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Title: EUTRA Uplink Macro-diversity
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1. Introduction

At the RAN1 Ad Hoc on LTE in Sophia Antipolis, some benefits of uplink macro-diversity (MD) and resource sharing (RS) (also referred to ‘muting’) were reported [2]. Such results indicating enhanced cell edge coverage and throughput are useful in determining whether the EUTRA/EUTRAN should support a macro-diversity and resource sharing capability. Of course other methods exist to improve cell edge coverage and throughput such as interference avoidance, HARQ, and the use of multiple antennas. This paper reviews the possible methods of enhancing inter-cell operation in terms of cell edge (or multi-cell coverage region) throughput along with uplink VoIP performance results for some of the key methods.

2. Cell Edge Performance Enhancement Techniques

Uplink cell edge throughput enhancement techniques may be needed to support the overall LTE requirements [3] and the goal of a competitive 3GPP long term evolution. Such uplink cell edge enhancement techniques should support or meet the following requirements.

UL cell edge requirements:

- Enable peak data rates of 50 Mbps for 20 MHz (5 bps/Hz)
- Increase the uplink bit rate at the cell edge (2 to 3 times Release 6)
- Improve the uplink spectrum efficiency (2 to 3 times Release 6)
- Reasonable system and terminal complexity, cost, and power consumption

Various cell edge performance enhancement methods exist and should be considered alone or in combination in light of the above requirements.

UL cell edge enhancement methods beyond hard handoff (HHO):

- Interference avoidance
- Macro-diversity
- UL Resource sharing (also referred to as ‘muting’)
- HARQ with soft combining (delay tradeoff – suitable to guarantee minimum data rate)
- Intra-cell soft combining
- SDMA (or spatial diversity with more than 2 BS receive antennas)
- UL MIMO
- HHO with fast cell selection (risk of resource allocation inefficiency)

3. Macro-diversity (MD) and Resource Sharing (RS)

To facilitate uplink operation in locations near cell boundaries, MD and uplink RS can be exploited. With MD, a non-serving base-station (BS) (termed the secondary BS here) may make provision for a particular time-frequency slot is to receive a transmitting UE (termed the ‘target’ UE here) that is

controlled (i.e. scheduled) by another BS – termed the primary BS. If this secondary BS is within the same site as the UE's primary BS, soft-combining can be used to increase the uplink (UL) SNR; otherwise, inter-site selection diversity (i.e. macro-diversity) is available to increase the chance of a successful decoding. If the secondary BS also does not schedule another UE during the same time-frequency slot that it is receiving the target UE then it has suppressed other UE transmission or in other words performed RS thus allowing a further SNR improvement for the target UE due to reduced interference.

Note that RS does not guarantee an overall uplink performance improvement since there is a net reduction in the time-frequency resources of a secondary cell performing RS to support a UE scheduled by another (primary) cell. Such a net resource reduction means that the cell must schedule users at a higher data rate and/or modulation resulting in more HARQ retransmissions or at lower data rates to sustain the same retransmission rate. Either way there is a trade-off affecting spectral efficiency.

It is beyond the scope of this paper (and RAN WG1) to explore the difficulties of selecting the secondary BS and coordinating the schedulers of the primary and secondary BS for a given UE in support of RS and MD. Obviously direct inter-BS communication or BS communications via a centralized RNC entity are possible methods to address such coordination where each method has its own network architecture implication. Communication may also be possible through the UE itself (e.g., via RACH messaging), at the cost of increased OTA signalling and possibly delay.

