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UCI Transmission via PUCCH in LTE Uplink

M. Jayalakshmi
M.Tech scholar, Department of ECE,
MZCE, Kadammanitta
Pathanamthitta, Kerala

***Abstract*—The Long Term evolution (LTE) in uplink has a resource limitation for transmitting uplink signaling information. There is no possibility to transmit Physical Uplink Shared Channel (PUSCH) and Physical Uplink Control Channel (PUCCH) simultaneously. PUCCH is designed for a large number of user equipment and a short Uplink Control Information (UCI) codeword. Description of PUCCH signal processing and the developed MATLAB link level LTE uplink control channel simulator is discussed. Results from a complete PUCCH performance analysis for different PUCCH payloads in the AWGN channel using receive diversity is included.LTE advanced technique is discussed as a future scope.**

Keywords—BER; Link level simulator; LTE;

Uplink; MATLAB; PUCCH

I. INTRODUCTION

The Long Term Evolution (LTE) is a standard for wireless communication of high-speed data for mobile phones and data terminals. The standard is developed by the Third Generation Partnership Project (3GPP) organization. Key aims of LTE uplink are flexible bandwidth support, time and frequency duplex division, peak uplink traffic data rate up to 50 Mbps when a SISO antenna mode is used, improved spectrum efficiency in comparison to HSUPA, etc. The LTE physical layer is based on the Orthogonal Frequency Multiplex (OFDM) and their transmission schemes. While the LTE downlink uses an Orthogonal Frequency Multiple Access (OFDMA), a Single-Carrier Frequency Division Multiple Access (SCFDMA) transmission scheme is used in uplink.

The LTE uplink physical layer has a triplet of physical channels; Physical Uplink Shared Channel (PUSCH), Physical Uplink Control Channel (PUCCH) and Physical Random Access Channel (PRACH). The PUSCH is used for transmitting user traffic data in multiplex with Uplink Control Information (UCI), if necessary. The PRACH is used only for initializing and registering user equipment (UE) to the network. Transferring UCI in the case of large number of UE and a short UCI codeword is provided by PUCCH. PUSCH and PUCCH are never transmitted in the same sub frame. UCI is transmitted via PUCCH in the case where UE has no traffic data to transfer to the base station (BS).

II. BACKGROUND

Cell phones are used millions and billions of users worldwide. In 1945, the zero generation (0G) of mobile telephones was introduced. Mobile telephone service was not officially categorized as mobile phones, since they did not support the automatic change of channel frequency during calls. The first generation (1G) (Time Division Multiple Access and Frequency Division Multiple Access) was the initial wireless telecom network system. Second generation (2 G) technologies are either time division multiple access (TDMA) or code division multiple access (CDMA).

A. 3G wireless system

International Mobile Telecommunications-2000 (IMT--2000), better known as 3G or 3rd Generation, is a generation of standards for mobile communication and mobile telecommunication services fulfilling specifications by International Telecommunication Union. Universal Mobile Telecommunications System (UMTS) is a third generation mobile cellular technology for networks based on the GSM standard. UMTS employs Wideband Code Division Multiple Access (W-CDMA) radio access technology to offer greater spectral efficiency and bandwidth to mobile network operators.

B. Enhancing Method(LTE(3GPP R8))

The overall objective for LTE is to provide an extremely high performance radio-access technology that offers full vehicular speed mobility and that can readily coexist with HSPA and earlier networks. Moreover, the 3GPP technologies continued to evolve, future releases by the 3GPP will see both combinations of dual carriers and MIMO as well as combinations of up to 4 carriers with both alternatives capable of supporting up to 84Mbps. Also higher bit rates are possible if combinations of MIMO and 4 carriers will be supported in the future. As specified in the 3GPP Release 8, OFDM/OFDMA technology is introduced for the LTE downlink, supporting very high data rates of up to 300Mbps while Single-Carrier FDMA (SC-FDMA) is used in the uplink with data rates of 80Mbps possible. Additionally, LTE supports operation both in paired and unpaired spectrum (FDD and TDD) using channel bandwidths of approximately 1.4MHz up to 20MHz.Nowadays, it is possible to browse the Internet or send e-mails using HSPA-enabled notebooks. Fixed DSL modems can be replaced conveniently with HSPA modems or USB dongles and we can also send and receive video or music using 3G phones.

LTE will make the user experience even better by enhancing more demanding applications such as interactive TV, mobile video blogging, advanced games and professional services.LTE is focusing on optimum support of Packet Switched (PS) Services.

