Active antenna system (AAS) capabilities for 5G systems: A field study of performance

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***Abstract*—Enhanced antenna technologies will be key enabling factors in the development of 5th-generation (5G) systems that will achieve significant improvements in system capacity. This paper presents a practical performance evaluation of an active antenna system (AAS) that can lead to high-capacity gain with vertical sectorization (VS). Active antennas have flexible radiation pattern control for adapting to changing situations in mobile networks. This study shows the capabilities of an AAS to improving cellular network capacity in a real High-Speed Packet Access (HSPA) network. The field trial results indicate that the AAS technology can offer 84.6% capacity gains in the downlink direction. Thus AAS technology is a promising development for 5G mobile cellular systems that demand more capacity.**

***Keywords*— active antenna system, beamforming, drive test, HSPA, vertical sectorization**

I. Introduction

One of the key driving forces for 5G mobile cellular systems is the quest for more capacity. Capacity can be improved by more efficient spectrum utilization, more bandwidth, and higher network density. The vision of the 5G cellular network also includes the idea of a user-centric communication system [1]. In fact, 5G networks will become more user-centric than network-centric. Specifically, 5G cellular networks will adapt to changing user and service requirements.

Antenna technology development is an important way to enhance the spectral efficiency of 5G networks. Massive multiple input multiple output (MIMO) antenna technology is seen as promising to enhance the performance of cellular systems [2]. In particular, three-dimensional MIMO (3D MIMO) with vertical sectorization (VS) can respond to capacity challenges by spatial reuse of radio resources. VS is a capability of active antenna technology that is being developed in parallel with MIMO technology [3].

An active antenna (AA) is a MIMO antenna that has active electronic components. AAs have flexible radiation pattern control. The beam of an AA is driven by software. This beam can be adjusted according to the capacity and coverage targets of the network [4],[5]. One of the benefits is that this makes it possible to deploy the same active antenna system (AAS) for the different phases of the network deployment, including the roll-out phase with large macro cells, and for the network capacity increase phase with small cells.

Beamforming is an AAS feature that allows the network service to adapt to changing situations in the cellular network [6], [7]. Combined with AAS, it provides a more efficient way to serve parallel users. It allows beam tilting by radio access technology or carrier. It also enables radiation pattern optimization, Rx and Tx tilts within one carrier, and VS.

The multiple vertical antenna elements of AAS make VS possible. One sector can be split into outer and inner sectors by controlling the beam patterns of antenna elements. This enables the use of optimal electrical tilt for each vertical sector. LTE downlink performance evaluations gave capacity gains of approximately 50 percent compared to a conventional system [8]. These results were from system simulations. Our prior practical field trial research with WCDMA also gave promising results of capacity gain that can be achieved with VS [9]. This research showed gains up to 154 percent in the uplink and 69 percent in the downlink direction.

This paper expands the previous work on AAS by conducting field trials in a larger environment with multiple base stations. The research first verified the earlier work of [9] by repeating the VS measurements in the developed environment. There were two sites and two AASs in use in the previous measurements; with VS there could be four sectors in use. In the study presented in this paper, there are three sites and four AASs. This enlarged environment consists of four macro cells with up to eight sectors using VS.

The rest of this paper is organized as follows. Section 2 describes field trial environment. Section 3 describes the measurement setup in detail. The results of the AAS capacity measurements are presented in section 4. The conclusion is given in section 5.

II. Field Trial Environment for Active Antenna Systems

A. *Active Antenna System (AAS)*

The developed field trial environment for the AAS consists of an antenna system described in [11] that can enhance cellular network coverage and/or capacity by its flexible radiation pattern control possibilities. It allows mobile network operators (MNOs) to deploy the same AAS hardware

5GU 2014, November 26-27, Levi, Finland

DOI 10.4108/icst.5gu.2014.258113

(HW) for the roll-out phase of a network, as AAS can provide very large macro cells by its high-gain antenna and multiple transceiver (TRX) structure. Later, when there is a need to increase network capacity by adding smaller cells or optimized coverage areas, the same AAS HW can provide enhanced capacity by vertical sectorization, and by several other radiation pattern optimization possibilities. Advanced features enabled by the AAS include flexible configuration of diversity beams, individually optimized uplink and downlink beams (tilts and beam widths), and different beams for different carriers or for different radio access technologies.

