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1 Introduction

USTS is applicable for low mobility and low dispersive environments such as pedestrian and indoor, where the system capacity is expected to improve significantly by reducing the uplink intra-cell interference by means of maintaining uplink synchronism and uplink orthogonality. UE Tx timing control and sharing a common scrambling code are necessary to implement USTS.

Many simulations have been done with a measure of SIR versus the number of UEs in the TR25.854 in a single cell environment [1]. And the additional complexity to support USTS is not significant with a pedestrian speed [2].

This document provides some more intensive theoretical and simulation results to show the USTS gain at system level in a multiple cell environment, which considers uplink orthogonality factor, imperfect synchronism, soft handover, other cell interference, code limitation, the penetration ratio.

Section 2 discusses the possible factors that impact the USTS gain such as multi-paths and imperfect synchronism, code limitation, other cell interference, penetration ratio, noise rise versus outage probability, and receiver antenna diversity. Then, the possible number of channelisation codes are tabulated according to the spreading factor and uplink orthogonality factor is derived. Section 3 investigates the USTS gain theoretically based on a same and different noise rise target levels, where impacts of noise rise target level, code limitation, other-to-own cell interference ratio, and penetration ratio are investigated. Section 4 shows the simulation results in various situations, taking into account more realistic factors. Different impact of soft handover is addressed and single cell and multiple cell capacities are compared based on noise rise target and outage probability. Section 5 draws our conclusions. Two appendices are given regarding the detailed derivation of orthogonality factor and the details of theoretical analysis.

2 System level performance of USTS

2.1 Possible factors that impact the USTS gain

2.1.1 Multi-paths and imperfect synchronism

Perfect synchronisation is not possible in uplink because of the multi-path effect and many other factors that impact on the propagation delay of the signals transmitted from the different UEs. This lack of synchronisation translates into a reduction of the orthogonality among the signals received by the BS, and therefore of the capacity gain provided by USTS. The main factors that impact on the orthogonality among the signals transmitted by the UEs are compiled in [1]:

- Only one of the detected paths of every signal received by the BS can be aligned in time.

- Alignment of the first path is not perfect, due to:
  - ✓ the timing control resolution,
  - ✓ errors in the transmission of the TAB, and the time variant properties of the channel.

The uplink orthogonality factor is calculated considering the above factors in Section 6 and the results are summarized in Section 2.4.

2.1.2 Code limitation

Unlike the downlink case, the Dedicated Physical Data Channel (DPDCH) and its associated DPCCH are not time-multiplexed in the uplink, and use different channelisation codes, because discontinuous transmission could cause audible interference to audio equipment that is very close to the terminal, such as hearing aids. This restriction makes the UE use double number of channelisation codes than in the downlink.

In USTS, the scrambling code is not UE specific but common to a number of UEs, and different channelisation codes are allocated to each UE. All the groups of UEs in a cell use the same scrambling code. However, the number of channelisation codes is over before than in the downlink. When a BS runs out of channelisation codes, newcomers are assigned an extended scrambling code, reusing the same set of channelisation codes. However, once this is done, the efficiency of USTS starts to decline. But the efficiency largely depends on the number of channelisation codes and the way of assigning the scrambling codes, e.g., equal sharing or sequential packing.

The number of channelisation codes are tabulated in Section 2.3 for different values of SF.

2.1.3 Other cell interference

USTS reduces the uplink intra-cell interference by means of making the own cell MAI orthogonal. Therefore, as other-to-own-cell interference ratio becomes lower, the USTS gain is likely to increase.

2.1.4 Penetration ratio

Since USTS is proposed within the UMTS standardisation process as an optional mode of operation of Release 5 systems, the impact of penetration ratio is an interesting aspect. The higher the penetration ratio, the higher the USTS gain.

2.1.5 Noise rise versus Outage probability

In WCDMA admission control is a very important functionality to ensure network stability. For the uplink direction noise rise is a common used load metric:

- A UE making a capacity request is granted access to the cell provided that the expected new noise rise (after admission) is below a certain pre-defined noise rise target.

The noise rise target is usually in the order of 0.6 times the theoretical pole capacity. As noise rise is defined as the total measured wideband power relative to the system noise level, the gain from having orthogonal paths in USTS is not taken into account. A system with USTS is therefore more stable than a conventional system for the same value of noise rise, and potentially a higher noise rise target can be used in USTS. The potential higher noise rise target for USTS depends strongly on the multi-path, the penetration rate of USTS terminals, and other-to-own cell interference ratio.

Without any admission control, the capacity can be estimated based on the outage probability [3], e.g., the outage is defined as users having a FER greater than 1%. The system capacity is defined as the maximum traffic throughput that makes the outage level smaller than 5%.

2.1.6 Receiver antenna diversity

In USTS, the synchronisation can be maintained at each antenna since the antenna separation is quite small compared to 1-chip duration which corresponds to 78 meters with a chip rate of 3.84 Mcps. Accordingly, basically both USTS and non-USTS can expected similar gain from antenna diversity. However, USTS is likely to be susceptible to code limitation with receiver antenna diversity.

2.2 Findings from [3]

At the last meeting, Ericsson presented Tdoc R1-01-0746 “System level performance of USTS”. The simulations were done based on static uplink orthogonality factor, which determines the amount of interference suppression of USTS. It was found that USTS can achieve 75 % capacity gain and 42 % capacity gain compared to normal systems without code limit in a multiple cell environment for Ped A and Ped B, respectively. However, this gain declines to 25 % and 12 % if we take into account the limited number of channelisation codes of 51 since no interference suppression can be expected among the users sharing different scrambling codes.

The followings factors seem to degrade USTS gain much;

(1) Equal sharing method for multiple scrambling codes

(2) Severe code limit problem due to high capacity[1]

However, if the capacity is moderate and SF=128 is used in the uplink for voice, the code limitation problem can be mitigated through sequential packing instead of equal sharing since 84 codes are available maximally from Table 1.

2.3 Channelisation codes for DPDCHs

There are two rules for channelisation codes assignment for both a DPCCH and DPDCH(s) [1]:

(1) The channelisation codes for DPDCH(s) and a DPCCH for a UE are chosen among OVSF codes unoccupied by other UEs from either upper half part or lower half part of OVSF code tree of a common scrambling code.

(2) Mapping rule of channelisation codes between DPDCH and DPCCH.

Table 1 shows the number of channelisation codes for DPDCHs given one DPDCH and one DPCCH per UE. The numbers in the column “TR25.854” is given when both rules are obeyed. However, if the second rule is taken away, then, the numbers are increased especially when SF >= 64 while this requires a signalling for DPCCH code at call set-up. The numbers in parenthesis can be obtained when both rules are not obeyed.

[1] Over 100 voice users even with activity factor = 1 possibly due to Rx antenna diversity, one-tier simulation, no admission control, and others??

Spreading factor	Number of codes for DPDCHs	
	TR25.854	Maximum
4	2	2(3)
8	6	6(7)
16	12	14(15)
32	24	28
64	48	50(51)
128	48	84(85)
256	48	128

Table 1. Number of channelisation codes for DPDCHs.

2.4 Uplink orthogonality factor

(NOTE: For detailed derivation, please refer to Section 6 of this document. This section briefly summarizes the results in Section 6.)

Orthogonality factors for different power delay profiles are summarized in Table 2 . If we assume the real orthogonality factor to be between the values obtained by considering approaches (16) and (17), the assumption made in (15) seems to be quite accurate for step sizes (δ) of 1/4 and 1/8 of chip time. By applying equation (5), it is possible to derive the values presented in Table 17 which are obtained based on [1].

Power delay profile	α based on (15)	α based on (16)			α based on (17)		
		$\delta = \frac{T_c}{2}$	$\delta = \frac{T_c}{4}$	$\delta = \frac{T_c}{8}$	$\delta = \frac{T_c}{2}$	$\delta = \frac{T_c}{4}$	$\delta = \frac{T_c}{8}$
Indoor A	0.16	0.20	0.18	0.16	0.56	0.52	0.51
Indoor B	0.41	0.44	0.41	0.40	0.61	0.58	0.57
Pedestrian A	0.11	0.17	0.12	0.09	0.21	0.16	0.13
Pedestrian B	0.66	0.72	0.70	0.69	0.81	0.80	0.79
Exponential PDP[2]	0.70	0.73	0.71	0.70	0.79	0.78	0.77

Table 2. Orthogonality factor obtained with different approaches.

3 Theoretical Analysis

3.1 Assumptions and Parameters

The following common assumptions are made for all the cases studied in this section:

- Perfect PC is assumed, which means that all users always reach their Energy-per-bit to Noise Ratio (Eb/No) target.

- Soft handover is not considered.

[2] The rms delay spread for the exponential PDP environment is 500ns.

- All users have the same Eb/No target ρ, and the same spreading factor G.

- Only one DPDCH per user is considered.

- All couples of users with the same scrambling code have the same orthogonality factor α.

- A voice activity factor φ is assumed throughout.

The rest of parameters used for modelling the system are:

- N_{total}, $N_{usts,j}$, and N_{no_usts} are respectively the total number of users in the BS, the number of users in USTS mode using scrambling code j, and the number of users which are not in USTS mode.

- $P_{usts,j}$ and P_{no_usts} are respectively the power received at the serving BS from a single UE in USTS mode with scrambling code j, and from a single UE that is not in USTS mode.

