Analysis of LTE Physical Hybrid ARQ Control Channel

Jiri MILOS, Stanislav HANUS

Dept. of Radio Electronics, Faculty of Electrical Engineering and Communication, Brno University of Technology, Technicka 12, 612 00 Brno, Czech Republic

xmilos01@stud.feec.vutbr.cz, hanus@feec.vutbr.cz

Abstract—**A Physical Hybrid ARQ Indicator Channel (PHICH) is a very important element of the Long Term Evolution (LTE), Release 8 communication system. Via the PHICH, a Hybrid ARQ Indicator (HI) acknowledge message is transmitted. The HI informs the result if the previous data transfer in uplink direction. Imperfect protection of PHICH transfer can cause superfluous repetitions of incorrect confirmed data and uplink overhead grows. In the paper, the PHICH signal processing and performance results of a single HI message in AWGN and fading channel models are presented depending on the representative antenna modes. The performance results for a number of HI messages greater than one within a single PHICH group, have not been found.**

Index Terms—**BER, Link level simulator, LTE, MATLAB, PHICH.**

I. Introduction

For transmitting user data in the LTE (Release 8) communication standard in uplink direction the Physical Uplink Shared Channel (PUSCH) is used. Reliability of data transmission via PUSCH is achieved in two ways. The first, traffic data payload is coded by Turbo channel coding and the second, LTE employs a Hybrid Automatic Repeat Request (HARQ) technique [1, 2]. In uplink direction, the synchronous adaptive HARQ is used. The New Data Indicator (NDI) and the corresponding HARQ indicator (HI) indicate if the previous transmission in uplink was correct or if the received data was erroneous. A Physical HARQ Indicator Channel (PHICH) forms a feedback channel for HI transmission in downlink direction. The HI value of 0 represents non-acknowledge (NACK) and the HI value of 1 represents acknowledge (ACK) [3, 4]. One or up to eight HARQ Indicators forms a vector called PHICH message or PHICH.

For PUSCH transmissions in subframe with index n, the UE determines the corresponding PHICH message in subframe with index $n+k_{\mathrm{PHICH}}$, where $k_{\mathrm{PHICH}}=4$ only for frame structure type 1 (FDD). For frame structure type 2 (TDD), the k_{PHICH} is defined in [5]. The corresponding uplink and downlink subframes for frame structure type 1 is depicted in Fig. 1. The PHICH message with a single or multiple HARQ Indicators is mapped to the identical set of resource elements and form a PHICH group. The individual HI within the PHICH message is separated by eight different orthogonal sequences for normal cyclic prefix (CP) length and four orthogonal sequences defined for extended CP length [3, 6]. Identification of the PHICH resource is defined by a pair of parameters $\left(N_{\mathrm{PHICH}}^{\mathrm{group}}, N_{\mathrm{PHICH}}^{\mathrm{seq}}\right)$, where $N_{\mathrm{PHICH}}^{\mathrm{group}}$ is the number of the PHICH group and $N_{\mathrm{PHICH}}^{\mathrm{seq}}$ is the orthogonal sequence index within the PHICH group.

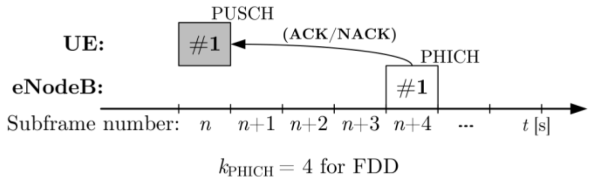

Figure 1. Scheme of the corresponding PUSCH and PHICH information in subframe for frame structure type 1

The number of PHICH groups is different for FDD and TDD frame structures. For an FDD frame structure (type 1), the number of PHICH groups is constant in all subframes and is defined by (1).

$$N_{\mathrm{PHICH}}^{\mathrm{group}}=\begin{cases}\left\lceil N_g\left(N_{\mathrm{RB}}^{\mathrm{DL}}/8\right)\right\rceil \text{... normal CP}\\ 2\times\left\lceil N_g\left(N_{\mathrm{RB}}^{\mathrm{DL}}/8\right)\right\rceil \text{... extended CP}\end{cases} \tag{1}$$

Parameter $N_g \in \left\{\frac{1}{6},\frac{1}{2},1,2\right\}$ is a scaling factor and it is provided by higher layers. The index of the PHICH group $N_{\mathrm{PHICH}}^{\mathrm{group}}$ ranges from 0 to $N_{\mathrm{PHICH}}^{\mathrm{group}}-1$. The parameter N_g is broadcasted in the Master Information Block (MIB) in downlink. For TDD frame structure (type 2), the number of PHICH groups may vary between downlink subframes and is given by the formula $m_i \times N_{\mathrm{PHICH}}^{\mathrm{group}}$, where the factor m_i (uplink/downlink configuration) is defined in [7]. The single PHICH group can contain up to 8 individual HI (normal CP) according to the number of possible orthogonal sequences.

