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E-VAM feature

Testing in live network

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Abstract—**Commercial deployments of MIMO have demonstrated that the technology is a very effective way to improve the system and individual user's data capacity across large coverage areas, without additional bandwidth. First implementations has shown that activation of MIMO was detrimental to non-MIMO device performance and terminals in the field. The objective of this paper is to provide an insight into a solution initially sought to resolve this MIMO co-existence issue using already available Virtual Antenna Mapping and its modification Enhanced Virtual Antenna Mapping which tunes the phase difference between the two physical antennas to obtain the best signal quality.**

***Keywords* - HDSPA; MIMO; VAM; E-VAM**

I. INTRODUCTION AND BACKGROUND

In the past few years, operators have seen huge growth in mobile internet usage. To cope with this growth, mobile operators are increasing the capacity of their networks, either by acquiring new spectrum, re-farming existing spectrum, and/or by relying on advanced technologies to increase efficiency of spectrum utilization.

Even in cases where new spectrum is available, acquiring new licenses and building out entirely new network can involve considerable CAPEX. A potentially quicker and less expensive option can be adopt new technologies, such as higher order modulation (HOM) or MIMO [1], or to deploy devices with improved receiver performance.

However, testing of MIMO in live HSPA networks revealed that its deployment using transmit diversity scheme STTD (Space Time Transmit Diversity) resulted in significant performance degradation on non-MIMO devices [2]. The issue is as follows: activation of STTD brings about in non MIMO HSDPA devices either the deactivation or non-operation of its chipset equalizer functionality resulting in significant performance degradation across all radio condition.

There was a need to find alternative solutions that permitted the deployment of MIMO functionality in a network but also permitting the coexistence with non MIMO terminals. For solving this task, 3GPP has been discussed for usage of VAM (Virtual Antenna Mapping) [3] in MIMO implementation as an alternative to the usage of the STTD transmit diversity scheme enabling co-existing MIMO and non-MIMO deployment, which, after solving some constraint, led to developing E-VAM (Enhanced VAM).

II. MIMO IN HSPA

A. The role of MIMO in HSPA

MIMO is one of the powerful tools that can significantly improve data rates, user experience and capacity within existing spectrum and through an upgrade to existing infrastructure.

MIMO is one of a slew of advanced antenna techniques in HSPA evolution roadmap. MIMO plays a central role in delivering the successively high peak rates in HSPA, from 28 Mbps in Rel7 to 168 Mbps in Rel10.

B. The backround of MIMO

MIMO, as the name suggests, involves leveraging multiple transmit and receive antennas available at the radio base station and the device to increase data rates, overall capacity and the user experience. Essentially, the MIMO system uses the antennas and processing at both transmitter and receiver to create multiple uncorrelated radio links (streams) between the transmitter and receiver. These streams use the same time and frequency resources, enabling capacity to be increased without an increase in spectrum.

The basic idea of MIMO is the benefit for all users in a cell. Users close to the cell center, being in good coverage, benefit from MIMO due to special multiplexing gain, which is achieved by transmission of multiple parallel streams, whereas users near the cell edge benefit from another manifestation of MIMO, called Beam-forming, which is achieved by dynamically switching to single stream transmission on the transmit antennas, when radio condition deteriorate.

The transmission of multiple data streams requires multiple separate PA (power amplifiers) per sector for transmission of multiple independent channels and each channel must have its own associate reference signal in order to achieve appropriate channel estimation. Given the necessity of multiple PAs, subsequent power balancing across PAs is highly desirable and the full utilization of PAs, thereby maintaining system efficiency in using available resources for all deployed carriers.

It was initially thought that such co-existence was possible given that there was an already defined feature for achieving balanced PAs and full utilization of available resources - STTD. However, it was quickly observed during trial activities that activation of STTD was detrimental to non-MIMO device performance.

C. *STTD (Space Time Transmit Diversity)*

STTD is an open loop technique in which the symbols are modulated using the technique described in [4]. This type of open loop TD has been adopted by the 3GPP because this type of transformation maximizes diversity gain.