- P_{total}, P_{own}, P_{other} and P_{noise} are respectively the total received power at the serving BS, the power received from its own UEs, the power received from UEs served by other BSs, and the background noise power.

- i is the other to own cell power ratio.

3.2 Performance Evaluation

The received signal power is derived based on the assumption that a same Eb/No target is satisfied for the USTS and non-USTS users. Then, the noise rise is obtained as described in Section 7.

3.3 Numerical results

The values of the orthogonality factor were chosen from the analysis made in Section 2.4 for pedestrian and exponential power delay profiles. The values of i and ρ are obtained from the assumptions made in [4].

	Micro-cell	Macro-cell
α	0.1	0.7
i	0.2	0.65
G	128	128
ρ	4 dB	4 dB
φ	0.5	0.5

Table 3 Assumptions for micro-cell and macro-cell environments for speech users

The user data rate considered is 12.2 kbps speech service with a spreading factor of 128 by considering channel coding and puncturing.

3.3.1 Noise rise curves

Figure 2 represents the noise rise generated in the cases of all users in the BS using USTS (with and without limit in the number of channelisation codes) and in the case where USTS is not used all, as a function of the number of users in the BS (N_{total}), for a micro-cell and a macro-cell environments.

By setting the maximum noise rise to 4dB, the maximum number of voice users with spreading factor 128 in a micro-cell environment without USTS is 51. With USTS, it becomes 68 for 48 codes and 86 for 84 codes. In the ideal case of USTS without limit in the number of channelisation codes per scrambling code, it is possible to serve up to 93 users. In the macro-cell case, the number of users if USTS is not supported is 37, and 42 if it is. In this case, the limit number of channelisation codes is not a problem.

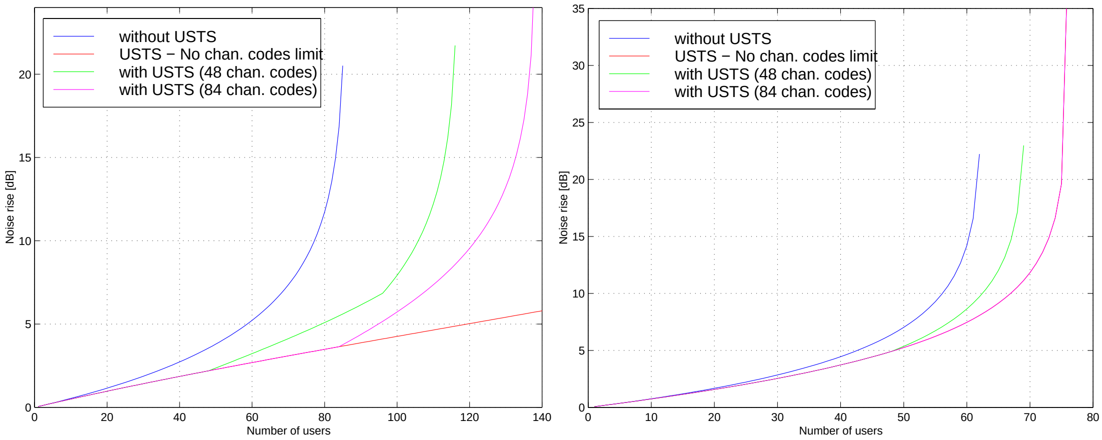

Figure 1 Noise rise vs number of speech users for micro-cell (left) and macro-cell (right) environments (SF=128 and code limit=48, 84, and infinite).

3.3.2 USTS gain with a same noise rise target level

Figure 2 shows the number of speech users that can be admitted in a micro-cell environment, allowing a maximum noise rise of 4dB, as a function of the spreading factor.

It can be seen that, for the chosen parameters, the limitation of the number of channelisation codes only affects the maximum available throughput for a spreading factor greater than 64. It is possible that in an environment with users that require different bit rates the problem of this limitation is much smaller. For spreading factors smaller than 128 it can be seen that the proportion of increase in the maximum throughput available in the BS due to USTS is approximately constant.

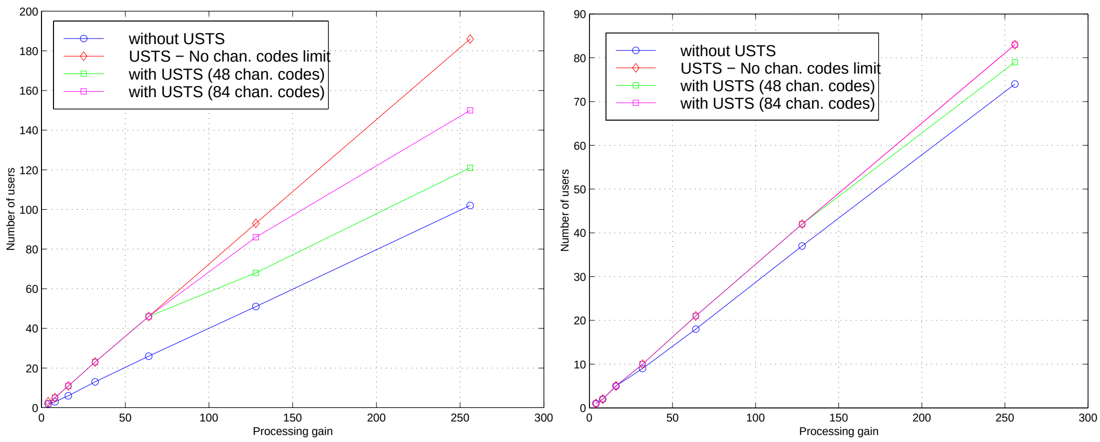

Figure 2. Maximum number of speech users vs spreading factor, for micro-cell (left) and macro-cell (right) environments (SF=128, code limit = 48, 84, infinite, and Nrtarget = 4dB).

Figure 3 represents the number of users that could be served in the BS as a function of the percentage of the users in the cell that are in USTS mode, assuming micro-cell and macro-cell environments with a noise rise target of 4 dB.

In the micro-cell environment there is a capacity gain of 25% and 33% when 80% and 100% of the users support USTS mode for 48 codes. However, this gain can be increased to 35% and 69% when 84 channelisation codes are maximally available. In the macro-cell case, the gain is respectively 8% and 13%.

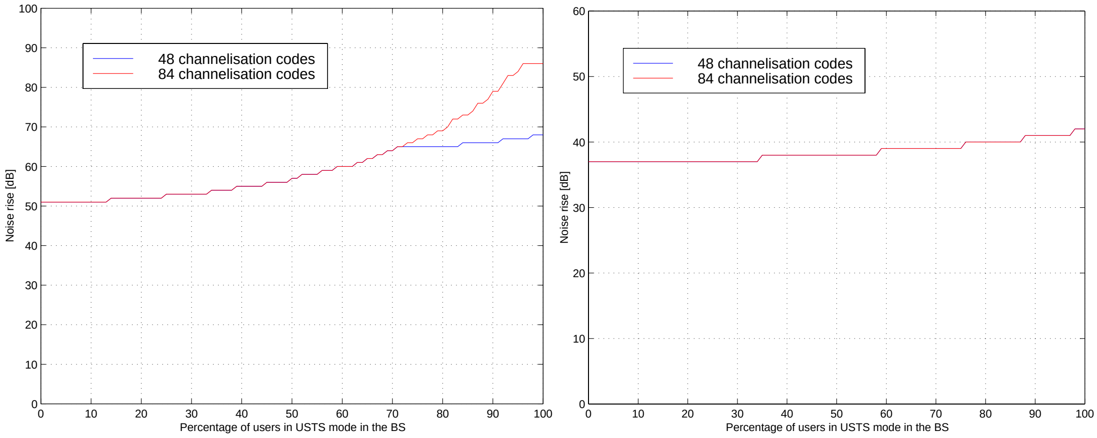

Figure 3. Maximum number of speech users vs percentage of users in USTS mode for micro-cell (left) and macro-cell environments (right) (SF=128, code limit=48 and 84, Nrtarget=4dB).

Figure 4 shows the evolution of the capacity gain with the other-to-own cell interference ratio, for different values of the orthogonality factor. It is noticed that if there was no limit in the number of channelisation codes, the capacity increase would be fairly high for low values of the factor i. However code limitation exists, thus at a certain point, the newcomer users will have to start using an extended scrambling code. Then, the interference from these new users in the existing ones would be completely non-orthogonal, the same as in the case where USTS is not employed. This makes that the capacity gain remains approximately constant for small values of the factor i for 48 codes. For 84 codes, the USTS gain is much higher and maximum points lie between i=0 and 0.5.

The noise rise gives the level of the wideband power with respect to the background noise, and is normally used as a measure of the system load. For the ideal case of i=0 and α=0, the interference seen by every user does not increase with the number of them, which would give an infinity capacity. However, in Figure 4 the capacity is determined as the maximum number of users in the BS without exceeding a noise rise target of 4 dB.

