# Optimal Modulation Technique for PCFICH Signaling in an LTE – Advanced Systems

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**Abstract:**

**The downlink control channel of a Long Term Evolution system has different control channels. In which the Physical Control Format Indicator Channel (PCFICH) is designed to transmit the Control Format Indicator (CFI). The CFI effective transmission gives the end user effective transmission of the data without effecting the time lapse in decoding the control channels. Hence, the paper discusses the BER of the CFI transmitted in BPSK, QPSK and 16QAM modulations through an AWGN channel. The best modulation techniques are estimated and suggested.**

***Keywords: Long Term Evolution, Long Term Evolution-Advanced, Orthogonal Frequency Division Multiple Access, Physical Control Format Indicator Channel, Control Format Indicator, Matrix Laboratory (MATLAB), Bit Error Rate (BER), Signal to Noise Ratio (SNR), Enhanced base station (eNodeB).***

## I. Introduction:

The Physical Control Format Indicator Channel [3] is one of the downlink control channels in an LTE system. It is defined as such to transmit the Control format indicator, a 32 bit code sequence that is defined to indicate the number of OFDM symbols. The OFDM symbols represent the size of the control region which is important for the user to know the position from which the data region starts.

The Long Term Evolution Physical Layer (LTE - PHY) is a highly efficient means of conveying both data and control information between an enhanced base station (eNodeB) and mobile user equipment (UE). The LTE PHY employs some advanced technologies that are new to cellular applications. These include OFDM and Multiple Input Multiple Output (MIMO) data transmission. In addition, the LTE PHY uses Orthogonal Frequency Division Multiple Access (OFDMA) on the downlink (DL) and Single Carrier – Frequency Division Multiple Access (SC-FDMA) on the uplink (UL).

Orthogonal Frequency Division Multiple Access (OFDMA)[3] is an excellent choice of multiplexing scheme for the 3GPP LTE downlink. Although it involves added complexity in terms of resource scheduling, it is vastly superior to packet-oriented approaches in terms of efficiency and latency. In OFDMA, users are allocated a specific number of subcarriers for a predetermined amount of time. These are referred to as physical resource blocks (PRBs) in the LTE specifications. PRBs thus have both a time and frequency dimension. Allocation of PRBs is handled by a scheduling function at the 3GPP base station (eNodeB).

To overcome the effect of multi path fading problem available in UMTS, LTE uses Orthogonal Frequency Division Multiplexing (OFDM) for the downlink - that is, from the base station to the terminal to transmit the data over many narrow band careers of 180 KHz each instead of spreading one signal over the complete 5MHz career bandwidth i.e. OFDM uses a large number of narrow sub-carriers for multi-carrier transmission to carry data.

Orthogonal frequency-division multiplexing (OFDM) [5], is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method.

OFDM meets the LTE requirement for spectrum flexibility and enables cost-efficient solutions for very wide carriers with high peak rates. The basic LTE downlink physical resource can be seen as a time-frequency grid, as illustrated in Figure below.

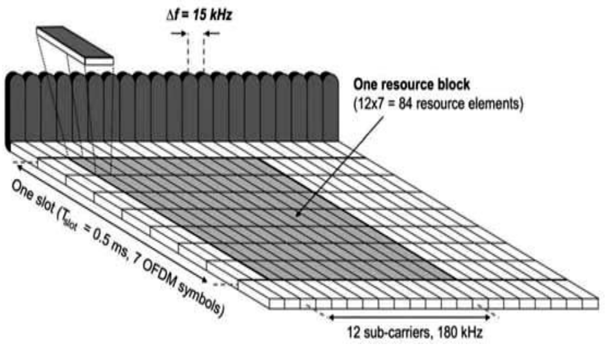


Figure 1: OFDM symbols grouped into resource blocks[5]

The OFDM symbols as show in Figure 1, are grouped into resource blocks. The resource blocks have a total size of 180 kHz in the frequency domain and 0.5ms in the time domain. Each 1ms Transmission Time Interval (TTI) consists of two slots (Tslot).

Each user is allocated a number of so-called resource blocks in the time-frequency grid. The more resource blocks a user gets, and the higher the modulation used in the resource elements, the higher the bit-rate. Which resource blocks and how many the user gets at a given point in time depend on advanced scheduling mechanisms in the frequency and time dimensions.

The user's information contains control region and data region transmitted adjacently as shown in Figure 2. While user needs to decode the control region and data region to acquire the required requested data. Hence, In order to make the user easier to distinguish the control and data region, the CFI is defined by the LTE standard. Therefore, the control format indicator plays a major role in an LTE downlink data transmission.

The PCFICH consists of two bits of information, corresponding to the three control region sizes of one, two, or three OFDM symbols (two, three or four for narrow bandwidths), which are coded into a 32-bit codeword. The coded bits are scrambled with a cell- and subframe-specific scrambling code to randomize inter-cell interference, QPSK modulated, and mapped to 16 resource elements. As the size of the control region is unknown until the PCFICH is decoded, the PCFICH is always mapped to the first OFDM symbol of each subframe.

