Enhanced Virtual Antenna Mapping (E-VAM)

Brendan McWilliams, Yannick Le Pézennec, Theodosia Papatheologou, Luis Anaya, Julio Urbano, Miguel Arranz
Vodafone Technology Networks,
Access Competence Centre,
Madrid, Spain and Newbury, United Kingdom
brendan.mcwilliams@vodafone.com, yannick.lepezennec@vodafone.com
theodosia.papatheologou@vodafone.com, luis.anaya@vodafone.com
julio.urbano@vodafone.com, miguel.arranz@vodafone.com

***Abstract*— 3GPP Release 7 introduced several new powerful features to the existing HSDPA (High Speed Downlink Packet Access) functionality including Single Input Multiple Output using 64 Quadrature Amplitude Modulation (SIMO 64 QAM) and Multiple Input Multiple Output (MIMO). Amongst these, first implementations of MIMO brought about inadvertent performance degradation in existing non MIMO devices 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 (VAM) and its modification which resulted in a valuable optimisation technique in itself – "Enhanced VAM" – irrespective of MIMO deployment.**

Keywords-component; HSPA+; MIMO; VAM;

I. Introduction & Background

"HSPA+" refers to the new additional HSPA capabilities introduced in 3GPP Rel'7 and thereafter. The flagship features of Rel'7 are 64QAM and MIMO [1] – with both relying on the use of the "Enhanced Layer 2" feature – have been tested [2] and to varying degrees deployed in wireless networks. Subsequent releases beyond 3GPP Rel'7 will further increase attainable throughputs with the introduction of these features deployed over two or more carriers in combination or separately.

However testing of MIMO in live networks revealed that its deployment using transmit diversity scheme Space Time Transmit Diversity (STTD) resulted in significant performance degradation on non MIMO devices [3] [4]

To summarise, 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 conditions.

In short, MIMO could not co-exist on carriers also used for non MIMO devices - thus, 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.

However it was via the attempts to find an enabler for MIMO i.e. a replacement for STTD using the already developed Virtual Antenna Mapping (VAM) [5] that led to what we call Enhanced VAM (E-VAM) which has the added – and arguably greater – advantage of bringing benefits even if MIMO is not deployed.

II. A Replacement for STTD

A. *Background to MIMO deployment*

Implementation of MIMO as the name suggests refers to the simultaneous transmission of 2 data streams using the same radio resources by employing 2 antennas for transmission at the Node B and requires 2 antennas for reception at the user equipment (UE). The transmission of these two data streams requires two separate power amplifiers (PAs) per sector i.e. one for each of the two antennas transmitting the two independent channels. Each channel must have its own associated reference signal – "pilot" - in order to achieve appropriate channel estimation.

Given the necessity of two PAs, subsequent power balancing across PAs is highly desirable i.e. the full utilisation of both 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 – although rarely if ever deployed - in 3GPP from R99, that of STTD. Whilst not required for MIMO deployment – it was seen as an enabler to deploy MIMO efficiently i.e. achieve balanced PAs and full utilisation of available resources.

However, it was quickly observed during trial activities that activation of STTD was detrimental to non MIMO device performance and so alternatives were sought to permit efficient deployment of MIMO.

B. *VAM (Virtual Antenna Mapping)*

Virtual Antenna Mapping (VAM) has been well known for some time and has been discussed in 3GPP for usage in MIMO implementation [8] as an alternative to the usage of the STTD transmit diversity scheme enabling co-existing MIMO and non MIMO deployments.

VAM itself 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. For non MIMO devices, the data itself remains unchanged i.e. the applied phase offset is transparent and "seen" only by MIMO devices.

