International Journal of Soft Computing and Engineering (IJSCE)
ISSN: 2231-2307, Volume-1 Issue-5, November 2011

Transmission Characteristics of 4x4 MIMO System with OFDM Multiplexing and Markov Chain Monte Carlo Receiver

R Bhagya, Pramodini D V, A G Ananth

Abstract*— A detailed analysis of the performance of 4×4 Multiple Input Multiple Output (MIMO) antenna system has been carried out using Orthogonal Frequency Division Multiplexing (OFDM) techniques. The transmission characteristics are determined for BPSK and 16-QAM digital modulation. Additive White Gaussian Noise (AWGN) has been used for the channel. On the receiver side, Markov Chain Monte Carlo (MCMC) receiver techniques have been employed for computing the BER performance. The simulation results show that, for BER of ~10^{-4}, the SNR achieved are significantly higher. The results indicate for BPSK modulation the SNR ~ 9 dB, and for 16-QAM modulation the SNR ~13 dB. The MIMO- OFDM multiplexing scheme show a overall improvement of ~ 4.0 dB for BER values of 10^{-4} between BPSK and 16-QAM modulation. A comparison of the performance of present MIMO-OFDM multiplexing system with MIMO-CDMA system and common MCMC receiver indicates that, the MIMO-OFDM Multiplexing exhibits a better BER performance for 16-QAM digital modulation. The simulations results are presented and discussed in the paper.

Index Terms:* Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Phase Shift Keying (PSK), Quadrature Amplitude modulation (QAM), Markov Chain Monte Carlo (MCMC) Bit Error Rate (BER), Signal to Noise Ratio (SNR), Code Division Multiple Access (CDMA).

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) wireless systems use multiple antenna elements at transmit and receive to improve capacity over single antenna topologies in multipath channel characteristics play key role in determining communication performance. OFDM can be used in conjunction with a MIMO transceiver to increase the diversity gain and/or the system capacity by exploiting spatial domain. Because the OFDM system effectively provides numerous parallel narrowband channels, MIMO-OFDM is considered a key technology in emerging high-data rate systems [2, 7].
The combination MIMO-OFDM is beneficial since OFDM enables support of more antennas and larger bandwidths since it simplifies equalization dramatically in MIMO systems. By adopting Multiple-Input Multiple-Output (MIMO) and Orthogonal Frequency-Division Multiplexing (OFDM) technologies, indoor wireless systems could reach data rates up to several hundreds of Mbits/s and achieve spectral efficiencies of several tens of bits/Hz/s, which are unattainable for conventional single-input single-output systems. The enhancements of data rate and spectral efficiency come from the fact that MIMO and OFDM schemes are indeed parallel transmission technologies in the space and frequency domains, respectively. MIMO-OFDM when generated OFDM signal is transmitted through a number of antennas in order to achieve diversity or to gain higher transmission rate then it is known as MIMO-OFDM. The present study involves a number of procedures namely simulations of the 4X4 MIMO transmission system, OFDM multiplexing, Digital modulation and computation and comparison of BER for different SNR. The aim of present work is to study the performance of MIMO systems with OFDM multiplexing and digital modulation techniques which gives better Bit Error Rate (BER) performance for MCMC receiver using MATLAB simulation [10].

Multiple Input Multiple Output (MIMO)

MIMO systems are designed to have additional antennas at the transmitter and receiver, providing spatial diversity not available to single antenna systems. Thus, information can be sent and received over multiple channels.
To achieve a high system capacity for multimedia applications in wireless communications, various methods have been proposed in recent years. Among them, the MIMO system using multiple antennas at both the transmitter and the receiver has attracted a lot of research interest due to its potential to increase the system capacity without extra bandwidth. MIMO exploits spatial diversity by having several transmit and receive antennas. Previous work has shown that the system capacity could be linearly increased with the number of antennas when the system is operating over flat fading channels [2, 4, 7].

Orthogonal Frequency Division Multiplexing (OFDM)

In a basic communication system, the data are modulated onto a single carrier frequency. The available bandwidth is then totally occupied by each symbol. This kind of system can lead to inter-symbol-interference (ISI) in case of frequency selective channel. The basic idea of OFDM is to divide the available spectrum into several orthogonal sub channels so that each narrowband sub channels experiences almost flat fading. OFDM is becoming the chosen modulation technique for wireless communications.

Manuscript Received 29 October, 2011.

