

Video Summary Application over Cross-layer Designed Wireless Networks Using Multi-carrier CDMA

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Abstract - Cross-layer design has become an emerging trend in the wireless network for efficient video transmission. In this paper, a cross-layer design approach is proposed for multi-user scenario by using multiple-input multiple- output antennas (MIMO) at the physical layer. The impact of multi-user system on the bit error rate performance is presented in Rayleigh fading channels. The cross-layer adaptation across physical layer, data link layer and application layer works well in multi-user environment. Results reveal that proposed cross-layer design attain 15 % distortion gain.

Key-Words - Cross-layer design, Quality-of-service (QoS), Multiple-input multiple-output (MIMO), Multi-carrier code-division multiple-access (MC-CDMA), Automatic repeat request (ARQ), Adaptive modulation coding(AMC).

1. Introduction

The recent development of communication theory and radio technology has considerable focus on multiple input-multiple output (MIMO) antennas which is an effective technique to overcome fading and channel interference. Multipath fading is one of the most fundamental features which impinge on the performance of wireless channels. Multiple replications of the transmitted signal may combine destructively or constructively at the receiver and lead to severe fades. The fades may vary according to space and frequency. A change on the transmitter or receiver location or in the frequency may lead to independent realization of the fading process. This is the fundamental concept behind the phenomenon of diversity. Transmit diversity techniques had not been well refined until 1990s. Albeit first proposed single-antenna receivers. Orthogonal Space Time Block Codes (STBC) can also be used in MIMO communication [1] i.e., when both transmitter

and receiver have a multiplicity of antennas. This allows additional diversity and reliability but does not increase the number of information symbols per MIMO symbol [2],[3],[10],[11],[12],[15].

Due to the limited bandwidth of available radio frequency, multiple access techniques have been widely deployed to provide the user's access to the communication channel. First generation communication systems used Frequency Division Multiple Access (FDMA) whereas second generation systems used Time Division Multiple Access (TDMA) along with FDMA. The third generation systems like IS-95 and Universal Mobile Telecommunication Systems (UMTS) used Direct Sequence Code Division Multiple Access (DS-SS) techniques [4], [5]. CDMA assigns uncorrelated codes to each user, which makes all users continuously utilize the full bandwidth without interference. Multi-carrier systems have earned a lot of focus due to their ability to support high data rate and to combat a frequency-selective multipath fading channel [6].

In a multi-carrier CDMA system, the individual user's data is first spread using the high rate spreading code and then modulated through a multi-carrier modulator [7]. The multi-carrier CDMA schemes can be categorized into two groups: One spreads the original data stream using a given spreading code, and then modulates a different subcarrier with each chip. The other spreads the serial to parallel (S/P) converted data streams using a given spreading code, and then modulates a different subcarrier with each data stream. The first arrangement is sometimes referred to as spreading in the frequency domain and the second as spreading in the time domain. The first scheme is generally known as MC-CDMA (multi-carrier CDMA) and the second scheme is called as MC-DS-CDMA (Multicarrier Direct sequence CDMA). It has been suggested that an MC-CDMA scheme is a most efficient form of transmission scheme. This is because in an MC-CDMA receiver, the received signal is combined, in a sense, in the frequency domain, therefore the receiver can always use all the received signal energy scattered in the frequency domain [1],[7],[8],[9],[16],[18].

The effective throughput is affected by a number of parameters, including transmission rate, payload and header size, constellation size, transmitted power and received noise characteristics. Previous analysis revealed that careful payload length adaptation significantly improves the throughput performance at low signal to noise ratios (SNRs), while at higher SNRs, rate adaptation with higher payload lengths provides better throughput performance. These payload sizes cover a wide range of applications from various voice codecs to H.264 video conferencing applications along with various data applications like web browsing, FTP, etc. Payload length was considered as an optimization parameter and tight coupling between payload length and data rate to maximize the single-user throughput on the AWGN and different fading channels was required [14],[19].

