J. Basic. Appl. Sci. Res., 1(11)2041-2050, 2011

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Bandwidth Efficient Cross-Layer Design Using Truncated Hybrid ARQ Approach for Wimax Networks

Seyed Hossein Hosseini Nazhad Ghazani, Jalil Jabari Lotf

Department of Computer Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran
S.HosseiniNejad@iau-ahar.ac.ir , J-Jabbari@iau-ahar.ac.ir

ABSTRACT

This paper presents a cross-layer design of Adaptive Modulation and Coding (AMC) at the Physical layer with Truncated Automatic Repeat request (TARQ) and Truncated Hybrid Automatic Repeat Request (THARQ) at the Medium Access Control (MAC) layer, to increase the spectral efficiency under the prescribed quality-of-service (QoS) constraints. For adaptive transmission over the channel, the AMC mode is chosen with the minimum SNR among the users to guarantee the target performance of all users. In the meanwhile, the minimum SNR required to support an AMC mode is aggressively designed by allowing retransmission with HARQ schemes. For the proposed design, the performance measures like the average packet error rate, average number of transmission, spectral efficiency and outage probability are numerically obtained after analyis. Numerical results show that the cross-layer design provides a significant performance gain at a small number of retransmissions. In particular, it is observed that AMC design with HTARQ is more beneficial in the low SNR region than TARQ.

KEY WORDS: Cross-Layer, Automatic repeat request (ARQ), adaptive modulation and coding, outage probability.

1. INTRODUCTION

The rapid advancement in wireless over wired has augmented the need for improving the Quality of Service (QoS) over such wireless links. Such QoS guaranteed services are necessary for future wireless networks, including cellular networks, mobile ad hoc networks, and wireless sensor networks, e.g, IEEE 802.16, IEEE 802.11 and 802.15 standard wireless networks. Such networks are envisioned to support multimedia services with different QoS requirements. But these standards define only QoS architecture and signalling. But do not specify the scheduling algorithms that ultimately will provide QoS support.

Usually, multimedia applications can be classified into two categories: QoS-guaranteed and best-effort ones [1]. The first category includes voice (e.g., VoIP), video/audio streaming, video/audio telephony and conferencing; while applications such as web-browsing, e-mail and FTP belong to the second category. For QoS guarantees in high-rate multimedia applications, the scarcity of transmission capacity, multipath fading and Doppler effects are common challenges to most communication networks, may be civilian or military in which mobile devices communicate a wide range of information over wireless links. The “bottleneck” in such networks is the wireless link, not only because wireless resources (such as bandwidth and power) are more scarce and expensive relative to their wire line counterparts, but also because the overall system performance degrades markedly due to multipath fading, Doppler, and time-dispersive effects introduced by the wireless air interface.

Today’s society demands fast and reliable wireless radio communication and the radio spectrum grow more and more crowded as a consequence of this. More spectrally efficient transmission schemes are therefore called for, being able to transmit more bits per Hz bandwidth, can relieve the pressure on bandwidth resources. The performance of wireless links is degraded due to channel fading which limits the overall system throughput considerably relative to wire-line alternatives. To enhance the throughput in future wireless data communication systems, Adaptive Modulation and Coding (AMC) have been studied extensively and advocated at the physical layer, in order to match transmission rates to time-varying channel conditions. Further for mitigating channel fading through Automatic Repeat Request (ARQ) protocol at the data link layer, that request retransmissions for those packets received in error is considered [2,3] under WLAN settings based on IEEE 802.11 specifications. Since retransmissions are activated only when necessary, ARQ is quite

***Corresponding Author:** SeyedHossein HosseiniNazhadGhazani, Department of Computer Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran. E-mail: S.HosseiniNejad@iau-ahar.ac.ir

effective in improving system throughput relative to using only Forward Error Coding (FEC) at the physical layer. To minimize delays and buffer sizes in practice, truncated ARQ protocols have been widely adopted to limit the maximum number of retransmissions [2].