Performance analysis results of wireless cellular standards are usually presented for traffic channels only. The analysis of the control channel performance is only a marginal problem. The performance analysis of PHICH LTE-FDD control channels was presented in [8] on a theoretical base only. Link level performance results of PHICH for physical antenna port in Vehicular A channel model were published in [9]. A complex performance analysis of the PHICH in AWGN and used fading channel models, depending on used antenna configuration and number of PHICH's greater than one, is missing.

The paper is organized as follows. First, the HARQ technique in LTE is described briefly. The next part describes PHICH signal processing in detail. Simulation

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results of the PHICH in AWGN and basic fading channel models for number of PHICH (n_{PHICH}) equal to one within a single PHICH group are mentioned in the third part together with simulation results where n_{PHICH} equals up to 8 in single transmitting and single receiving antenna (SISO) mode in AWGN channel model. All simulation results are summarized in the conclusion.

II. Physical Hybrid ARQ control channel

In the case of PHICH, emphasis was put on the overall simplicity of channel coding and decoding process. The complete PHICH channel coding processing is shown in Fig. 2. First, the individual HI message is channel coded by repetition coding with code rate $R = 1/3$, which results in a vector of bits $\mathbf{b} = [b_0, b_1, b_2]$ according to Table I.

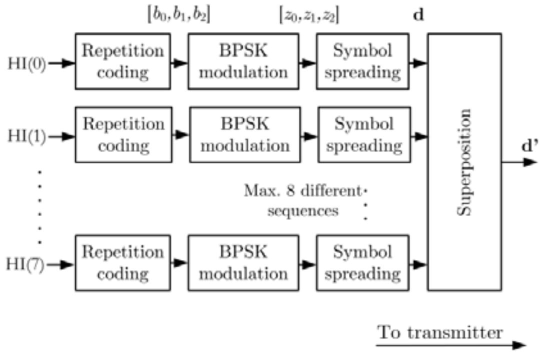

Figure 2. PHICH channel coding signal processing chain

Using the repetition coder is very simple [10]. Triplicating the individual HI together with the modulation scheme and symbol spreading should provide better conditions for receiving. This type of signal processing in the channel coder block allows to use a simple version of decoding mechanism – matched filter. The overall spreading factor can be defined as the multiplication of the repetition coder code rate R and the orthogonal sequence spreading factor $N_{\mathrm{SF}}^{\mathrm{PHICH}}$. In the case of normal CP, the overall spreading factor equals 12. This value gives the length of the matched filter in the receiver.

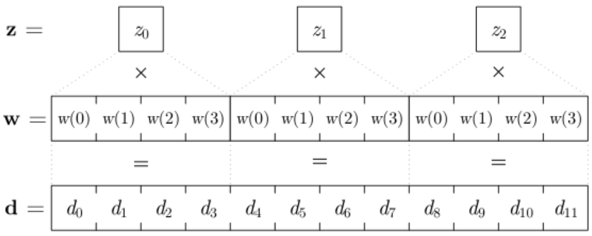

Figure 3. Symbol spreading of individual modulated symbol z (normal cyclic prefix length, $N_{\mathrm{SF}}^{\mathrm{PHICH}} = 4$)

Individual bits in HI codeword $\mathbf{b}$ are modulated using BPSK modulation and produce a vector of complex-valued symbols $\mathbf{z} = [z_0, z_1, z_2]$. Each element of the $\mathbf{z}$ vector is symbol spread using the orthogonal sequence $\mathbf{w} = \left[w(0), \ldots, w\left(N_{\mathrm{SF}}^{\mathrm{PHICH}} - 1\right) \right]$ and form a vector of complex-valued symbols $\mathbf{d}$ [7]. The scheme of symbol spreading is illustrated in Fig. 3.

