Evaluation of Control Channel Performance with Adaptive Radio Unit Activation in LTE

Pål Frenger(*), Havish Koorapaty(**), and Jiann-Ching Guey(**)
(*) Ericsson AB, Ericsson Research, Linkoping, Sweden; (**) Ericsson Research, San Jose, CA 95134, USA
{pal.frenger, havish.koorapaty, jiann-ching.guey}@ericsson.com

***Abstract*— *Link level performance results for physical antenna port muting in LTE are presented. In this paper we examine the block error rate performance of the LTE downlink control channels (PBCH, PCFICH, PDCCH, and the PHICH) for different antenna muting configurations. Also the throughput performance of the LTE downlink data channel (PDSCH) is studied for 2Tx and 4Tx transmit diversity formats. The results show that the combination of logical antenna port merging with physical antenna port muting provides a very minor performance loss. Since antenna muting should only be used when the traffic in a cell is low, this performance loss is not significant in practice. With antenna muting we can save energy by activating radio units only when motivated by the traffic load in the cell.*

Keywords: Energy Efficiency, Mobile Networks, Energy Consumption, Radio unit de-activation, antenna port muting, MIMO adaptation, 3GPP Long Term Evolution, LTE, EARTH.

I. INTRODUCTION

Reducing energy consumption in a radio base station brings many positive effects. Obviously the OPEX cost for the operator is decreased as the energy bill reduces. Also the CAPEX cost reduces since e.g. battery backup and cooling systems can be designed with more relaxed requirements. Cheaper components may become feasible to use, e.g. when battery backup does not need as high capacity it may be possible to select battery cells with acid-lead instead more expensive lithium-ion. When passive fans can be used for cooling instead of expensive air conditioning the cost is also decreased. Today there is a significant amount of new energy efficient base stations sold that are replacing old base stations. The return of investment (ROI) for such investments can be in the order of 2 years and this makes equipment swapping an attractive option for many operators, creating good business for vendors.

Lower RBS energy consumption creates less heat inside the cabinets which can enable a reduced RBS form factor. The fundamental limit on how much volume a base station need to have is set by the amount of heat that must be dissipated from it. There must be sufficient room for air flow and cooling fins around the hot components. Reducing energy consumption is thus the most important thing that enables compact and yet highly capable base stations. With reduced footprint finding new sites may become less problematic in some deployment scenarios.

For many operators energy is the most important key performance indicator (KPI). The amount of trouble tickets that are related to energy can be as high as 90% in some markets. Energy reliability is inversely proportional to the amount of energy that is needed, i.e. it is much easier to provide a small amount of energy with high reliability than a large amount. Lower energy consumption also means decreased CO_2 footprint for the operator, which is something that all operators today have made public commitments do work with.

A significant fraction of the energy consumption of mobile wireless networks occurs in Radio Base Stations (RBSs) which represent the largest number of nodes in the network. Each RBS may have multiple Radio Units (RUs) with each RU connected to a physical antenna to which a maximum amount of output power may be delivered. At higher powers, e.g., 20W, that are typical in macro-cellular networks, the power consumption of radio units can be quite high even when the RU is idle. For example, for a 3G RBS with 40 W output power, the RU power consumption with zero output radiated power can be in the order of 55% of the maximum. Therefore, one method for saving energy is based on adaptive activation of Radio Units (RUs) in a RBS based on the load in the network. The energy saving through this method was evaluated and found to result in 50% energy saving for a RBS that has 4 RUs per sector, each having a maximum transmit power of 10W [1]. The gain was about 30% for a RBS that has 2 RUs per sector with a maximum transmit power of 20W per RU. A more detailed system level examination is also found in [4].