III. SYSTEM MODEL AND CONSIDERATION

UCI consists of three types of control information; Channel quality information, Scheduling Request (SR) and Uplink Hybrid Automatic Repeat Request (HARQ) acknowledge or non-acknowledge information. Note that SR information is transmitted via PUCCH only. Channel quality information is also divided to the following components: Channel Quality Indicator (CQI), Precoding Matrix Indicator (PMI) and Rank Indicator (RI). The CQI and PMI are usually grouped together into a single CQI/PMI codeword. The CQI carries information about the current channel state which is measured by UE. The PMI gives feedback information to the BS about the set of precoding weights for BS when closed-loop spatial multiplexing or multiuser MIMO transmission modes are used. The RI gives feedback to the BS about the number of transport blocks for transmission to the BS.

Other control information in uplink is a Hybrid Automatic Repeat Request Indicator (HARQ-ACK) which is used to inform the BS about data transferred via the Physical Downlink Shared Channel (PDSCH). Here, an HARQ-ACK indicator equaling one means successful data transfer. PUCCH has six transmission formats; format 1, 1A, 1B, 2, 2A and 2B.These formats are defined by the type of transmitted information. The scheduling request is transmitted via PUCCH, format 1. The modulation scheme for SR is not defined. The SR requirement from UE is given only by power emissions in the control region in the resource grid. PUCCH format 1A/1B transmits a one or two-bit HARQACK codeword which is modulated using the BPSK or QPSK modulation scheme. PUCCH format 2 carries CQI/PMI and RI information. The format 2 codeword has a length from 4 to 11 bits. It uses the QPSK modulation scheme. In the case of format 2A/2B codeword, one or two bit HARQ-ACK information is only added to format 2.In the case of format 2A, a one bit HARQ-ACK codeword is modulated using BPSK and in the case of format 2B, a two bit HARQ-ACK codeword is modulated using QPSK . Link level performance analysis of the above mentioned control information is necessary to analyze and further optimize the process of the LTE uplink physical layer signal processing chain. Several authors present partial performance results of PUCCH transmission in LTE uplink. In the block error rate (BLER) performance analysis results only for PUCCH format 2A/2B are presented.

IV. HARDWARE ARCHITECTURE

A. PUCCH signal processing description

The overall PUCCH signal processing chain is depicted in figures 1 and 3. These signal processing chains became the base for the developed link level PUCCH model. PUCCH format 1 gives UE an alternative method to require a scheduling grant. PUCCH format 1 is used in the case of network overloading and when PRACH signalization is not successful. PRACH is not investigated in this paper due to the fact that there is no possibility to determine the bit or block error rate. In format 1A/1B, a one or two-bit HARQ-ACK codeword is transmitted. First, HARQ-ACK is multiplexed with an SR, if necessary.

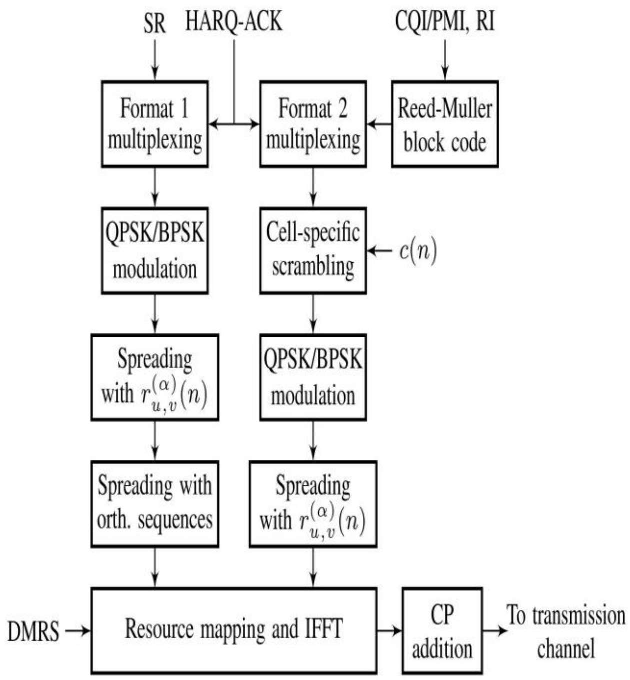

Fig. 1. PUCCH signal processing in transmitter

A multiplexed vector of bits is modulated using QPSK or BPSK and the modulated signal is spread with Zadoff-Chu sequence. The r sequences are used for minimizing cross-correlation between different user signals in a cell. Next, the complex-valued signal is spread with orthogonal sequences to separate users mapped into the same resources. Format 2, CQI/PMI and RI, is channel coded using the (20;A) Reed-Muller code, where A is the length of input codeword in bits When channel coding is performed, the output sequence of 20 bits in length is multiplexed with the one or two-bit HARQ-ACK codeword and scrambled using a cell-specific pseudo-random sequence c(n). Are modulated using QPSK and BPSK modulation (BPSK is only used for the 21st bit in the codeword in the case of transmitting format 2A). The modulated, complex-valued signal is spread with Zadoff-Chu sequence in the same way as in the case of format 1A/1B.Next, the modulated and spread signal is led to the resource mapping block and IFFT is performed. After the addition of a cyclic prefix (CP), the signal in the time domain enters the transmission channel. PUCCH resources are always doubled (additional frequency diversity) and placed on the edge of time frequency resource grid, as is depicted in figure 2.

