Active Antenna System:
Utilizing the Full Potential of Radio Sources in the Spatial Domain

November 27, 2012
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<th>Description</th>
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<tbody>
<tr>
<td>2D</td>
<td>Two-Dimensional</td>
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<tr>
<td>3D</td>
<td>Three-Dimensional</td>
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<td>3GPP</td>
<td>Third Generation Partnership Project</td>
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<td>AAS</td>
<td>Active Antenna System</td>
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<tr>
<td>ACLR</td>
<td>Adjacent Channel Leakage Power Ratio</td>
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<tr>
<td>BF</td>
<td>Beamforming</td>
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<td>BS</td>
<td>Base Station</td>
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<td>CSI</td>
<td>Channel State Information</td>
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<tr>
<td>HetNet</td>
<td>Heterogeneous Network</td>
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<tr>
<td>ICIC</td>
<td>Inter-Cell Interference Coordination</td>
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<td>MBB</td>
<td>Mobile Broadband</td>
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<tr>
<td>MIMO</td>
<td>Multiple-Input Multiple-Output</td>
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<td>RAN</td>
<td>Radio Access Network</td>
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<td>MU-MIMO</td>
<td>Multi-User MIMO</td>
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<td>SNR</td>
<td>Signal-to-Noise Ratio</td>
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<td>UE</td>
<td>User Equipment</td>
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1. Utilizing the Full Potential of Radio Resources in the Spatial Domain

Capacity demands on mobile wireless networks are increasing at an explosive rate. This has led the entire wireless industry to seek out new means of utilizing radio resources that are more efficient. Given the current state of wireless technology development, there exists a very significant potential in utilizing the spatial domain to improve radio resource efficiency.

One approach has been to reduce cell size in the macro-spatial domain, whereby radio resources are re-used due to the geographic isolation of different cells’ radio signals. To this effect, great interest has been shown in various small cell technologies, the most recent example being the deployment of heterogeneous networks (HetNet). But while deploying a large number of small cells may enable gains in capacity, the result is a higher need for backhaul resources and a more complex networking of numerous low-power base stations (BS).

Multi-antenna technologies have been shown to improve spectrum efficiency in the spatial domain, in particular, in the micro-spatial domain, a product of the various transmissions and receptions of radio resources between multiple antennas. Existing efforts to explore the micro-spatial domain have resulted in the development of multiple-input multiple-output (MIMO) technologies.

The potential to improve upon the efficiency of radio resources in the micro-spatial domain is coming to the forefront as further technologies become available that improve signal processing in both the horizontal and vertical domains. But this is not always possible for legacy BSs, which were installed with antenna arrays typically geared toward processing only the horizontal domain.

Active Antenna System

The Active Antenna System (AAS) is an advanced BS platform with optimized structure, cost, and performance features that meet operator requirements for mobile broadband (MBB) services. Its 3D-MIMO technologies fully utilize radio resources in both the micro- and macro-spatial domains.

In the macro-spatial domain, an AAS configured for large array dimensioning can be used to solely support backhaul. This realizes boosts in capacity while addressing the backhaul requirements of using advanced MIMO technologies on static, low-power BSs.

Three-dimensional beamforming (3D-BF) is a key component of the AAS’s 3D-MIMO technologies along with spatial multiplexing and transmission diversification.
From Linear Arrays to 2D and 3D Arrays

As a BS system evolves, the AAS integrates the active transceiver array and the passive antenna array into one radome. Supported two-dimensional (2D) and 3D antenna array configurations include linear, planar, circular, and cylindrical. The antenna element of the 2D or 3D AAS array can also be adaptively/semi-adaptively weighted.

The AAS offers freedom in controlling radiation patterns on both the vertical and horizontal domains. This is different from legacy BSs whereby antennas use linear arrays with fixed radiation patterns in the vertical domain. For legacy BSs, adaptive/semi-adaptive weighting is applied on the horizontal antenna ports, offering freedom in the horizontal domain only.

A generic AAS architecture is defined in Section 4 of the 3GPP Technical Report TR37.840. An AAS BS enjoys cost and performance advantages measured by how well it manages the relationship between its active transceiver array and its passive antenna array. The size of the passive antenna array determines the level of signal power collected from the spatial domain, which eventually determines the signal-to-noise ratio (SNR) level realized at the transceiver array.

