Downlink B3G MIMO OFDMA Link and System Level Performance

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***Abstract*— This paper provides a link and system level study of the downlink in a B3G system using MIMO OFDMA techniques. A 3GPP/LTE-like scenario, in terms of frame structure and system main parameters, is considered in this study. At the link level, the double Alamouti MIMO scheme is studied and the performances of various Modulation and Coding Schemes (MCS) are provided. The impact of real MIMO channel estimation (including RF impairments, CFO compensation and Automatic Gain Control AGC) on the MCSs link performance is also presented. System level study is thus carried out to assess the performance of the downlink OFDMA in terms of coverage and cell throughput. Several scheduling disciplines and MIMO schemes are investigated and the impact of the spatial diversity on the cell throughput is provided. This study has been carried out in the scope of the French RNRT OPUS project.**

I. INTRODUCTION

The Third Generation Partnership Project (3GPP) is currently normalizing the Long Term Evolution (LTE) of the third generation (3G) cellular system [1]. A first release is expected by end of 2007. This paper is focusing on LTE downlink (DL). DL LTE targets are challenging: a 100 Mb/s peak data rate in 20 MHz spectrum allocation, an average user throughput per MHz multiplied by 3-4, a cell-edge user throughput per MHz multiplied by 2-3 and a spectrum efficiency multiplied by 3-4 compared to 3GPP Release 6 HSDPA (High Speed Downlink Packet Access). These targets must be held at low speed (up to 15 km/h) and for 5 km coverage. Nevertheless, the system must also work for high speeds (350 km/h) and very large ranges (100 km). In addition, in order to cope with spectrum fragmentation, the spectrum allocation of the system is flexible. Finally, attention is also given to reduction of latency and increase of the number of active users per cell.

The DL LTE air interface is based on orthogonal frequency division multiple access (OFDMA), which offers good flexibility and performance for a reasonable complexity. The users of a same cell are multiplexed in frequency, each user's data being transmitted on a subset of the sub-carriers of an orthogonal frequency division multiplexing (OFDM) symbol. Depending on its speed and the reliability of its channel quality indicator (CQI), a user may be allocated either a subset of sub-carriers scattered over the whole bandwidth (distributed user) or a subset of adjacent sub-carriers (localized user). Distributed users experience randomized interference as the interference level varies in frequency whereas localized users experience high signal to interference plus noise ratio (SINR) thanks to channel-dependent frequency scheduling based on CQI. Thus, proper resource allocation is able to mitigate the impact of inter-cell interference. In order to achieve the challenging spectral efficiency and user throughput targets, multiple antenna schemes, turbo coding and fast link adaptation are also included in the specifications.

The LTE-like link level and system level studies presented in this paper have been carried out in the framework of the French RNRT OPUS project. The OPUS project is aiming at validating by experimental results the feasibility of the 5 bit/s/Hz spectral efficiency corresponding to the peak data rate. In addition to link and system level studies, a multiple-input multiple-output (MIMO) prototype has been developed including base band, RF and MAC (Medium Access Control) layer in order to validate the resource allocation mechanisms in a multi-cellular LTE-like context.

The paper is organized as follows. Section II presents a detailed description of the LTE-like system with the main parameters, section III and section IV give the link level performance and the system level performance respectively. Conclusion and perspectives are finally given in section V.

II. SYSTEM DESCRIPTION

A. *Description of the LTE-like transmission chain*

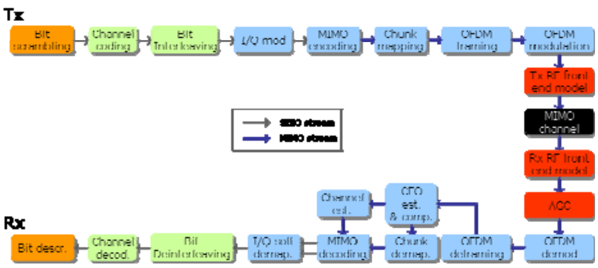


Figure 1: Block diagram of the transmission chain.

