Encoder and Decoder Implementation of LTE Physical Hybrid ARQ Indicator Channel (PHICH)

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Thank you very much.

Abstract

As mobile communication technologies have evolved rapidly during the last few years, wireless communication standards such as WiMax and LTE are developed with the need of new services on mobile devices. In this thesis, the design and implementation of the encoder and decoder of Physical Hybrid ARQ Indicator Channel (PHICH) of LTE are presented. PHICH carries Acknowledgements (ACKs) and Negative Acknowledgements (NACKs) from the base station (eNodeB) to the mobile devices (UE). The encoder is designed to encode the ACK/NACK sent from the base station to the UE while the decoder is designed to decode the encoded data and provide control information for the UE. The encoder and decoder are implemented in MATLAB.

Nomenclature

3GPP-Third Generation Partnership Project

ACK –Acknowledgement

CDMA - Code Division for Multiple Access

eNodeB - Base Station

EDGE - Enhanced Data for GSM Evolution

GPRS – General Packet Radio Service

GSM - Global System for Mobile Communications

HSDPA - High Speed Downlink Packet Access

HSUPA - High Speed Uplink Packet Access

LTE-Long Term Evolution

MIMO- Multiple Input Multiple Output

NACK - Negative Acknowledgement

PHICH - Physical Hybrid ARQ Indicator Channel

PUSCH - Physical Uplink Shared Channel

UE – User Equipment

WiMax – World Wide interoperability for Microwave Access

Contents

Declaration..ii
Approval Sheet..iii
Acknowledgements..iv
Abstract..v

Nomenclature vi

1 Introduction to LTE 1

1.1 Motivation for LTE..2

1.2 Parameters of LTE 2

2 Overview of LTE..4

2.1 Definitions and Symbols..4

2.2 Channels in LTE 6

2.2.1 Physical Uplink and Downlink Channels..6

2.2.2 Downlink Control Signaling..7

3 PHICH Transmitter 8

4 PHICH Receiver 13

4.1 Channel Estimation and Interpolation 13

4.2 PHICH Decoder..14

5 Results..17

6 Figures 19

References..20

Chapter 1

Introduction to LTE

The cellular wireless communications industry has witnessed a tremendous growth in the past decade with over four billion wireless subscribers worldwide. The first generation (1G) of analog cellular systems supported voice communication with limited roaming. The second generation (2G) of wireless standards like GSM (Global system for Mobile Communications), CDMA (Code Division for Multiple Access) promised higher capacity and better voice quality than did their analog counterparts. They provided data rates as high as 10kbps. In the later release of these standards, capabilities were introduced to support data transmission. A set of standards like GPRS (General Packet Radio Services) and EDGE (Enhanced Data for GSM Evolution) which are referred as standards between 2G and 3G (also called 2.5G) started providing data rates as high as 200 kbps. Both the GSM and CDMA camps formed their own separate 3G partnership projects (3GPP and 3GPP2) to develop IMT-200 compliant standards based on CDMA technology. The 3G standard in 3GPP is referred to as wideband CDMA (WCDMA) because it uses a larger 5 MHz bandwidth relative to 1.25 MHz bandwidth used in 3GPP2's CDMA2000 system. These standards provide data rate as high as 384 kbps. These standards support services like voice transmission, data transmission and video calling.

Other standards like HSDPA/HSUPA (High Speed Downlink/Uplink Packet Access) which are referred to as 3.5G claim to provide data rate as high as 30 Mbps.

The fourth generation (4G) of wireless standards like WiMax claim to provide data rate as high as 100-200 Mbps. The introduction of Mobile WiMax led both 3GPP and 3GPP2 to develop their own version of beyond 3G systems based on the OFDMA technology and network architecture similar to that in Mobile WiMax. The beyond 3G system in 3GPP is called Long Term Evolution (LTE) while 3GPP2's version is called UMB (Ultra Mobile Broadband). Apart from services provided by previous standards these standards support online gaming, HDTV, etc.

The evolution from 3G systems to LTE is driven by the development of mobile devices and the need for more services on mobile devices.

The need for more services on mobile devices is a result of the rapid spreading usage of the internet.

1.1 Motivation for LTE

1) **Increased subscribers:** There has been a exponential increase in the number of subscribers for High Speed Packet Access (HSPA).
2) **Growth of Mobile Data:** Because of the increased number of users and demand for better services there has been an explosion in the number and use of mobile applications (as shown in the figure 1). As a result the 2G and 3G networks started to become congested in the years around 2010, leading to a requirement to increase network capacity.
3) **Reduced Latency:** 3G networks introduce delays of the order of 100 ms for data applications, in transferring data packets between network elements and across the air interface. This is hardly acceptable as it creates a lot of trouble for more demanding application such as real time interactive games. Thus, another driver is the wish to reduce the end-to-end delay or latency in the network.

