INDIAN INSTITUTE OF TECHNOLOGY KANPUR

UNDER GRADUATE PROJECT

DESIGN AND IMPLEMENTATION OF TRANSMITTER CHAIN FOR MACHINE TYPE COMMUNICATION ON LTE NETWORKS

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ABSTRACT

The LTE technology has become most popular recently due to the high data rates, high capacity and spectrum efficiency. LTE is being continuously developed so as to include newer and innovative applications. Release 12 and 13 of LTE has specified Machine type communication using LTE. Unlike normal LTE usage, MTC requires very less data-rates. Data rates of 1Mbps has been specified in release 13 of LTE.

Machine Type Communication is generally characterized by communication between large number of devices with less or no human interaction. On a broad scale, MTC can be divided into massive-MTC and critical-MTC. In massive MTC, large number of devices are connected together and the difficulty lie in connecting remote devices. Radio technology supporting massive-MTC applications must therefore be able to operate properly with very high path loss between base stations and devices.

Critical-MTC are often associated with requirements on extremely high reliability and extremely high availability within the area where the application is to be supported. Many of these applications also have requirements on very low and predictable latency.

The main advantage of MTC using LTE is mobility. Presently, the radio access architecture for MTC is of short-range. Using LTE for MTC can be advantageous for devices requiring data transfer from distant devices/servers.

This project involves design, implementation and then demonstration of transmitter chain for LTE system capable of Machine Type Communication. The system would be based on version 13 LTE standards by 3GPP and built on an existing framework of version 8 LTE. Implementation and demonstration would be done on a Software Defined Radio from National Instruments.

INTRODUCTION

LTE:

LTE is a standard for high-speed wireless communication for mobile devices and data-terminals that is developed by 3GPP and specified in its release 8 and 9. It is also referred to as 4G LTE. Later releases provided various enhancements (Multi Antenna Support, Network Densification etc.).

Release 13 (early 2015) included enhancements in machine type communication (MTC).

LTE PROTOCOL STACK:

LTE protocol stack shows various layers of implementing the LTE and the flow of data.

1. **PDCP Layer:** Performs header compression of received IP Packet at eNodeB. Also, responsible for integrity protection, sequence numbering and ciphering.

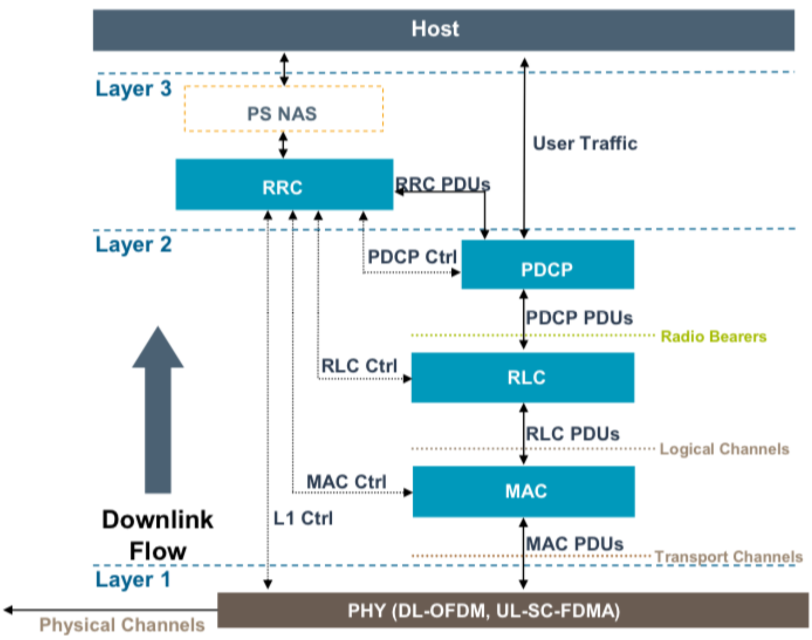

Figure 1: Downlink Protocol Stack

2. **RLC Layer:** Performs segmentation or concatenation of received data depending on the channel conditions and available bandwidth at eNodeB. It also takes care of retransmission of corrupt or not received packets. At receiving end, it performs reordering of received packets.
3. **MAC Layer:** Takes care of priority handling. Multiplexing of Logical to Transport channels. MAC Layer adds MAC header to the data. Checks for data error using CRC Check and acknowledges the transmitter.