In addition to achieving higher capacity, the AAS can also provide better energy efficiency with lower wind load on the mast. As a result, AAS helps MNOs reduce site-related costs (e.g. power supply, site fee, and maintenance) and to cost-effectively meet the dynamically evolving demands of their customers (e.g. throughput, service availability, energy efficiency, etc.) [12].

Fig. 1. The active antenna module outlook and internal structure [12].

A complete AAS consists of a traditional base transceiver station (BTS) system module with the active antenna (AA) module [11] installed on the antenna site. An AA module combines traditional antenna elements and several parallel active RF paths into one common antenna casing. RF paths of an AAS implement the same functionality normally found in any remote radio head (RRH): duplex filtering, power amplifiers, RF receivers and transmitters, and a digital interface towards main base band (BB) processing units. The main difference compared to a traditional RRH BTS site is that radiation and reception patterns of an AAS can be controlled digitally with extreme speed and flexibility.

The SW configurable VS capability of an AAS makes it possible for the network to adapt to changing situations. Active antennas allow operators to control the beam in the vertical direction, so that it is possible to create two or even more cells in the space of one traditional sector, as illustrated in figure 2 [9]. The inner cell is shown in dark gray, and the outer cell in white. All cells have their own cell identifiers (cell IDs), which allow the duplication/multiplication of the resources offered by the network. MNOs can also adjust the size and location of cells according to the requirements of user distribution.

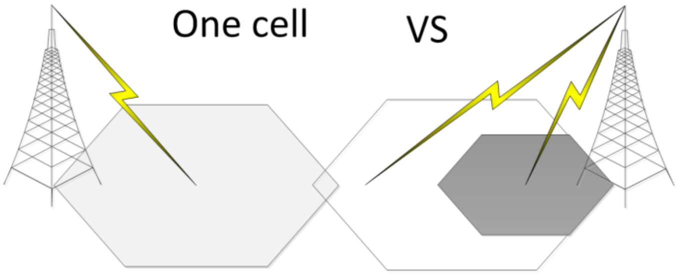

Fig. 2. Expansion of coverage using vertical sectoring [9].

B. *Cellular network*

AAS practical demonstrations were performed at a cellular field trial environment in a rural/suburban area of Ylivieska, Finland. This field trial environment was developed during CORE and CORE+ projects [13]. The AAS environment is part of a cognitive radio trial environment that was used to showcase the world's first live LSA trials, described in [14].

Figure 3 depicts the overall structure of the field trial environment. AASs were located in three sites at Ylivieska, Finland. WCDMA and LTE Core networks are located in the Nokia Networks core network cloud at Oulu, Finland. FTP traffic for load testing was provided from the Nokia Networks core network cloud. Centria cloud, also located at Ylivieska, has remote control connections to the trial network.

Table I presents the test parameters of the trial network. The approximate size of the field test environment is 4.4 km². The environment consists of three macro-cellular HSPA base stations operating in the 2.1 GHz band. Site C has two AA modules, and the others have one AA module. The distance between the BSs varies from 2.05 to 3.37 km. The antenna height is 42 to 50 m. Figure 4 presents the locations of the antennas. It also shows the approximate coverage area of the sites with VS.