STTD is defined for two antennas. Assume that x_o and x_e are the odd and even symbols, respectively. Then the transmissions over two antennas, s_1 and s_2 are given by

$$s_{1e} = x_o W,$$

$$s_{2e} = x_e W,$$

$$s_{1o} = -x_e^* W,$$

$$s_{2o} = x_o^* W,$$

Where *W* is the orthogonal Walsh code used (Fig.1).

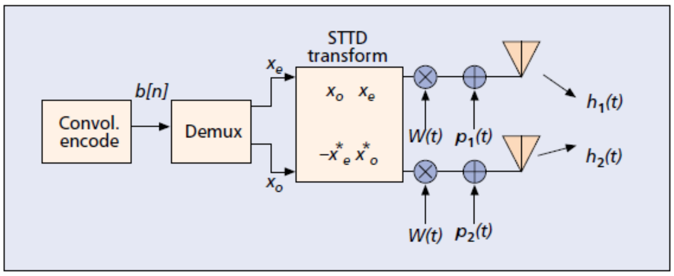


Figure 1. *STTD transmitter*

The received symbol is decoded over two consecutive time epochs. The received symbol may be represented in vector form as

$$\begin{bmatrix} r_e \\ r_o \end{bmatrix} = \begin{bmatrix} h_1 x_o W + h_2 x_e W \\ -h_1 x_e^* W - h_2 x_o^* W \end{bmatrix} + \begin{bmatrix} \gamma_e \\ \gamma_o \end{bmatrix}.$$

Neglecting the Walsh codes, an estimate of the transmitted symbols may be formed as

$$\begin{bmatrix} \hat{x}_e \\ \hat{x}_o \end{bmatrix} = \begin{bmatrix} h_2^* r_e - h_1 r_o^* \\ h_1^* r_e + h_2 r_o^* \end{bmatrix}.$$

The STTD scheme is particularly simple, in the sense that it implements Alamouti's space-time block code (2x2 code matrices) and follows it by separate spreading and scrambling, as in the non-diversity mode. The orthogonality property of the code matrices allows the symbols from the two transmit antennas to be separated at the receiver front-end. There is no need for separate Walsh codes on the two transmit antennas for the traffic channel because the orhogonality between space-time code matrices is realized in the time domain, just as in frequency nonselective fading. However, separate Walsh codes are needed for the antenna pilot signals in order to distinguish the channels.

III. VAM (*Virtual Antenna Mapping*)

A. *Co-existence of MIMO and Legacy Terminals*

An HSPA terminal can be categorized by the performance level of its receiver. 3GPP TS25.101 specifies the minimum throughput performance for both and advanced receiver architecture. However, the specific performance requirements are derived from the following assumptions:

- The basic HSDPA receiver is based on the standard RAKE receiver used with the WCDMA radio interface
- The Type2 receiver is based on a linear equalizer, which improves performance, especially when multiple paths are used by the radio signals travelling between the base station and the device
- The Type3 receiver supports dual-antenna reception, together with equalization on each branch.

Device equipped with advanced receivers of type2 and type3 have all been rolled out commercially. However, some commercial devices have been equipped with an equalizer that will fall back to the lower performance RAKE receiver functionality if the serving cell is an STTD mode.

MIMO can be operate in one of two modes. In STTD mode, the base station transmits primary CPICH (P-CPICH) and diversity CPICH, while, in PSP (Primary Secondary Pilot) mode, the base station transmits in both primary and secondary CPICH (S-CPICH).

In theory, STTD mode provides the largest capacity gain, since both MIMO users and non-MIMO users can benefit from transmit diversity. However, this mode will result in a net degradation of performance when a large proportion of user devices have equalizers that fall back to RAKE receiver functionality in STTD mode. In such circumstances, the PSP mode is preferable.

B. *VAM description*

When the base station transmit in S-CPICH, the transmit power of the two antennas may differ, which can lead to the non-optimum use of power amplifier resources. To overcome this problem, Virtual Antenna Mapping is used.