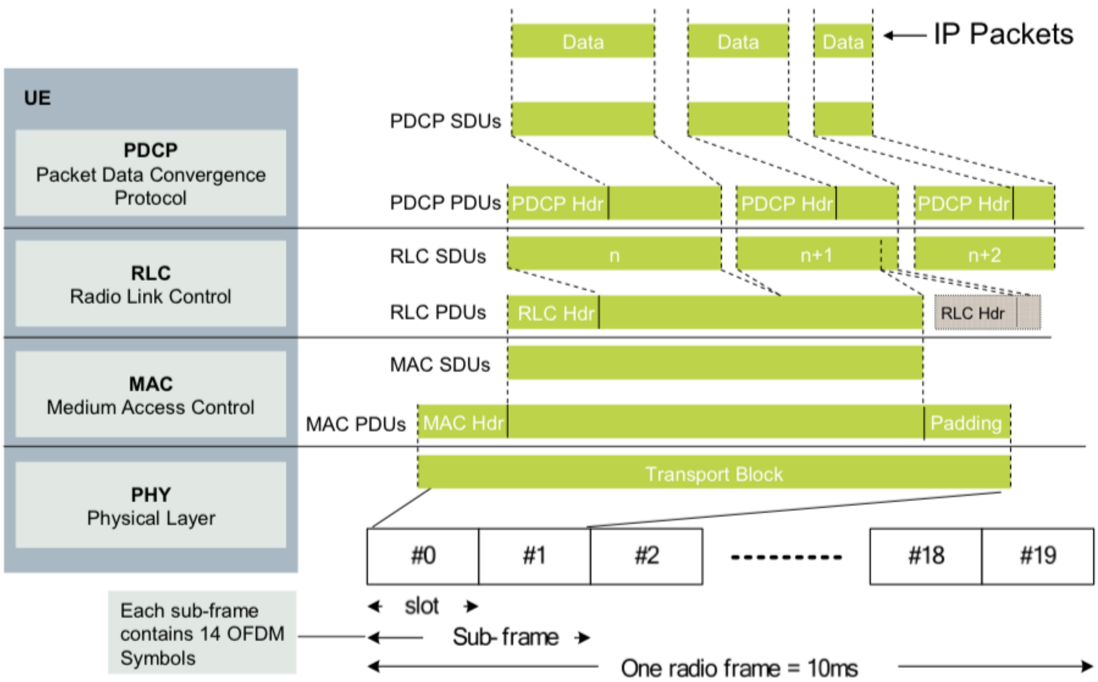

Figure 2: Data travel though protocol stack

4. **PHY Layer:** Physical layer does a variety of tasks. It includes CRC attachment, bit scrambling, complex modulation symbol generation and constellation mapping along with attaching cyclic prefix and OFDM symbol generation.

OFDM MODULATION:

In OFDM (Orthogonal Frequency Division Multiplexing) Modulation, given bandwidth consists of subcarriers spaced at 15KHz. Data is put on each sub-carrier and transmitted simultaneously. There will not be any interference due to orthogonality of the sinc signals in frequency domain. Advantages include Increased spectrum efficiency and resistance to frequency selective fading (due to long symbol time) and inter-symbol interference. LTE downlink uses OFDMA Modulation while uplink uses a modified OFDM called SC-FDMA.

LTE BANDWIDTHS:

LTE supports a handful of bandwidths. They are 1.4MHz, 3Mhz, 5MHz, 10MHz, 15MHz, 20MHz. The normal working of LTE is generally in 10 or 20MHz.

MTC devices work in 1.4MHz bandwidth because less amount of data rate is required. These devices are often called (Narrow Band) NB-IoT devices.

LTE PHYSICAL RESOURCES:

In LTE, physically, data is transmitted in the form of frames. Each frame is 10ms and each frame consists of 10 subframes each 1ms in time axis. Each subframe consists of two slots also called physical resource block. Each slot in turn consists of 7 OFDM symbols (generally) including cyclic prefix.

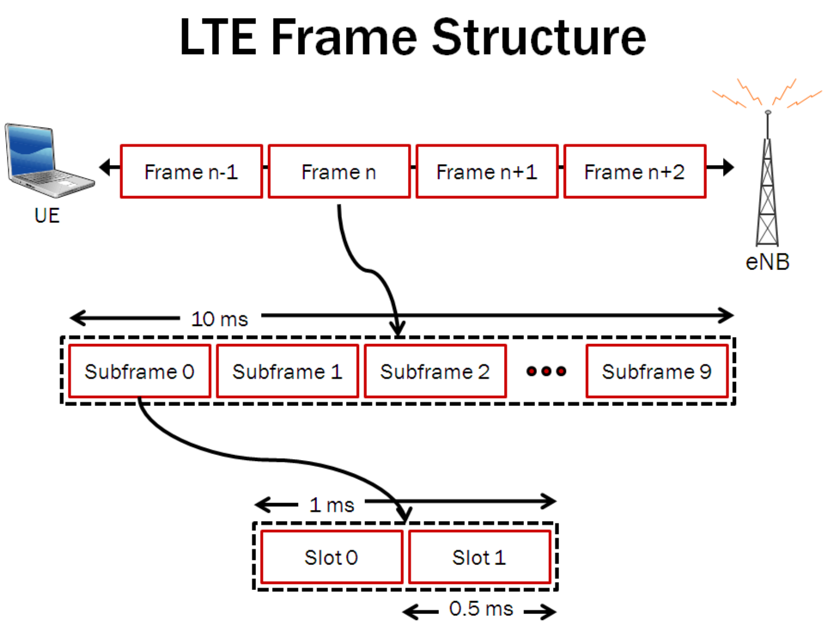

Figure 3: LTE Frame Structure

On frequency axis, each frame/subframe/slot span over 12 subcarriers spaced at 15KHz. The grid of 12 subcarriers and 7 OFDM symbols is called a resource block. Each resource block consists of 84 (12 x 7) resource elements. Two resource blocks make up a Physical Resource Block (PRB).

