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Baseband Analysis of Long Term Evolution Systems

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Abstract- *This paper focuses on the universal mobile telecommunications system long term evolution LTE[1 to16] and discusses the requirements for device technologies pertaining to mobile terminals. The LTE[1 to16] represents the next generation cellular phone technology that is intended to achieve a high peak data rate, low latency, and high radio efficiency in addition to low cost and sufficiently high mobility characteristics. Vigorous discussion regarding the specifications for LTE[1 to16] is currently ongoing in the 3rd generation partnership project. This paper also introduces various device technologies that support current mobile terminals besides emphasizes has been given to OFDM[1 to16] with 64 QAM[1 to16] technique while down linking has been done.*

I. INTRODUCTION

What is LTE

Long Term Evolution LTE [1 to 16] describes standardization work by the Third Generation Partnership Project (3GPP) to define a new high-speed radio access method for mobile communications systems.

LTE [1 to 16] is the next step on a clearly-charted roadmap to so-called '4G' mobile systems that starts with today's 2G and 3G networks. Building on the technical foundations of the 3GPP family of cellular systems that embraces GSM, GPRS and EDGE as well as WCDMA and now HSPA (High Speed Packet Access), LTE [1 to 16] offers a smooth evolutionary path to higher speeds and lower latency. Coupled with more efficient use of operators' finite spectrum assets, LTE [1 to 16] enables an even richer, more compelling mobile service environment.

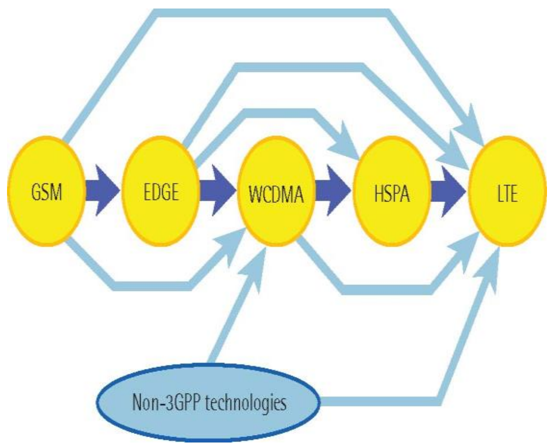

Figure 1
Choice of Upgrade Paths[1]

In parallel with its advanced new radio interface, realising the full potential of LTE [1 to 16] requires an evolution from today's hybrid packet/circuit switched networks to a simplified, all-IP (Internet Protocol) environment. From an operator's point of view, the pay-off is reduced delivery costs for rich, blended applications combining voice, video and data services plus simplified interworking with other fixed and wireless networks.

By creating new value-added service possibilities, LTE [1 to 16] promises long-term revenue stability and growth for around two hundred mobile operators that are already firmly committed to the UMTS/HSPA family of 3G systems. Just as importantly, it provides a powerful tool to attract customers who are provided with an increasing number of technology options for broadband connectivity on the move.

Based on the UMTS/HSPA family of standards, LTE [1 to 16] will enhance the capabilities of current cellular network technologies to satisfy the needs of a highly demanding customer accustomed to fixed broadband services. As such, it unifies the voice-oriented environment of today's mobile networks with the data-centric service possibilities of the fixed Internet.

Another key goal of the project is the harmonious coexistence of LTE [1 to 16] systems alongside legacy circuit switched networks. This will allow operators to introduce LTE's all-IP concept progressively, retaining the value of their existing voice-based service platforms while benefiting from the performance boost that LTE [1 to 16] delivers for data services.

From an operator's perspective, the flexible channel bandwidths and harmonised FDD/TDD modes of LTE [1 to 16] provide a more efficient use of carriers' existing and future spectrum resources. LTE [1 to 16] also provides a more robust platform for operators to offer compelling value-added services in the mobile domain.

From a technical point of view, a fundamental objective of the LTE [1 to 16] project is to offer higher data speeds, for both down- and uplink transmission. Apart from this increase in raw data rates, LTE [1 to 16] is characterised by reduced packet latency; the restriction that determines the responsiveness of gaming, VoIP, videoconferencing and other real-time services.

The key characteristics of LTE [1 to 16] are summarised here, with specific comparison with today's UMTS/HSPA networks:

- Enhanced air interface allows increased data rates: LTE [1 to 16] is built on an all-new radio access network based on OFDM[1 to 16] (Orthogonal Frequency-Division Multiplexing) technology. Specified in 3GPP Release 8, the air interface for LTE [1 to 16] combines OFDM[1 to 16] based modulation and multiple access scheme for the downlink, together with SC-FDMA (Single Carrier FDMA) for the uplink.

- All OFDM[1 to 16] schemes split available spectrum into thousands of extremely narrowband carriers, each carrying a part of the signal. In LTE [1 to 16], the innate spectral efficiency of OFDM[1 to 16] is further enhanced with higher order modulation schemes such as 64QAM [1 to 16] and sophisticated FEC (Forward Error Correction) schemes such as tail biting, convolutional coding and turbo coding, alongside complementary radio techniques like MIMO and Beam Forming with up to four antennas per station.