TABLE I. HARQ INDICATOR CHANNEL CODING

HI	HI codeword $\mathbf{b} = [b_0, b_1, b_2]$
0 (NACK)	$[0,0,0]$
1 (ACK)	$[1,1,1]$

The above mentioned operations are provided stepwise with the individual HI. All of the processed symbol vectors $\mathbf{d}_{n_{\mathrm{PHICH}}^{\mathrm{seq}}}$ within one PHICH group are combined with the other corresponding $\mathbf{d}_{n_{\mathrm{PHICH}}^{\mathrm{seq}}}$ sequences. The superposition is defined by equation (2).

$$d'(n) = \sum_{n_{\mathrm{PHICH}}^{\mathrm{seq}}}^{\max\left(n_{\mathrm{PHICH}}^{\mathrm{seq}}\right)} d_{n_{\mathrm{PHICH}}^{\mathrm{seq}}}(n) \qquad (2)$$

where $d'(n)$ is the n-th element of the resulting complex-valued vector $\mathbf{d'}$ after superposition combining, $d_{n_{\mathrm{PHICH}}^{\mathrm{seq}}}(n)$ is the n-th element of the individual symbol-spread vector $\mathbf{d}_{n_{\mathrm{PHICH}}^{\mathrm{seq}}}$ and n is the index of the element [7, 11].

In the case of $n_{\mathrm{PHICH}} > 1$ the superposition process (2) creates different modulation schemes than BPSK. The resulting modulation scheme of the PHICH channel depends on the number of PHICHs within a single PHICH group.

Every possible combination of logical values of $\mathrm{HI}(0), \mathrm{HI}(1), \ldots, \mathrm{HI}(\max(n_{\mathrm{PHICH}}^{\mathrm{seq}}))$ codewords has a characteristic pattern of modulation symbols. This fact is well used on the receiving side in the channel decoding process.

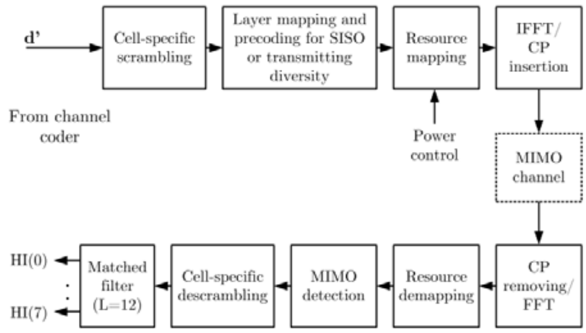

Figure 4. PHICH overall (TX-RX) signal processing chain

A subsequent PHICH signal processing chain is shown in Fig. 4 [12]. Channel coded information $\mathbf{d'}$ enter the block of cell-specific scrambling and there it is scrambled by using the cell-specific scrambling sequence [7].

The vector of scrambled symbols shall be mapped to υ-layers and precoded. The layer mapping operation is provided in a similar way as in PCFICH and PDCCH. The number of layers υ is defined by the system according to the number of transmitting antennas [7]. The PHICH is transmitted on the same set of antenna ports as the Physical Broadcast Channel.

The next operation is precoding for SISO mode or transmitting diversity (TxD). In the case of one transmitting antenna (SISO mode), precoding is not provided. In the case of two or four transmitting antennas, the Space-frequency diversity block code (SFBC) is used [3, 7]. In this block, the input matrix of layer mapped complex-valued symbols

$\mathbf{X}^{(\upsilon)}$ is precoded using SFBC and results to $\mathbf{Y}^{(\upsilon)}$.

TABLE II. PHICH POWER WEIGHT COEFFICIENTS ACCORDING TO THE VALUE OF n_{PHICH}

n_{PHICH}	1	2	3	4	5	6	7	8
$P_{\text{weight}}^{\text{PHICH}}$	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{3\sqrt{2}}$	$\frac{1}{2\sqrt{5}}$	$\frac{1}{5}$	$\frac{1}{4\sqrt{2}}$

Precoded symbols grouped in matrix $\mathbf{Y}^{(\upsilon)}$ are mapped into the defined elements (3 resource groups) in the resource grid, always to the first OFDM symbol (normal CP). In the case of $n_{\text{PHICH}} > 1$, it is necessary to perform power control by multiplying precoded symbols $\mathbf{Y}^{(\upsilon)}$ by the power weight coefficient $P_{\text{weight}}^{\text{PHICH}}$, according to Table II. Further, IFFT is provided and complex-valued symbols are transformed into the time domain and the CP is attached. After passing through the channel, the CP is removed and symbols are transformed back into the frequency domain using FFT.