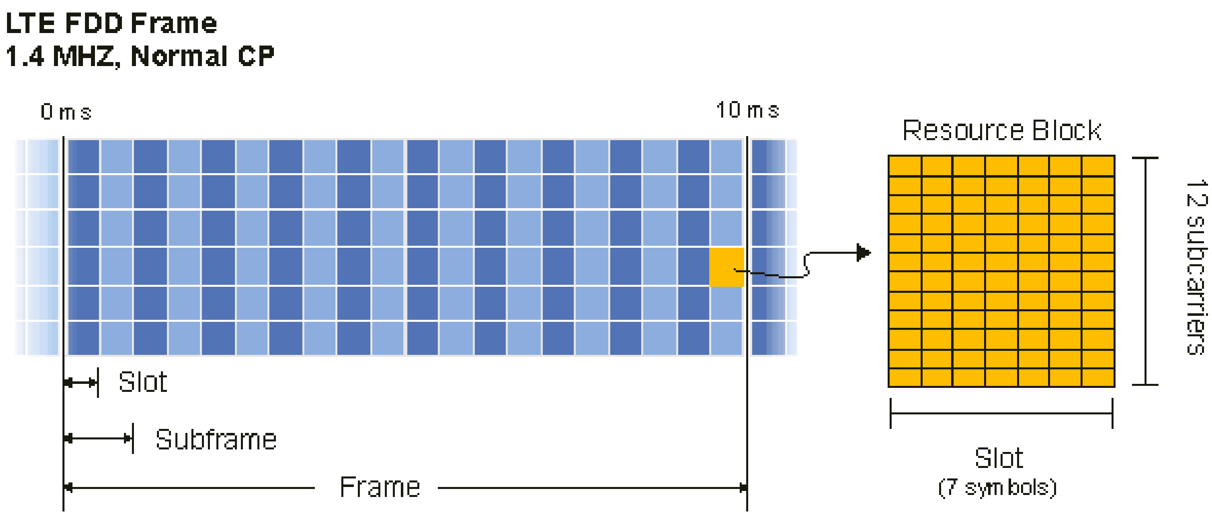

Figure 4: Resource Block

Channel Bandwidth (MHz)	Maximum Number of Resource Blocks (Transmission Bandwidth Configuration)	Maximum Occupied Bandwidth (MHz)
1.4	6	1.08
3	15	2.7
5	25	4.5
10	50	9.0
15	75	13.5
20	100	18.0

Figure 5: Usable RBs for different bandwidths

<u>RESOURCE MAPPING:</u>

SYNCHRONISATION SIGNALS: UE first finds primary synchronization signal (PSS) located on last OFDM symbol of first slot of first and fifth subframes. This helps UE with slot timing detection. UE also finds secondary synchronization signal (SSS) which helps UE detect frame timing, cyclic prefix length and FDD/TDD detection.

PSS uses Zadoff Chu sequence of length 63 while SSS uses BPSK modulation.

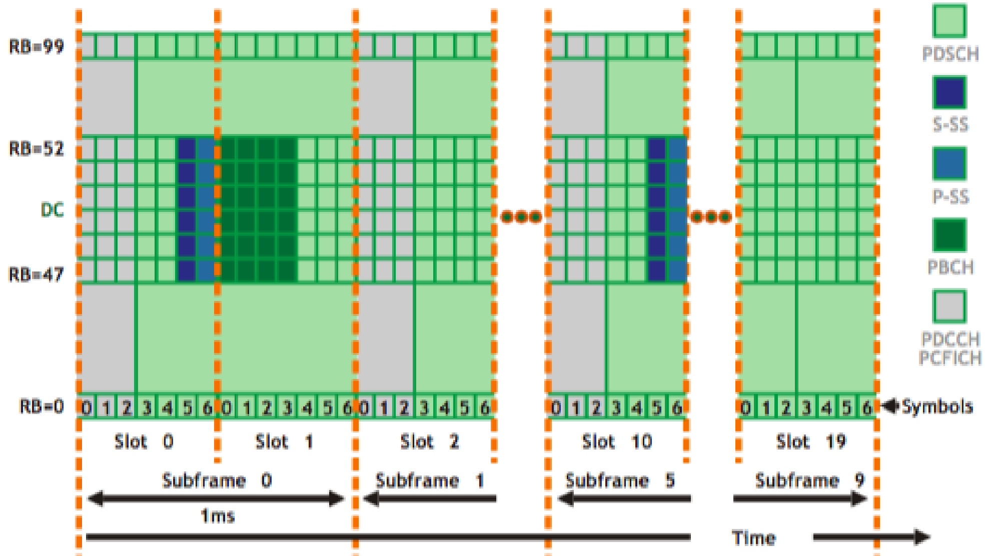

Figure 6: Resource Mapping

PDCCH: The Physical Downlink Control Channel (PDCCH) carries Downlink Control Information (DCI) which contains UE-specific scheduling assignments for Downlink resource allocation, power control commands, and common scheduling assignments for signaling messages (such as system information, paging, etc.).

PDCCH occupies first 1, 2 or 3 symbols of the subframe. The actual number of symbols occupied is given by PCFICH (Physical Control Format Indicator Channel) which is present in the first symbol of each frame.

PDCCH is always QPSK Modulated.

PDSCH: The Physical Downlink Shared Channel (PDSCH) mainly carries user data along with system information block, paging etc.

PDSCH can be modulated by either QPSK or 16 QAM or 64 QAM etc.