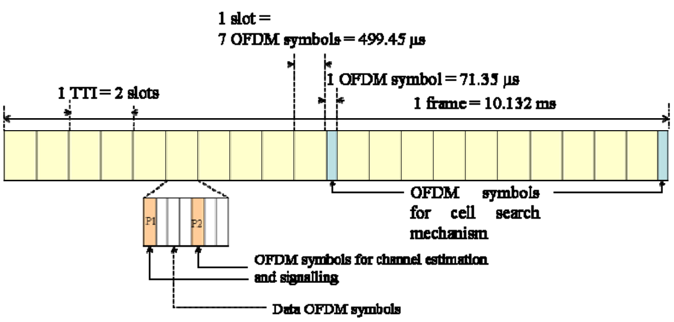
The block diagram of the complete LTE-like transmission chain is depicted in Figure 1. Firstly, information bits of each user are scrambled with a pseudo-random sequence in order to avoid long series of '0' or '1' at the input of the channel encoder. Duo-binary convolutional turbo coding with mother code rate equal to 1/2 is then performed on the scrambled bits, using two quaternary recursive systematic 8-state convolutional codes. Channel coding is performed on a Time Transmission Interval (TTI) basis. The advantage of using non binary codes is that the complexity per decoded bit with the duo-binary 8-state trellis is 35% lower than with the binary one, while achieving the same performance. Then the coded bits are interleaved on a TTI basis to take benefits from the channel diversity, and modulated into QAM complex symbols. QPSK, 16-QAM and 64-QAM are considered in the studies. MIMO encoding is performed afterwards in order to exploit the spatial diversity of the channel. At the link level, the double Alamouti MIMO scheme is considered whereas several MIMO schemes are studied at the system level.

The resulting data blocks are allocated on the physical resource block(s) (PRB) selected by the MAC layer, where a PRB is defined as N_{symb}^{DL} consecutive OFDM symbols in the time domain and N_{sc}^{RB} consecutive sub-carriers in the frequency domain. Both block-wise transmission (localized) and transmission on non-consecutive (distributed) sub-carriers are supported as a mean to maximize frequency diversity. In the localized mode, the logical resource block is directly mapped onto the PRBs, and the order of the logical carriers is the same as the one of the physical carriers. In the distributed mode, the logical carriers are mapped onto the PRBs in a distributed manner, with a predefined rule aiming at maximizing the distance between two consecutive physical carriers for one user.

The resulting signals of each user are multiplexed and reference symbols are added. After the frequency/time transposition with the IFFT, a cyclic prefix is inserted as a Guard Interval (GI) that prevents from inter-symbol interference. The transmitted signal is then convoluted by the MIMO channel and the resulting signal is corrupted by a complex additive white Gaussian noise.

Impairments caused by RF front-end processing were analyzed and measured for the RF front-end specifically designed for the purposes of the RNRT OPUS project. RF impairments are modelled in the simulation chain in order to assess the degradation they may cause and to evaluate the necessity for their potential compensation. For that purpose, phase noise (PHN) from the intermediate frequency IF (38.4 MHz) to the RF (2.5 GHz) at transmitter and vice-versa at the receiver were modelled, as well as the carrier frequency offset (CFO) between the transmitter and receiver local oscillators. An Automatic Gain Control (AGC) module that maintains the level of the input signal at some nearly constant mean power value follows RF impairments.

Then, the signals from the two antennas are transposed in the frequency domain thanks to the FFT, after GI removal. The estimation of the CFO is based on the complex correlation between the replicas of a same pilot symbol for each receive antenna. Both data and pilot symbols are then compensated prior to the channel estimation processing, which is performed according to the following steps. First, the observed pilot symbols on each receive antenna are correlated with the training sequences of all transmit antennas. Then, a Wiener filtering in the frequency domain is applied for each Tx/Rx pair, in order to interpolate the channel coefficients on the whole bandwidth. Eventually, channel estimation is refined thanks to a linear interpolation in the time domain. The two data streams of a user are applied at the input of the MIMO decoder, which estimates the QAM symbols thanks to the channel estimates. These two streams interfere with each other and the interference is encountered by the space-time combiner based on minimum mean square error (MMSE) criterion. Finally, a specific module computes the Log-Likelihood Ratios (LLRs) and Max-Log-MAP based channel decoding is performed to recover the transmitted information bits.