On the receiving side, symbols corresponding with PHICH channel mapping are picked out from the resource grid together with estimated channel coefficients $\hat{\mathbf{H}}_{\text{PHICH}}$. MIMO detection is performed according to the number of transmitting and receiving antennas. The cell-specific descrambling block provides an inverse operation with the same scrambling sequence as into the transmitting side. The last operation on the receiving side is channel decoding. Using repetition coding and the fact that every possible combination of HI codeword creates the characteristic pattern of symbols allows to provide channel decoding in a fast and effectively way. A bit valued pattern of possible combinations corresponding with $\mathbf{d'}$ is known on the receiving side. Received bits are compared with patterns of possible HI combinations and individual HI are determined using a simple majority vote technique.

III. PHICH SIMULATIONS

As a base simulator, the Link level simulator is used [13, 14]. In the first phase, the missing PHICH channel model was added into the simulator. The second phase was focused on creating and testing the PHICH channel model and its implementation into the simulator. A performance analysis was made by way of analyzing the BER of the PHICH and the results are presented in this section.

The simulator only works with an FDD frame structure. The number of transmitted subframes was 5000 and 10000 (for simulations when $n_{\text{PHICH}} > 1$). Normal CP length and Soft-sphere decoders (SSD) were used. The first part of simulations was performed for $n_{\text{PHICH}} = 1$ in AWGN, Pedestrian B, Vehicular A, Typical Urban and Rural Area channel models with block fading [15]. Channel estimation is not used in simulator (perfect knowledge of channel parameters). The BER simulation results are presented depending on the antenna configuration (SISO and TxD mode).

The results of the PHICH simulation and BER analysis depending on the Signal-to-noise ratio (SNR) for the above mentioned antenna configurations and used AWGN and fading channel models are listed in this section. The PHICH BER curves according to the used antenna configurations are shown in Fig. 5–7. The simulations were provided for $n_{\text{PHICH}} = 1$ and the orthogonal sequence with index $n_{\text{PHICH}}^{\text{seq}} = 0$ was used. The PHICH BER was calculated from a one bit HI value at the beginning and at the end of the transmission chain. The value of SNR at which the BER in PHICH reaches the level 10^{-3} is called a SNR reference level. The SNR reference level is given by the target quality value for NACK to ACK or ACK to NACK error [16].

The BER curves for antenna configuration with one transmitting antenna and one receiving antenna [1×1] are shown in Fig. 5. When considering fading channel models only, the worst BER results are indicated for the Rural area channel model. In this case, the PHICH BER reference level was reached in SNR = 10 dB. The coding gain for other fading channel models is better by 3 to 4 dB. For the configuration with two transmitting antennas and one receiving antenna (TxD), the PHICH BER curves are shown in Fig. 6. The BER results for the Rural area channel model are better by 5.5 dB when compared with the [1×1] antenna configuration. The PHICH BER curves for antenna configuration [4×2] are shown in Fig. 7.

The results of the PHICH simulation and BER analysis depending on the SNR for configuration with 1 transmitting and 1 receiving antenna and used AWGN channel model for different n_{PHICH} value from 1 to 8 within a single PHICH group are shown in Fig. 8. The simulations were provided for $n_{\text{PHICH}} = 1,2,\ldots,8$ and the orthogonal sequences with index $n_{\text{PHICH}}^{\text{seq}} = 0,1,\ldots,7$ were used.

The PHICH BER values were calculated from a one to up to eight bits in length of HI value at the beginning and at the end of the transmission chain in dependence on the number of PHICHs within a single PHICH group. Note, that the Minimal SNR value in dB for $n_{\text{PHICH}} = 2$ is estimated from the trend of the curve. The simulation results for $n_{\text{PHICH}} = 1,2,\ldots,8$ are provided and shown for the configuration with used AWGN channel model and SISO antenna mode only due to transparency.