VAM introduces a power balancing network to enable base stations with P-CPICH and S-CPICH to fully exploit the power of the two PAs when transmitting to non-MIMO devices (Fig.2). Generally, VAM is a transmit diversity scheme whereby a matrix of fixed phase offsets are to applied to the incoming data before the PAs via a 2-port signal processing matrix such that two orthogonal data flows result:

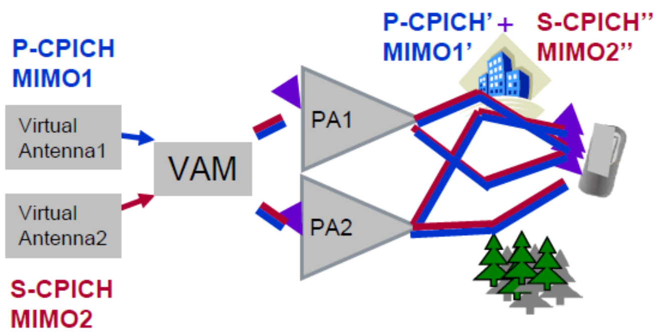


Figure 2. *Virtual Antenna Mapping with MIMO*

- For non-MIMO devices, the data itself remains unchanged, the phase offset is transparent and seen only by MIMO device
- In addition to the required P-CPICH in WCDMA deployments, the usage of VAM to enable efficient MIMO deployment requires the usage of Secondary CPICH (S-CPICH) for MIMO as each data stream over the air interface requires its own reference to interpret the orthogonal outputs

In order to optimize SINR, optimal weight (w_2) is chosen by NodeB on basis of feedback information from UEs via PCI (Pre-coding Control Indication) sent on HS-DPCCH channel (Fig.3).

For single stream transmission, the pre-coding codebook is restricted to two allowed values only (for dual stream – for values). These are fix and independent of VAM phase offset.

The spread and scrambled signals are fed to Tx branches and weighted with pre-coding weights w_1, w_2, w_3, w_4.

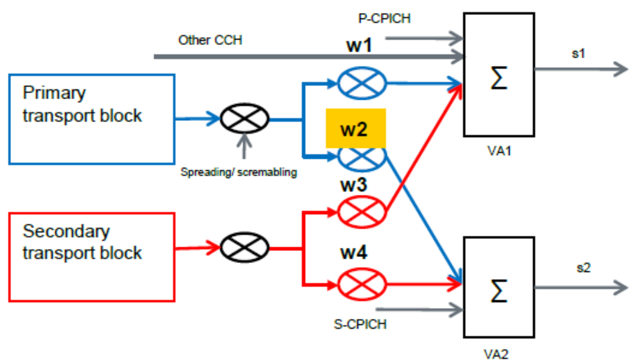


Figure 3. *VAM block diagram*

There are two possible way to use VAM and those are with and without MIMO.

For first method, VAM matrix is orthogonal for the MIMO1 and MIMO2 signals thus keeping the two MIMO streams independent.

For second method (VAM without MIMO) P-CPICH is sent thorough the same matrix, non-MIMO UE experiences the signal as a single antenna transmission but with added power and polarization diversity (Fig.4).

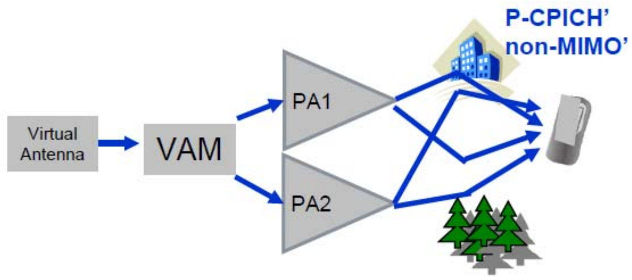


Figure 4. *VAM without MIMO*

From the legacy user point of view the VAM technique is like a single antenna transmission, i.e. the user terminal demodulates the HSDPA signal as if there were no Transmission diversity in the system. Seen from the transmit side for legacy non-MIMO users, VAM amounts to transmitting the same signal (common channel, Rel'99 and HSDPA non-MIMO) on the two transmit antenna ports but with a different phase.

However, from extensive field testing of VAM functionality (measurements over a large amount of static points which statistically shows the impact of VAM [5]), the following results have been obtained:

- When there is no concurrent HSDPA and active MIMO user equipment e.g. only HSDPA (non-MIMO) user equipment in the cell, VAM has little or no impact on HSDPA performance i.e. throughputs observed of HSDPA user equipment with VAM active are nearly the same as the throughputs of HSDPA without VAM (single antenna transmission as in most 3G networks today).
- The performance of MIMO with VAM is also very similar to the performance of MIMO with Tx diversity (STTD)
- However whenever there is concurrent HSDPA and MIMO traffic, it has been observed that the performance of HSDPA legacy devices is impacted negatively by around 10% for a legacy type 3 device (Rx diversity and equalizer implemented in receiver) and by around 15-20% for a legacy type 2 HSDPA device (no Rx diversity, only equalizer implemented in receiver) whenever the secondary pilot is present in the second virtual antenna and more degradation is observed whenever the MIMO user is fully active with continuous downloads.

