PERFORMANCE OF ENHANCED-UMTS HSDPA USING TRANSMIT DIVERSITY AND POWER CONTROL SCHEMES

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Abstract: This paper addresses the performance of the downlink High Speed Data Packet Access (HSDPA) in QPSK mode. Transmit Diversity (TD) enhancement schemes such as Space Time Transmit Diversity (STTD) and Selective Transmit Diversity (STD), alongside a Power Control (PC) scheme, are covered to improve the system capacity. To evaluate the performance and the advantages of all the schemes under different conditions, several combinations of these were simulated in the AWGN, Indoor A and Pedestrian A channels. For the best combination, a gain of 11.5dB can be achieved, for a BLER of 1%.

1 INTRODUCTION

The 3G cellular system, known as UMTS, is in the standard phase since 1999 and has the maximum capacity of 2 Mbps. Although UMTS is being licensed throughout Europe and implementation involves huge investments, it is recognized that, at the eve of implementation and deployment of the system, still many aspects need to be investigated. This is mainly related to the fact that there is no previous experience on mobile cellular systems operating in multi-service and multi-rate.

Furthermore, some applications require much higher bit rates than those currently offered in UMTS, like real-time audio/video on demand, web browsing, etc.

This paper was elaborated as a result of the participation in the B-BONE (Broadcasting and Multicasting over Enhanced UMTS Mobile Broadband Networks) project. The B-BONE project aims to provide a fundamental contribution to the evaluation and development of Enhanced UMTS networks.

Future Enhanced-UMTS Systems are mostly based on the current UMTS Systems but also add new ‘Space Time Processing’ techniques, ‘namely Adaptive Antennas, MIMO Systems, Space-Time

Coding and spectrally efficient coding/ modulation/ spreading schemes, to increase the capacity of the access network up to 10 Mbps.

Recently, the HSDPA mode was introduced in the standards, and the maximum downlink bit-rate was increased significantly. Two possible modulations were defined: QPSK and 16 QAM. The latter mode delivers higher bit rate than the former and is intended for good channel conditions. This work addresses solely the usage of the QPSK reference mode, though the main conclusions are valid for both modes. The main parameters and physical channel segmentation for the HSDPA-QPSK mode are summarized in Figures 1 and 2, respectively. Note that the turbo code has a rate of

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1/3, and 50% puncturing is applied to its output. Five physical channels are used, which are spreaded with a Spreading Factor (SF) of 16. Sub-frames of 2 ms are used, corresponding to 3 time slots of the normal UMTS mode. A link level simulator was built, from the transport block level, turbo coding, transmission of the encoded chips, emulation of the channel, RAKE receiver, turbo decoding, and all necessary operations up to the received transport block. All modules specified in the standards were built (3GPP, 25.211-213), with the addition of the STD, STTD (3GPP 25.211) and PC (3GPP 25.101) modules. Although HSDPA is based on Adaptive Coding and Modulation (AMC), PC was considered in order to further improve the performance of the system, although the AMC itself is not considered. Results were drawn with and without the enhancement schemes, in order to evaluate the performance gains.

This paper is structured as follows: in section 2, the STD, STTD and PC are summarized, and section 3 analyzes the obtained results. Conclusions are drawn in section 4.

2 ENHANCEMENT SCHEMES

Both STD and STTD schemes are based on the usage of 2 antennas, though more antennas could be employed. The STTD scheme consists on having the message bits transmitted by two antennas (Figure 3), encoded as shown in Figure 4. The hand-set receives both transmissions from the antennas, and performs the STTD decoding, as explained in Figure 6 and Equations (1) and (2). From Figure 6, the signal after the RAKE receiver is:

$$
\begin{aligned}
rk_1(T) &= \left(S_0 \cdot c \cdot h_0 - S_1^* \cdot c \cdot h_1 + n_0\right) \times c^* \cdot h_0^* = \\
&= S_0 \cdot |c|^2 \cdot |h_0|^2 - S_1^* \cdot |c|^2 \cdot h_1 \cdot h_0^* + n_0' \\
rk_2(T) &= \left(S_0 \cdot c \cdot h_0 - S_1^* \cdot c \cdot h_1 + n_0\right) \times c^* \cdot h_1^* = \\
&= S_0 \cdot |c|^2 \cdot h_0 \cdot h_1^* - S_1^* \cdot |c|^2 \cdot |h_1|^2 + n_0' \\
rk_1(2T) &= \left(S_1 \cdot c \cdot h_0 + S_0^* \cdot c \cdot h_1 + n_1\right) \times c^* \cdot h_0^* = \\
&= S_1 \cdot |c|^2 \cdot |h_0|^2 + S_0^* \cdot |c|^2 \cdot h_1 \cdot h_0^* + n_1' \\
rk_2(2T) &= \left(S_1 \cdot c \cdot h_0 + S_0^* \cdot c \cdot h_1 + n_1\right) \times c^* \cdot h_1^* = \\
&= S_1 \cdot |c|^2 \cdot h_0 \cdot h_1^* + S_0^* \cdot |c|^2 \cdot |h_1|^2 + n_1'
\end{aligned} \tag{1}
$$

The final STTD-decoding combination yields:

$$
\begin{aligned}
\tilde{S}_0 &= rk_1(T) + rk_2(2T)^* = S_0 \cdot |c|^2 \cdot \left(|h_0|^2 + |h_1|^2\right) + n'' \\
\tilde{S}_1 &= rk_1(2T) - rk_2(T)^* = S_1 \cdot |c|^2 \cdot \left(|h_0|^2 + |h_1|^2\right) + n''
\end{aligned} \tag{2}
$$

The STD algorithm is quite simple; the mobile chooses the best antenna for transmission, and uses such antenna until the other antenna starts yielding better estimated values for the channel state. The equivalent received power for the STD scheme is thus $P_{STD} = \max\left(|h_0|^2, |h_1|^2\right)$ instead of $P_{STTD} = \frac{\left(|h_0|^2 + |h_1|^2\right)}{2}$. Note that, in the STTD scheme, both antennas transmit the original message, though the second antenna uses a modified version of the message. There is no feedback for these kind of transmit diversity. In the STD scheme, only one antenna transmits the message, whereas the other antenna transmits pilot bits to assess the channel quality, with the mobile transmitting back control bits in order to choose the best antenna (closed loop scheme – Figure 5). The antenna that transmits the message may vary, according to the channel state associated to each antenna.

At the receiver side, a soft decision Rake receiver was built, and a turbo decoder using the Maximum A Posteriori (MAP) algorithm (Bahl, 1974), was employed. A maximum of 8 iterations were used, with iteration stop criteria linked to the Cyclic Redundancy Check (CRC) result. The simulated PC mechanism was the standardized downlink type 1, with a step size of 1dB (which is the value mandatory for the UTRAN to support, though other values can also be used) and a delay of 1 Time Slot (TS), due to being the PC scheme that yields best results (Silva, 2003). A dynamic range of ±15dB was employed, to simulate saturation. Figure 7 shows a simple diagram illustrating the downlink Power Control scheme. At a time resolution equal to 1 TS (0,667ms), the power control algorithm instructs the hand-set to increase/ decrease its power level by 1dB. There is a delay of 1TS for the simulated case, since the corrected power level for the current TS takes into account the power level of the previous TS.

The Tapped Delay Line (TDL) model specified for UMTS (ETSI, 1998), (3GPP 25.943) was simulated, and a speed of 3 km/h was used for the Indoor A channel, whereas a velocity of 10 km/h was used for the Pedestrian A channel. Only fast fading was considered; slow fading/ shadowing was assumed to be completely compensated. Perfect channel estimation was assumed. For the STD simulations, a delay equivalent to 1 TS was used, in order to model a realistic scenario. When the STD was combined with PC, a smart mechanism was activated which reduced the STD delay to 0, thus simulating a STD capable of predicting what the power control is about to do for the next TS, and to anticipate what the next channel value will be. Though the latter assumption is not very realistic, the practical deviation of results that arises from it is negligible for channels with low speed values, such as those simulated.

3 NUMERICAL RESULTS

Bit Error Rates (BER) and Block Error Rates (BLER) were obtained via Monte Carlo simulation of the different scenarios with the link level simulator using a total number of iterations sufficient enough to ensure convergence.

The simulated results are depicted in Figures 8-19. After analyzing the results, the performance gain by applying transmit diversity can be quantified. We note that STD has always a better performance than STTD, as would be expected, due to always choosing the best antenna for transmission.