1. **Macro-diversity + Resource Sharing (RS)**: the secondary BS (or BS's) will not schedule any UE in the specified time-frequency resource but rather receive the target UE at the specified time-frequency slots, as specified (e.g.) by the RNC (or other network edge node). If the secondary BS is at *the same site* as the primary BS, soft-combining may be used; otherwise inter-site selection diversity is applied. Note that in the case of co-located primary and secondary cells, signalling via the RNC is not required.
2. **Macro-diversity only**: similar to case 1 (at least signalling wise) but secondary BS can still schedule another UE in the specified time-frequency slots and try to decode both its scheduled UE and the target UE at the same time, even though there may be mutual interference. Therefore, the handover BS must have the ability to suppress interference from UE's other than the target UE, either using spatial interference suppression or multi-user detection or scheduling its UE appropriately.
3. **Resource Sharing only**: the secondary BS knows the time-frequency slots that the target UE will use, and it will not schedule UE's in its regime to use the same resources. However, the secondary BS will not attempt to receive the target UE.
4. **Intra-site macro-diversity + RS**: it is similar to macro-diversity + RS case, but only if the secondary BS belongs to the same cell site as the primary BS (co-located primary and secondary cells). Inter-sector soft-combining will be used to increase the SNR. No inter-site macro-diversity (e.g., selection diversity) is performed but only HHO.
5. **Intra-site macro-diversity only**: similar to case 3, but along with soft-combining MUD may be required to exploit intra-cell macro-diversity when the adjacent cell schedulers (co-located primary and secondary cell schedulers) each assign a different UE for the chosen time+frequency resource.
6. **Hard Handover**: the UE's signals will always be decoded only by its scheduling BS. Fast cell selection can be used at the risk of leaving resources unused.

When the uplink is not fully loaded during a frame (i.e., some time-frequency resources are not assigned to users in the sector), the remaining resources can be reserved via the RS procedure for users

in other sectors/sites that would not normally *require* handoff. Such users may almost be in handoff conditions, or be close to a sector/site boundary. These users would benefit from the selection (inter-site) or combining diversity (inter-sector), and scheduling (rate determination) in the system may be improved by providing a more uniform interference level.

4. Interference avoidance & HARQ

Alternatives to macro-diversity with RS to improve uplink inter-cell (cell edge) performance are HARQ retransmissions with some trade-off in delay and interference avoidance requiring some a-priori coordination between BS schedulers. For example, the *secondary BS might schedule UE's for transmission which are a) close to the secondary BS and therefore offering reduced interference to primary BS, or b) operating at low coding rates and modulation orders and hence radiating low power levels.* Difficulties are to make sure that separate resources supporting interference avoidance are fully utilized. This also may applied in the macro-diversity only case where RS is not applied, such that the coordination has the multiple BTS place users generating less interference in the overlapping resources.

5. Performance

Coverage and throughput results are given for different techniques that handle UEs operating in inter-cell or intra-cell multi-coverage areas (i.e. cell edge operation). The techniques are:

- a) HHO,
- b) HHO + intra-cell MD -- HHO with intra-cell macro-diversity (no RS or inter-cell MD),
- c) MD -- inter-cell and intra-cell macro-diversity (no RS),
- d) MD + RS -- inter-cell and intra-cell macro-diversity with RS.

All techniques employ PF frequency non-selective (TDM) scheduling and HARQ with IR. The time frequency resource consisting of at least one or more DFT-SOFDM symbols is allocated to each scheduled UE. The 1.25MHz bandwidth option (75 sub-carriers per DFT-SOFDM symbol with 5 of 7 DFT-SOFDM symbols available for data) with the same numerology as the baseline DL OFDM numerology [1] (15kHz sub-carrier spacing and 0.5ms sub-frame size) agreed to at the RAN WG1 Ad hoc on LTE in Sophia Antipolis. The UL cell layout and other simulation assumptions are as described in [1,4] and in Tables 2 and 3.

Figure 1 and 2 show user residual FER CDF for a loading of 50 and 100 VoIP UEs/sector. Residual FER refers to voice packets that were dropped either due to excess delay (not received successfully in time) or the maximum allowed transmissions were reached.

With regard to MD we account for signalling and coordination delays by not always picking the scheduling cell to be the best serving cell but by allowing any cell to be the scheduling cell with received pilot SNR that falls within a 3dB (or 6dB) window relative to the best cells pilot SNR. Any other cells within the 3dB (or 6dB) window contribute to MD. With regard to HHO we do not always connect UEs to the best serving cell but to any one of the cells within the 3dB (or 6dB) window for the simulation duration of that Monte Carlo drop.

For RS up to N symbols are allowed for each cell for sharing. Simulations were done for N=1, 2 or 3 where the best results were seen for N=2 (see Figure 1).