Hence, it is shown that even though the VAM technique has a better performance than previously used techniques such as STTD, it has still a negative impact in HSDPA legacy devices when there is concurrent HSDPA and MIMO traffic. There is therefore a need in the art for transmission schemes which further improve the performance of legacy HSDPA devices in concurrent HSDPA-MIMO traffic while maintaining the advantages of using VAM techniques.

IV. E-VAM (*ENHANCED VAM*)

A. *Improving VAM via phase insertion*

Whilst noting that the usage of VAM to enable MIMO was partially successful due remained some impact on non-MIMO devices, an enhanced version of this solution was sought to fully permit the co-existence of MIMO and non MIMO devices in any such MIMO deployment.

The basic difference of VAM and E-VAM is phase offset. While VAM has random phase offset and it is determined by several components such as the power amplifier and the antenna cables, the E-VAM phase difference between signals from two antennas is maintained at the level that allows the best possible HSDPA signal properties (Fig.5)

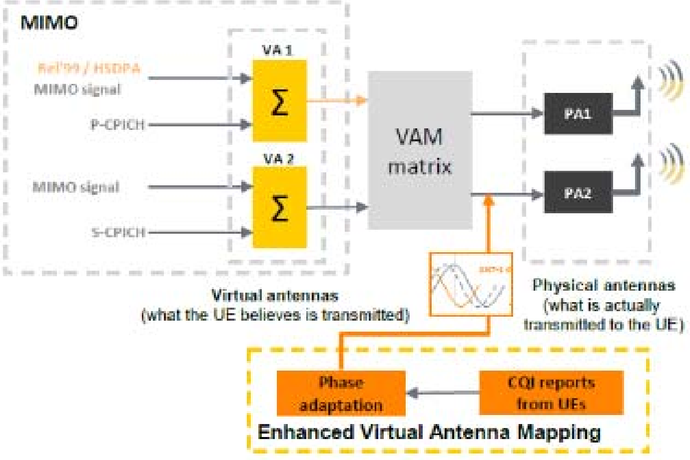


Figure 5. *E-VAM block diagram*

B. *Identification of the optimal phase*

For obtaining the best phase difference between the two physical antennas, the CQI (Channel Quality Indicators) of active non-MIMO UEs in the cell are used and there is no impact on MIMO performance as this solution is effectively transparent for MIMO devices.

Identification of the optimal phase to be applied, is achieved by performing applying different phases across the full spectrum (0º-360º) at different sequential intervals and noting a combination of the reported CQI and throughput reports from the UEs. CQI reports are used by the network to gauge radio conditions at the UE then to determine the transport block size and modulation scheme to be used for subsequent data transmission.

Instead of CQI, other alternative parameters can be taken into account to select the phase as CPICH (Control Pilot Channel), RSCP (Received Signal Code Power), CPICH Ec/No, NACK info. The drawback of these is a slower adaptation of the phase as the phase scan would have to be longer, however once selecting the phase it is not necessary to have very frequent updates of the phase hence this approach is possible. [5]