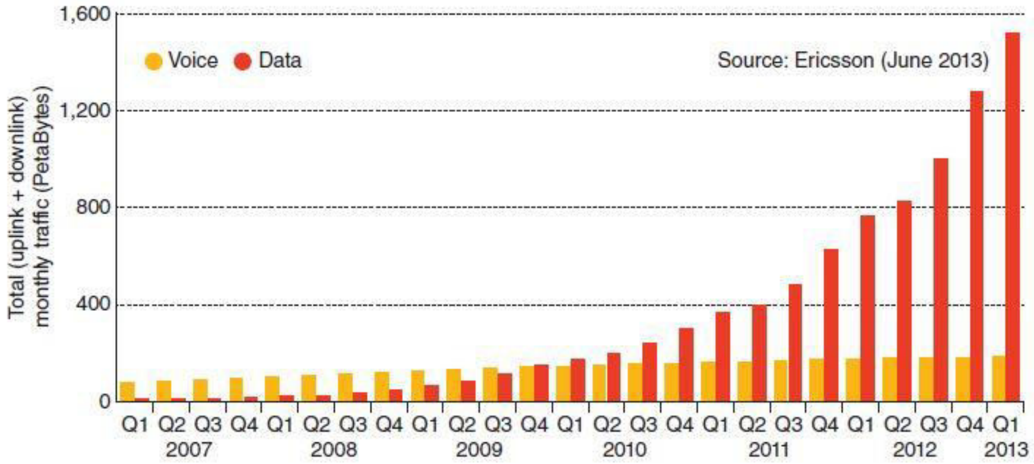


Figure 1

1.2 Parameters of LTE

1) **Data Rate:** Services like web browsing, online gaming and streaming require a very high data rate. LTE supports data rates as high as 100 Mbps on Downlink Channel and as high as 50 Mbps on Uplink Channel.

2) **Low Latency:** Services like online gaming which are based on real time operation require very low delay in the system. LTE supports very low latency.
3) **Flexibility:** Unlike previous standards like WCDMA which supported bandwidths of 5 MHz, LTE supports 6 bandwidths: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz , 15 MHz and 20 MHz. Thus higher spectrum flexibility is provided in LTE systems.
4) **Capacity:** As the bandwidth and number of base stations for mobile broadband are limited, capacity becomes a very important parameter in LTE systems. It is measured by the total data rate in the system averaged from each serving base station and per Hertz available spectrum. If the capacity of a system is low, the Quality of service of users may be degraded. Thus, a higher capacity is required in the LTE systems.
5) **Duplexing:** LTE supports FDD, TDD and half duplex FDD. FDD refers to transmission of data on two separate frequencies at the same time while TDD refers to transmission of data on the same frequency at different times.
6) **MIMO:** LTE supports 1×2, 1×4 configuration in the Uplink and 2×2, 4×2 and 4×4 configuration in the Downlink.

Chapter 2

Overview of LTE

2.1 Definitions and Symbols

UE: The terminal is referred as UE which stands for User Equipment.

Frame: For FDD LTE, the downlink transmission is processed by transmitting radio frames. The time of transmitting one radio frame is 10 ms.

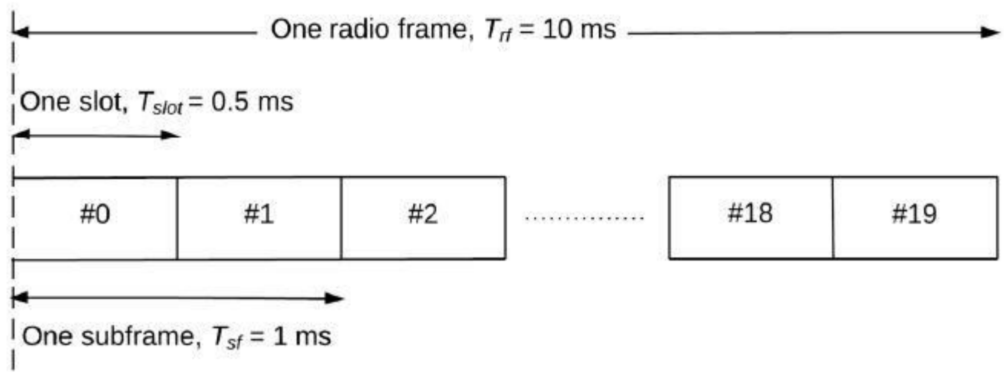


Figure 2

Subframe: A 10 ms frame is made up of 10 Subframe each of 1 ms duration numbered from 0 to 9.

Slot: There are 2 slots within a Subframe which makes 20 slots within a radio frame. The time of transmitting one slot is 0.5 ms.

OFDM Symbol: The transmission is divided into OFDM symbols in time domain. The number of OFDM symbols within a slot is 7 when we use a normal cyclic prefix.

Subcarriers: The transmitted signal is divided into subcarriers in the frequency domain.

Resource Element: It is represented by one subcarrier on one OFDM symbol.

Resource Grid: The transmitted signal in a slot is represented as resource grids which contain all resource elements within the slot.

Resource Block: A Resource Grid can be separated into several resource blocks in the frequency domain. Number of subcarriers within a Resource Block depend on the cyclic prefix type and downlink bandwidth.

