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MIMO-OFDM Wireless Broadband System With Adaptive Transmission Mode (ATM) Controller

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Abstract: Multiple-input multiple-output (MIMO) antenna system with Orthogonal Frequency Division Multiplexing (OFDM) [1] [2] technology is proven physical layer technology for the wireless broadband system. With the advent of this combined technology in the wireless broadband system, we observe a great increase in capacity. This spring, however, build upon right selection of transmission parameters suitable to present channel condition. To address this problem, we propose a smart adaptive transmission mode (ATM) controller for use with MIMOOFDM wireless broadband system. The proposed ATM controller is triggered by channel information and provides the transmitter with control signals used to set transmission parameters according to channel conditions. To deal with the vast varying environment in radio path, conventional OFDM based link adaptive systems rely on modifying only modulation coding scheme (mcs). However, the ATM controller considers the guard interval between OFDM symbols and MIMO mode (space-time block coding (STBC) or spatial division multiplexing (SDM)) as an additional transmission parameters in the link adaptive transmission process along with the modulation and coding. Consequently, we can observe a great improvement in the throughput performance of the system in a fading radio environment. We evaluate the throughput performance of IEEE 802.11n [3] [4] [5] based MIMO OFDM wireless broadband system with ATM controller under the constraint of target bit error rate. Simulations over TGn fading channel [6] show that the system with the proposed ATM controller performs very better than a conventional scheme of link adaptation.

Index Terms: ATM Controller, Broadband System, Coding, Guard Interval, IEEE 802.11n, MIMO, OFDM, Modulation,

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1. INTRODUCTION

THE MIMO OFDM air interface technology in wireless broadband systems (IEEE 802.11n, ac) has enhanced spectral as well as power efficiency of system compared to legacy broadband standards (IEEE 802.11a, g). This technology supports very high data transmission rates while ensuring transmission reliability. Paper [7] explains the basics of MIMO OFDM air interface scheme. In paper [8] effect of SDM on throughput of system is discussed. Paper [9] [10] discuss the STBC encoding and its effect on the BER performance of the system. Radio link in the wireless system is characterized by vast and random variations. Inter-Symbol Interference (ISI) and Inter-Carrier Interference (ICI) is resulted due to time and frequency dispersive characteristic of the radio channel. Therefore, in order to reduce the interference problem and enhance wireless system performance in the hostile radio environment, there is a compelling need for an adaptive controller, which can sense the radio environment and help system in adjusting one or more parameters according to the channel condition. To improve wireless system performance in a fading radio environment, various link adaptive transmission methods have been devised and used by researchers [11] [12] [13] [14] in the past. However, most of these methods rely only on adaptive modulation coding (AMC) for link adaptation. Guard interval also called as cyclic prefix ensures sub-carrier orthogonality and helps system in avoiding ICI as well as ISI. Typically, the guard interval is chosen to be many times larger than the channel delay spread. However, under good channel conditions, the use of an unnecessarily long guard interval reduces spectral efficiency. Given the IEEE802.11n supports using two guard intervals (long or short), the objective of this work is link adaptive selection of guard interval that could maximize throughput in varying channel environment. Although an effective adaptive transmission parameter, there is very less research work in the context of guard interval adaptation. Recent research on adaptive guard interval [15] [16] [17] [18] is based on estimating channel delay spread. Paper [19] presents a method of estimating the length of channel impulse response to determine the optimum value of guard interval. However, estimating channel delay spread or length of channel impulse response increases system complexity. The proposed ATM controller uses a novel but less complex BER based adaptive guard interval (AGI) algorithm. MIMO mode is also an adaptive transmission parameter. Based on channel condition MIMO can be exploited either to increase throughput or to increase data transmission reliability. Papers [9] [8] explain the effect of adapting MIMO transmission mode on the performance of wireless local area network (WLAN). Our ATM controller incorporates a simple algorithm for selection of link adaptive MIMO mode (AMM). Performance of the proposed ATM controller depends on accurate channel state information. One of the triggering information that ATM controller uses is, the estimated average value of received signal to noise ratio ($\overline{\gamma}_{rx}$). This paper contributes in joint determination of link adaptive modulation-coding scheme and MIMO transmission mode (STBC or SDM) based on ($\overline{\gamma}_{rx}$). ATM controller uses estimated bit error rate (BER_{est}) as another triggering information to determine the optimum value of guard interval suitable to present channel state. The major contribution of this paper is a novel yet simple BER based AGI algorithm. We determine the BER threshold analytically to switch the guard interval value between long and short. To explain the proposed ATM controller algorithm, the paper is organized as follows: system model with the proposed ATM controller is described in section II. Section III explains system mathematically. In section IV problem formulation and ATM controller algorithm is given. Section V presents simulation results while Section VI concludes the paper.

2 MIMO OFDM WIRELESS BROADBAND SYSTEM MODEL

We consider IEEE 802.11n (WLAN) standard as an example of the system model. Fig. 1 shows the block schematic of IEEE 802.11n based MIMO OFDM wireless broadband system with ATM controller. For simplicity, we assume 2x2 MIMO antenna configuration with two transmit and two receive antennas (A_T =2 and A_T=2). The system specifications are listed in table 1.

