A Study on Interference Suppression to Adjacent Cells/Sectors using window-control based Adaptive Multipath Control Technique

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Abstract—This paper proposes an adaptive multipath control technique using window size controlled wide null creation technique (WNCT) for the adaptive array antenna (AAA) systems in rich scattering channel conditioned broadband wireless communication systems. In the proposed scheme, deep null creation technique (DNCT) and WNCT are employed to create antenna directivity for transmission so Host unwanted radiation to the adjacent sectors or cells can be suppressed. Moreover, to efficiently utilize small number of degree of freedom of the AAA under rich scattering channel conditions, we will introduce an window size control technique in the WNCT by which we can create wider null to a direction of interference cluster with strong and large angle spread. Computer simulation confirms that WNCT with the proposed window controlling technique can achieve higher carrier to interference plus noise power ratio (CINR) than the original WNCT in the uplink.

Keywords—adaptive multipath control, interference suppression, adaptive array antenna, degree of freedom

I. Introduction

In the beyond 3G (third generation) systems [1], support of the user rate of 100M -1G bit/s under various environments is the most important requirement because demand for high peak user rate is increasing with the wide-spread of broadband services using cable Internet and asymmetric digital subscriber line (ADSL). For this purpose, the most serious requirements are the reduction of transmit power to prevent electro-magnetic compatibility (EMC) problems and minimization of unwanted radiation to the unnecessary directions to prevent interference with other wireless communication systems.

To satisfy these requirements, we have proposed an Adaptive Multipath Control (AMC) technique [2] using adaptive array antenna (AAA) [3] [4] to suppress interference radiation to the non-target sectors or cells in indoor wireless communication systems. The limitation of the number of antenna degree of freedom against the number of interference waves have been a problem when introducing AAA in rich scattering conditions. Therefore, we have proposed a Deep Null Creation Technique (DNCT) and a Wide Null Creation Technique (WNCT) to effectively direct main beam to the target sector while suppressing unwanted radiation for other sectors using a small number of degree of freedom of the AAA.

However with original WNCT we have previously proposed in the AMC, which aims to create equal width of nulls to all the dominant interference radiated directions for all the non-target sectors, radiated interference power are indeed deeply suppressed in specific propagation environment, it lacks flexible adaptation to more diversified propagation environment, because antenna pattern is fully dependent on the angle of departure (AOD) of the dominant interference radiated directions. For example, when most of the dominant interference radiated directions are angle-clustered in a specific direction, it could be more efficient to increase the width of one null rather than to create plural number of nulls to different directions. On the other hand, when angle of the dominant interference radiated directions are uniformly distributed, it is more efficient to create ample number of nulls rather than to increase the width of each null.

Thus in this paper, we will propose a window size control technique in the WNCT by which we can create an adjusted wider null to a direction of interference cluster with strong and large angle spread in order to adapt WNCT more diversified propagation environment and use antenna degree of freedom more effectively. With this window size controlled WNCT, because it aims to give priority to create a wide null to the specific direction where dominant interference waves are densely exist, although in some situations it cannot suppress interference radiation to some directions, it improves the performance of interference suppression in terms of the whole system stand point of view because it use limited number of antenna degree of freedom more effectively by creating an adjusted width of null to the dominant interference radiated directions.

Computer simulation confirms that the window size controlled WNCT shows improvement of the Carrier to Interference plus background Noise power Ratio (CINR) performance in the uplink in various propagation environments.

II. Antenna Pattern Forming in AMC

In the proposed system, optimum antenna weights are calculated using delay profile measurement based antenna weight controlled technique based on minimum mean square error (MMSE) criterion [5]. In this section we will briefly explain DNCT and WNCT in AMC and theoretically analyze relationship between degree of freedom in AAA and antenna pattern characteristic by deriving Wiener-Hopf equation that provides the optimum antenna weights when antenna weights are calculated using MMSE criterion. Here we will make it clear what are the problems in the originally proposed WNCT, when we try to employ AMC to various propagation environment. Then we will explain the window size controlled WNCT by modification of originally proposed WNCT.

