Null Steering Network for Low Profile 2×2 Switched Beam Antennas

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Abstract

This paper presents a design of null steering network for 2×2 switched beam antennas. This network can locate nulls to given directions simultaneously. The prototype is constructed and tested to validate the performance of proposed null steering network.

1. Introduction

Wireless Local Area Networks (WLANs) are the link of two or more computers or wireless devices, which enable the wireless communication between those devices in a limited area [1]. Recently WLANs have become an infrastructure in every building. In WLANs, access points communicate to each other using cables. This causes an expense and somehow introduces difficulty in accessibility for some areas. To tackle these impairments, the idea of exploiting radio signal instead of cables has been recently proposed, so called Wireless Mesh Networks (WMNs) [2]. These networks are constituted by radio nodes organized in a mesh topology. Recently, a draft extension of the IEEE 802.11 standard for WLANs is under development [3]. As radio signal is utilized in WMNs, co-channel interference remains a limiting factor which the system designers have to concern. To deal with this impairment, lot of attention in area of WMNs has been paid to smart antenna technologies. This relies on beamforming algorithm to provide maximum gain at a desired direction and steer nulls or sidelobes to undesired directions. Taking a concept of smart antenna technologies into account in WMNs still leaves a trace of shortcomings. First of all, switched-beam antennas have the limitation of interference suppression as it cannot control nulls’ directions. Although, this problem can be avoided when utilizing fully adaptive smart antennas, its complexity makes the concept impractical. Moreover, Medium Access Control (MAC) protocols must be modified to be compatible with utilized smart antenna systems. This may result in the delay for a draft extension of the IEEE 802.11 standard for WMNs. Therefore, this paper proposes a low profile beamformer for 2×2 antenna array which is suitable for WMNs. This beamformer can simultaneously produce 4 beam patterns. In addition, null steering network included in the beamformer is able to produce 3 nulls in 3 given directions at the same time. With this concept, MAC protocols do not need any modification from IEEE 802.11 standard currently used in WLANs.

This paper is organized as follows. In Section 2, beamforming concept is described. Then, null steering algorithm is shown in Section 3. In this section, the prototype of null steering network is constructed and tested to validate the proposed method. Finally, Section 4 concludes the paper.

2. Beamforming Concept

Fig. 1 show configuration of beamformer consisting of 2×2 antenna array spaced $\lambda/4$ in two orthogonal directions. This 2×2 is a minimum number of antenna elements which is able to take responsibility for signals coming from $0^\circ$ to $360^\circ$ around the array. The modified Butler matrix presented in [4] is utilized to be beamforming network for this compact beamformer. The beamforming network is constituted by four 64$^\circ$ - hybrid couplers and one crossover. The four outputs, form four beams, are conveyed to null steering network. The methodology of null steering network is shown in next section.
3. Null Steering Network

From literatures, there are many works proposing null steering methods e.g.,[5],[6]. However, they employ high level of computation which can be handled by expensive signal processor. Therefore, this paper presents a straightforward null steering network which requires only multiplying some suitable coefficients at the output signals from beamforming network described in previous section. The mentioned coefficients can be calculated as follows. The end of this section shows one example of prototype for null steering network to validate its performance.

Assuming directions of incoming signals from azimuth directions, weighting coefficients at \((m,n)\)th antenna element corresponding to desired and undesired signals can be express as

\[
w_d(m,n) = e^{j(m-1)\left(\frac{\pi}{2}\cos\phi_d \right) + (n-1)\left(\frac{\pi}{2}\sin\phi_d \right)}
\]

\[
w_{i,q}(m,n) = e^{j(m-1)\left(\frac{\pi}{2}\cos\phi_{i,q} \right) + (n-1)\left(\frac{\pi}{2}\sin\phi_{i,q} \right)}
\]

where \(\phi_d\) and \(\phi_{i,q}\) are direction of arrival for desire signal and \(q\)th interfere signals, respectively. The signal vector including desired and interference signals can be expressed as

\[
y_{\text{total}} = y_d + \sum_{q=1}^{Q} k_q y_{i,q}
\]

\[
= s_d \left( w_d + k_1 w_{i,1} + \ldots + k_Q w_{i,Q} \right)
\]

\[
+ \sum_{q=1}^{Q} s_{i,q} \left( w_d + k_1 w_{i,1} + \ldots + k_Q w_{i,Q} \right)
\]

where \(y_d\) and \(y_{i,q}\) present desired and interference signals. The parameter \(k_q\) stands for interference suppressing coefficient which can be calculated as follows. With the concept of interference rejection, the 2nd term of (2) must be vanished as following expression.