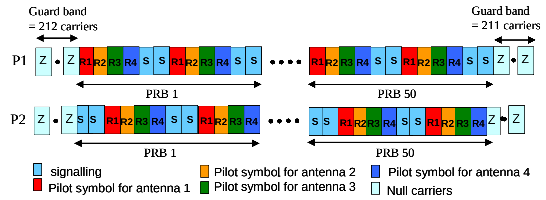


Figure 2: Frame structure.

B. *Overview of the LTE-like frame structure*

In the following, the frame structure of the OPUS system, which is mainly derived from [6], is described. As shown in Figure 2, the frame is divided into 20 slots, where each slot is composed of N_{symb}^{DL} =7 OFDM symbols. Each user is allocated consecutive PRBs in two consecutive slots, i.e. the TTI equals 1 ms. The frame is of 10.32 ms including the synchronization symbols. We consider a bandwidth of 10 MHz, which leads to 50 PRBs of N_{sc}^{RB} =12 carriers (180 kHz). Two additional OFDM symbols are inserted in this frame, in order to perform the cell search mechanism through hierarchical synchronization channels (SCH). This mechanism includes fine time/coarse frequency synchronizations and identification of the cell. The first and fifth OFDM symbols of each slot are devoted to pilot symbols for channel estimation and signalling. Pilot symbols for each transmit antennas are multiplexed in the frequency domain.

III. LINK LEVEL PERFORMANCE

To assess the performance of the LTE downlink, link level simulations are conducted in various scenarios and for two different mobile speeds (3 or 120 km/h). The channel used in the simulation is the SCME (Space Channel Model Extension) channel model in [2] and [3] that corresponds to the SCM-B channel typical of the "Urban Macro with low spread" and close to the well known "Typical urban" environment. Two modes of RBs mapping are considered: localized and distributed. Due to page limit, the performance results depicted in figures 3 to 6 consider three MCSs only: QPSK 1/2, 16QAM 2/3 and 64QAM 3/4 with perfect and real channel estimation. The link level performance with real channel estimation provided in this section includes RF impairments, CFO compensation and AGC. The MIMO scheme considered in this section is the Double Alamouti (4x2) that combines the robustness of the Alamouti coding [5] with rate doubling ability. Data are separated in two streams, each one using the Alamouti space-time block coding principle on a pair of antennas. In order to allow a better granularity, each transmitted stream can have a different MCS on the same resource block. Note that the performance study conducted in this paper is not limited to the case of Double Alamouti. In the next section, system level performances of various MIMO schemes are depicted in figures 7 to 11.

Figures 3 and 4 show that real channel estimation results in a degradation of 2 dB of the QPSK 1/2 scheme performances, and this for various mobile speeds and for both distributed and localized RB mapping modes. This impact is of 2 dB for 16QAM 2/3 and 3 dB for 64QAM 3/4 at 3 km/h as one can see in figures 5 and 6. Figure 6 shows also that the performance of 64QAM 3/4 degrades drastically especially in the case of real channel estimation at 120 km/h. Furthermore, figures 3-4-5 show that performances obtained with the distributed mode are 5 dB better than the ones obtained with the localized mode in the QPSK case and 10 dB better in the 16-QAM mode, when considering 1 RB per codeword. This difference is due to the fact that we do not consider frequency-dependent scheduling in this section. The results obtained with 10 RBs in the localized mode are not shown here because this mode achieves same performances as the ones obtained in the distributed mode. Additional performance results, not shown here due to space limitation, have shown that degradation due to

PHN and AGC is almost negligible. Only CFO requires compensation. In addition, we can note that the channel estimation method is robust whatever the MCS.