TABLE I. TEST PARAMETERS

Configuration	Site A	Site B	Site C
HSPA system bandwidth	5 MHz		
Carrier band	2100 MHz (3GPP Band 1)		
BS Max Tx power	43 dBm		
The height of BS	50 m	42 m	43
Number of AA	1	1	2
The height of MS	1.5 m		
Number of stationary UEs	2		
Number of mobile UEs	1		

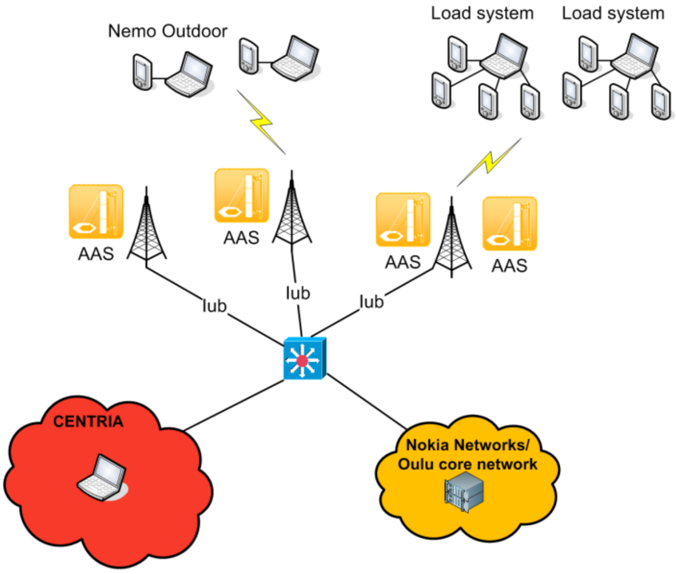

Fig. 3. Topology diagram of the AAS field trial environment

C. *Measurement tools*

Drive test software [15] was used in field trials to evaluate test network performance. MNOs use drive testing to evaluate cellular network quality from the mobile device's point of view. During the field trials, a test car was driven along roads in the trial environment. The car was equipped with the drive test software, a USB HSPA dongle, a test SIM card, and external antennas, which minimize the effects of a vehicle's structure. The received signal level, throughput, and serving cell were network quality indicators gathered during the measurements. The drive test software also has the ability to analyze layer 2/3 signaling messages, quality-of-service (QoS) and quality-of-experience (QoE) measurements, real-time missing neighbor detection, pilot pollution analysis, LTE automatic neighbor relation (ANR) reporting, and GSM interference [15]. It is possible to analyze results on the map view, because all results have a time stamp and location identifier. A global positioning system (GPS) was used for location identification.

Load systems were used to generate maximal traffic to the field test trial network. Load systems generated data and call traffic to make the test network resemble a real cellular network situation as much as possible. During the test-case measurements, load devices transferred files by file transfer protocol (FTP).

III. Measurement Setup

The field testing environment was expanded for this research from the previous study [9], in which two sites with four sectors were used. In the enhanced setup, an additional site, site C, was deployed to the environment. There was a total of four AASs in use for the measurements. The environment can encompass four macro cells, or when VS was used, eight sectors. Fig. 4 shows the complete field trial network with VS.

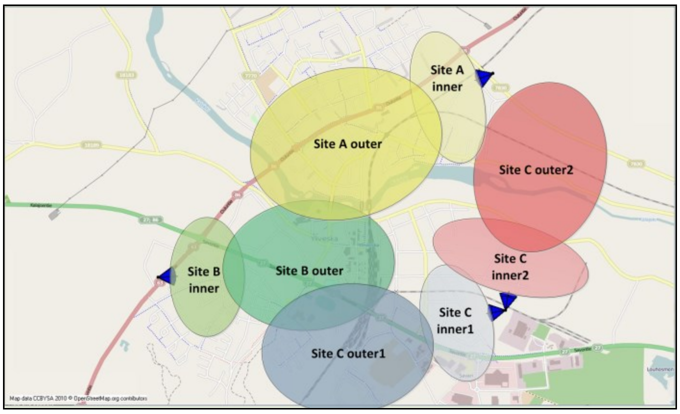

Fig. 4. Field trial network with vertical sectorization

Both mobile and stationary user equipment (UEs) were used in the measurements. The mobile UE used a drive test tool to gather information about the cell area in order to view the coverage area. The mobile UE gathered information on mobility in the network. The stationary UEs were used to study the effect of the VS on the network capacity. Stationary UEs generated normal traffic loads to the field trial network.