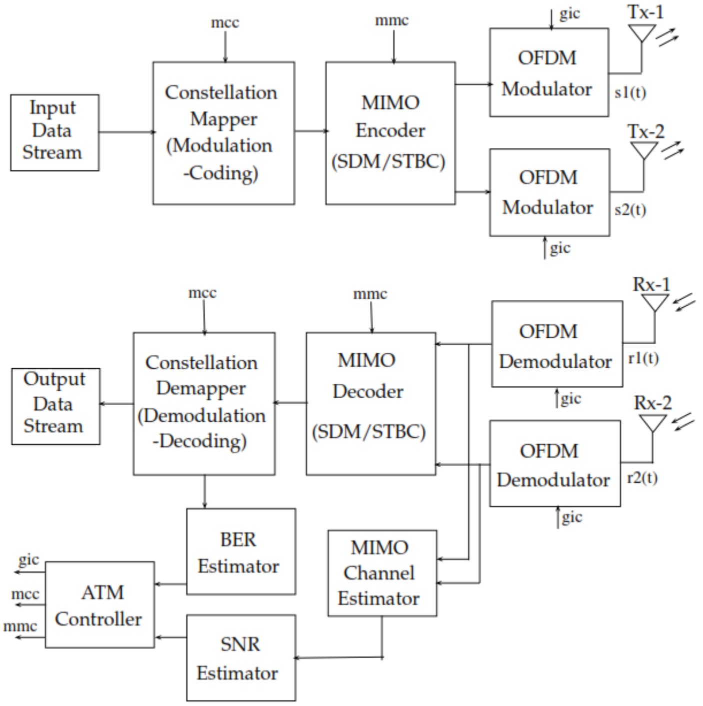


***Fig. 1** System model*

***Table 1** System specifications*

Base wireless standard	IEEE 802.11n
Transmit antennas	2
Receive antennas	2
Carrier	5.2 GHz
Channel Bandwidth	20 MHz
Total sub-carriers	64
Data sub-carriers	52
Power (normalized)	1
Sub-carrier Bandwidth	312,5 KHz
Modulation	BPSK, QPSK, M-QAM
Coding	BCC
Guard Interval	Short (400 ns) or long (800 ns)

2.1 Transmitter

At the transmitter, the binary information data stream is first encoded using binary convolution coder (BCC) with the adaptive code rate supporting 1/2, 2/3, 3/4 and 5/6. The encoded symbols are then modulated using adaptive mapper, which supports using different constellation structures such as BPSK, QPSK, 16-QAM, and 64-QAM. After passing through adaptive MIMO encoder, the symbol sequence is OFDM modulated

2.2 Receiver

At the receiver, the received vectors are passed through OFDM demodulators, MIMO decoding is then carried out and finally demodulated and decoded using adaptive de-mapper and decoder subsystem. MIMO channel estimator, bit error rate (BER) estimator, and signal to noise ratio (SNR) estimator provide required channel state information to the ATM controller. ATM controller generates necessary control signals and sends it to the transmitter over the feedback channel.

3 MATHEMATICAL MODELS AND TRANSMISSION MODES

The system is assumed to be transmitting over MIMO fading channel (TGn channel). The TGn channel is assumed constant during the maximum packet period (= 1:2ms). Use of OFDM technology converts wideband frequency selective fading channel to many narrowband flat (non-frequency selective) fading channels. System switches between different transmission modes based on channel condition.

3.1 Rate adaptive transmission modes

System being considered supports using different rate adaptive transmission modes based on different combinations of modulation and coding method. This section presents new theoretical equations for BER as a function of γ_{rx} and mcs. It also discusses about the effect of different mcs on BER and throughput Performance of MIMO system.

3.1.1 BER Equations for different mcs

BER equations for Rayleigh fading channel given in [20] [21] is function of modulation scheme and signal to noise ratio per bit (EbNo). However, these equations do not consider the effect of BCC [22]. Modified BER equations for coded transmission (BCC) over Rayleigh fading channel for different modulation schemes are as given below.

BER for coded BPSK

$$P_e(\bar{\gamma}_{rx}, mcs)\Big|_{BPSK;BCC} = \frac{1}{2}\left[1 - \sqrt{\frac{\beta\cdot\bar{\gamma}_{rx}}{1+\beta\cdot\bar{\gamma}_{rx}}}\right] \tag{1}$$

Where $\bar{\gamma}_{rx}$ is average received signal to noise ratio related to average signal to noise ratio per bit ($\overline{E_bN_o}$) as below.

$$\bar{\gamma}_{rx} = \overline{E_bN_o}\left(\frac{R_{bit}}{BW}\right)G_{BCC} \tag{2}$$

$$G_{BCC} = R_c \cdot d_{\min} \tag{3}$$

Where G_{BCC} is coding gain of BCC, R_C is code rate, and d_{min} is minimum distance of BCC code.