Residual FER CDFs for different uplink performance enhancement schemes given VoIP traffic are shown in Figure 1 and 2 and summarized in Table 1 below. For the 50 VoIP UEs/sector load, the MD case improves 1% residual FER CDF from 99.0% to 99.7% compared to HHO with the MD+RS (single symbol) case only achieving marginal improvement over MD (note single antenna receiver case shows more improvement for MD+RS over MD). However, by increasing delay resulting in more HARQ transmissions (from 4 to 10) then the HHO case was improved beyond the MD and MD+RS cases.

Table 1 – Residual FER CDF performance

UL Enhancement technique	50 VoIP UE/sector 1% Residual FER CDF point	100 VoIP UE/sector 1% Residual FER CDF point
HHO (up to 4 tx/packet)	99.0%	98.3%
MD 2cells* (up to 4tx/packet)	99.7%	99.6%
MD + RS 2cells (up to 4tx/packet)	99.8%	99.7%
HHO (up to 10 tx/packet)	100.0%	100.0%

* ‘2 cells’ indicates that any two cells with DL pilot SNR within 6dB of best cell are randomly selected as the MD cells

6. Conclusion

For the same delay constraint MD and MD+RS improve residual FER for VoIP compared to HHO.

However, by a very marginal increase of delay (12 ms) to allow for an increase in the maximum number of HARQ retransmissions allowed, the residual FER for HHO **is improved** beyond that of MD and MD+RS using the tighter delay constraint. In addition, the amount of inter-cell communications required to support different MD and MD+RS algorithms should carefully be considered, since some of the benefit of improved UL system performance can come from other UL enhancement sources requiring less communication such as:

- 1) Using HARQ to trade off delay for more capacity/coverage (better residual FER in VoIP case).
- 2) Interference avoidance
- 3) Increase number of Node-B receive antennas beyond 2.

References

- [1] 3GPP TR 25.814 V0.1.1 (2005-05), “Physical Layer Aspects for Evolved UTRA.”
- [2] 3GPP, R1-050624, Ericsson, “On Macro Diversity for E-UTRA.”
- [3] 3GPP TR 25.913 v2.10 (2005-05), “Requirements for Evolved UTRA and UTRAN.”
- [4] 3GPP, R1-050680, Motorola, “Text Proposal: Simulation Assumptions and Evaluation for EUTRA.”

50 VoIP UEs/sector:

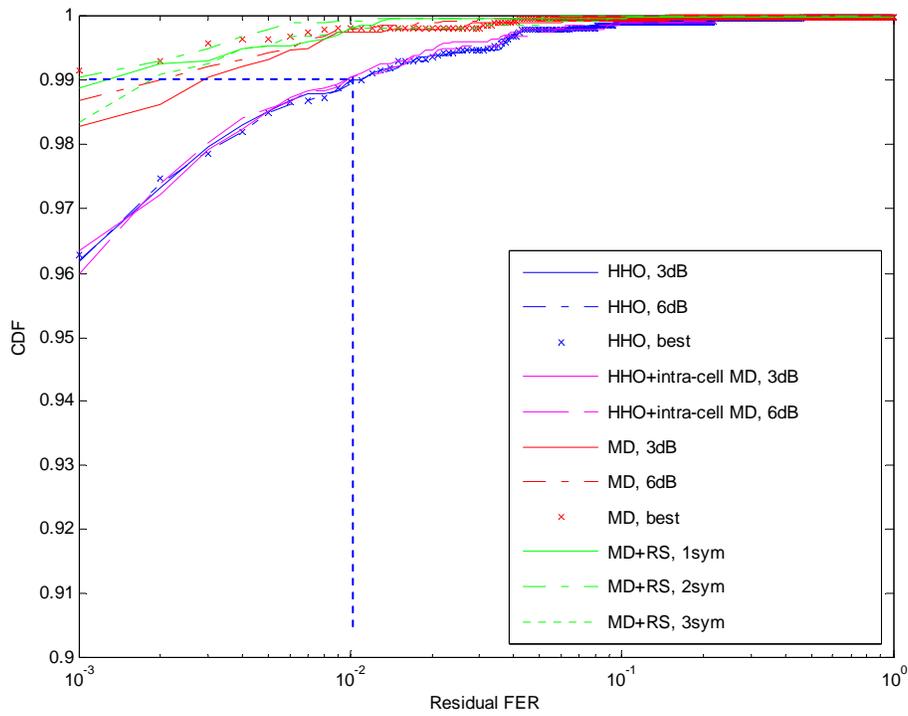
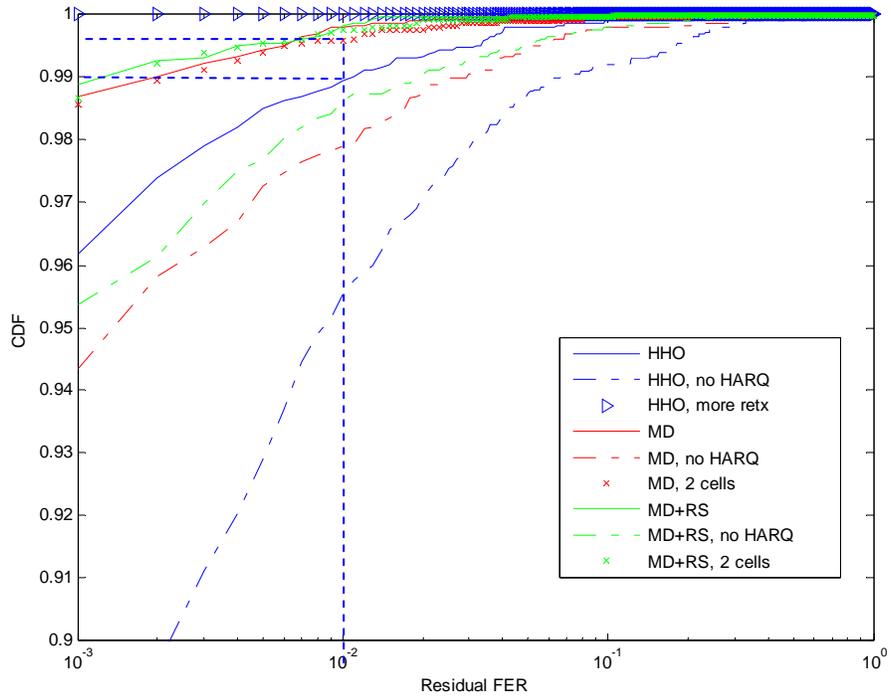


