Analysis of DS-CDMA System with Smart Antenna for Different Bandwidths in the Wideband Multipath Channel

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Abstract: In this paper, the performance of DS-CDMA system with smart antenna is analyzed for different bandwidths (1.25MHz, 5MHz) and different channel environments (rural, urban).

For the analysis of smart antenna system, the vector channel having the spatio-temporal correlation is modeled as a time-variant linear filter in time, and each multipath is assumed as a reflective wave from only one direction (only one cluster) in space. Several multipaths within one chip are distinguished into each one and the strongest signal is selected.

DS-CDMA system with smart antenna using wider bandwidth present better performance than that using narrow bandwidth. It is shown that the smart antenna is more effective in urban area when using 2D-RAKE receiver.

1. Introduction

Recently, the demand of mobile communication is being increased and the services having various forms are needed. Various techniques to offer higher quality communication service are being studied.

The smart antenna technique using array antenna elements becomes one of them. It improves service quality by receiving only one signal propagated from desired user's direction and relatively rejecting other signals from other directions, which can be achieved by multiplying each received signal from each antenna element by optimum weighting value.

In this paper, we analyze the performance of the smart antenna system applied to the DS-CDMA system with different bandwidths to see how the performance is getting better compared to that without smart antenna. The resolution time of each multipath is 100[nsec], and the amplitude coefficient is Rayleigh distributed.

Dividing multipaths in one chip duration into the minimum resolvable path of channel and regarding the strongest signal as the signal of desired user, we analyze the performance of N-CDMA and W-CDMA system using smart antenna for different spreading bandwidths in urban and rural areas.

2. Vector channel modeling

In this paper, wideband multipath channel is modeled as time-variant linear filter. Also array response vector is inserted for considering spatial information. [1]

$$\mathbf{h}_k(t) = \sum_{d=1}^{D} \sum_{l=1}^{L} \rho_{k,d,l}\,\delta(t - t_{k,d,l}) \exp(\, j\beta_{k,d,l})\,\mathbf{a}(\theta_{k,d,l}) \quad (1)$$

D stands for the total number of cluster (the number of resolvable multipath), and each cluster is composed of the number of sub-multipath L, which has respectively different time delay, amplitude and phase. And we assume that each sub-multipath has small AOS (angle of spread) having Δ-angles in the average DOA (direction of arrival). $\rho_{k,d,l}$ is equal to $A\alpha_{k,d,l}e^{-\delta_{k,d,l}}$, where A is the average of $\rho_{k,d,l}$, and $\alpha_{k,d,l}$ is a normalized Rayleigh random variable with average A as we assume each power of received signals to be equal. $\delta_{k,d,l}$ stands for exponentially decreasing slope and $t_{k,d,l}$ is time delay in the path and $\beta_{k,d,l}$ represents the uniform phase shift occurred in the physical channel. $\mathbf{a}(\theta_{k,d,l})$ is the array response vector caused by the direction of the l-th scatterer in the d-th cluster by the signal of the k-th user. Also, this value is determined by the construction of antenna array.

$$\mathbf{a}(\theta_{k,d,l}) = \left[1 \;\; e^{-j\varphi_{k,2}} \;\; \cdots \;\; e^{-j\varphi_{k,M}}\right] \quad (2)$$

M is the total number of antenna elements, $\varphi_{k,m}$ is equal to $\frac{2\pi}{\lambda_k} d_{1,m} \sin(\theta_{k,d,l})$, and $d_{1,m}$ represents the space between the 1-st antenna element and the m-th antenna element.

3. 2D-RAKE receiver in smart antenna system

In this paper we place correlator in front of beamformer in order to improve the SNR of input signal. Fig. 1 shows the 2D-RAKE receiver structure used in this paper.