Bhagya. R, Assistant professor in Dept of Telecommunication, RVCE. Bangalore, Karnataka India. (Email: **bhagyar.rvce@gmail.com**

Pramodini D V, Assistant professor in Dept of Information Science and Engineering, PESSE, Bangalore, Karnataka, India. (Email: **pramodinidv@gmail.com**)

Dr. A G Ananth working as Professor in Telecommunication Department of R.V College of Engineering, Bangalore, India (Email: **antisro@yahoo.com**).

OFDM can provide large data rates with sufficient robustness to radio channel impairments. In an OFDM scheme, a large number of orthogonal, overlapping, narrow band sub-carriers are transmitted in parallel. These sub-carriers divide the available transmission bandwidth. The separation of the sub-carriers is such that the efficiency of spectral utilization is high. With OFDM, it is possible to have overlapping sub channels in the frequency domain, thus increasing the transmission rate. The use of FFT technique to implement modulation and demodulation functions makes it computationally more efficient.

The attractive feature of OFDM is the way it handles the multipath interference at the receiver. Multipath phenomenon generates two effects: Frequency selective fading and Inter-symbol interference (ISI). The "flatness" perceived by a narrowband channel overcomes the frequency selective fading. On the other hand, modulating symbols at a very low rate makes the symbols much longer than channel impulse response and hence reduces the ISI. Insertion of an extra guard interval between consecutive OFDM symbols can reduce the effects of ISI even more but leads to low system capacity. To combat the effect of frequency selective fading, MIMO is generally combined with OFDM technique, which transforms the frequency-selective fading channels into parallel flat fading sub channels, as long as the cyclic prefix (CP) inserted at the beginning of each OFDM symbol is longer than or equal to the channel length. In this case, the signals on each subcarrier can be easily detected by a one-tap frequency domain equalizer (FDE). In cases where a short CP is inserted for increasing bandwidth efficiency, or because of some unforeseen channel behavior, the effect of frequency-selective fading cannot be completely eliminated, and inter-carrier interference (ICI) and inter-symbol interference (ISI) will be introduced. In this case, the signals on each subcarrier can be easily detected by a one-tap time domain equalizer (TDE). Equalization techniques are thus important in MIMO-OFDM systems [5,8,9].

OFDM is an alternative wireless modulation technology to CDMA. OFDM has the potential to surpass the capacity of CDMA systems and provide the wireless access method for 4G systems. OFDM is a modulation scheme that allows digital data to be efficiently and reliably transmitted over a radio channel, even in multipath environments.

Markov chain Monte Carlo (MCMC)

Methods (which include **random walk Monte Carlo** methods) are a class of algorithms for sampling from probability distributions based on constructing a Markov chain that has the desired distribution as its equilibrium distribution. The state of the chain after a large number of steps is then used as a sample of the desired distribution. The quality of the sample improves as a function of the number of steps.

Usually it is not hard to construct a Markov chain with the desired properties. The more difficult problem is to determine how many steps are needed to converge to the stationary distribution within an acceptable error. A good chain will have rapid mixing*;* the stationary distribution is reached quickly starting from an arbitrary position described further under Markov chain mixing time.

Typical use of MCMC sampling can only approximate the target distribution, as there is always some residual effect of the starting position. More sophisticated MCMC-based algorithms such as coupling from the past can produce exact samples, at the cost of additional computation and an unbounded running time.

The most common application of these algorithms is numerically calculating multi-dimensional integrals. In these methods, an ensemble of "walkers" moves around randomly. At each point where the walker steps, the integrand value at that point is counted towards the integral. The walker then may make a number of tentative steps around the area, looking for a place with reasonably high contribution to the integral to move into next. Random walk methods are a kind of random simulation or Monte Carlo method. Whereas the random samples of the integrand used in a conventional Monte Carlo integration are statistically independent, those used in MCMC are correlated. A Markov chain is constructed in such a way as to have the integrand as its equilibrium distribution [1, 3].

Multi-dimensional integrals often arise in Bayesian statistics, computational physics, computational biology and computational linguistics, so Markov chain Monte Carlo methods are widely used in those fields.