BER for coded M-QAM

$$P_e(\bar{\gamma}_{rx}, mcs)\Big|_{M-QAM;BCC} = \left(2\left(1-\frac{1}{\sqrt{M}}\right)\frac{1}{\log_2}\right)\cdot\alpha \tag{4}$$

Where,

$$\alpha = \sum_{i=1}^{\sqrt{\frac{M}{2}}}\left(1 - \sqrt{\frac{1.5(2i-1)^2\beta\cdot\bar{\gamma}_{rx}\cdot\log_2 M}{(M-1)+1.5(2i-1)^2\beta\cdot\bar{\gamma}_{rx}\cdot\log_2 M}}\right. \tag{5}$$

3.1.2 Throughput of system with different mcs

Throughput an important performance metric of system is function of mcs and can be determined using following equation

$$Thr = R_{bit}(1 - P_e(\bar{\gamma}_{rx}, mcs)) \quad (6)$$

3.2 MIMO transmission mode

The input-output relation for MIMO channel is

$$r = Hs + n \quad (7)$$

Where, r is receive symbol vector, s is transmit symbol vector, H is MIMO channel matrix, and n is additive white Gaussian noise (AWGN) vector. IEEE 802.11n based broadband system being considered allows link adaptive switching between the following two MIMO modes.

3.2.1 MIMO-STBC mode

When the channel condition observed at the receiver is not good enough then MIMO-STBC transmission mode is selected to increases the reliability of the system. In this transmission mode system activates two transmit antennas and one receive antenna.

Encoding

The scheme of transmission for 2X1 MIMO-STBC is based on Alamouti coding explained in [23]. Encoder assumes that the channel is flat and constant during two transmission periods (Ts-1 and Ts-2) each of the length equal to an OFDM symbol period (T_{FFT}). A pair of successive OFDM symbols (s1 and s2) is transmitted using the encoding rule as shown in Fig. 2.

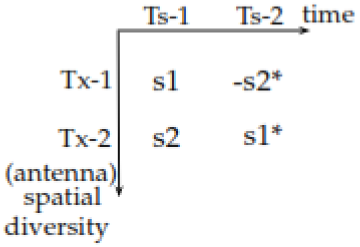


Fig. 2 *MIMO-STBC Encoding rule*

The matrix representation of encoded symbol is given as

$$s = \begin{pmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{pmatrix} \quad (8)$$

Decoding

The Mathematical model for 2x1 MIMO-STBC [23] systems is same as in equation (7). Where r is received signal given as

$$r = (r_1 \quad r_2)^T \quad (9)$$

With r_i (for i = 1; 2) is the received symbol during i^{th} time slot of period equal to T_{FFT}. For 2X1 MIMO-STBC mode channel matrix H in equation (7) becomes.

$$h = (h_1 \quad h_2) \quad (10)$$

With h_i (for i = 1; 2) representing the complex channel gain of the path between I transmit antenna and a receiver. Zero Force (ZF) detection [7] considers following pseudo-inverse matrix.

$$W_{zf} = (H^H H)^{-1} H^H \quad (11)$$

The received signal decoding using ZF scheme is as given below

$$\begin{pmatrix} \hat{s}_1 \\ \hat{s}_2 \end{pmatrix} = W_{zf} \begin{pmatrix} r_1 \\ r_2 \end{pmatrix} \quad (12)$$

Diversity Gain

MIMO-STBC transmission mode offers spatial diversity. Effect of spatial diversity on BER of the system is as given below

$$P_{e(STBC)} = \binom{2L-1}{L}(P_e(\bar{\gamma}_{rx}, mcs))^L \quad (13)$$

Where, L is diversity order (defined as a number of i.i.d. faded radio paths that an OFDM symbol passes through). For 2x1 MIMO-STBC; L = 2. Therefore, BER of a system with 2x1 MIMO-STBC becomes

$$P_{e(STBC)_{2\times1}} = 3(\bar{\gamma}_{rx}, mcs)^2 \quad (14)$$

3.2.2 MIMO-SDM Mode

When channel conditions are better, then MIMO-SDM transmission mode can be selected to increases spectral efficiency (or capacity) of the system. This transmission mode activates two transmit and two receive antennas.

Encoding

When MIMO-SDM mode is selected then the transmitter as shown in Fig. 1 transmits two independent OFDM symbols parallel over two transmit antennas [7]. Matrix form representation of encoding scheme used at the transmitter is

$$s = \begin{pmatrix} s_1 & s_2 \end{pmatrix}^T \tag{15}$$

Where s_i (for i = 1, 2) is transmitted symbol on the i^th^ transmitting antenna.

Decoding

The mathematical model for 2x2 MIMO-SDM channels is same as equation (7), where r is received signal given as

$$r = \begin{pmatrix} r_1 & r_2 \end{pmatrix}^T \tag{16}$$

With r_i (for i = 1, 2) is received symbol on the i^th^ receive antenna. For 2x2 MIMOSDM mode channel matrix in equation (7) becomes.

$$H = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \tag{17}$$

With h_{ij} (for i = j = 1, 2) representing the complex channel gain of the path between i^th^ transmit antenna and j^th^ receive antenna. The received signal decoding using ZF scheme considers equation (12) and (13).

