Performance Analysis of PCFICH and PDCCH LTE Control Channel

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***Abstract*—Control channels play a key role in the evaluation of mobile system performance. Authors have evaluated the performance of control channels implementation in a Long Term Evolution (LTE) system. The paper deals with simulating a complete signal processing chain for the Physical Control Format Indicator Channel (PCFICH) and Physical Downlink Control Channel (PDCCH) in an LTE system, Release 8. We implemented a complete signal processing chain for downlink control channels as an extension of the existing MATLAB LTE downlink simulator. The paper shows results of the PCFICH and PDCCH control channel computer performance analysis in various channel conditions. The presented results can be compared with the performance of data channels.**

Keywords-Long Term Evolution; Physical Control Format Indicator Channel; Physical Downlink Control Channel; MATLAB; link level simulator;

I. Introduction

Link level simulators are typically focused in the performance analysis of traffic channels [1], [2]. For an overall system performance and comparison with real network deployment it is necessary to include control channels in the simulations. Control channels are typically designed with more robust forward error correction and modulation than traffic channels. In the case of the 3GPP LTE system, the Orthogonal Frequency Division Multiple Access (OFDMA) access method and robust scrambling of control channel information is used [3], [4].

Our motivation is to implement control channels as an extension of the existing MATLAB LTE downlink simulator developed at Vienna University of Technology. After completion of the model of control channels, we can look into the influence of the propagation environment to overall throughput of the LTE system, using computer simulation.

The paper is organized as follows. First the LTE system is described briefly. The next part brings a short description of the signal processing chain of surveyed control channels. Simulation and their results are mentioned in the third part and it is summarized in the conclusion.

II. LTE Physical Channels

The LTE physical layer in a downlink includes a triplet of control channels [5], [6]. The list of LTE control channels in downlink and their control information is shown in Table I.

TABLE I
LIST OF LTE CONTROL CHANNELS - DOWNLINK

Control Information	Corresponding Physical Control Channel
CFI	Physical Control Format Indicator Chan. (PCFICH)
HI	Physical Hybrid-ARQ Indicator Channel (PHICH)
DCI	Physical Downlink Control Channel (PDCCH)

The above-mentioned control physical channels are not used to transfer information from higher layers [7]. They are not associated with transport channels. This article deals with signal processing and Bit error rate (BER) in the Physical Control Format Indicator Channel and Physical Downlink Control Channel, performance analysis of the Physical Hybrid-ARQ Control Channel is not included.

A. Physical Control Format Indicator Channel (PCFICH)

Via this channel, the Control Format Indicator (CFI) is transmitted. The value stored in CFI determines the number of resource elements in the resource grid (in time domain) carrying the data of the PDCCH control channel. It determines a PDCCH control area in each subframe in downlink. PCFICH is transmitted in the first OFDM symbol in the resource grid [3].

The CFI parameter takes values 1, 2 or 3 only. The block diagram of PCFICH signal processing is shown in Fig. 1. The first operation in the signal processing chain is channel coding. A bit sequence of 32 bits in length is assigned to each value in CFI, according to Table II.

A codeword of 32 bits in length is scrambled with a pseudo-random scrambling sequence, which is unique for

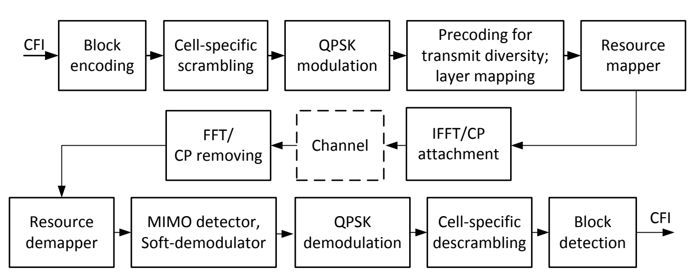

Figure 1. PCFICH processing chain.