In this paper, there is a proposal to support the aforementioned services through the 802.16 standard. The observation from literature survey reveals that the enhanced throughput performance of 802.16 over 802.11. For Adaptive Modulation and Coding design the focus is on the single user case. For further performance enhancement, hybrid ARQ (HARQ) integrating the ARQ with channel coding could be applied at the cost of complexity [4,5]. Traditionally, the parameters of AMC and ARQ are designed separately to meet the requirement of the layer where each method is implemented. However, many recent works reveal that cooperation of two or more improves resource utilization. In particular, [6] has combined AMC and truncated ARQ by designing the SNR regions for AMC modes taking into consideration the effect of retransmission under the prescribed delay and error performance constraints. The work of [6] and [7] show that the cross-layer design approaches significantly improve the spectral efficiency.

In this paper, the AMC at the Physical Layer and truncated ARQ (TARQ) / truncated Hybrid ARQ (THARQ) schemes at the Data Link Layer together to maximize the spectral efficiency under prescribed delay and constrained error performance are considered. Depending on the error correcting capability of the ARQ schemes that depends on the maximum number of retransmissions, the AMC transmissions are designed to guarantee the required performance. The performance of the proposed cross- layer approach is analyzed and thus maximizes the average spectral efficiency.

The rest of the paper is organized as follows. We introduce the system and channel models in section II. We develop the cross layer design in section III, combining the AMC at the physical layer with ARQ at the data link layer in section IV, analytical procedure to investigate the performance of the combined queuing with AMC in section V, present the results in section VI and finally draw the concluding remarks in section VII.

2. SYSTEM MODEL

The wireless link from the access point to each wireless user in star topology is taken for implementing the proposed Cross-Layer scheduler. In this star network topology as in Fig.1, multiple subscriber stations are connected to the Base Station (BS) or relay station over wireless channels, where multiple connections (sessions, flows) can be supported by each Subscriber Station (SS) [8]. This kind of star topology is not only applicable to cellular networks but is also used to describe the connections between each relay station and multiple SS in mobile ad hoc networks and wireless sensor networks.

Fig.1 Wireless Network Model

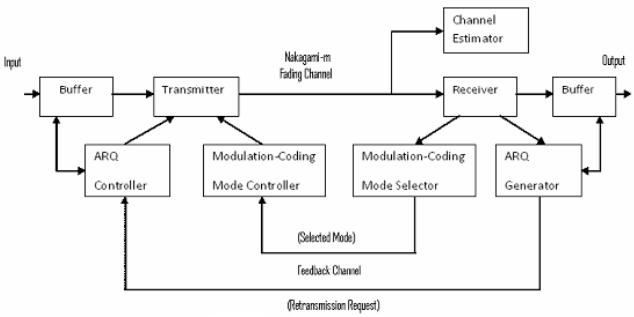

Fig .2 Wireless link model from BS to SS

As depicted in Fig.2, a finite-length queue (buffer) is implemented at the transmitter and operates in a first- in-first-out mode. The queue feeds the AMC controller at the transmitter. The AMC selector is implemented at the receiver similarly the transmitter and receiver involves the inclusion of ARQ controller and ARQ generator respectively thus enabling the selective repeat ARQ protocol at data link layer. At the wireless link (PHY), multiple transmission modes are available, with each mode representing a pair of a specific modulation format, and a Forward Error Correcting (FEC) code as in IEEE 802.11/15/16 standards. The AMC design considered assigns the exact mode based on channel estimation at the receiver. The AMC selector determines the modulation-coding pair (mode), which is sent back to the transmitter through a feedback channel, for the AMC controller to update the transmission mode as discussed in [8,9]. Coherent demodulation and Maximum Likelihood (ML) decoding are employed at the receiver. The decoded bit streams are mapped to packets, which are pushed upward to the data link layer.