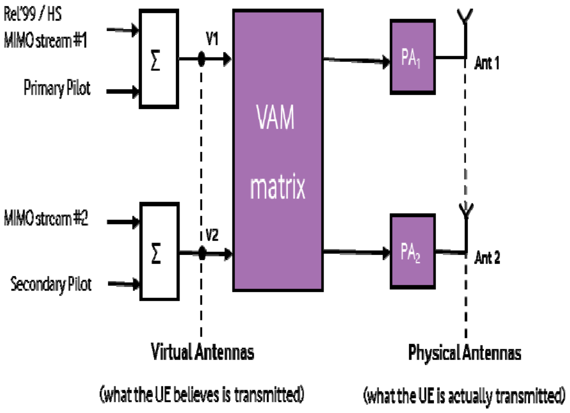

Figure 1. VAM Block diagram

Note that in addition to the required Primary Common Pilot Indication Channel (P-CPICH) in WCDMA deployments, the usage of VAM to enable efficient MIMO deployment requires the usage of a Secondary Common Pilot Indicator Channel (S-CPICH) for MIMO as each data stream over the air interface requires it's own reference to interpret the orthogonal outputs – in this case different polarised – data streams.

Extensive testing of the VAM functionality brought the following conclusions:

- Usage of VAM permits PA power balancing.
- Usage of VAM without activation of MIMO has negligible impact on non MIMO HSDPA device performance.
- Usage of VAM to enable MIMO i.e. when MIMO and non MIMO traffic were coexisting impacted negatively on the non MIMO device performance – but to a lesser degree than STTD.
- For the MIMO devices, peak MIMO throughputs were still obtained and no degradation was observed.

The above conclusions were derived via testing over a large amount of static points across good, medium and bad radio conditions and led to the conclusion that deployment of MIMO using VAM in the same carrier resulted in unacceptable performance degradation with non MIMO devices i.e. MIMO and non MIMO devices could not co-exist in the same WCDMA "carrier" without customer impact.

III. IMPROVING VAM VIA PHASE INSERTION

Whilst noting that the usage of VAM to enable MIMO was partially successful i.e. there 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.

Testing and investigation of various aspects of the application of VAM were carried out both under laboratory conditions and via field testing (in a test cluster closed to commercial traffic) led to the following observations:

- A phase component could be added after the VAM matrix itself but before the PAs – see Figure 2.

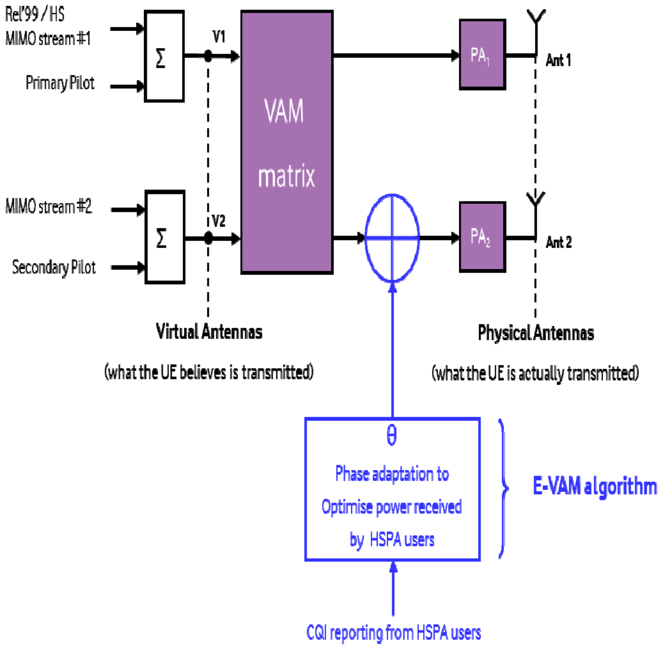

Figure 2. Phase Insertion post VAM

- Given that Transmit Diversity by definition requires different but sufficiently *un*-correlated transmit components within the antennas being used – note that cross polar antennas are very typical (which provides good un-correlation between the two transmit signals radiated) in wireless networks – it would appear that varying this phase shift across the full 0º > 360º spectrum revealed that there was a direct relationship in the phase offset applied and the resulting performance observed in non MIMO device(s) measured throughput in a cell within the aforementioned test cluster – see Figure 3.