Results were obtained for using PC Type 1 with 1 TS resolution simulated alone and also in combination with STTD and STD. From the results, it can be seen that the usage of PC combined with either STD or STTD is clearly the solution with greatest performance increase over the normal QPSK simulations.

It can also be seen that both Indoor A and Pedestrian A channels are similar in performance, though the Indoor A channel is slightly better without power control, and the Pedestrian A channel is better with schemes involving PC. This result is simply explained by the fact that PC schemes usually work better in channels that are close to a single Rayleigh path, such as the Pedestrian A channel. This is due to the minimization of intersymbolic interference, effectively aiding the PC algorithm, since all the power adjustments are practically for the main path of the message.

Figures 20 and 21 show the Eb/N0 values for the different schemes, operating under considered normal operation points (BLER of 0.1 for non-real time applications and of 0.01 for real-time applications).

4 CONCLUSIONS

By direct inspection of the results, it was shown that the HSDPA mode alone, without the enhancement schemes such as transmit diversity and power control, performs very poorly. Thus, in order to achieve high bit rates, and use the UMTS to its full potential, enhancement schemes, such as STD, STTD and PC need to be employed, in conjunction with each other.

In order to further close the gap to the AWGN results, more complex schemes can be employed. This can be done by using Adaptive Antennas, MIMO Systems, higher order Space-Time Coding techniques (the work in this paper considered an order 2 system, using 2 antennas for the STD and STTD scheme), Power Control with less delay and spectrally efficient coding/ modulation/ spreading schemes, namely the use of Code-Spread (CS) CDMA schemes (Souto, 2004). The usage of AMC effectively combined with the proposed schemes could also further improve the system's performance.

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Parameter	Unit	Value	
Nominal Avg. Inf. Bit Rate	kbps	1600	2352
Inter-TTI Distance	TTI's	1	1
Number of HARQ Processes	Processes	6	6
Information Bit Payload (N_{INF})	Bits	3200	4704
Number Code Blocks	Blocks	1	1
Binary Channel Bits Per TTI	Bits	4800	7680
Total Available SML's in UE	SML's	57600	57600
Number of SML's per HARQ Proc.	SML's	9600	9600
Coding Rate		0.67	0.62
Number of Physical Channel Codes	Codes	5	4
Modulation		QPSK	16QAM

Figure 1: HSDPA main parameters

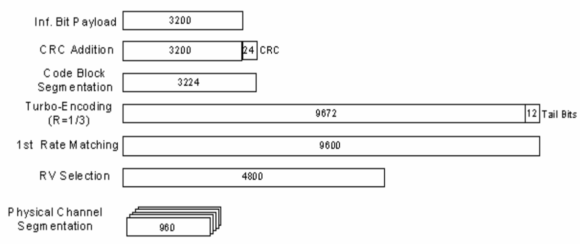


Figure 2: Physical channel segmentation for HSDPA

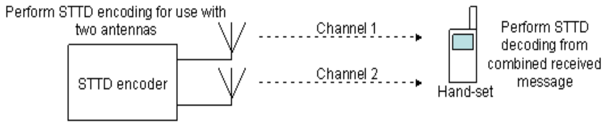


Figure 3: Schematics of STTD operation

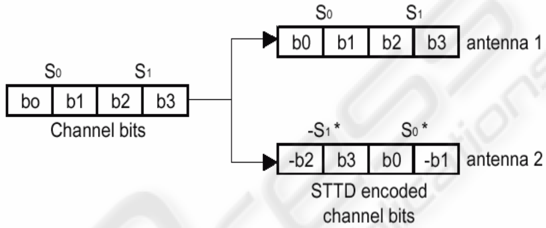
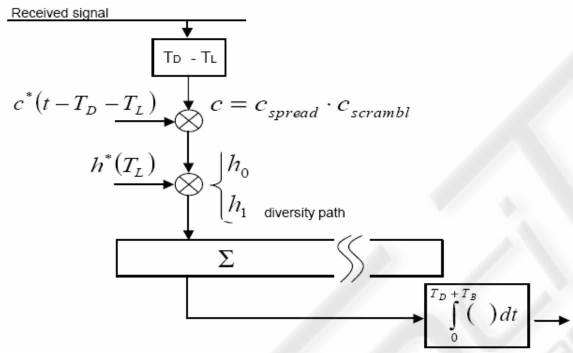