The idea with adaptive radio unit activation, or antenna muting, is to avoid having to keep all RUs active when there is no or little traffic in a cell. Previous evaluations of energy savings from adaptive activation of RUs did not however consider the effect of such RU deactivation on control channel performance. The performance of control channels in a mobile network is crucial to the operation of the network in a robust manner. Thus it is very important to determine the performance of control channels and their impact on the operation of the system under an energy saving regime that actively turns off RUs based on load. This paper investigates the performance of key control channels in an LTE network when RUs are adaptively deactivated. The impact of the degraded performance of the control channels and their implications on system operation are then discussed. This leads to recommendations on how adaptive deactivation of RUs can be used in a mobile network while ensuring a robust operation of the system taking control channel performance into account.

Section II briefly reviews the main control channels in LTE and their role in the operation of an LTE network. Section III

978-1-4673-0990-5/12/$31.00 ©2012 IEEE

presents the performance of these LTE control channels when different numbers of RUs are deactivated and discusses the implications of the performance results and presents recommendations for operation of the network with adaptive activation of radio units. Section IV concludes the paper.

II. MODELS AND ASSUMPTIONS

A. LTE Control Channels

The key LTE control channels evaluated in this paper with RU deactivation are the Physical Downlink Control Channel (PDCCH), Physical Control Format Indicator Channel (PCFICH), Physical Hybrid-ARQ Indicator Channel (PHICH) and the Physical Broadcast Channel (PBCH). In addition, the performance of the Physical Downlink Shared Channel (PDSCH) is also investigated since it is used for sending some important control information.

An LTE base station that supports MIMO can have 2 or 4 transmit antennas per sector. When a cell has no traffic, even for as short duration as a few milliseconds, we would like de-activate radio units in order to reduce energy consumption. During low traffic there are also a lot of low rate services that can be handled perfectly well with only one radio unit (status updates, checking for emails, etc). However all antenna ports are needed for transmission of the system information. In order to read system information the UEs blindly decodes the PBCH to determine the number of antenna ports of the cell. The PBCH contains the master information block (MIB) while the rest of the system information is transmitted in system information blocks (SIBs) on the PDSCH. In order to retrieve the SIBs the UEs need to first decode the PCFICH to determine the size of the downlink control region. Then the UE need to find and decode the PDCCH inside the downlink control region which provides information on how to find and decode the PDSCH. To demodulate all these channels (PBCH, PCFICH, PDCCH, and PDSCH) the UE relies on cell specific reference signals (CRSs) that are transmitted from all antenna ports.

When there are no, or only little, traffic in a cell there might still be UEs reading the system information transmitted from the cell. Therefore, in order to ensure that radio unit de-activation works in practice we need to verify that all DL channels mentioned above continue to operate with acceptable performance.

B. Antenna port muting and antenna port merging

In order to de-activate a radio unit we can either simply de-activate radio units as shown in Figure 1a. This is equivalent to a constant fading on the muted physical antennas. Alternatively we can add (merge) the signals corresponding to the different logical antennas first and then mute all physical antennas except one, as shown in Figure 1b. This is equivalent to creating a channel where the correlation between the antennas equals 1. Combinations are also possible where we e.g. merge signals on antennas 0 and 1 while we mute signals on antennas 2 and 3.

The base-band processing required for muting and merging antenna ports can be expressed as an antenna pre-coder matrix operation. The normal operation mode is to use an identity matrix, i.e. [1,0,0,0; 0,1,0,0; 0,0,1,0; 0,0,0,1] as pre-coder matrix where each row corresponds to each physical antenna port while each column corresponds to each logical antenna port, or transmission layer. The antenna port muting operation in Figure 1a then corresponds to the pre-coder matrix [1,0,0,0; 0,0,0,0; 0,0,0,0; 0,0,0,0] while the antenna port merging operation in Figure 1b corresponds to [1,1,1,1; 0,0,0,0; 0,0,0,0; 0,0,0,0].