MTC & 3GPP STANDARDS

MTC - GENERAL CHARACTERISTICS:

1. Communication that involves little or no human interaction.
2. Involves large number of devices.
3. Periodic or intermittent network access.
4. Small amount of data per session.

OPERATION IN 1.4MHz:

General LTE devices work in 20MHz bandwidth but as specified above, MTC requires small amount of data only. Hence a bandwidth of 1.4MHz is specified standard (LTE Cat-M1). The peak downlink and uplink data rate for this bandwidth is 1Mbps. At a given time, a MTC device can send or receive on a single narrowband (6 RBs). Thus, physical channels which inherently span over wideband cannot be received by MTC.

DOWNLINK TRANSMISSION:

As present before, MTC device can only see a single narrowband at a time. Hence MPDCCH must be confined to 6 RBs. For compatibility with legacy LTE devices, MPDCCH is transmitted along with legacy PDCCH. MTC devices only read MPDCCH.

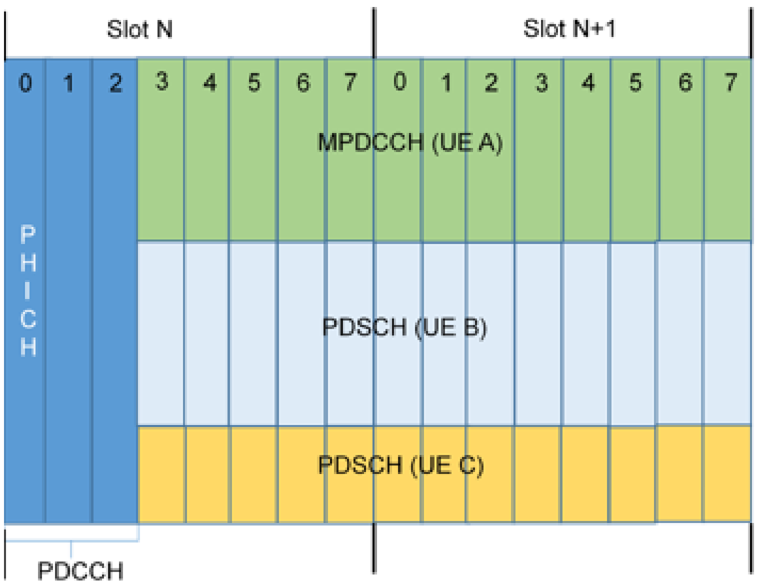

Figure 7: PDCCH, MPDCCH and PDSCH for different UEs

MPDCCH is transmitted in Resource Elements which otherwise was occupied by PDSCH. In first few sub frames, PDCCH along with MPDCCH is transmitted. In these subframes PDSCH is not transmitted. In the last subframes, P DCCH and PDSCH is transmitted.

DCI format 6 is used for MPDCCH. This DCI contains information about narrow-band indicator, resource block indicator, PDSCH repetition mode, MPDCCH repetition mode, modulation scheme, HARQ process number, power control, DCI format fag, Frequency hopping flag.

COVERAGE ENHANCEMENT:

Coverage enhancement is important part of MTC for supporting remote devices. Coverage enhancement as explained below is done at the cost of data-rate. Coverage enhancement is done by repetitions. A subframe is replicated and send multiple times in consecutive subframes.

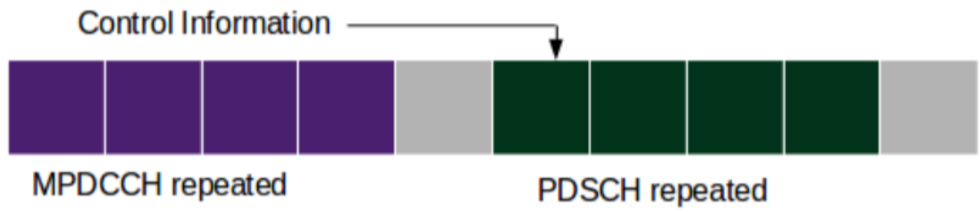

Figure 8: MPDCCH and PDSCH Repetitions

There are two modes of repetitions CE Mode A and CE Mode B where Mode B offers extensive coverage. Decoding parameters for PDSCH is extracted from last repeated set of MPDCCH sub-frames.

Instead of using same Frame for repetitions, Frequency hopping can also be used where subframes are repeated in different narrow bands at different times.

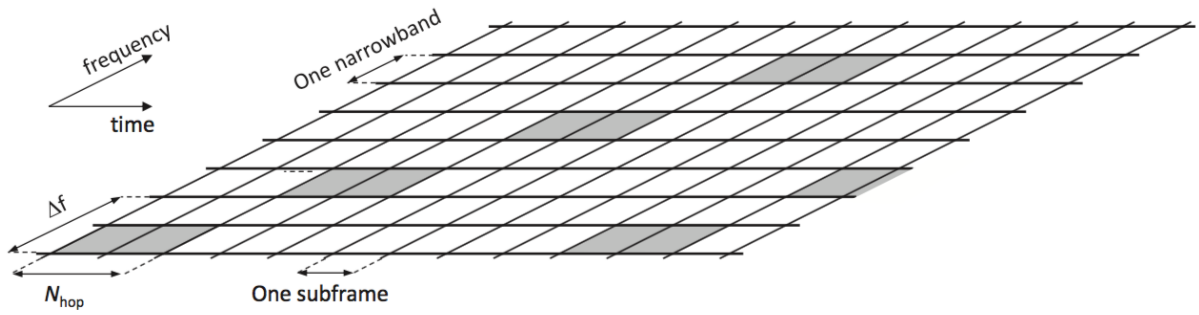

Figure 9: Frequency Hopping

TYPE-B HALF DUPLEX OPERATION:

In half duplex operation, data cannot be transmitted and received at same time. It is done at different times (different subframes in our case). This type of communication reduces device complexity and cost. In Type-B, the time gap between reception and transmission is increased. This given enough time for MTC device to process and switch.