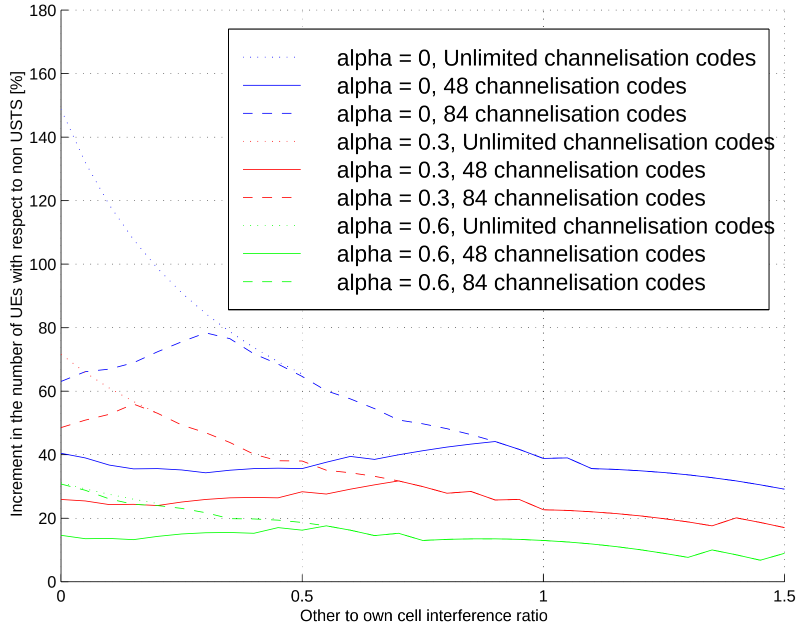

Figure 4. Increase in the available number of users per BS by using USTS (SF=128 and Nrtarget=4dB, code limit=48, 84, and infinite, alpha=0, 0.3, and 0.6).

3.3.3 USTS gain with different noise rise target levels

In general, for a same value of noise rise, a system with all UEs in USTS mode is more stable than a system where USTS is not employed. Thus, it is possible to see from Figure 2 that the slope of the noise rise curve for non USTS at 4 dB is much higher than any of the other USTS cases. New comparison is done for the case of Pedestrian A with a noise rise threshold of 7 dB, which according to the theoretical approach gives approximately the same slope that non USTS with a threshold of 4dB.

		Normal	USTS					
NrTarget		4 dB	4dB			7dB		
# of codes		-	Infinite	48	84	Infinite	48	84
Ped A	#	51	93	68	86	170	96	107
	Gain	-	82.4 %	33.3 %	68.6 %	233 %	88.2 %	110 %
Ped B	#	37	42	42	42	58	55	58
	Gain	-	13.5 %	13.5 %	13.5 %	56.8 %	48.6 %	56.8 %

Table 4 Number of voice UEs per BS for a same and different noise rise targets in multi cell environment (micro cell, SF=128, and code limit=48 and 84)

Figure 5 represents the number of users that could be served in the BS as a function of the percentage of the users in the cell that are in USTS mode with noise rise target giving the same slope as non USTS with a threshold of 4dB.

There is a capacity gain of 50% and 90% when 80% and 100% of the users support USTS mode with 48 channelisation codes. They are increased to 100% and 112%, respectively with 84 channelisation codes.

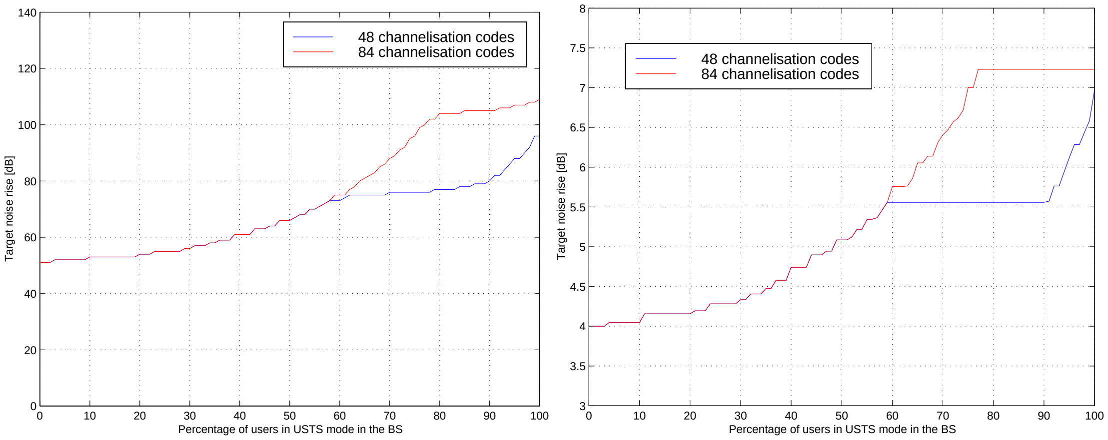

Figure 5 Maximum number of speech users vs percentage of users in USTS mode for micro-cell and the Noise rise target giving the same slope as non USTS with a threshold of 4dB (SF=128 and code limit=48 and 84)

Since the NR target offset between USTS and non-USTS networks may in practice be not easy to determine as it depends on many time-variant factors such as the orthogonality, penetration of UE's supporting USTS, other-to-own cell interference ratio, etc. Hence, in order to obtain the ultimate gain from using USTS, it requires modifications to the existing RRM algorithms such as admission control, packet scheduler, etc.

4 System Level Simulations

An uplink WCDMA dynamic network simulator has been developed to allow having more accurate information on the performance of USTS, as well as to include the impact of some factors in USTS, like soft handover, fast fading, etc. Time-variant orthogonality factor is reflected in the simulator.

4.1 System Model

4.1.1 Cellular Model

The simulator is developed in such a way that it considers a whole service area divided into 24 cells, each one with a radius R, contained by a rectangle with dimensions $12R \times 4\sqrt{3}R$, as shown in Figure 6. Wraparound scheme is considered, i.e. the extreme sides of the rectangle are assumed to be joint (see Figure 6), so that BSs only see UEs from the closest distance.

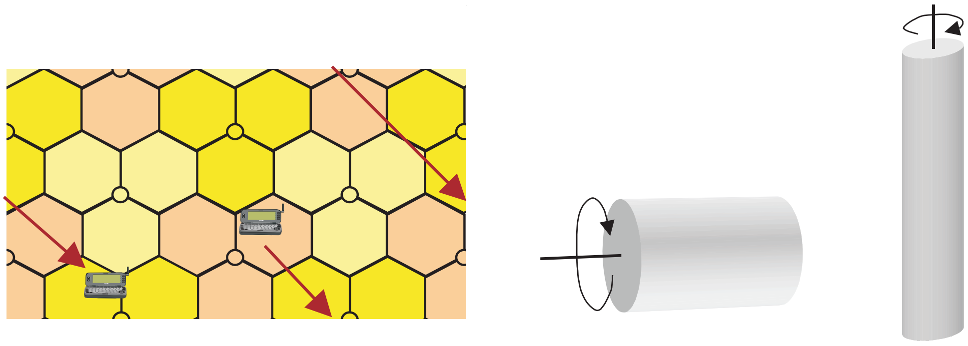

Figure 6. Network layout and wraparound description.

UEs are uniformly distributed inside the rectangle of dimensions $12R \times 4\sqrt{3}R$. They move with constant speed and direction. Once a UE gets out of the rectangle that marks the boundaries of the service area, it is automatically relocated on the opposite border, according to the picture showed in Figure 6.

A site is placed in the centre of every group of 3 cells, with three sector antennas.

4.1.2 Interference Model

A UE arriving in the system will choose its serving cell so that the attenuation between the UE and the BS of its serving cell is minimised. This attenuation is composed of the radio propagation losses and the gain provided by the antenna of the BS.

4.1.2.1 Normalized radiation pattern of the BS antennas

The power radiation pattern of every sector antenna has a 3 dB beam-width of 70 degrees:

$$g(\phi) = \begin{cases} \cos^{3.2}(\phi) & -90 < \phi < 90 \\ 0 & otherwise \end{cases}, \quad (1)$$

where ϕ is the angle formed by the main direction of the antenna and the line that joins the UE to the site.

4.1.2.2 Radio propagation model

The radio propagation attenuation from a UE to a BS is composed of the path loss with distance, a Log-Normal shadow fading and a fast fading. For modelling the path loss with distance, pedestrian and vehicular environments are considered [5]:

$$L_d(dB) = 147.7 + 40\log d \quad \textbf{(pedestrian),}$$

$$L_d(dB) = 128.1 + 37.6\log d \quad \textbf{(vehicular),} \quad (2)$$

where d is the distance in km. Shadow fading is modeled with a Log-Normal distributed random variable, with an exponential decaying spatial auto-correlation function. Fast fading is modelled by means of taps (paths) separated by a fixed time, whose related amplitude follows a Rayleigh distribution. The power included is supposed to be concentrated in a single path. Several cases are considered.

a) Pedestrian A ([5])

Tap	Relative delay	Average gain
1	0	-0.44 dB
2	$0.42T_c$	-10.15 dB

Table 5. Power delay profile for Pedestrian A.

b) Pedestrian B ([5])

Tap	Relative delay	Average gain
1	0	-3.91 dB
2	$0.38T_c$	-4.81 dB
3	$0.77T_c$	-8.81 dB
4	$1.15T_c$	-11.91 dB
5	$1.92T_c$	-11.71 dB

Table 6. Power delay profile for Pedestrian B.

c) Exponential decreasing channel profile

An exponential average delay profile with a rms delay spread of 500ns is used. Only taps with a relative gain bigger than -15dB with respect to the first tap are considered.