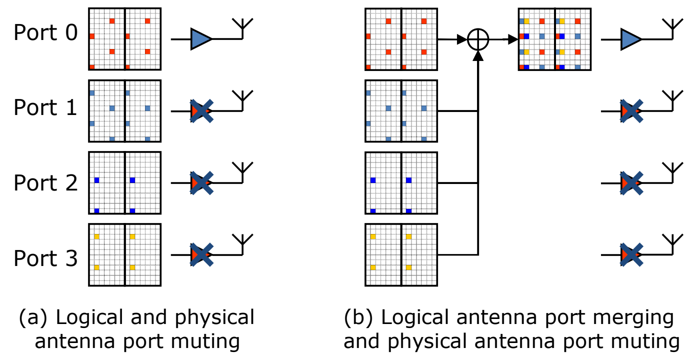

Figure 1: (a) Resource elements on muted radio units are not transmitted. (b) Merging logical antenna ports before muting radio units.

C. Evaluation assumptions

For the link level evaluations an LTE system with two or four transmit antennas is considered. The system is normally calibrated for transmitting with all available antenna ports, which is also the configuration used as reference when we examine different antenna muting alternatives. Some main parameters used in the simulator are listed in Table 1.

Table 1: Simulation parameters

Parameter	Value
Carrier Frequency	2.6 GHz
System bandwidth	5 MHz
Duplex	FDD
PDCCH coding (uncoded bits / coded bits)	20 / 72
PDSCH modulation	16-QAM (2×2) QPSK (4×2)
PDSCH coding rate	0.4385
Doppler spread	5 Hz
Transmission mode	LTE Tx-diversity
Channel model	Vehicular A

III. NUMERICAL RESULTS

A. 4x2 Results

In Figure 2 we show the PDSCH throughput versus SINR results for different antenna muting configurations. Compared to the reference case without antenna muting (circles) we see that muting only antenna port 3 provides an acceptable performance loss in the order of 3.5 dB (squares). When we mute antenna ports 2 and 3 (diamonds) and 3, 2, and 1 (triangles) the performance degrades much more. We also note that the performance of the merging and muting scheme (crosses) is only around 1 dB worse than the reference case.

One reason why the PDSCH performs so badly when we mute more than one antenna can be seen in Figure 3 which shows the PCFICH block error rate (BLER) as function of SINR. In order to correctly decode the PDSCH the mobile first need to determine the size of the downlink control region and this information is signaled on the PCFICH. If the mobile fails to decode the PCFICH then it will not find the PDCCH inside the control region and then it will not be able to decode the PDSCH. We note that the performance of the PCFICH is completely destroyed when muting antenna ports 1, 2, and 3 (triangles). When muting two antenna ports (ports 3 and 2) the performance loss is in the order of 7 dB (diamonds). The merging and muting scheme (crosses) performs only around 2.2 dB worse at BLER 10^{-2}. It is worth noting that there is a way to avoid decoding of the PCFICH. The master information block (MIB) that is signaled on the PBSCH carries information about the duration of the PHICH. The PHICH can either have extended or normal duration, and in case of a normal cyclic prefix an extended PHICH uses 3 OFDM symbols. Since the PHICH must be transmitted in the downlink control region the mobile knows that the downlink control region must equal 3 OFDM symbols in case the PHICH is "extended" and hence there is no need for the mobile to decode the PCFICH in that particular case.

In Figure 4 we show the performance of the PDCCH and here we also see a similar behavior as for the PHICH case. It is worth noting that the results in Figure 3 show the combined decoding performance of the PDCCH and the PHICH. If the PHICH goes wrong then the PDCCH will also go wrong. This could have been avoided by fixating the downlink control region size to 3 symbols by signaling an extended PHICH as discussed above.

In Figure 5 we show the PHICH BLER performance versus SINR. The PHICH signals ACK/NACK feedback related to the uplink HARQ processes. One could argue that antenna muting should not be used when there are active users in a cell and hance the antenna muting performance of the PHICH would not be interesting to show. However, since the PDSCH throughput curve for the merging and muting scheme in Figure 2 (crosses) is so close to the 4Tx reference case (circles) we believe that antenna muting may be used also when there are some low rate services ongoing in the cell, and for that reason it is important to verify that the PHICH performance is not severely degraded when antenna muting is applied. We see that PHICH performance is degraded by 1 dB and BLER 10^{-1} in the merging and muting case (crosses) which should be manageable.

