neq 0$) when $\tau = \zeta$, otherwise the autocorrelation function of the output signal is 0. For different filters, the autocorrelation sequence of the output signal is linearly independent. Substitute $\zeta_6 \geq \ldots \geq \zeta_1 \geq \zeta_0 \geq 1$ into the formula (4), and seven filters were designed for $B_i(i = 0, 1, \ldots, 6)$ in Fig. 1, which was used as a prefilter on the sending end of the base station. Both signal $m_0(t)$ and $s_i(t)$ outputted by the prefilter are not overlapped in autocorrelation domain.

Define their autocorrelation sequences and the autocorrelation matrix,

$$\mathbf{r}_{\mathrm{m}_0} = \left[\mathrm{r}_{\mathrm{m}_0}(\zeta_0), \ldots, \mathrm{r}_{\mathrm{m}_0}(\zeta_6)\right]^T \tag{5}$$

$$\mathbf{r}_{\mathrm{s}_i} = \left[\mathrm{r}_{\mathrm{s}_i}(\zeta_0), \ldots, \mathrm{r}_{\mathrm{s}_i}(\zeta_6)\right]^T \tag{6}$$

$$\mathbf{T} = \left[\mathrm{r}_{\mathrm{m}_0}\mathrm{r}_{\mathrm{s}_1}\ldots\mathrm{r}_{\mathrm{s}_6}\right] = \begin{bmatrix} \mathrm{r}_{\mathrm{m}_0}(\zeta_0) & \mathrm{r}_{\mathrm{s}_1}(\zeta_0) & \ldots & \mathrm{r}_{\mathrm{s}_6}(\zeta_0) \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{r}_{\mathrm{m}_0}(\zeta_6) & \mathrm{r}_{\mathrm{s}_1}(\zeta_6) & \cdots & \mathrm{r}_{\mathrm{s}_6}(\zeta_6) \end{bmatrix} \tag{7}$$

Assume that the original signal $\mathrm{x}_i(t)$ is a white random signal with a mean value of 0 and a variance of 1, then the autocorrelation matrix can be further simplified,

$$\mathbf{T} = \begin{bmatrix} \mathrm{r}_{\mathrm{m}_0}(\zeta_0) & 0 & \cdots & 0 \\ 0 & \mathrm{r}_{\mathrm{s}_1}(\zeta_1) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \mathrm{r}_{\mathrm{m}_6}(\zeta_6) \end{bmatrix} \tag{8}$$

In matrix (8), T is a diagonal matrix of 7 * 7. Obviously, T is also a matrix of full column rank. So $\mathrm{r}_{\mathrm{m}_0}$ and $\mathrm{r}_{\mathrm{s}_i}$ are independent linearly. Therefore, the transmitted signal $\mathrm{m}_0(t)$ of base station in this local distract and the transmitted signal $\mathrm{s}_i(t)$ of base station in the adjacent distract are not overlapped in the autocorrelation domain.

2.4 Design of Receive Filter

Assume that $\mathbf{m}_0(t)$, $\mathbf{s}(t)$ and $\mathrm{n}(t)$ are uncorrelated each other. Given $\tau \geq 0$, the autocorrelation function of the received signal in formula (2) can be obtained,

$$\mathbf{R}_{\mathrm{y}}(\tau) = P_0 r_{\mathbf{m}_0}(\tau)\mathbf{h}_0\mathbf{h}_0^* + \mathbf{FPR_s}(\tau)\mathbf{P}^*\mathbf{F}^* + \mathbf{R}_{\mathrm{n}}(\tau) \tag{9}$$

In formula (9), $\mathbf{R}_{\mathrm{y}}(\tau) = E[\mathrm{y}(t)\mathrm{y}^*(t-\tau)]$, $\mathbf{R}_{\mathrm{s}}(\tau) = E[\mathrm{s}(t)\mathrm{s}^*(t-\tau)]$, $\mathbf{R}_{\mathrm{n}}(\tau) = E[\mathbf{n}(t)\mathbf{n}^*(t-\tau)]$. $\mathbf{n}(t)$ is white Gauss noise. $\mathbf{R}_{\mathrm{n}}(\tau) = 0$ when $\tau > 0$. Since the transmitted signals were uncorrelated each other, the co-variance matrix of $\mathrm{s}(t)$ can be further written to be,

$$\mathbf{R}_{\mathrm{s}}(\tau) = \mathrm{diag}\left[r_{\mathrm{s}_1}(\tau)\cdots r_{\mathrm{s}_6}(\tau)\right] \tag{10}$$