- The result of these radio interface features is significantly improved radio performance, yielding up to five times the average throughput of HSPA. Downlink peak data rates are extended up to a theoretical maximum of 300 Mbit/s per 20 MHz of spectrum. Similarly, LTE [1 to 16] theoretical uplink rates can reach 75 Mbit/s per 20 MHz of spectrum, with theoretical support for at least 200 active users per cell in 5 MHz.

- As explained in the following paragraphs, the performance of HSPA is itself evolving through the use of technologies like 64QAM [1 to 16] and MIMO. These features are part of 3GPP Release 7, while a combination of 64QAM [1 to 16] and MIMO for HSDPA (FDD) is specified in Release 8. LTE [1 to 16] however, delivers even greater improvements in overall performance and efficiency through the use of OFDM [1 to 16] technology for the air interface, rather than the WCDMA-based UTRAN common to WCDMA and HSPA systems, and through more complex MIMO and beam forming antenna configurations.

- The capabilities of LTE [1 to 16] will also evolve, with improvements specified in forthcoming Releases allowing LTE [1 to 16] (advanced) to fulfill the requirements of IMT-Advanced, the ITU term for so-called '4G' systems that will be the eventual successors to evolved 3G and 3G+ technologies.

- High spectral efficiency: LTE's greater spectral efficiency allows operators to support increased numbers of customers within their existing and future spectrum allocations, with a reduced cost of delivery per bit.

- Flexible radio planning: LTE [1 to 16] can deliver optimum performance in a cell size of up to 5 km. It is still capable of delivering effective performance in cell sizes of up to 30 km radius, with more limited performance available in cell sizes up to 100 km radius. See Section 4 for more information on spectrum for LTE and deployment flexibility.

- Reduced latency: By reducing round-trip times to 10ms or even less (compared with 40–50ms for HSPA), LTE [1 to 16] delivers a more responsive user experience. This permits interactive, real-time services such as high-quality audio/videoconferencing and multi-player gaming.

- An all-IP environment: One of the most significant features of LTE [1 to 16] is its transition to a 'flat', all-IP based core network with a simplified architecture and open interfaces. Indeed, much of 3GPP's standardisation work targets the conversion of existing core network architecture to an all-IP system. Within 3GPP, this initiative has been referred to as Systems Architecture Evolution (SAE) – now called Evolved Packet Core (EPC). SAE/EPC enables more flexible service provisioning plus simplified interworking with fixed and non-3GPP mobile networks.

- EPC is based on TCP/IP protocols – like the vast majority of today's fixed data networks – thus providing PC-like services including voice, video, rich media and messaging. This migration to an all-packet architecture also enables improved interworking with other fixed and wireless communication networks.

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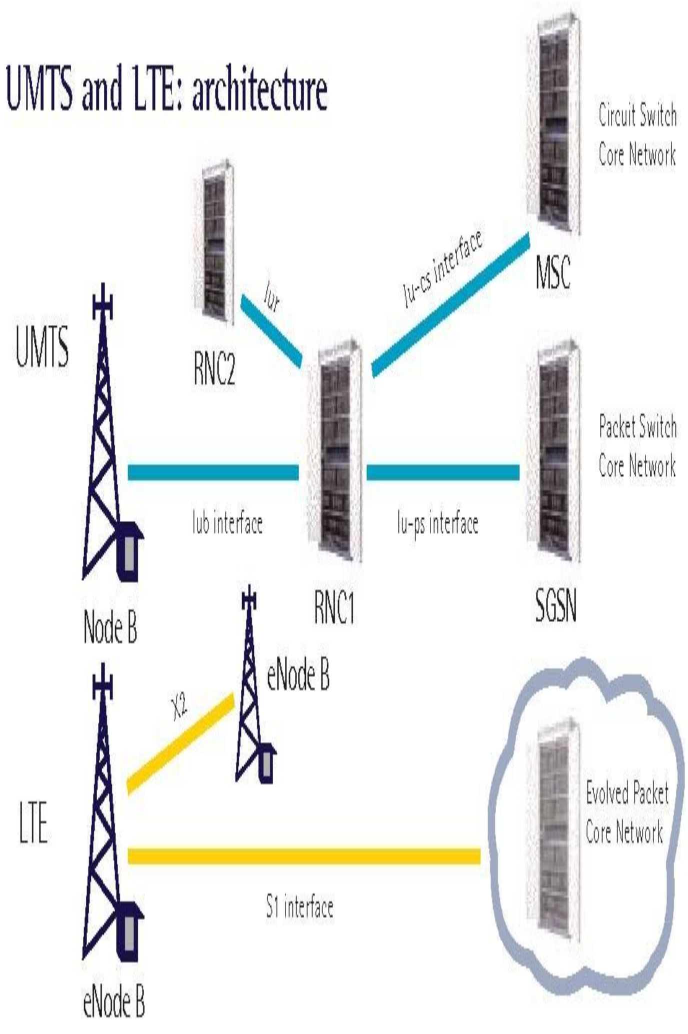


Figure 2

LTE gives operators the benefits of evolution to a simplified, all-IP network architecture.[1]

- Co-existence with legacy standards and systems: LTE [1 to 16] users should be able to make voice calls from their terminal and have access to basic data services even when they are in areas without LTE [1 to 16] coverage.