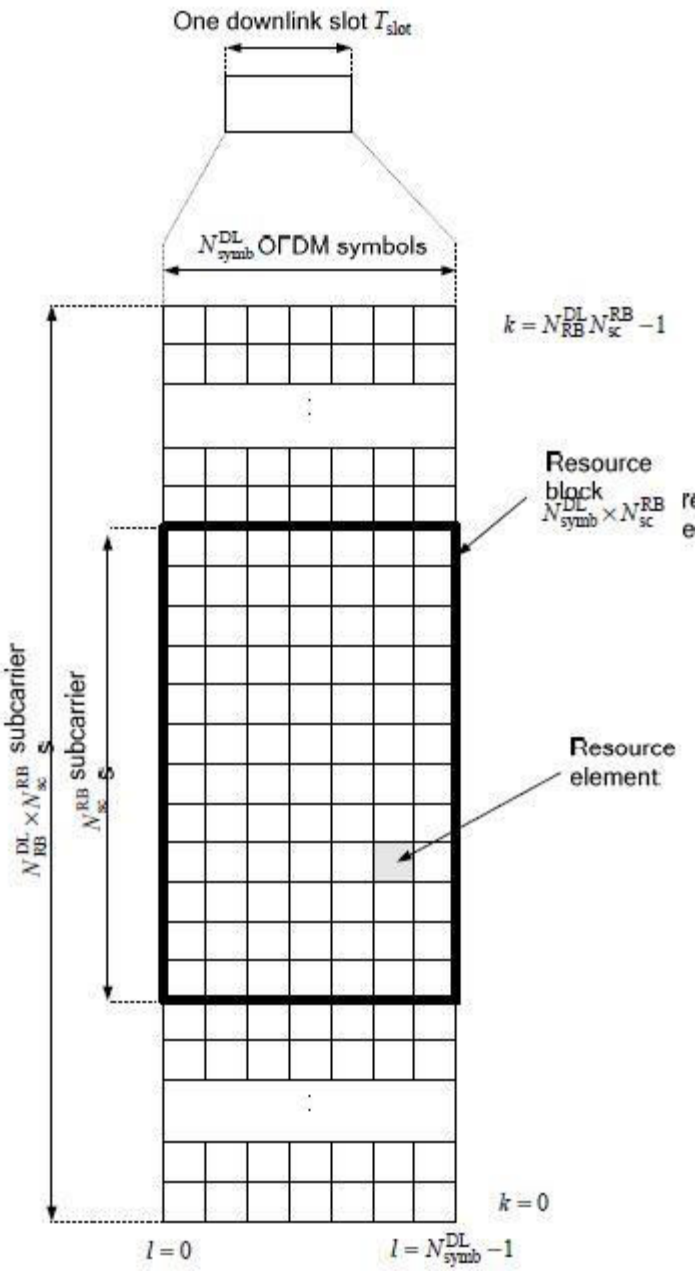


Figure 3

2.2 Channels in LTE

Mobile communication consist of two parts: Uplink (when the UE transmits signal to the Base station) and the Downlink (when the Base station transmits signals to the UE). There are three categories into which various LTE channels can be grouped:

1) **Transport Channels**: They offer information transfer to Medium Access Control (MAC) and higher layers. E.g. MCH, BCH,PCH,DL-SCH,RACH,UL-SCH
2) **Logical Channels**: Provide services for the Medium Access Control (MAC) layer within the LTE protocol structure. E.g. DTCH,DCCH,PCCH,BCCH,MCCH,MTCH
3) **Physical Channels**: These carry user data and control messages. Eg. PUSCH, PRACH, PUCCH, PDCCH, PHICH, PMCH, PBCH, PDSCH, PCFICH.

2.2.1 Physical Uplink and Downlink Channels

Uplink Channels

1) **Physical Uplink Control Channel (PUCCH)**: Is carries uplink control information like channel Quality Indication (CQI) ,ACK/NACK responses of the UE , and uplink scheduling requests.
2) **Physical Uplink Shared Channel (PUSCH):** It is used to transport user data.
3) **Physical Random Access Channel (PRACH):** It transmits access requests(bursts) when a mobile device desires to access the mobile system(paging response). It carries the random access preamble and coordinates and transports random requests for service from mobile devices.

Downlink Channels:

1) **Physical Downlink Control Channel (PDCCH):** It carries mainly scheduling information of different types: 1) Downlink resource scheduling 2) Uplink Power Control instructions 3) Uplink Resource Grant. 4) Indication for Paging or system information. The PDCCH contains Downlink Control Information-a message carrying control information for a particular UE or a group of UEs.
2) **Physical Broadcast Channel (PBCH):** It carries the system information for UEs requiring to access the network.
3) **Physical Control Format Indicator Channel (PCFICH):** It indicates the number of OFDM symbols used for the PDCCHs , whether 1,2 or 3. This information is essential as UE does not have prior information about the size of control region.
4) **Physical Hybrid ARQ Indicator Channel (PHICH):** It is used to indicate whether a transport block has been correctly received or not.

5) **Physical Downlink Shared Channel (PDSCH):** Used to transport user data. It is designed for high data rates. The resource blocks associated with this channel are shared among users via OFDMA.

6) **Physical Multicast Channel (PMCH):** Carries Multicast information.

2.2.2 Downlink Control Signaling

The downlink control signaling contains 3 types of Physical Channels: **PCFICH**(informs the terminal about number of OFDM symbols used for control region), **PDCCH** (used to signal downlink scheduling assignments and uplink scheduling grants for a single terminal or group of terminals), **PHICH**(used to carry ACKs or N'ACKs in response to PUSCH). If control information is more, control region occupies more OFDM symbols, otherwise it is usually smaller and more OFDM symbols are used for data region. Control region occupies the first several OFDM symbols and the data region is decoded immediately after it. The UE searches if there is any information for it and if it finds not then it goes to sleep mode using its power efficiently. In order to support transmission of uplink and downlink transport channels, Downlink Control Signaling is required. It carriers downlink Scheduling Assignments, Information for terminal to decode downlink signals assign uplink transmission and Hybrid-ARQ acknowledgements in response to uplink transmission.

