Dynamic Rate Adjustment (DRA) Algorithm for WiMAX Systems Supporting Multicast Video Services

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Abstract. This paper presents a dynamic rate adjustment (DRA) algorithm for WiMAX systems supporting multicast services. A scalable video coder with layered coding capability is assumed to be used to encode the multicast video information as a single base layer and multiple enhancement layers. The DRA algorithm first determines the portion of the base layer according to the QoS requirement of the multicast video service. It then dynamically adjusts the remaining portions of the enhancement layers to maximize the average throughput of the cell. In this paper, an analytical solution is presented to determine the best portions of the enhancement layers based on the estimated users' signal-to-noise-ratio (SNR). The accuracy of the analysis is verified via simulations. Simulation results indicate that DRA always achieves a higher average throughput than that of either uniform allocation algorithm or location-based allocation algorithm.

Keywords: multicast video services, scalable video coding, WiMAX

1 Introduction

In recent years, broadband and wireless are two of the key technologies that lead to the remarkable growth of the telecommunications industry. Many industry observers believe that to combine the convenience of wireless with the rich performance of broadband will be the next frontier for growth in the industry. IEEE 802.16, which is also known as WiMAX, is one of the air interface standards designed for offering broadband wireless access services in a metropolitan area network (MAN) [1]. With WiMAX, end users are expected to be able to enjoy multimedia applications, such as real-time audio and video streaming, multimedia conferencing, and interactive gaming, in a more flexible manner (i.e., anytime and anywhere).

Currently, most of the network operators use their network resource to provide point-to-point services. However, there is a strong interest for them to offer multicast and broadcast services (MBS) over their broadband wireless access networks. The MBS allow unidirectional point-to-multipoint transmission of multimedia data (e.g. text, audio, picture, video) from a single source point to a multicast group in a multicast area. Normally, users are expected to be charged for subscribing these multimedia services and thus, they may demand for a certain level of quality of service (QoS). In MBS, there may be only two or hundreds of users that simultaneously subscribe the same service from the same base station (BS). Hence, from the profit point of view, the network operator may try to accommodate more users at the same time since a single copy of the MBS packets need to be transmitted. However, users at different locations may experience wireless channel errors at the same time. The network operator has to reserve extra radio resource in order to guarantee the QoS for users with bad channel condition. Therefore, from the spectral-efficiency point of view, the network operator may reject some service requests from users with bad channel conditions. Hence, one of the challenges for MBS is to achieve both high transmission efficiency and good scalability (with respect to number of users) [2].

The wireless channel error is characterized as bursty and location-dependent. Hence, users at different locations may observe different channel states at the same time [2]. In IEEE 802.16, techniques of automatic repeat request (ARQ) and adaptive modulation and coding (AMC) are supported to combat these wireless channel errors. ARQ is a packet re-transmission technique to achieve reliable data transmissions at the link layer. ARQ-enabled connections require each transmitted packet to be acknowledged by the receiver; unacknowledged packets are assumed to be lost and are retransmitted. In [2], the authors proposed an ARQ-based method to combat with wireless channel errors for video multicast service over WLAN. However, these methods are not applicable in WiMAX since IEEE 802.16 [1] does not support ARQ for their multicast connections. The ARQ-based approaches have the following disadvantages. First, either BS should reserve dedicated resource or the users may contend with each other to send negative acknowledgments (NACKs) in uplink. The reservation may waste network resource and the contention may cause unnecessary latency. Second, the sender may have to re-transmit the same packet multiple times if it receives multiple NACKs from different receivers. The implosion of NACK may reduce the transmission efficiency.

AMC is another effective mechanism to maximize throughput at the physical layer under a time-varying channel. IEEE 802.16 supports a number of modulations and forward error correction (FEC) coding schemes. IEEE 802.16 allows the AMC scheme to be changed on a per-user and per-frame basis based on the reported channel qualities [3]. The adaptation algorithm typically uses the highest modulation and coding scheme that can be supported by the signal-to-noise ratio (SNR) at the receiver such that each user is provided with the highest possible data rate in its respective link. AMC relies on instantaneous channel measurement of MS's uplink signal strength and thus, is not suitable for unidirectional multicast connections. With AMC, the BS shall reserve extra dedicate uplink resource for users to report their channel qualities. Even though, it is not easy for the BS to decide the best modulation and coding scheme for the multicast packets based on multiple channel feedbacks sent by users at different locations (i.e., a decision that favors users with good SNRs may not be proper for users with poor SNRs and vice versa).