Substitute it into formula (9),

$$\mathbf{R}_{\mathrm{y}}(\tau) = P_0 r_{\mathrm{m}_0}(\tau)\mathbf{h}_0\mathbf{h}_0^* + \sum_{i=1}^{6} P_i r_{\mathrm{s}_i}(\tau)\mathrm{f}_i\mathrm{f}_i^* \quad \tau > 0 \tag{11}$$

By formula (8), $r_{\mathrm{m}_0}(\tau) = 0$ when $\tau > \zeta_0$,

$$\mathbf{R}_{\mathrm{y}}(\tau) = \sum_{i=1}^{6} P_i r_{\mathrm{s}_i}(\tau)\mathrm{f}_i\mathrm{f}_i^* \quad \tau > \zeta_0 \tag{12}$$

In the autocorrelation function of the received signal, only the downlink interference information is left. In addition, by formula (8),

$$\mathbf{R}_{\mathrm{y}}(\zeta_i) = P_i r_{\mathrm{s}_i}(\zeta_i)\mathrm{f}_i\mathrm{f}_i^* \quad 1 \le i \le 6 \tag{13}$$

Construct a $6N_r \times N_r$ matrix R as follows,

$$\mathbf{R} = \begin{bmatrix} \mathbf{R}_{\mathrm{y}}(\zeta_1) \\ \vdots \\ \mathbf{R}_{\mathrm{y}}(\zeta_6) \end{bmatrix} = \mathrm{diag}[P_1 r_{\mathrm{s}_1}(\zeta_1)\mathrm{f}_1, \cdots, P_6 r_{\mathrm{s}_6}(\zeta_6)\mathrm{f}_6]\mathbf{F}^* \tag{14}$$

Both the diagonal matrix and $\mathbf{F}$ are all matrix of full column rank with rank 6 in formula (14). $\mathbf{F}^*\mathbf{W} = 0$ when $\mathbf{R}^*\mathbf{W} = 0$. If $\mathbf{W}^*\mathbf{F} = 0$, Receiving filter $\mathbf{W}$ can be obtained directly by singular value decomposition of $\mathbf{R}$, as follows,

$$\mathbf{R} = \mathbf{U}\begin{bmatrix} \sum & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \mathbf{V} & \mathbf{V}^{\perp} \end{bmatrix} \tag{15}$$

In formula (15), $\sum$ is non-zero singular value diagonal matrix. Both $\mathbf{U}$ and $[\mathbf{V} \quad \mathbf{V}^{\perp}]$ are unitary matrix. Since the rank of matrix $\mathbf{R}$ is 6, it can be computed at last,

$$\mathbf{W} = \mathbf{V}^{\perp}\mathbf{c} \tag{16}$$

In the formula (16), $\mathbf{V}^{\perp}$ is a $N_r \times (N_r - 6)$ dimensional matrix, and $\mathbf{c}$ is any one-dimensional vector. Therefore, the filter $\mathbf{W}$ is solvable when the N_r is larger than 6. Therefore, at least 7 receiving antennas are required in the present method. After passing through the filter $\mathbf{W}$, the inter-distract downlink interference was eliminated. The resulting signal was obtained,

$$\hat{x}(t) = \sqrt{P_0}\mathbf{W}^*\mathrm{h}_0\mathrm{m}_0(t) + \mathbf{W}^*\mathrm{n}(t) \tag{17}$$

Finally, the original signal $\mathrm{x}_0(t)$ can be recovered by the inverse filter $F^{-1}(z)$ of formula (4).