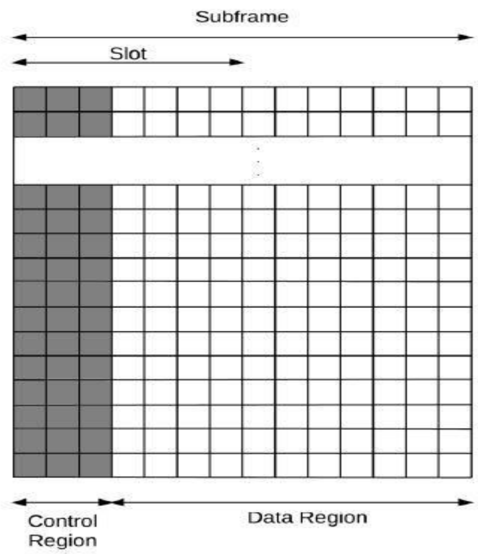


Figure 4

Chapter 3
PHICH Transmitter

It is a Physical Downlink Control Channel available in LTE for sending the feedback of uplink data received on PUSCH (Physical Uplink Shared Channel). For a PUSCH transmission in sub-frame n, UE shall always determine the PHICH in sub-frame n+4. The feedback is in terms of ACKs (bit 1) and NACKs (bit 0). If an ACK is decoded as NACK then it leads to unnecessary retransmission of correctly decoded transport block and if NACK received as ACK then it leads to loss of transport block. Hence error rate requirement of PHICH is strict. A PHICH is carried by several Resource Element Groups (REGs). Multiple PHICHs share the same set of REGs and are differentiated by orthogonal sequences. These PHICHs which share the same resources are called a PHICH group. A specific PHICH is identified by 2 parameters-PHICH group number and the orthogonal sequence number.

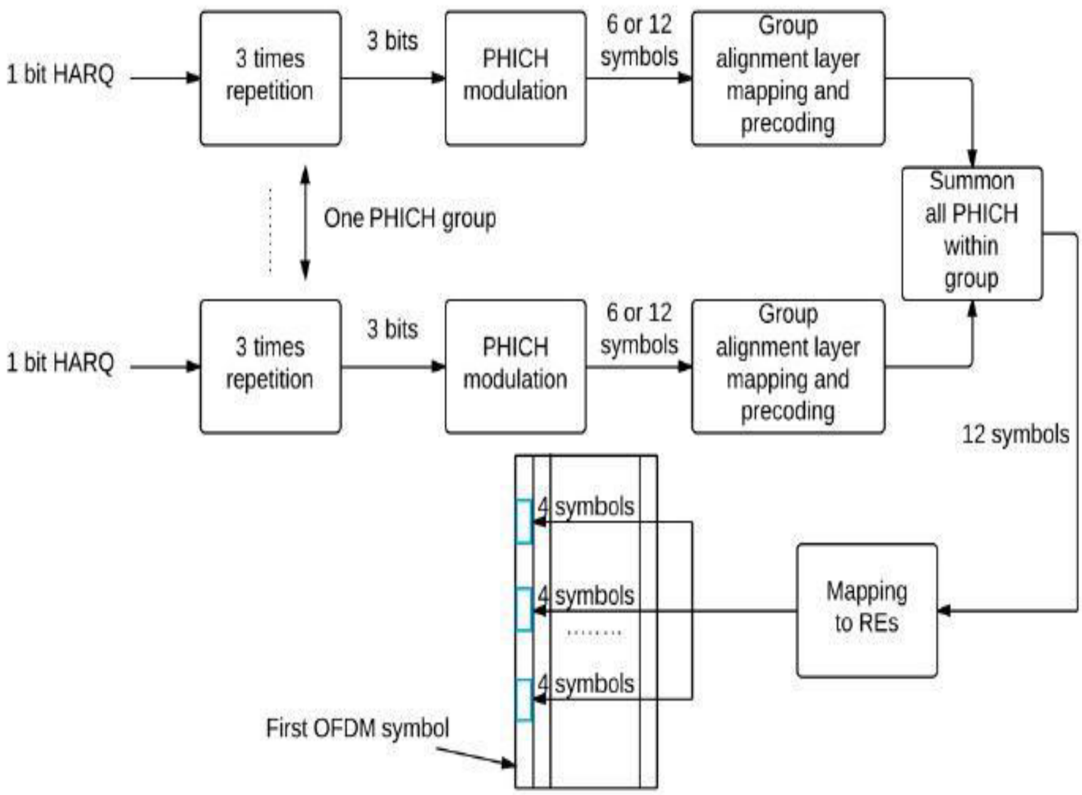


Figure 5

The number of PHICH groups to be transmitted depends upon the number of Resource Blocks and ultimately on the Bandwidth employed. The number of PHICH groups that can be transmitted is given by:

$N_{PHICH}^{group} = \lceil N_g (N_{RB}^{DL}/8) \rceil \; where \; N_g = \left\{\frac{1}{6}, \frac{1}{2}, 1, 2\right\}$

This is provided by higher layers and is a scaling factor to control the number of PHICH groups. For instance for a bandwidth of 10 MHz which provides for 50 Resource Blocks there can be at the most 7 PHICH groups each addressing 8 UEs at a time.