Recently, many advanced video encoding techniques have been developed. Among them, the scalable video coding offers the users with capability of reconstructing lower resolution or lower quality signals from partial bit streams. This allows network providers with simple solutions in adaptation to network and terminal capabilities [3]. For example, MPEG-2 has implemented the layered coding, where video information is encoded as a single base layer (BL) and multiple enhancement layers (ELs). The standalone availability of enhancement information (without the BL) is useless, because differential encoding is performed with reference to the BL [4]. With scalable video coding, the network operators may utilize different AMC modes to protect the BL and ELs of the multicast video. Therefore, we may guarantee a minimum level of video quality for users with poor SNRs while offering better video quality for users with good SNRs.

This paper focuses on the radio resource allocation issue of wireless video multicast services adapting scalable video coding. A dynamic rate adjustment (DRA) algorithm is proposed to determine the best modulation and coding scheme for transmitting the BL and EL(s) portions of the multicast video. The rest of the paper is organized as follows. The system model adopted by this paper is described in Section 2. Section 3 presents the details of the proposed DRA algorithm. Section 4 presents the simulation results. Conclusions and future work are finally drawn in Section 5.

2 System Model

IEEE 802.16 standard families support several physical layers. For operational frequencies between 10-66 GHz, the physical layer of single-carrier modulation (SC) is supported. For frequencies below 11GHz, where propagation without a direct line-of-sight (LOS) must be accommodated, three alternatives physical layers are provided: single-carrier modulation (SCa), frequency-division multiplexing (OFDM), orthogonal frequency-division multiple access (OFDMA). In this paper, OFDM physical layer is utilized as an example and the results can be easily extended to other physical layers. Table 1 summarizes the SNR requirements and the data rates for various combinations of modulation and coding scheme in the IEEE 802.16 OFDM physical layer [1].

	Coding rate	SNR requirement (dB)	Data rate (Mbps)
BPSK	1/2	6.4	2.5
QPSK	1/2	9.4	5
QPSK	3/4	11.2	7.5
16QAM	1/2	16.4	10
16QAM	3/4	18.2	15
64QAM	2/3	22.7	20
64QAM	3/4	24.4	22.5

Table 1. The SNR requirements and the data rates supported by IEEE 802.16 OFDM

The system model adopted in this paper is shown in Fig. 1, in which a single cell comprising one BS and multiple subscriber stations (SSs) is considered. In this paper, *n* modes of modulation and coding schemes of the OFDM physical layer, which are referred as AMC modes herein, are used to transmit the layered coding of multicast video packets as an example. In this paper, $n = 4$ is assumed and the chosen AMC modes include BPSK with coding rate 1/2; QPSK with coding rate 1/2; 16QAM with coding rate 1/2, and 64QAM with coding rate 2/3. Conceptually, the cell can be divided into n non-overlapping areas based on the SNR requirements of the four AMC modes. Let the number of SSs that use AMC modes of 64QAM, 16QAM, QPSK, and BPSK be N_1, N_2, N_3, and N_4, respectively. Note that, N_1, N_2, N_3, and N_4 can be estimated based on the signal qualities of SSs measured during periodic ranging.