B. 2x2 Results

The performance for two transmit and two receive antennas is shown in Figure 6 through Figure 10. In Figure 6 we examine the PBCH performance for the 2×2 antenna configuration and we note that the merging and muting configuration (crosses) outperforms all the other tested muting schemes. The performance degradation at BLER 10^{-2} is in the order of 2 dB. The other results in this sub-section are consistent with the 4×2 results shown in the previous sub-section. The main difference is that the results are more stable for the muting only configurations ([1 0;0 0] and [sqrt(2) 0;0 0]) compared to the corresponding 4Tx muting only configurations. Also for the 2×2 cases the merging and muting configuration performs well. In Figure 7 we observe a SNIR degradation of only around 0.7 dB for the [1 1;0 0] configuration compared to the reference normal mode configuration (circles). Results on BLER versus SINR for PCFICH, PDCCH, and PHICH are provided in Figure 8, Figure 9, and Figure 10 respectively.

IV. DISCUSSION AND CONCLUSIONS

The link level impact of adaptive radio-unit activation on the performance of some important control channels in LTE is evaluated in this paper. We note that the performance we obtain by first merging the different layers (or logical antenna ports) and then transmitting the composite signal from a single (physical) antenna port is sufficient for situations when the traffic in the cell is close to zero. By doing this we can obtain significant energy savings in the radio base station since this enables us to de-activate radio units that are not needed.

The antenna muting operation can be further improved by gradually re-mapping power between the physical antennas. The gradual re-mapping of power between the antenna-ports should then be coordinated with a modified scheduler behavior and/or a modified radio configuration. When operating in a muting mode the scheduler should limit the available transmission formats to the transmit diversity formats defined by the LTE standard. Multi-stream transmission and closed loop beam-forming makes little sense to use when only one physical antenna port is active. In addition the total scheduled power might need to be limited when operating in a muting mode. Since only one PA is active the available power is less in the muting modes than in the normal operation mode. This can be compensated by reducing the number of resource blocks that the scheduler can assign in each sub-frame.

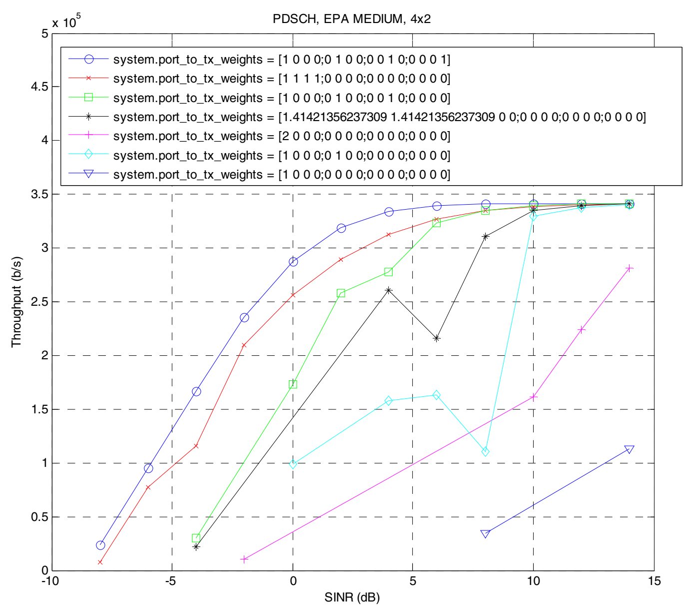

Figure 2: PDSCH throughput versus SINR, 4 Tx and 2 Rx antenna configuration.