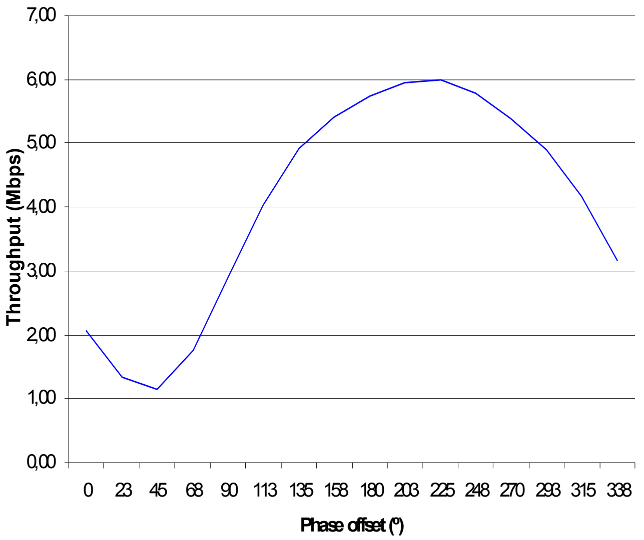

Figure 3. Measured throughput for VAM applying 0° > 360°

- Figure 3. shows that applying additional phase offset on one branch to what was already being transmitted using Transmit Diversity via VAM *does* impact reception at the UE and as such a specific offset could be identified to maximise reception at the UE.

- Insertion of this phase component after the VAM matrix itself – has no impact on MIMO device performance i.e. the inherent MIMO control mechanism - precoding control indication (PCI) [1] – is sufficiently robust such that any additional phase applied after the VAM is effectively transparent to MIMO performance.

IV. MAKING E-VAM WORK

Knowing that the performance of VAM could be improved upon following the search for a "MIMO enabler", and given that MIMO itself would be a fraction of HSDPA deployment i.e. non MIMO deployments pre-dominate, investigations continued in order to verify if this improvement could be utilised in such a way as to improve upon (existing) HSDPA performance in non MIMO deployments.

Any solution based upon this "enhanced" VAM had to include the following:

- Identification of and subsequent application of optimal phase shift to be applied to maximise cell capacity for the non MIMO devices present.

- Ability to apply the aforementioned phase shift for a given period of time.

- Ability to repeat the process of identification and application of this optimal phase shift in a dynamic environment i.e. UE mobility, variable data session(s) length.

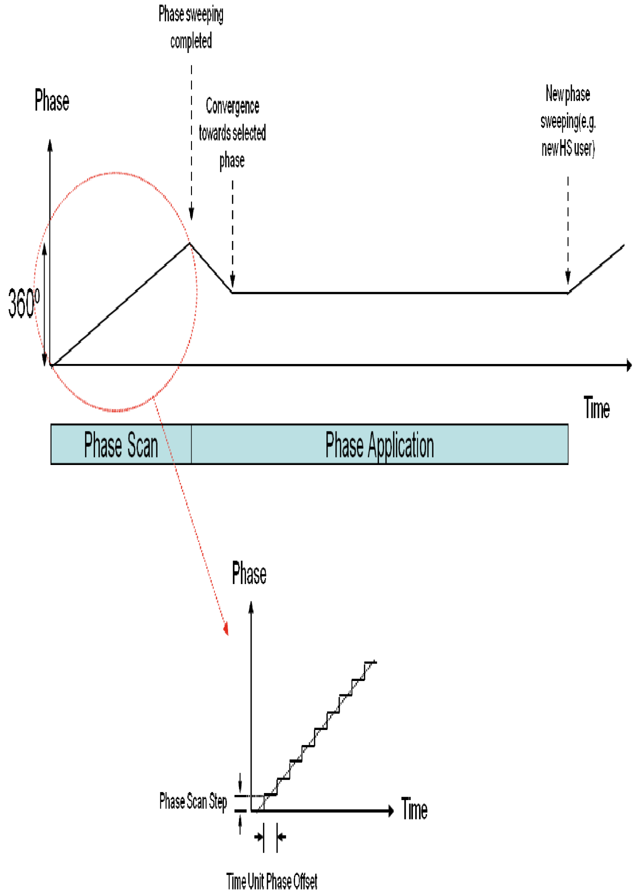

Figure 4. E-VAM Phase Adaptation

Identification of this optimal phase to be applied - "Phase Sweeping" - is achieved by performing applying different phases across the full spectrum (0° > 360°) at different sequential intervals and noting a combination of the reported Channel Quality Indicator (CQI) – a unit described in [7] - 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 transmissions.