- LTE [1 to 16] therefore allows smooth, seamless service handover in areas of HSPA, WCDMA or GSM/GPRS/EDGE coverage. Furthermore, LTE/SAE supports not only intra-system and inter-system handovers, but inter-domain handovers between packet switched and circuit switched sessions.

- Extra cost reduction capabilities: The introduction of features such as a multi-vendor RAN (MVR) or self optimising networks (SON) should help to reduce opex and provide the potential to realise lower costs per bit.

- In order to achieve high data rates the first most aspect which should be looked after is the physical layer of the LTE [1 to 16]. This paper focuses on the combination of two efficient modulation and multiplexing schemes used in the LTE [1 to 16].

  1. Orthogonal Frequency Division Multiplexing (OFDM)
  2. 64- Quadrature Amplitude Modulation (64-QAM)

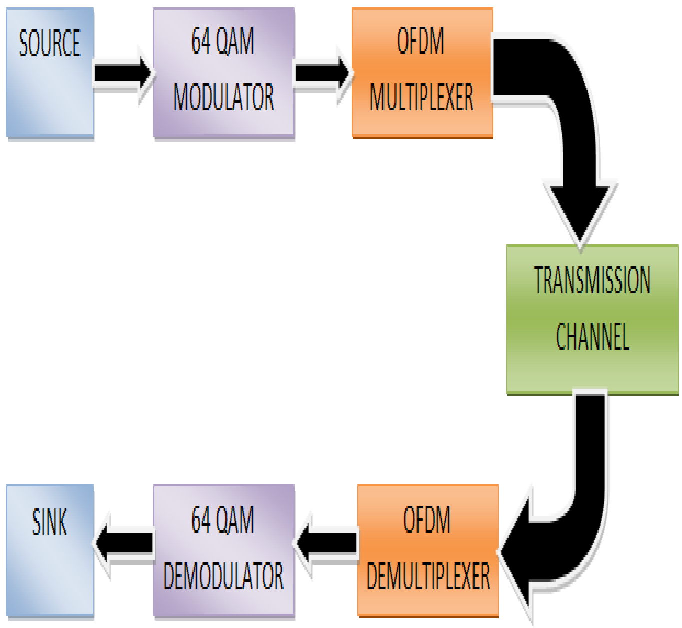


Figure 3

Proposed Baseband Model for Long Term Evolution System

OFDM

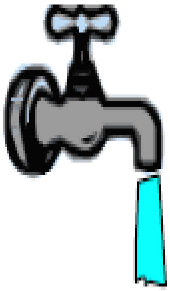
Firstly the fundamental difference between modulation and multiplexing shall be discussed.

Modulation - *a mapping of the information on changes in the carrier phase, frequency or amplitude or combination.*

Multiplexing - *method of sharing a bandwidth with other independent data channels.*

- OFDM[1 to 16] is a combination of modulation and multiplexing. Multiplexing generally refers to Independent signals, those produced by different sources. So it is a question of how to share the spectrum with these users. In OFDM[1 to 16] the question of multiplexing is applied to independent signals but these independent signals are a sub-set of the one main signal. In OFDM[1 to 16] the signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM[1 to 16] carrier.

- OFDM[1 to 16] is a special case of Frequency Division Multiplex (FDM). As an analogy, a FDM channel is like water flow out of a faucet, in contrast the OFDM[1 to 16] signal is like a shower. In a faucet all water comes in one big stream and cannot be sub-divided. OFDM[1 to 16] shower is made up of a lot of little streams



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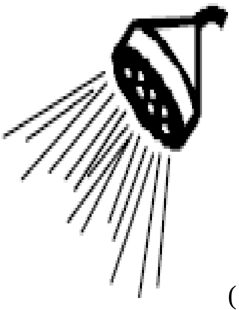

(

(2)

Figure 4.1 A Regular-FDM single carrier – A whole bunch of water coming all in one stream.[2]

Figure 4.2 Orthogonal-FDM – Same amount of water coming from a lot of small streams.[2]

- Think about what the advantage might be of one over the other? One obvious one is that if I put my thumb over the faucet hole, I can stop the water flow but I cannot do the same for the shower. So although both do the same thing, they respond differently to interference.

- Another way to see this intuitively is to use the analogy of making a shipment via a truck.

- We have two options, one hire a big truck or a bunch of smaller ones. Both methods carry the exact same amount of data. But in case of an accident, only 1/4 of data on the OFDM[1 to 16] trucking will suffer.