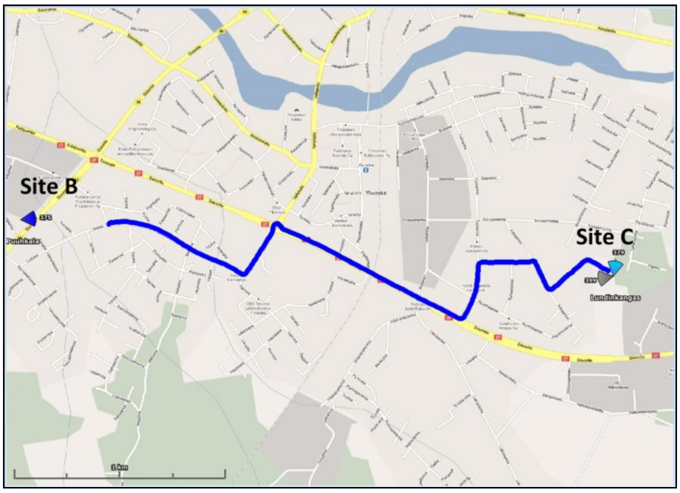

Fig. 5. The drive test route

The drive test route is shown in Fig. 5. The test results of the mobile UE indicated coverage area and verified the handover functionality of the network. The drive test route was planned to cover sites B and C as evenly as possible. The site A was active during study. The route was driven in both directions between sites B and C. The measured route length was 3.1 km in one direction. One test drive measurement took an average of six minutes, depending on traffic conditions. The measurement campaign focused on the DL direction measurements.

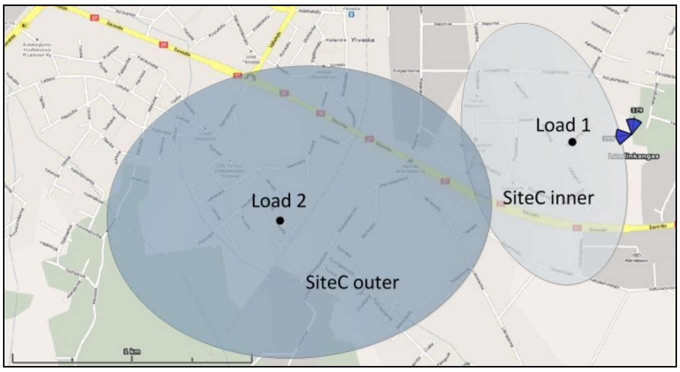

Fig. 6. Loads were located in the inner and outer cell of Site C

There were two sets of stationary loads in the measurements. Stationary loads were located in the coverage area of the site as shown in Fig. 6. The measurements were conducted to study the performance of site C with and without VS. The total measured traffic (in Mbit/s) was considered to be the maximum capacity of the current site. Other sites were on air, but empty during the measurement. Stationary loads were located in the areas of inner and outer cells (Fig. 6). Load UEs had line-of-sight access to site C.

IV. RESULTS

The performance of the AAS was evaluated by gathering instantaneous throughput data from the UEs. Fig. 7 shows an example of the changes in the throughput with respect to time. Throughput of an inner cell UE is shown in blue, and that of an outer cell UE in red. The green curve indicates the throughput of the moving UE. Figures 8, 9, and 10 illustrate the averaged results of all measurements. The theoretical maximum throughput offered by HSPA with one cell was 21.1 Mbps. There were created two cells with VS and theoretical maximum throughput was doubled to 42.2 Mbps.