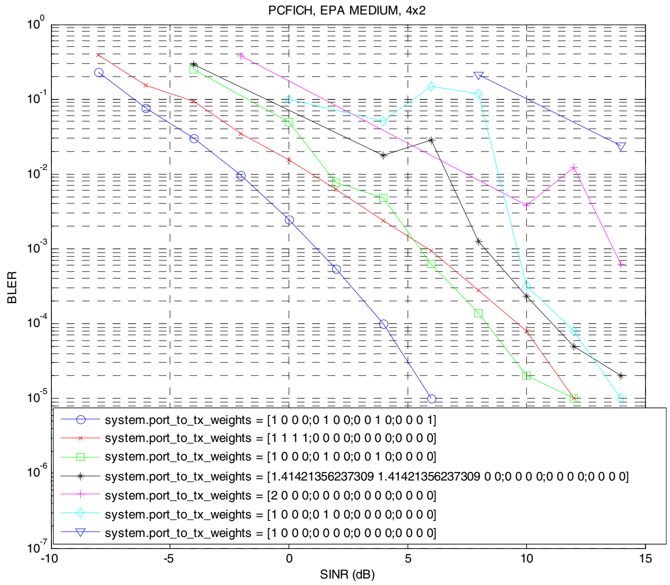

Figure 3: PCFICH BLER versus SINR, 4 Tx and 2 Rx antenna configuration.

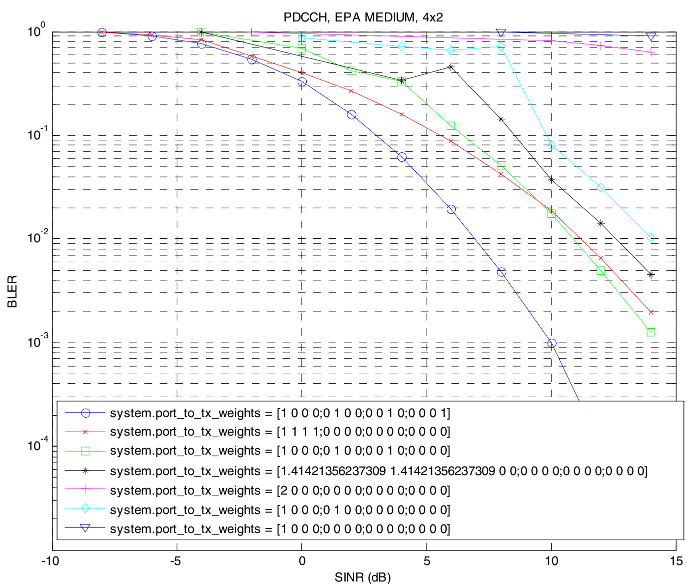

Figure 4: PDCCH BLER versus SINR, 4 Tx and 2 Rx antenna configuration.

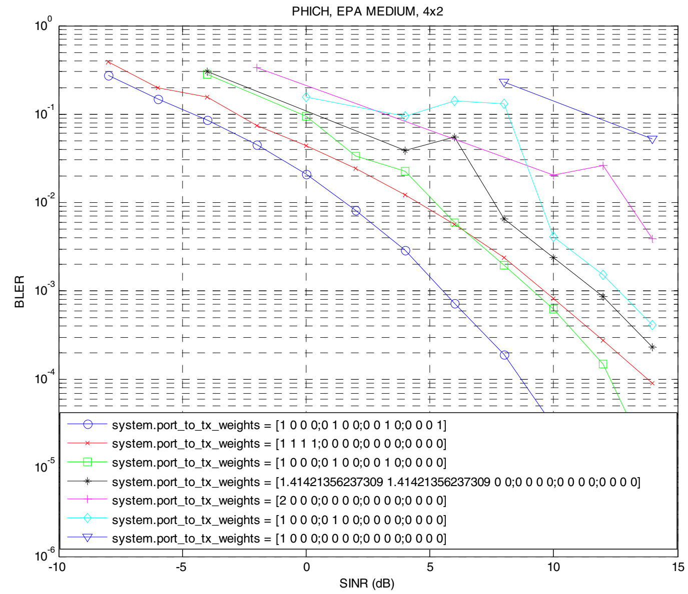

Figure 5: PHICH BLER versus SINR, 4 Tx and 2 Rx antenna configuration.