1) **HARQ Indicator Channel Coding[1][6]**:

HARQ Indicator	HARQ Indicator Word
0	000
1	111

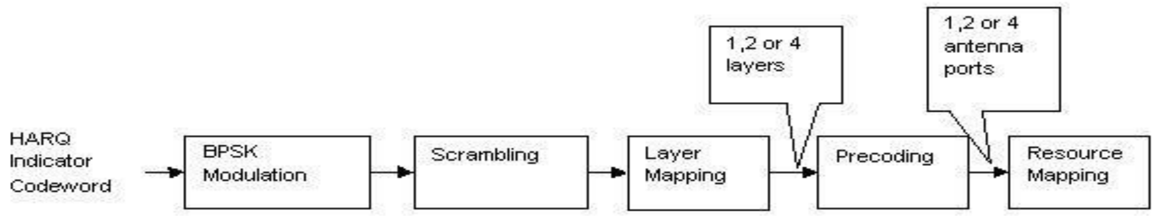


Figure 6

2) **BPSK Modulation:**

BPSK Modulation is employed to generate complex valued symbols z_0, z_1, z_2.

Bit 0 = 1/√2+j 1/√ (2

Bit 1 = −1/√2 −j 1/√2

3) **Scrambling:**

The block of modulated symbols are bitwise multiplied with an orthogonal sequence and a cell specific sequence to create sequence of symbols $d(0), d(1) \ldots d(Msymb-1)$

$$M_{symb} = 3 \times N_{SF}^{PHICH}$$

N_{SF}^{PHICH} Parameter is the spreading factor. Orthogonal Sequence allows multiple PHICHs to be mapped to the same set of resource elements.

$$d(i) = w(i \bmod N_{SF}^{PHICH}) \times (1 - 2c(i)) \times z(\lfloor i/N_{SF}^{PHICH} \rfloor)$$

Where c is a cell specific pseudo random sequence created using a length-31 Gold sequence. The scrambling sequence is initialized using the slot number within the radio frame,

$$c_{init} = \left(\frac{n_s}{2} + 1\right) \times \left(2N_{ID}^{cell} + 1\right) \times 2^9 + N_{ID}^{cell}$$

In short these equations define what is happening

$$z_0 \quad z_0 \quad z_0 \quad z_0 \quad z_1 \quad z_1 \quad z_1 \quad z_1 \quad z_2 \quad z_2 \quad z_2 \quad z_2$$

×

Sequence w with index n_{PHICH}^{seq}

×

Scrambling sequence c

=

d(0) d(1) d(2) d(3) d(4) d(5) d(6) d(7) d(8) d(9) d(10) d(11)

n_{PHICH}^{seq}	W orthogonal sequences
0	[+1 +1 +1 +1]
1	[+1 -1 +1 -1]
2	[+1 +1 -1 -1]
3	[+1 -1 -1 +1]
4	[+j +j +j +j]
5	[+j -j +j -j]
6	[+j +j -j -j]
7	[+j -j -j +j]

4) PHICH Resource Group Alignment:

As resource element groups contain 4 resource elements (each able to contain 1 symbol) the block of scrambled symbols are aligned to create blocks of 4 symbols.

$$d^{(0)}(i) = d(i)$$

5) PHICH Layer Mapping:

The complex symbols are mapped to one layer as this is the number of antennas which are used for transmission. If a single antenna is used only one layer is used.

$$x^{(0)}(i) = d^{(0)}(i)$$

6) Precoding:

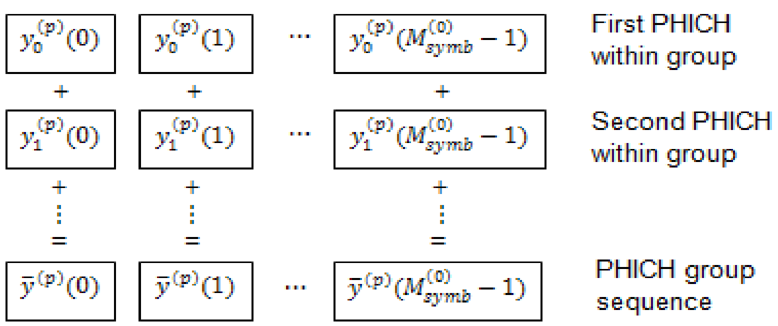
The precoder takes a block from layer mapper and generates a sequence for each antenna port. For transmission over a single antenna port, no processing is carried out resulting in

$$y^{(p)}(i) = d^{(0)}(i)$$

7) Resource Mapping:

The number of OFDM symbols used to carry the PHICH is configurable by the PHICH duration. In normal PHICH duration, PHICH is present only in the first OFDM symbol while in the case of extended PHICH duration PHICH is present in the first three OFDM symbols. These are the steps followed to map the data onto the resource elements

a) Corresponding elements of each PHICH sequence are summed to create the sequence for each PHICH group



b) Mapping to Resource element groups: Each mapping unit contains twelve symbols. To map these twelve symbols to REGs, the mapping units are split into three groups of four symbols (quadruplets). Each of the three symbol quadruplets

$$z^{(p)}(i), i = \{0,1,2\} \text{ is mapped to } REG(k', l')$$

The value of l'=0 (since the PHICH gets mapped onto the first OFDM symbol)