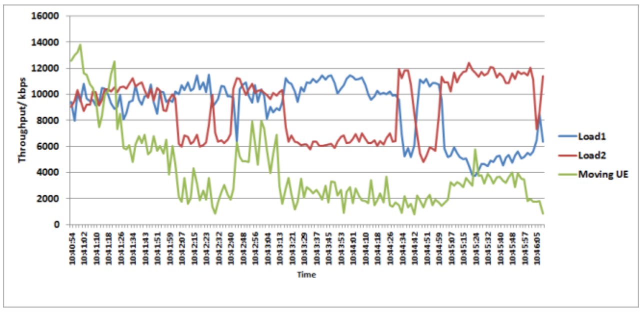

Fig. 7. Instantaneous DL throughputs when VS is on

Figure 8 represents the throughput variation of mobile UEs. There are ten measurement results with VS (VSon 1-10) and two results without VS (VSoff 1-2). These measurements were part of the larger measurement campaign of the AAS. Current measurement results without VS were similar to the results of previous measurements. That was why they were repeated only twice. This study focused only sites B and C. Measurements were performed in both directions between sites B and C. Throughput of the mobile UE varied from 3.82 to 4.60 Mbit/s when VS was on. VS had little effect on the throughput for mobile UEs. Throughput values were in general slightly higher without VS because the mobile UE performed more handovers when VS was used.

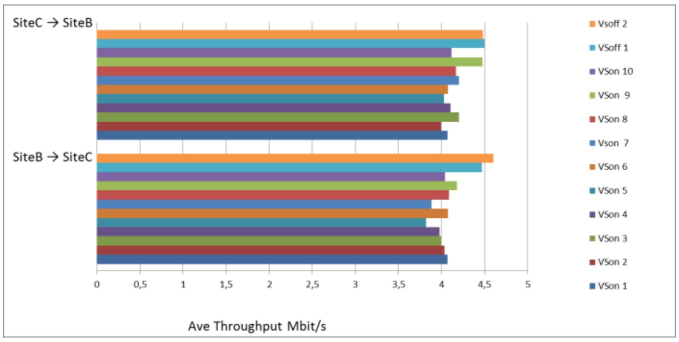

Fig. 8. DL throughputs with mobile UE

Measurement results of two stationary loads are presented in figure 9 and figure 10. Results from the inner cell are shown in figure 9, and from the outer cell in figure 10, with and without VS. Results are presented according to the direction of mobile UE movement in a way similar to that of figure 8 with the moving UE case. This way, it was possible to see the effects of the moving UE on the throughput values of the inner and outer cells.

The throughput of the UE in the inner cell coverage area was 3.35 to 3.63 Mbit/s without VS. Correspondingly, the throughput with VS was 6.65 to 8.91 Mbit/s. Capacity gain for the UE located in the inner cell coverage area was up to 165 percent with VS, indicating the potential of the AAS technology to offer significant capacity gains.

The second stationary load was located in the outer cell of site C. The throughput of the outer cell UE was 3.60 to 4.08 Mbit/s without VS. Performance of the outer cell UE varied more with VS than the inner cell UE. The throughput values were 4.43 to 10.09 Mbit/s. Capacity gain was 180 percent in the best case.

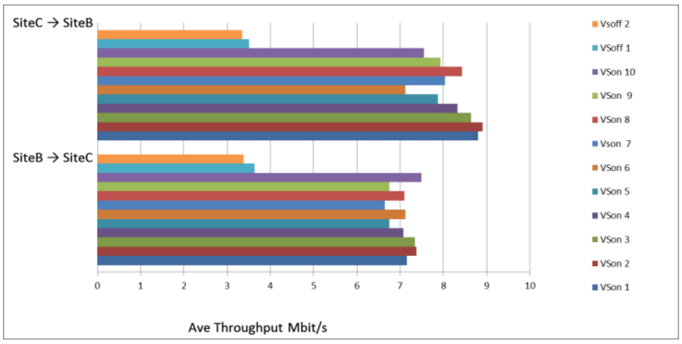

Fig. 9. DL throughputs with stationary UE in Site C inner cell

Table II presents the summary of measurement results with VS. The total throughput of two stationary loads varied from 12.35 to 17.79 Mbit/s between different measurements with VS. In this case, the capacity gain was 143 percent for static UEs. The total throughput of mobile and stationary UEs were