Incorporating the advantages of MIMO to increase the QoS is the core of our cross-layer work which will perform better in Rayleigh scattering environment. Now we realize the cross-layer design for multi-user scenario with MC-CDMA. In this article, a cross-layer

optimized framework that incorporates adaptation across application layer with other layers is proposed in order to meet the requirements of QoS capabilities for video transmission over wireless networks. This cross-layer approach jointly optimizes physical layer, data link layer and the application layer. Transmission of video summary at application layer is based on MIMO transmit/receive diversity for multi-user with MC-CDMA, ARQ at the data link layer and the source coding at the application layer. The performance is analyzed by delay, distortion and effective throughput parameters. The rest of the paper is organized as follows. Section II gives the system model. Section III describes the performance analysis. Section IV provides the numerical results and shows the effectiveness of the system model. Finally Section V concludes the paper.

2. System Model

The system model is shown in Fig.1. This consists of a structure of physical layer, data link layer and application layer. A system controller which sends optimization parameters is based on the Channel State Information (CSI) input.

The DS/SS signal is sent with different intentional time delay through N_t transmit antennas to achieve MIMO diversity scheme. As shown in Fig.1 at the transmitter side, we store the video summary frames at the buffer. Source coding is adapted at the application layer. The video summary frames are fragmented into multiple packets for transmission at lower layers. The lost packets are again retransmitted by the ARQ performed at data link layer. After the spreading procedure, the signal is transmitted from N_t antennas and the reverse operations are performed at the receiver in order to get the original summary frames. If the fragmented packets are received correctly, the frames will be stored at the buffer and the video clip frames will be reconstructed. If the packets are not received after the retransmission limit N_{max} , it will have to be reconstructed from the previous summary frames.

We consider the channel as Rayleigh fading channels. The channel remains static for the first packet transmission, but it varies during the

subsequent packet transmission. Adaptive modulation technique is automatically adopted for every transmission and retransmission attempt.

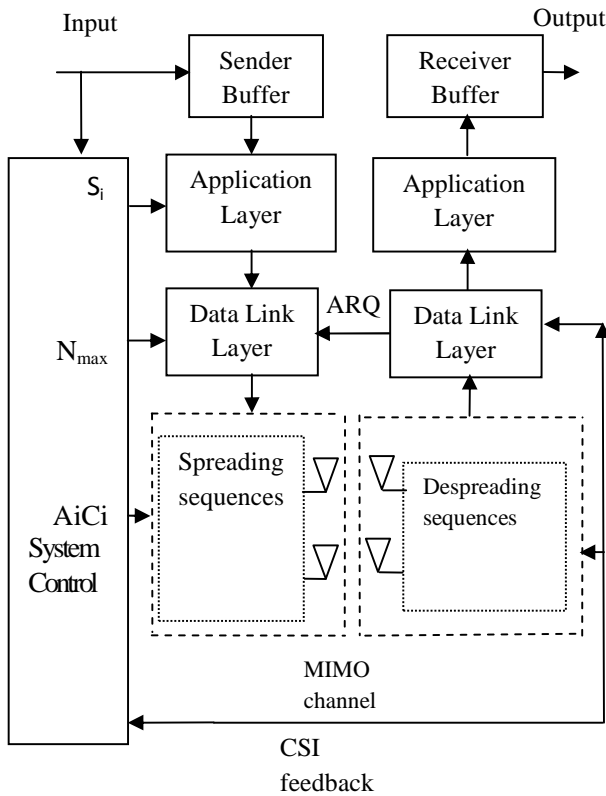


Fig.1. System Model

2.1. MC-CDMA Scheme

In MC-CDMA system, the incoming bit stream of each user is assumed to be binary. This binary input stream is binary phase shift keying modulated (BPSK) i.e., bits are mapped into symbols. The symbols are replicated into N copies (serial to parallel converter). Each replicated copy is being multiplied by one chip of the spreading sequence corresponding to the particular user. The spreading sequence used is Walsh Hadamard Code. Walsh Hadamard Codes are optimum in maintaining the orthogonality between the sub-carriers. Each N spread symbol is modulated into N different orthogonal sub-carrier frequencies. The IFFT block performs

this. Different users use different code sets to achieve multiple access. This is shown in Fig.2.