The mapping of the PCFICH to resource elements in the first OFDM symbol in the subframe is done in groups of four resource elements, with the four groups being well separated in frequency to obtain good diversity. Furthermore, to avoid collisions between PCFICH transmissions in neighboring cells, the location of the four groups in the Frequency Domain depends on the physical-layer cell identity.

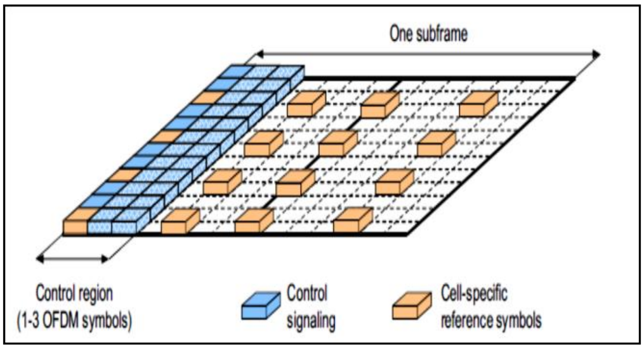


Figure 2: Control Region (1-3 OFDM symbols) [3].

This paper mainly concentrates in transmitting the CFI through an AWGN channel with different modulations to estimate the BER in the given SNR and aims to suggest the best modulations for an LTE system. The paper is implemented in MATLAB the output BER for the given SNR is tabulated for the respective BPSK, QPSK and 16QAM modulations.

The paper contains a brief introduction of importance of PCFICH, followed by the transmitter receiver circuit description, simulation results, followed by the analysis and their inferences.

**Implementation of System Design:**

The circuit for transmitting the CFI sequence is shown in the below Figure 3.

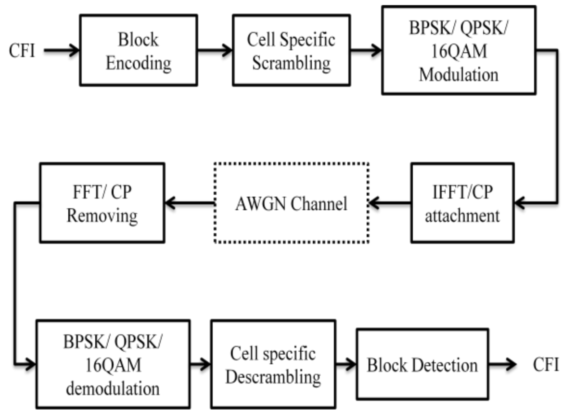


Figure 3: Transmitter and Receiver circuit [1]

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The Control Format Indicator sequence is determined by the LTE standard it is as shown in the Figure 2.

| CFI | CFI code word < $b_0, b_1, \ldots, b_{31}$ > |
|---|---|
| 1 | <0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1> |
| 2 | <1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0> |
| 3 | <1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1> |
| 4 (Reserved) | <0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0> |

Figure 4: CFI code word.

CFI parameter takes the value of 1, 2, 3, and 4 according to which a 32 bit sequence is assigned to it. These 32 bit sequences are scrambled with pseudo random sequence. The pseudo random sequence is generated using Gold sequence generator.

The 32 – bit coded CFI block undergoes a bit wise exclusive OR (XOR) operation with a cell specific scrambling sequence. The scrambling sequence is a pseudo random sequence created using a length 31 Gold sequence generator. The Gold sequence generator uses two PN sequence generator blocks to generate he preferred pair of sequences and then XOR these sequences to produce the output sequence.

The gold sequences [6] are defined using preferred pair of sequences u and v, of period $N = 2^{(n-1)}$. The set $G(u,v)$ is defined as,

$$G(u,v) = \{u, v, u \oplus v, u \oplus Tv, \ldots, u \oplus T^{n-1}v\} \quad (1)$$

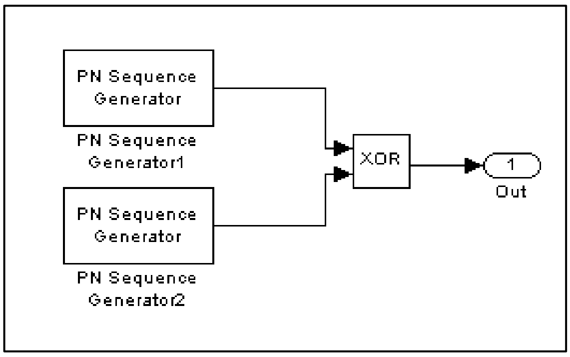


Figure 5: Gold Sequence Generator.

Where, T represents the operator that shifts vectors cyclically to the left by one place and ⊕ represents modulo 2 additions.

The Gold sequence generator uses two PN sequence generator blocks to generate he preferred pair of sequences and then XOR these sequences to produce the output sequence.