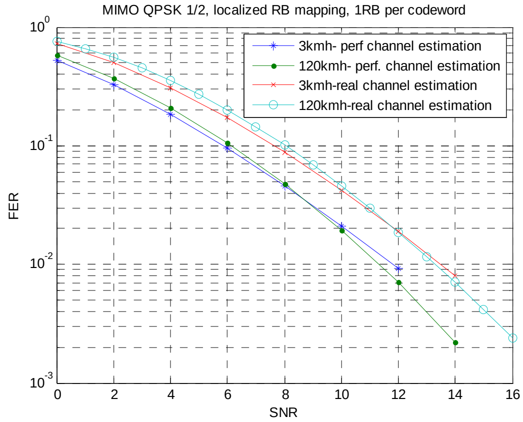


Figure 3: Performance of MIMO QPSK 1/2, localized mode, mobile speed 3 and 120 km/h, with perfect/real channel estimation.

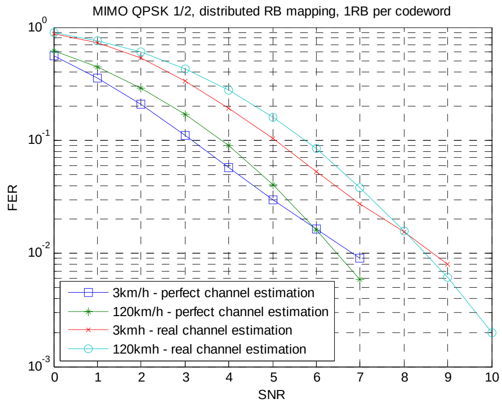


Figure 4: Performance of MIMO QPSK 1/2, distributed mode, mobile speed 3 and 120 km/h, with perfect/real channel estimation.

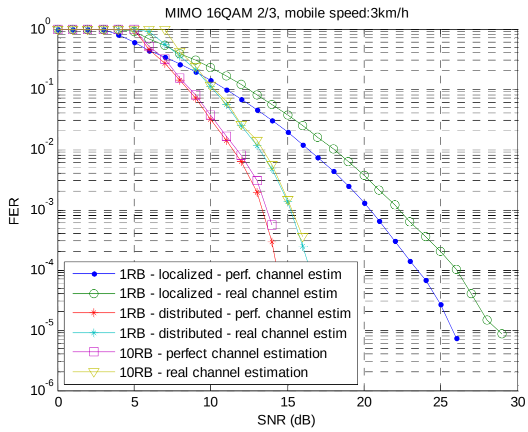


Figure 5: Performance of MIMO 16QAM 2/3, localized/distributed mode, 1 or 10 RBs per user, with perfect/real channel estimation.

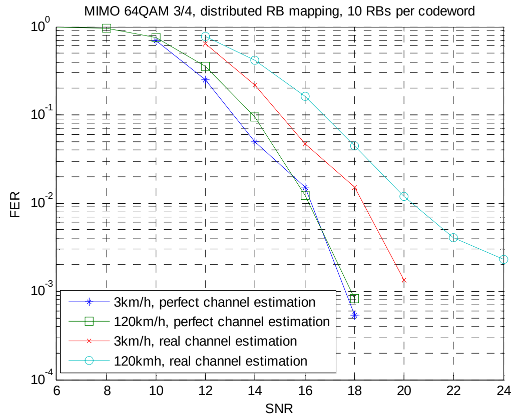


Figure 6: Performance of MIMO 64QAM 3/4, distributed mode, mobile speed 3 and 120 km/h, with perfect/real channel estimation.

IV. System level performance

In this initial system level study, we have focused our analysis on orthogonal MIMO schemes and compared them with the single-input single-output (SISO) context. The purpose of this type of MIMO schemes is not to increase the spectral efficiency but to improve the link condition. Thus, results will be constrained by the link layer performance.

The considered orthogonal MIMO schemes are:

- 2x1 Space Frequency Transmit Diversity (SFTD) Alamouti
- 1x2 Receiver Diversity (RxDiv)
- 2x2 SFTD and RxDiv
- 2x2 Transmit (Tx) Antenna selection and RxDiv

Before giving the performance results, we first introduce the methodology and the main parameters of the simulation.