MIMO-OFDM and MCMC Receiver

The receiver first must estimate and correct for the frequency offset and the symbol timing, e.g., by using the training symbols in the preamble. Subsequently, the CP is removed, and the N_c-point discrete fourier transformation (DFT) is performed per receiver branch. MIMO detection has to be done per OFDM subcarrier. Therefore, the received signals of subcarrier are routed to the i^{th} MIMO detector to recover N_t the data signals transmitted on that subcarrier. Next, the symbols per TX stream are combined, and finally, de-mapping, de-interleaving ($\prod^{-1}$), and decoding are performed for the N_t parallel streams and the resulting data are combined to obtain the binary output data. Figure 1 represents block diagram of MIMO-OFDM receiver.

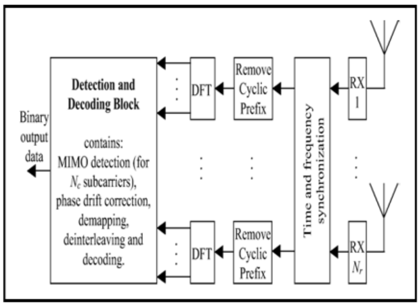

Figure 1: Block Diagram of MIMO-OFDM Receiver

Markov Chain Monte Carlo Methods

Suppose to compute a complex integral $\int h(x).dx$, decompose h(x) into the product of a function f(x) and a probability density function p(x) defined over the interval (a, b), then note that

$$\int h(x).dx= \int f(x)p(x).dx= E_{p(x)}[f(x)]$$

so that the integral can be expressed of f(x) over the density p(x). Thus, if a large number of random variables x_1, x_2……,x_n are drawn from the density p(x), then

$\int h(x).dx = E_{p(x)}[f(x)] = 1/n \sum f(x_i)$
where: i = 1 to n. This is referred to as Monte Carlo integration. Monte Carlo integration can be used to approximate posterior (or marginal posterior) distributions required for a Bayesian analysis. Consider the integral $I(y) = \int f(y \mid x)\, p(x).dx$ Which can be approximated as $I(y)= 1/n \sum f(y \mid x_i)$, where: i =1 to n.

MCMC Algorithms for MIMO Detection

Consider a MIMO (V-BLAST) communication system with Nt transmit antennas and Nr receive antennas. The channel is assumed to be flat fading. The
Nr x 1 received signal y vector is given by
y=Hd+n. where n is additive noise vector. Let the samples of n are zero-mean and independent identically distributed (i.i.d.), and $E[nn^H] = \sigma^2_n I_{Nr}$ $d = [\, d_1 d_2 \ldots d_{Nt}\,]^T$
are data symbols transmitted by the Nt transmit antennas. H denotes the channel gain matrix of size Nr X Nt.
Figure 2 represents a block diagram of an iterative receiver. It consists of SISO (soft input soft output) multi-user detector and a set of parallel SISO FEC [Forward Error Correction] decoders. A set of soft output sequences for the data symbols $d_1, d_2, \ldots d_{Nt}$ is generated by the SISO multi-user detector. They are generated based on the observed input vector sequence and the a priori (soft) information from the previous iteration of the FEC decoders.

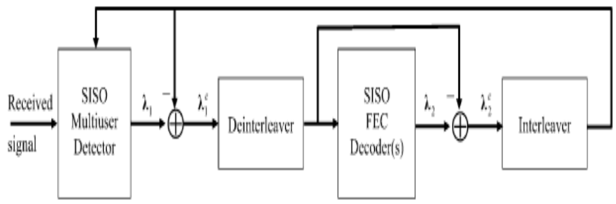

Figure 2: Receiver Structure: Multilayer Detectors and FEC Decoders

The priori information is subtracted from the output of the multi-user detector. The information remaining in the subtracted value, which is new (extrinsic) to the FEC decoders is passed to them. Further processing of the information is done in the FEC decoder. Before passing the information to SISO multi-user detector, soft input information to each FEC decoder is subtracted from its output to generate the new (extrinsic) information.
$\lambda_l(d_k)$ has been used to denote the soft output of SISO multi-user detector for the trans mitted data symbol dk, and use $\lambda_2(d_k)$ to denote the a posteriori output of the FEC decoder for the symbol dk. $\Lambda_l^e(d_k)$ and $\lambda_2^e(d_k)$ are used to denote the corresponding extrinsic information for $\lambda_l(d_k)$ and $\lambda_2(d_k)$, respectively. The vector is defined as $\lambda_2^e = [\, \lambda_2^e(d_1)\, \lambda_2^e(d_2) \ldots \lambda_2^e(d_{Nt})]$. When data symbols are binary taking values of +1 and -1, the log likelihood ratio (LLR) of a transmitted + 1 and a transmitted -1, given extrinsic information, is given by