Let θ be the percentage of BL in the encoded multicast video. Note that, θ can be determined, for example, based on the basic QoS requirement of the perceived multicast video. It is assumed that BS uses the most robust AMC mode (i.e., BPSK) to transmit the BL portion of the multicast video such that the BL can be correctly received by all SSs in the cell. This assumption ensures that basic QoS of all SSs in the cell can be guaranteed. It is further assumed that the EL generated by the scalable video coder contains (n-1) portions and the percentage of each portion can be adjusted by BS during runtime [5]. Let α, β, and γ be the percentage of the three portions of EL, respectively, as illustrated in Fig. 2. Note that, $\alpha + \beta + \gamma = 1-\theta$ and the standalone availability of higher part of the EL (e.g., α portion) is useless because differential encoding is performed with reference to the lower parts of the ELs (i.e., β, and γ portions) [4]. In this paper, BS shall transmit the α, β, and γ portions of EL using AMC modes of 64QAM, 16QAM, and QPSK, respectively.

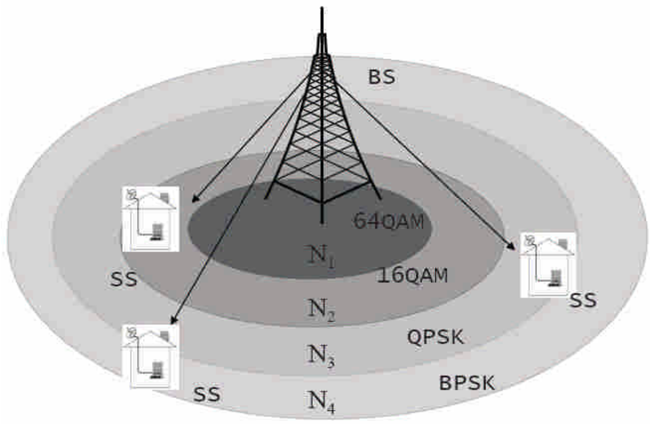

Fig. 1. Multicast system architecture

In this paper, the *average throughput* and *the net profit of the cell* are chosen to be the two key performance indexes for a multicast video service. The definition of the two parameters is given as below:

$$\text{Average throughput} = \frac{D_R}{T \times N_S} = \frac{\left(\sum_{i=0}^{N_S} (P_B D_T + P_{E,i} D_T) \right)}{T \times N_S}, \tag{1}$$

and

$$\text{Net profit} = \text{Total revenue - Total cost} = \left(\sum_{i=0}^{N_S} (P_B D_T + P_{E,i} D_T) \right) \times C_d - TC_a, \tag{2}$$

where D_R is total amount of data received by all SSs; T is total transmission time required to transmit the BL and EL of the multicast video; N_S is the total number of SSs (i.e., N_S=N_1+N_2+N_3+N_4); $P_B D_T$ is the percentage of the data coded by BL, which is common for all SSs; $P_{E,i}$ is the EL percentage received by the i-th SS; D_T is total transmission data amount; C_d is the profit received for a unit data volume of the multicast video, and C_a is the cost required for a unit air time.

The main focus of the paper is to maximize the average throughput and the total profit of the cell by adjusting α, β, and γ.

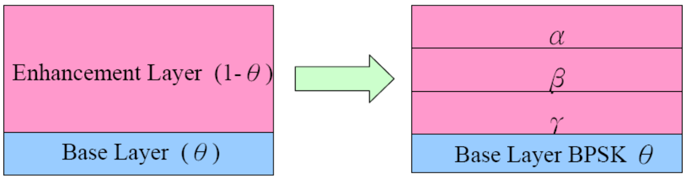

Fig. **2**. Multicast system architecture

3 DRA

In this section, the proposed DRA algorithm is introduced.

The average throughput of the cell defined in Eq. (1) can be written as a function of α, β, and γ, which is given by

$$\text{Average throughput} = \frac{\theta(N_1+N_2+N_3+N_4)+\gamma(N_1+N_2+N_3)+\beta(N_1+N_2)+\alpha N_1}{(\frac{\theta}{2.5}+\frac{\gamma}{5}+\frac{\beta}{10}+\frac{\alpha}{20})\times(N_1+N_2+N_3+N_4)}. \tag{3}$$