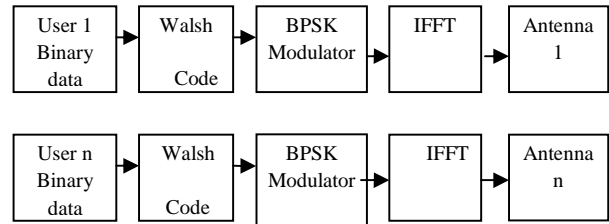


Fig.2. MC-CDMA Transmitter simulation model

2.2 MIMO Diversity Scheme

The selected modulation is transmitted via N_t transmit and N_r receive antennas. The different diversity techniques [12], are adopted as per the channel condition as shown in TABLE I. If perfect CSI is available at both sides of the wireless link, maximal-ratio transmission (MRT, also known as beamforming) and maximal-ratio combining (MRC) will become the optimal transmit- and receive-diversity schemes respectively. If CSI is not available at the transmitter side, space-time block coding (STBC) will be the good choice to achieve transmit diversity. The selection combining (SC) at either the transmitter or receiver side is a good tradeoff at both the performance and complexity levels.

Table 1: MIMO DIVERSITY PARAMETERS

MIMO Schemes	Diversity	M	L	β
Tx-MRT/Rx-1		1	N_t	1
Tx-STBC/Rx-MRC		1	N_t N_r	N_t
Tx-SC/Rx-MRC		N_t	N_r	1
Tx-MRT/Rx-SC		N_r	N_t	1
Tx-STBC/Rx-SC		N_r	N_t	N_t
Tx-SC/Rx-SC		$N_t N_r$	1	1
Performance Upper-bound		1	N_t N_r	1

The probability density function (pdf) of the combined signal-to-noise ratio (SNR), denoted by $P_{\Gamma}(\gamma)$ can be derived as a *unified* expression [10] as follows:

$$P_{\Gamma}(\gamma) = \frac{M}{\Gamma(mL)} \sum_{i=0}^{M-1} (-1)^i \binom{M-1}{i} \exp\left(- (i+1) \frac{\beta m}{\gamma} \gamma\right) \sum_{j=0}^{i(mL-1)} \xi_{ji} \left(\frac{\beta m}{\gamma}\right)^{j+mL} \gamma^{j+mL-1} \quad (1)$$

where, $\Gamma(\cdot)$ represents the Gamma function, $\bar{\gamma}$ denotes the average SNR of the combined signal, m denotes the fading parameter, ξ_{ji} the multinomial expansion coefficients determined by $\xi_{ji} = \sum_{p=a}^b \xi_{p(i-1)/[(j-p)!]}$ with $a = \max\{0, j - (M-1)\}$, $b = \min\{j, (i-1)(M-1)\}$, $\xi_{j0} = \xi_{0i} = 1$, $\xi_{j1} = 1/(j!)$, and $\xi_{1i} = i!$. The parameters M , L and β depend on MIMO diversity schemes as specified in the TABLE I. Here M denotes the selection diversity order and L denotes the combining diversity order. β will vary only when STBC scheme is used. The total diversity order is determined by $M \times L$ i.e., $N_t \times N_r$.

3. Performance Analysis

The cross-layer optimization parameters from various layers are used to design the cross-layer controller. We take different parameters from the three layers, i.e., application, data link and physical layers. S_i , B_i are the coding parameters from application layer and N_{max} is the maximum retransmission number for one packet from data link layer. $A_{i,q,n}$, $C_{i,q,n}$ are the modulation order and coding rate of BPSK scheme based on channel SNR, $\gamma_{i,q,n}$. Let $R_{i,q,n}(A_{i,q,n}, C_{i,q,n})$ be the rate(bits/symbol) of BPSK modulation. Based on the above parameters as $\rho(S_i, B_i, N_{max}, A_{i,q,n}, C_{i,q,n}, \gamma_{i,q,n})$, the loss probability can be designed for the i^{th} summary frame.

The AMC technique has emerged as one of the key solutions to increase the spectral-efficiency of wireless networks. The entire SNR range is partitioned into 7 non overlapping consecutive intervals as $\Gamma_k \leq \gamma < \dots \Gamma_{k+1}$. $\Gamma_1 = 0$ corresponds to outage mode. $\Gamma_2 \dots \Gamma_7$ corresponds to BPSK, QPSK, QPSK, 16-QAM, 16-QAM and 64-QAM respectively. If the SNR increases, the system will select higher modes to transmit data, otherwise lower modes will be selected.