The value of *k'* is calculated as:

$$k' = \begin{cases} \left(\left|N_{ID}^{cell} \cdot \frac{n_{l_i'}}{n_0}\right| + m'\right) mod\ n_{l_i'} & \text{i=0} \\ \left(\left|N_{ID}^{cell} \cdot \frac{n_{l_i'}}{n_0}\right| + m' + \left\lfloor n_{l_i'}/3 \right\rfloor\right) mod\ n_{l_i'} & \text{i=1} \\ \left(\left|N_{ID}^{cell} \cdot \frac{n_{l_i'}}{n_0}\right| + m' + \left\lfloor 2n_{l_i'}/3 \right\rfloor\right) mod\ n_{l_i'} & \text{i=2} \end{cases}$$

m' varies from 0 to 6

n_0=Number of REGs that has not been assigned to PCFICH on the first symbol

$n_{l_i'}$ =Number of REGs not assigned to PCFICH on l OFDM symbol

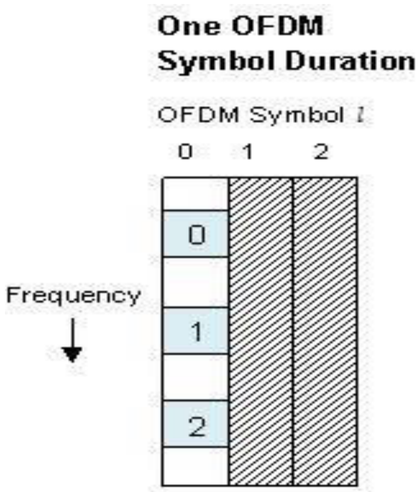


Figure 7

Chapter 4

PHICH Receiver

4.1 Channel Estimation and Interpolation

The received OFDM symbol is *y(n)* which is of the form

$$y(n) = h(n) * x(n) + w(n)$$

After the FFT operation at the Receiver the result is $Y(k)$

$$Y(k) = H(k)X(k) + W(k)$$

$$Y(k)/X(k) = H(k) + W(k)/X(k)$$

For this we use pilots or reference symbols which are known to the receiver.

Using linear Interpolation we estimate the channel and extract the data from it.

$$\hat{H}_I(k) = [(\hat{H}(j) - \hat{H}(i))/(x_j - x_i)](x_k - x_i) + \hat{H}(i)$$

$$\hat{X}(k) = Y(k)/\hat{H}_I(k)$$

$\hat{X}(k)$ is the estimate of the data extracted using interpolation

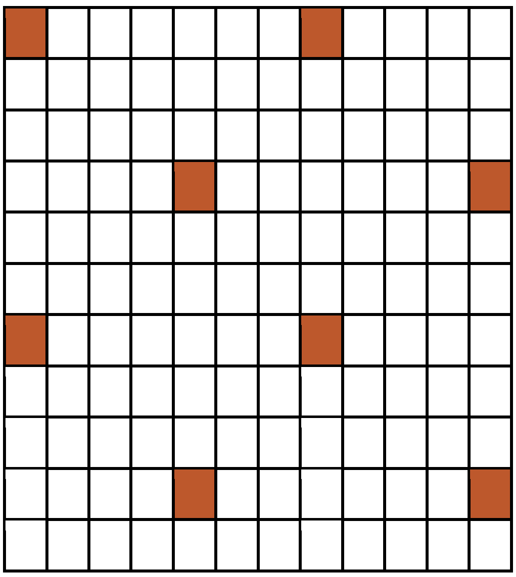


Figure 8

4.2 PHICH Decoder

1) Read PHICH symbols:

To decode the PHICH, UE shall first find the REGs used for mapping the expected group of PHICH quadruplets and the PHICH symbols of all groups.

2) PHICH Layer Demapping and Deprecoding:

$$d_i = y(i) \; where \; i = 0,1,..11$$

3) PHICH Group Dealignment:

The block of complex valued symbols d_i the reverse group Dealignment depending on the cyclic prefix type of the sub-frame. For normal cyclic prefix the output of this block is :

$$e_i = d_i \; where \; i = 0,1,..11$$

4) PHICH Descrambling and Orthogonal Sequence Decode:

The scrambling sequence is generated as in the transmitter section. The UE needs to decode the expected PHICH within the PHICH group. As the PHICH within the PHICH group is multiplexed with different orthogonal sequence, the PHICH has to be separated from the added result. The received PHICH group r is of the form, where r is

$$r = \begin{matrix} z_1^{(1)} w_0 C_1 \; ; & z_2^{(1)} w_0 C_2 \; ; & z_3^{(1)} w_0 C_3 \\ + & + & + \\ z_1^{(2)} w_1 C_1 \; ; & z_2^{(2)} w_1 C_2 \; ; & z_3^{(2)} w_1 C_3 \\ . & . & . \\ . & . & . \\ z_1^{(8)} w_7 C_1 \; ; & z_2^{(8)} w_7 C_2 \; ; & z_3^{(8)} w_7 C_3 \end{matrix}$$

Where w_j is a 1 × 4 vector and C_i is a 4×4 matrix where i=1,2,3 and j=1,2,3,4,5,6,7,8.