When the signal passes through the transmission channel, CP is removed and FFT is performed. PUCCH resource blocks are picked-up from the resource grid and the corresponding signal is despread using Zadoff-Chu sequence. Next, IDFT of length equaling 12 is provided with the despread signal and the signal of individual users is separated. Simultaneously, the same operations on the receiving side are provided with the corresponding estimated channel coefficients HPUCCH.

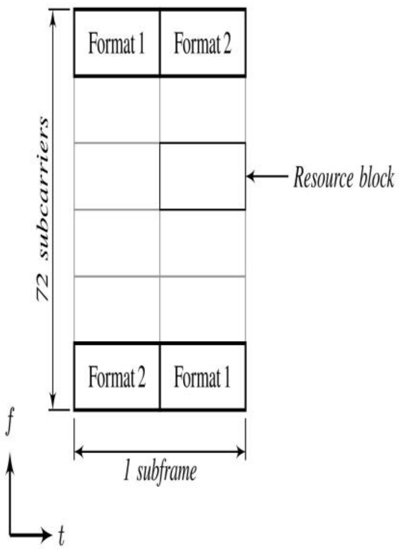

Fig. 3. Example of PUCCH mapping into time frequency resource grid

In the case of format 2/2A/2B QPSK or BPSK, soft demodulation with Maximal Ratio Combining (MRC) is provided and CQI/PMI, RI and HARQ-ACK bits are demultiplexed, if necessary. The CQI/PMI, RI bits are decoded using the Reed- Muller block decoder. The format 1A/1B signal separated by the user is despread with orthogonal sequences and soft demodulated with MRC using QPSK or BPSK modulation.

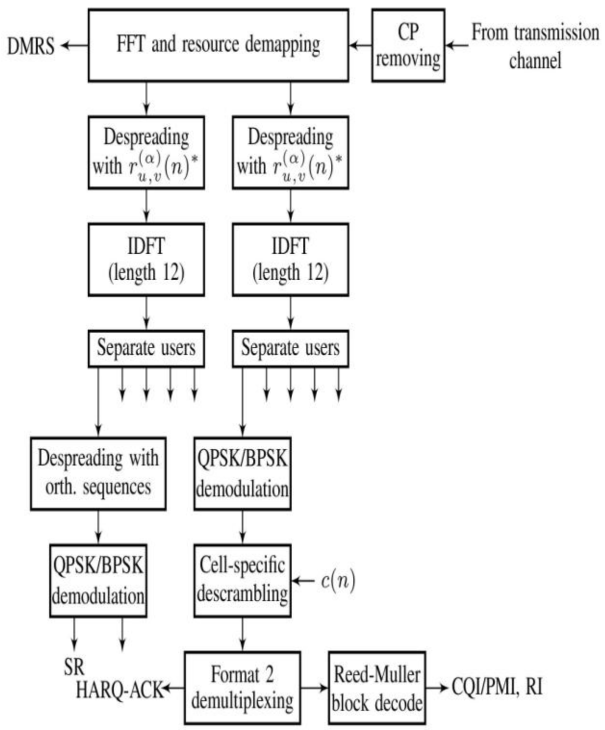

Fig. 2. PUCCH signal processing in receiver

B. *Link level LTE uplink control channel simulator*

The baseband link level LTE uplink control channels simulator was developed in MATLAB environment. The block scheme of the simulator is depicted in figure 4. The generated control information leads to the transmitter and the time domain signal enters the used channel model and AWGN is added. The signal from the transmission channel model enters processing in the receiver. The received control information is led to the BER or BLER calculation block. In LTE uplink standards, using transmit diversity is not explicitly defined. The simulator supports receiving diversity. The simulator allows to set a system bandwidth, signal-to-noise ratio (SNR), a number of transmitted sub frames Nsubf, a number of receiving antennas (NRX = 1; 2; _ _ _ ; 9), used channel models and different combinations of simulated PUCCH formats.