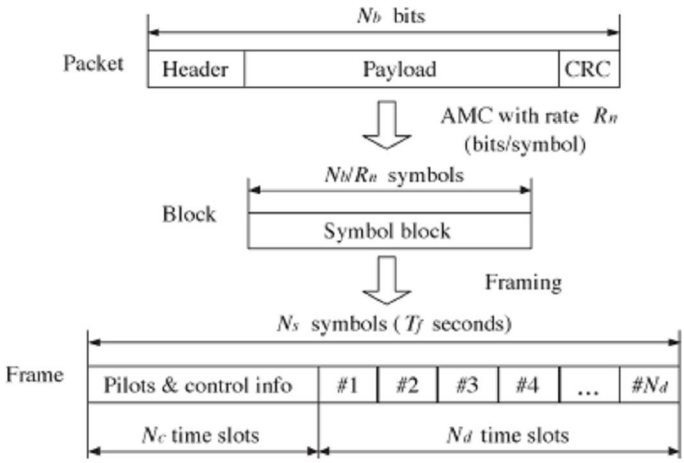

Fig.3 Processing units at MAC and PHY layers.

The layer structure of the system under consideration is shown in Fig.3. We assume multiple transmission modes are available, each representing a pair of a specific modulation format and forward error correcting code as in HIPERLAN/2 and IEEE 802.11a standards. Based on CSI estimated at the receiver, the AMC selects the modulation coding pair and transmits it to the AMC controller to update the transmission mode.

At the data link layer, the selective repeat ARQ protocol is implemented If an error is detected in a packet, a retransmission request is generated by the ARQ generator and is communicated to the ARQ At the physical layer the Convolution ally coded M*n*-ary rectangular or Square QAM modes, adopted from HIPERLAN/2 or IEEE 802.11a standards transmission modes are considered.

As in Fig.3, at the physical layer of the wireless link, the data are transmitted frame by frame, where each frame contains a fixed number of symbols (N_s) of duration (T_f) seconds. With Time Division Multiplexing (TDM), each frame is divided into $N_c + N_d$ time slots. The N_c time slots contain pilots and control information and the N_d time slots convey data, which are scheduled to different users with Time-Division Multiple Access (TDMA) dynamically [8]. For convenience, let each time slot contains a fixed number of N_b/R_1 symbols, where N_b denotes the number of information bits per packet and R_1 denotes the transmission rate with mode 1(QPSK modulation with coding rate of 1/2). Thus, each time slot can transmit exactly R_n/R_1 packets with transmission mode n. As per IEEE 802.16 specification, one time slot can accommodate 1 packet ($=R_1/R_1$) with mode n = 1, $R_2/R_1 = 2$ packets with mode $n = 2$ and so on. Each user is allocated a certain number of time slots per frame.

Some of the assumptions made in the simulation are:

1. The wireless channel quality of each connection remains constant per frame, but is allowed to vary from frame to frame. This corresponds to a fading channel model. Thus, AMC is implemented on a frame-by-frame basis [10].

2. Perfect Channel State Information (CSI) is available at the receiver. The corresponding transmission mode selection is fed back to the transmitter without error and with a zero delay . The assumption is that the feedback channel is error free.

3. Error detection based on CRC is perfect, provided that sufficiently reliable error detection CRC codes are used per packet.

4. If a packet is received incorrectly after error detection, packet loss is declared.

III. DESIGN OF AMC AT THE PHYSICAL LAYER

The maximization of data rate and efficient bandwidth utilization for a prescribed PER performance at the PHY layer can be accomplished with AMC schemes, which match transmission parameters to the time-varying wireless channel conditions adaptively [9] and have been used by many standard wireless network specifications, such as IEEE 802.11/15/16 [10]. Each connection with rtps, Nrtps, and BE services relies on AMC at the PHY layer. The objective of AMC is to maximize the data rate by adjusting transmission modes to channel variations while guaranteeing prescribed PER P_o, and the design procedure is similar to that proposed in [11,12].