$$\lambda_1(d_k(i)) = \ln \frac{P\left(d_k(i) = +1 \mid \mathbf{y}(i), \boldsymbol{\lambda}_2^e(i)\right)}{P\left(d_k(i) = -1 \mid \mathbf{y}(i), \boldsymbol{\lambda}_2^e(i)\right)}$$

and after decoding has been done

$$\lambda_2(d_k(i)) = \ln \frac{P\left(d_k(i) = +1 \mid \boldsymbol{\lambda}_1^e(k), \text{decoding}\right)}{P\left(d_k(i) = -1 \mid \boldsymbol{\lambda}_1^e(k), \text{decoding}\right)}.$$

Here, the standard turbo decoding algorithm is used to obtain the LLR values. The prime objective is finding the values of $\lambda_l^e(d_k)$ in a computationally efficient manner. Let us consider the equations

$$\begin{aligned} P\left(d_k(i) = +1\ \mathbf{y}(i), \boldsymbol{\lambda}_2^e(i)\right) &= \sum_{\mathbf{d}_{-k}(i)} P\left(d_k(i) = +1, \mathbf{d}_{-k}(i)\ \mathbf{y}(i), \boldsymbol{\lambda}_2^e(i)\right) \\ &= \sum_{\mathbf{d}_{-k}(i)} P\left(d_k(i) = +1 \mid \mathbf{y}(i), \mathbf{d}_{-k}(i), \boldsymbol{\lambda}_2^e(i)\right) \\ &\quad \times P\left(\mathbf{d}_{-k}(i) \mid \mathbf{y}(i), \boldsymbol{\lambda}_2^e(i)\right) \end{aligned}$$

where $d_{\_k}$ denotes $[d_1 \ldots d_{k-1} \ldots d_{Nt}]^T$ i.e., the data vector excluding k^{th} data symbol, and chain rule is applied to get the second identity. It is seen that as the number of antennas Nt grows, summation over all possible values of $d_{\_k}$ will become difficult since the number of combinations that $d_{\_k}$ takes grow exponentially.

MCMC Simulation

MCMC method is used to generate samples of d from the distribution P (d | y, λ_2^e). This is done by defining a Markov chain in which each state corresponds one selection of d. Gibbs sampling can be used to control the problem of complexity since it is observed in the previous section that the number of states in the Markov chain grows exponentially with the size of d. The Gibbs sampling algorithm is given by:

- Initialize $d^{(-N_b)}$ (randomly),
- for $n = -N_b + 1$ to N_s

draw sample $d_1^{(n)}$ from $P\left(d_1\ d_2^{(n-1)}, \ldots, d_K^{(n-1)}, \mathbf{y}, \boldsymbol{\lambda}_2^e\right)$

draw sample $d_2^{(n)}$ from $P\left(d_2\ d_1^{(n)}, d_3^{(n-1)}, \ldots, d_K^{(n-1)}, \mathbf{y}, \boldsymbol{\lambda}_2^e\right)$

$\vdots$

draw sample $d_K^{(n)}$ from $P\left(d_K\ d_1^{(n)}, \ldots, d_{K-1}^{(n)}, \mathbf{y}, \boldsymbol{\lambda}_2^e\right)$

The value of $d^{(\_Nb)}$ is initialized randomly. The values of d^n are observed at each n. The first N_b iterations of the loop is called as the burn-in period. This period is to let the Markov chain converge to its stationary distribution. The samples of the last N iterations, i.e., $d^{(n)} =[\, d^n_1\, d^n_2 \ldots\ldots d^n_K]$ for n = 1, 2,... , Ns are used for LLR calculations.

II. IMPLEMENTATION

MCMC Detector

When the number of transmit antennas increases, i.e., as N increases, the dimension of d becomes large, and hence summation become cumbersome. In order to develop computationally efficient methods for calculation of $P(d_k = \mid y, \lambda_2^e)$, Monte Carlo integration methods are used and the Gibbs sampling procedure.

Statistical Inference (SI) Algorithm

Consider MCMC detection using the statistical inference for obtaining LLR values. In this approach, P (d_k= | y, λ_2^e) is obtained by collecting samples that is the samples of the last Ns iterations through a Gibbs sampler and then evaluating the statistical average as

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$P\,(d_k = \mid y, \lambda_2^e) \approx 1/Ns \sum \delta\,(d^{(n)}_k = +1)$

where: n=1 to Ns, where δ(.) is an indicator function that takes value of 1 if its argument is true and value of 0 otherwise.