A. Process of WNCT & DNCT

Fig. 1 shows how to generate quasi-received signals to create a wide null with DNCT and WNCT. In Fig. 1, k and l are the number of sectors and number of delayed paths respectively. $S_k(t)$ denotes the reference signal sequence of k-th sector, and $\sum_{l=0}^{L_k-1} P_l^k \delta(t-\tau_l^k)$ denotes the estimated delay profile, where $L_k$ is the number of delay paths and $P_l^k, \tau_l^k$ are the complex amplitude and delay time of each delayed path respectively. The WNCT process is listed as follows.

1. From the estimated delay profile for each sector in the AP $(\sum_{l=0}^{L_k-1} P_0^k \delta(t-\tau_l^0))$, select the strongest path $(P_0^k)$ and generate virtual delay profile $(P_0^k \delta(t-\tau_l^0))$.  
2. Estimate direction of AOA of the strongest path from each non-target sector, and generate virtual arrived paths in each window, which are centered by the estimated direction of
AOA of the strongest path from each sector, while window size are fixed to a certain size determined by the propagation path environment.

3) Insert virtual arrived paths in the virtual delay profile and regenerate virtual delay profile \((P_k^0 + \sum_{l=1}^{K} P_k^l \delta(t - \tau_k^l))\) for each non-target sector, where \(V_k\) denotes the number of delayed waves of virtual delay profile from \(k\)-th sector, and \(P_k^0\) denote complex amplitude of each virtual path and selected strongest path respectively.

To further create deeper attenuation to the direction of adjacent cells/sectors, delay profiles for the quasi-received interference signals are amplified by 30 dB. Eq. (1) and Eq. (2) show quasi-received signals from the target sector and non-target sectors respectively, where \(k_0\) denotes the target sector. Eq. (3) shows the quasi-received signals from all sectors.

\[
S_{k_0}^{h}(t) = \sum_{l=0}^{L_{k_0}-1} P_{k_0}^l \delta(t - \tau_{k_0}^l) \otimes S_{k_0}^{h}(t) \\
S_k^{h}(t) = \sum_{l=1}^{L_k} \sqrt{10^{3I_k}} P_k^l \delta(t - \tau_k^l) \otimes S_k^{h}(t) \\
S_k(t) = \sum_{l=0}^{L_k} S_k^{h}(t) 
\]

**B. Wiener-Hopf equation**

We consider the equidistant circular AAA, in which antenna elements are arranged in circle with its radius of \(r\). The steering vector of this equidistant AAA is depicted in Eq. (4), where \(K\) and \(\theta\) show total number of antenna elements and the AOA of arrived path respectively. (In order to make discussion simple, we assume 2-dimensional plain wave and assume far-field assumption of AAA in which the distance between each antenna elements are negligible compared with the distance between the transmitter and the receiver)

\[
V(\theta, \lambda) = [v_1(\theta, \lambda), v_2(\theta, \lambda), ...., v_L(\theta, \lambda)]^T \\
v_k(\theta, \lambda) = \exp\left(\frac{2\pi j \rho \cos(\theta - 2\pi \lambda)}{r (k - 1)}\right)
\]

With this steering vector \(V(\theta, \lambda)\), received signal vector \(X(t)\) is given by in Eq. (5), where \(s(t)\), \(u(t)\), \(n(t)\) denote time sequence of desired signal, undesired signal, and background noise in the receiver respectively. \(\theta_s\), \(\theta_u\) denote AOA of the desired signal wave and undesired signal wave respectively.

\[
X(t) = [x_1(t), x_2(t), ...., x_K(t)]^T = s(t)V(\theta_s) + u(t)V(\theta_u) + n(t) 
\]

By employing DNCT and WNCT in Eq. (5), quasi-received signals are calculated as follows,

\[
X(t) = s(t)V(\theta_s) + \sqrt{10^{3I_s}} u(t)V(\theta_u) + \sum_{l=1}^{L} u(t)V(\theta_l) + n(t) 
\]

where,

\[
\theta_s = \left\{ \begin{array}{ll}
\theta_s^0 - \frac{W}{2} + i \theta_s^0 & (0 < i \leq \frac{1}{2}) \\
\theta_s^0 + \frac{W}{2} + i \theta_s^0 & (\frac{1}{2} < i \leq 1)
\end{array} \right.
\]

I (even number) and \(W\) denote the total number of Interference waves and the window size, and \(\theta_s\), \(\theta_u\) are the AOA of the strongest interference wave from each sector and AOA of virtual interference wave respectively.