Let N denote the total number of transmission modes available at the wireless link between BS and SS (say N=6 for IEEE 802.16). As in [11], constant power transmission is assumed and partition the entire Signal-to-Noise Ratio (SNR) range in N+1 non-overlapping consecutive intervals, with boundary points denoted as $\{\gamma_n\}_{n=0}^{N+1}$. In this case mode n is chosen when,

$$\gamma \in [\gamma_n, \gamma_{n+1}) \qquad \text{for } n = 1,2, \ldots ,N \tag{1}$$

To avoid deep-channel fades, no data are sent when $\gamma_0 \le \gamma \le \gamma_1$ which corresponds to the mode $n = 0$ with rate R_o =0 bit/symbol.

The design objective of AMC is to determine the boundary points $\{\gamma_n\}_{n=0}^{N+1}$. To simplify the AMC design, we approximate the PER expression in AWGN channels as

$$\mathrm{PER}_n(\gamma) \approx \begin{cases} 1, & \text{if } 0 < \gamma < \gamma_{pn} \\ a_n \exp(-g_n \gamma), & \text{if } \gamma \ge \gamma_{pn} \end{cases} \tag{2}$$

Where n is the mode index and γ is the received SNR. Parameters a_n, g_n, and γ_{pn} in (2) are mode-dependent and are obtained by fitting (2) to the exact PER via simulations presented in [13]. The mode fitting parameters for each transmission modes as per IEEE 802.11 and IEEE 802.16 are provided in Table I & II.

Table I: Transmission Modes specified in IEEE 802.11 standard

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Modulation	BPSK	QPSK	QPSK	16-QAM	16-QAM	**64-QAM**
Coding rate R_n	1/2	1/2	3/4	9/16	3/4	**3/4**
Rate(bits/sym)	0.50	1.00	1.50	2.25	3.00	**4.50**
a_n	274.7229	90.2514	67.6181	50.1222	53.3987	**35.3508**
g_n	7.9932	3.4998	1.6883	0.6644	0.3756	**0.0900**
γ_{pn}(dB)	**-1.5331**	**1.0944**	**3.9722**	**7.7021**	**10.2488**	**15.9784**

Table II: Transmission modes specified in IEEE 802.16 standard

MODE	**1**	**2**	**3**	**4**	**5**	**6**
Modulation	QPSK	QPSK	16QAM	16QAM	64QAM	**64QAM**
RS code	(32,24,4)	(40,36,2)	(64,48,8)	(80,72,4)	(108,96,6)	**(102,108,6)**
CC Code Rate	2/3	5/6	2/3	5/6	3/4	**5/6**
Coding rate	1/2	3/4	½	3/4	2/3	**5/6**
R_n(bits/symbol)	1	1.5	2	3	4	**4.5**
a_n	232.9242	140.7922	264.0330	208.5741	216.8218	**220.7515**
g_n	22.7925	8.2425	6.5750	2.7885	1.0675	**0.8125**
$\gamma_{pn}(dB)$	**3.7164**	**5.9474**	**9.6598**	**12.3610**	**16.6996**	**17.9629**

3. DESIGN OF ARQ SCHEMES AT THE DATA LINK LAYER

In this section, a cross layer design is developed by combining AMC at the Physical layer and TARQ / THARQ at the data link layer, for which the following delay constraints are adopted.

C1) The maximum number of retransmissions allowed per packet is $N_r^{\max}$. Since only finite retransmissions are allowed, error-free delivery cannot be guaranteed. If a packet is not received correctly after retransmissions, packet is dropped and packet loss is declared.

To maintain an acceptable packet stream the following performance constraints is adopted

C2) The probability of packet loss after $N_r^{\max}$ retransmissions is no larger than P_{loss} .

The delay constraint C1 dictates that truncated ARQ with up to $N_r^{\max}$ retransmissions should be performed at the data link layer. The special case with $N_r^{\max}$ =0 corresponds to no retransmission.