POWER SAVING:

As given in the characteristics, MTC devices does not send data continuously. For many devices, there are specific sampling times and data output rates. In Power saving mode, the device although connected to the network, remains idle without any RF activity. This type of mod prevents the need of reconnecting to the network after the device wakes up.

DESIGN AND PROTOTYPING

SOFTWARES:

- **LabVIEW Communication System Design Suite 2017:** The software offers a design environment closely integrated with NI SDR for rapid prototyping of communication systems.
- **LabVIEW LTE Application Framework 2.0.1:** The LTE Application Framework provides a ready to run, real-time physical layer (PHY) and lower medium access control (MAC)-layer reference design based on the LTE wireless standard.

HARDWARE:

- **NI USRP RIO 2952 R:** Software Defined Radio Reconfigurable Devices are built on the reconfigurable I/O (RIO) and universal software radio peripheral (USRP) architectures. They include a powerful FPGA for advanced DSP and include 2x2 MIMO transceivers or four-channel super heterodyne receivers, supporting center frequencies from 400 MHz to 4.4 GHz, with up to 120 MHz of instantaneous bandwidth.

<u>IMPLEMENTATION:</u>

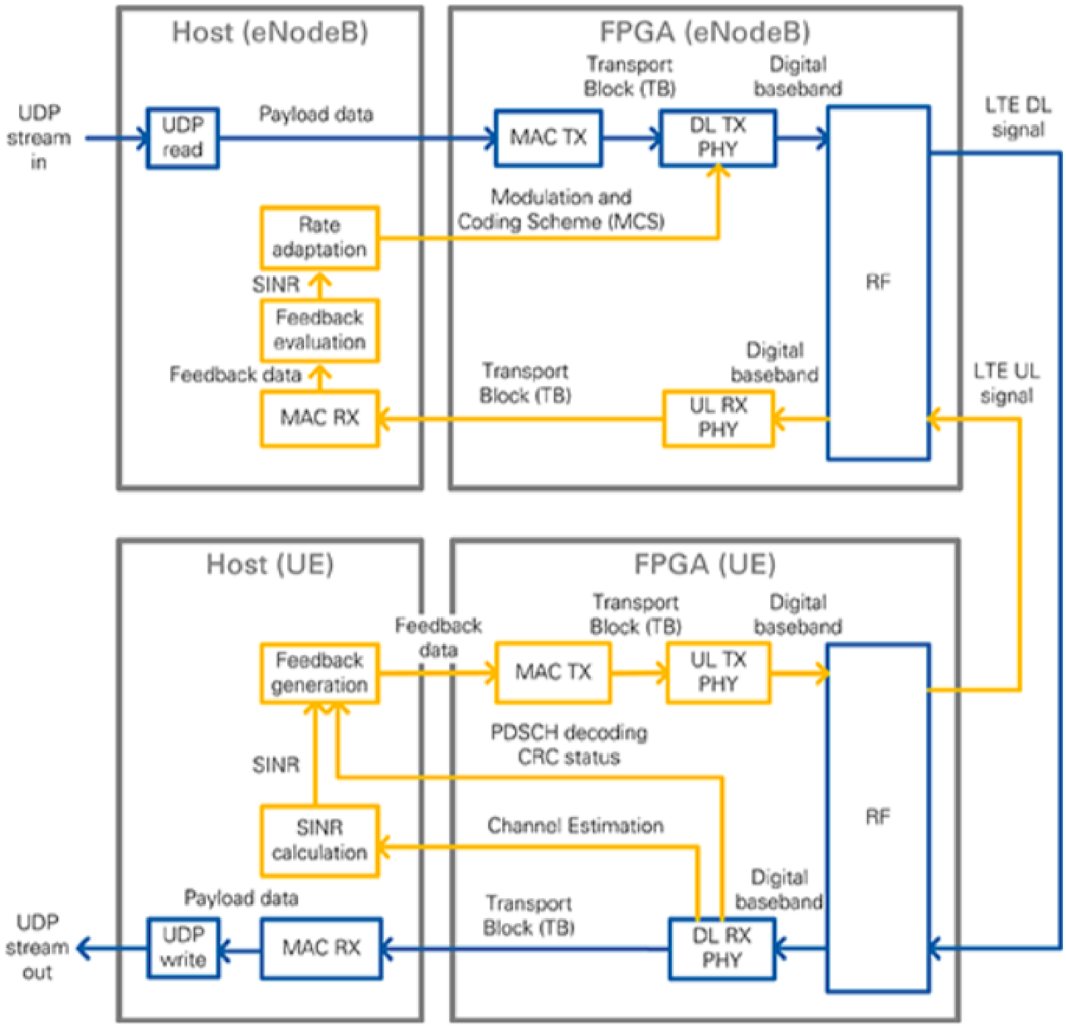

Figure 10: Overview of Implementation

The overall LTE implementation is as shown in the figure 10. As can be seen, host (PC) is used to send the UDP data to FPGA, where most of the processing and implementation is done in real time. The signals are then transmitted and received via Tx and Rx ports physically. To this basic implementation, MTC was added as shown below.