TABLE II
PCFICH CHANNEL CODING

CFI	CFI codeword $[b_0, b_1, \ldots, b_{31}]$
1	[01101101101101101101101101101101]
2	[10110110110110110110110110110110]
3	[11011011011011011011011011011011]
4 (reserved)	[00000000000000000000000000000000]

each cell. The scrambled bits are modulated by QPSK modulation and this block of complex-value symbols is mapped into ν-layers, depend on the number of transmitting antennas, where $\nu = \{1, 2, 4\}$. In the case of one transmitting antenna, layer mapping is not used. In the case of one transmitting antenna, transmit diversity precoding is not provided [8]. In the case of two or four transmitting antennas, it is necessary to provide precoding for transmit diversity.

Complex symbols for each transmitting antenna are grouped to quaternary symbols, so-called symbol quadruplets, which are mapped to defined positions in the resource grid [9]. Furthermore, a IFFT operation with symbols in the resource grid is performed and cyclic prefix (CP) is inserted.

After passing through the channel, CP is removed and FFT is performed. In a resource demapping block, PCFICH symbols are collected. When using more than one transmitting antenna, MIMO detection is provided. Complex-value symbols are demodulated and descrambled by pseudo-random sequention which is the same as in the transmitter. The last part of the signal processing chain is a CFI codeword detection block.

B. Physical Downlink Control Channel (PDCCH)

Physical Downlink Control Channel is the most important control channel in a downlink. It supports signalling for data channels in downlink and uplink. Via this channel Downlink Control Information (DCI) is transmitted.

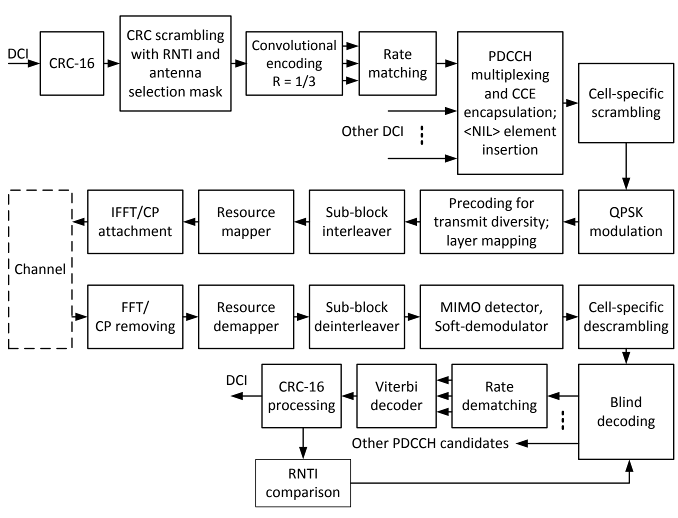

Figure 2. PDCCH processing chain.

PDCCH supports various formats of DCI messages [10]. They contain information about resource scheduling for downlink and uplink, Transmit Power Commands (TPC), etc.

The block diagram of the PDCCH signal processing chain is shown in Fig. 2. Individual DCI messages of different formats are channel encoded. Cyclic redundancy check (CRC-16) of 16 bits in length is added to the DCI message [4]. Afterwards, the CRC is scrambled with a Radio Network Temporary Identifier (RNTI) value and antenna's mask if needed. The next block in the processing chain is a convolutional encoder with coding rate R=1/3. In the rate matching block, interleaving is provided and decreases the length of the encoded DCI message.

These operations with all DCI messages are provided in parallel and these messages come into a PDCCH multiplexing block. The encoded DCI messages are encapsulated into so-called Control Channel Elements (CCE). These elements are mapped into individual PDCCH formats. The PDCCH frame is scrambled in the same way as in the case of PCFICH.

Scrambled bits are modulated by QPSK modulation and then form a block of complex-value symbols which are mapped into ν-layers and precoding for transmit diversity is performed. These symbols, split into ν-parallel streams and mapped to the quadruplets of symbols are interleaved using Free-quadratic Permutation Polynomial technology (QPP). When the interleaving is performed, quadruplets are mapped into defined positions in the resource grid. A distribution of PDCCH quadruplets is given by a value in CFI.

