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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. Then the smart antenna technique which uses array antenna elements becomes one of them. It satisfies desired service quality by receiving only one signal propagated from desired user's direction and relatively rejecting other signals from other directions to multiply optimum weighting vector by each received signal through each element. The IS-95 CDMA system on business is the interference-limited system, in which the signals of other users in the same cell are behaved as interferences. If the number of users or data rate is increased, then interference is increased. So this phenomenon causes system performance worse. 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. We divide multipaths in one chip duration into the minimum resolvable path of channel and regard 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. Channel modeling

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

$$\boldsymbol{h}_k(t)=\sum_{d=1}^{D}\sum_{l=1}^{L}\rho_{d.l}\,\delta(t-t_1)\exp(j\beta_{d.l})\boldsymbol{a}(\theta_{k.d.l}) \quad (1)$$

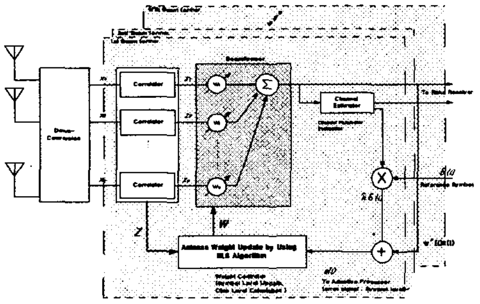
D is the number of clusters (the number of resolvable multipath), and each cluster is composed of the number of sub-multipath L which has respectively different time delay, AOS (Angle of Spread) having Δ-angles in the average DOA(Direction of Arrival), amplitude and phase. $\rho_{d.l}$ is equal to $A\alpha_{d,l}e^{-\delta_{d,l}}$. Where A is the average of $\rho_{d.l}$ and $\alpha_{d,l}$ is a normalized Rayleigh random variable with average A, as we assume each power of received signals to be equal. $\delta_{d,l}$ stands for exponentially decreasing slope and t_1 is time delay in the path and $\beta_{d.l}$ represents the uniform phase shift occurred in the physical channel. $\boldsymbol{a}(\theta_{k.d.l})$ 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.

$$\boldsymbol{a}(\theta_{k.d.l})=[1 \quad e^{-j\phi_{k,2}} \cdots e^{-j\phi_{k,M}}] \qquad (2)$$

M is the number of antenna elements, $\psi_{k.m}$ 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 CDMA system, received signal before despreading usually have very low SNR (Signal to Noise Ratio) because other users in the same cell use the equal frequency band comparing with FDMA or TDMA system. If received signal before despreading is used as the input signal of adaptive algorithm, accurate operation can not be expected because of the low SNR although correct reference signal is generated. Figure 1 is the 2D-RAKE receiver structure used in smart antenna system.



[Figure 1] The 2D-RAKE receiver structure used in smart antenna system

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

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

$m_k(t)$ is the binary random data of the k-th user, and $c_k(t)$ represents the spreading code of the k-th user. The total received signal of antenna is given by eq.(4).

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

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

1. desired user's signal
2. multipath components from desired user
3. multipath components from undesired users
4. additive Gaussian noise

$$\begin{aligned} r(t) = &\sum_{l=1}^{L}\rho_{1,1,l}m_1(t-\tau_{1,1,l})c_1(t-\tau_{1,1,l}) \\ &\exp\{j(\omega_c t+\phi_{1,1,l})\}\,a(\theta_{1,1,l}) \\ &+ \sum_{d=2}^{D}\sum_{l=1}^{L}\rho_{1.d.l}\, m_1(t-\tau_{0.d.l})c_1(t-\tau_{1.d.l}) \\ &\exp[j\{w_c(t-\tau_{1.d.l})+\beta_{1.d.l}\}]\,a(\theta_{1.d.l}) \\ &+ \sum_{k=2}^{K}\sum_{d=1}^{D}\sum_{l=1}^{L}\rho_{k.d.l}\, m_k(t-\tau_{k.d.l})c_k(t-\tau_{k.d.l}) \\ &\exp[j\{w_c(t-\tau_{k.d.l})+\beta_{k.d.l}\}]\,a(\theta_{k.d.l}) + n(t) \\ = &S_0(t)+S_i(t)+I(t)+N(t) \qquad (5) \end{aligned}$$

We assume a BPSK modulation scheme. The output of a correlator at t=T (T : symbol duration) is given by eq.(6).

$$\begin{aligned} Z(T) &= \int_0^T 2r(t)c_1(t)\cos(\omega_c t+\phi_1)dt \\ &= \int_0^T 2\{S_0(t)+S_i(t)+I(t)+N(t)\}c_0(t) \\ &\quad \times\cos(\omega_c t+\phi_1)dt = S+I+N \qquad (6) \end{aligned}$$

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

$$\begin{aligned} S = Re[&\sum_{l=1}^{L}\rho_{1,1,l}m_1(t-\tau_{1,1,l})\exp\{j(\phi_{1,1,l}-\beta_1)\} \\ &\times\int_0^T c_1(t-\tau_{1,1,l})c_1(t)dt\; a(\theta_{1,1,l})] \qquad (7) \end{aligned}$$

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).

