INVESTIGATING THE IMPACT OF SPECTRUM EFFICIENT OFDM-MIMO AND MC-CDMA-MIMO COMMUNICATION SYSTEM FOR ITS

NIRMALENDU BIKAS SINHA[1] AND M.MITRA[2]

[1]College of Engineering & Management, Kolaghat, K.T.P.P Township, Purba Medinipur, 721171, W.B, India.

[2] Bengal Engineering and Science University, Shibpur, Howrah, W.B, India.

ABSTRACT

For future wireless communications systems, parameters like high transmission data rate, spectral efficiency, and reliability are extremely necessary. In a multipath wireless channel, deploying multiple antennas at both the transmitter and receiver help us achieve higher data rate without increasing the total transmission power or bandwidth. When perfect knowledge of the wireless channel conditions is available at the receiver, the capacity has been shown to grow linearly with the number of antennas. The implementation of wideband MIMO system imposes major challenge to hardware designers due to the huge processing power required for MIMO detection. This can be overcome by using optimizing channel coding and MIMO detection. Orthogonal frequency division multiplexing (OFDM) and multi-carrier code division multiple access (MC-CDMA) have been attracting much attention in this field of study. In this paper, a comparative study for OFDM-MIMO is presented regarding BER/PER performance and hardware complexity. All the simulations are conducted within MIMO-OFDM framework and with a packet structure similar to that of IEEE 802.11a/g standard. We have derived a channel capacity expression for MC-CDMA MIMO in a multi-user environment and confirmed by numerical evaluation that MC-CDMA MIMO provides a slightly higher capacity than OFDM MIMO assuming perfect ICI cancellation (ICIC) is always higher than or equal to that of OFDM MIMO. Furthermore, we compare the channel capacities of MIMO multiplexing and multiple single-input multiple output (SIMO) system. As per the results obtained, the MC-CDMA-MIMO appears to be an affordable solution for wideband MIMO system targeting Giga-bit speed wireless transmission and ITS applications.

Index Terms – *CDMA, OFDM, MIMO, V-BLAST and ITS.*

I. INTRODUCTION

Wireless systems continue to strive for even higher data rates than the ones existing in the market. This goal is particularly challenging for systems that are power, bandwidth, and complexity limited. Digital communication using Multiple-input multiple output (MIMO) processing have revolutionalised the way wireless systems perform today. It provides solution to speed and range which are two of the major problems facing any wireless technology today. But the MIMO system with a fast framing rate of around 1-2 µs is exposed to ISI. This causes pollution in the system when operational in an environment having a typical time delay spread of 200 µs. Thus an ISI value of 200/2 =100 is an undesirable multipath effect for the real MIMO system. Hence, MIMO cannot achieve zero ISI and therefore cannot be utilized alone . Among the presently existing air-interface techniques, orthogonal frequency division multiplexing (OFDM) [1] [2] [3] [4] technique has shown a number of advantages and so it has attracted substantial interest in wireless broadband systems. But in case of using OFDM, parameters like synchronization and channel estimation are very important. OFDM based multicarrier approach may be used as an enabler for the MIMO based broadband operation. So the fast frames are slowed down first and converted to several slow sub frames and modulated to multiple carriers of OFDM. Recent research suggests that the implementation of MIMO-aided OFDM is