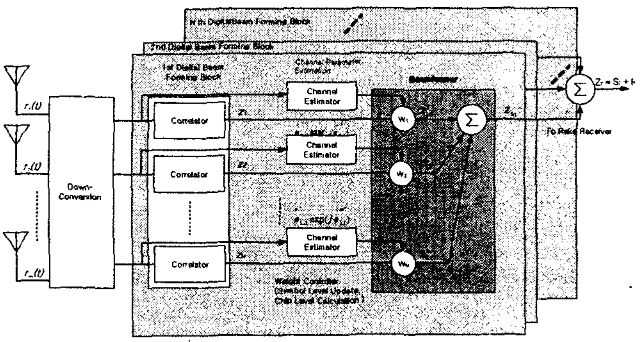

Fig. 1. The 2D-RAKE receiver structure used in smart antenna system

The transmitted signal of the k-th user is given by eq.(3).

$$s_k(t) = m_k(t)c_k(t)\exp(j\omega_c t) \quad (3)$$

$m_k(t)$ is the binary random data of the k-th user, and $c_k(t)$ epresents the spreading code of the k-th user. The total received signal can be represented as a vector form r(t) in eq(4), whose one value is a received signal from one antenna element. Each value is represented as $r_i(t)$ (i=1,···, m) in Fig.1.

$$\mathbf{r}(t)=\sum_{k=1}^{K}\sum_{d=1}^{D}\sum_{l=1}^{L}\rho_{k,d,l}m_k(t-\tau_{k,d,l})c_k(t-\tau_{k,d,l})$$
$$\times\exp[j\{\omega_c(t-\tau_{k,d,l})+\beta_{k,d,l}\}]\mathbf{a}(\theta_{k,d,l})+\mathbf{n}(t) \quad (4)$$

We assume that the index k=1, d=1 represents the desired user and the cluster respectively. We divide $r_i(t)$ into four parts.

1. Desired user's main path signal
2. Multipath components from desired user
3. Multipath components from undesired users
4. Additive Gaussian noise

And we can rewrite eq.(4) as eq.(5).

$$\mathbf{r}(t)=\sum_{l=1}^{L}\rho_{1,1,l}m_1(t-\tau_{1,1,l})c_1(t-\tau_{1,1,l})$$
$$\exp\{j(\omega_c t+\phi_{1,1,l})\}\mathbf{a}(\theta_{1,1,l})$$
$$+\sum_{d=remainder}\sum_{l=1}^{L}\rho_{1,d,l}m_1(t-\tau_{1,d,l})c_1(t-\tau_{1,d,l})$$
$$\exp\{j(\omega_c(t-\tau_{1,d,l})+\beta_{1,d,l}\}\mathbf{a}(\theta_{1,d,l})$$
$$+\sum_{k=2}^{K}\sum_{d=1}^{D}\sum_{l=1}^{L}\rho_{k,d,l}m_k(t-\tau_{k,d,l})c_k(t-\tau_{k,d,l})$$
$$\exp\{j(\omega_c(t-\tau_{k,d,l})+\beta_{k,d,l}\}\mathbf{a}(\theta_{k,d,l})+\mathbf{n}(t) \quad (5)$$

In eq.(5) the summation ($\sum_{d=remainder}$) are desired user's multipath signal components except maximum signal component within one chip duration. If we assume a BPSK modulation scheme here, then the output of a correlator at t=T (T : symbol duration) is given by eq.(6).

$$\mathbf{Z}m=[Z_1,Z_2,Z_3,\cdots Z_M]^T,$$
$$\mathbf{Z}m=\int_0^T 2\mathbf{r}(t)c_1(t)\cos(w_c t+\phi_1)dt$$
$$=\int_0^T 2\{\mathbf{S}_l(t)+\mathbf{S}_i(t)+\mathbf{I}\ (t)+\mathbf{N}(t)\}c_1(t)$$
$$\times\cos(w_c t+\phi_1)dt\ =\mathbf{S}+\mathbf{I}+\mathbf{N} \quad (6)$$

We first analyze the statistical characteristic of S,I constituting Zm in order to obtain the SIR (Signal to Interference Ratio) of RAKE receiver output.

$$\mathbf{S}=\mathrm{Re}[\sum_{l=1}^{L}\rho_{1,1,l}m_1(t-\tau_{1,1,l})\exp\{j(\phi_{1,1,l}-\beta_1)\}$$
$$\times\int_0^T c_1(t-\tau_{1,1,l})c_1(t)dt\ \mathbf{a}(\theta_{1,1,l}) \quad (7)$$

β_1 is the carrier phase generated in the receiver. If we ignore the delay between sub-multipaths, and assume a perfect code synchronization, then eq.(7) can be rewritten as eq.(8).