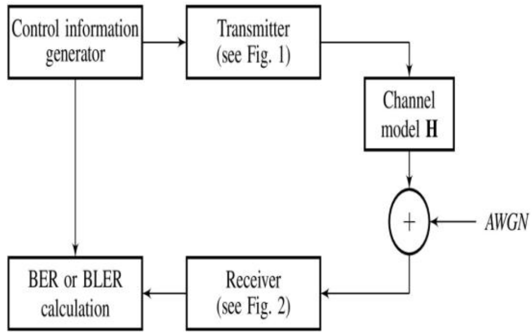

Fig. 4. General PUCCH simulator block scheme

V. EXPERIMENTAL RESULTS

Performance analysis was performed for all possible PUCCH formats except format 1. The number of sub frames Nsubf equals 50000 due to the reference BER/BLER level equaling. The reference level was determined according to the required target quality for LTE uplink control information reception. The AWGN channel model was only used in simulations, thus channel coefficient matrix H has all coefficients equal to 1. Simulations assume perfect knowledge of the transmission channel model and a single UE and single BS within a cell. In Fig. 5.1, the BER of HARQ-ACK information transmitted via PUCCH format 1A and 1B in the AWGN channel model for various numbers of receiving antennas is shown.

The difference between the SNR value of format 1A and 1B (BPSK and QPSK modulation scheme) is 3 dB. Bit error probability for PSK modulation schemes is computed according to

$$P_b = \frac{1}{2} erfc\sqrt{\frac{E_b}{N_0}} \qquad (1)$$

Where erfc() is the complementary error function, Eb is signal energy per bit and N0 is noise power spectral density. For OFDM-based transmission and access schemes we can write relation between signal to noise ratio and bit energy to noise power spectral density ratio

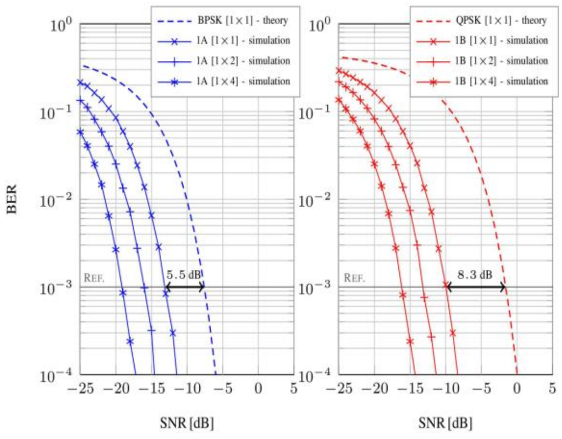

Fig. 5. BER of HARQ-ACK information transmitted using PUCCH, format 1A (left) and format 1B (right) in AWGN channel

$$\frac{E_b}{N_0} = \frac{S}{N}\frac{B}{f_b}\frac{N_{SC}}{N_{FFT}}\frac{T_d}{T_d + T_{cp}}\log_2 M \quad (2)$$

. Difference between theoretical value for uncoded BPSK in SC-FDMA and simulated BER value for PUCCH format 1A with one transmitting and one receiving antenna equals 5:5 dB, for format 1B, the difference equals 8:3 dB. In Fig. 6, the BER of HARQ-ACK information transmitted via PUCCH format 2A and 2B in the AWGN channel model for various numbers of receiving antennas is shown. It is obvious that transmitting HARQ-ACK using PUCCH format 1A/1B has a lower BER. The difference between the SNR value of format 1A and 2A, when BER equals the BER reference level is 6.3 dB. Using four receiving antennas adds a diversity gain equaling 6 dB in comparison to the SISO mode. Difference between theoretical value for uncoded BPSK in SC-FDMA and simulated BER value for PUCCH format 2A with one transmitting and one receiving antenna equals 5:5 dB, for format 2B, the difference equals 8.5 dB.

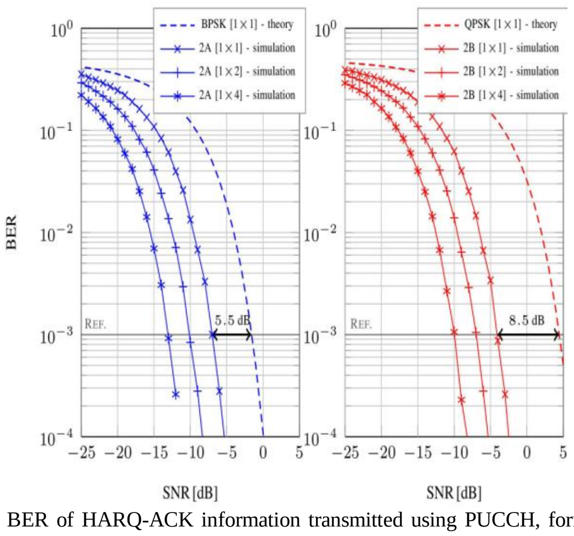

Fig. 6. BER of HARQ-ACK information transmitted using PUCCH, format 2A (left) and format 2B (right) in AWGN channel, various antenna mode