Tap	Relative delay	Average gain
1	0	-3.72 dB
2	T_c	-5.98 dB
3	$2T_c$	-8.24 dB
4	$3T_c$	-10.51 dB
5	$4T_c$	-12.77 dB
6	$5T_c$	-15.03 dB

Table 7. Exponential decreasing channel power delay profile.

4.1.2.3 Interference calculation

Maximal ratio combining is used for detecting the paths at the receivers. With this assumption, the Eb/No obtained at a certain BS from a UE i is calculated by the simulator with the following expression

$$\rho_i = G_i \sum_{l=1}^{L} \frac{P_i h_i a_{i,l}}{\sum_{j=1}^{N} \sum_{\substack{m=1 \\ (m \neq l \\ or \\ j \neq i)}}^{L} P_j h_j a_{j,m} \chi_{i,j}(l-m)}, \tag{3}$$

where P_i is the power transmitted by the UE, h_i is the propagation gain from UE i to the BS (considering path loss with distance, shadow fading and antenna gain), N is the number of users in the network, L is the number of paths defined for the channel model, $a_{i,l}$ is the relative gain associated to the l-th path of UE i, and $\chi_{i,j}$ is a factor defined as

$$\chi_{i,j}(k) = \begin{cases} 0 & if\ k = 0\ and\ UE_i\ and\ UE_j \\ & use\ the\ same\ Gold\ code \\ 1 & otherwise. \end{cases} \tag{4}$$

If the UE is in soft handover mode, selection combining is applied to the signals received from the different BSs, and the final Eb/No is assumed to be the highest of them. If the UE is in softer handover, maximal ratio combing is applied to the received signals, and the final Eb/No is calculated as the sum of the Eb/Nos obtained in every BS in the active set.

4.1.3 Handover Control

Soft handover is considered in the system. The operation of the handover control is as follows. If the ratio between the strongest pilot measurement from a BS and the one received at another BS is smaller than W_add, and the active set is not full, then this last BS is added to it. If the ratio between the strongest pilot measurement and the one received at a BS in the active set is smaller than W_drop during a period of time T_tdrop then this BS is dropped from the active set. If the active set is full but a BS that does not belong to it receives a pilot measurement which is T_comp times greater than another from the active set, the first one replaces the second one.

In this network simulator the maximum number of BS in the active set of a UE is two. If both BSs in the active set belong to the same site, then the UE is in softer handover.

The gain provided by the use of soft handover is smaller in the case of USTS because the UEs cannot maintain synchronism with more than one BS. This can be seen in Figure 7, where it is plotted the CDF of the noise rise per BS for simulations made with 16 voice users per cell with spreading factor 128. The cases run correspond to full penetration of USTS and no USTS, with and without soft/softer handover. The rest of parameters are the ones presented in Table 9 for the case of Pedestrian A.

By considering the median values of the noise rise, the use of soft/softer handover allows reducing the noise rise in 1.6 dB if USTS is not employed, whereas this reduction declines to 1.0 dB with USTS.

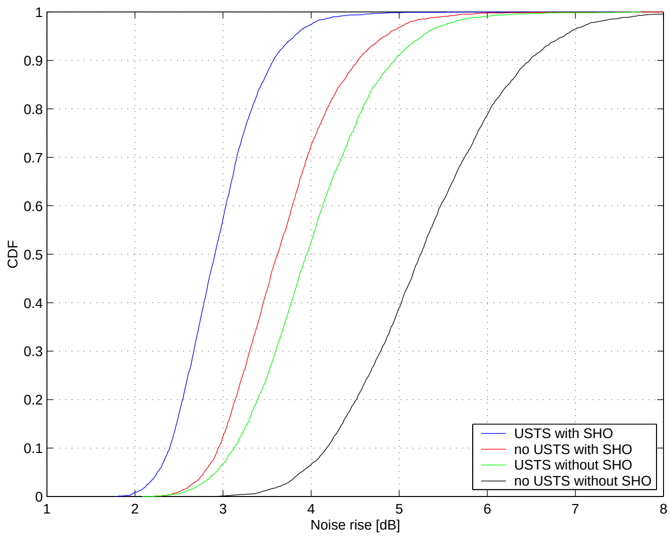

Figure 7. CDF of the noise rise with and without USTS, and with and without soft/softer handover (SF=128 and # of voice=16)

4.1.4 Power Control

UEs are power controlled by their serving BSs. Fast closed-loop PC is simulated at slot level.

Outer-loop PC is run every speech frame (30 slots = 20ms) for every UE. Mapping tables are used to get a measurement of the quality of the received signal for every UE as a function of the current Eb/No. The input to these tables is actually the measured Eb/No averaged over one speech frame.

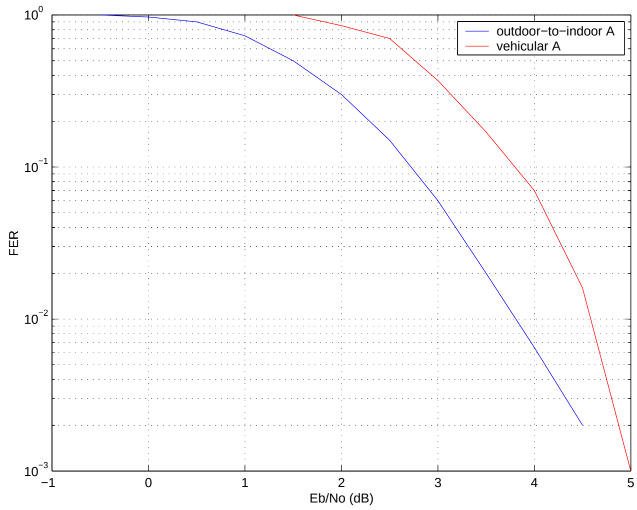

Figure 8. Mapping functions employed to convert from Eb/No (before channel decoding at the output of the RAKE) to FER in Outdoor-to-indoor A and Vehicular A environments.

Figure 8 shows the mapping functions employed for the simulations.

Notice that for the same value of the average Eb/No, the mapping function for Vehicular A gives a higher frame error rate (FER). This happens because the channel estimation errors are higher in environments where the power is spread over many paths (like it happens in Vehicular A and Pedestrian B [5]), since the power available to estimate the channel for every single path is smaller than in the case of having only one strong path.

The outer-loop PC is used to keep the quality of the communication at the required level by setting the Eb/No target for the fast closed-loop PC. The outer loop provides the required quality: no worse, no better.

The mapping function employed for every environment is depicted in Table 8. In the Pedestrian B case the mapping functions for Vehicular A are more suitable, since its channel model is defined by multiple paths, all of them with high relative power.

Channel model	**Macro cell**
Pedestrian A	Outdoor-to-indoor A
Pedestrian B	Vehicular A
Exponential decreasing PDP	Vehicular A

Table 8. Mapping function employed to convert from Eb/No to FER for different environments.

4.2 USTS gain based on Outage Probability

In this first set of simulations, advanced functions like admission control, load control and outer-loop PC are turned off. The outcome is the outage as a function of the number of UEs per cell. The outage is defined for every user as the probability of not being unsatisfied, which is the probability of having a FER greater than 1%. The system capacity is defined as the maximum traffic throughput that makes the outage level smaller than 5%.

4.3 Parameters

The parameters employed for these simulations are presented in Table 9.

Parameter	**Value**
Cell radius	1000 m
Power delay profile	Pedestrian A, B
Eb/No target	4.5 dB for Pedestrian A 5.0 dB for Pedestrian B
Path loss with distance	Vehicular model
Fast closed-loop PC step size	1 dB
T_comp	2 dB
W_add	2 dB
W_drop	4 dB
T_tdrop	0.02 s
Algorithm for synchronising in soft handover	Candidate 3
Receiver antenna gain	15 dBi
Thermal noise level	-102.9 dBm
Standard deviation of shadow fading	5 dB
Coherence distance for shadow fading	110 m
Max. power transmitted by the UEs	21 dBm
Effective bit rate for UEs	12.2 kbps

UEs' speed	3 km/h
Simulation time	180 s

Table 9. Parameters used for the simulations based on the outage.

4.4 Results

4.4.1 Single cell

A first set of simulations has been run for a single micro cell (i.e., no other cell interference and no soft handover) with omni antenna in Pedestrian A and Pedestrian B environments. Results are depicted in Figure 9. By fixing the maximum outage level to 5%, it is possible to have the maximum number of users presented in Table 10.

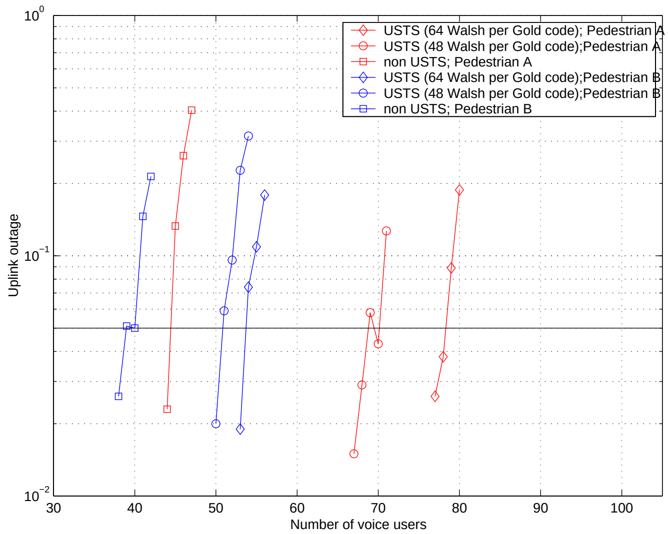

Figure 9. Outage probability as a function of number of voice user per BS for single cell environment.