$$\mathbf{S}=\mathrm{Re}[\sum_{l=1}^{L}\rho_{1,1,l}\exp(j\phi_{1,1,l})\exp(-j\beta_1)$$
$$\times R_c(\tau_{1,1,l})\,\mathbf{a}(\theta_{1,1,l})] \quad (8)$$
$$=\mathrm{Re}[\{|R|\exp(j\beta')\exp(-j\beta_1)\sum_{l=1}^{L}\mathbf{a}(\theta_{1,1,l})$$

R is equal to $\sum_{l=1}^{L}\rho_{1,1,l}\exp(j\phi_{1,1,l})R_c(\tau_{1,1,l})$, β' is the phase of R, and $\phi_{k,d,l}$ is equal to $-\omega_c\tau_{k,d,l}+\beta_{k,d,l}$. If we assume that the signal phase, β_1, generated in the local oscillator is always adjusted to β' for synchronization, the correlator output of a standard antenna element is equal to $|R|$. As we use the same β_1 in other antenna elements, each signal is equal to Re[·] multiplied each array response. Among the despreading signal vectors in the eq.(8), the output signal of the m-th antenna element considering the interference of the m-th antenna is given by eq.(9).

$$Y_{1,1}^m=\rho'_{1,1}R'_c(\tau_{1,1})\exp(j\phi_{1,1}'^m)+I+N \quad (9)$$

Weight vector is calculated by channel estimation value. $\hat{\rho}'_{1,1}\exp(j\hat{\phi}_{1,1}'^m)$ is the optimum weight vector of m-th antenna for obtaining the largest SIR as showed in Fig.1, same as obtaining the largest output power. $\hat{\rho}'_{1,1}$ is an estimated path amplitude, which is calculated from the signal of the desired user, arrived from all sub-multipaths of the first cluster by channel estimation. $\hat{\phi}_{1,1}'^m$ is an estimated phase. In eq.(9), *spatial filtering is carried out by adding all signals from* all antenna elements. The last decision variable for the first Digital Beam Forming Block (DBFB) is given by eq.(10).

$$Z_{1,1}=\sum_{m=1}^{M}Z_{1,1}^m=\rho'_{1,1}\hat{\rho}'_{1,1}\sum_{m=1}^{M}\sum_{l=1}^{L}\exp[-j$$
$$\times(m-1)\pi(\sin\theta_{1,1,l}-\sin\hat{\theta}_{1,1,l})] \quad (10)$$
$$+I_{SI}+I_{MAI}+N$$

The SIR of the first DBFB is $SIR_{1,1}=\dfrac{Desired\ user's\ signal\ power}{SI\ power+MAI\ power}$. Received power produced by adding all sub-multipaths in the first cluster of the first user is given by eq.(11).

$$P_{1,1}=\rho_{1,1}'^2\hat{\rho}_{1,1}'^2\left|\sum_{m=1}^{M}\sum_{l=1}^{L}\exp[-j(m-1) \quad (11)\right.$$
$$\left.\times\pi(\sin\theta_{1,1,l}-\sin\hat{\theta}_{1,1,l})]\right|^2$$

We calculate interference power by approximating the *signals of other users and the self interference caused by* multipaths as Gaussian. AWGN is not considered.[2],[3]

$$P_{MAI}=\frac{(K-1)}{3}\sum_{d=1}^{D}\sum_{i=1}^{L}\rho_{k,d,l}'^2\hat{\rho}_{1,1,l}'^2$$
$$\times\left|\sum_{m=1}^{M}\exp[-j(m-1)\pi(\sin\theta_{k,d,l}-\sin\hat{\theta}_{1,1,l})]\right|^2 \quad (12)$$
$$P_{self}=\frac{1}{3}\sum_{d=reminder}\sum_{i=1}^{L}\rho_{1,d,l}'^2\hat{\rho}_{1,1,l}'^2$$
$$\times\left|\sum_{m=1}^{M}\exp[-j(m-1)\pi(\sin\theta_{1,d,l}-\sin\hat{\theta}_{1,1,l})]\right|^2$$

The 2D-RAKE receiver for smart antenna system is used to improve the performance of mobile system. We use the different number of branch for different spreading bandwidths.