The packet-error rate (PER) for the k^{th} AMC mode for $k= 2, 3 \dots K$ can be approximated by

$$PER_k(\gamma) = 1, \quad \text{if } 0 < \gamma < \gamma_k \\ = a_k \exp(-g_k \gamma), \text{ if } \gamma \geq \gamma_k \quad (2)$$

The AMC is in mode k , if the SNR γ falls in to the range $\Gamma_k \leq \gamma < \Gamma_{k+1}$. γ_k can be expressed as below:

$$\gamma_k = \frac{1}{g_k} \ln\left(\frac{PER_k(\gamma)}{a_k}\right) \quad (3)$$

We consider only the BPSK modulation scheme for multi-user scenario and the parameters are $C_k = 1/2$, spectral efficiency R_k (bits/sym) = 0.50, modulation order $a_k = 1.1369$ and the corresponding coding rate $g_k = 7.5556$.

The average packet error rate \overline{PER}_k is,

$$\overline{PER}_k = \frac{1}{P_k} \int_{\Gamma_k}^{\Gamma_{k+1}} PER_k(\gamma) P_{\Gamma}(\gamma) d\gamma \\ = \frac{1}{P_k} \int_{\Gamma_k}^{\Gamma_{k+1}} \left[1 - (1 - a_k \exp(-g_k \gamma))\right]^{La} P_{\Gamma}(\gamma) d\gamma$$

$$= \frac{1}{P_k} \cdot \frac{M}{\Gamma(mL)} \sum_{i=0}^{M-1} (-1)^i \binom{M-1}{i} \sum_{j=0}^{i(mL-1)} \xi_{ji} \left(\frac{\beta m}{\gamma}\right)^{j+mL} [PER_{k+1}(\gamma) - PER_k(\gamma)] \quad (4)$$

Thus the average PER_k can be expressed as

$$PER_k = \frac{\sum_{k=2}^K R_k P_k \overline{PER_k}}{\sum_{k=2}^K R_k P_k} \quad (5)$$

Where, R_k denotes the spectral-efficiency of the BPSK mode which is 0.50 and P_k denotes the probability that the SNR falls into mode k which is determined by

$$P_k = \int_{\Gamma_k}^{\Gamma_{k+1}} P_{\Gamma}(\gamma) d\gamma \quad (6)$$

The average delay for one transmission attempt at physical layer can be found as

$$\bar{T} = \frac{1}{P_k} \sum_{k=1}^K \int_{\Gamma_k}^{\Gamma_{k+1}} \left(\frac{L_a}{R_k \cdot r} + T_{RTT} \right) P_{\Gamma}(\gamma) d\gamma \quad (7)$$

Where, L_a = actual packet length.
 T_{RTT} = Round trip time.
 r = channel transmission rate.

The expected distortion $E[D]$ of the video clip can be calculated by

$$E[D] = \sum_{k=0}^{n-1} E[D(f_k, \tilde{f}_k)] = \sum_{i=0}^{m-1} \sum_{j=l_i}^{l_{i+1}-1} \sum_{b=0}^i \{ (1 - \rho_{i-b}) d[f_j, \tilde{g}_{i-b}(S_{i-b})] \prod_{a=0}^{b-1} \rho_{i-a} \} \quad (8)$$

If the continuous summary frames are lost due to the channel error, then the coverage of the received summary for the original clip will be degraded significantly. To avoid such a problem, we define L such that the case of L or more than L consecutive summary frames being lost will never happen. So if $L=2$ then, no neighbouring frames can be lost together during transmission. So the distortion can be written as

$$E[D] = \sum_{i=0}^{m-1} \sum_{j=l_i}^{l_{i+1}-\min(i,L-1)} \sum_{b=0}^i \{ (1 - \rho_{i-b}) d[f_j, \tilde{g}_{i-b}(S_{i-b})] \prod_{a=0}^{b-1} \rho_{i-a} \} \quad (9)$$

The same distortion measure for the video summary result has been used in [12]. If we set $L=2$, then there are two possibilities like: either the frame is received or it is lost but its previous frame is successfully received. Let us take G_i the chance of the i^{th} summary frame being not lost. Hence $G_i = 1$ means it is guaranteed to be received. Otherwise it is not guaranteed. Based on the constraint, we need $\max(G_i, G_{i-1}, \dots, G_{i+1-L}) = 1$ for all $i \in [0, m-1]$. So that G_i can be guaranteed.

$$\text{Min } E[D] \text{ s.t } \max(G_i, G_{i-1}, \dots, G_{i+1-L}) = 1, \quad i \in [0, m-1] \quad (10)$$

The expected distortion of the video clip should be within tolerable time delay. So time delay should be bounded within some delay budget T_{max} as

$$\text{Min } E[D], \text{ s.t } T \leq T_{max}, \quad (11)$$

So eqn(11) can be written as

$$\text{Min } E[D], \text{ s.t } T \leq T_{max} \text{ and } \text{Max}(G_i, G_{i-1}, \dots, G_{i+1-L}) = 1, i \in [0, m-1] \quad (12)$$

T_{max} is the given delay budget for delivering the whole video clip.