more efficient because of the straightforward matrix algebra invoked for processing the MIMO-OFDM signals [5][6]-[7]. It thus seems to be an attractive solution for future broadband wireless systems. MIMO OFDM, which is claimed to be invented by Airgo Networks [8] has formed the foundation of all candidate proposed for IEEE 802.11n [9]. In recent years, this topic has attracted substantial research efforts, addressing its numerous aspects such as system capacity [9], [10], space/time/frequency coding [11]–[15], improvement of transmission rate, the transmission range and the transmission reliability[8], peak-to-average power ratio (PAPR) control[16]–[21] and power efficiency. Considerations in channel estimation [19]–[21], receiver design [22]–[25] etc are made for MIMO-OFDM systems. Recently, Paulraj et al. [26] and Stuber et al. [27] provided compelling overviews of MIMO OFDM communications. Furthermore, Nortel Networks has developed a MIMO OFDM prototype [28] during late 2004, which demonstrates the superiority of MIMO OFDM over today's networks in terms of the achievable data rate. OFDM-MIMO is therefore useful for both communication and remote sensing (radar) applications. The system efficiency will be further enhanced if coding in the form of CDMA can be added to the OFDM which will result in a coded orthogonal frequency división multiplexing (MC-CDMA system. OFDM and multi-carrier code division multiple access (MC-CDMA), which is a combination of OFDM and CDMA is also gaining popularity [29]. Using frequency domain equalization (FDE), MC-CDMA can take advantage of the channel frequency-selectivity and improve the transmission performance due to the frequency diversity gain obtained from FDE. However, if code-multiplexing is used to increase the achievable transmission rate, the MC-CDMA transmission performance severely degrades due to the presence of intercede interference (ICI) [30]. Many works concerning ICI cancellation (ICIC) techniques for MC-CDMA and direct sequence-CDMA (DS-CDMA)[31][32] has been done before. Multiple-input multiple-output (MIMO) space division multiplexing is a very promising technique to increase the transmission rate without expanding the signal bandwidth [33]. Recently, we investigated the channel capacity of MC-CDMA-MIMO in a cellular system and showed that assuming perfect ICIC, the MC-CDMA can improve the information outage probability over OFDM [34]. Thus hybrid /MC-CDMA-MIMO technology is able to achieve the goal of a data rate of 100 MBPS at user terminal for 4G Mobile communication.

In this paper, we first analyze a comparative study for OFDM-MIMO regarding BER/PER performance and then compare channel capacities of MC-CDMA versus OFDM and MC-CDMA versus OFDM system

2. OFDM-MIMO (V-BLAST) SYSTEM MODEL

The multiuser MIMO-OFDM scheme which includes arrays of M transmitter antennas which performs a MIMO vertical encoding (VE) or convolution encoding and N receive antennas (V-BLAST requires $N \geq M$) is illustrated in Fig. 1(a) and Fig.(b). Assume that the system is operating in a frequency-selective Rayleigh fading environment and that the channel coefficients remain constant during packet transmission, i.e., quasi-static fading.

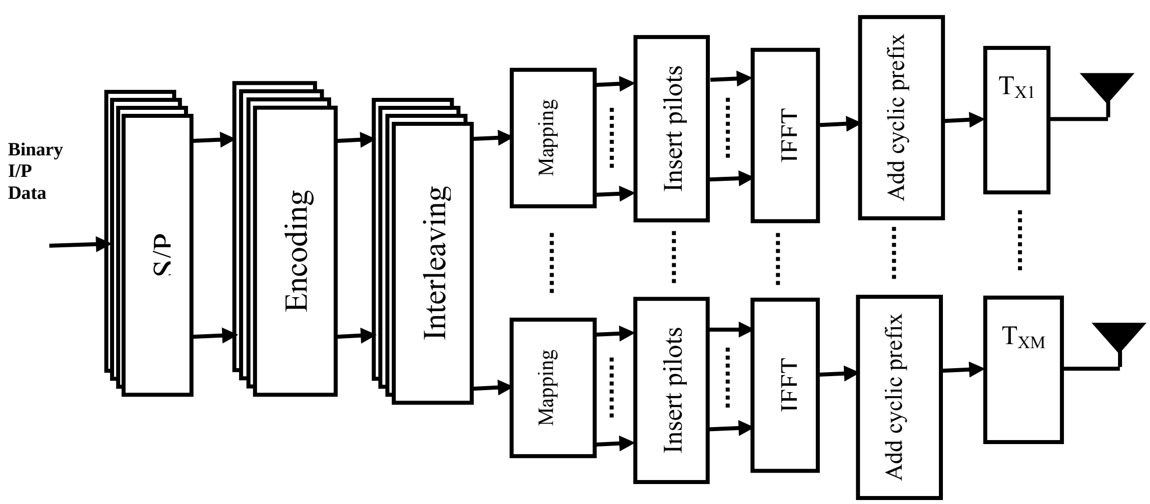

Fig. 1(a): Block diagram of OFDM-MIMO Transmitter System.