If we set reference signal \(s(t)\) as \(r(t) = s(t)\), we can calculate optimum antenna weights \(\mathbf{W}_{opt}\) by Minimum Mean Square Error (MMSE) criterion as follows

\[
\mathbf{W}_{opt} = \mathbf{R}_{xx}^{-1} \mathbf{r}_{sr} 
\]

where \(\mathbf{R}_{xx}\) denotes the auto-correlation matrix of the received signal vector \(X(t)\) and \(\mathbf{r}_{sr}\) denotes cross-correlation vector between received signal vector \(X(t)\) and reference signal \(r(t)\).

If we assume desired signal \(s(t)\), undesired signal \(u(t)\), and back ground noise \(n(t)\) are random variables and independent to each other, we can calculate \(\mathbf{R}_{xx}\) and \(\mathbf{r}_{sr}\) as follows,

\[
\begin{align*}
\mathbf{R}_{xx} &= E[\mathbf{X}(t)\mathbf{X}^H(t)] \\
&= P_s[V(\theta_s)V^H(\theta_s)] + P_s[V(\theta_u)V^H(\theta_u)] + P_s I
\end{align*}
\]

\[
\begin{align*}
\mathbf{r}_{sr} &= P_s[V(\theta_s)] \\
&= P_s[V(\theta)^H(\theta)] + \sum_{l=1}^{L} R_{si} + P_s I
\end{align*}
\]

where,

\[
\begin{align*}
P_s &= E[|s(t)|^2] \\
P_u &= E[|u(t)|^2] \\
P_n &= E[|n(t)|^2] = E[|n_s(t)|^2] = .... = E[|n_K(t)|^2] \\
R_{ij} &= P_s[V(\theta_i)V^H(\theta_j)]
\end{align*}
\]

**C. Some numerical example of antenna pattern**

Table 1 shows numerical parameters we use in the following analysis. Fig. 2 shows an example of antenna pattern where AAA of the desired wave and undesired wave are set to 0 degree and 200 degree respectively, where the number of antenna elements are set to 4 and window size is set to 50 degree or 100 degree. On Fig. 2, “○” denotes the AOA of the desired signal wave and “□”
Fig. 2. antenna pattern  
Fig. 3. antenna pattern

denotes the AOA of the interference signal waves. From Fig. 2, when window size is set at 50 degree, width of a null is created for 50 degree, which is as the same as the window size. However when window size is set to 100 degree, width of the null is not created as wide as 100 degree, because, as window size increases, the required number of degree of freedom in the AAA increases, and we can conclude that, in the case of 4 antenna, degree of freedom (which is equal to the number of antenna elements) is too small a number to create a null as wide as 100 degree.

Fig. 3 shows the antenna patterns where AOA of the desired wave is set at 0 degree and AOA of interference waves are set at 30, 100, 200 degree, respectively, where the window size is set to 50 degree and the number of antenna elements are set to 4 or 8. From Fig. 3, when the number of antenna elements is set at 8, width of each nulls are created as wide as 50 degree which is as the same as the window size. However when the number of antenna elements is set to 4, width of each nulls is not 50 degree because, as the number of wide nulls is increased the required number of degree freedom in the AAA increases, and we can conclude that, in this case, 4 antenna elements are too small a number to create 3 nulls in which the width are as wide as 50 degree.

From numerical examples shown in Fig. 2 and Fig. 3, these problems become apparent when we employ AMC to various propagation environment because the number and the width of nulls cannot be controlled in the originally proposed WNCT method. For example, when most of the dominant waves are angle-clustered in a specific direction, it could be more efficient to increase the width of one null rather than to create plural number of nulls to different directions. On the other hand, when angle of the dominant waves are uniformly distributed, it is more efficient to create ample number of nulls rather than to increase the width of each null.

D. window size controlled WNCT

In the original WNCT method we select one dominant path for every interference source and after setting a specific size of window around this dominant path, virtual waves are inserted to the window to make virtual delay profile. On the other hand, in the window size controlled WNCT method, we do not try to make window around every dominant path. Instead we try to make a window to the direction where dominant interference paths are densely clustered.

Fig. 4 shows an image of creating virtual delay profiles in the window size controlled WNCT and the process is described as follows.