The maximization of Eq. (3) is a linear fractional programming problem [6] for given constants N_1,N_2, N_3, N_4, and θ. By theory of linear programming, if optimal solution of linear programming exists, optimal solution might be on the boundary of feasible region (especially on the apex of feasible region) [7], as shown in Fig. 3. The boundary of feasible region is given by the equations of $\alpha+\beta=1\text{-}\theta$, $\alpha+\gamma=1\text{-}\theta$, and $\beta+\gamma=1\text{-}\theta$. It can be shown that extreme value of Eq. (3) is given by

$$\begin{cases} \alpha = 0, \beta = 0, \gamma = 1-\theta, \text{ if } \theta > \dfrac{N_1+N_2-N_3}{2N_3-N_4}, \\ \alpha = 0, \beta = 1-\theta, \gamma = 0, \text{ if } \dfrac{N_1-N_2}{6N_2-N_3-N_4} < \theta < \dfrac{N_1+N_2-N_3}{2N_3-N_4}, \\ \alpha = 1-\theta, \beta = 0, \gamma = 0, \text{ if } \dfrac{N_1-N_2}{6N_2-N_3-N_4} > \theta. \end{cases} \quad (4)$$

Normally, the net profit defined in Eq. (2) will be maximized when the average throughput of the cell reaches its maximum. However, the net profit could become negative if the air time cost factor C_a is relatively higher than that of the subscription fee factor C_d (e.g., the cell is almost fully loaded). In this case, the best strategy is to send BL only. Figure 4 shows that case that the net profit may become negative when the air time cost is relatively high or the total number of SSs subscribing the multicast video service is relatively small.

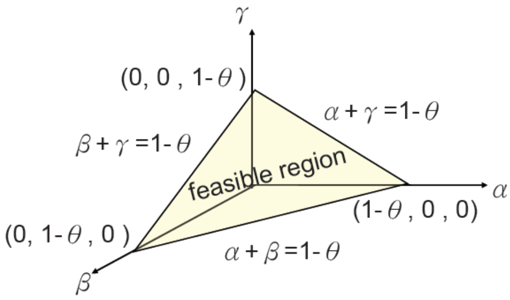

Fig. 3. Feasible region.

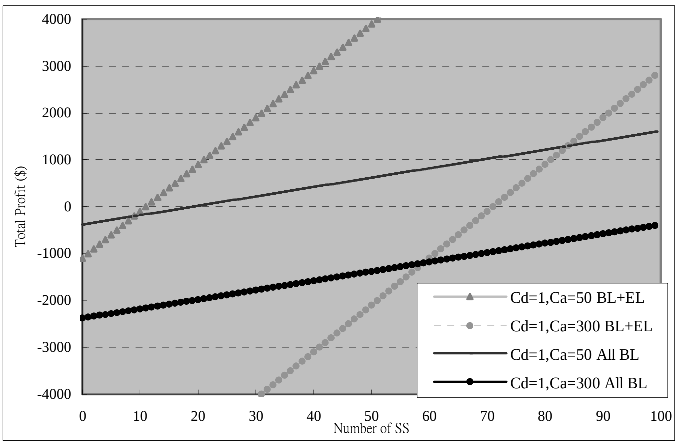

Fig. 4. Net profit with various number of SSs.

The proposed DRA algorithm is executed as follows. Initially, the BS has to determine the BL percentage of the multicast video, θ, based on basic QoS requirement of the given video multicast service. The BS then estimates the number of SSs in each non-overlapping area, N_1, N_2, N_3, and N_4, according to the SNR estimated during network entry. With N_1, N_2, N_3, and N_4, the BS will determine three portions of EL, α, β, and γ, according to Eq.(4) and transmit these portions using AMC modes of 64QAM, 16QAM, and QPSK, respectively. Note that, the BS may decide not to transmit the EL part if the air time cost is relatively high. In other words, Eq.(2) must be kept non-negative.

4 Simulation Results

In this section, the numerical analysis is first verified by the simulation and the effectiveness of the proposed algorithm is illustrated. In the simulation, a single cell with radius r = 3.4 km was assumed. A transmission bandwidth of 6 MHz operating in 3.5 GHz band was investigated. The channel model of ECC-33 was used, in which the BS transmission power of 43 dBm; BS antenna height of 17 m, and SS antenna height of 10 m, were assumed [8]. With these setting, the path loss from the BS to a given SS can be calculated and the SNR experienced by the SS can be easily obtained. The population of N_1, N_2, N_3, and N_4 can then determined according to the SNR requirement of the four AMC modes. In the following examples, the simulation results of the proposed DRA algorithm are all coincided with the numerical analysis.