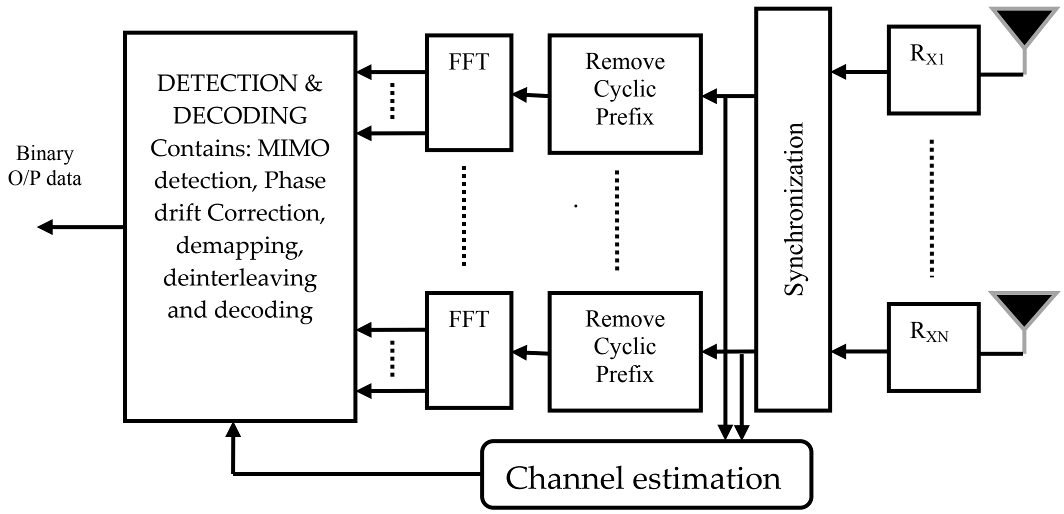

Fig.1(b): Block diagram of OFDM-MIMO Receiver System

The MIMO OFDM V-BLAST system operates in the 17 GHz unlicensed frequency band with an available bandwidth of 200 MHz (17.1–17.3 GHz) that is divided into four 50 MHz channels which are not simultaneously selectable. The binary input data is initially sent to a 127 bit long pseudorandom sequence scrambler (frequency sub channels). It is designed for each of these 50 MHz wide channels. The purpose of the scrambler is to prevent a long sequence of 1s and 0s. The signal is then sent to a convolution/VE encoder. The de facto standard for this encoder is (2,1,7). The other half of code rate is achieved by puncturing the output of this encoder. Puncturing involves deleting coded bits from output data sequence such that ratio of non-coded bits to coded bits is greater than the source code. The signal is then sent to an interleaver. The idea of interleaving is to disperse a block of data in frequency so that the entire block does experience deep fade in the channel. This prevents burst errors at the receiver. Otherwise the convolution of VE decoder will not perform very well in presence of burst errors. The interleaved data are grouped together to form symbols. Therefore the coded bits are mapped to some symbols. It has been established that OFDM is a spectrally efficient modulation technique. Thus, spectral efficiency depends mainly on the bandwidth of the symbol (B_S). This depends on the modulation technique used to modulate the individual subcarriers. It is the mapping that corresponds to the choice of modulation technique which should minimize B_S. The symbols are then modulated using BPSK, QPSK and 16QAM schemes. These symbols are put through the IFFT modulator. Since each input to IFFT corresponds to an OFDM subcarrier, hence we get a time-domain OFDM symbol that corresponds to the input symbols in the frequency domain at the output. In other words, the symbols constitute the frequency spectrum of the OFDM symbol. These subcarriers are then padded with zeroes to make the full OFDM symbols which will then convert parallel to serial in a multiplexer and append the cyclic prefix (CP) .At last it will be transmitted by the antenna M. Once we have the OFDM symbol, a cyclic extension (with length depending on the channel) is performed. The final length of the extended OFDM signal will be the length of the original OFDM symbol plus the length of the channel response. For the length of the guard interval which is longer than the channel spread, the OFDM symbol will remain intact.Hence the information is transmitted in packets. The Rx is the exact inverse process after the incoming packets are stripped of their CP. The magnitude of degradation depends on the type of constellation used and the spectral width of the phase noise of the carrier oscillator. For BPSK, there is no appreciable degradation but in the case of 16 QAM, this degradation is 0.5 dB for a phase noise of 40 KHz. Hence, the 10 Hz phase noise is considered negligible.