Whilst the definition, calculation and scale (from 0 to 30) of CQI is defined by 3GPP [7], in the UE itself this calculation takes place post receiver and across UE manufacturers receiver performance may vary. Any margin of error – if not a specific standard deviation – will be due to UE receivers, CQI reporting window, UE speed, channel fading etc. However usage of CQI is considered a good indicator of channel radio conditions – and a key metric in this activity.

During this interval the reported CQIs are monitored and noted such that at the end of the cycle it will be known which phase to be applied to maximise cell capacity. Given that traffic frequency varies in a cell this process should be repeated at regular intervals to accommodate varying traffic e.g. more/less active and/or moving users. Unless in the case of a single active user in a cell, any selected phase to be applied is always likely to be a compromise for all users as only one phase can be selected.

E-VAM can be considered as an open loop transmit diversity scheme based upon CQI reporting from the UEs i.e. "open" in that no new additional signalling to the UE from the network takes place.

V. TESTING E-VAM

A. Overview

The evaluation of E-VAM was performed in both a trial environment (i.e. isolated from commercial traffic) and in the Vodafone Spain live network in collaboration with a leading WCDMA infrastructure supplier. Then commercially available datacards were used at the time of this trial i.e. usage of E-VAM does not require any modifications at UE or RRC.

B. Measuring Improvement

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 functionally different HSPA devices present and/or active in the cell at a particular point in time.

Therefore when testing continued to the application of the technique in live network (1 NodeB, 3 sectors), the Channel Quality Indicator (CQI) reports as sent from each UE were deemed more reliable – if still imperfect - indication of radio conditions for those active HSPA devices in the cell.

Higher CQIs should in turn lead to higher cell throughput although it is acknowledged that the CQI reports sent from UEs are calculated depending upon a number of factors e.g. different device receivers, the modulation scheme used.

In addition, calculation of optimal phase by noting CQI reports should only include those CQI reports from those actively transmitting (i.e. data being sent) HSPA devices and not RRC connected only devices i.e. not actively transmitting data – this was included within E-VAM - nor indeed those sent from MIMO devices to the network.

C. Field Trial

1) Setup

The field trial consisted of a cluster of 3 NodeBs in a semi urban environment in an industrial estate on the outskirts of the city of Madrid, Spain, using the Vodafone España network.

The main characteristics of the trial setup used to test E-VAM are listed below:

- A real network implementation using a Radio Network Controller (RNC) and Node Bs of at least 3 sites with 3 cells per site (isolated from commercial users as pre-commercial software was used in each setup). An overview of the field trial setup is given in Figure 5. .