1) First we equally devide AOA into several windows. Fig. 4 (a) shows the case in which AOA is equally devided into $k$ windows, and therefore each window size is $360/k$ degree.
2) We estimate the AOA and it’s received power for the strongest path from all interference sources, and according to the AOAs and the received powers of each path we calculate every received power at all windows. Then we select first $M$ windows with decending order of the received power at each window.
3) For the $M$ windows selected at (2), if the interval of any two windows are less than $\Delta N$, we merge those two windows and create one wide window (Fig. 4 (b)).
4) After selecting and merging operation is done (window size control), we insert virtual interferece waves in the window range.

Key parameters for the window size contolled WNCT are as follows.

- equally devided window size ($W$)
- number of windows selected to insert virtual waves ($N$)
- max interval to merge adjacent window into one ($\Delta N$)

In Fig. 4, we set $N$ as 3, $\Delta N$ as 2, and we can see that window $\#1$, $\#4$, $\#6$ is selected for inserting virtual waves, and interval between window $\#4$ and $\#6$ is smaller than $\Delta N$, a newly wide window is created by merging the window $\#4$ and $\#6$. 
Fig. 5. System configuration

Tab. 2. Propagation path model parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Frequency</td>
<td>5 GHz</td>
</tr>
<tr>
<td>Delay Spread</td>
<td>30 ns</td>
</tr>
<tr>
<td>Scatter radius around AP</td>
<td>10 m</td>
</tr>
<tr>
<td>Scatter radius around TE</td>
<td>1 m</td>
</tr>
<tr>
<td>Number of scatters around AP</td>
<td>64</td>
</tr>
<tr>
<td>Number of scatters around TE</td>
<td>8</td>
</tr>
<tr>
<td>Number of clusters around AP</td>
<td>2, 8, 64</td>
</tr>
<tr>
<td>Radius of cluster</td>
<td>1 m</td>
</tr>
</tbody>
</table>

III. SYSTEM CONFIGURATION

Fig. 5 shows system configuration of the proposed system. We used Direct Sequence–Code Division Multiple Access (DS-CDMA) scheme. We employ a sector configuration at the AP. As shown in Fig. 5, from each sector, a pilot channel (PCH) that is used for delay profile measurement as well as the sector indicator, is transmitted with the traffic channel (TCH).

In the TE, after the received signals are down-converted, delay profiles for all the sectors are estimated at Channel Estimator using the PCHs. Then, for the downlink, at Weight Controller for Rx, we create quasi-received signals using the estimated delay profiles and calculate optimum antenna weights for the downlink.

On the other hand, for the uplink, at delay profile Controller, we create virtual delay profiles using the estimated delay profiles by the window size controlled WNCT. After virtual delay profiles are properly created, interference wave power of the virtual delay profiles is increased by DNCT before the operation at Weight Controller for Tx. Then at Weight Controller for Tx we create quasi-received signals and calculate optimum antenna weights for the uplink.

IV. COMPUTER SIMULATION

A. Propagation model

Table 2 shows parameters of the propagation model used in computer simulation. This propagation model [6] is geometrically based model in which propagation route is modeled by the single bounce at each scatter, while holding consistency with the conventional delay profile model on the point that its delay profile measured in the receiver can be statistically matched to the conventional delay profile. Therefore with this propagation model we can simulate the performance of the system with AAA, where spatial characteristic such as AOA and AOD are needed. Moreover for the model of scatters around AP we employ a clustered model, in which scatters around AP are clustered in several clusters while the number of whole scatters around AP are kept constant and we can model various propagation environment by changing the number of clusters around AP.

B. Computer simulation parameter

Table 3 shows computer simulation parameters. We consider single cell environment and set two terminals in a cell and each terminal select a sector (target sector) to transmit signals, where we assume perfect open-looped transmit power control at each terminal. The method to select the target sector is described below.

1) Temporarily select one sector as target sector (we will refer this sector as $j$). The received power at sector $i$ ($i \neq j$) is calculated as

$$ C^i_j = \sum_{l=0}^{L-1} P_T \times GT^{i}_j \times PLOSS_l \times GR $$

where $P_T$ denotes transmit power at TE, $GT^{i}_j$ and $PLOSS_l$ denote antenna gain at TE and and path loss, where $l$ is the path number. $GR$ is the antenna gain of the omni-directional antenna employed at AP.