2.1 Performance analysis of OFDM-MIMO (V-Blast) SYSTEM

In many data transmission arrangements, the transmission is not continuous over the channel but it tends to be bursty. In communication systems, information bits are typically grouped into a frame or packet format and transmitted to a receiver. The received packets may be lost or may include errors because of a noisy channel for transmitting the data. The packet error rate (PER) is the percentage of received packets that include an error. PER in a coded system depends on the ratio of the bit energy to noise spectrum density (SNR), the FEC code rate, ARQ scheme and the packet size. Bit Error Rate (BER) is the fundamental parameter to access the quality of any digital transmission and quality measurement of recovered data. BER

is the number of erroneous bits received divided by the total number of bits transmitted. We note that as the diversity order increases the performance of V-Blast improves, which is to be expected. The diversity order at the receiver is between N-M + 1 and N. Using FFT approach, The accuracy increases as the number of subcarrier increases due to higher number of points. Hence data rate will also increase. Comparing the three modulation schemes by varying receiver elements and keeping the transmitter elements fixed in the unpadded case for BPSK and QPSK modulation, it has been found that BER is slightly better than with padding as shown in Fig. 2- Fig.3 which is mainly due to its receiving diversity technique.

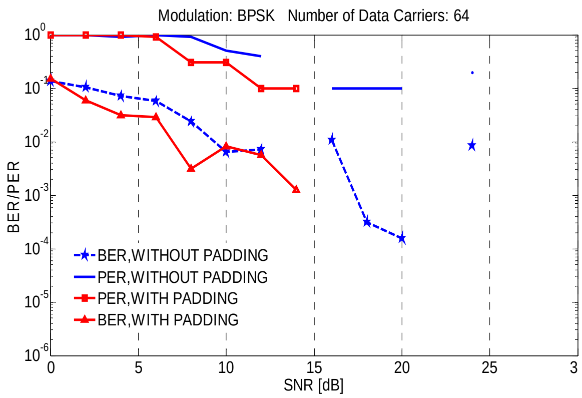

Fig. 2: Performance of a BPSK modulation for with& without padding.

Parameters: No. of FFT points= 64; Modulation = BPSK; Channel = Rayleigh, For M = 2 and N =3

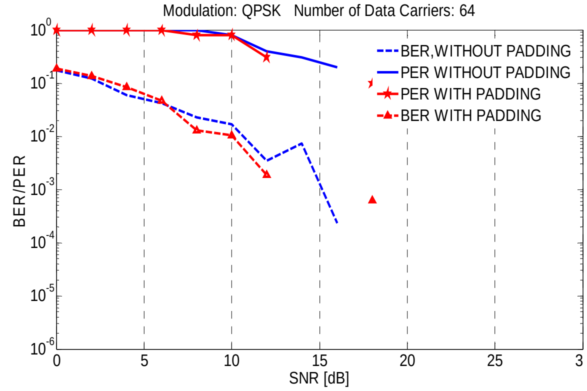

Fig 3: Performance of a QPSK modulation for with& without padding.

Parameters: No. of FFT points= 64; Modulation = BPSK; Channel = Rayleigh, For M = 2 and N =4

At an operating BER of 10^{-3}, there is no modulation scheme that gives us our desired performance at an SNR below 10dB. Therefore, we choose QPSK as it is the most robust. Between 10 and 17dB, QPSK gives us performance below 10^{-3}. Between 17 and 23dB, 16QAM gives us our desired BER and better spectral efficiency than QPSK. So, with and without padding OFDM-MIMO (V blast) system performance of BER, SNR of QPSK is better (Fig.4-Fig.5) than BPSK than16 QAM for different receiver elements. The performance of BPSK for OFDM-MIMO system can improve BER and data rate even at a small value of SNR. PER almost remain constant but for higher values it improves as depicted in Fig.4.

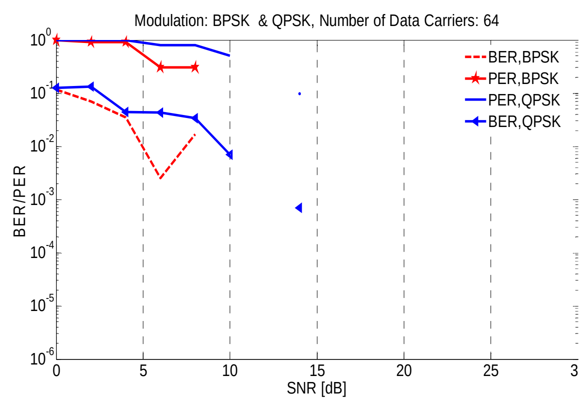

Fig 4: Performance of a QPSK &BPSK modulation without padding

Parameters: No. of FFT points = 64; Modulation = QPSK and BPSK; Channel = Rayleigh for M=1, N=2 System.