Channel model	0% usage of USTS	100% usage of USTS			
		48 Walsh codes per Gold code		64 Walsh codes per Gold code	
	Number of voice UEs	Number of voice UEs	Gain with USTS	Number of voice UEs	Gain with USTS
Pedestrian A	44	68	55%	78	77%
Pedestrian B	38	50	24%	53	39%

Table 10. Network load parameters BS for a 5% outage in single cell environment.

4.4.2 Multiple cell

Figure 10 shows the outage probability as a function of the number of voice users per BS for Pedestrian A and Pedestrian B, with and without USTS in multi cell environment. Table 11 shows the maximum number of users per BS for a same outage probability of 5%.

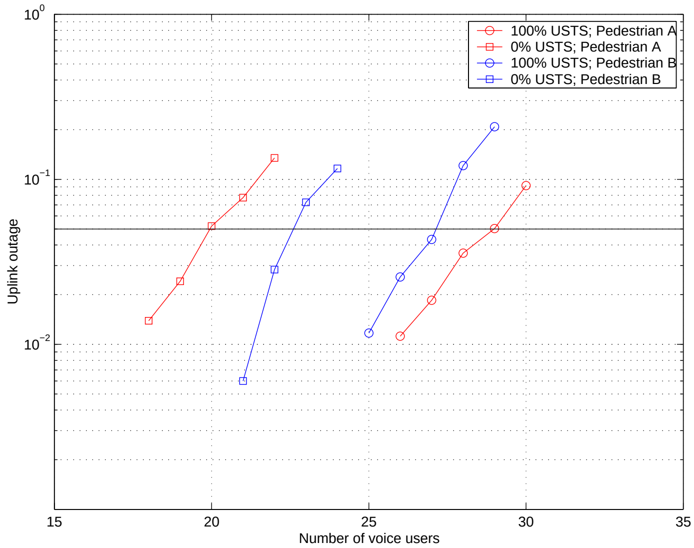

Figure 10. Outage probability as a function of number of voice user per BS for multi cell environment.

Channel model	0% usage of USTS		100% usage of USTS		Gain by using USTS
	Number of UEs per BS	Average NR per BS	Number of UEs per BS	Average NR per BS	
Pedestrian A	19	6.5 dB	28	7.8 dB	47 %
Pedestrian B	22	8.9 dB	27	10.6 dB	23 %

Table 11. Network load parameters BS for a 5% outage in multi cell environment.

Although for the same FER in Pedestrian B it is necessary a higher Eb/No (see Figure 8), it yields a higher capacity without using USTS, because its more spread power delay profile gives some diversity gain in the reception. However, this reduces the orthogonality when using uplink synchronism, which explains why in the case of Pedestrian A environment USTS gives a better performance.

While in the multi cell case the maximum number of channelisation codes per scrambling code is never reached, it is possible to appreciate that in the single cell (where there is no interference from other cells) this has a great impact on the performance of USTS.

Notice that the percentage of outage does not give a measurement of the noise rise level at every BS, since quite different values are obtained for all the cases. Anyway, these values reveal that the system is in a fairly loaded situation.

4.5 USTS gain based on Noise Rise Target

4.5.1 Loading the network

The purpose of the simulations is to load the system in such a way that a target noise rise is fulfilled. The network is loaded with speech users. Calls have unlimited duration. Users transmit with a effective bit rate of 12.2 kbps. Convolutional channel coding is assumed, with coding rate 1/3. After that, interleaving and puncturing are applied, and the raw bit rate per user is finally 30 kbps, which requires a spreading factor of 128. Discontinuous transmission is not considered.

In a first step, the network is initially loaded with 300 UEs uniformly distributed in the whole network area. This yields that the number of UEs per cell is approximately Poisson distributed. Then, a new UE is generated and located following the same uniform distribution with a constant arrival rate. The UE is admitted in the system if

- the current noise rise at the BS with the highest pilot report measurement is smaller than the noise rise target value, and

- the average current noise rise in all the BSs of the network does not exceed that noise rise target value.

The current noise rise is calculated by averaging over 150 slots (100ms). The procedure is represented in the flow chart of Figure 11

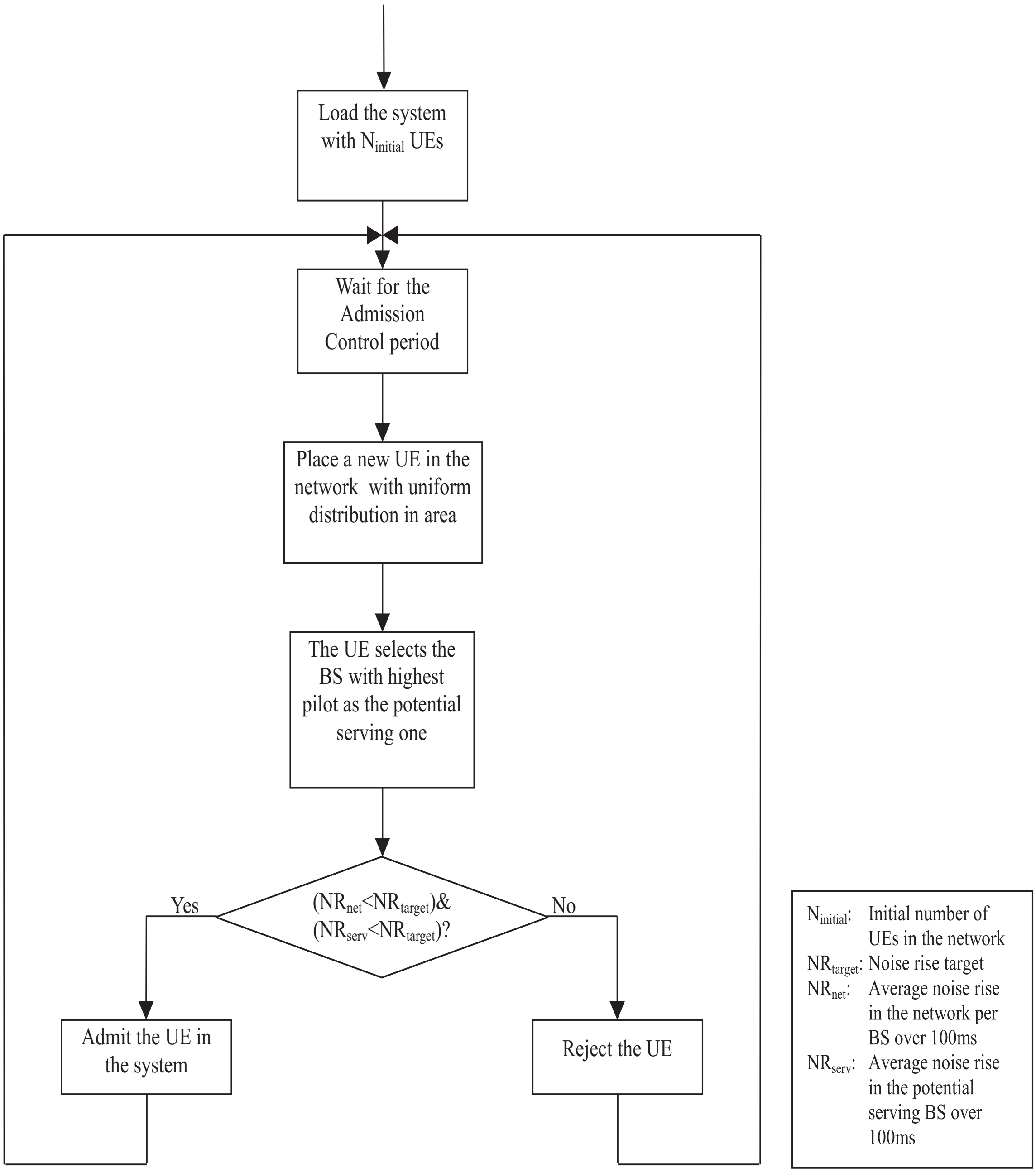

Figure 11. Flow chart of the procedure for loading the system.

Due to outer-loop PC actions, if there are too many errors in the reception of the frames associated to the same UE, this UE will increase its Eb/No target continuously. Then, when this burst of errors is over, it is possible that the UE keeps on transmitting at its maximum power for a long time, since the step for decreasing the Eb/No target is much smaller than for increasing it. This would cause that the rest of UEs had to compensate the extra interference by increasing their own power, which could lead to a potential instability.

In order to control the load of the network, UEs with bad quality calls are dropped. A call is considered to have bad quality if more than 4 frames are received with wrong CRC consecutively.

4.5.2 Parameters

Parameter	Value
Outer-loop PC step size	0.3 dB
FER target	1 %
Noise Rise Target	4 dB
T_USTS	0.02 s
Algorithm for synchronising in soft handover	Candidate 3, 4
Standard deviation of shadow fading	10 dB
Coherence distance for shadow fading	50 m
Max. power transmitted by the UEs	24 dBm
UEs' speed	2.7 km/h
Admission Control period	100 ms

Table 12. Default parameters used for the simulations based on the noise rise level.