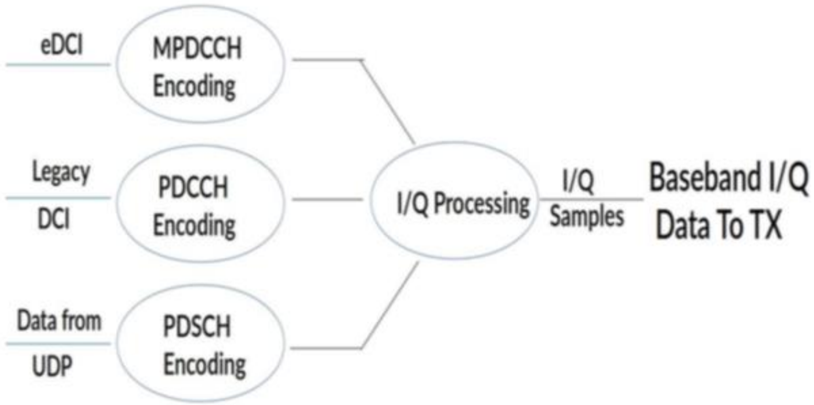

Figure 11: Block Diagram of Modified Physical Layer

MPDCCH ENCODING:

DCI Format 6 is transferred from Host to FPGA via a DMA FIFO. The components of DCI are Narrow-band indicator (4 bits), Modulation Coding Scheme (5 bits), Resource Block indicator (5 bits), TPC command for PUCCH (2 bits), MPDCCH and PDCSH Repetition Flag (8 bits each) totaling to 32 bits. This message is encoded and a CRC is attached which is checked at the receiver end. It then undergoes Convolution Encoding and Re- serializing after which it becomes 144 bits in size (Figure 13). The message is passed to scrambler and multiplexer before passing through a QPSK modulator finally producing I/Q Samples.

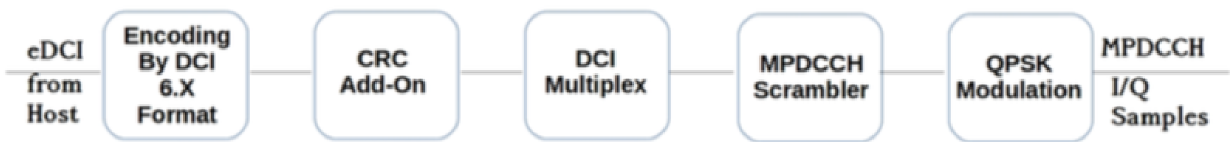

Figure 12: MPDCCH processing

PDCCH ENCODING:

PDCCH Encoding is done in a very similar manner to MPDCCH but DCI Format 1 is used. This module is triggered every subframe because there must be a PDCCH in first 1/2/3 OFDM symbols of every subframe.

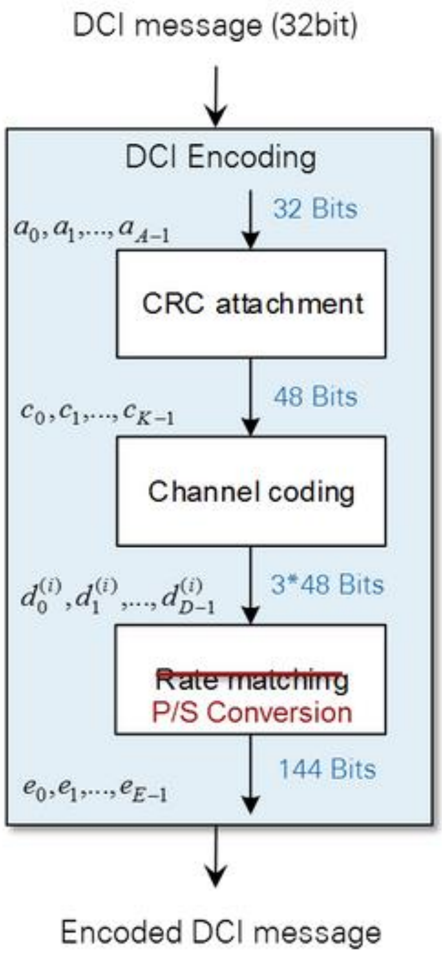

Figure 13: DCI Encoding

PDSCH ENCODING:

The user data is transmitted to FPGA via a FIFO Buffer. The user data is transmitted via UDP connection.