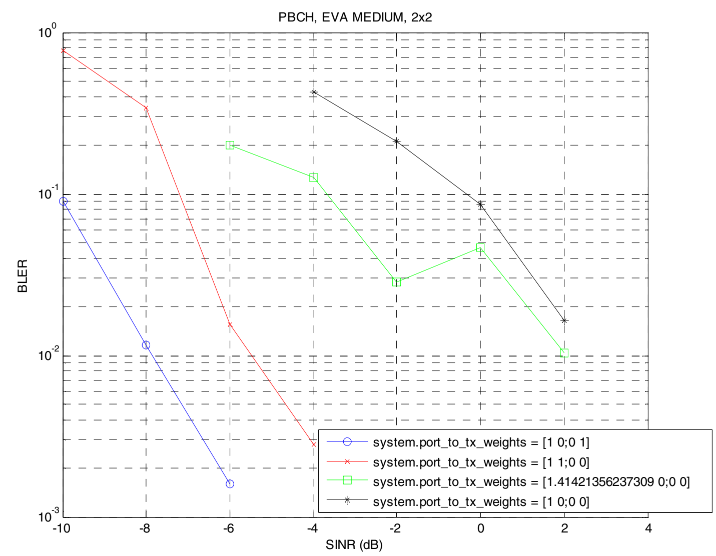

Figure 6: PBCH BLER versus SINR, 2 Tx and 2 Rx antenna configuration.

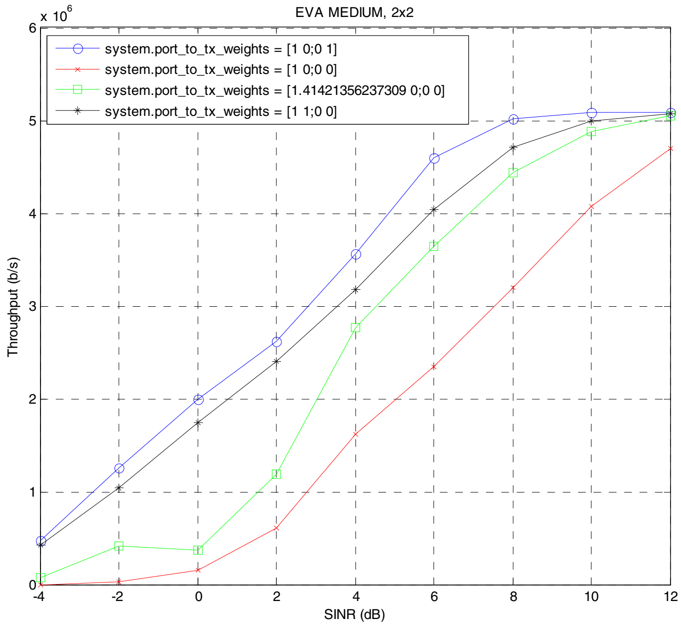

Figure 7: PDSCH throughput versus SINR, 2 Tx and 2 Rx antenna configuration.

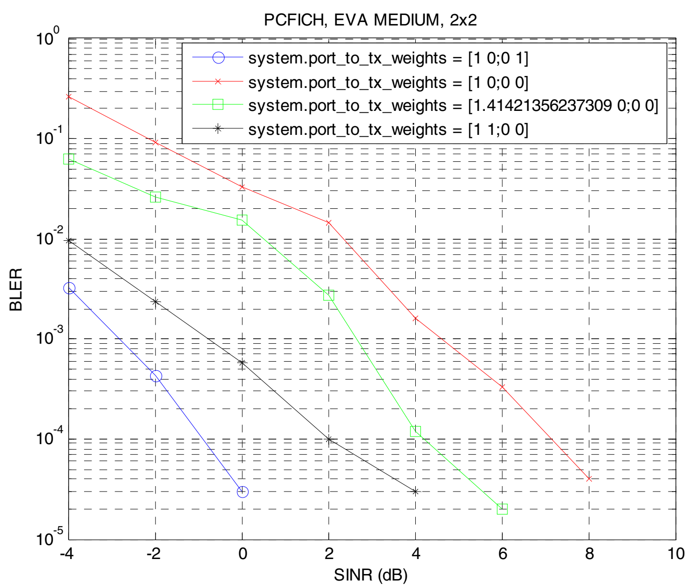

Figure 8: PCFICH BLER versus SINR, 2 Tx and 2 Rx antenna configuration.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 247733 – project EARTH.