III. RESULTS AND DISCUSSIONS

The simulation results are obtained for the performance of MIMO - OFDM system using different modulation techniques for AWGN channel using MATLAB. The BER values as function of SNR are determined. for BPSK and 16-QAM modulation .

The BER values determined from MATLAB simulation as a function of SNR for BPSK modulation. The Figure 3 shows the BER performances of 4X4 MIMO system for OFDM multiplexing as a function of SNR for the BPSK digital modulation.

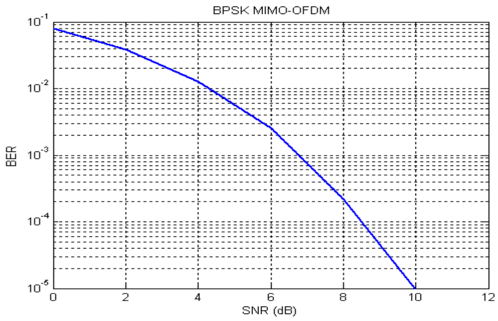

Figure 3: BER plot for BPSK with 4x4 OFDM and MCMC detector.

It can be seen from the Figure 3 that the BER values decreases as SNR increases. The figure indicates that for BER ~10^{-4}, the SNR ~9dB is achievable in case of BPSK modulation for MIMO-OFDM transmission with MCMC receiver system.

Similarly Figure 4 shows the performance of 4X4 MIMO transmission system with OFDM multiplexing using 16-QAM modulation.

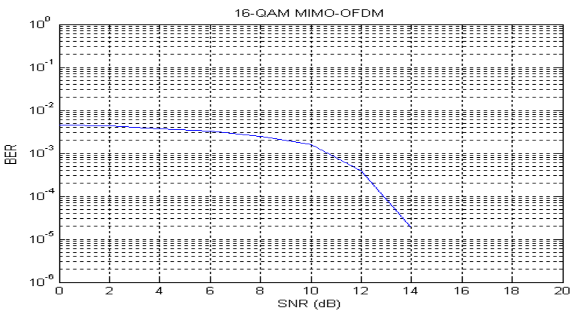

Figure 4: BER plot for 16-QAM with 4×4 OFDM and MCMC detector.

The Figure 4 shows that that the BER decreases with SNR for the 16-QAM modulation. For BER values ~10^{-4}, the achievable SNR ~ 13.0 dB for the MIMO-OFDM transmission using a MCMC receiver at the detector end.It is evident from the Figures 3 and 4 that for 4X4 MIMO-OFDM transmission, significant improvement in SNR performance can be achieved for 16-QAM modulation compared to BPSK modulation. Also it is seen that for BER ~10^{-4} and 16-QAM modulation, there is considerable improvement of SNR ~4 dB compared to BPSK modulation. These observations clearly indicate that for MIMO-OFDM system with MCMC receiver, there is significant increase in the SNR ~4 dB between BPSK to 16-QAM modulation schemes.

Further comparison of the simulation results presented in the paper and the performance of 4X4 MIMO-CDMA transmission system for different digital modulation techniques and MCMC detector reported by Parhang Boroujeny et al (2006) [1] show that at BER ~10^{-4} for QPSK modulation the SNR~2.5 dB and for 16-QAM modulation the SNR ~ 6.5dB. Where as the present analysis for 4X4 MIMO-OFDM transmission system with MCMC detector indicate a significant improvement in the performance over MIMO-CDMA system with MCMC detector. For 16 QAM modulations the improvement in the SNR ~ 6.5 dB (a factor of 2) has been observed between the MIMO-OFDM and MIMO-CDMA multiplexing transmission.

The results of the present analysis show that the transmission characteristics of a MIMO (4X4) system employing OFDM transmission and MCMC receiver, exhibits better improvement in SNR values compared to CDMA multiplexing. .