Table 12 shows the default parameters used for all the simulations, while in Table 13 the specific parameters employed for simulating the micro and the macro cell environments are depicted. The other parameters not shown in Table 12 are the same as in Table 9.

Parameter	Value	
	Micro cell	Macro cell
Cell radius	300 m	1000 m
Path loss with distance	Pedestrian model	Vehicular model
Power delay profile	Pedestrian A and B	Exponential decrease

Table 13. Specific parameters used in the simulations based on the noise rise level for micro and macro cell environments.

4.5.3 Results

4.5.3.1 With a same noise rise target level

A campaign of simulations has been run in order to get the average number of voice UEs in a BS for the different cases under study when an average noise rise target level of 4 dB per BS is reached.

In a first step, preliminary simulations were run for a single micro cell (i.e., no other cell interference and no soft handover) with omni antenna in Pedestrian A and Pedestrian B environments. In Table 14, simulation results are compared to the theoretical values obtained by applying the same parameters to equations (37) and (38). The Eb/No target for the theoretical calculations is the one obtained from the mapping functions in Figure 8 by applying a 1% FER.

Channel model	Average number of UEs per BS from simulations			UEs per BS from theoretical analysis		
	0% USTS	100% USTS		0% USTS	100% USTS	
		Limited no. of Walsh codes	Unlimited no. of Walsh codes		Limited no. of Walsh codes	Unlimited no. of Walsh codes
Pedestrian A	32	50	61	32	54	70
Pedestrian B	29	33	33	30	38	38

Table 14. Number of voice UEs in a single micro cell for a noise rise target of 4 dB.

Notice that simulation results are quite close to what it is predicted from the ideal theoretical study. In this single cell case, 56% and 14% more throughput is obtained when using USTS with 48 codes.

For the multi cell case, the average number of voice users per BS obtained from the simulations is presented in Table 15, as well as the theoretical values that would be got by applying the same parameters to equations (37) and (38). The factor i used for the theoretical calculations is the average value measured in the simulations (shown in Table 15), whereas the Eb/No target is the same that the one employed in Table 14.

Case	Average number of UEs per BS from simulations			UEs per BS from theoretical analysis		$i = \frac{P_{rx\_other}}{P_{rx\_own}}$
	0% USTS	100% USTS		0% USTS	100% USTS	
		Cand[3] 3	Cand[3] 4			
Micro cell with Pedestrian A PDP	19.6	24.0	24.1	20	29	0.61
Micro cell with Pedestrian B PDP	18.2	20.1	20.1	22	26	0.36
Macro cell with Exponential PDP	18.0	19.5	19.5	22	25	0.37

Table 15. Number of voice UEs per BS for a noise rise target of 4 dB in multi cell environment.

From simulation results, it is possible to appreciate that with Pedestrian A environment, USTS provides a 22% and 23% capacity increase with candidate 3 and candidate 4 algorithms for synchronisation during soft handover.

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[3] Candidate algorithm employed for synchronisation during soft handover

In Pedestrian B and exponential PDP models gives a smaller capacity increase with USTS (10% and 8%).

The USTS provides a higher capacity gain in the Pedestrian A case due to good orthogonality properties, which allows reducing the intra-cell MAI because the interference coming from users with the same scrambling code is strongly mitigated. However, as seen in Table 15, the simulations with Pedestrian A case present a very high other-to-own-cell interference ratio (0.6, compared to the value 0.2 assumed in [4]), due to the high power transmitted by UEs during deep fading states.

In the rest of the cases, the presence of secondary paths with higher relative power reduces the interference coming from other cells, which gives in general a higher throughput, but also reduces the orthogonality among the UEs in USTS mode.

In general, without using USTS, the number of UEs per BS should be higher when the power is spread among more paths. This is reflected in Table 15 for all cases but from the ones that use mapping functions to convert from Eb/No to FER based on Vehicular A environment. In this case, the extra energy required to have the target FER compared to the Outdoor-to-indoor A case is greater than the diversity gain obtained from multiple paths.

4.5.3.2 With different noise rise target levels

An issue to consider is that by applying the same noise rise level for USTS as without USTS, may lead to conservative results for USTS, especially in the single cell case or in enviroments with very good orthorgonality factor, (i.e. Pedestrian A and Indoor A profiles). In general, for a same value of noise rise, a system with UEs in USTS mode is more stable than a system where USTS is not employed. Thus, it is possible to see from Figure 2 that the slope of the noise rise curve for non USTS at 4 dB is much higher than any of the other USTS cases. New simulations where done for the case of Pedestrian A with a noise rise threshold of 7 dB, which according to the theoretical approach gives approximately the same slope that non USTS with a threshold of 4dB.

Results are depicted in Table 16. They show that with the mentioned assumptions, it is possible to have a 74% increase in capacity by using USTS with candidate 3 algorithm for synchronisation during soft handover. However the network is still in a situation where the channelisation code limit is not reached, because the voice activity factor is not considered. Considering a voice activity of, for example 0.5, a single canalisation code tree would be insufficient, and then degrade the gain results of USTS shown in Table 16. If 84 codes are available for voice, the degradation can be avoided.

<table>
<tr><td colspan="4">Average number of UEs per BS from simulations</td><td colspan="2">UEs per BS from theoretical analysis</td><td rowspan="3">$i = \frac{P_{rx\_other}}{P_{rx\_own}}$</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">0% USTS, NRtarget=4dB</td><td colspan="2">100% USTS</td><td rowspan="2">0% USTS, NRtarget=4dB</td><td rowspan="2">100% USTS</td></tr>
<tr><td>Cand 3</td><td>Cand 4</td></tr>
<tr><td rowspan="2">Nrtarget=7dB</td><td>19.6</td><td>34.1</td><td>34.5</td><td>20</td><td>46</td><td>0.61</td></tr>
<tr><td>-</td><td>74 %</td><td>76 %</td><td>-</td><td>130 %</td><td>-</td></tr>
<tr><td rowspan="2">Nrtarget=4dB</td><td>19.6</td><td>24.0</td><td>24.1</td><td>20</td><td>29</td><td>0.61</td></tr>
<tr><td>-</td><td>22.4 %</td><td>23 %</td><td>-</td><td>45 %</td><td>-</td></tr>
</table>

Table 16. Number of voice UEs per BS in multi cell with Pedestrian A environment by using different noise rise target in USTS and in non USTS.

5 Conclusions

USTS has been presented as an optional operation mode for UEs and BSs to reduce the intra-cell interference by means of introducing synchronism in the uplink.

If the variation of the channels allows synchronism with misalignment errors smaller than 1/16 chips or 1/8 chip, like in low mobility environments, an orthogonality factor of approximately 0.1 can be reached for Pedestrian A environment. In the simulated macro-cell environments the orthogonality factor can not be maintained below 0.7.

As a first step, a theoretical analysis has been developed to estimate the potential capacity gain of USTS. It shows that the throughput can be increased in more than 60% for micro-cell environments, although a very ideal model is employed. However, there are lots of aspects that impact on the performance of USTS and were not considered in this theoretical model, like the use of SHO, non-perfect PC, or the fast fading profile.

As a second step, a WCDMA dynamic network simulator for the uplink has therefore been employed in order to include all these effects that impact on the performance of USTS.

Simulations performed with Pedestrian A environment without considering outer-loop PC reveal and admission control that it is possible to get a 47% increase in capacity with USTS for a 5% outage probability with a voice factor equal to 1. However such great results are obtained when the network is in a very high load situation. Furthermore, once that discontinuous transmission is included in the model, the number of users that can be admitted in the system would increase, and it is very likely that a second scrambling code had to be used, which would reduce considerably the capacity gain with USTS when 48 codes are available.

Further simulations were run by setting a noise rise target to 4 dB, considering outer-loop PC as well as admission control. In this case, with Pedestrian A environment, USTS provides a 22% increase in the average number of voice users available per BS. This setting may give a conservative USTS gain since a possible increase in noise rise target is not taken into account.

As an additional case, different noise rise target values were considered for USTS and non USTS cases, since for a same degree of stability, a system with USTS is able to support higher interference power. 74% capacity gain is obtained for a USTS system with a noise rise target of 7 dB with respect to a non USTS system with a target value of 4 dB. This is a bit optimistic result since the potential capacity gain corresponding to this high noise rise level will require RRM support in order to ensure network stability. NR target offset between USTS and non-USTS mode may be difficult to determine for an operational network. Hence, in order to get the full benefit from deploying USTS, the RRM algorithms should be modified to take the potential reduction of narrowband own cell interference into account.