A Look Up Table (LUT) is used for modelling the physical layer behaviour since simulating the full physical layer functionalities is unfeasible. A link to system (L2S) interface is used in order to faithfully reflect the impact of the instantaneous channel condition on the received codeword. For OFDM access technique, coded data symbols are sent over different sub-carriers. Thus, they experience different channel conditions. In order to reflect this issue, the L2S must take into account the channel frequency variation. This is done through EESM (*Effective Exponential Snr Mapping*) methodology as proposed initially in [4]. EESM method allows mapping the channel decoding performance under any channel condition, reflected by its instantaneous frequency response, onto its performance under AWGN channel. This mapping depends on the used MCS: i.e. the used modulation, the channel coding rate and the channel coding block size. A calibration procedure is done in order to adjust a variable value, usually called β, required for the EESM model. Table 1 summarizes EESM calibration variable values. The calibration was done by minimizing the mean square error (MSE) between the AWGN curve and the calibrated points.

For this study, only seven MCS have been considered for system performance evaluation.

Two kinds of allocation strategy have been considered:

- Frequency Adaptive Scheduling (FAS): every chunk's link quality is available at the transmission side.
- Non Adaptive Frequency Scheduling (nAFS): only channel quality on the entire bandwidth is available. In this case, chunk allocation is done in a round robin fashion.

The simulated traffic is a full queue buffer: users have always data waiting for transmission.

Two different schedulers are simulated: MaxC/I scheduler and time Proportional Fair (PF) scheduler [7]. The former one allows maximizing the system cell throughput regardless of the user quality of service. This results in a starvation of the users at the cell border. In order to overcome this problem, PF tries to balance the trade off between fairness and capacity by allocating the channel to the user having the best instantaneous rate (over the entire bandwidth) relative to its mean served rate. The mean served rate is calculated using a smoothed average over an observation time window.

MCS	Modulation	Channel coder rate	EESM β value
0	QPSK	1/3	2.3
1		1/2	2.9
2		3/4	2.4
3	16 QAM	1/2	6.2
4		3/4	8
5	64 QAM	1/2	12.6
6		3/4	27.1

Table 1: EESM calibration variable values for the considered MCS's

Table 2: presents all parameters considered for system simulations.

To sump up the performance results obtained in figures 7 to 11, SFTD does not provide high benefit at system level, at least not as high as at the link level. Receiver diversity scheme is preferred in addition to transmission diversity scheme for all cases. The best 2x2 orthogonal MIMO scheme is Antenna selection at the transmission side combined with reception diversity. The enhancement in this case can reach almost 80% for service cell and service user throughput.

Results show that in SISO case, we have more gain when comparing nAFS and AFS techniques with 8 users per TTI than in MIMO environments where the gains are less significant. When comparing the antenna diversity, we can note that if we associate the antenna selection with Rx diversity, AFS scheme does not provide any gain compared to nAFS scheme. Indeed, for users with relatively good channel conditions, the addition of diversity techniques achieves the optimal channel diversity. Further diversity increase does not improve performance.

Simulations have also shown that the scale of MaxC/I scheduler is very limited. It maximizes the overall system throughput at the expense of the coverage and cell edge user throughput. Time PF improves the coverage by balancing the trade-off between the overall system throughput and the cell edge user throughput.

We have also noticed that for some cases (MaxC/I scheduler and 2x2 Antenna selection and RxDiv), the maximum transmission rate is reached by several users within the cell. This may suggest introducing higher level modulation with higher spectral efficiency in order to allow further increase of the cell throughput.

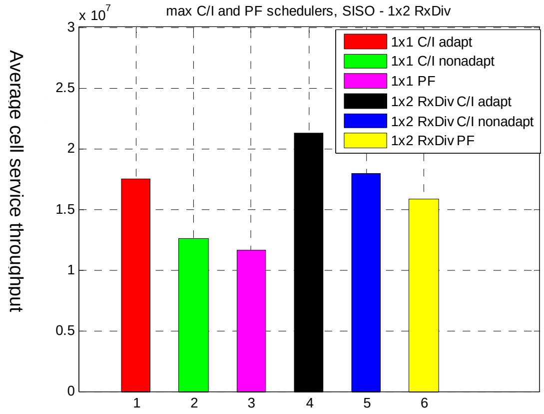


Figure 7: Comparison of the max C/I and PF schedulers in SISO and 1x2 Receiver Diversity (RxDiv) MIMO scheme