To satisfy C2 there is a need to impose

$$P_0 N_r^{\max} + 1 \le P_{loss} \tag{3}$$

From this it is possible to obtain $P_{t\arg et}$ as

$$P_0 \le P_{loss}^{\;N_r^{\max}+1} \tag{4}$$

Hybrid Automatic Repeat request (Hybrid ARQ or HARQ) is a variation of the ARQ error-control method. In standard ARQ, Error Detection (ED) information bits are added to the data to be transmitted (such as Cyclic Redundancy Check). In Hybrid ARQ, Forward Error Correction (FEC) bits are also added to the existing Error Detection (ED) bits (such as Reed Solomon or Turbo Code). As a result Hybrid ARQ performs better than ordinary ARQ in poor signal conditions.

4. PERFORMANCE ANALYSIS

In this section, the average PER and the spectral efficiency of the cross layer design along with the outage probability measures are derived. The joint effects of finite-length queuing along with AMC and ARQ schemes are analyzed.

The average PER is evaluated at the physical layer. According to AMC rule in (1), the transmission mode, and thus the instantaneous PER depend on the received SNR γ. Since $P_{t\arg et} < 1$ in general, then for the selected γ_{pn}, γ_{pn} will be less than γ_n .

Each mode n will be chosen with probability (cf. [8, eq. (34)])

$$P_r(n) = \int_{\gamma_n}^{\gamma_{n+1}} P_r(\gamma)\, d\gamma$$

$$= \frac{\Gamma(m, \frac{m\gamma_n}{\bar{\gamma}}) - \Gamma(m, \frac{\gamma_{n+1}}{\bar{\gamma}})}{\Gamma(m)} \tag{5}$$

Where *Γ(m,x)* is the complementary incomplete Gamma function.

Let $\overline{PER_n}$ denote the average packet error rate for mode *n* (the ratio of the number of incorrectly received packets over those transmitted using mode *n*). The $\overline{PER_n}$ can be obtained as

$$\overline{PER}_n = \frac{1}{P_n(n)} \int_{\gamma_n}^{\gamma_{n+1}} PER_n(\gamma) P_r(\gamma)\, d\gamma$$

$$= \frac{1}{P_r(n)} \frac{a_n}{\Gamma(m)} \left(\frac{m}{\bar{\gamma}}\right)^m \frac{\Gamma(m, b_n \gamma_n) - \Gamma(m, b_n \gamma_{n+1})}{(b_n)^m} \tag{6}$$

Where $b_n := \frac{m}{\bar{\gamma}} + g_n$.

The average PER of AMC can then be computed as the ratio of the average number of incorrectly received packets over the total average number of transmitted packets (cf. [8, eq.(34)]

$$\bar{PER}_n = \frac{\sum_{n=1}^{N} R_n P_r(n) PER_n}{\sum_{n=1}^{N} R_n P_r(n)} \tag{7}$$

Since truncated ARQ is implemented at the data link layer, the packets in error during the original reception may be retransmitted, up to a maximum of $N_r^{\max}$ times. The average number of transmissions per packet can be found as (cf.[8, p 397])

$$\bar{N}(\bar{PER}, N_r \max) = 1 + \bar{PER} + (\bar{PER})^2 + ------ + (\bar{PER})^{N_r}$$

$$= \frac{1 - (\bar{PER})^{N_r \max + 1}}{1 - \bar{PER}} \tag{8}$$

When mode n is used, each transmitted symbol will carry $R_n = R_c \log_2(M_n)$ bits of information for the mode adhering to Mn- QAM constellation and rate Rc FEC code. A Nyquist pulse shaping filter with bandwidth $B = 1/T_s$, where T_s is the symbol rate is selected. Therefore, the average spectral efficiency (bit rate per unit bandwidth) achieved at the physical layer without considering possible packet retransmission is

$$\bar{S}_{e,AMC\,only} = \sum_{n=1}^{N} R_n P_r(n) \tag{9}$$

When truncated ARQ is implemented, each packet and thus each information bit is equivalently transmitted $\bar{N}(\bar{PER}, N_r \max)$ times. So the overall average spectral efficiency is obtained as

In this section, the average PER and the spectral efficiency of the cross layer design along with the outage probability measures are derived. The joint effects of finite-length queuing along with AMC and ARQ schemes are analyzed.