As a summary,

- The USTS gain has been investigated theoretically and by simulations, which depends on other cell interference, code limitation, and the penetration ratio. Lots of results have been provided to show the USTS gain expected in various situations.
- The USTS gain obtained through simulations is approximately half of the theoretical USTS gain possibly due to different SHO gain and more realistic factors considered in simulations.
- The capacity can be expected between conservative (without any modification in RRM) and optimistic results (with proper RRM) from simulations. It reaches 22.4 ~ 76 % in Pedestrian A.
- In the case of SF=128 for 12.2 kbps voice without voice activity, code limitation is never reached because the capacity is much less than 48. Even when voice activity and antenna diversity are taken into account, the code limitation problem can be mitigated if 84 codes instead of 48 codes are available for SF=128 from Table 1.
- Basically, as other-to-own-cell interference ratio becomes lower, the USTS gain is likely to increase. However, as the capacity also increases, the actual USTS gain is impacted by code limitation. From Figure 4, the USTS gain is almost constant regardless of other-to-own cell interference ratio when this ratio is less than 0.6 for 48 codes. However, the USTS gain significantly improves with 84 codes.
- If the penetration ratio is higher than 0.7, the degradation due to non-USTS users is not significant and the impact of penetration ratio also depends on the RRM method. For example, at the penetration ratio of 0.8, the USTS gain is 25% and 35% for a same Nrtarget of 4dB for 48 and 84 codes, respectively, from Figure 3. The gain comes to 50% and 100% respectively for different Nrtarget levels from Figure 5.

6 Appendix I: Uplink orthogonality factor

This section introduces the effect of misalignment among the different users in the degree of orthogonality when they are operating in USTS mode and employ the same Gold code.

The orthogonality factor between a couple of users is defined as

$$\alpha \equiv \frac{\Gamma_T}{\Gamma_N}, \quad (5)$$

where Γ_T is the signal-to-total interference power ratio and Γ_N is the signal-to-spillover interference power ratio between that couple of users. The spillover interference is the part of the total interference power that is not cancelled after the despreading operation and can only be reduced by the spreading factor.

The orthogonality factor gives the proportion of the interference that one of the users causes in the other one if both of them employ the same scrambling code, with respect to the interference generated if they use different scrambling codes.

Using a time dispersive channel with equal power per branch, the resulting signal-to-noise ratio using maximal ratio combining is given as the sum of the branch (path) SNR's

$$\Gamma = \sum_{l=1}^{L} \Gamma_l, \quad (6)$$

where L is the number of paths in the channel. For the calculation of the signal-to-spillover interference ratio, the branch SNR's can be approximated as

$$\Gamma_{N,l} \approx \frac{a_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}}, \quad (7)$$

where a_l is the power associated to the l-th path, and $\gamma_{l,m}$ is the proportion of the power from the m-th interfering path that cannot be cancelled in the reception of the l-th path of the desired signal. This factor γ depends on the delay relative to both paths, and is approximately equal to one if the delay is too long, and 0 if they are fully aligned. The expression in (7) is only approximate because the branches have unequal noise power. The branch SNR's for the signal-to-total interference ratio calculation are given as

$$\Gamma_{T,l} = \frac{a_l}{\sum_{m=1}^{L} a_m}. \quad (8)$$

The orthogonality factor can therefore be approximated as

$$\alpha = \frac{1}{\sum_{l=1}^{L} \frac{a_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}}}. \quad (9)$$

Let us now consider a scenario in which only one path is received from a UE i, and one path from one interfering UE j, which have relative delay τ. The baseband block diagram for the physical layer in this situation is equivalent to the one described in Figure 12.

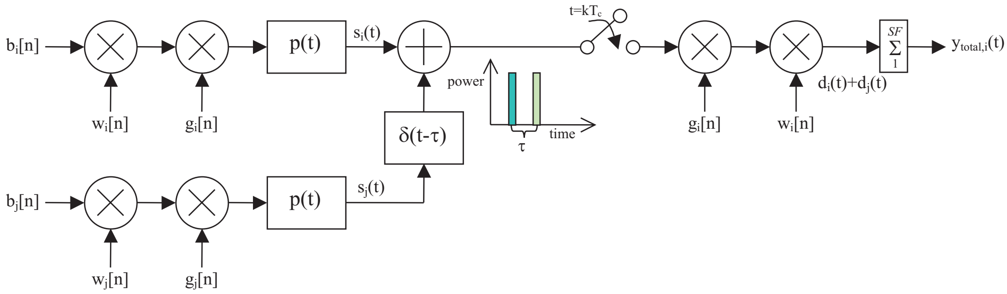

Figure 12. Block diagram of the equivalent baseband structure of the physical layer of UMTS by considering one path per user and only one interferer.

Let also assume that the data bits sent by both users $b_i[n]$ and $b_j[n]$ are constant and equal to one. The signals at the output of the pulsing shape filter are

$$s_i(t) = \sum_{n=-\infty}^{+\infty} p(t - T_c \cdot n) \cdot w_i[\mathrm{n}] \cdot g_i[\mathrm{n}],$$
$$s_j(t) = \sum_{n=-\infty}^{+\infty} p(t - T_c \cdot n) \cdot w_j[\mathrm{n}] \cdot g_j[\mathrm{n}], \qquad (10)$$

where T_c is the chip time, w_i and w_j, and g_i and g_j are the Walsh and Gold codes employed by UE i and UE j, and p(t) is the basic pulsing shape employed for transmitting every chip. For the case of UMTS, it is the result of convoluting the impulse response of two square root raised cosine filters with roll factor β=0.22, which yields a raised cosine filter impulse response

$$p(t) = \mathrm{sinc}\left(\pi \frac{t}{T_c}\right) \cdot \frac{\cos\left(\beta\pi \frac{t}{T_c}\right)}{1 - \left(2\beta \frac{t}{T_c}\right)^2}. \qquad (11)$$

The signals at the output of the despreading block are

$$d_i[\mathrm{n}] = s_i(nT_c) \cdot w_i[\mathrm{n}] \cdot g_i[\mathrm{n}],$$
$$d_j[\mathrm{n}] = s_j(nT_c + \tau) \cdot w_i[\mathrm{n}] \cdot g_i[\mathrm{n}]. \qquad (12)$$

Let us denote as $d_{j,same}$ the signal d_j if UE j uses the same Gold code as UE i; $d_{j,different}$ is the signal d_j when UE j and UE i are allocated different Gold codes.

Let us finally define the factor γ between one path of a UE and another one from an interferer with relative delay τ as

$$\gamma(\tau)=\frac{E[R_{d_i,d_{j,same}}(\tau)]}{E[R_{d_i,d_{j,different}}(\tau)]}, \quad (13)$$

where $E[R_{d_i,d_j}(\tau)]$ is the expectation of the cross correlation of d_i and d_j by considering only lengths relative to one bit duration:

$$E\left[R_{d_i,d_j}(\tau)\right]=E\left[\sum_{k=nSF}^{SF(n+1)-1} d_i(kT_c)d_j(kT_c+\tau)\right]. \quad (14)$$

For the case of one single path per user, the orthogonality factor α between a couple of UEs can be denoted as γ and Figure 13 plots the factor versus the amount of misalignment. Notice that if UEs move slow enough so that a quite accurate synchronisation can be maintained by fixing a low time step size like 1/8 chip, γ is close to zero. For a misalignment error smaller than 1/4 of chip, the factor γ remains below 0.38, whereas for an error smaller than 1/8 and 1/16 of chip, γ remains below 0.18 and 0.09, respectively. For the case of having a power delay profile (PDP) consisting of one single path per user, the orthogonality factor α between a couple of UEs is exactly this factor γ.

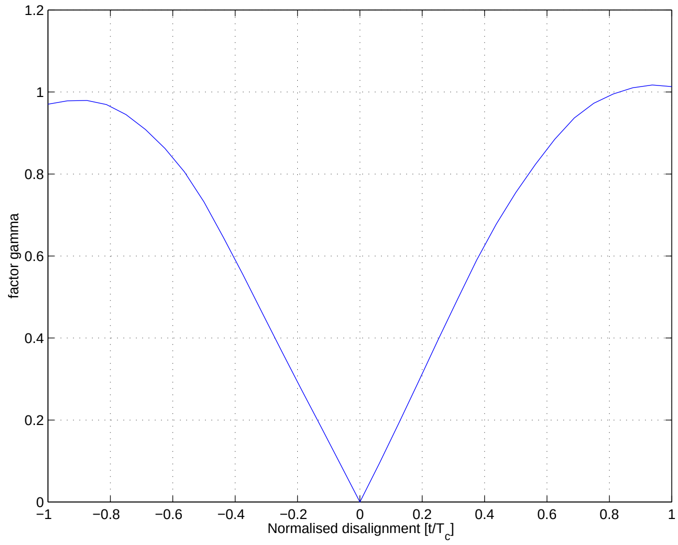

Figure 13 Evolution of the factor γ with the misalignment.

By assuming the time step size employed to correct the arrival time to be 1/2, 1/4 and 1/8 of chip time, and considering the misalignment error for every user to be uniformly distributed within half of that range (note that a misalignment error of 1/8 chip corresponds to the step size of 1/4 chip), the behaviour of the factor γ can be described by the CDFs represented in Figure 14. Notice that if UEs move slow enough so that a quite accurate synchronisation can be maintained by fixing a low time step size like 1/8 chip, γ is close to zero.