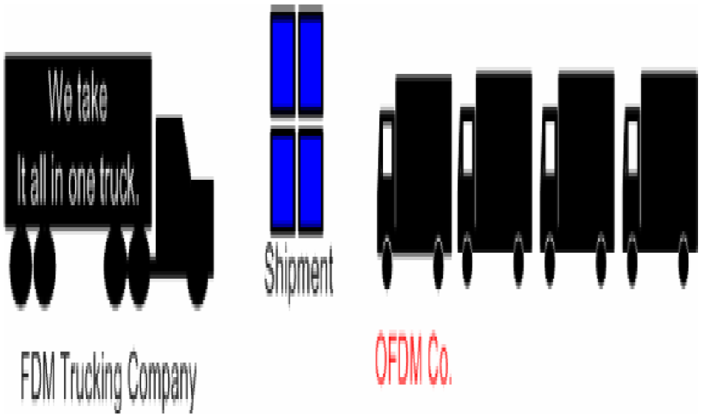

Figure 5

FDM v/s OFDM[2]

- These four smaller trucks when seen as signals are called the sub-carriers in an OFDM[1 to 16] system and they must be orthogonal for this idea to work. The independent sub-channels can be multiplexed by frequency division multiplexing (FDM), called multi-carrier transmission or it can be based on a code division multiplex (CDM), in this case it is called multi-code transmission.

The importance of being orthogonal

The main concept in OFDM[1 to 16] is orthogonality of the sub-carriers. Since the carriers are all sine/cosine wave, we know that area under one period of a sine or a cosine wave is zero. This is easily shown.

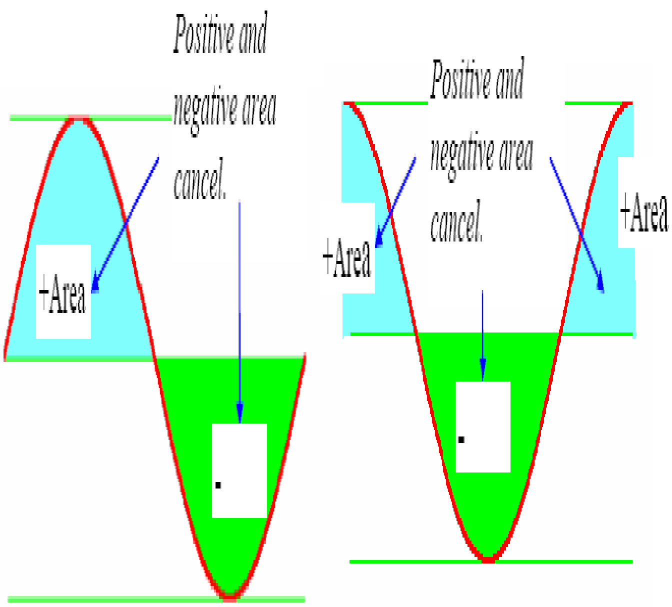

Figure 6

The area under a sine and a cosine wave over one period is always zero. [2]

Let's take a sine wave of frequency m and multiply it by a sinusoid (sine or a cosine) of a frequency *n*, where both *m* and *n* are integers. The integral or the area under this product is given by

$f(t) = \sin mwt \times \sin nwt$

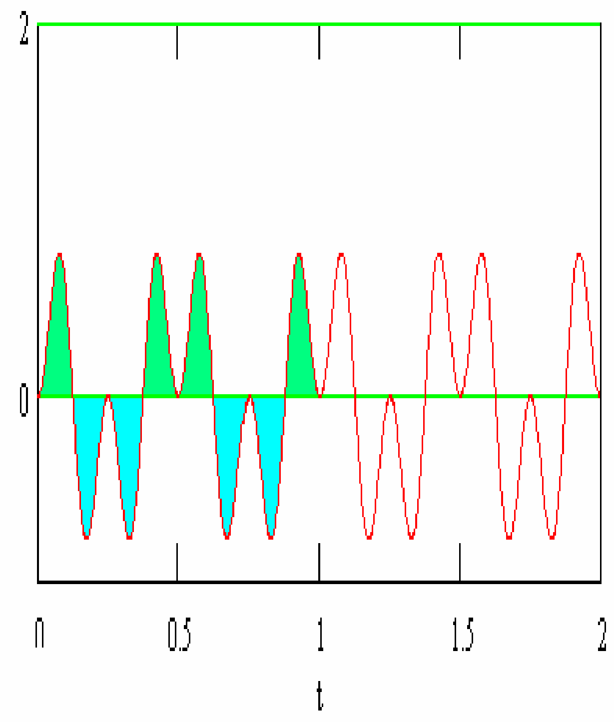

Figure 7

The area under a sine wave multiplied by its own harmonic is always zero. [2]

By the simple trigonometric relationship, this is equal to a sum of two sinusoids of frequencies *(n-m)* and *(n+m)*

$$= \frac{1}{2}\cos(m-n) - \frac{1}{2}\cos(m+n)$$

These two components are each a sinusoid, so the integral is equal to zero over one period.

$$= \int_0^{2\pi} \frac{1}{2}\cos(m-n)\omega t - \int_0^{2\pi} \frac{1}{2}\cos(m+n)\omega t$$
$$= 0 - 0$$

We conclude that when we multiply a sinusoid of frequency *n* by a sinusoid of frequency *m/n*, the area under the product is zero. In general for all integers *n* and *m*, sin*mx*,cos*mx*, cos *nx*,sin *nx* are all orthogonal to each other. These frequencies are called harmonics.

This idea is key to understanding OFDM[1 to 16]. The orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight frequency space without interference from each other. In essence this is similar to CDMA, where codes are used to make data sequences independent (also orthogonal) which allows many independent users to transmit in same space successfully.