Figure 1 – Residual FER CDF for different multi-coverage techniques (50 VoIP/sector)

100 VoIP UEs/sector:

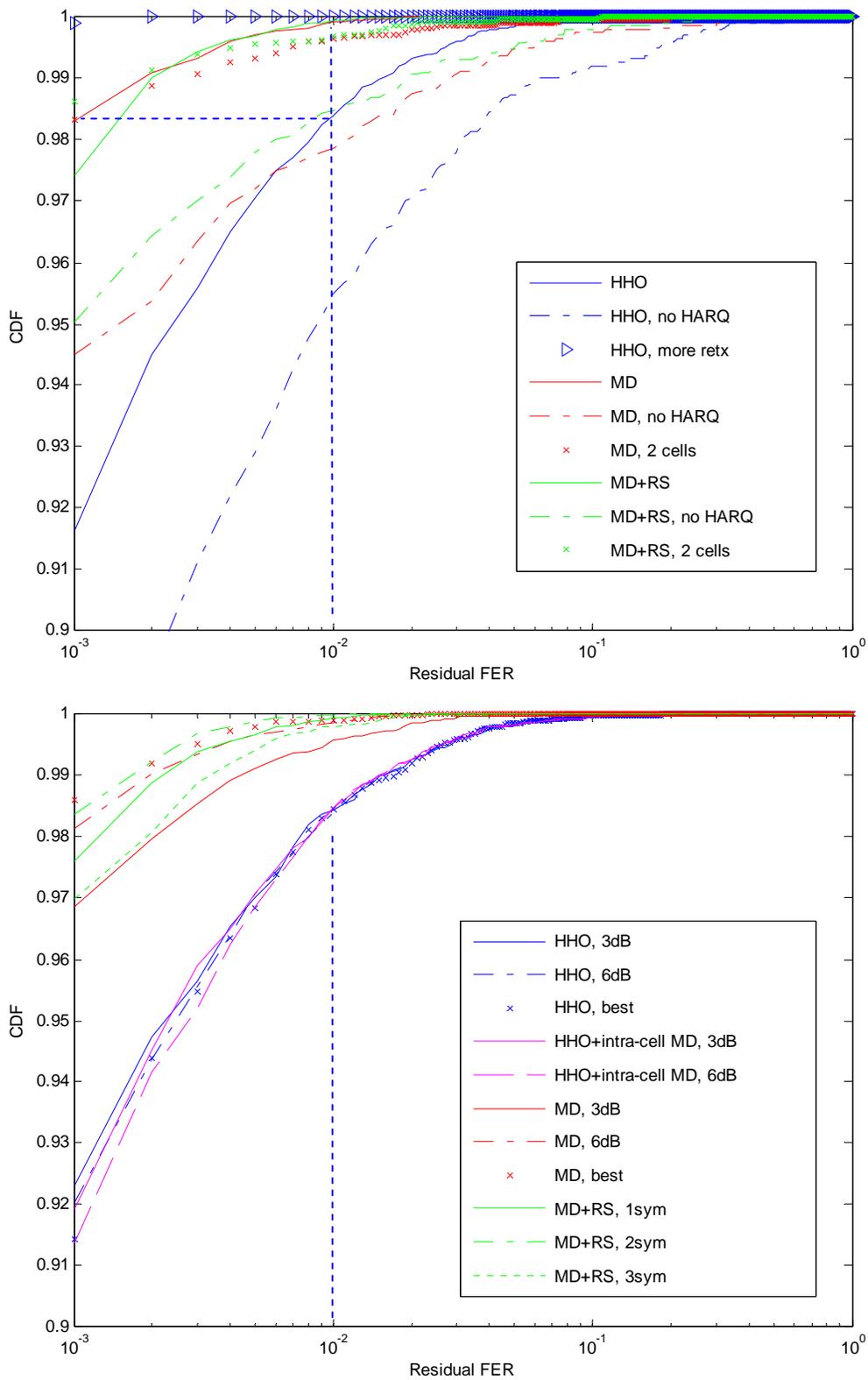


Figure 2 – Residual FER CDF for different multi-coverage techniques (100 VoIP/sector)

Table 2 – Macro-cell system simulation baseline parameters

Parameter		Assumption
Cellular Layout		Hexagonal grid, 19 cell sites, 3 sectors per site
Inter-site distance		1000m
Distance-dependent path loss		$L=120.9 + 37.6\log_{10}(.R)$, R in kilometers
Lognormal Shadowing		Similar to UMTS 30.03, B 1.41.4
Shadowing standard deviation		8 dB
Correlation distance of Shadowing		50 m (See D,4 in UMTS 30.03)
Shadowing correlation	Between cells	0.5
	Between sectors	1.0
Penetration Loss		10 dB
Antenna pattern (horizontal) (For 3-sector cell sites with fixed antenna patterns)		$A(\theta) = -\min \left[12 \left(\frac{\theta}{\theta_{3dB}} \right)^2, A_m \right]$ $\theta_{3dB} = 70 \text{ degrees}, A_m = 20 \text{ dB}$
Carrier Frequency / Bandwidth		900MHz / 1.25MHz
Channel model		Typical Urban (TU)
UE speeds of interest		3km/h
Total BS TX power (Ptotal)		43dBm
UE power class		24dBm (250mW)
Inter-cell Interference modelling		UL: Explicit modelling (all cells occupied by UEs),
Antenna Bore-sight points toward flat side of cell (for 3-sector sites with fixed antenna patterns)		
Users dropped uniformly in entire cell		
Minimum distance between UE and cell		≥ 35 meters

Table 3 – Other Simulation conditions

Simulation method	UL EUTRA System simulation - with wraparound
AMC	ON (any MCS with $0.4 < \text{MPR} < 4.5$) MPR = modulation x encoding rate
HARQ	On (IR)
Antenna Diversity	Yes (2 antennas)
Receiver	DFT-SOFDM/IFDMA/OFDMA (integer #DFT-SOFDM symbols allocated per user)
Channel-dependent scheduling	PF: Frequency Non-selective (TDM) Each user assigned some number of DFT-SOFDM symbols per 0.5ms subframe based on ideal uplink CQI estimate
Evaluation method	CDF of user residual FER
User Bandwidth	1.25 Mhz
Traffic Model	VoIP - 256 bit voice packets (inc headers) generated every 20ms - average voice activity of 0.30 and no SID equivalent - 2 state Markov speech source model
Power Control	Off
Link Mapping	EESM