\[
\sum_{q=1}^{Q} s_{i,q} \left( w_d + k_1 w_{i,1} + \ldots + k_Q w_{i,Q} \right) = 0
\]

Solving (3), the interference suppressing coefficients can be obtained as shown in (4).

\[
\begin{bmatrix}
k_1 \\
\vdots \\
k_Q
\end{bmatrix} =
\begin{bmatrix}
w_{i,1}s_{i,1} & \cdots & w_{i,Q}s_{i,1} \\
\vdots & \ddots & \vdots \\
w_{i,1}s_{i,Q} & \cdots & w_{i,Q}s_{i,Q}
\end{bmatrix}^{-1}
\begin{bmatrix}
w_{d}s_{i,1} \\
\vdots \\
w_{d}s_{i,Q}
\end{bmatrix}
\]

The simplicity of null locating method for this paper is indicated in (4). With simply multiplying \(k_q\) at output signal from \(q\)th beam produced from beamforming network, the \(q\)th interference signal can be simply eliminated from the systems. In practice, these coefficients can be found when the direction of desired and interference signals are known. These directions can be derived from many direction finding algorithms available in literatures.

To confirm the performance of null steering method presented in (4), the prototype of null steering network is constructed and tested. The directions of interest are given at 45°, 135°, 225°, 315°. If one direction is chosen to be desired direction, the rest directions become interference directions. Fig. 2 shows a prototype of null steering network which has to be connected to the beamformer presented in Section 2. The width and length of strip shown in Fig. 2 represent amplitude and phase for interference suppressing coefficients calculated in (4). Table 1 shows the measured outputs from the constructed prototype of null steering network shown in Fig. 2.

Next, the performance of constructed prototype is shown in Figs. 3 to 5 whereas dash line represents radiation pattern of the array without null steering and solid line indicates the one when
null steering in (4) is taken place. As we can see, we can steer nulls to the given directions for all four cases. Note that Figs. 3 to 5 are occurred at the same time in real circumstances. However, the exception is occurred in two cases; i2 in Fig. 3 and i3 in Fig. 4. This is because manufacturing error in phase shifting for null steering network. However, the constructed prototype can confirm the concept of null steering method presented in this paper.

4. Conclusion

This paper has proposed a simple beamformer capable of producing main beam and nulls at given direction simultaneously. This beamformer is constituted by 2×2 antenna array, beamforming network and null steering network. The prototype has been constructed and tested to confirm its interference suppressing capability. The measured results have revealed that the beamformer succeed in null locating while maintaining the maximum gain at the desired direction. This beamformer is considerably suitable for WMNs as the locations of mesh routers are fixed and MAC protocols do not need any modification.

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Table 1. Interference suppressing coefficients measured from prototype shown in Fig. 2.

<table>
<thead>
<tr>
<th>Coefficient($k_q$)</th>
<th>$k_1$</th>
<th>$k_2$</th>
<th>$k_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main beam</td>
<td></td>
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<tr>
<td>45°</td>
<td>$-0.0941-0.3628j$</td>
<td>$-0.2405+0.0414 j$</td>
<td>$-0.0938-0.3518 j$</td>
</tr>
<tr>
<td>135°</td>
<td>$-0.1456+0.3625 j$</td>
<td>$-0.1165-0.2275 j$</td>
<td>$0.2334+0.0085 j$</td>
</tr>
<tr>
<td>225°</td>
<td>$-0.0820-0.2210j$</td>
<td>$-0.1731+0.3328 j$</td>
<td>$-0.1355+0.3912 j$</td>
</tr>
<tr>
<td>315°</td>
<td>$-0.1536+0.3541j$</td>
<td>$0.1821+0.0356 j$</td>
<td>$-0.1157-0.2515 j$</td>
</tr>
</tbody>
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References