The average PER is evaluated at the physical layer. According to AMC rule in (1), the transmission mode, and thus the instantaneous PER depend on the received SNR γ. Since $P_{t\arg et} < 1$ in general, then for the selected γ_{pn}, γ_{pn} will be less than γ_n .

Each mode n will be chosen with probability (cf. [8, eq. (34)])

$$P_r(n) = \int_{\gamma_n}^{\gamma_{n+1}} P_r(\gamma)\, d\gamma$$

$$= \frac{\Gamma\left(m, \frac{m\gamma_n}{\bar{\gamma}}\right) - \Gamma\left(m, \frac{\gamma_{n+1}}{\bar{\gamma}}\right)}{\Gamma(m)} \tag{5}$$

Where *Γ(m,x)* is the complementary incomplete Gamma function.

Let $\overline{PER_n}$ denote the average packet error rate for mode *n* (the ratio of the number of incorrectly received packets over those transmitted using mode *n*). The $\overline{PER_n}$ can be obtained as

$$\bar{PER}_n = \frac{1}{P_n(n)} \int_{\gamma_n}^{\gamma_{n+1}} PER_n(\gamma) P_r(\gamma) d\gamma$$

$$= \frac{1}{P_r(n)} \frac{a_n}{\Gamma(m)} (\frac{m}{\bar{\gamma}})^m \frac{\Gamma(m, b_n \gamma_n) - \Gamma(m, b_n \gamma_{n+1})}{(b_n)^m} \tag{6}$$

Where $b_n := \frac{m}{\bar{\gamma}} + g_n$.

The average PER of AMC can then be computed as the ratio of the average number of incorrectly received packets over the total average number of transmitted packets (cf. [8, eq.(34)]

$$\bar{PER}_n = \frac{\sum_{n=1}^{N} R_n P_r(n) PER_n}{\sum_{n=1}^{N} R_n P_r(n)} \tag{7}$$

Since truncated ARQ is implemented at the data link layer, the packets in error during the original reception may be retransmitted, up to a maximum of $N_r^{\max}$ times. The average number of transmissions per packet can be found as (cf.[8, p 397])

$$\bar{N}(\bar{PER}, N_r \max) = 1 + \bar{PER} + (\bar{PER})^2 + ------ + (\bar{PER})^{N_r}$$

$$= \frac{1 - (\bar{PER})^{N_r \max + 1}}{1 - \bar{PER}} \tag{8}$$

When mode n is used, each transmitted symbol will carry $R_n = R_c \log_2(M_n)$ bits of information for the mode adhering to Mn- QAM constellation and rate Rc FEC code. A Nyquist pulse shaping filter with bandwidth $B = 1/T_s$, where T_s is the symbol rate is selected. Therefore, the average spectral efficiency (bit rate per unit bandwidth) achieved at the physical layer without considering possible packet retransmission is

$$\bar{S}_{e,AMC\,only} = \sum_{n=1}^{N} R_n P_r(n) \tag{9}$$

When truncated ARQ is implemented, each packet and thus each information bit is equivalently transmitted $\bar{N}(\bar{PER}, N_r \max)$ times. So the overall average spectral efficiency is obtained as

$$\bar{S}_e(T_r \max) = \frac{\bar{S}_{e,AMC\,only}}{\bar{N}(P, N_r \max)}$$

$$= \frac{1}{\bar{N}(P, N_r \max)} \sum_{n=1}^{N} R_n P_r(n) \tag{10}$$

Each mode n will be chosen with the probability given by (5). From this the $\overline{PER_n}$ is derived using (6). The average PER is found using (7) which is the ratio of the average number of incorrectly received packets

over the total average number of transmitted packets.
The average number of transmissions per packet can be found as

$$N(P, N_r^{\max}) = 1 + P + P^2 + \cdots + P^{N_r^{\max}}$$

$$= \frac{1 - P^{N_r^{\max}} + 1}{1 - P} \tag{11}$$

With C1 and C2 satisfied, to evaluate the spectral efficiency,

$$\overline{S}_{e,Phy} = \sum_{n=0}^{N-1} R_n \Pr(n) \tag{12}$$

The overall spectral efficiency is obtained as

$$\overline{S}e,(N_r^{\max}) = \frac{\overline{S}_{e,Phy}}{N(P, N_r^{\max})} \tag{13}$$