In the first simulation, SSs were uniformly distributed within the cell. Figure 5 shows the average throughput of the cell using different rate assignment algorithms for θ =0.2. Two rate assignment algorithms were chosen as the benchmarks. The first algorithm, which is referred as the uniform allocation algorithm herein, assigns the portions of EL uniformly. That is, $\alpha=\beta=\gamma=(1-\theta)/3$. The second algorithm, which is referred as the location-based allocation algorithm, assigns the portions of EL based on the number of SSs in the non-overlapping areas, which gives $\alpha=\frac{N_1(1-\theta)}{N_1+N_2+N_3}$, $\beta=\frac{N_2(1-\theta)}{N_1+N_2+N_3}$, and $\gamma=\frac{N_3(1-\theta)}{N_1+N_2+N_3}$. From Eq. (4), it can be found that the average throughput of the cell reaches its maximum when $\alpha=0,\beta=0,\gamma=1-\theta$. That it, BS shall transmit the BL and EL with BPSK and QPSK, respectively. It is shown in Fig. 5 that DRA achieves the maximum average throughput for different N_s, which verifies the numerical analysis.

Figure 6 shows the case that the distance between each SS and BS is uniformly distributed for θ =0.3. It can also be found that DRA achieves the highest average throughput of the cell compared with uniform allocation and location-based allocation algorithms.

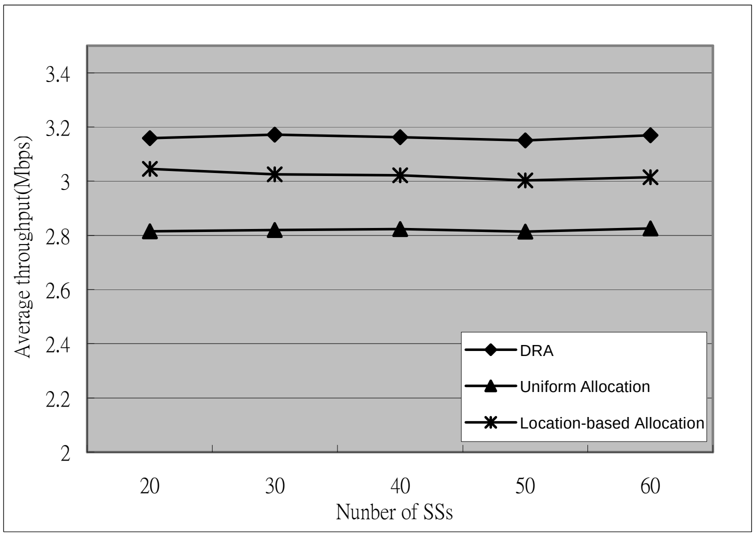

Fig. 5. The average throughput of the cell for uniformly distributed SSs.

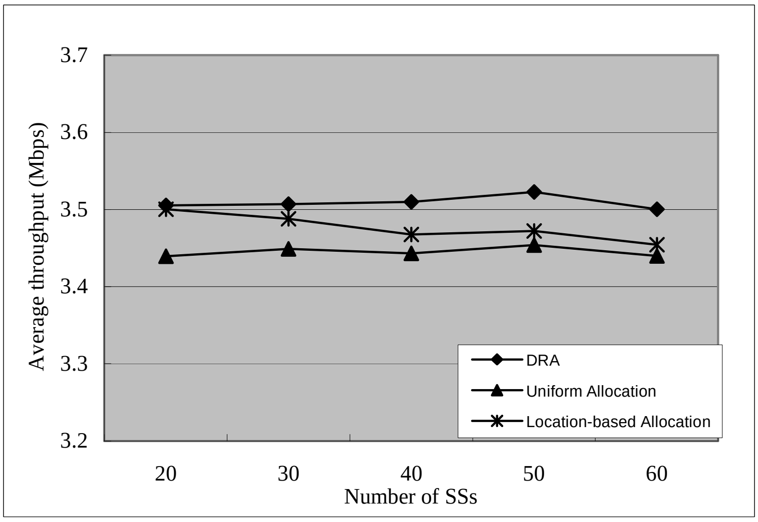

Fig. 6. The average throughput of the cell for uniformly distributed distance.