Let's first look at what a Frequency Division Multiplexing FDM is. If I have a bandwidth that goes from frequency *a* to *b*, I can subdivide this into a frequency space of four equal spaces. In frequency space the modulated carriers would look like this. OFDM[1 to 16] is a special case of FDM.

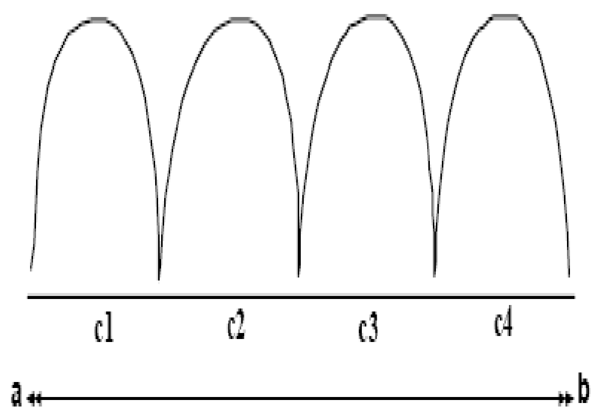

Figure 8

FDM carriers are placed to next to each other. [2]

The frequencies *a* and *b* can be anything, integer or non-integer since no relationship is implied between *a* and *b*. Same is true of the carrier center frequencies which are based on frequencies that do not have any special relationship to each other. But, what if frequency c_1 and c_n were such that for any *n*, an integer, the following holds.

$c_n = n \times c_1$
So that
$c_2 = 2c_1$
$c_3 = 3c_1$
$c_4 = 4c_1$

All three of these frequencies are harmonic to c1. In this case, since these carriers are orthogonal to each other, when added together, they do not interfere with each other. In FDM, since we do not generally have frequencies that follow the above relationship, we get interference from neighbour carriers. To provide adjacent channel interference protection, signals are moved further apart.
The symbols rate that can be carried by a PSK carrier of bandwidth *b*, is given by

$Rs = 2Bl = Bp$

where B_l is lowpass bandwidth and Bp, the passband bandwidth. This relationship assumes a perfect Nyquist filtering with rolloff = 0.0. Since this is unachievable, we use root raised cosine filtering which for a roll-off of α gives the following relationship.

$$Rs = \frac{Bp}{1+\alpha}$$

So if we need three carriers, each of data rate = 20 Mbps, then we might place our BPSK carriers as shown below. With Rs = 20 and B = 20 x 1.25 = 25 MHz. Each carrier may be placed (25 + 2.5) 27.5 MHz apart allowing for a 10% guard band. The frequencies would not be orthogonal but in FDM we don't care about this. It's the guard band that helps keep interference under control.
The following figure shows the OFDM[1 to 16] signal in time and frequency domains. The subcarriers and guard intervals have been shown. The guard intervals have been placed between two adjacent symbols. Inter Symbol Interference is avoided by means of guard intervals. As a result bandwidth is conserved. Capacity of the channel is increased subsequently.

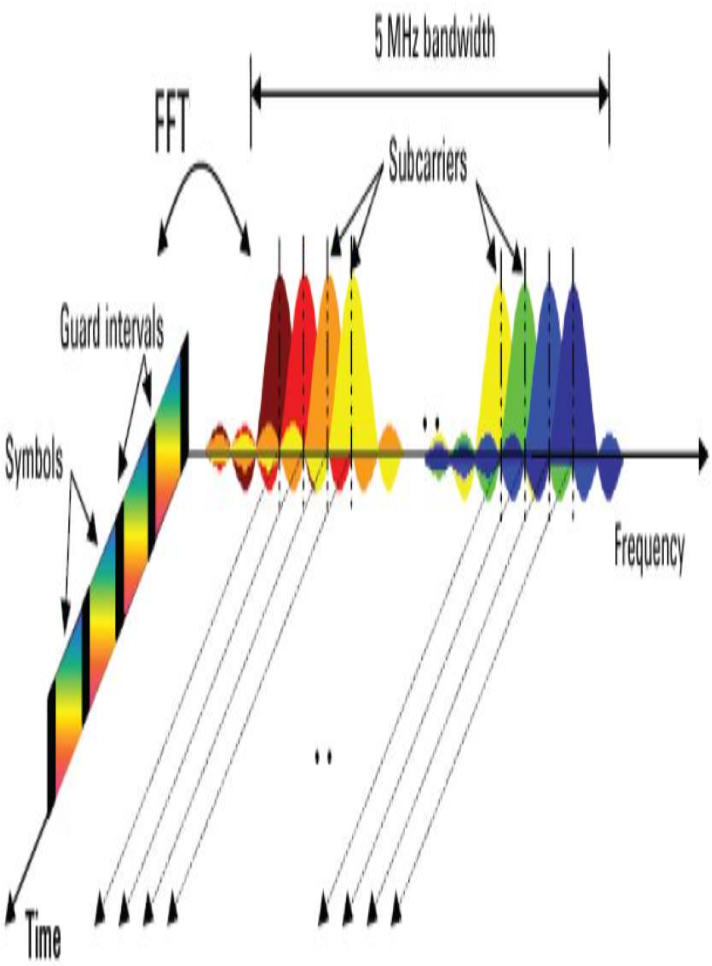

Figure 9

OFDM signal represented in frequency and time[2]

QAM

QAM, Quadrature amplitude modulation is widely used in many digital data radio communications and data communications applications. A variety of forms of QAM[1 to 16] are available and some of the more common forms include 16 QAM, 32 QAM, 64 QAM, 128 QAM, and 256 QAM. Here the figures refer to the number of points on the constellation, i.e. the number of distinct states that can exist.