Further, complex-valued symbols are transferred into the time domain by using an IFFT and CP is added. After passing through the channel, on the receiving side, CP is removed and FFT is performed. In the resource demapper block, a matrix of PDCCH symbols and a matrix of corresponding channel coefficients $\mathbf{H}_{\mathrm{PDCCH}}^{-1}$ are collected. Reverse interleaving is performed with both of these matrices. Modified symbols lead into the MIMO detector and soft-demodulator. A vector of demodulated bits is descrambled by the same cell-specific pseudo-random sequence as in the transmitting side and blind decoding is performed.

III. SIMULATIONS

Performance analysis of the LTE link level simulator is usually presented only for traffic channels [1]. The fundamental performance analysis of control channels is mentioned in [11] for PCFICH and PHICH. Similar problem examines [12], which presents PDCCH performance analysis results in AWGN channel model.

As was mentioned, the Link level simulator was used as a basic physical layer model of LTE. The simulator was developed at the Vienna University of Technology [1]. The model was extended by adding control channels. A performance analysis was done; the physical layer BER

 ISBN: 978-1-61208-262-2

TABLE III
SIMULATION PARAMETERS

Parameters	Description
Frame structure	FDD
System bandwidth	1.4 MHz
Cyclic prefix	Normal and extended
Antenna configuration	1×1, 2×1, 2×2, 4×1, 4×2
Subcarrier spacing	15 kHz
Channel estimation method	Perfect
Receiving algorithm	Soft-sphere decoder (SSD)

performance of PCFICH and PDCCH and their results are presented in this section. The main parameters of the simulation system are listed in Table III.

The simulator works with an FDD frame structure only. Due to a system bandwidth of 1.4 MHz, there were 6 resource element blocks (RB). In the case of using the CP with normal duration, there are 7 OFDM symbols in one slot (the first OFDM symbol in the slot has greater duration than the others [3]). In the case of using the CP with

TABLE IV
PARAMETERS OF PEDESTRIAN B AND VEHICULAR A CHANNEL MODEL

Pedestrian B		Vehicular A	
Av. Power [dB]	Delay [ns]	Av. Power [dB]	Delay [ns]
0.0	0	0.0	0
−0.9	200	−1.0	310
−4.9	800	−9.0	710
−8.0	1200	−10.0	1090
−7.8	2300	−15.0	1730
−23.9	3700	−20.0	2510

TABLE V
PARAMETERS OF TYPICAL URBAN AND RURAL AREA CHANNEL MODEL

Typical Urban				Rural Area	
Av. Power [dB]	Delay [ns]	Av. Power [dB]	Delay [ns]	Av. Power [dB]	Delay [ns]
−5.7	0	−17.4	1349	−5.2	0
−7.6	217	−19.0	1533	−6.4	42
−10.1	512	−19.0	1535	−8.4	101
−10.2	514	−19.8	1622	−9.3	129
−10.2	517	−21.5	1818	−10.0	149
−11.5	674	−21.6	1836	−13.1	245
−13.4	882	−22.1	1884	−15.3	312
−16.3	1230	−22.6	1943	−18.5	410
−16.9	1287	−23.5	2048	−20.4	469
−17.1	1311	−24.3	2140	−22.4	528

TABLE VI
COMPARISON OF THE SIMULATION RESULTS OF MINIMAL SNR FOR BER EQUAL TO 10^{-4} IN PCFICH CHANNEL - NORMAL CP

Antenna configuration	Minimal SNR value in dB for different channel model type				
$N_{TX} \times N_{RX}$	AWGN	Ped B	Veh A	TU	RA
1×1	0.8	9.6	11.4	8.5	16.2
2×1	1.0	5.8	5.7	4.8	8.5
2×2	−2.2	0.0	0.0	−0.2	1.5
4×1	0.8	3.8	3.5	3.0	4.7
4×2	−2.2	−1.0	−0.4	−1.0	−0.3