T is the delay in transmitting the whole summary frame which can be expressed as

$$T = \sum_{i=0}^{m-1} \sum_{q=1}^{Q_i} \sum_{n=1}^{N_{i,q}} \left[\frac{F_{i,q}(S_i, B_i)}{R_{i,q,n}(A_{i,q,n}, C_{i,q,n}) * r} + T_{RTT} \right] \quad (13)$$

T_{RTT} is the maximum allowed RTT to get the acknowledgement packet via the feedback channel before a retransmission trial.

The packet success rate is defined as the probability of receiving a packet correctly, if the SNR γ falls in to the range $\Gamma_k \leq \gamma < \Gamma_{k+1}$. From Equation (5)

$$PSR_k = 1 - PER_k \tag{14}$$

The effective throughput can be defined as the number of payload bits per second received correctly. The payload overhead should also be taken into account and for the initial analysis; we consider the acknowledgements are error free. The payload overhead takes into account the CSMA/CA channel access time and the header overheads as specified by the IEEE 802.11 protocol. Based on the data rate, the overhead is varying. So the transmit time of packet including MAC, PHY headers and DCF protocol overheads can be defined as [14]

$$P_k = D_k * P_{to} \tag{15}$$

Here, P_{to} = Total protocol overhead
 D_k = Data rate corresponding to AMC mode.

The total protocol overhead is calculated as specified by the IEEE 802.11 protocol. Each MAC frame consists of MAC header or MAC protocol data unit (MPDU), variable length frame body and frame check sequences (FCS) as shown in Fig.3. The MAC header and FCS consist of 28 bytes and the ACK is 14 bytes long.

MAC Header 24bytes	IP Header 20bytes	RTP/UDP Header 20bytes	Payload Data	FCS 4bytes
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Fig.3. Frame format of a data frame MPDU

The effective throughput corresponding to the payload length is

$$T_k = (L_a / L_a + P_k) * D_k * PSR_k \tag{16}$$

We next list the operating assumptions adopted in this paper.

- (i) We consider $L = 2$ such that P_L is 10^{-2} , so no neighboring summary frames can be lost together during transmission.
- (ii) We assume fading parameter $m = 2$ indicating the Rayleigh fading channel and the average SNR $\bar{\gamma} = 10$ dB. The channel can be estimated from the received SNR which is a random variable with a probability density function(pdf):

$$P_r(\gamma) = \frac{1}{\gamma} \exp\left(-\frac{\gamma}{\gamma}\right)$$
- (iii) We assume fixed channel transmission rate $r = 6 * 10^6$ symbols/second and fixed round trip time $T_{RTT} = 100$ millisecond and maximum retransmission number $N_{max} = 3$.
- (iv) The OFDM PHY characteristics of IEEE 802.11a are summarized in TABLE III. The Payload overhead is taken as 40 bytes as the MAC header and FCS consists of 28 bytes and the ACK is of 14 bytes long.
- (v) We have taken the SNR of 2dB. We consider the different modes of AMC as the data rate of 6Mbps, 12Mbps, 18Mbps, 24Mbps, 36Mbps and 54Mbps. The payload length is varied from 2500 bytes to 5000 bytes.
- (vi) The MIMO parameters are $M = 2$, $L = 2$ and $B = 1$ which in nothing but Tx-SC/Rx-MRC system.

Parameter	Value	Notes
tSlot	9 μ s	Slot Time
tSIFS	16 μ s	SIFS Time
tDIFS	34 μ s	DIFS=SIFS+2*Slot
CW _{min}	15	min.contention window size
CW _{max}	1023	max.contention window size
tPLCP_Preamble	16 μ s	PLCP preamble duration
tPLCP_SIG	4 μ s	PLCP SIGNAL Field duration
tsymbol	4 μ s	OFDM symbol interval

Table.2.OFDM PHY Characteristics

4. Numerical Results

In this section, numerical results are presented and cross layer design with MIMO for single user and multi-user are considered. Experiments are designed using H.264/AVCJM 10.2 for the video clip called "Glasgow" which is a typical test clip. For ease of comparison we summarize the first 300 frames into 30 frames. For easy computation we compress the summary by choosing different quantization step size and the values are like 10, 20, 30, 40, 50. According to each QP, the frames have different rates and distortion values. If more summary frames mean higher sampling rate, distortion will be less. The simulation parameters for MC-CDMA are chosen as the transmitted bits of 8, Walsh codes dimension of 2x2. The number of subcarriers are 16 and modulation scheme is BPSK.