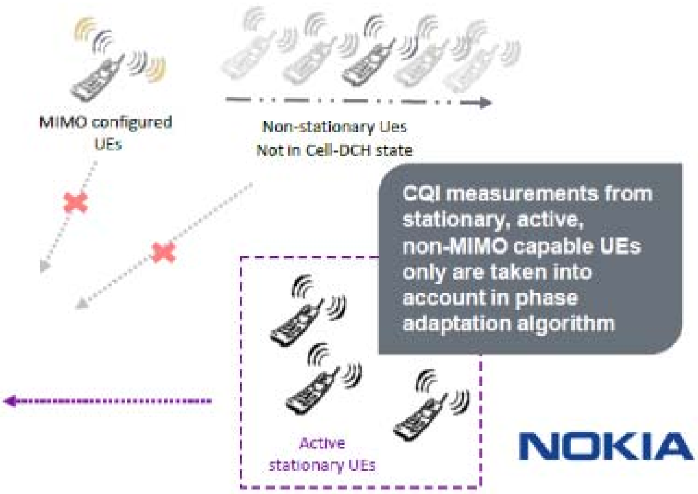
V. TESTING E-VAM

A. *Overview*

The evaluation of E-VAM feature is performed in a trial environment within commercial traffic in the VIP mobile live network based on Nokia Flexi Multiradio BTS WCDMA equipment. This trial did not require any hardware modifications at UE or BTS side.

B. *Measuring*

Identifying E-VAM improvements using cell capacity via measurement of throughput can only be performed in a controlled environment. In a live network with real traffic, using such a metric could be skewed either way by the wide range of functionality different HSPA devices present or active in the cell at a particular point of time.



Therefore when testing continued of the application of the feature in live network, the CQI (Channel Quality Indicator) reports as sent from each UE are the most reliable indication of the radio condition for active HSPA devices in the cell.

1) *CQI*

CQI stands for Channel Quality Indicator. As the name implies, it is an indicator carrying the information on how good/bad the communication channel quality is. The UE estimates the SINR of each stream and transmits the according CQI. In HSDPA, the CQI value ranges from 0 - 30. 30 indicates the best channel quality and 0,1 indicates the poorest channel quality. Depending which value UE reports, network transmit data with different transport block size. If network gets high CQI value from UE, it transmit the data with larger transport block size and vice versa.

2) *Happy Bit Ratio*

One more indicator for quality that is used for observation in this trial is in relationship with UL throughput and it is called Happy Bit Ratio.

The scheduling signaling sent in the uplink direction is used as control information by the UEs to indicate the NodeB the amount of resources they required. This type of signaling can be seen as a request for resources from the UE to the NodeB. 3GPP release 6 specifies the signaling used by the UE to make a request. A single bit field is included in the

E-DPCCH for every E-DCH transmission. This bit, called "happy bit", takes two values, "not happy" and "happy", indicating respectively whether the UE could use increase data rate or not. It defines whether the device could use a higher uplink data rate or not. If, not, the bit is set to the "happy" position and thus, there is no need for the scheduler to increase the uplink data rate.

C. Field Trial

1)

The third sector of base station BA1155 was chosen for E-VAM trial, which is located in Bela crkva town and it is covering more or less the whole city with 3G signal. It has two carriers, named BA1155U3 and BA1155D3, and they have sufficiently high traffic.

The max power before setting E-VAM was 30W per carrier and practically, after settings, the cells was working with 2x30W polarized diversity.

The parameters for this trial was configured in the following way:

- Phase scan: 2.16 sec
  During this interval average CQI is calculated from the CQI's of UEs whose reports are within the configured range. The phase offset for this trial was chosen to be 45º (8 phases during 2.16 sec)
- Phase application: 10.8 sec
  Optimal phase is set as the center value of the best phase offset range and then kept for the given amount of time. After the time expire new optimal phase is being search.

The results of this trial are following:

- HSDPA setup Success Rate was slightly increased (~0.5%) while HSUPA setup Success Rate remains the same, as was expecting because E-VAM influences only on downlink
- The average reported CQI was improved from 22.35 to 23.70, which is great improvement.
- The Happy bit rate was significantly improved, almost 8%.
- Due polarization diversity the coverage was improved too.

CONCLUSIONS

E-VAM can be considered as an open loop transmit diversity scheme based upon CQI reporting from the UEs. E-VAM feature improves the HSPA throughput for non-MIMO users. Exact gain depends on actual radio conditions and CQI reports sent by the UE are the main measure of the radio conditions. Live network testing showed that E-VAM provides gain in the order of 0.7-1 CQI units and E-VAM should be considered as a technique that has great potential to optimize performance. Greater CQI values reported by UEs forces the BTS to determine and use the greater Transport Block Size and higher number of HS-PDSCH codes and higher order of modulation used by UE.

The drawback of E-VAM feature is that it require 2 Tx ports and the more power than the normal cell with 1Tx+2Rx ports.

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