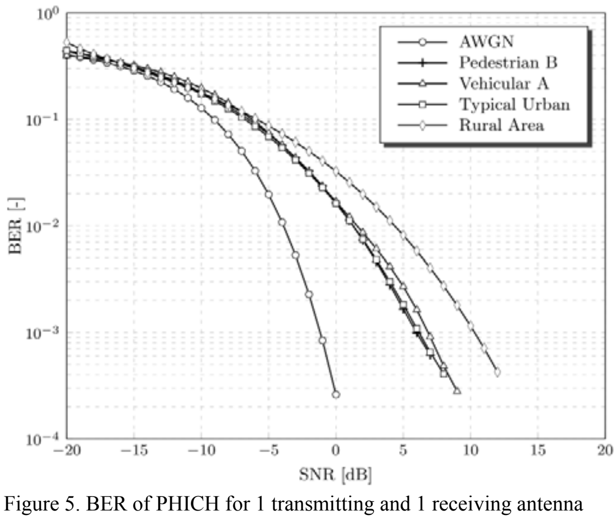

Figure 5. BER of PHICH for 1 transmitting and 1 receiving antenna

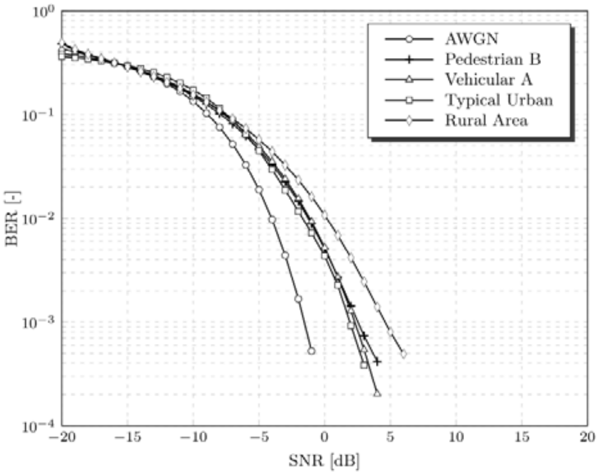

Figure 6. BER of PHICH for 2 transmitting and 1 receiving antenna

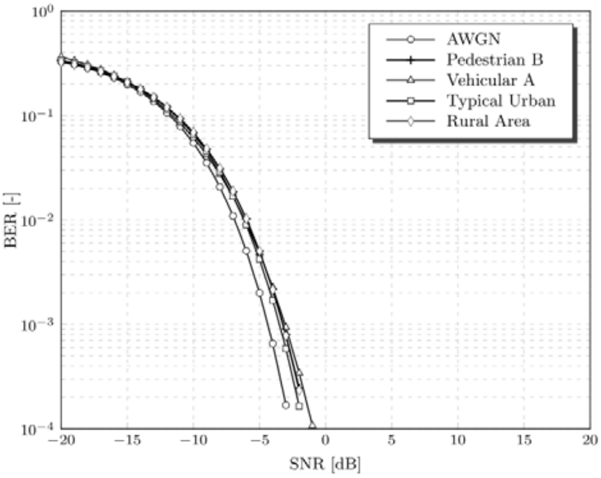

Figure 7. BER of PHICH for 4 transmitting and 2 receiving antennas

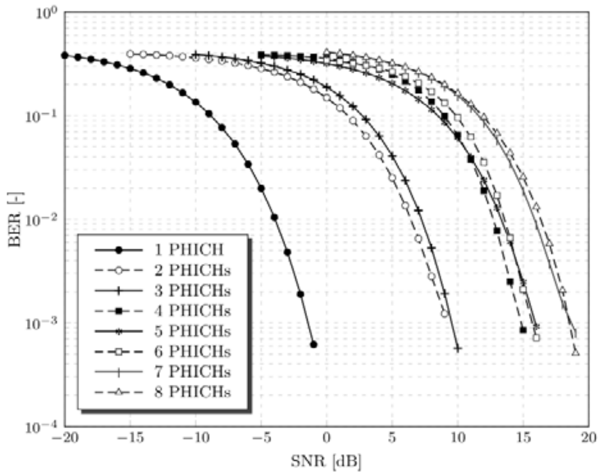

Figure 8. BER of PHICH for $n_{\mathrm{PHICH}} = 1,2,\ldots,8$ in AWGN channel model, 1 transmitting and 1 receiving antenna

As we can see in the Fig. 8, some curves for different numbers of PHICHs are grouped together with minimal differences in SNR value. Thus, in some cases, increasing or decreasing of the number of HI input bits has a minor influence on the BER value.

IV. Conclusion

The presented paper is focused on LTE PHICH signal processing and its performance analysis. The PHICH BER simulation results are presented in dependence on SISO or transmitting diversity antenna mode. Presented results for single HI indicate that PHICH is reliable for using in fading channels (especially if the environment is changed) if the transmitting diversity technique is used. The performance results for the case of n_{PHICH} is equal or greater than one show large difference between reference SNR values for 1 and 8 HI within a PHICH group. This fact is due to a large number of constellation symbols in the case of $n_{\mathrm{PHICH}} = 8$ and absence of a better channel coding technique instead of the repeat coding technique. On the other hand, it is compensated by great simplicity and efficiency of the decoding process. Absence of Gray coding also has an influence on the BER value.

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