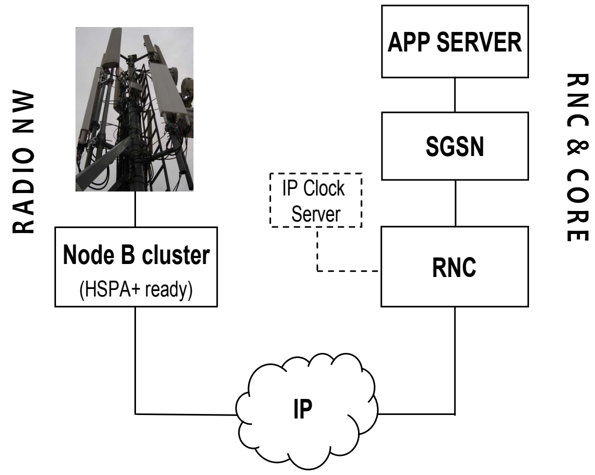

Figure 5. E-VAM Trial Setup

- Full buffer traffic model based on downloads of large files over UDP.
- The NodeBs were connected via an IP based transmission network to the RNC, and this to a laboratory Core Network using a commercial SGSN and Application Server.
- User throughput measured at Layer 2 Medium Access Control (MAC) level using both Network and User Equipment (UE) level traces.
- UEs used: both a Type 3 receiver (i.e. 2 way Rx diversity & equaliser) and Type 2 (1 Rx & equaliser) Receiver used.
- Full buffer traffic model was based on downloads of large files via FTP.
- In the backhaul transmission network, IP transport was used.

2) Procedure

As in the testing of any new technology a baseline scenario was agreed upon with which to compare throughput performance with and without E-VAM.

In this case, the baseline scenario was the performance of regular HSDPA 10.8 (SIMO 16QAM) devices i.e. not HSPA+ devices across various radio conditions with Enhanced VAM on and off. Whilst lacking statistical traffic, this exercise was conducted in order to measure the "pure" gains of E-VAM.

TABLE I. below describes the reference radio conditions used when obtaining measurements.

TABLE I. REFERENCE RADIO CONDITIONS

Radio Conditions	Average CQI	Received Power (RSCP)
Good	28	RSCP ≥ -70dBm
Medium	24-25	-70dBm ≤ RSCP ≤ -90dBm
Bad	16-17	RSCP < -90 dBm

Within each of the good, medium and bad radio conditions tests were performed over 5 different static points to ensure sufficient confidence in results.