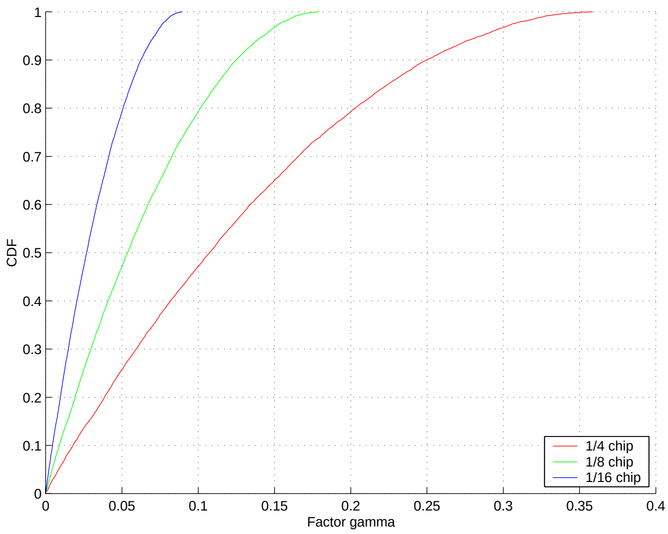

Figure 14. CDF of the factor γ between couples of UEs when the misalignment error for a single UE is uniformly distributed between -1/4 and 1/4 of chip time, -1/8 and 1/8 of chip time and -1/16 and 1/16 of chip time.

In the dynamic network simulator, the factor γ is assumed to be ideal

$$\gamma_{l,m} = \begin{cases} 0 & if\ l = m \\ 1 & otherwise. \end{cases} \qquad (15)$$

Notice that in (15) paths from different UEs arriving in the same order are supposed to be aligned in time.

A second approximation would be

$$\gamma_{l,m} = \begin{cases} \gamma_m(\delta) & if\ |\tau_l - \tau_m| < T_c \\ 1 & otherwise, \end{cases} \qquad (16)$$

where γ_m is the median value of the distribution depicted in Figure 14 for a step size δ, and τ_l and τ_m are the relative delays for paths l and m.

However, in practice, the rest of the paths of different UEs do not have the same relative delay among them as the first ones. The most pessimistic approximation of the factor γ would consider the rest of paths to be completely misaligned

$$\gamma_{l,m} = \begin{cases} \gamma_m(\delta) & if\ l = m = 1 \\ 1 & otherwise. \end{cases} \qquad (17)$$

Let us consider the cases adopted in the network simulator. Table 2 shows the values of the orthogonality factor obtained by means of using the approaches described in (15), (16) and (17) for different environments.

Notice that in Indoor A and Indoor B cases, the paths are too close to each other and the assumption made in (15) is not fulfilled at all. To solve this, a resampling of the power delay profile has been made to have the factor γ based on (15) obtained in Table 2.

If we assume the real orthogonality factor to be between the values obtained by considering approaches (16) and (17), the assumption made in (15) seems to be quite accurate for step sizes of 1/8 and 1/16 of chip time.

By applying equation (5), it is possible to derive the values presented in Table 17 for the orthogonality factor in different environments. For the cases presented, the values are not excessively different from those depicted in Table 2. However, although the relative powers for every path are very similar in Indoor A and Indoor B, in Indoor A all the important paths arrive within one chip time. Therefore, it is expected to have a higher orthogonality (smaller orthogonality factor) than for Indoor A, as it actually occurs by observing Table 2.

Channel model	Orthogonality factor
Indoor A	0.28
Indoor B	0.30
Pedestrian A	0.11
Pedestrian B	0.54

Table 17. Orthogonality factor according to [1]

The assumption made in (15) is going to be held for the simulator.

7 Appendix II: Theoretical Performance Analysis

The Eb/No reached by a user that is not in USTS mode and for a user in USTS employing scrambling code j are

$$\rho_{no\_usts} = G \cdot \frac{P_{no\_usts}}{E\left[I_{no\_usts}\right]}, \tag{18}$$

$$\rho_{usts,j} = G \cdot \frac{P_{usts,j}}{E\left[I_{usts,j}\right]}, \tag{19}$$

where $E[I_{no\_usts}]$ and $E[I_{usts,j}]$ are the expectations of the interference received by a user that does not support USTS and by a user in USTS mode with scrambling code j respectively, defined as

$$I_{no\_usts} = P_{noise} + P_{other} + P_{own} - P_{no\_usts} v, \tag{20}$$

$$I_{usts,j} = P_{noise} + P_{other} + P_{own} - P_{usts,j} \sum_{k=1}^{N_{usts,j}} v(1-\alpha) - P_{usts,j} \alpha v, \tag{21}$$

where v is a random variable that models the voice activity for a certain UE, and is defined as

$$v = \begin{cases} 1 & with \;\; probability \;\; \varphi \\ 0 & with \;\; probability \;\; 1-\varphi. \end{cases} \quad (22)$$

The expectation of power from users belonging to the own cell can be expressed as

$$E[P_{own}] = E\left[P_{no\_usts} \sum_{k=1}^{N_{no\_usts}} v + \sum_j \left(P_{usts,j} \sum_{k=1}^{N_{usts,j}} v \right) \right] = \\ = N_{no\_usts} P_{no\_usts} \varphi + \sum_j N_{usts,j} P_{usts,j} \varphi. \quad (23)$$

By assuming $E[P_{other}]$=i $E[P_{own}]$, the expectation of the interference for UEs is

$$E[I_{no\_usts}] = P_{noise} + (1+i)E[P_{own}] - P_{no\_usts}\varphi, \quad (24)$$

$$E[I_{usts,j}] = P_{noise} + (1+i)E[P_{own}] - N_{usts,j}P_{usts,j}(1-\alpha)\varphi - P_{usts,j}\alpha\varphi. \quad (25)$$

In the sequel, for simplicity, let us call as P_{own} and P_{other} the expectation of the power from the own and the other cell respectively.

The Eb/No reached by a user that is not in USTS mode and for a user in USTS employing scrambling code j can be finally expressed as

$$\rho_{no\_usts} = G \cdot \frac{P_{no\_usts}}{P_{noise} + P_{other} + P_{own} - P_{no\_usts}\varphi}, \quad (26)$$

$$\rho_{usts,j} = G \cdot \frac{P_{usts,j}}{P_{noise} + P_{other} + P_{own} - N_{usts,j}P_{usts,j}(1-\alpha)\varphi - P_{usts,j}\alpha\varphi}. \quad (27)$$

From (26) and (27) it is possible to work out the value of P_{no_usts} and $P_{usts,j}$

$$P_{no\_usts} = \frac{P_{noise} + P_{own}(1+i)}{M_{no\_usts}}, \quad (28)$$

$$P_{usts,j} = \frac{P_{noise} + P_{own}(1+i)}{M_{usts,j}}, \quad (29)$$

where

$$M_{no\_usts} = \frac{G}{\rho} + \varphi, \quad (30)$$

$$M_{usts,j} = \frac{G}{\rho} + N_{usts,j}(1-\alpha)\varphi + \alpha\varphi. \tag{31}$$

The power received by the BS from its UEs is

$$\begin{aligned} P_{own} &= N_{no\_usts} P_{no\_usts} \varphi + \sum_j N_{usts,j} P_{usts,j} \varphi = \\ &= N_{no\_usts} \frac{P_{noise} + P_{own}(1+i)}{M_{no\_usts}} \varphi + \sum_j N_{usts,j} \frac{P_{noise} + P_{own}(1+i)}{M_{usts,j}} \varphi. \end{aligned} \tag{32}$$

Working out the value of P_{own} from (32) it yields

$$P_{own} = P_{noise} \varphi \frac{Q}{1 - Q(1+i)\varphi}, \tag{33}$$

where

$$Q = \frac{N_{no\_usts}}{M_{no\_usts}} + \sum_j \frac{N_{usts,j}}{M_{usts,j}}. \tag{34}$$

Let us recall that the total power received by the BS can be expressed as

$$P_{total} = P_{noise} + P_{own}(i+1). \tag{35}$$

After substituting (33) in (35) and making some manipulations, the following expression is obtained

$$P_{total} = P_{noise} \frac{1}{1 - Q(1+i)\varphi}. \tag{36}$$

By making N_{total}=$N_{usts,1}$ and N_{no_usts}=$N_{usts,k}$=0 for k>1 in equation (36) we have the expression of the total received power in a BS where all the users are in USTS mode and there is no limit in the number of channelisation codes per scrambling code

$$P_{ideal\_USTS} = P_{noise} \frac{\frac{G}{\rho} + N_{usts,1}(1-\alpha)\varphi + \alpha\varphi}{\frac{G}{\rho} - N_{usts,1}(\alpha + i)\varphi + \alpha\varphi}, \tag{37}$$

whereas if N_{total}=N_{no_usts} and $N_{usts,k}$=0 for any value of k it is obtained the total power received by the BS when none of the UEs is in USTS mode:

$$P_{no\_USTS} = P_{noise} \frac{\frac{G}{\rho} + \varphi}{\frac{G}{\rho} - N_{no\_usts}(1+i)\varphi + \varphi}. \qquad (38)$$

8 References

[1] TR25.854: USTS WG1 TR

[2] TR25.839: USTSWG3 TR

[3] Tdoc R1-01-0746 “System level performance of USTS”, Ericsson

[4] H. Holma and A. Toskala (Editors). *WCDMA for UMTS. Radio Access for Third Generation Mobile Communications.* John Wiley & Sons, Ltd, England, 2000.

[5] TR 101 112 (UMTS 30.03): Selection procedures for the choice of radio transmission technologies of the UMTS.

[6] M.M. Zonoozi and P. Dassanayake. *Shadow fading in mobile radio channel.* Seventh IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 1996, Vol. 2, pp. 291-295, 1996