TABLE VII
COMPARISON OF THE SIMULATION RESULTS OF MINIMAL SNR FOR BER EQUAL TO 10^{-4} IN PCFICH CHANNEL - EXTENDED CP

Antenna configuration	Minimal SNR value in dB for different channel model type				
$N_{TX} \times N_{RX}$	AWGN	Ped B	Veh A	TU	RA
1×1	0.7	10.5	10.5	8.6	13.5
2×1	0.8	5.5	6.6	4.6	8.6
2×2	−2.3	−0.2	1.0	0.5	1.7
4×1	0.7	3.8	3.7	3.6	4.6
4×2	−2.2	−1.0	−0.7	−0.5	−0.2

extended duration there are 6 OFDM symbols in one slot. The Soft-sphere receiving algorithm was used. Used fading channel models and their specification are listed in Table IV and Table V. All used fading channel models are included in the basic LTE simulator.

A. Performance Analysis of the PCFICH

The results of the PCFICH control channel transmission simulation and subsequently, analysis of BER depending on the Signal to Noise Ratio (SNR) for all antenna configuration and models of used transmission channels are listed in this section. The BER is calculated from the two- bit CFI values at the beginning and at the end of the transmission chain. The PCFICH BER curves sorted according to the available antenna configurations and both types of CP are shown in Fig. 3 to 7.

The summarized results of PCFICH BER in configuration with normal CP are shown in Table VI. The summarized results of PCFICH BER in configuration with extended CP are shown in Table VII. Here we see values of SNR at which the BER in PCFICH channel reaches the reference level of 10^{-4}. In the presented figures, observe the BER curves for configuration with normal CP length and extended CP length are without marked differences. The

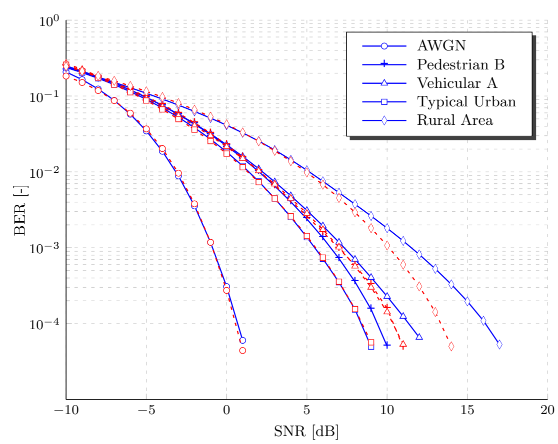

Figure 3. BER of the PCFICH for 1 transmitting and 1 receiving antenna (CP: normal - blue solid line, extended - red dotted line).

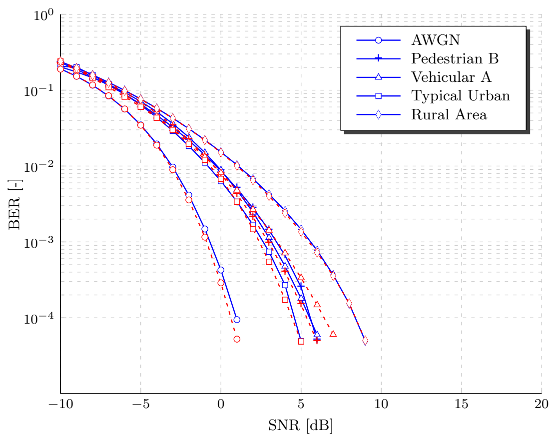

Figure 4. BER of the PCFICH for 2 transmitting and 1 receiving antenna (CP: normal - blue solid line, extended - red dotted line).