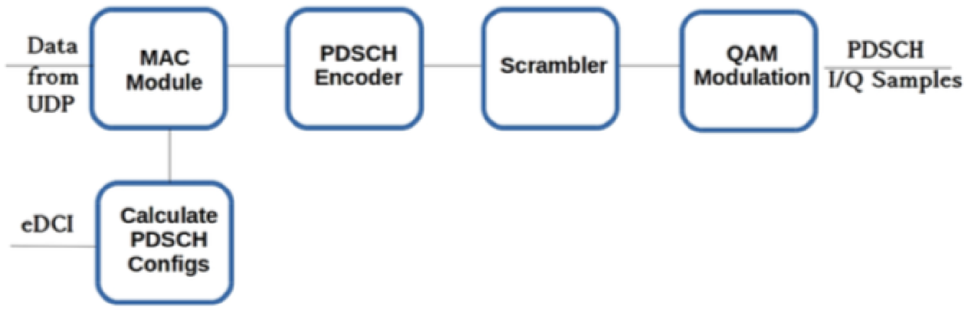

Figure 14: PDSCH Processing

As the DCI of MPDCCH has information about PDSCH, required parameters are extracted from DCI and used in MAC Layer. MAC layer decides the transport block size according to the configuration parameters of DCI of MPDCCH. Once the size is confirmed, FIFO and thus the user data is read. Due to use of repetitions, the data is stored in second FIFO which is used for repeating subframes. The MAC layer, adds MAC header and padding and creates the transport block.

The transport block from MAC layer now enters Physical Layer, where it goes through an encoder, scrambler and a modulator, producing I/Q Samples.

TX I/Q PROCESSING:

Once all the above symbols are generated, this module is triggered. An Index Generator generates timing information for each OFDM symbol based on sub-carrier index, resource block index, symbol index, sub-frame index and triggers for starting of a symbol and a sub-frame.

The I/Q Samples are read from a FIFO according to the above timing indication.

It also takes care of mapping from various physical channels and synchronization signals to sub-carriers. PDSCH is mapped according to the DCI information and PDCCH is mapped to wideband.

MPDCCH and PDSCH are mapped according to subframe index. MPDCCH is mapped to first four subframes while PDSCH is mapped to subframes 5,6,7,8.

An FFT is performed and cyclic prefix is attached there by completing the time domain signal formation. This is further sent to DAC registers from where it is wirelessly transmitted.

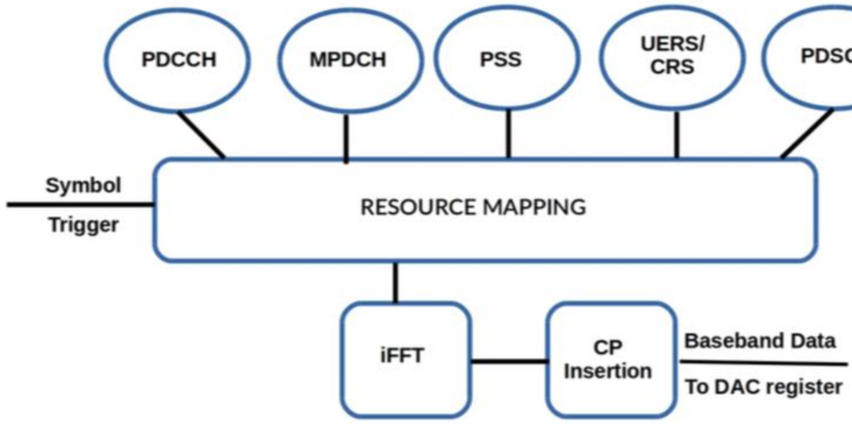

Figure 15: TX I/Q Processing

WORK DONE AND ARCHITECTURE IMPLEMETED

- UDP:

Implemented interface between host and FPGA via FIFO for taking UDP Data and passing it as PDSCH.

- TIMINGS:

Solved certain timing errors and timeout errors.

FINAL IMPLEMENTATION AND DEMONSTRATION

The whole system was implemented and prototyped on NI USRP 2952R. It consists of a inbuilt Xillinx FPGA and supports a maximum bandwidth of 120MHz.

Figure 16: NI USRP 2952R

Python code was used to implement UDP via socket library. Port 50000 was used for transmission while 60000 was used for reception.

RESULTS:

Maximum data-transfer rate is 360kbps for 16 QAM modulation while it is 80kbps for QPSK modulation, which is quite good for MTC applications.