- The various flavors of QAM[1 to 16] may be used when data-rates beyond those offered by 8-PSK are required by a radio communications system. This is because QAM[1 to 16] achieves a greater distance between adjacent points in the I-Q plane by distributing the points more evenly. And in this way the points on the constellation are more distinct and data errors are reduced. While it is possible to transmit more bits per symbol, if the energy of the constellation is to remain the same, the points on the constellation must be closer together and the transmission becomes more susceptible to noise. This results in a higher bit error rate than for the lower order QAM[1 to 16] variants. In this way there is a balance between obtaining the higher data rates and maintaining an acceptable bit error rate for any radio communications system.

- QAM[1 to 16] is used in many radio communications and data delivery applications. However some specific variants of QAM[1 to 16] are used in some specific applications and standards.

For domestic broadcast applications for example, 64 QAM and 256 QAM are often used in digital cable television and cable modem applications. In the UK, 16 QAM and 64 QAM[1 to 16] are currently used for digital terrestrial television using DVB - Digital Video Broadcasting. In the US, 64 QAM and 256 QAM are the mandated modulation schemes for digital cable as standardised by the SCTE in the standard ANSI/SCTE 07 2000.

In addition to this, variants of QAM[1 to 16] are also used for many wireless and cellular technology applications.

Constellation diagrams for QAM

The constellation diagrams show the different positions for the states within different forms of QAM[1 to 16], quadrature amplitude modulation. As the order of the modulation increases, so does the number of points on the QAM[1 to 16] constellation diagram. Since the number of bits per symbol gets increased so does the packaging efficiency of the QAM increases. The diagrams below show constellation diagrams for a variety of formats of Quadrature Amplitude modulation technique:

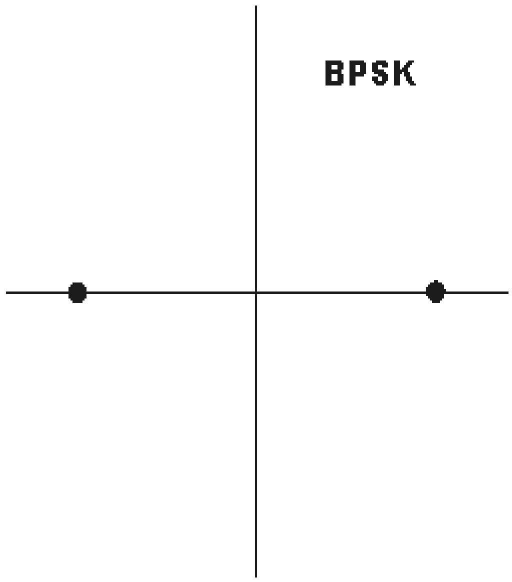

Figure 10

BPSK Constellation Diagram[17]