Bit error rate results of CQI/PMI, RI codeword transmitted using PUCCH format 2 is presented in Fig. 7. These simulations were provided only with a CQI codeword of 4 bits in length. The difference between the SNR value of format 2 for the SISO antenna mode and mode with 4 receiving antennas, when BER equaling BER reference level is 6 dB. Difference between theoretical value of uncoded QPSK modulation scheme in SC-FDMA and simulated BER value for PUCCH format 2 with one transmitting and one receiving antenna equals 7.4 dB.

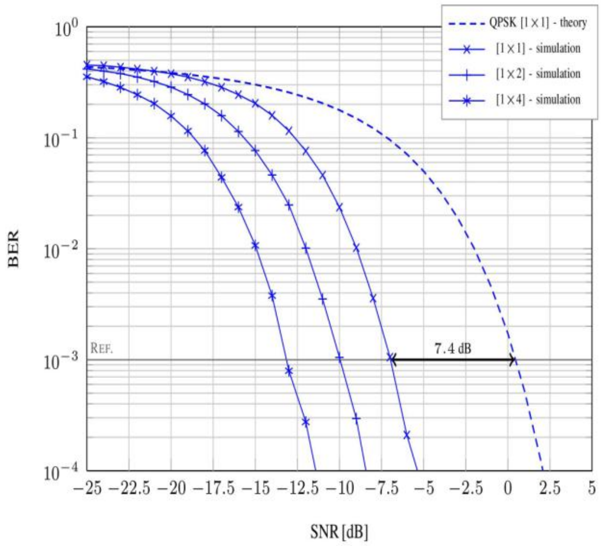

Fig. 7. BER of CQI/PMI and RI information transmitted using PUCCH format 2 in AWGN channel for various antenna configurations

VI. FUTURE SCOPE

In this seminar, the simulation of air interface is carried out and the simulation of core network can be simulated. It will lead to better performance evaluation as well as implementation. The next generation LTE will be known as ADVANCED LTE. Hence the simulation of Air interface of ADVANCED LTE have a widened in mobile communication performance evaluation and also in the implementation of ADVANCED LTE. In MIMO of LTE till 4x4 system is implemented, as a future scope it can be upgraded to 8x8 or further. In this project HSPA+ is considered as the existing system and it is taken as the basic block for comparison with LTE. WCDMA+ is an advanced technology, which give access to high speed mobile telephony. Hence WCDMA+ can be taken as a basic comparing element to LTE, which may leads to better implementation of LTE.

A. Lte Advanced

LTE Advanced is the next major milestone in the evolution of LTE. It incorporates many dimensions of enhancements including the aggregation of multiple radio channels (carriers), advanced antenna techniques and others

LTE Advanced can aggregate up to 5 carriers (up to 100 MHz) to increase user data rates and capacity for busty applications such as web browsing. Aggregation (multicarrier) when combined with higher order MIMO can provide extremely high peak data rates, theoretically up to 1Gbps. The driving force to further develop LTE towards LTE–Advanced LTE Release10 is set to provide higher bitrates in a cost efficient way and, at the same time, completely fulfill the requirements set by ITU for IMT Advanced, also referred to as 4G.

VII. CONCLUSION

The analysis and simulation of UCI control information transmitted via the PUCCH physical control channel in LTE uplink is focussed. Performance analysis of UCI transmission via PUCCH was performed in the AWGN channel model. As can be seen from presented graphs, BER results of an one or two-bit HARQ-ACK codeword using PUCCH format 1A or 1B gives better performance results than HARQ-ACK transmission using format 2A and 2B. HARQ-ACK transmission using PUCCH format 1A and 1B is more suitable than transmission using format 2A and 2B, but occupied resources are an additional cost. Performance results of transmitting a CQI/PMI, RI codeword via PUCCH format 2 shows, that using Reed-Muller coding has lower efficiency than signal processing of PUCCH format 2B by 1 dB only. If we consider a longer input codeword length in the case of PUCCH format 2 and low overall complexity of the Reed-Muller channel coding, the Reed-Muller channel coding is suitable for using in LTE uplink PUCCH. As a further phase of the analysis, simulations in fading channel models will be performed.

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