Up to now, we find out the power of each S_T, I_T which comprise Z_T, where we define Z_T, S_T, I_T as the total output signal of 2D-RAKE receiver, desired user's signal, total interference respectively as shown at the final stage of Fig.1. We consider statistics of Z_T for given S_T.

$$E[Z_T|S_T]=E[S_T+I_T+N_T]=s_T+E[I_T]+E[N_T]=s_T$$
$$\mathrm{var}[Z_T|S_T]=\mathrm{var}[I_T+N_T]=\mathrm{var}[I_T]+\mathrm{var}[N_T] \quad (13)$$

The probability of error for a given S_T can be written as following eq.(14)

$$f(error \mid S_T) = Q(\frac{E[Z_T \mid S_T]}{\sqrt{\mathrm{var}[Z_T \mid S_T]}}) \\ = Q(\frac{s_T}{\sqrt{\mathrm{var}[I_T] + \mathrm{var}[N_T]}}) \quad (14)$$

And, the average probability of error P_e is given by eq.(15)

$$P_e = \int_{s_T} f(error \mid s_T) f(s_T) ds_T \quad (15)$$

In eq.(15), $f(s_T)$ is the probability density function of desired user's signal. In this paper we simulated only the average error probability versus SNR.

4. Simulations

We design the channel model having a fixed channel bandwidth, 10MHz, in simulation, and use the channel estimation to form a beam pattern. Parameters used in this simulation is given in Table 1.

chip rate (bandwidth)	1.2288Mcps (1.25)	4.096Mcps (5)
carrier frequency	1.9GHz	
symbol rate	100Kbps	
Modulation	BPSK	
total number of RAKE branch (urban)	3	12
total number of RAKE branch (rural)	1	2
total number of antenna element	8	
weighting algorithm	Channel estimation	

Table 1. Parameters used in the simulation

We assume all transmitted data as +1. Also we assume a perfect power control and a code synchronization but do not use a channel coding at this time. We generate the signals of forty users whose phases are random between -90°and 90°for urban area. Also 24 multipaths are generated during maximum excess delay (2.3 [μs]), and 8 sub-multipath signals are generated for respective multipaths. Then, we compare the performance of 1.25MHz system with that of 5MHz system. We search maximum power multipath in each chip duration for the suitable signal of desired user. Assuming that the maximum excess delay for rural area is 0.3[μs], we repeat the same experiment to use the signals of forty users having random phase between -90°and 90°, -30°and 30° for rural area.

The distribution of SIR is plotted in Fig 2 according to the number of antenna elements when the total number of users is 10.

If we use 8 antenna elements, SIR is distributed around higher value of SIR. On the contrary, if only one element is used, SIR is distributed around lower value of SIR, which can cause more errors if noise present. Therefore, we know that the performance of W-CDMA system can be improved by using more number of array antenna elements. We plot the BER versus the number of users in Fig.3.

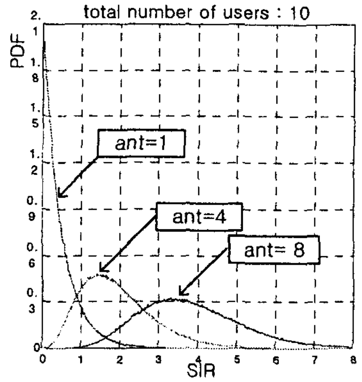

Fig.2. The pdf of SIR according to the total number of antenna elements

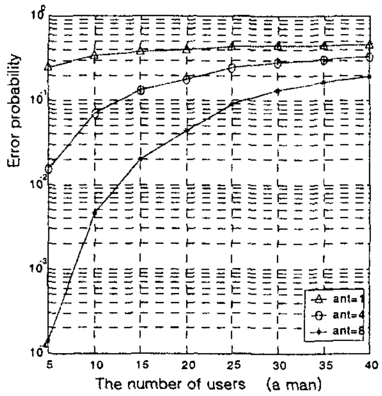

Fig.3. BER according to the number of users

As the number of users is increased, the SIR is decreased and the BER is increased. We confirm this fact from Fig.2 and Fig.3.

Fig.4 shows the result of simulation that represents SIR comparison between 1.25MHz and 5MHz by the number of users, and this equals to the performance comparison by DOA and AOS for each system bandwidth.