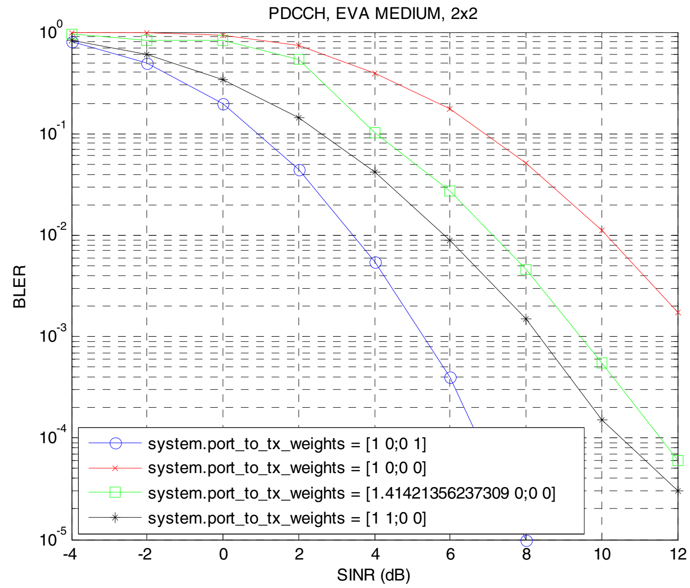

Figure 9: PDCCH BLER versus SINR, 2 Tx and 2 Rx antenna configuration.

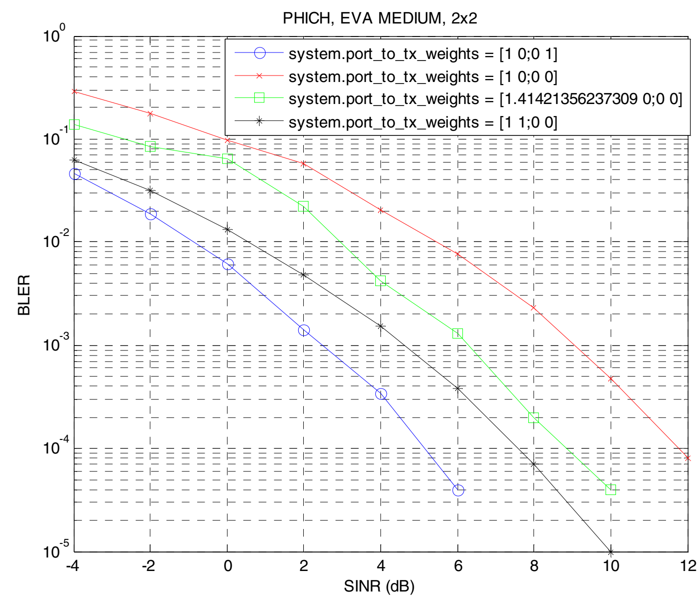

Figure 10: PHICH BLER versus SINR, 2 Tx and 2 Rx antenna configuration.

REFERENCES

[1] EARTH, www.ict-earth.eu

[2] M. Hedayati, M. Amirijoo, P. Frenger and J. Moe, "Reducing Energy Consumption Through Adaptation of Number of Active Radio Units", in Proc. *IEEE Vehicular Technology Conference*, Spring 2011.

[3] P. Frenger, P. Moberg, J. Malmodin, Y. Jading and I. Godor, "Reducing Energy Consumption in LTE with Cell DTX", in Proc. *IEEE Vehicular Technology Conference*, Spring 2011.

[4] P. Skillermark and P. Frenger, "Enhancing Energy Efficiency in LTE with antenna muting," in Proc. *IEEE Vehicular Technology Conference: VTC2012-Spring*, 6-9 May 2012, Yokohama, Japan.