The performance of the proposed work in terms of average spectral efficiency is shown in Fig. 4. It is understand from Fig.4 that the average spectral efficiency achieved using THARQ mechanisms is 4.5 bps / Hz at high SNR region of 23- 30 dB whereas TARQ achieves the same only when it gains 30 db SNR. At medium SNR region of 12 -23 dB, there is a moderate change of about 0.5 to 0.7 bps/Hz improvement in the spectral efficiency when using THARQ than TARQ.

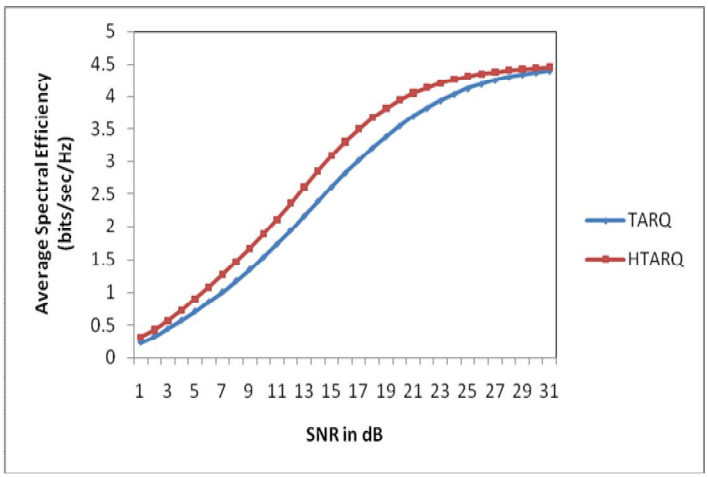

Fig.4 Performance measure when number of retransmissions allowed, $N_r^{\max} = 3$.

The performance in terms of Outage Probability can also be discussed. It is the probability that an outage will occur within a specified time period. In fading channels, the received signal has no constant power which is depending on the channel, can be described by probability models. Thus, signal to noise ratio will also become a random variable and thus the maximum capacity of the channel also becomes a random variable. Outage probability says according to the variable signal to noise ratio at the received end, what is the probability that a rate is not supported due to variable signal to noise ratio.

The outage probability is a performance metric for the channel. It gives the information about the capacity or throughput of data that can be transmitted through the channel due to noise and fading assuming to have a low-level margin for signal to noise ratio. The signal outage occurs if the signal drops below the noise power level. From fig.5, it is understand that the proposed THARQ scheme is more suitable for Wimax applications than for WLAN applications. The outage deviation for these networks from the simulation found to be 0.45.