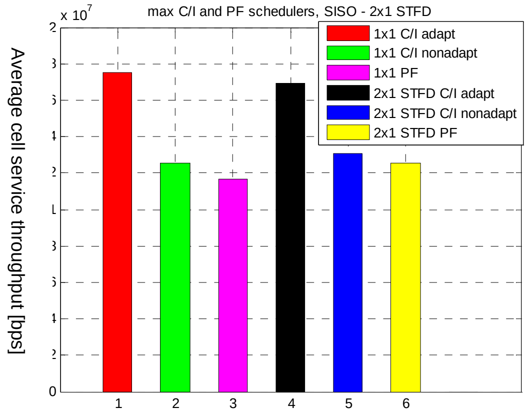


Figure 8: Comparison of the max C/I and PF schedulers in SISO and 2x1 STFD scheme

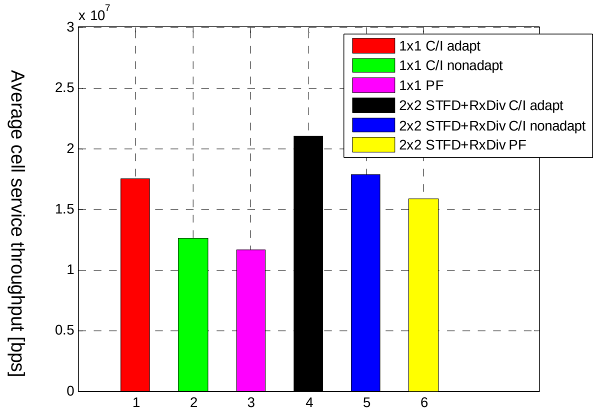


Figure 9: Comparison of the max C/I and PF schedulers in SISO and 2x2 STFD + Rx diversity schemes.

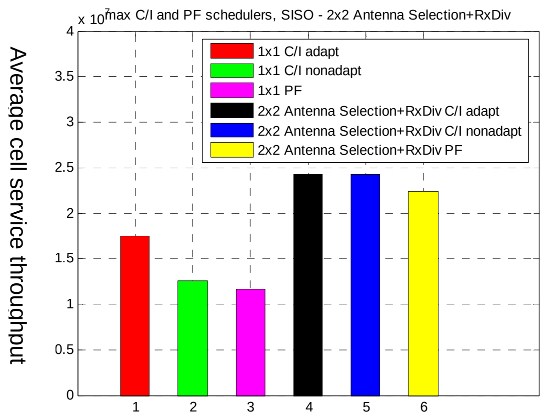


Figure 10: Comparison of the max C/I and PF schedulers in SISO and 2x2 antenna selection + Rx diversity schemes

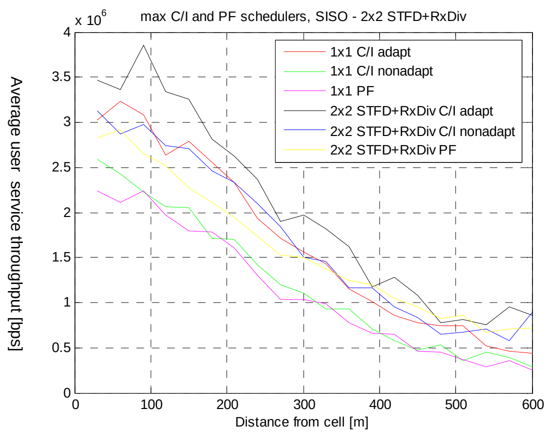


Figure 11: Comparison in terms of coverage of the max C/I and PF schedulers in SISO and 2x2 STFD + Rx diversity scheme