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

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 $-\omega_0\tau_{k.d.l}+\beta_{k.d.l}$. 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 $Re[\,\cdot\,]$ 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).

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

And weight vector is calculated by adaptive algorithm. $\hat{\rho}'_{1,1}\exp(j\hat{\phi}'^{m}_{1,1})$ is an optimum weight vector for obtaining the largest SIR in the m-th antenna, same as obtaining largest output power. $\hat{\rho}'_{1,1}$ is an estimated path loss, which is calculated from the signal of desired user arrived from 8 sub-multipaths of the first cluster by adaptive algorithm. $\hat{\phi}'^{m}_{1,1}$ is an estimated phase. In eq.(9), spatial filtering is carried out by adding the signals of the number of antenna element multiplying weight vector by antenna output. The last decision variable for the first Digital Beam Forming Block is given by eq.(10).

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

The SIR of the first DBFB is $\frac{1,1\ power}{1,1 self Interference\ power + MAI\ power}$. Received power produced by adding 8 sub-multipaths in the first cluster of the first user is given by eq.(11).

$$\begin{aligned} P_{1,1} = \rho'^{2}_{1,1}\hat{\rho}'^{2}_{1,1} \Big| \sum_{m=1}^{M}\sum_{l=1}^{L} \exp[-j(m-1) \\ \times \pi(\sin\theta_{1,1,l} - \sin\hat{\theta}_{1,1,l})]\Big|^{2} \end{aligned} \tag{11}$$

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]

$$\begin{aligned} P_{MAI} &= \frac{(K-1)}{3} \sum_{d=1}^{D}\sum_{l=1}^{L} \rho'^{2}_{k,d,l}\hat{\rho}'^{2}_{1,1,l} \\ &\times \Big| \sum_{m=1}^{M} \exp[-j(m-1)\pi(\sin\theta_{k,d,l} - \sin\hat{\theta}_{1,1,l})]\Big|^{2} \\ P_{self} &= \frac{1}{3} \sum_{d=2}^{D}\sum_{l=1}^{L} \rho'^{2}_{1,d,l}\hat{\rho}'^{2}_{1,1,l} \\ &\times \Big| \sum_{m=1}^{M} \exp[-j(m-1)\pi(\sin\theta_{1,d,l} - \sin\hat{\theta}_{1,1,l})]\Big|^{2} \end{aligned} \tag{12}$$

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

4. Simulation

We design the channel model having a fixed channel bandwidth, 10MHz, in simulation, and use the RLS algorithm to form a beam pattern. The RLS equation to update weight vector is given by eq.(13). [4]

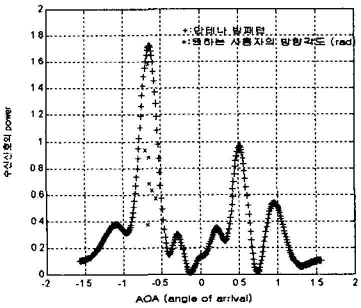
$$\begin{aligned} \boldsymbol{v}_n &= \boldsymbol{P}_{n-1}\boldsymbol{u}_n \\ \boldsymbol{k}_n &= \frac{\lambda^{-1}\boldsymbol{v}_n}{1+\lambda^{-1}\boldsymbol{u}_n^{H}\boldsymbol{v}_n} \\ \alpha_n &= d_n - \hat{\boldsymbol{w}}_n^{H}\boldsymbol{u}_n \\ \hat{\boldsymbol{w}}_n &= \hat{\boldsymbol{w}}_{n-1}^{H} + \boldsymbol{k}_n\alpha_n^{*} \\ \boldsymbol{P}_n &= \lambda^{-1}(\boldsymbol{I} - \boldsymbol{k}_n\boldsymbol{u}_n^{H})\boldsymbol{P}_{n-1} \end{aligned} \tag{13}$$

We give '1' only to the first antenna element and '0' to other antenna elements for initial weight value. Then the smart antenna operates on omni directional antenna in the early stage. $\boldsymbol{P}_0$ is equal to $\delta^{-1}\boldsymbol{I}$. Where δ is an arbitrary constant. λ is a forgetting factor, $0<\lambda<1$. Parameters used in this simulation is given in the following Table 1.