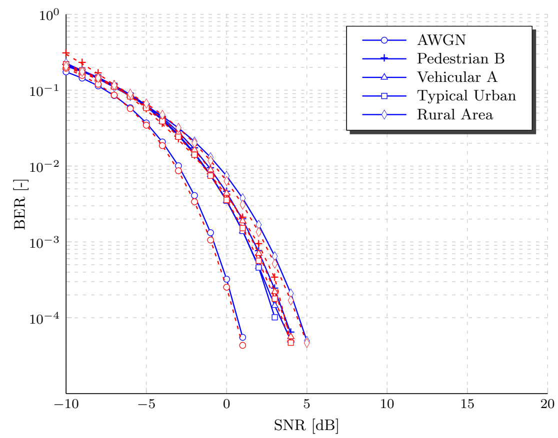

Figure 6. BER of the PCFICH for 4 transmitting and 1 receiving antenna (CP: normal - blue solid line, extended - red dotted line).

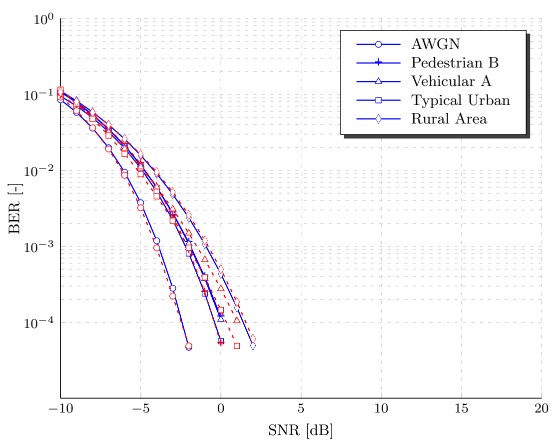

Figure 5. BER of the PCFICH for 2 transmitting and 2 receiving antennas (CP: normal - blue solid line, extended - red dotted line).

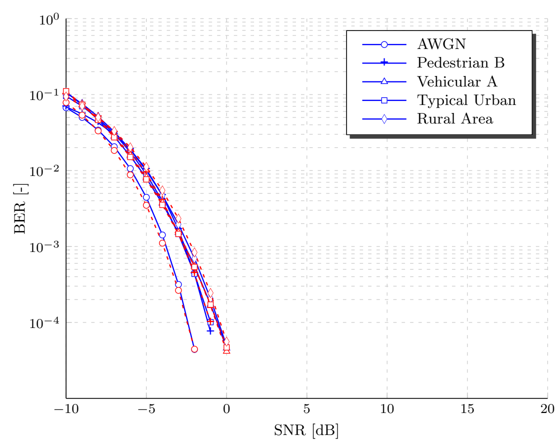

Figure 7. BER of the PCFICH for 4 transmitting and 2 receiving antennas (CP: normal - blue solid line, extended - red dotted line).

figure configured with 1 transmitting and 1 receiving antenna shows the greatest difference in the case of the rural area channel model. In this case, for extended CP, the coding gain is 2.7 dB.

B. Performance Analysis of the PDCCH

The results of the PDCCH control channel transmission simulation and subsequently, analysis of BER depending on the SNR for all antenna configurations and models of used transmission channels are listed in this section. The BER is calculated from the DCI value in bits (format 0 - set as the test case) at the beginning and at the end of the transmission chain. The PDCCH BER curves sorted according to the available antenna configurations are shown in Figs. 8 to 12.