2) Select $C^i_{\text{max}}$ which gives the maximum value of $C^i_j$

$$ C^i_{\text{max}} = \max(C^i_1, C^i_2, \ldots, C^i_j) $$

3) Repeat process 1 and 2 to calculate the maximum value $C^j_{\text{max}}$ for all sectors $j$ to which each user can connect.

4) Select minimum value $C^i_{\text{min}}$ among all $C^i_{\text{max}}$ calculated above. Then we decide this sector number $J_{\text{max}}$ as the target sector.

$$ C^{i}_{\text{min}} = \min(C^i_{\text{max}}, C^{i}_{\text{max}}, \ldots, C^{i}_{\text{max}}) $$

Tab. 3. Computer simulation parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cell</td>
<td>1</td>
</tr>
<tr>
<td>Cell radius</td>
<td>10 m</td>
</tr>
<tr>
<td>Number of users in a cell</td>
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</tr>
<tr>
<td>Transmission rate (downlink)</td>
<td>100 Mchip/s</td>
</tr>
<tr>
<td>Transmission rate (uplink)</td>
<td>100 Mchip/s</td>
</tr>
<tr>
<td>Target CNR</td>
<td>10 dB</td>
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<tr>
<td>Number of sectors at AP</td>
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</tr>
<tr>
<td>Number of antenna elements</td>
<td>8</td>
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<td>AOA Estimation</td>
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<td>Estimation algorithm</td>
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<td>About window control width</td>
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</tr>
<tr>
<td>Number of window to select</td>
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</tr>
<tr>
<td>Max interval to merge</td>
<td>2</td>
</tr>
<tr>
<td>Interval of vertical wave insertion</td>
<td>2.0 degree</td>
</tr>
</tbody>
</table>
angle at TE, we can suppress radiated interference power effectively. On the other hand for the case in which the number of clusters around AP is small, therefore most of the scatters are tend to be uniformly distributed around AP, although AODs of interference waves from TE are tend to be clustered in specific areas, we can suppress radiated interference power at TE more effectively by merging plural number of windows and create wider null to the direction. Therefore from these results, we can conclude that proposed widow size controls WNCT to be effective in various propagation environment.

Fig. 8 - Fig. 10 shows cumulative distribution function of CINR at targetsector in the uplink, where the number of clusters around AP is set 2, 8, 64 respectively. From Fig. 8 - Fig. 10 we can see that in every case the performance is improved by employing the window size control technique to WNCT. Therefore we can conclude that window size controlled WNCT is also very effective in suppressing interference from the whole system point of view.

C. Computer simulation results

Fig. 7 shows the Suppressed Interference Power (SIP) performance of which the number of cluster around AP is set to 2, 8, 64 respectively. This SIP performance is defined as the ratio of received signal power at non-target sectors between for the AAA employed case and that for the omni-directional antenna employed case. From Fig. 7 we can see that by employing window size control technique to WNCT, the performance of the SIP is improved in every cases.

This is because for the case in which the number of clusters around AP is small, therefore most of the scatters are tend to be clustered in specific areas, although AOD (Angle of Departure) of the interference waves from TE are tend to be clustered in specific angles, we can suppress radiated interference power at TE more effectively by merging plural number of windows and create wider null to the direction. On the other hand for the case in which the number of clusters around AP is large, therefore the scatters are tend to be uniformly distributed around AP, although AODs of interference waves from TE are tend to be widely distributed in angle at TE, we can suppress radiated interference power effectively not by merging windows but instead create rather small size of nulls for plural number of directions. Therefore from these results, we can conclude that proposed widow size controls WNCT to be effective in various propagation environment.

Fig. 8 - Fig. 10 shows cumulative distribution function of CINR at targetsector in the uplink, where the number of clusters around AP is set 2, 8, 64 respectively. From Fig. 8 - Fig. 10 we can see that in every case the performance is improved by employing the window size control technique to WNCT. Therefore we can conclude that window size controlled WNCT is also very effective in suppressing interference from the whole system point of view.

In this paper we have proposed an adaptive multipath control technique using window size controlled WNCT for the adaptive array antenna systems in rich scattering channel conditioned broadband wireless communication systems. With computer simulations we confirm two points below.

- window size controlled WNCT is effective in various propagation environment and it improves the performance of Suppressed Interference Power in various propagation environment in the uplink.
- With window size controlled WNCT because the whole interference among the system is deeply suppressed, CINR performance at targetsector is improved in the uplink.

REFERENCES