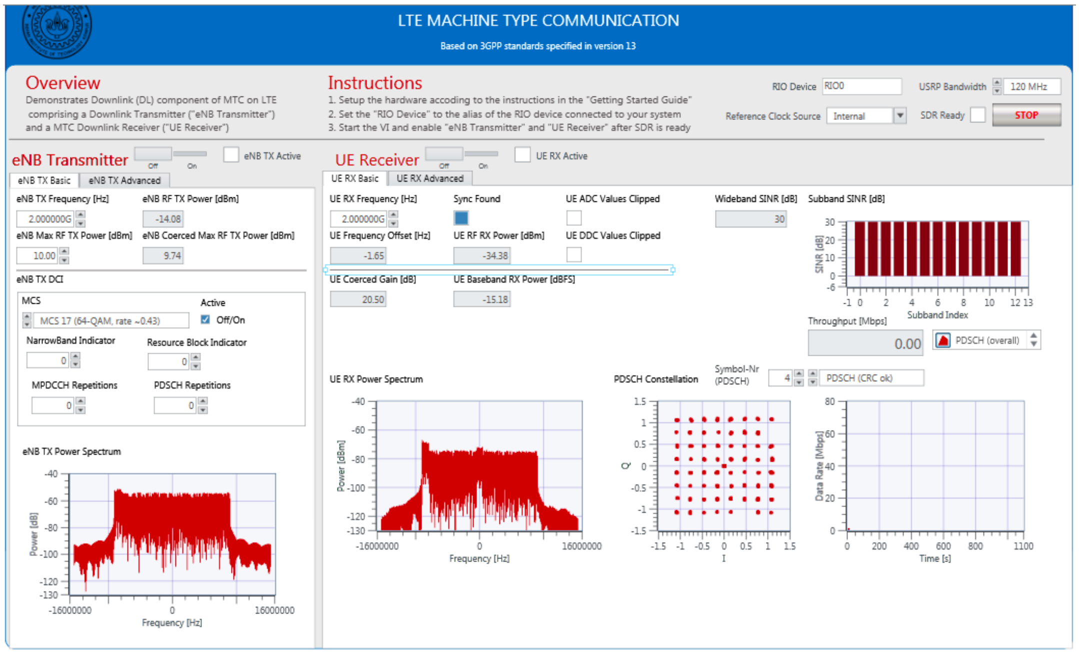

Figure 17: Application Panel

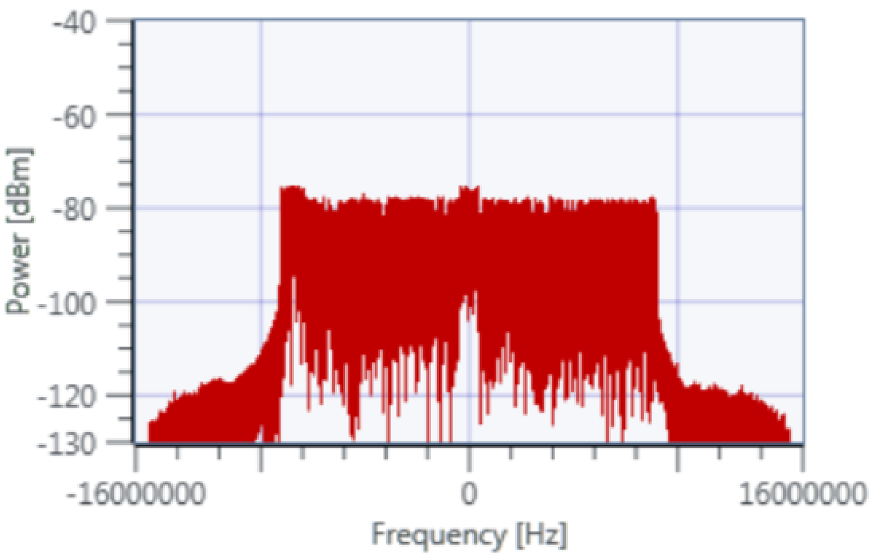

Figure 18: Power Spectrum of Received Signal

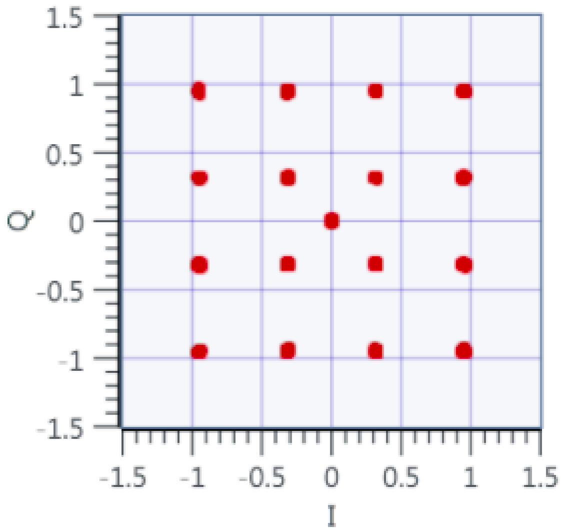

Figure 19: PDSCH Constellation

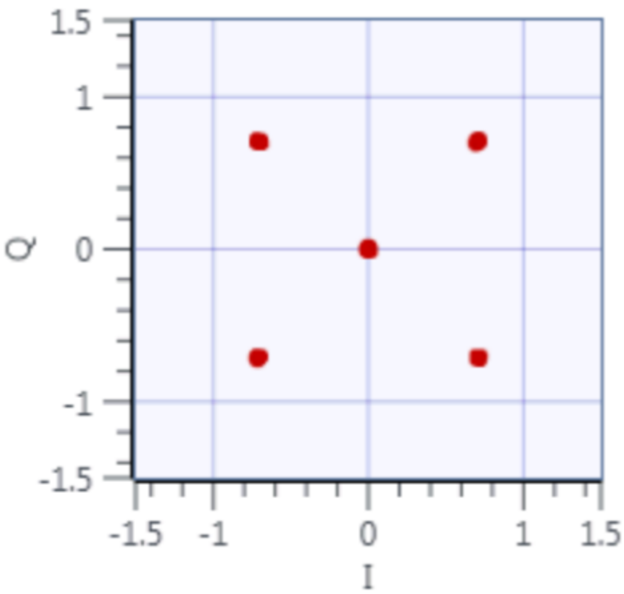

Figure 20: MPDCCH Constellation

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