The summarized results of PDCCH BER configured with normal CP are shown in Table VIII. The summarized results of PDCCH BER configured with extended CP are shown in Table IX. Here we see values of SNR at which BER in the PDCCH channel reaches the reference level of 10^{-4}. In Fig. 8, we can observe that simulations fail in all models of fading channels and both types of CP. The BER curves

TABLE VIII
COMPARISON OF THE SIMULATION RESULTS OF MINIMAL SNR FOR BER EQUAL TO 10^{-4} IN PDCCH CHANNEL - NORMAL CP

Antenna configuration $N_{TX} \times N_{RX}$	Minimal SNR value in dB for different channel model type: AWGN	Ped B	Veh A	TU	RA
1×1	5.9	–	–	–	–
2×1	6.0	13.6	13.4	13.0	16.2
2×2	2.9	6.2	6.8	5.9	8.5
4×1	5.9	15.2	14.8	16.0	15.1
4×2	2.7	7.0	7.0	7.9	6.8

TABLE IX
COMPARISON OF THE SIMULATION RESULTS OF MINIMAL SNR FOR BER EQUAL TO 10^{-4} IN PDCCH CHANNEL - EXTENDED CP

Antenna configuration $N_{TX}\times N_{RX}$	Minimal SNR value in dB for different channel model type AWGN	Ped B	Veh A	TU	RA
1×1	5.8	–	–	–	–
2×1	5.8	12.6	13.8	13.8	15.8
2×2	2.9	6.7	6.6	6.7	7.8
4×1	5.7	–	13.3	–	13.9
4×2	2.9	7.8	6.7	7.8	6.4

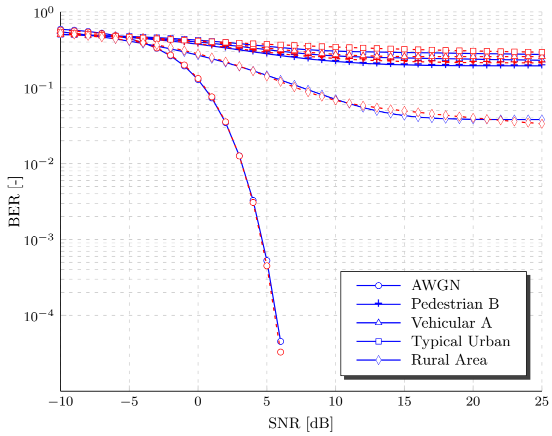

Figure 8. BER of the PDCCH for 1 transmitting and 1 receiving antenna (CP: normal - blue solid line, extended - red dotted line).

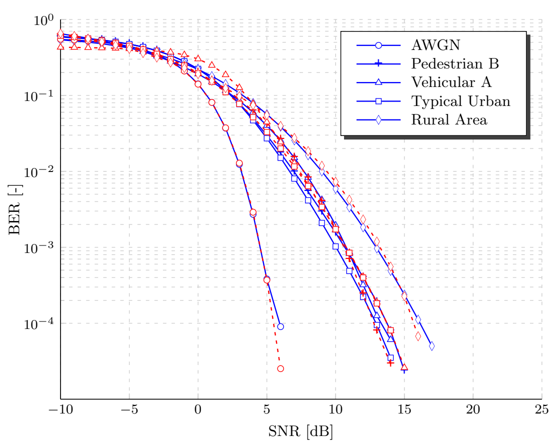

Figure 9. BER of the PDCCH for 2 transmitting and 1 receiving antenna (CP: normal - blue solid line, extended - red dotted line).

reach the reference value of BER in the case of the AWGN channel model only. In this case the convolutional encoding aborts. In Fig. 11, extended CP, BER for Pedestrian B and TU channel models reach BER= 10^{-3} only. This abnormality is caused by ISI.

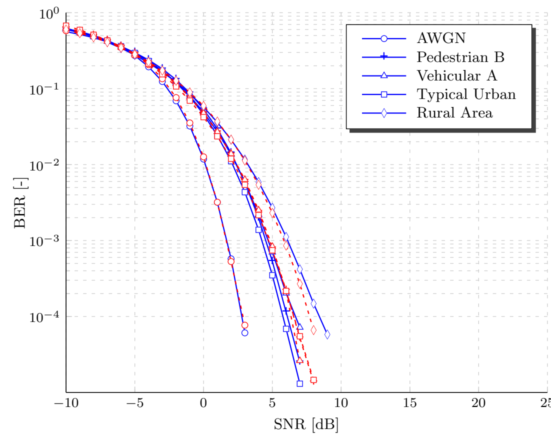

Figure 10. BER of the PDCCH for 2 transmitting and 2 receiving antennas (CP: normal - blue solid line, extended - red dotted line).