Figure 4: Schematics of STTD encoder



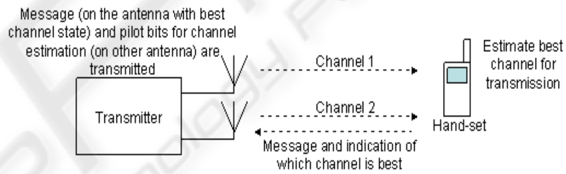


Figure 5 – Schematics of STD algorithm

Figure 6: STTD reception scheme

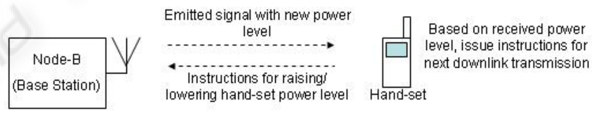


Figure 7: Schematics of downlink Power Control algorithm

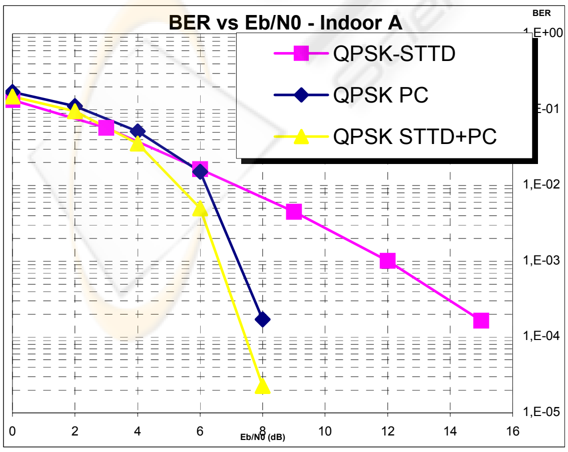


Figure 8: HSDPA BER results for Indoor A (PC, STTD and PC+STTD)

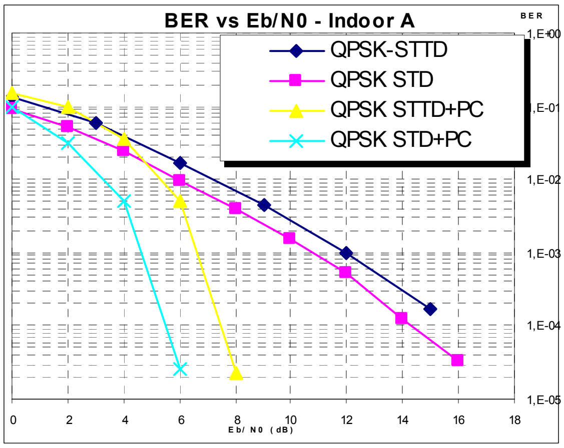


Figure 9: HSDPA BER results for Indoor A (Comparison of STD and STTD, with and without PC)

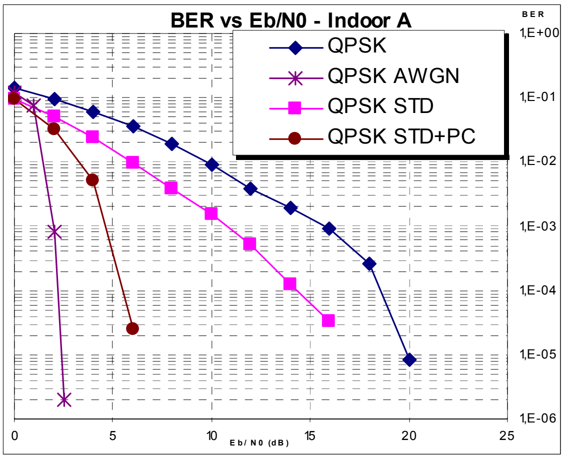


Figure 10: HSDPA BER results for Indoor A
(Normal, STD, PC+STD and AWGN)

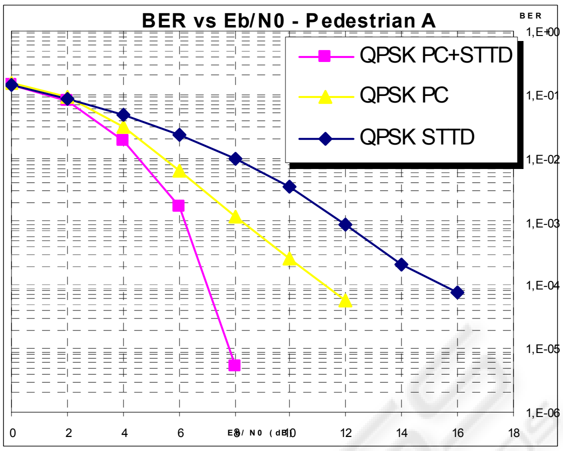


Figure 11: HSDPA BER results for PedestrianA
(PC, STTD and PC+STTD)