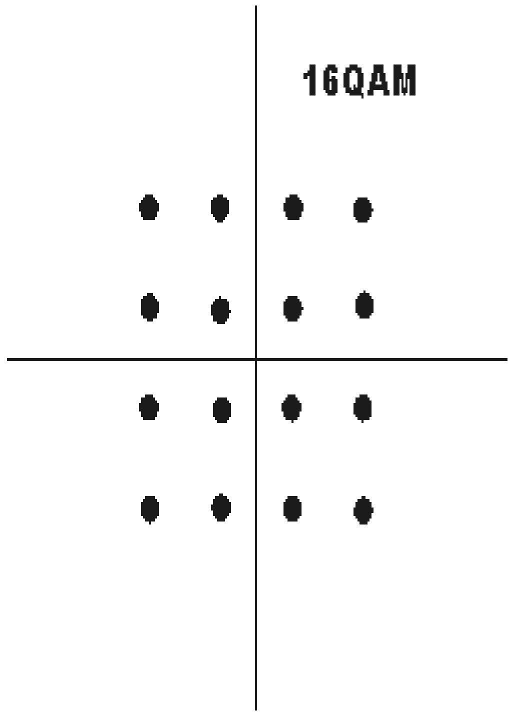

Figure 11

16 QAM Constellation Diagram[17]

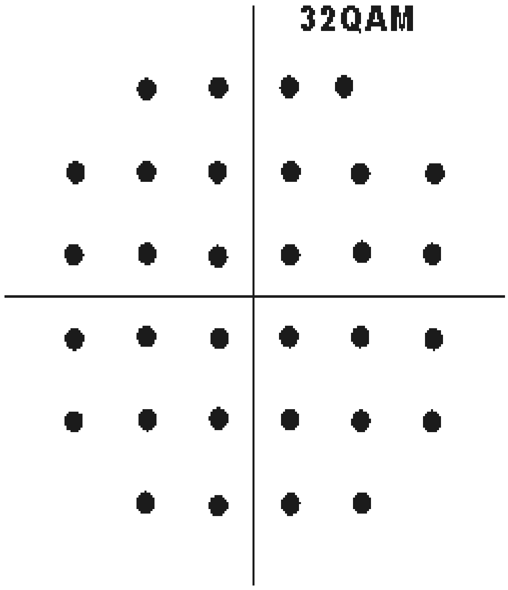

Figure 12

32 QAM Constellation Diagram[17]

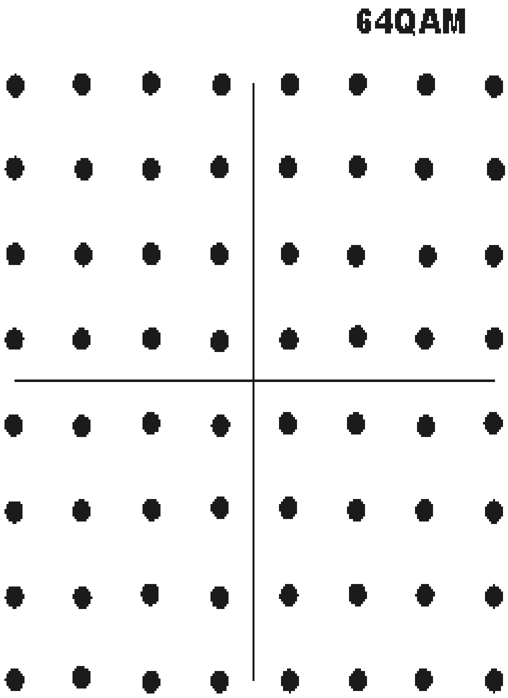

Figure 13

64 QAM Constellation Diagram[17]

QAM bits per symbol

The advantage of using QAM[1 to 16] is that it is a higher order form of modulation and as a result :

1. Bit Packaging Ratio is increased.
2. Bandwidth efficiency is increased.
3. Over all channel capacity is increased.
4. More number of customers can be catered.
5. The trade off between bandwidth and signal to noise ratio can be made i.e. same channel capacity is achievable at a lower signal to noise ratio value because of higher bandwidth.
6. Less transmission power is being required by the transmitter.
7. Power budget of both the transmitter and receiver reduces by many folds thus reducing the over all cost of the system.
8. The data rate of a link can be increased.

The table below gives a summary of the bit rates of different forms of QAM[1 to 16] and PSK.

MODULATION	BITS PER SYMBOL	SYMBOL RATE
BPSK	1	1 x bit rate
QPSK	2	1/2 bit rate
8PSK	3	1/3 bit rate
16QAM	4	1/4 bit rate
32QAM	5	1/5 bit rate
64QAM	6	1/6 bit rate

Table 1

The more the number of bits per symbol increased simultaneously Bit Packaging Ratio increases. One Bit in 64 QAM carries information equivalent to 6 Bits. Thus making it a very efficient Modulation Mechanism

QAM noise margin

While higher order modulation rates are able to offer much faster data rates and higher levels of spectral efficiency for the radio communications system, this comes at a price. The higher order modulation schemes are considerably less resilient to noise and interference.

As a result of this, many radio communications systems now use dynamic adaptive modulation techniques. They sense the channel conditions and adapt the modulation scheme to obtain the highest data rate for the given conditions. As signal to noise ratios decrease errors will increase along with re-sends of the data, thereby slowing throughput. By reverting to a lower order modulation scheme the link can be made more reliable with fewer data errors and re-sends.

The use of 64- QAM[1 to 16] has become more prevalent in cable systems, as both a video and data modulation. With its six bits per digital symbol (6 bits/symbol), it offers the highest bandwidth efficiency available today among digital cable signals. Expectations are that 64- QAM[1 to 16] will evolve to become a dominant modulation format of the digital multiplex. With the value of bandwidth at a premium, particularly based on bandwidth consumption trends of the past, it is of continued interest to find techniques that increase throughput capability. In HFC systems, there are various ways to create more bandwidth, such as increasing fibre counts, implementing equipment segmentation in the plant, adding wavelengths, or improving compression techniques in digital television signals. The migration of 16- QAM[1 to 16], which represents 4 bits/symbol, to 64- QAM[1 to 16] and its 6 bits/symbol, provides 33% more efficient bandwidth usage. Of course, this is at the expense of a higher SNR requirement, as well as increased sensitivity to other impairments, such as phase noise and interference.

Theoretical AWGN Performance

The bit error rate (BER) curves for M-QAM are straightforward to develop in an AWGN-only channel, since symbol-by-symbol, hard-decision decoding is optimal and symbols are uniformly affected. Recognizing that most symbols are bounded on four sides with decision boundaries for large M easily generates upper bounds. However, more accurate solutions are not difficult to develop. Assuming one bit error for every symbol error, a situation that can be assured under what is referred to as Gray encoded mapping of bits to symbols (adjacent symbol differ by one bit only), we can show the following bit error probabilities as a function of SNR, assuming the SNR associated with optimal detection mechanisms.