In Fig.4, the delay and distortion effects are shown for single user and multi-user scenario of the video summary that contains 30 frames. The

square nodes show the distortion-delay pairs of single user and the 'v' nodes refer to multi-user based on MC-CDMA. We can observe that there is no much distortion variation in multi-user scenario as it increases from 1.001% to 1.006%. Hence distortion gain of 15% is still achieved using our MIMO system for multi-user compared with single user.

Fig.5 plots the distortion vs. delay budget with $P_L = 10^{-2}$ ($L=2$) and $N_{max} = 3$ for system using single user and multi-user. It is observed that the difference is marginal. This is because with larger N_{max} , the actual PER is much lower than P_L . From this figure, we can conclude that the maximum transmission number impacts much the video transmission quality with cross-layer optimization framework. With same delay budget, a larger allowed maximum transmission number leads to better video transmission quality.

Fig.6 shows the distortion vs. SNR comparison with QP adaptation and $N_{max} = 3$. Initially the distortion is reduced by the means of increasing the SNR values. Further due to link adaptation performed by ARQ there has been a stable distortion level along all SNR values. The same conclusion can also be applicable if summary frames are increased considerably.

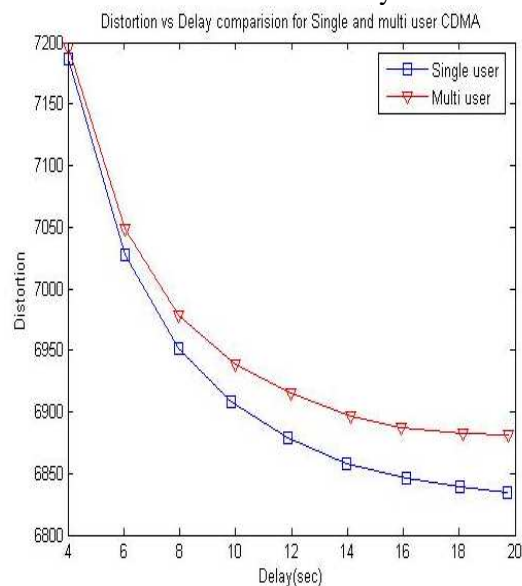


Fig.4. Distortion vs Delay comparison for system model with single user and multi user CDMA