Multiplexing gain

Spatial multiplexing gain is a factor by which the capacity or throughput of the system increases due to the use of multiple antennas. MIMO channel can be viewed as parallel SISO channels with spatial multiplexing gain or (number of spatial streams) [20].

$$\upsilon = \min(A_{T,} A_R) \tag{18}$$

Multiplexing gain is also defined as a number of OFDM symbols transmitted over the MIMO channel per symbol period. The MIMO can be exploited to achieve full multiplexing gain with diversity order approximately equal to one. Therefore, throughput (as defined in equation (7)) for MIMO-SDM mode of transmission becomes

$$Thr_{(SDM)2\times2} = \upsilon \cdot R_{bit}(1 - P_e(\bar{\gamma}_{rx}, mcs)) \tag{19}$$

For 2x2 MIMO-SDM; υ = 2, and L = 1. Therefore, at high SNR, the throughput of the proposed system becomes

$$Thr_{(SDM)2\times2} = 2R_{bit}(1 - P_e(\bar{\gamma}_{rx}, mcs)) \tag{20}$$

3.2.3 Guard Interval transmission mode

The Shannon capacity [22] of the system is given as

$$C = \frac{1}{T_{FFT} + T_g} \log_2(1 + \bar{\gamma}_{rx}) \tag{21}$$

Where T_{FFT} is FFT period (OFDM symbol period without guard interval), T_g is guard interval between OFDM symbols and $\bar{\gamma}_{rx}$ is received signal to noise ratio. Guard interval between OFDM symbols helps to maintain sub-carrier orthogonality. It eliminates ISI and ICI and reduces bit error probability. Our system supports using short or long guard interval.

Long Guard Interval

IEEE 802.11n based systems normally operate with a long guard interval. Due to longer guard time (idle time), use of LGI decreases the spectral efficiency or capacity of the system as in equation (22). However, when the channel condition is worst LGI helps in maintaining reliable transmission and better throughput can be achieved even under the worst channel scenario.

Short Guard Interval

When we intend to increases spectral efficiency or capacity of the system we can use short guard interval. However, throughput gain can only be achieved when channel conditions are much better. If channel conditions are not good (sever fading environment) then short guard interval may be insufficient to avoid ISI and ICI [21] and throughput gain is not possible.

4 PROPOSED ADAPTIVE TRANSMISSION MODE (ATM) CONTROLLER

Proposed ATM controller comprises the following two adaptive algorithms.

4.1 Adaptive modulation-coding and MIMO mode (AMC-AMM) algorithm

The objective of this algorithm is the joint determination of mcs and MIMO mode most suitable to present channel state. This algorithm maximizes the throughput of the system while maintaining the BER of the system below the pre-defined target value. $\bar{\gamma}_{rx}$, which represents the accurate channel state information (CSI) triggers this algorithm. Therefore, appropriate selection of mcs and MIMO mode for next packet is possible. AMC-AMM algorithm generates two control signals; Modulation-coding control (mcc) signal, and MIMO mode control (mmc) signal. Controller sends these signals to the transmitter over the most reliable feedback channel to make link adaptive transmission mode selection possible at the transmitter as shown in the table 2.

4.1.1 Algorithm steps

The general steps as follows summarize the AMC-AMM algorithm.

a. Extract and Demodulate high throughput long training field (HT-LTF) symbols at the receiver to estimate MIMO channel matrix.

b. Calculate $\overline{\gamma}_{rx}$ using elements of channel matrix as given below.

c. Select MIMO mode (STBC or SDM) based on $\overline{\gamma}_{rx}$

d. Select mcs based on $\overline{\gamma}_{rx}$

4.1.2 Average received signal to noise ratio estimation

Average received signal power can be estimated as given below

$$\overline{P_s} = \frac{1}{N_s}\sum_{k=1}^{N_s}\left|H(k)\right|^2 \qquad (22)$$

Where $H(k)$ is estimated kth sub-carrier channel gain, and N_s a total number of sub-carriers in training OFDM symbols transmitted in HT packet as preamble. For estimation of $\overline{\gamma}_{rx}$ we use the following equation.

$$\overline{\gamma}_{rx} = 10\log_{10}\left(\frac{\overline{P_s}}{\sigma_n^2}\right) \qquad (23)$$

4.1.3 Determination of SNR switching threshold for MIMO mode selection

Simulations are carried out over different TGn channels to find and plot throughput of the system employing AMC, separately for each MIMO mode. The crossing point of throughput curves plotted for each MIMO mode is considered as SNR switching threshold (α_{mm}) for MIMO mode selection. Note: Empirically derived α_{mm} for different TGn channels is different.

Selection of MIMO mode

MIMO mode appropriate to present channel condition is selected by comparing $\overline{\gamma}_{rx}$ with α_{mm} as given in algorithm 1.

4.1.4 Determination of SNR switching threshold vectors for mcs selection

In order to determine SNR switching threshold vectors for mcs selection, BER equations given in (1) to (6) can be inverted with respect to $\overline{\gamma}_{rx}$ for target BER value = 10^{-1}. We define two sets of SNR switching thresholds applicable separately for each MIMO mode.

$$\alpha = \{\alpha_1, \alpha_2, \alpha_3, \ldots\ldots, \alpha_8\} \qquad (24)$$

$$\alpha' = \{\alpha'_1, \alpha'_2, \alpha'_3, \ldots\ldots, \alpha'_8\} \qquad (25)$$

Where $\alpha_0 = 0$, $\alpha_8 = \alpha'_0 = \alpha_{mm}$, and α'_8 = infinity. These two sets of switching thresholds sub-divide the SNR range applicable to each MIMO mode into nine bins.