V. Conclusion

In this paper, we have studied B3G MIMO OFDMA link and system level performance by considering 3GPP/LTE-like scenario. At the link level, the performance results have shown that double Alamouti MIMO scheme combined with robust MIMO channel estimation allow to obtain a spectral efficiency of 5.4 bit/s/Hz in 64QAM with channel coding rate of 3/4 but at low velocity. At the system level, several MIMO schemes have been compared. The results indicate that the system throughput in the case of spatial diversity MIMO does not meet the 3GPP/LTE-like requirements. The use of multiplexing MIMO schemes for which an independent stream is transmitted on each antenna (spatial multiplexing for instance as implemented at the link level) is necessary to improve the system performance. Ongoing system level studies will then focus on other MIMO schemes such as Double Alamouti in order to increase the peak data rate and overall throughput of the system. System level simulations will also be pursued in order to evaluate the impact of real time channel estimation on the system performance.

References

[1] 3GPP TSG-RAN, “36 series: Evolved UTRA aspects”, http://www.3gpp.org.

[2] 3GPP TSG-RAN, “3GPP TR 25.814, Physical Layer Aspects for Evolved UTRA (Release 7)”, v1.3.1 (2006-05).

[3] An Interim Channel Model for Beyond-3G Systems - Extending the 3GPP Spatial Channel Model (SCM). Daniel S. Baum and Jan Hansen, Giovanni Del Galdo and Marko Milojevic, Jari Salo, Pekka Kyösti – VTC 2005.

[4] 3GPP TR 25.892, "Feasibility Study for OFDM for UTRAN Enhancement", v1.1.1, May 2004

[5] S. M. Alamouti, “A simple transmit diversity technique for wireless communications”, *IEEE Journal on Selected Areas in Communications*, 16(8):1451-1458, Oct. 1998.

[6] 3GPP TSG-RAN, “3GPP TS 36.211, Physical Channels and Modulation (Release 8)”, v1.1.0 (2007-05)

[7] J.M. Holtzman, “Asymptotic analysis of Proportional Fair algorithm” In Proc. of 12th IEEE PIMRC 2001, San Diego, USA

	Parameter description	Value
	Inter-site distance (ISD)	900 m
	Carrier frequency	2.0 GHz
	Bandwidth	10 MHz
	Slot length	0.5 ms
	Cell lay-out	Hexagonal grid, 19 cell sites, 3sectors per site
	Number of considered mobiles during simulation	35 per 3 sectors
	Link to System interface	EESM
	Trafic model	Full queue
Node B		
Node B	Total available power	43dBm (~20 W)
	Power assigned to pilot/data	2 W / up to 18W
	Number of TX antennas	1, 2 (Tx Diversity, Antenna Selection)
	Antenna gain plus cable loss	14 dBi
	Antenna pattern	$\min\left(12\left(\frac{\theta}{70}\right)^2, 20\right)$ dB (θ is angle in degrees) ; 70-degree sectored beam.
Propagation		
Propagation	Path loss	$128.1 + 37.6\log_{10} R$ (R is distance in km)
	Slow fading – Standard deviation	8 dB
	Slow fading – Correlation between sites	0.5
	Fast fading	Typical urban 6-tap model, 3 km/h
	Penetration loss	20 dB
	Interference	white
UE		
UE	Thermal noise Power density	-174 dBm/Hz in 10MHz
	UE noise figure	9 dB
	Antenna pattern	0 dBi
	Number of RX-antennas	1, 2 (RX diversity)
	Channel estimation	Ideal
	CQI reporting	Ideal
	H-ARQ processing	Chase combining
	Turbo decoder	Max-log MAP with up to 8 iterations
H-ARQ		
H-ARQ	type	Asynchronous
	Number of processes	6
	Delay from CQI-report to 1st transmission	3 slots or 1.5 ms
	Time between retransmissions	6 slots or 3 ms
	Maximum number of transmissions	1 initial transmission + 6 re-transmissions
	Combining technique	Chase
Scheduler		
Scheduler	Transport formats	All MCS
	User traffic multiplexing	localized sub-bands, scheduled each TTI
	Ordering policy	MaxC/I, time Proportionally Fair
	RB allocation strategy	Frequency dependent, frequency independent

Table 2: System evaluation simulation parameters