3) Field Trial Results: E_ VAM On vs Off

a) Single HSDPA User, Cat 8, Type 2 Receiver: Throughput

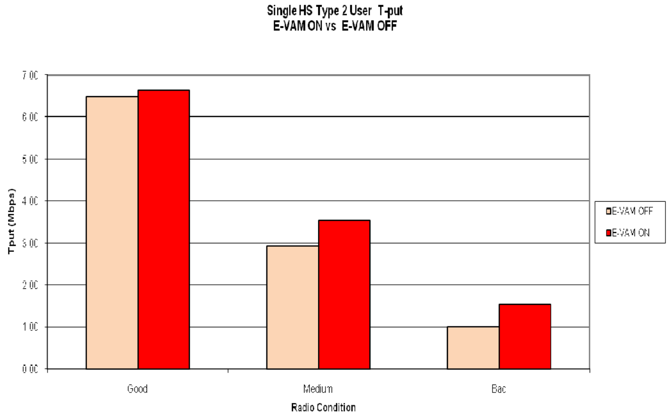

Figure 6. Single HSDPA User, Type 2 Receiver – Throughput Performance

b) Single HSDPA User, Cat 8, Type 3 Receiver: Throughput

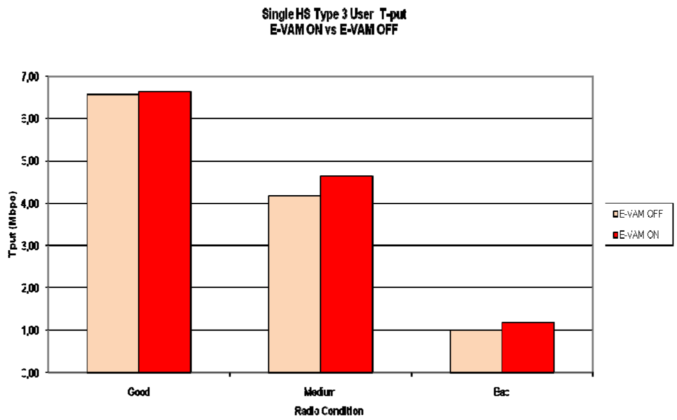

Figure 7. Single HSDPA User, Type 3 Receiver – Throughput Performance

c) Single MIMO User, Cat 18, Type 3 Receiver: T-put

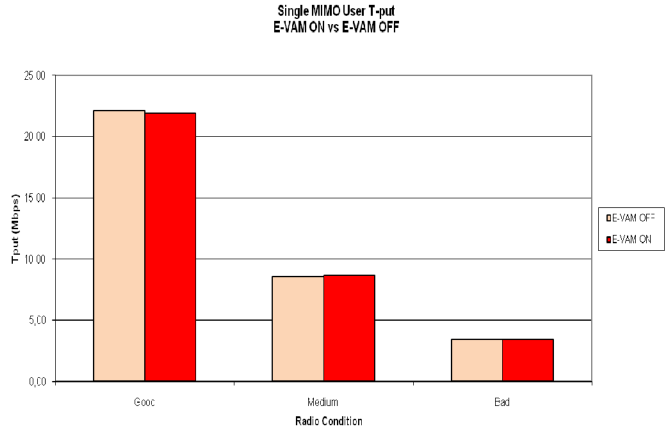

Figure 8. Single MIMO User, Throughput with E-VAM

4) Field Trial Conclusions

The following conclusions were reached following field testing of E-VAM:

- E-VAM improves substantially single user HSDPA throughput in medium and bad radio conditions:
  - 20-50% for Type 2 Receiver devices (typically Smartphones).
  - 10-20% for Type 3 Receiver devices (typically USB datacard dongles).
- E-VAM provides similar performance as VAM for MIMO i.e. MIMO PCI precoding weights are robust enough to overcome adjustment in phase.

D. Live Network Testing

1) Setup

Live network testing took place in Vodafone Spain, activating E-VAM in a highly loaded NodeB (3 sectors) located in an urban area.

MIMO was not activated in order to measure the "pure" benefits of E-VAM on non MIMO devices.

2) Procedure

No active testing as such took place during this exercise rather CQI statistics were collected during a 24 hour period in each of the 3 sites with E-VAM activation/deactivation taking place every 30 minutes to minimise traffic bias that may occur in a live traffic (i.e. load) during this period.

3) Live Network Testing Results

The following figures show the reported CQIs as sent by the UEs in each of the three sectors where E-VAM was activated. As mentioned previously, in a live network throughput was not considered as a reliable indicator in determining the merits of E-VAM rather recording the CQI reports was preferred instead. The results are presented below using cumulative distribution function (CDF) graphs of all the recorded CQIs in each sector during the period of the testing.