Note: SNR range applicable to different MIMO modes (SDM and STBC) is different.

Selection criteria for mcs

The mcs that maximizes the throughput performance of the system while keeping the average BER below the specified target value is selected. We consider a finite set consisting of sixteen mcs modes as specified in IEEE 802.11n standard satisfying above criteria.

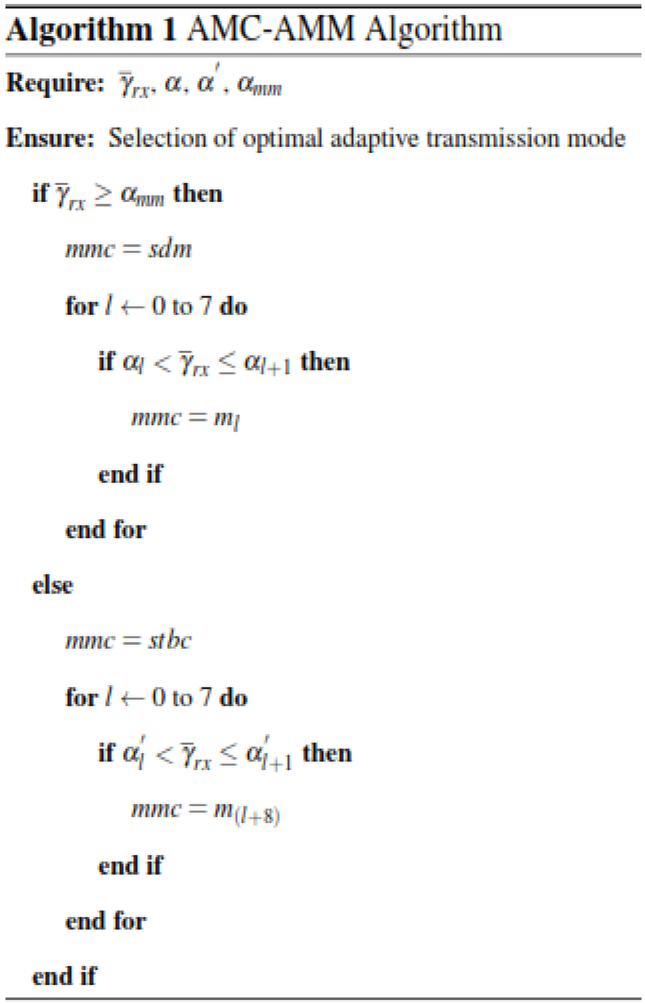
Table 2

TRANSMISSION MODES AND CORRESPONDING TRANSMISSION PARAMETER

Mcc		Modulation	R_c	Capacity or R_{bit} (Mbps)			
mmc=stbc	mmc=sdm			mmc=stbc		mmc=sdm	
				gic=short		gic=long	
m_0	m_8	BPSK	1/2	7.2	6.5	14.4	13
m_1	m_9	QPSK	1/2	14.4	13	28.8	26
m_2	m_{10}	QPSK	3/4	21.7	19.5	43.4	39
m_3	m_{11}	16-QAM	1/2	28.9	26	57.8	52
m_4	m_{12}	16-QAM	3/4	43.3	39	86.6	78
m_5	m_{13}	64-QAM	2/3	57.8	52	115.6	104
m_6	m_{14}	64-QAM	3/4	65	58.5	130	117
m_7	m_{15}	64-QAM	5/6	72.2	65	144.4	130

$$mcs = \{m_0, m_1, m_2, \ldots\ldots, m_{15}\} \qquad (26)$$

mcs appropriate to present channel condition is selected by comparing $\overline{\gamma}_{rx}$ with α and α' separately as given in algorithm 1.



Algorithm 1 AMC-AMM Algorithm

Require: $\overline{\gamma}_{rx}, \alpha, \alpha', \alpha_{mm}$

Ensure: Selection of optimal adaptive transmission mode

```
if $\overline{\gamma}_{rx} \geq \alpha_{mm}$ then
    $mmc = sdm$
    for $l \leftarrow 0$ to 7 do
        if $\alpha_l < \overline{\gamma}_{rx} \leq \alpha_{l+1}$ then
            $mmc = m_l$
        end if
    end for
else
    $mmc = stbc$
    for $l \leftarrow 0$ to 7 do
        if $\alpha'_l < \overline{\gamma}_{rx} \leq \alpha'_{l+1}$ then
            $mmc = m_{(l+8)}$
        end if
    end for
end if
```

4.2 guard interval (AGI) algorithm

AGI algorithm is triggered by the estimated value of bit error rate (BER) at receiver after every received packet. BER of the system is a function of SNR (Channel state parameter) and is one of the important system performance parameters. Therefore, we use BER (which reflects channel state accurately) as a triggering signal for AGI algorithm to select the optimal guard interval for the next packet. The efficiency of the proposed AGI algorithm is better as only minimal information transmitted over the feedback channel to the transmitter. In this algorithm, BER_{est} is compared with average bit error rate (BER_{avg}) and bit error rate threshold (BER_T) for AGI as explained in the algorithm 2.