Enabling Complete Freedom in the Spatial Domain

A weighted 2D or 3D array reinforces the free transmission of radio signals in the spatial domain by controlling the horizontal and vertical domains of the array’s beam pattern. This allows the AAS to manage gains offered by freedom in the vertical domain, something not available in legacy BSs.

The potential of MIMO technologies for state-of-the-art spatial processing in both the vertical and horizontal domains can further improve system performance, as detailed in the following sections of this white paper.
2. AAS Benefits and Key Values

The AAS’s integration of the active transceiver array and the passive antenna array into one radome allow for benefits of reduced cable loss and significantly simplified site engineering. Its key value is its capability to utilize the full potential of the spatial domain to boost radio access network (RAN) capacity and coverage.

**Reduced Cable Loss**

Integrating the active transceiver array and the passive antenna array into one radome reduces cable attenuation and thusly increases network capacity and coverage. Since a reduction of 1 to 3 dB cable loss is possible with an AAS BS, the AAS can realize the same capacity and coverage of a legacy BS with 1 to 3 dB less power.

**Clean Sites and Reduced Site Costs**

Space and costs issues become more complex with advanced multi-antenna deployments. The one-radome design of the AAS BS gives it the same size as a standard multiple-column passive antenna connected to BS servers via optical fiber. This reduces the number of installed boxes, saving installation time and site rental fees while cutting down on tower wind load.

The AAS significantly simplifies site engineering costs, including site rental fees and labor costs for site setup, which can sometimes be more than the cost of the BS equipment itself. The AAS is also software-configurable so its cost savings are more significant during network expansion or re-configurations.
Full Utilization of the Spatial Domain

Overview of AAS Applications

As mentioned in Section 1, the AAS provides electronic beam control in both the horizontal and vertical domains. This allows many spatial processing techniques to extend into the vertical domain. The following figures from a Huawei proposal given at the Ninth AWG meeting illustrate several AAS applications:

- **Separate UE Beam-Steering**
- **Flexible Rx Diversity**
- **Separate Tx-Rx Tilting**
- **Separate Carrier-Tilting**
- **Separate Service/RAT-Tilting**
- **Vertical/Horizontal Cell-Splitting**

An AAS BS can direct vertical beams in different horizontal and vertical directions for different operations, frequency bands, network standards, and link directions (downlink and uplink). This establishes a dedicated tilt for a specific operation to boost performance.

An AAS BS can also enable semi-static changes in the horizontal and vertical beams throughout a cell to adapt to variations in traffic distribution. This ensures the highly efficient use of BS equipment to intelligently track the flow of traffic.

Furthermore, the AAS BS is able to form multiple cells in the vertical domain by establishing multiple static beamforming vectors in a vertical array. This type of cell-splitting doubles available radio resources by separating user equipment (UE) in the vertical domain and therefore improves system capacity.

The AAS’s 3D spatial processing capability can be used to dynamically adapt individual beams to user-specific 3D channel conditions. Through joint dynamic horizontal and vertical spatial domain processing, spatial multiplexing performance and inter-cell interference coordination (ICIC) performance is improved, as detailed below.
Dynamic 3D-BF: Expanding Capacity and Coverage

3D-BF is an efficient way to expand capacity and boost both downlink and uplink coverage. As shown in Figure 2, with horizontal-only BF, users located far from the main beam suffer from transmission loss in the vertical domain.

When dynamic 3D-BF is applied to a single user, the BS guides the steered beams in both the horizontal and vertical domains for a clear propagation path to the targeted user for each instance of a data transmission. This allows operators to extend BS coverage to higher vertical planes like tall buildings in dense urban areas.

3D-BF allows operators to provide better services without changing transmitted power since the amount of energy delivered by the BS is more concentrated on the target user. The additional energy is equivalent to the reduction of consumed power on the network that has deployed the AAS.
Legacy BSs are typically capable of providing simultaneous service for individual users in the horizontal domain, but are not capable of beam shaping or steering in the vertical domain. An AAS with 3D-BF capability simultaneously serves multiple users distributed either on the horizontal domain or vertical domain.

Multi-User MIMO (MU-MIMO) also allows for better beam nulling to suppress inter-user interference caused by multiple users using the same time-frequency resources. This enables the AAS to have full utilization of available spatial resources to maximize frequency efficiency and boost network capacity.