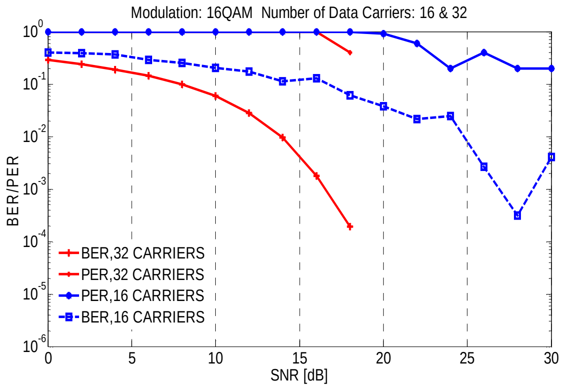

Fig.5: Performance of a 16 QAM. Modulation with padding for 16& 32 carriers

Parameters: No. of FFT points = 64; Modulation = 16 QAM; Channel = Rayleigh, for M=N=2 System.

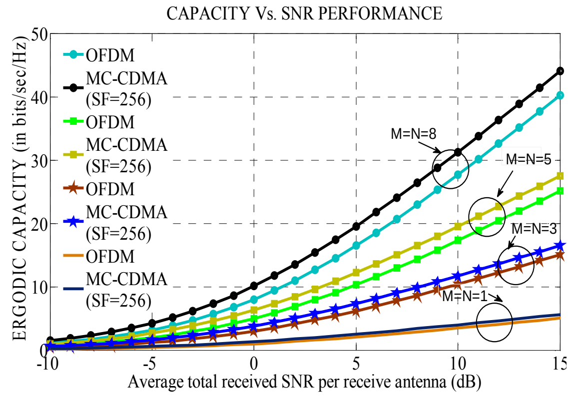

Fig.6. Impact of number of antennas.

3. Performance Comparison between MC-CDMA MIMO and OFDM-MIMO

The channel capacities of MC-CDMA and OFDM are compared in Fig. 6 as a function of the average Es/N_0 with the number of transmitter or receiver antennas (M=N) as a parameter. It can be seen from Fig. 6 that MC-CDMA always provides higher channel capacity than OFDM irrespective of the number of transmitter or receiver antennas. As the number of antennas increases, both capacities of MC-CDMA and OFDM increase. However, the capacity difference between MC-CDMA and OFDM becomes larger. From Fig.6, it can be seen that MIMO multiplexing provides slightly lower channel capacity than that of SIMO in a lower Es/N_0 region since the transmission power per each antenna is reduced by a factor of N.However, the channel capacity in case of MIMO multiplexing increases greatly for large Es/N_0 region owing to the spatial diversity gain and spatial multiplexing gain. It can also be seen from Fig. 6 that the capacity difference between MC-CDMA and OFDM is smaller for SIMO and STBC than for MIMO multiplexing. The advantage of MC-CDMA over OFDM is the frequency diversity gain obtained from frequency domain spreading. However, the frequency diversity gain becomes relatively small compared to the spatial diversity gain when SIMO or STBC-MISO is used.

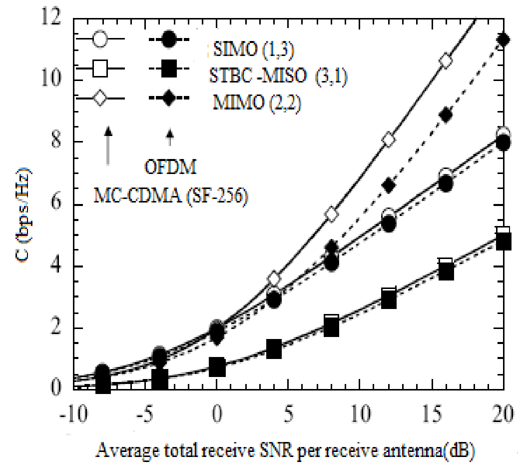

Fig.7. Comparison between spatial multiplexing and spatial diversity

Fig. 7. show the channel capacity comparison between MC-CDMA and OFDM when the total number of transmitter and receiver antennas is kept to M+N = 4. From Fig. 7, it can be seen that MIMO multiplexing provides slightly lower channel capacity than that of SIMO in a lower SNR region since the transmission power per each antenna is reduced by a factor of M.