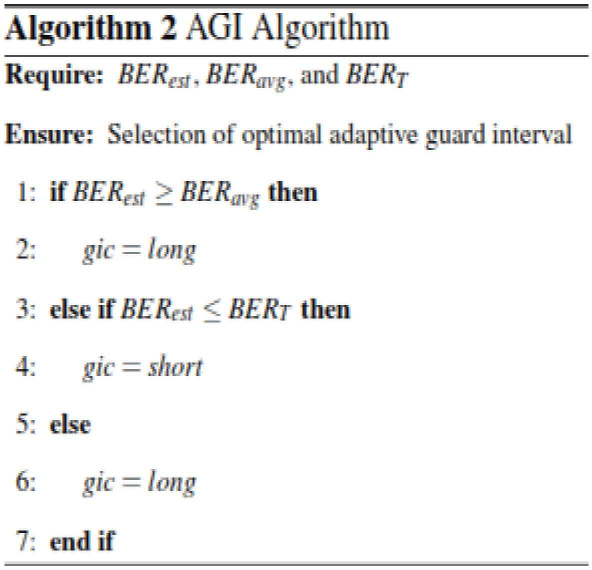
4.2.1 Determination of optimal bit error rate threshold

In order to determine analytically the optimal BER_T (for use with AGI algorithm) we can equate maximum achievable throughput of the system with short and long guard interval.

$$Thr_{(SGI)} = Thr_{(LGI)}$$
(27)

$$R_{b(SGI)}(1 - P_{e(SGI)\max}) = R_{b(LGI)}(1 - P_{e(LGI)\max})$$
(28)

Let $BER_{(LGI)\max} = BER_T = 10^{-1}$ and = $BER_{(SGI)\max} = BER_T$ Using bit rate values corresponding to different transmission modes as given in table 2 in the equation (28), we can determine the value of BER_T.



Algorithm 2 AGI Algorithm

Require: BER_{est}, BER_{avg}, and BER_T

Ensure: Selection of optimal adaptive guard interval

```
if $BER_{est} \geq BER_{avg}$ then
    $gic = long$
else if $BER_{est} \leq BER_T$ then
    $gic = short$
else
    $gic = long$
end if
```

5 SIMULATION RESULTS

This section provides simulation results to evaluate the effect of the proposed ATM controller on the performance of the wireless broadband system. In all simulation cases, we consider adaptation time interval = 1 packet period with maximum packet period= 1:2ms. Simulations carried over a wide class of TGn fading channel models consider the following controller algorithms for comparison.

1. Adaptive transmission mode (ATM) controller
2. Adaptive modulation coding and space-time block coding (AMC-STBC)
3. Adaptive modulation-coding and spatial division multiplexing (AMC-SDM)
4. Adaptive modulation-coding and adaptive MIMO mode (AMC-AMM)

5.1 Comparison of ATM controller with conventional AMC controller

Simulation curves in figure 3 to figure 10 show a comparison of throughput and BER performance of the system with the ATM controller, AMC-STBC and AMC-SDM schemes under the constraint of target BER= 10^{-1}. The ATM controller considers three different transmission parameters (MCS, MIMO mode, and Guard Interval) in the adaptation process. This results in 10 to 15 percent increase in throughput if compared with a conventional scheme of adaptation that is based on modifying only the modulation and coding (AMC scheme). Numerical values of simulation results given in a table 3 indicate the performance of MIMO-OFDM wireless broadband system with ATM controller.

5.2 Effect of guard interval adaptation

In order to investigate the effect of guard interval adaptation, the throughput, and BER performance of the system with the ATM controller is compared to that with AMC-AMM scheme in all simulation scenarios. We observe a 5 to 8 percent increase in throughput due to guard interval adaptation over fixed guard interval scheme. Effect of guard interval adaptation is channel dependent. From the analysis of simulation results, we can put following concluding remark about guard interval adaptation.

- Scheme of guard interval adaptation is more effective for channels with small delay spread (TGn B, and TGn C) and will not be that effective for channels with long delay spread (TGn E)
- However, the scheme of guard interval adaptation is maintaining the required reliability in all channel scenarios and provides maximum possible throughput.

5.3 Effect of MIMO mode adaptation

Separate simulation is carried out over different TGn channel models, with the objective of analyzing the effect of adapting MIMO mode or antenna configuration according to the channel condition. We can observe from simulation curves that AMCSTBC is suitable for lower values of SNR while AMC-SDM performs better when SNR is sufficiently large. Therefore, performance optimization in terms of throughput is obvious with AMC-AMM. Performance figure in the table 3 shows significant improvement in throughput because of MIMO mode adaptation. The major goal of simulations is to evaluate the efficacy of the proposed ATM controller for IEEE 802.11n based system. Simulation results in a table 3 indicate the usefulness of the proposed ATM controller for the wireless broadband system. Simulations over the different class of fading channels demonstrate the reliability and effectiveness of ATM controller in all channel conditions.