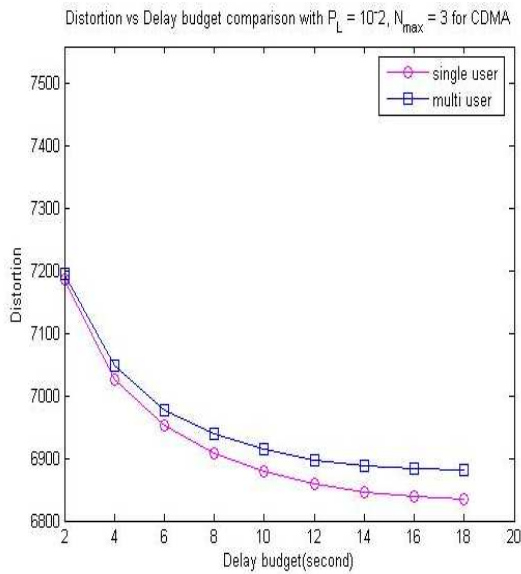


Fig.5. Comparison of distortion vs.delay budget

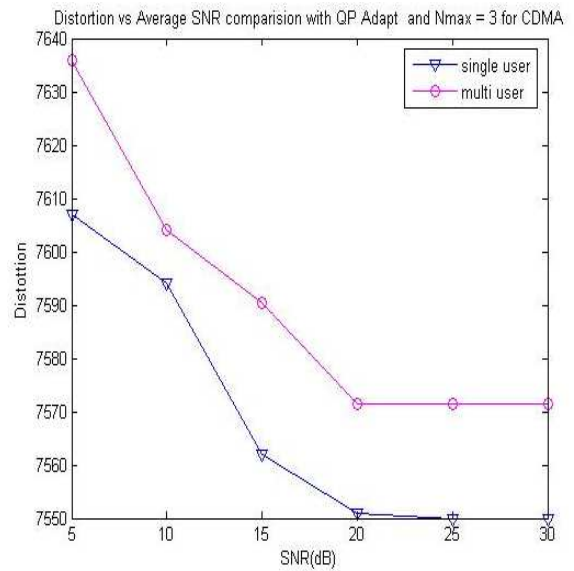


Fig.6. Distortion vs.average SNR comparison for single user and multi user

In Fig.7, the effective throughputs for the data rate of lower AMC orders such as 6Mbps, 9Mbps and 12Mbps are compared. Initially, increasing payload length increases the effective throughput. After an optimum value, it will increase the packet error rate. Thus, selecting the lowest data rate is too conservative while higher data rate can significantly reduces the effective throughput. The comparison is for single user and from our earlier results we know that there will be a minimum deviation of 1% for multi-user. And this results also applicable to multi-user.

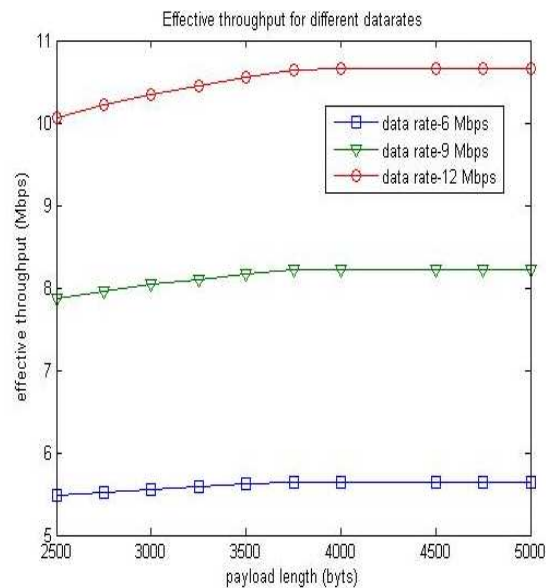


Fig.7.Effective throughput for differernt lower data rates

In Fig.8, the effective throughputs for the data rate of higher AMC orders such as 18Mbps, 36Mbps and 54Mbps are compared. The effective throughput is 34.5Mbps for 36Mbps date.

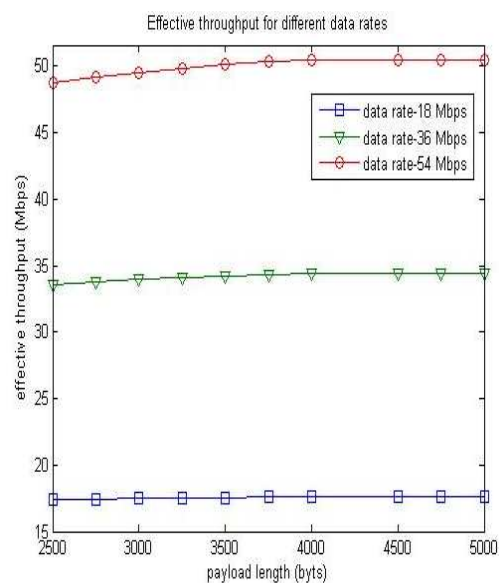


Fig.8.Effective throughput for different higher data rates

5. Conclusions

In this paper, performance of MC-CDMA with MIMO is assessed in terms of average probability of bit error. The cross layer design is achieved using the co-ordination of MIMO combined with ARQ at the data link layer and source coding at the application layer. The optimization parameters from all three layers are jointly considered to get the video summary with less delay and distortion. We have derived the closed form expressions for MIMO-diversity employed at the physical layer with upper protocol layers for multi-user scenario. Our numerical results show that MIMO-diversity employed with MC-CDMA distortion is lower than the single user as approximately 1.006%. Our cross layer design can still achieve significant distortion gain of 15% in the multi-user environment. We consider the performance analysis in terms of effective throughput also.

Further scope is that instead of summary frames, normal video can also be transmitted. Another useful extension will be to add more optimization parameters like video coding parameters from application layer and routing options from network layer.

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