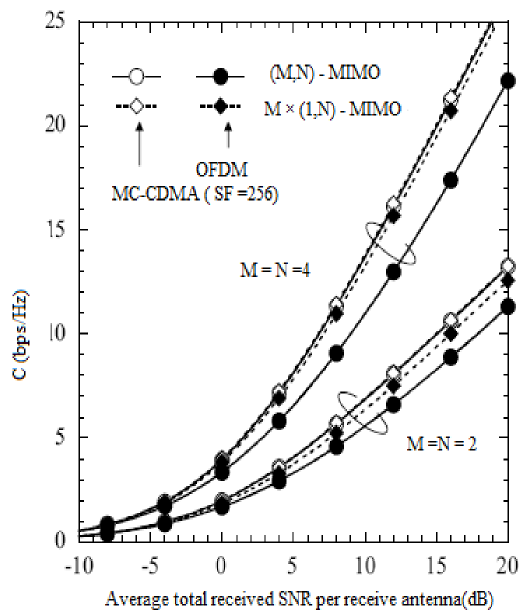

Fig. 8. Comparison of MIMO and multi-SIMO.

Fig. 8 plots the channel capacities of MC-CDMA and OFDM for the cases of (M,N)-MIMO and M × (1,N) – SIMO. From Fig.8, it can be seen that MC-CDMA MIMO provides almost the same capacity as multiple SIMO while OFDM MIMO cannot. The reason for this is due to the residual IAI discussed earlier. MC-CDMA MIMO can efficiently suppress the IAI (inter-antenna interference) by using frequency domain spreading.

4. CONCLUSION

The performance of the proposed OFDM-MIMO (V-BLAST) and MC-CDMA-MIMO/Hybrid systems for different antenna configurations and propagation conditions are analyzed based on our lab model. It has been found that V-BLAST can have potentially higher spectral efficiency because no orthogonal transmitted signals and received co-channel signals are separated by decorrelation (processing algorithm) due to multipath. The results shows that the proposed system is fairly capable of improving bit rate without increasing total transmitted power or required bandwidth with V-BLAST processing at the receiver as an efficient CCI cancellation technique. Finally we compare the channel capacity of MC-CDMA MIMO with perfect ICIC (inter-code interference Cancellation) to that of OFDM -MIMO and show that the channel capacity of MC-CDMA MIMO with perfect ICIC is always larger than or equal to that of OFDM - MIMO. MC-CDMA MIMO can approach the capacity of multiple SIMO while OFDM- MIMO cannot is also an important derivations from the above performed experimentation.

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Prof. Nirmalendu Bikas Sinha received the B.Sc (Honours in Physics), B. Tech, M. Tech degrees in Radio-Physics and Electronics from Calcutta University, Calcutta,India,in1996,1999 and 2001, respectively. He is currently working towards the Ph.D degree in Electronics and Telecommunication Engineering at BESU. Since 2003, he has been associated with the College of Engineering and Management, Kolaghat. W.B, India where he is currently an Asst. Professor is with the department of Electronics & Communication Engineering & Electronics & Instrumentation Engineering. His current research Interests are in the area of signal processing for high-speed digital communications, signal detection, MIMO, multiuser communications,Microwave /Millimeter wave based Broadband Wireless Mobile Communication ,semiconductor Devices, Remote Sensing, Digital Radar, RCS Imaging, and Wireless 4G communication. He has published large number of papers in different international Conference, proceedings and journals.He is presently the Chief-editor, Editor and Reviewers in different international journals.

Dr. Monojit Mitra is an Assistant Professor in the Department of ETC of BESU, Shibpur. He obtained his B.Tech, M.Tech & Ph. D .degrees from Calcutta University. His research areas are in the field of Microwave & Microelectronics, especially in the fabrication of high frequency solid state devices like IMPATT. He has published large number of papers in different national and international journals. He has handled sponsored research projects of DOE and DRDO. He is a member of IETE (I) and Institution of Engineers (I).