We know that the performance of 5MHz system is superior to that of 1.25MHz system in rural area. The comparison by DOA and AOS, the performance of 5MHz system using small DOA and AOS is superior to that using large DOA and AOS. But we obtain the opposite result in 1.25MHz system.

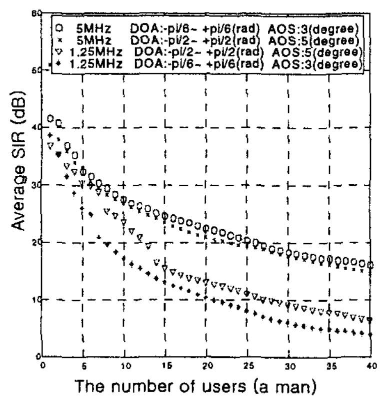

Fig. 4. The SIR comparison between 1.25MHz system and 5MHz system in rural area

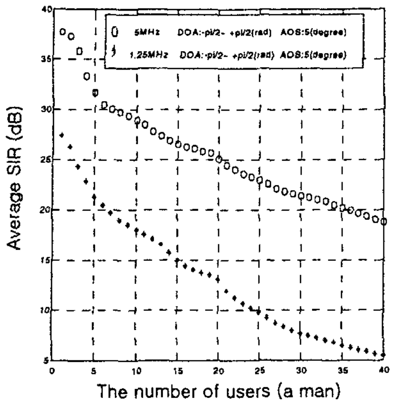

Fig. 5. The SIR comparison between 1.25MHz system and 5MHz system in urban area

Fig.5 is the result of simulation that represents SIR comparison between 1.25MHz system and 5MHz system in urban area.

Fig.6 is the result of simulation that represents BER comparison between 1.25MHz system and 5MHz system in rural area. A5MHz system using two branches of the 2D-RAKE receiver shows better performance than 1.25MHz system using one branches of the 2D-RAKE receiver. Both systems use MRC combining diversity.

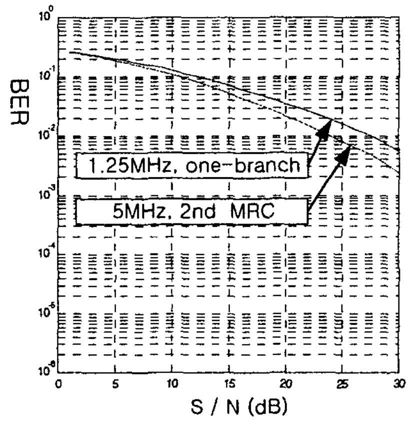

Fig. 6. BER of 1.25MHz system and 5MHz system in rural area

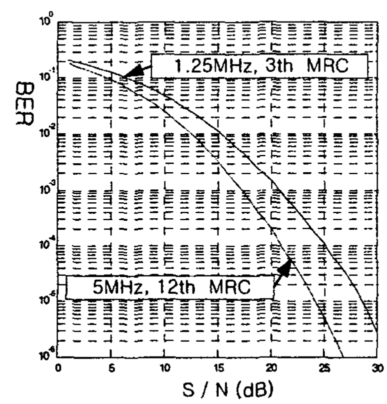

Fig. 7. BER of 1.25MHz system and 5MHz system by S/N in urban area

Fig.7 is the result of simulation that represents BER comparison between 1.25MHz system and 5MHz system in urban area. A 5MHz system using twelve branches of the 2D-RAKE receiver shows better performance than 1.25MHz system using three branches of the 2D-RAKE receiver. Both systems use MRC combining diversity.

5. Conclusion

In this paper, firstly we compared the performance of the smart antenna system using 1, 4 and 8 antenna elements respectively. Next we compared the performance of two systems having different spreading bandwidths for fixed number of antenna elements. We select the maximum power multipath received in each chip duration as the suitable signal of desired user.

We confirm that the performance of the smart antenna system using 8 antenna elements shows better performance than that using 1 or 4 antenna elements. Also we confirm that the performance of 5MHz system using 8 antenna elements shows better performance than 1.25MHz system by employing many number of branches of 2D-RAKE receiver in urban area. Therefore, we will expect that better service can be provided by using the smart antenna in wide bandwidth system, and this feature makes IMT-2000 system handle heavy traffic data or offer larger capacity.

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