Table 3

PERFORMANCE FIGURES OF MIMO-OFDM SYSTEM WITH ATM CONTROLLER

Sr. No.	Channel Model	Throughput (Mbps)			
		AMC-STBC	AMC-SDM	AMC-AMM	ATM
1	TGn-B (shadowed) with d=100m	31.08	43.12	44.33	47.64
2	TGn-C (shadowed) with d=100m	30.18	40.49	42.42	45.79
3	TGn-D with d=100m	32.34	49.28	49.38	53.43
4	TGn-E (shadowed) with d=100m	29.97	44.57	45.06	52.64

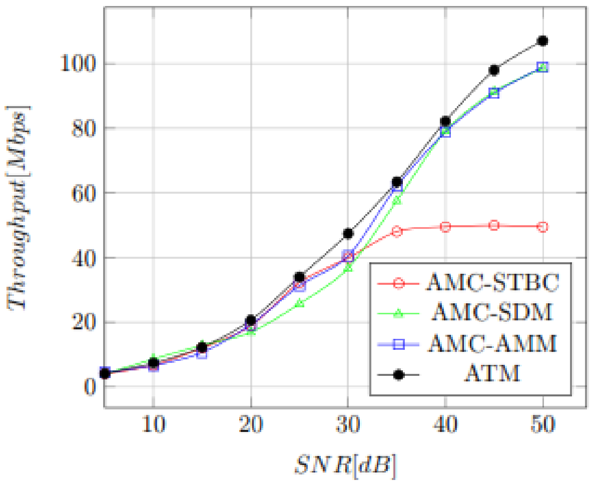


***Fig.3** Throughput v/s SNR over TGn B channel with shadowing effect and d=100m*

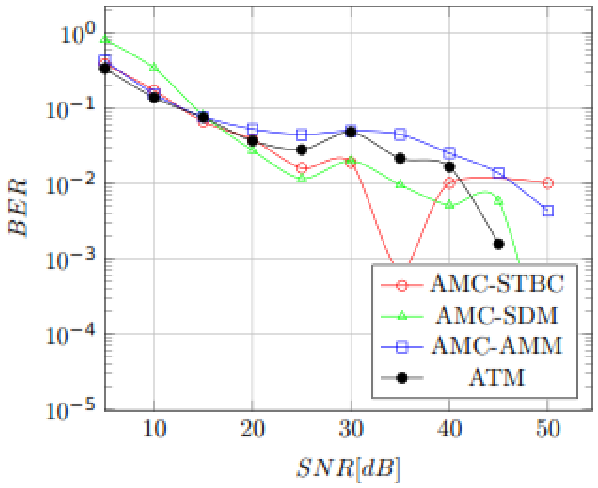


***Fig. 4** BER v/s SNR over TGn B channel with shadowing effect and d=100m*

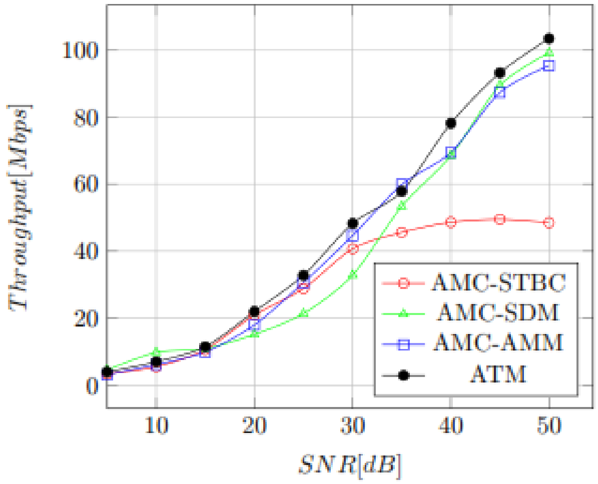


***Fig. 5** Throughput v/s SNR over TGn C channel with shadowing effect and d=100m*

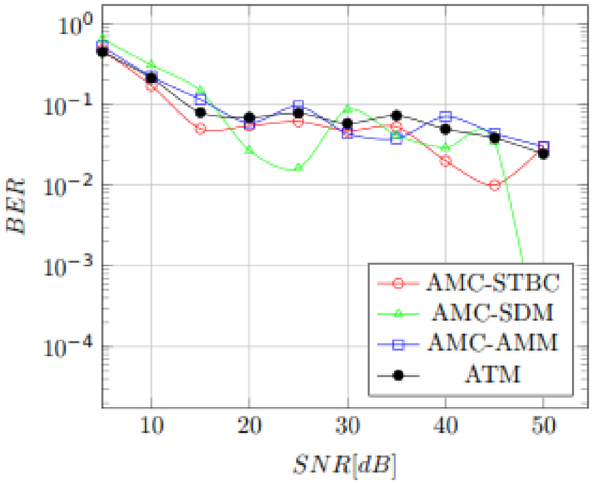


***Fig. 6** BER v/s SNR over TGn C channel with shadowing effect and d=100m*

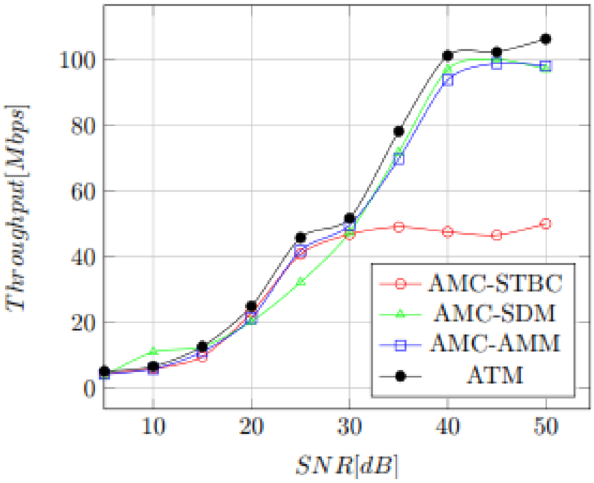


Fig. 7 *Throughput v/s SNR over TGn D channel with no large scale fading effect and d=10m*

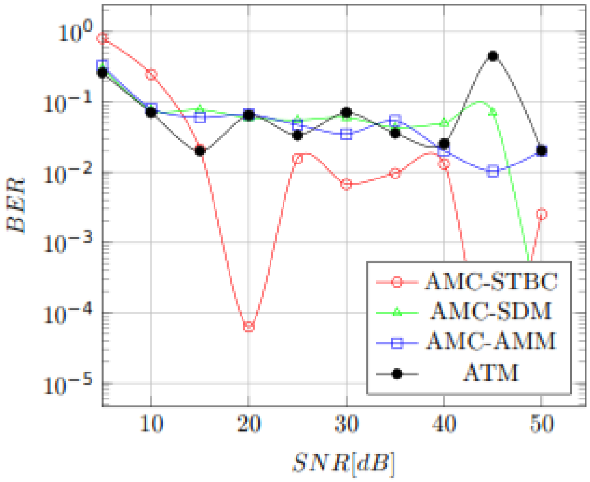


Fig. 8 *BER v/s SNR over TGn D channel with no large scale fading effect and d=10m*

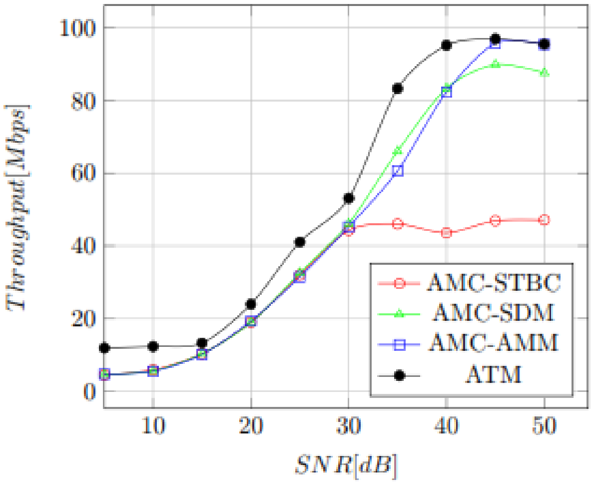


Fig. 9 *Throughput v/s SNR over TGn E channel with no large scale fading effect and d=10m*

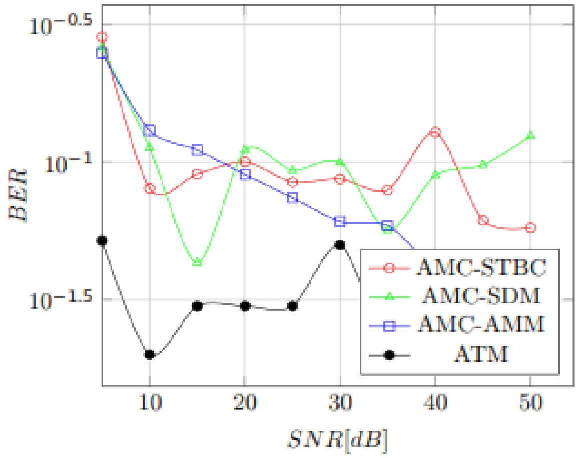


Fig. 10 *BER v/s SNR over TGn E channel with no large scale fading effect and d=10m*

CONCLUSION

In this paper, we evaluate the throughput and BER performance of the wireless broadband system with the proposed ATM controller. Our findings, from simulation results for IEEE 802.11n based MIMO-OFDM system shows that the introduction of the ATM controller significantly increases the throughput while maintaining required data reliability. The enhancement in throughput of the system is found valid for a wide class of TGn fading channel models such as TGn-A, B, C, D and E. The performance of adaptive system largely depends on the accuracy of the channel estimation algorithm. The SNR estimator presented in this paper performs very closely. Furthermore, we have developed a novel algorithm for guard interval adaptation based on BER estimation. In addition, this paper presents an analytical method to determine optimum BER threshold to use with adaptive guard interval algorithm. A throughput gain of 10 to 15 percent is observed with the ATM controller over conventional AMC based link adaptation scheme. Although the effect of ATM controller is evaluated for the IEEE 802.11n system, the same kind of controller could improve the performance of systems such as IEEE 802.11ac, ad, and other emerging wireless standards.

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