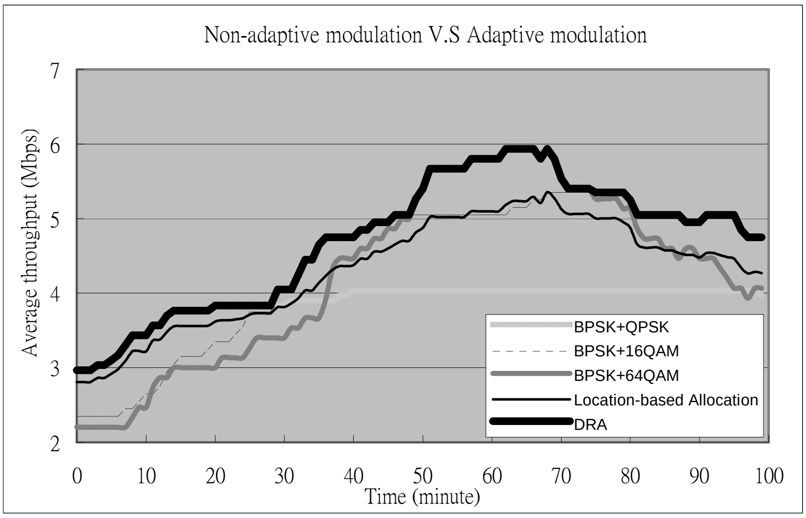

Fig. 7. Average throughput of the cell for mobile SSs.

Although the DRA algorithm is designed for fixed SSs, the results can be extended to accommodate mobile SSs assuming the location of SS can be monitored by BS through, for example, periodic ranging. The BS will utilize DRA to dynamically adjust the AMC mode based on the estimated N_1, N_2, N_3, and N_4 obtained in each reporting interval. The simulation result is illustrated in Fig. 7. In the simulation, each SS was assumed to move toward BS in first 50 minutes and then moves away from BS in next 50 minutes. The total simulation time was 100 minutes. Initially, Ns was set to 50 and is uniformly distributed in the cell; the velocity of each SS was uniformly distributed from 0 to 1 m/s. θ= 0.2 and the periodic ranging interval of 1 minute were assumed. In Fig. 7, the dotted line represents the AMC mode decided by DRA. It can be found that the proposed DRA algorithm can always achieve the maximum throughput regardless of the location distribution of SS. In the figure, DRA chooses BPSK+QPSK as the best AMC mode at the beginning since the number of SS is uniformly distributed within the cell. As time went by, the SS moved toward BS, which resulted in increased N_1 and reduced N_4. Hence, the best AMC mode changes to BPSK+64QAM. After 50 minutes, all SSs moved away from BS, which changed the AMC mode to be BPSK+16QAM and then BPSK+QPSK, consequently.

5 Conclusion

This work presented the DRA for WiMAX systems supporting video multicast services. A layered coding scheme is chosen to encode the multicast video information into one BL and three ELs. The portion of the BL is suggested to be determined based on the QoS requirement of the multicast services. A DRA algorithm is then proposed to allocate the three portions of EL in order to maximize the average throughout of the cell. An analytical method is presented to calculate the three portions of ELs and the accuracy of the analysis is verified via simulations. Simulation results indicate that DRA achieves a higher average throughput than that of either location-based allocation algorithm or uniform allocation algorithm.

Acknowledgments. This work was supported in part by National Science Council, Taiwan, under Contract No. NSC 96-2219-E-011-005, 96-2219-E-011-007, and 95-2218-E-011-008, and by BenQ Inc. under Contract No. 0247.

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