Now, UE1 has to extract $z_1^{(1)}, z_2^{(1)}, z_3^{(1)}$, UE2 has to extract $z_1^{(2)}, z_2^{(2)}, z_3^{(2)}$ ....UE8 has to extract $z_1^{(8)}, z_2^{(8)}, z_3^{(8)}$

1. $z_1^{(1)} w_0 C_1 + z_1^{(2)} w_1 C_1 + \cdots . z_1^{(8)} w_8 C_1 \qquad \times C_1$

$z_1^{(1)} w_0 + z_1^{(2)} w_1 + \cdots . z_1^{(8)} w_8$

(Since $C_1 \times C_1$ =Identity matrix)

To get $z_1^{(1)}$ from 1. We multiply by w_0^T, and $w_i \times w_j = 0$ if $i \neq j$ and $w_i \times w_j = 1$ if $i = j$

2. $z_2^{(1)} w_0 C_2 + z_2^{(2)} w_1 C_2 + \cdots . z_2^{(8)} w_8 C_2 \qquad \times C_2$

$z_2^{(1)} w_0 + z_2^{(2)} w_1 + \cdots . z_2^{(8)} w_8$

(Since $C_2 \times C_2$ =Identity matrix)

To get $z_2^{(1)}$ from 2. We multiply by w_0^T, and $w_i \times w_j = 0$ if $i \neq j$ and $w_i \times w_j = 1$ if $i = j$

And so on.

5) Demodulation:

If Real (z) + Imag (z) >0 →Bit 0

If Real (z) + Imag (z) <0 →Bit 1

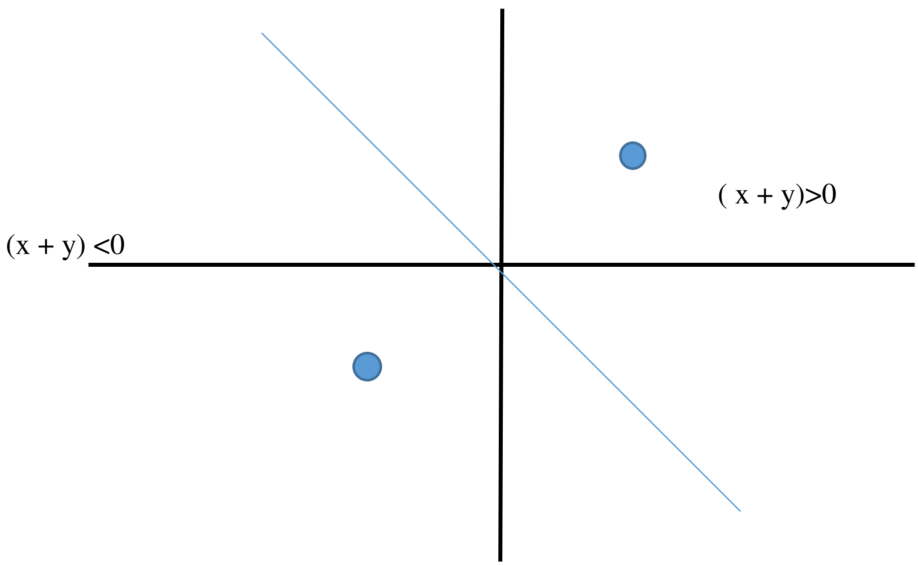


Figure 9

6) HARQ Decoding:

111 is decoded as 1 and
000 is decoded as 0

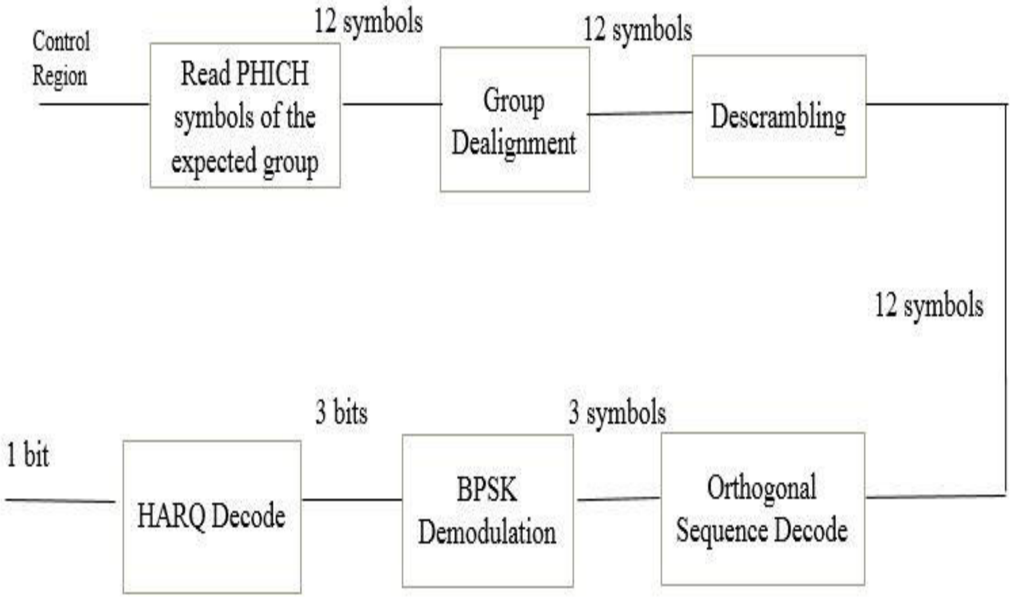


Figure 10

Chapter 5
Results

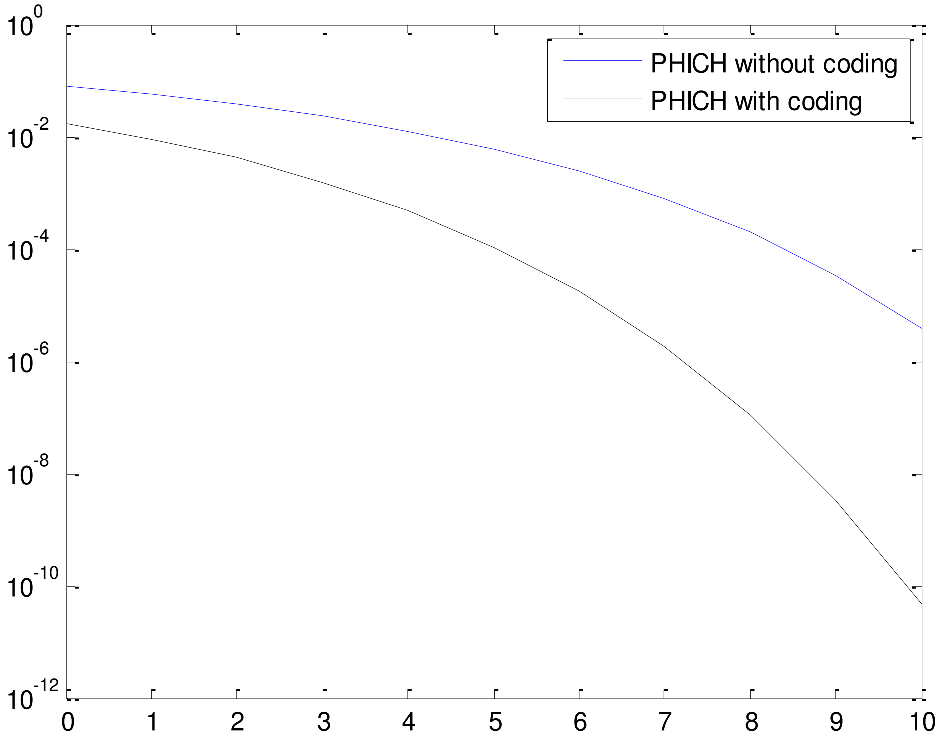


Figure 11

When multiple PHICHs are passed through several continuous frames through a AWGN channel and the SNR vs BER performance is measured we find that with channel coding the performance is better low error rate.

This can be intuitively inferred as well because when we introduce channel encoding the probability of error decreases but it comes at the cost of low date rate.

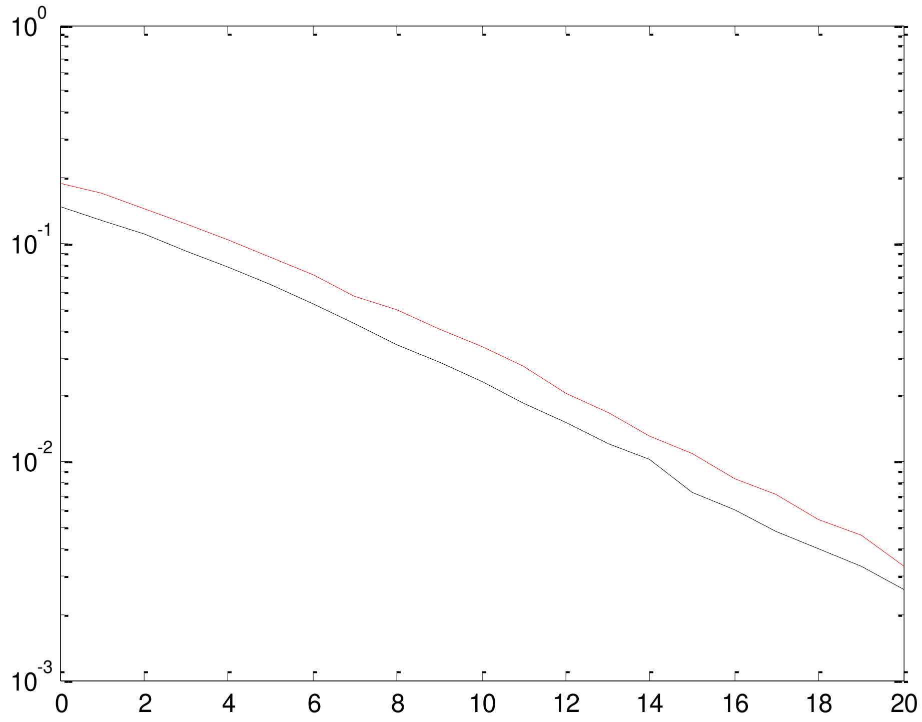


Figure 12

When multiple PHICHs are transmitted in the presence of Rayleigh Channel and the SNR vs BER performance is measured then there is more than 1 dB loss when channel estimation and interpolation is used.

This is intuitively correct too as there is bound to be some error getting introduced due to channel estimation and interpolation and leads to loss.

Chapter 6

Figures

Figure 1: Year wise increase in mobile data traffic

Figure 2: Frame structure in LTE

Figure 3: Resource Grid in time and frequency domain

Figure 4: Control Region and Data Region in a Subframe

Figure 5: PHICH Transmitter Block

Figure 6: PHICH transmitter block with diversity.

Figure 7: Resource Block containing PHICHs in first OFDM symbol

Figure 8: Pilot symbols transmitted within a Subframe

Figure 9: BPSK Demodulation with decision boundary

Figure 10: PHICH Decoder structure

Figure 11: SNR vs BER performance in the presence of AWGN

Figure 12: SNR vs BER performance In the presence of Rayleigh Channel

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