16.67 to 21.78 Mbit/s with VS, and 11.69 to 12.07 Mbit/s without VS. The resulting capacity gain was 84.6 percent (table III).

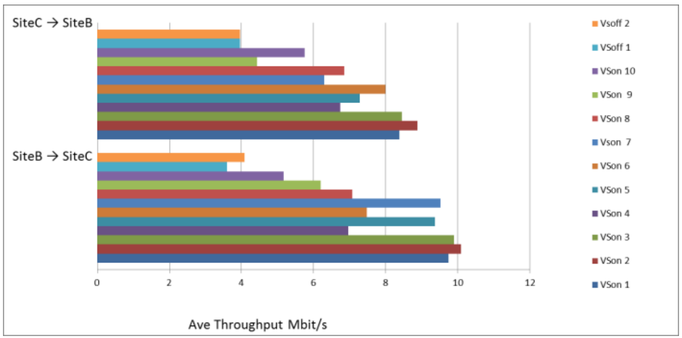

Fig. 10. DL throughputs with stationary UE in site C outer cell

TABLE II. SUMMARY OF VS RESULTS

DL Average Throughputs Mbit/s with VS				
	Min	***Max***	***Average***	***St. Dev.***
Moving UE	3.82	4.,48	4.08	0.13
Inner cell UE	6.65	8.91	7.62	0.69
Outer cell UE	4.43	10.09	7.63	1.60
Summary of stationary UEs	12.36	17.79	15.25	1.65
Total	16.69	21.78	19.33	1.60

TABLE III. GAIN COMPARISON FOR TOTAL THROUGHPUTS

DL Total Throughputs Mbit/s			
Route Direction	***VS off***	***VS on***	***GAIN***
Site B-> Site C	11.70	21.50	83.8%
Site C-> Site B	11.80	21.78	84.6%

More detailed analysis reveals that the main benefit of VS was for stationary loads in the inner cell, although the outer cell UE had the best gain in the individual measurement case. The UE of the inner cell had capacity gain even in the worst case, of 83 percent. The worst result for outer cell was 12 percent. The mobile UE did not benefit from VS because the number of handovers increased.

The results of the broader measurement of the AAS were similar to the results of the previous measurements. VS can offer benefits to network performance of even 84.6 percent in downlink direction.

V. CONCLUSIONS

The field trial described in this article evaluated an Active Antenna System (AAS) capacity gain in a macro cellular environment in the suburban/rural area of Ylivieska, Finland. Results confirmed earlier measurements, indicating that significant capacity improvements can be achieved using vertical sectorization (VS). The AAS and VS can improve the capacity that is demanded by 5G systems. VS was shown to deliver a capacity gain of up to 84.6 percent in the downlink direction. This enhancement was achieved by creating two individual vertical sectors with own resources using VS.

Future trials are planned to research beamforming with AAS, and AAS performance with LTE. Further plans include research on the possibilities of the AAS concerning the capability to adapt to changing situations in the network operating in shared spectrum bands under the Licensed Shared Access (LSA) concept.

ACKNOWLEDGEMENT

The authors acknowledge the CORE+ project research consortium that consists of VTT Technical Research Centre of Finland, University of Oulu, Centria University of Applied Sciences, Nokia, PehuTec, EXFO, Elektrobit, Anite, Rugged Tooling, the Finnish Defense Forces, the Finnish Communications Regulatory Authority, and Tekes—the Finnish Funding Agency for Innovation.

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