IV. CONCLUSIONS

It can be concluded from the results presented above that,

1. For a 4X4 MIMO system, the OFDM multiplexing techniques and MCMC receiver promotes achieving better SNR performances for digital transmission.
2. For MIMO-OFDM transmission at BER values of $10^{-4,}$ the SNR performance increases by ~4 dB with different modulation schemes between BPSK to 16- QAM.
3. The comparison of performance between 4X4 MIMO system with OFDM and CDMA transmission indicates SNR improvement for BPSK modulation ~ 6.5 dB for 16-QAM modulation.
4. It can be concluded from the simulation studies that the MIMO-OFDM transmission systems offers better SNR performances compared to CDMA system for higher digital modulation and MCMC receiver configuration

ACKNOWLEDGEMENT

We wish to acknowledge the support given by Principal, RV College of Engineering, Bangalore, and PES School of Engineering for carrying out the present research work and HOD department of telecommunication for constant encouragement. We also wish to thank Shabrin for software support.

REFERENCES

1. B. Farhang-Boroujeny, H. zhu, and Z. Shi, "Markov chain monte carlo Algorithms for CDMA and MIMO communication systems," *IEEE Trans. Signal Process*, vol. 54, no. 5, pp. 1896-1909, May 2006.
2. Helmut Bölcskei, "MIMO-OFDM Wireless Systems: Basics, Perspectives and Challenges," *IEEE Wireless Communications, Volume 13, Issue 4*, August 2006.
3. B. Walsh, "Markov chain monte carlo and Gibbs Sampling," Lecture notes for EEb 581, version 26, April 2004.
4. A. Paulraj, D. Gore, R. Nabar, and H. Bolcskei, *"An overview of MIMO communications A key to gigabit wireless," Proc. IEEE*, vol. 92, no. 2, pp. 198–218, Feb. 2004.
5. B. Muquet, Z. Wang, G. B. Giannakis, M. de Courville, and P. Duhamel, *"Cyclic prefixing or zero padding for wireless multicarrier transmissions?" IEEE Trans. Commun.*, vol. 50, no. 12, pp. 2136–2148, Dec. 2002.

6. Mosier, R. R., and Clabaugh, R.G.," *A Bandwidth Efficient Binary Transmission System," IEEE Trans., Vol. 76, pp. 723 - 728, Jan. 1958.*
7. S. Ma and T. S. Ng*"Semi-Blind Time-Domain Equalization for MIMO-OFDM Systems," IEEE Trans. Vehicular Technology*., vol. 57, no. 4, pp. 2219-2227 Jul, 2008.
8. Heidi Steendam, Marc Moeneclaey, *"Optimization of OFDM on Frequency-Selective Time Selective Fading Channels," IEEE Trans. Signal Processing*, vol. 32, no. 10, pp. 1431–1441, Sep. 1998.
9. S. B. Weinstein, "Data Transmission by Frequency-Division Multiplexing Using the Discrete Fourier Transform," *IEEE Transactions on Communication Technology, Volume 19, Issue 5*, October 1971
10. David R. Pauluzzi and Norman C. Beaulieu, "A Comparison of SNR Estimation Techniques for the AWGN Channel," *IEEE Transactions on Communications, Volume 48, Issue 10*, October 2000.

AUTHORS PROFILE

Bhagya.R was born in Bangalore on 14/12/1974, Karnataka. She received B.E (Electronics & Communication) degree in 1997 from Bangalore University and M.Tech (Electronics) degree in 2007 from VTU, Belgaum, and Perusing PhD in Kuvempu University. Presently working as a Assistant professor in Dept of Telecommunication, RVCE. Bangalore, Karnataka India. Research interests include Wireless Communication, Wireless Networking.
bhagyar.rvce@gmail.com

Pramodini. D. V was born in Davanagere on 05/02/1981, Karnataka. She received B.E (Electronics & Communication) degree in 2002 from Visveshwariah Technical University, Belgaum, Karnataka and M.Sc (Information Technology) degree in 2007 from Kuvempu University, Shimoga, Karnataka and persuing PhD in Kuvempu University. Presently working as a Assistant professor in Dept of Information Science and Engineering, PESSE, Bangalore, Karnataka, India. Research interests include MIMO systems, Microprocessors and Microcontrollers, Embedded System design, Wireless Communication, Wireless Networking.
pramodinidv@gmail.com

Dr.A.G. Ananth was born on Bangalore on 3 November 1947 at Bangalore Karnataka,. India .He received M.Sc degree in 1969 in Nuclear Physics from Bangalore University. In 1975 Physical Research Laboratory Ahmedabad awarded him Ph.D degree in Space physics. He served as Deputy Director in ISRO, currently working as Professor in Telecommunication Department of R.V College of Engineering, Bangalore. His research interests include Space physics, Biomedical signal processing, Image processing and MIMO systems.
antisro@yahoo.com

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