3 Eliminate the Downlink Interference Between Two Adjacent Distracts

The necessary condition for the existence of receiving filter is that the number of receiving antenna is larger than six. That is, if the interference from the six adjacent distracts is to be eliminated, the mobile station must be equipped with at least seven receiving antennas. However, this is not realistic for the design of mobile station. The downlink interference received by the mobile station is closely related to the distance between the mobile station and the base station in the adjacent distracts. The distances between the mobile station and the base stations in the six adjacent distracts are different, as a result, the strengths of the six downlink interference are different. A nearer base station has a stronger interference to the mobile station. If the strongest downlink interference is eliminated by using fewer receiving antennas, then the system performance may be greatly improved. Especially for the users at the edge of the distract, the interference from adjacent distract is as strong as the signal transmitted by the base station in its own distract. Therefore, if the downlink interference from the adjacent distract was to be eliminated, the SINR of the mobile station may be greatly improved. Next, an improved method is proposed. By using two receiving antennas, the single strongest downlink interference from adjacent distract may be eliminated. The system model, the signal model and the signal design of transmitter were adopted in the base station in Sect. 2. The receiving filter of the mobile station was redesigned. In order to eliminate the downlink interference when the signal from the adjacent base station B_6 is $\mathrm{s}_6(t)$, a new receiver filter should be adopted in the mobile station, meeting the requirements $\mathbf{W}^*\mathrm{f}_6 = 0$. When $\tau > 0$, the autocorrelation function of the received signal (2) is,

$$\mathbf{R}_{\mathrm{y}}(\tau) = P_0 r_{\mathrm{m}_0}(\tau)\mathrm{h}_0\mathrm{h}_0^H + \sum_{i=1}^{5} P_i r_{\mathrm{s}_i}(\tau)\mathrm{f}_i\mathrm{f}_i^* + P_6 r_{\mathrm{s}_6}(\tau)\mathrm{f}_6\mathrm{f}_6^* \tag{18}$$

Since the autocorrelation sequences of the transmitted signals from each base stations are independent of each other, and meet the requirements of formula (8), then when $\tau = \zeta_6$,

$$\mathbf{R}_{\mathrm{y}}(\xi_6) = P_6 r_{\mathrm{s}_6}(\xi_6)\mathrm{f}_6\mathrm{f}_6^* \tag{19}$$

The $\mathbf{R}_{\mathrm{y}}(\xi_6)$ is a $N_r \times N_r$-dimensional matrix. $\mathrm{f}_6^*\mathrm{w} = 0$ when $\mathbf{R}_{\mathrm{x}}(\xi_6)\mathrm{w} = 0$. The receiver filter that meet $\mathbf{W}^* f_6 = 0$ may be obtained directly by making the singular value decomposition of $\mathbf{R}_{\mathrm{y}}(\xi_6)$ as follows,

$$\mathbf{R}_{\mathrm{y}}(\xi_6) = \mathbf{U}_1 \begin{bmatrix} \sum_1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{V}_1 & \mathbf{V}_1^{\perp} \end{bmatrix} \tag{20}$$

In formula (20), $\sum_1$ is non-zero singular value diagonal matrix. $\mathbf{U}_1$ and $\begin{bmatrix} \mathbf{V}_1 & \mathbf{V}_1^{\perp} \end{bmatrix}$ are all unitary matrix.

Since the rank of matrix $\mathrm{f}_6\mathrm{f}_6^*$ is 1, then,

$$\mathbf{W} = \mathbf{V}_1^{\perp} c_1 \tag{21}$$

In formula (21), $\mathbf{V}_1^{\perp}$ is a $N_r \times (N_r - 1)$-dimensional matrix, and c_1 is any $(N_r - 1)$-dimensional vector. As a result, the filter $\mathbf{W}$ is solvable when N_r is larger than 1. After passing through receiving filter $\mathbf{W}$, the resulting signal is,

$$\hat{\mathrm{y}}'(t) = \sqrt{P_0}\mathrm{W}^*\mathrm{h}_0\mathrm{m}_0(t) + \sum_{i=1}^{5}\sqrt{P_i}\mathrm{W}^*\mathrm{f}_i\mathrm{s}_i(t) + \mathrm{W}^*\mathrm{n}(t) \tag{22}$$

In the improved method, the mobile station only needs to be equipped with two receiving antennas, which can eliminate the strongest downlink interference between this local distract and adjacent distract. It is realistic that the mobile station is equipped with two receiving antennas. In fact, the improved method may be used to eliminate the downlink interference from any of the six adjacent distracts. For example, if you were to eliminate the downlink interference s_i from the base station in distract B_i, substitute $\tau = \zeta_i$ into formula (18), then,

$$\mathbf{R}_{\mathrm{y}}(\zeta_i) = P_i r_{\mathrm{s}_i}(\zeta_i)\mathrm{f}_i\mathrm{f}_i^* \tag{23}$$

Similarly, a reception filter satisfying $\mathrm{w}_i^*\mathrm{f}_i = 0$ may be obtained in making the singular value decomposition of $\mathbf{R}_{\mathrm{y}}(\zeta_i)$.