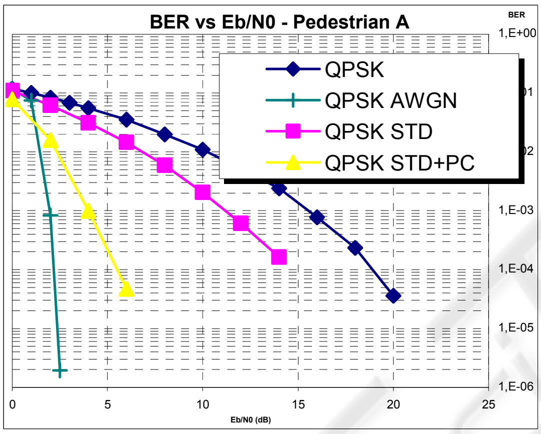


Figure 12: HSDPA BER results for PedestrianA
(Normal, STD, PC+STD and AWGN)

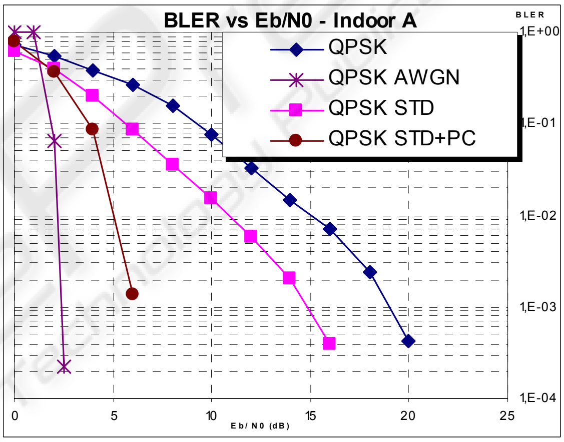


Figure 13: HSDPA BLER results for IndoorA
(Normal, STD, PC+STD and AWGN)

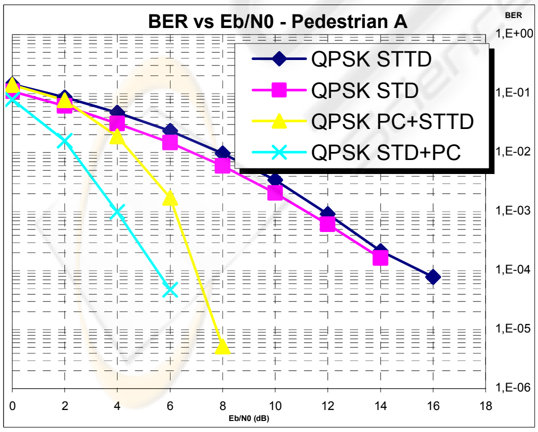


Figure 14: HSDPA BER results for PedestrianA
(Comparison of STD and STTD, with and without PC)

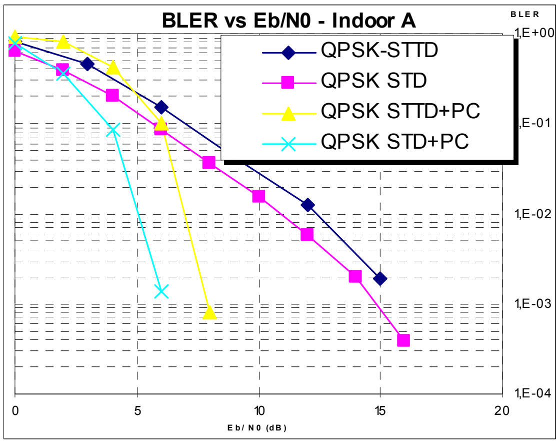


Figure 15: HSDPA BLER results for IndoorA
(Comparison of STD and STTD, with and without PC)