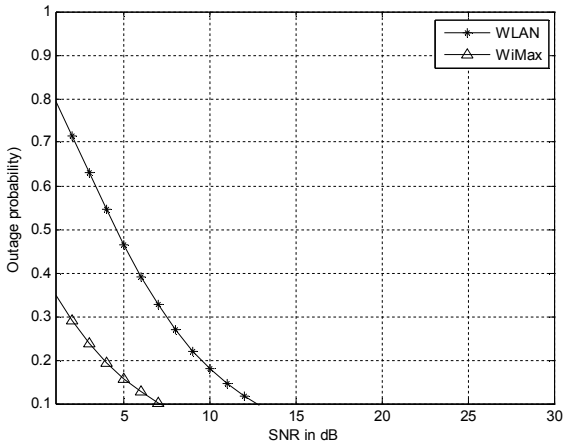

Fig.5 Outage probability performance

5. **Conclusions**

In this paper, we developed cross-layer design, which combines adaptive modulation and coding at the physical layer with Truncated ARQ (TARQ) and Trundated Hybrid ARQ (THARQ) at the data link layer, in order to maximize system throughput and Spectral Efficiency under prescribed packet error rate and delay constraints. Numerical results demonstrated the rate improvement of our cross-layer design over AMC alone, as well as TARQ / THARQ with fixed modes. Retransmissions alleviate stringent error-control requirements on modulation and coding, and bring considerable spectral efficiency gain.Thus sharing knowledge about layer state and conditions proved to be a promising paradigm for performance optimization in wireless systems. Also the performance is analyzed in terms of outage probability measure. In our work, providing knowledge about channel conditions like SNR from PHY and target error rate and delay requirement fixing at the MAC between each other to improve efficient utilization of bandwidth is proved.

REFERENCES

[1] S.Shakkotai, T.S.Rappaport and P.C.Karlsson, " 3Cross-layer design for wireless networks," IEEE Communication Magazine, vol.41, no.10, pp.74-80, Oct.2003.

[2] Q. Liu, S. Zhou, and G. B. Giannakis, "Cross-layer combining of adaptive modulation and coding with truncated ARQ over wireless links," *IEEE Trans. on Wireless Commun.*, vol. 3, no. 5, pp. 1746-1755, Sept. 2004.

[3] Q. Liu, S. Zhou, and G. B. Giannakis, "Queuing with adaptive modulation and coding over wireless links: cross-layer analysis and design," *IEEE Trans. on Wireless Commun.*, 2005.

[4] E.Hossain and V.K.Bhargava, " Link level traffic scheduling for providing predictive QoS in wireless multimedia networks," IEEE Trans. Multimedia, vol.6, no.1, pp.199-217, Feb.2004.

[5] M.-S. Alouini and A.J. Goldsmith, "Adaptive modulation over Nakagami fading channels," Kluwer J. wireless Commun., vol.13, no. 1-2, May 2000.

[6] E. Malkamaki and H. Leib, "Performance of truncated type-II hybrid ARQ schemes with noisy feedback over block fading channels," IEEE Trans. Commun., vol. 48, sept. 2000.

[7] F. Frederiksen and T. E. Kolding, "Performance and modeling of WCDMA/HSDPA transmission/H-ARQ schemes," *Proc. IEEE VTC,* vol. 1, pp. 472-476, Vancouver, Canada, Sep. 2002.

[8] Q. Liu, S. Zhou, and G.B. Giannakis, "cross-layer combining of adaptive modulation and coding with truncated ARQ over wireless links," *IEEE Trans. Commun.*, vol. 3, pp. 1746-1755, Sept. 2004.

[9] S. H. Park, J. W. Kim, and C. G. Kang, "Design of adaptive modulation and coding scheme for truncated HARQ," *ISWPC,* Feb. 2007.

[10] A.J.Goldsmith and S.G.Chua, "Adaptive coded modulation for fading channels", IEEE Transaction Communication, vol.47,pp.595-602,May1998.

[11] Qingwen Liu, Shengli Zhou, Georgios B. Giannakis, "Cross-Layer Scheduling with Prescribed QoS Guarantees in Adaptive Wireless Networks," IEEE journal on selected areas in communications, vol.23, no.5, pp-1056-1066, May 2005.

[12] Qingwen Liu, Shengli Zhou, Georgios B. Giannakis, "Cross-Layer Modeling of Adaptive Wireless Links for QoS Support in Heterogeneous Wired-Wireless Networks". Wireless Networks, Vol. 12, No. 4. pp. 427-437, Aug. 2006.

[13] Qingwen Liu, Xin Wang, and Georgios B. Giannakis, "A Cross-Layer Scheduling Algorithm With QoS Support in Wireless Networks," IEEE Transactions on Vehicular Technology. vol. 55, no. 3, pp-839-43, May 2006.