P_e(64-QAM) = (7/12) Q [(SNR/21)^{½}]

Recognizing that signal power is related to energy per symbol as $E_s = P_s \cdot T_s$, and that

$E_b = E_s / \log_2 M$, these expression can be written in the form common to digital communication theory, which uses E_b/N_o, as

P_e(64-QAM) = (7/12) Q [(2E_b/7N_o)^{½}]

In this case, No is the noise power *density*, and the Q( ) function is a well-known, oft-tabulated function associated with the solution to the integral under the upper tail of the Gaussian probability density function (PDF), which is thus accounting for the statistical nature of the AWGN.

II. RESULTS

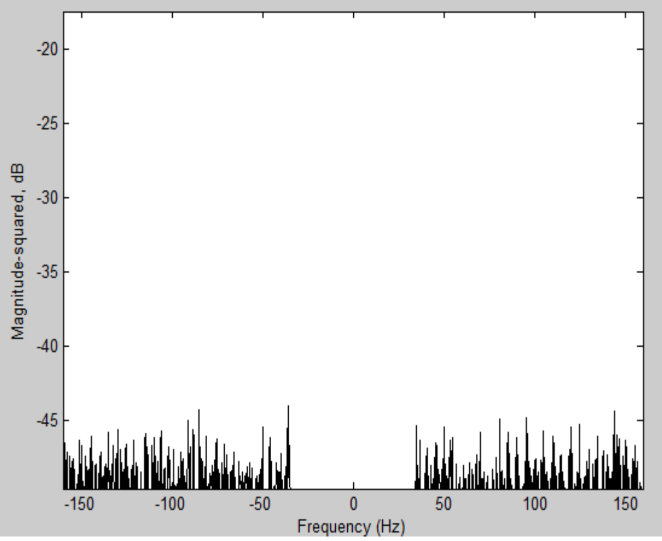

Figure 14
Transmitted Signal

In the above figure the signal generated at the transmitted side is shown

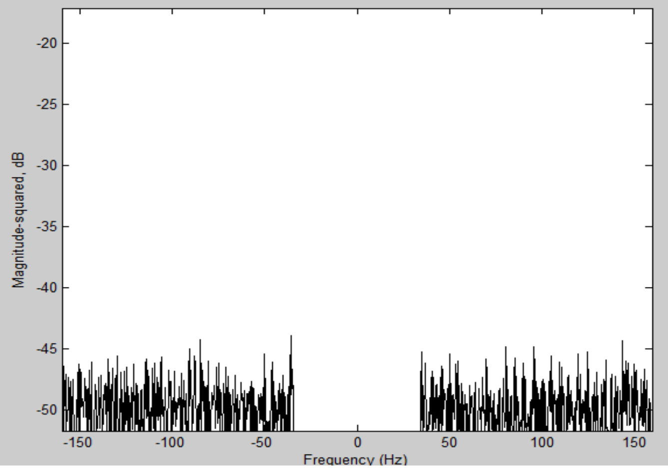

Figure 16
Received Signal

In the above figure the signal received at the receiver side is shown.

- Both the signal have been shown in the frequency domain hence they represent the power spectrum of the signal at both the sides.
- There is a notable difference in both the spectrums incurred due to channel loss.

III. CONCLUSION

Based on the results no Bit Loss and Packet Loss have been recorded. Although simulation environment differs from the real world scenario. Despite Orthogonal Frequency Division Multiplexing and 64 Quadrature Amplitude Modulation Techniques are very powerful transmission mechanisms but there are following few problems which they have to encounter in the real world. The few such problems are:

1. Multipath Fading
2. Space Diversity
3. Path Loss
4. High Bit error rate

Besides we require efficient coding techniques in order to perform Error Detection and Correction.

IV. PRACTICAL SCOPE

The practical scope of this project involves hardware implementation of the block diagram. If the same is implemented very high data rates will be achievable in the mobile environment and implementation of 100Mbps of LAN on mobile phones will become feasible. The higher data rates will support following Value Added Services:

1. **Rich voice**
   a. High Quality Video Conferencing.
   b. VoIP
2. **Photo messaging**
   a. Instant Messaging
   b. Mobile
   c. Email
   d. Video messaging
3. **Browsing**
   a. Super fast browsing.
   b. Uploading content to the social networking sites.
4. **Paid Information**
   a. E-newspapers
   b. High Quality Audio Streaming.
5. **Video on demand**
   a. Broadcast television services.
   b. True on demand television.
   c. High quality video streaming.

6. **Music**
    a. High quality music downloading and storage.
7. **Online gaming**
8. **Content messaging and cross media**
    a. Wide scale distribution of video clips.
    b. Video based mobile advertising.
9. **M-commerce**
    a. Mobile handsets as payment devices, with payment details carried over high speed networks to erasable rapid completion of transaction.
10. **Mobile data networking**
    a. P2P file transfer.
    b. Business Applications
    c. Application sharing
    d. M2M communication
    e. Mobile intranet/extranet

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