a) Sector 1

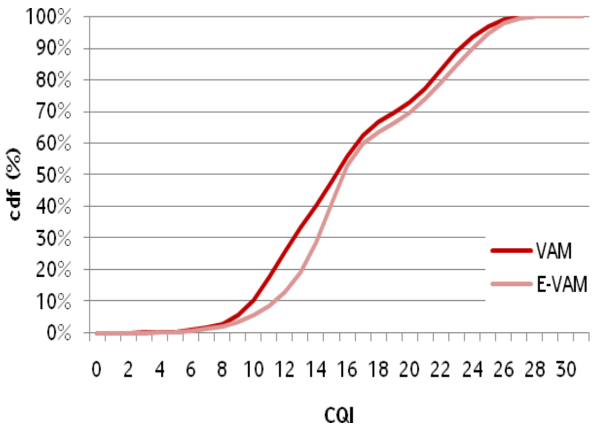

Figure 9. E-VAM in Vodafone Spain, Live Network, Sector 2

b) Sector 2

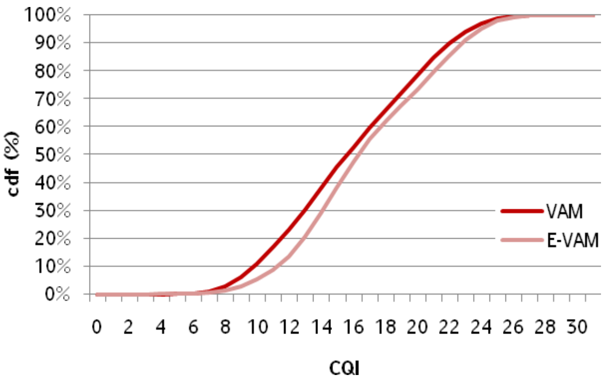

Figure 10. E-VAM in Vodafone Spain, Live Network, Sector 2

c) Sector 3

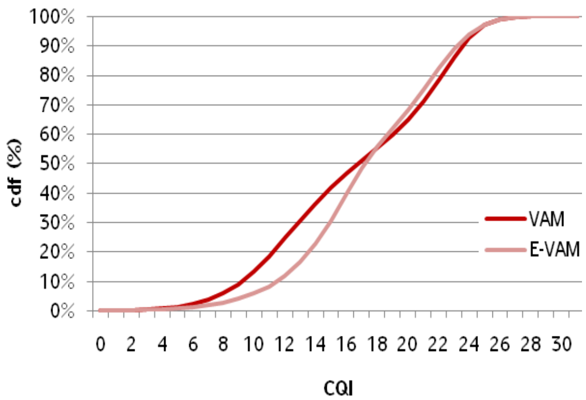

Figure 11. E-VAM in Vodafone Spain, Live Network, Sector 3

4) Live Network Testing Conclusions

Although it was not possible to distinguish between the CQIs reported by Type 2 or Type 3 HSDPA devices, the results obtained – albeit in one NodeB (3 sectors) - align with the results osbserved in the field trial: notable improvement in medium and bad radio conditions with less gain observed in good radio conditions.

It was observed that overall the activation of E-VAM resulted in gains in the order of 0.7>1 CQI units. Again, it is acknowledged that whilst this CQI calculation can vary – as mentioned previously in IV – it does serve as a reliable indicator showing that notable benefits were obtained particularly given that this is an improvement obtained via software (in cross polar antenna deployments).

VI. CONCLUSIONS

As dual PA NodeB deployment is becoming widespread there is an opportunity now to use E-VAM as an optimisation technique. Testing via field trial and live network testing showed that E-VAM provides gains in the order of 0.7>1 CQI units and E-VAM should be considered as a technique that has great potential to optimise performance

From a UE point of view, this is a fully backwards compatible technique and can be deployed irrespective of MIMO activation – in fact given that double PAs per sector is common and becoming the norm in WCDMA deployments, E-VAM can be considered a useful optimisation technique.

REFERENCES

[1] 3GPP TR 25.876 V7.0.0 (2007-03) Multiple Input Multiple Output in UTRA.

[2] Santiago Tenorio, Kyriakos Exadaktylos, Brendan McWilliams, Yannick Le Pézennec, “Mobile Broadband Field Network Performance with HSPA+”, European Wireless April 12 – 15, 2010, Lucca, Italy.

[3] RP-090625, “Dealing with UTRA single antenna UEs with transmit diversity”, Nokia Siemens Networks, Nokia Corporation, 3GPP TSG-RAN Plenary Meeting #44, Aruba, Netherlands, 26th – 29th May 2009

[4] R1-092745, “Performance evaluation of 2 TX antennas network”, Huawei, 3GPP TSG RAN WG1 Meeting #57bis, Los Angeles, USA, 29th June – 3rd July, 2009.

[5] William C.Y.Lee, Yu S. Yeh, “Polarization Diversity System for Mobile Radio”, IEEE Transactions on Communications, October 1972

[6] Santiago Tenorio, Yannick Le Pézennec, and Manuel Sierra, "3G HSDPA evolution: MIMO and 64QAM performance in macrocellular deployments" in Proc. European Wireless Conference 2008, Prague, Czech Republic, June 22-25. 2008, pp. 1-5.

[7] 3GPP TS 25.214 V6.11.0 (2006-12) Physical layer procedures (FDD)

[8] R1-095029, *HSDPA MIMO Codebook Restriction*, Ericsson,STEricsson, 3GPP TSG-RAN WG1 Meeting #59, Jeju, Korea, 9-13, November, 2009.