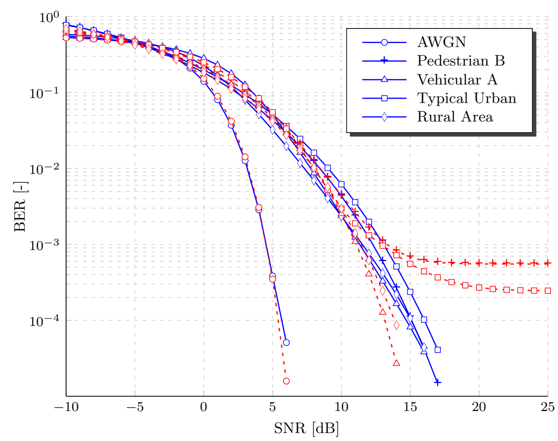

Figure 11. BER of the PDCCH for 4 transmitting and 1 receiving antenna (CP: normal - blue solid line, extended - red dotted line).

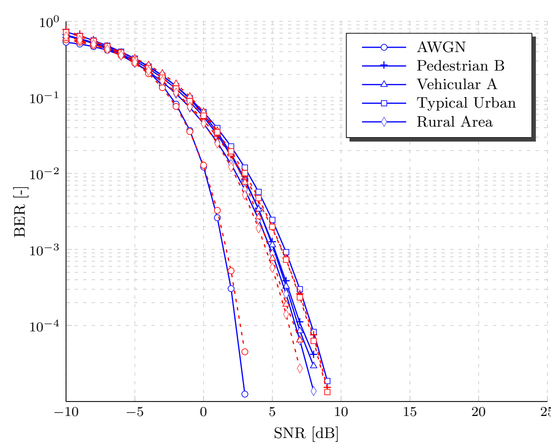

Figure 12. BER of the PDCCH for 4 transmitting and 2 receiving antennas (CP: normal - blue solid line, extended - red dotted line).

IV. CONCLUSION

In this paper, the PCFICH and PDCCH LTE downlink control channels were analyzed and simulated. The paper is focused on studying two selected control channels due to their functions being linked together. The performance of these two control channels was analyzed in AWGN channel model and in basic types of fading channels. As we can see from the presented graphs, the PCFICH BER is markedly lower than the PDCCH BER. It is given by the size of transmitted data and used channel coding. While in the case of the PCFICH channel, a two-bit CFI codeword is carried and this codeword is spread with SF $= 16$, whereas in the case of the PDCCH, many more bits are transmitted. In particularly bad cases of some fade channels, the used convolutional encoder fails, despite the use of other error protection techniques.

The BER curves for normal or extended CP length are without marked differences. In the case of PCFICH analysis, usage of transmitting diversity brings expected results. In the case of PDCCH analysis, results from the antenna configuration with one transmitting and one receiving antenna (SISO mode) are absolutely unusable in all types of fading channels for normal and extended CP length. However, these are only results from computer analysis. In a real LTE system, the SISO mode is very usable. In the case of four transmitting and one receiving antenna for extended CP length, the BER curves for Pedestrian B and Typical Urban channel model reach a BER value of 10^{-3} only. It is caused by ISI in this computer simulation.

As a further phase of the downlink control channel analysis, simulations impacting BER in control channels on overall throughput of the LTE system will be performed.

ACKNOWLEDGMENT

The authors would like to thank the support of the project CZ.1.07/2.3.00/20.0007 WICOMT, financed from the operational program Education for competitiveness, SIX project no. CZ.1.05/2.1.00/03.0072 and SYWIC project LD11081 in frame of COST IC 0906, are gratefully acknowledged.

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 ISBN: 978-1-61208-262-2