For n = 5, N = 31, the preferred polynomials are give as,

Polynomial 1 = [5 2 0]
Polynomial 2 = [5 4 3 2 0]
Polynomial 1 = $1 + z^2 + z^5$
Polynomial 2 = $1 + z^2 + z^3 + z^4 + z^5$

The PN sequence generator block generates a sequence of pseudorandom binary numbers using a linear – feedback shift registers (LFSR).

The 32 bit scrambled sequence is modulated using Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), and 16- Quadrature Amplitude Modulation (16 - QAM) techniques, forming a block of complex-value symbols in each modulation. These symbols are operated with IFFT and cyclic prefix is inserted.

The Cyclic prefixed IFFT complex data is transmitted through the Additive White Gaussian Noisy channel. After passing through the channel, the Cyclic Prefix (CP) is removed and FFT operation is performed to the complex data. Then, the symbols are demodulated by the respective demodulation techniques and is descrambled by the pseudo random noise sequence attaining the transmitted sequence.

The process is implemented in MATLAB and the simulations results are analyzed. The simulation results of the system design are tabulated in the following section.

**II Simulation Results:**

The theoretical BER SNR curve for the given SNRdB is represented in the following figure 3. This shows the BER reduces gradually as the SNR increases. The three BER vs SNR curves between the BPSK, QPSK, and 16QAM are plotted in the below plot, Figure 6. The bit error rate for the BPSK modulated data is low compared to the other two modulation techniques.

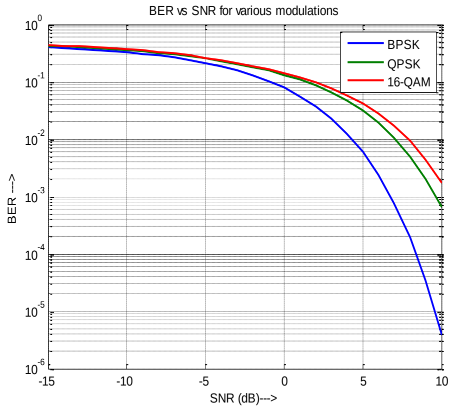


Figure 6: Simulation Results

Below Table I gives the BER-SNR relation to the Binary Phase Shift Keying (BPSK) modulation. As the SNR range increases the errors occurred gradually decreases to zero providing error free transmission at higher Signal to Noise ratio.

| SNR | BER | Errors | SNR | BER | Errors |
|---|---|---|---|---|---|
| -15 | 0.5625 | 18 | -5 | 0.2500 | 8 |
| -14 | 0.5000 | 16 | -3 | 0.1250 | 4 |
| -13 | 0.4686 | 15 | -1 | 0.0938 | 3 |
| -12 | 0.4063 | 13 | 1 | 0.0625 | 2 |
| -11 | 0.3750 | 12 | 2 | 0.0313 | 1 |
| -9 | 0.3125 | 11 | 3 | 0 | 0 |
| -7 | 0.2500 | 8 | 4 | 0 | 0 |

Table I: SNR-BER values for BPSK

The Quadrature Phase Shift Keyed (QPSK) signal Bit error rate for its Signal to noise ratio is shown in the Table II.

| SNR | BER | Err-ors | SNR | BER | Err-ors |
|---|---|---|---|---|---|
| -11.98 | 0.4688 | 15 | 0.0103 | 0.3125 | 10 |
| -12.98 | 0.4375 | 14 | 1.0103 | 0.2812 | 9 |
| -9.98 | 0.4063 | 13 | 4.0103 | 0.2500 | 8 |
| -7.98 | 0.3750 | 12 | 8.0103 | 0.2187 | 7 |
| -4.98 | 0.3438 | 11 | 11.010 | 0.1875 | 6 |

Table II: SNR-BER values for QPSK

Table III shows the Signal to Noise Ratio and its respective Bit Error Rate of the 16 Quadrature Amplitude Modulated Signal.

| SNR | BER | Err-ors | SNR | BER | Err-ors |
|---|---|---|---|---|---|
| -8.979 | 0.5937 | 19 | 10.020 | 0.4687 | 15 |
| -6.979 | 0.5625 | 18 | 12.020 | 0.4375 | 14 |
| -3.979 | 0.5312 | 17 | 14.020 | 0.4062 | 13 |
| 2.020 | 0.500 | 16 | 16.020 | 0.3750 | 12 |

Table III: SNR-BER values for 16-QAM

## III Inference:

Simulated results show the Bit Error Rate for BPSK, QPSK and 16QAM of the modulated data for the given Signal to Noise Ratio.

- For BPSK, at low SNR, BER is low; at high SNR, BER is zero.
- For QPSK, at low SNR, BER is moderate; at high SNR, BER is low.
- For 16QAM, at low SNR, BER is very high; at high SNR, BER is moderate.

## IV Conclusion:

Hence, from the observation opting for BPSK is best with increased SNR which gives error free transmission. But, for LTE system data rate is an important concern. Hence, QPSK modulation can provide moderate BER with remarkable data rate.

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