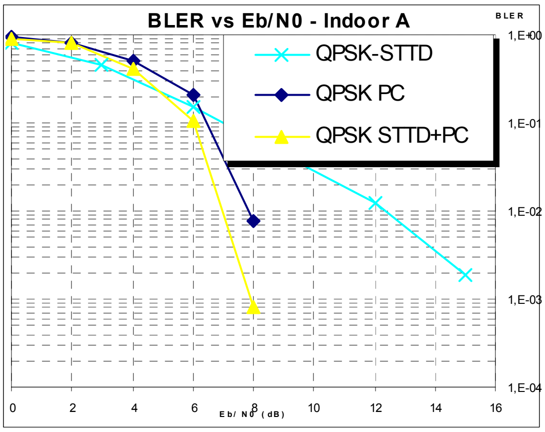


Figure 16: HSDPA BLER results for IndoorA (PC, STTD and PC+STTD)

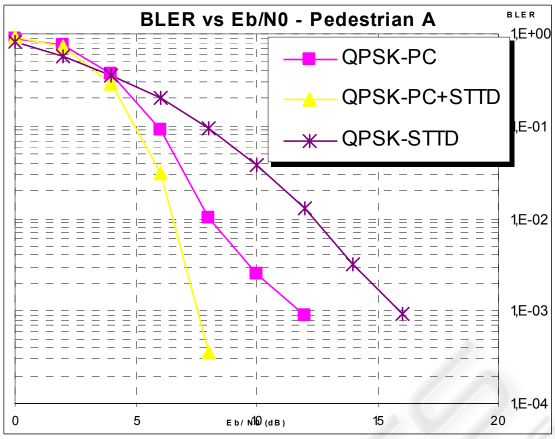


Figure 17: HSDPA BLER results for PedestrianA (PC, STTD and PC+STTD)

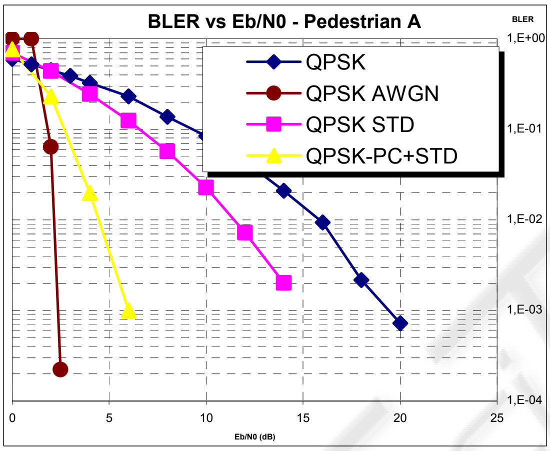


Figure 18: HSDPA BLER results for PedestrianA (Normal, STD, PC+STD and AWGN)

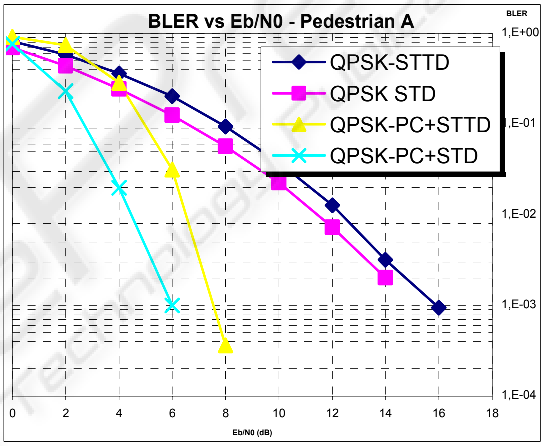


Figure 19: HSDPA BLER results for PedestrianA (STD and STTD, with and without PC)

BLER of 0,1		
Channel	Scheme	Eb/N0
AWGN	none	1.7
IndoorA	none	9.3
	STD	5.7
	STTD	7
	PC	6.5
	PC+STD	3.7
	PC+STTD	6
PedestrianA	none	9.3
	STD	6.5
	STTD	8
	PC	6
	PC+STD	2.7
	PC+STTD	5

Figure 20: Results for BLER of 0,1

BLER of 0,01		
Channel	Scheme	Eb/N0
AWGN	none	2,3
IndoorA	none	15
	STD	11
	STTD	12,3
	PC	7,7
	PC+STD	5
	PC+STTD	7
PedestrianA	none	16
	STD	11,3
	STTD	12,3
	PC	8
	PC+STD	4,5
	PC+STTD	6,5

Figure 21: Results for BLER of 0,01