With 3D-BF: Users at same horizontal but different vertical positions are simultaneously served

Figure 3: 3D-BF enhances multi-user spectrum efficiency
Coordinated multi-point (CoMP) transmission/reception performance is further improved by 3D-BF. When multiple BSs are dedicated to covering a cell-edge or high-priority user, legacy BSs with horizontal BF can only steer beams in the horizontal domain toward the targeted user, as shown in Figure 4 below.

BSs with 3D-BF can steer the beams in both the horizontal and vertical domains to put the targeted users in the spotlight-paths of multiple beams. This improves user experience for cell-edge and high-priority users by offering more a uniform network performance for anytime, anywhere high-quality services.

The benefits of 3D-BF on ASS BSs also apply to other features like carrier aggregation and enhanced ICIC. The aggregate gains of each feature deployed with 3D-BF can be higher than deploying each individual feature separately.
3. Realizing Industrywide Benefits

The AAS has the potential to realize industrywide benefits if aligned industry efforts are made to adopt the AAS as a set of advanced array BS equipment and as a new platform for enabling new wireless networking technologies.

A Better Platform for Advanced Array Technologies

Huawei is leading the study of AAS for 3GPP, drawing industrywide attention to the AAS. Results of the AAS study are documented in the 3GPP report TR37.840. The methodologies for the definition of radio requirements shall be extended from 2D to 3D which involves the modeling of 3D antenna patterns.

Areas for study include the spatial characteristics and radio requirements of an AAS with an integrated antenna accompanied by measurement steps to verify requirements. Methodologies for investigating AAS radio requirements are slightly different than legacy BSs, which have radio requirements primarily based on reference antennas with certain assumptions, as detailed in TR36.942 and TR25.942.

One of the key features of the AAS is its different spatial directionality for different transmission emissions. The Adjacent Channel Leakage Power Ratio (ACLR) for legacy BSs is flat in the spatial domain, while far field ACLR for the AAS is shown to be dependent on the correlation level between transmitters.

ACLR measurements taken after the combination of multiple transmitters can be misleading for the AAS with large dimension of transmitter array as the coexistence performances are primarily determined by the ACLR performance at each individual transmitter for typical deployment scenarios.

A new set of requirements may be specified for the AAS but will not impact AAS products designed with individual transceivers that follow existing single antenna connector requirements.
Making Gains and Standardizing Practices

For real network scenarios, there are circumstances in which the number of dimension elements of a passive antenna array is much larger than that of an active transceiver array. This requires a radio distribution network to exist between the passive antenna array and active transceiver array.

In these cases, the number of antenna ports required for dynamic weighting is much smaller than the number of array elements in the passive antenna array. This type of radio distribution network serves as a "dimension reduction transformer" that can be carefully designed to optimize performance gains, cost, and network complexity for an AAS offering 3D-MIMO.

For downlink transmissions, BSs with 3D-MIMO capabilities require downlink Channel State Information (CSI) to precisely shape or steer the beam for single-user and multiple-user MIMO. CSI standardized for 2D-MIMO may be extended to include the vertical domain, in particular, for the vertical direction of the propagation paths. Standardizing the measuring and reporting of complete horizontal-vertical CSI information would enable BSs and UE to better work in concert with one another to enable a 3D-MIMO feature’s full potential.

Inter-cell interference environments become more complex, however, when 3D-MIMO and 3D-BF is enabled on the network. Interference in an adjacent cell is increased if the beam is steered toward a cell-edge user or a user on a higher vertical plane. This interference is reduced if the beam is instead steered toward a cell-center user or user on a lower vertical plane. Inter-cell interference management acts as an immediately viable solution for these types of interference scenarios.
4. Looking Forward

Much more than a simple antenna element that provides tunable phase shifts, the AAS is an advanced multiple-antenna BS system for optimizing network infrastructure, costs, and performance to meet the growing requirements of future mobile broadband services. The AAS accomplished this by utilizing the full potential of radio resources in the spatial domain.

Huawei’s AAS research began roughly ten years ago, while demonstrations of working AAS solution prototypes were unveiled three years ago. Trial commercial networks based on Huawei’s AAS solutions were later deployed for multiple operators worldwide.

To foster industrywide acceptance of the AAS and array-BSs with integrated antennas, Huawei initiated an AAS 3GPP study in Rel-11 that led to the inclusion of multi-dimensional (horizontal and vertical domain) MIMO technologies (3D-MIMO) as a major feature for LTE Rel-12.

Huawei’s AAS solutions are based on a deep understanding of advanced and innovative spatial domain technologies that provide the best network antenna performance while reducing network costs and complexity.
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