1.2288Mcps (1.25)	chip rate (bandwidth)	4.096Mcps (5)
1.9GHz	carrier frequency	1.9GHz
100Kbps	symbol rate	100Kbps
BPSK	modulation	BPSK
3	the number of RAKE branch (urban)	12
1	the number of RAKE branch(rural)	2
8	the number of antenna element	8
RLS	adaptive algorithm	RLS

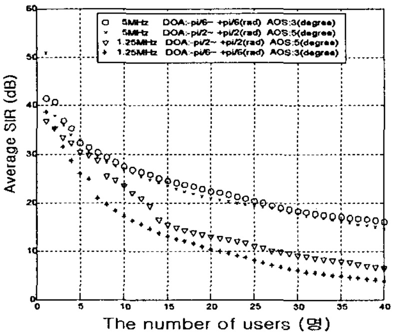
[Table 1] The parameter used in simulation

We assume all transmitted data as +1 and perfect channel estimation. Weight and average SIR are calculated for 100 times iteration. Also we assume a perfect power control and code synchronization and do not use channel coding. We generate the signals of forty users whose phases are random between -180° and 180° for urban area. Also 24 multipaths are generated during maximum excess delay $2.3[\mu s]$ and 8 sub-multipaths are generated for respective multipaths. Then, we compare the performance of 1.25MHz system with that of 5MHz system by the method which 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 $0.3[\mu s]$, we repeat the same experiment to use the signals of forty users being random phase between -180° and 180°, -30° and 30° for rural area. The example of beampattern is given by Figure 2.



[Figure 2] The example of beampattern

The Figure 2 is a beam pattern for the first RAKE branch using the 1.25MHz system in urban area. We assume that the direction of desired user is -35° and the angle spread is 5°. The number of iteration is 100. Figure 3 shows the result of simulation that represents SIR comparison of 1.25MHz with 5MHz by the number of users and this represents 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 although maximum excess delay including the multipath component of desired user is short. In 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.



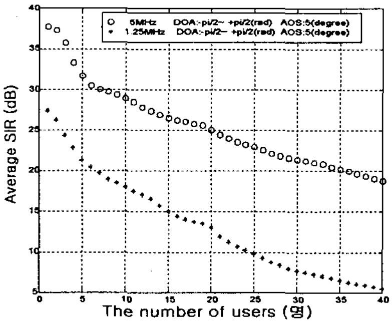
[Figure 3] The SIR comparison of 1.25MHz system with 5MHz system in rural area & The SIR comparison by DOA and AOS for each system bandwidth

The numerical result of Figure 3 is given in Table 2

the number of user bandwidth	2	5	10	20	30	40
5MHz & 3 °	40.9	32.3	27.6	22.5	18.3	16.2
5MHz & 5 °	37.8	33	26.8	20.9	17.6	14.6
1.25MHz & 3 °	35.2	26	17.1	10.4	5.9	3.8
1.25MHz & 5 °	35.3	30.3	23.5	13.1	9.2	6.4

[Table 2] The SIR comparison by the number of user for each system bandwidth (rural area)

3 ° and 5 ° mean the range of angle for AOS. Figure 4 is the result of simulation that represents SIR comparison of 1.25MHz system with 5MHz system in urban area.



[Figure 4] The SIR comparison of 1.25MHz system with 5MHz system in urban area

the number of user bandwidth	2	5	10	20	30	40
5MHz & 5 °	37.2	31.8	28.9	25.1	21.5	18.8
1.25MHz & 5 °	26.3	21.2	18	13.1	7.8	5.4

[Table 3] The SIR comparison by the number of user for each system bandwidth (urban area)

5. Conclusion

In this paper, we compared the performance of two systems having different spreading bandwidths. We select the maximum power multipath received in each chip duration as the suitable signal of desired user. We know that the performance of 5MHz system using smart antenna shows better performance than 1.25MHz system by employing many number of branches of 2D-RAKE receiver. Also, we verify that the performance of W-CDMA system with the smart antenna in urban area is considerably improved as shown in the result of simulation. Therefore, we will expect that better service can be provided by using the smart antenna in wide bandwidth system, and this feature makes the service quality of IMT-2000 system to handle heavy traffic data.

Reference

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