In the two methods in Sects. 2 and 3, the solution of receiving filter is only related to the autocorrelation function of the received signal and the autocorrelation function of the transmitted signal of each base station. The solution of the receiving filter is independent of signal strength and channel parameters. Consequently, the method of eliminating downlink interference based on signal autocorrelation technology is a blind algorithm, the downlink interference may be effectively eliminated no matter how strong its power is.

4 Simulation Analysis

When there is a downlink cellular system in the seven distracts, the system parameters [8] are present in Table 1.

Table 1. System parameters

Distract radius	Path loss constant	Path loss index factor	Shadow fading factor	Noise power	Small-scale fading (Rayleigh fading model)
2 km	−137 dB	4	8 dB	−129 dB	$h \sim CN(0,\ 1)$

The mobile station is equipped with two receiving antennas, the single strongest downlink interference from adjacent distract is eliminated by using the improved method proposed above. By using Monte and Carlo simulation, the SINR of the signal was compared and analyzed before and after the method was used. In the simulation, the following three SINR parameters are involved:

(1) the SINR of the signal before receiving the filter W:

$$SINR_b = \frac{E\left[P_0|\mathbf{h}_0\mathbf{m}_0(t)|^2\right]}{E\left[\left|\sum_{i=1}^{6}\sqrt{P_i}\mathbf{f}_i\mathbf{s}_i(t))\right|^2\right] + E\left[|\mathbf{n}(t)|^2\right]} \tag{24}$$

(2) the SINR of the signal after being processed by the filter W:

$$SINR_a = \frac{E\left[P_0|\mathbf{w}^H\mathbf{h}_0\mathbf{m}_0(t)|^2\right]}{E\left[\left|\sum_{i=1}^{6}\sqrt{P_i}\mathbf{w}^H\mathbf{f}_i\mathbf{s}_i(t))\right|^2\right] + E\left[|\mathbf{w}^H\mathbf{n}(t)|^2\right]} \tag{25}$$

(3) the SINR of the received signal after a single strongest downlink interference from adjacent distract was theoretically removed:

$$SINR_n = \frac{E\left[P_0|\mathbf{h}_0\mathbf{m}_0(t)|^2\right]}{E\left[\left|\mathbf{x}(t) - \sqrt{P_0}\mathbf{h}_0\mathbf{m}_0(t) - \sqrt{P_6}\mathbf{f}_6\mathbf{s}_6(t)\right|^2\right]} \tag{26}$$

In formula (26), the SINR was used to compare the effectiveness of filter W. When the mobile station was located at the edge of the distract, the SINR of the received signals was compared before and after the improved method was used. As can be seen from Fig. 2, after using the improved method, the SINR of mobile station is obviously improved, no matter how strong the transmitter power is.

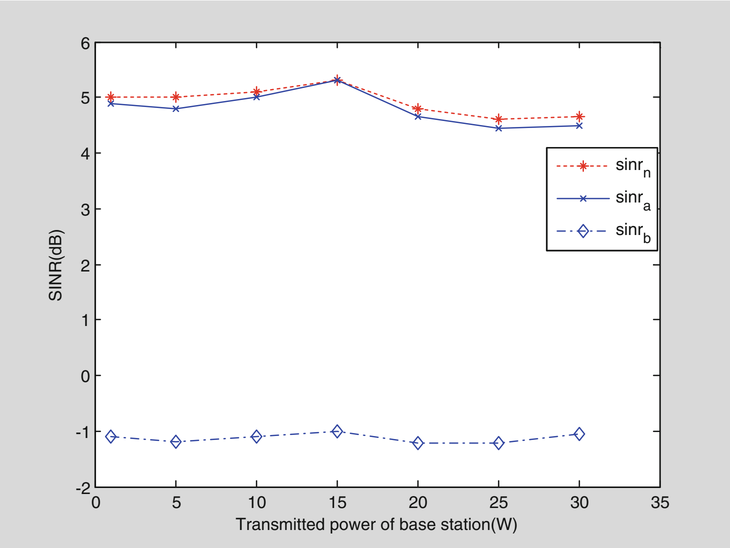

Fig. 2. SINR comparison for different transmit power of the base station

It is apparent that $SINR_a$ is very closed to $SINR_n$ in Fig. 2. This indicated the strongest downlink interference from adjacent distract may be effectively eliminated after passing the filter W.

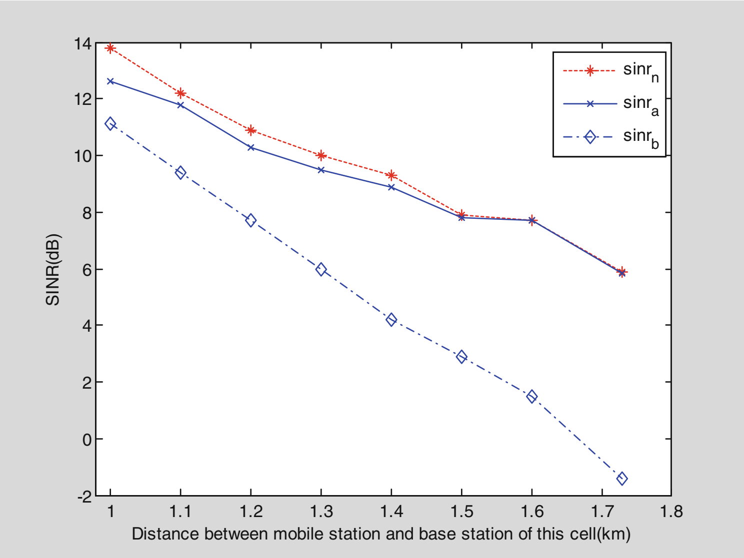

Fig. 3. SINR comparison for different locations of the mobile station in the distract

Assume the transmitting power of the base station was 20 W and the mobile station moved toward the distract edge when the mobile station was 1 km away from the base station in the distract. In Fig. 3, the SINR of the received signals was compared before and after the improved method was used when the mobile station was located in different positions in the distract. When the mobile station is close to the base station in the local distract, the power of useful signal from this base station was relatively stronger and the downlink interference from adjacent distract is relatively weaker, so the downlink interference may be ignored. With the mobile station moved away from the base station in the local distract, the power of useful signal was reduced and the power of downlink interference was increased, resulting in a decrease in SINR. Using the improved method, the SINR was improved and the improvement in SINR was more apparent when the mobile station was farther away from the base station in the local distract. This is because the single strongest downlink interference was increased when the mobile station was near the edge of the distract, and its ratio in total interference was increased. Consequently, a larger improvement in SINR was achieved when the single strongest downlink interference was eliminated. in Fig. 3, $SINR_a$ approaches $SINR_n$ when the mobile station was nearer the edge of the distract, and the precision of the receiving filter W was gradually improved. When the mobile station was on the edge of the distract, $SINR_a$ and $SINR_n$ were nearly overlapped. This showed that the strong interference was effectively eliminated. Consequently, the improved method was very effective in eliminating the interference for the user on the edge of the distract.

5 Conclusion

In this paper, a method of eliminating inter-distract downlink interference based on signal autocorrelation was present. In this method, each base station is equipped with a transmitting antenna, and each mobile station is equipped with a plurality of receiving antennas. The prefilter was used to process the signal at the transmitter of base station. The transmitted signals did not overlap in the autocorrelation domain. Therefore the processed signal can be transmitted at the same time with the same frequency and spreading sequence. In the receiver of mobile station, the received signal passed through the receiving filter, and then recovered to the original signal through the inverse process of prefilter. The receiving filter was designed according to the autocorrelation function of the transmitted signal and the autocorrelation function of the received signal, no channel state information and the intensity of interference were involved. In order to eliminate the downlink interference from the adjacent distracts, the mobile station needed to be equipped with receiving antennas more than those equipped in the adjacent distracts. This makes the design of mobile station more difficult. In the improved method present in this paper, only two receiving antennas are required in the mobile station to eliminate the single strongest downlink interference from the adjacent distract. The simulation result indicated that this method is especially suitable for the mobile station located in the edge of the distract.

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