H.264 Video Delivery over Wireless Mesh Networks Based on Joint Adaptive Cross-Layer Mapping and MDCA MAC

Byung Joon Oh[1] and Ki Young Lee[2]

[1] Dept. of Engineering, Link Communications, Ltd., Annapolis Junction, MD 20701, USA
byungjoonoh@lnkcom.com
[2] Dept. of Info and Telecom Engineering, University of Incheon, Incheon 406-749, Korea
kylee@incheon.ac.kr

Abstract. This paper presents a QoS-guaranteed transmission of H.264 video over Wireless Mesh Networks (WMNs) based on an adaptive cross-layer mapping of IEEE 802.11e MAC strategy. We call this MDCA (Mesh Distributed Channel Access) MAC strategy as it is based on 802.11e standard with adaptive mechanism in response to dynamic nature of mesh networks. This novel MDCA strategy employs the channel reservation control packets at the MAC layer to exchange timely Channel State Estimation information for an optimal FEC at the application layer as well as the QoS-centric GEDSR model [1] for an optimal adaptation. The proposed scheme offers an optimized transmission to guarantee the minimum packets delay and drop rate needed for video over WMNs. In this research, we resolve the problem associated with 802.11e standard by designing an integrated scheme that allows the system to achieve the optimal transmission via a FEC implemented in the application layer. We evaluate the proposed scheme based on network-level metrics, including bit rate, packets delay and drop rates in comparison with the static cross-layer mapping scheme based on 802.11e WMNs. We can confirm that the adaptive cross-layer mapping strategy MDCA outperforms the static cross-layer mapping scheme by a significant margin.

1 Introduction

In recent years, WMNs have gained massive research interest [2]-[5]. Due to their fast configuration and low cost, they can be easily deployed for multimedia delivery, such as IPTV, VOD, and mobile digital video recorder systems [3]. However, it is difficult to guarantee the QoS for video streaming over WMNs because of their dynamic nature. In particular, the QoS issue has not yet been adequately investigated based on the recently finalized H.264 video coding standard [4]-[7]. Therefore, there are still several research challenges that need to be addressed in all protocol layers such as physical layer[1] and MAC [5][7][11][12], network and transport layer [8], application layer [1], and cross-layer design [8]-[10] for WMNs to support H.264 video streaming applications. The issue of QoS has been addressed in WMNs applications. Shen et al. proposed in [5] an admission control based on available bandwidth estimation for WMNs. It was shown that admission control algorithm at the MAC layer

J.J. Park et al. (Eds.): GPC 2013, LNCS 7861, pp. 846–853, 2013.

could resolve the QoS issue for both real-time and non-real-time traffic. However, they considered only throughput, delay, and jitter, not packet loss rate which is crucial QoS factors that significantly affect the performance of video streaming [10]. In [7], an Enhanced Distributed Channel Access scheme with resource reservation (EDCA/RR) that provides deterministic, contention-free medium access is proposed. However, only the QoS of EDCA/RR MAC, not the QoS of video streaming is studied. In [2], we addressed the network-level performances including throughput, packet loss rate and delay for robust H.264 video transmission over WMNs. We developed an Opportunistic Multi Rate MAC that can be viewed as static cross-layer framework without adaptation. Two key innovations of the proposed joint adaptive scheme are: (1) a novel MDCA (Mesh Distributed Channel Access) scheme based on 802.11e standard of MAC layer [11] and (2) an adaptive FEC implemented in application layer based on effective QoS (GOP-level Estimation Decodable Slice Rate (GEDSR)) Model [1]. Based on channel state estimation and GEDSR model, the joint adaptation based on MDCA and adaptive FEC is designed to improve the quality of the link under error-prone transmission conditions. We apply an unequal error protection for H.264 video traffic through an adaptive cross-layer mapping strategy in order to dynamically adapt Access Category (AC) [10]. This adaptive strategy is able to overcome unnecessary transmission delays and packet losses as we encountered in static cross-layer mapping in [2].

2 Architecture of Adaptive Cross-Layer Mapping Strategy

2.1 Analysis of Adaptive Cross-Layer Mapping Scheme

As MDCA supports different precedence AC queues according to video coding significance, encoded H.264 data is also allocated accordingly. When the mapping scheme is static and non-adaptive, the video data mapped to lower priority AC such as AC[1] and AC[0] may cause packet loss and unnecessary transmission delays even when the network load is light. Therefore, when the AC[2] queue is empty (which indicates the video traffic load is light), the static mapping algorithm will lead to high packet losses as well as unnecessary transmission delays if both AC[1] and AC[0] are almost full simultaneously. Figure 1 illustrates the proposed architecture for adaptive cross-layer mapping policy.

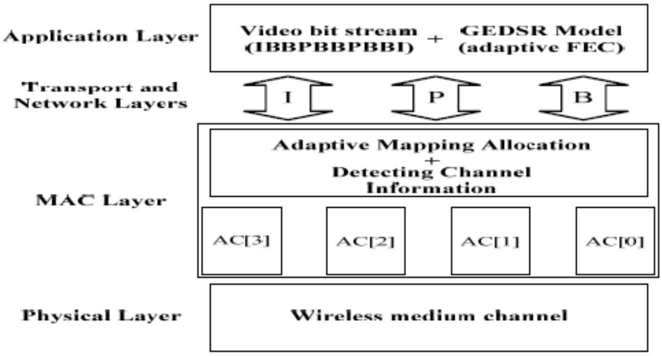

Fig. 1. Architecture of Adaptive Cross-layer Mapping Scheme

Based on the significance of video type and the current load of network traffic, the proposed mapping algorithm dynamically distributes the video data into the most appropriated AC so as to guarantee the QoS metrics as well as the visual quality of delivered video at the MAC layer. At 802.11e MAC layer, we allocate an important video data (I-slice) into higher priority AC queue and we defined different mapping probabilities as *P(Type)* to different video slice types according to its coding significance. Less important video slice types will be assigned larger *P(Type)*.Therefore, for H.264 codec, the downward mapping probability relationship of these three video slice types is $P(B)>P(P)>P(I)$, and these probabilities are between 0 and 1. When transmitted over an 802.11e WMNs, H.264 video packets are placed in AC[2] category will have better opportunity to admit to the channel than lower priority ACs. The proposed mapping algorithm reschedule most recently received video packets into other available lower priority queues, while the AC[2] queue is getting filled. To predicatively avoid the upcoming congestion by performing a queue supervision in advance, we define two parameters, $Threshold_{low}$ and $Threshold_{high}$. To incorporate these two parameters into the algorithm, the integrated function will be:

$$P(New) = P(Type) \times \frac{Qlen_{AC[2]} - Threshol_{low}}{Threshold_{high} - Threshold_{low}} \tag{1}$$

The original predefined downward mapping probability of each type of video slice in this equation *P(Type)* will be adjusted according to the current queue length and threshold values. The result is a new downward mapping probability *P(New)*. The higher the value of *P(New)*, the greater the chance for a packet to be mapped into a lower priority queue. Table 1 presents the notations used in the proposed adaptive cross-layer mapping algorithm.

Table 1. Parameter Notations in Proposed Adaptive Mapping Algorithm

Term	Definitions
$P(Type)$	Download mapping probability of each type video packet ($P(I)$, $P(P)$, $P(B)$)
$P(New)$	New computed downward mapping probability
$Threshold_{low}$	The lower threshold of queue length
$Threshold_{high}$	The lower threshold of queue length
$Qlen_{AC[2]}$	The queue length of Access Category 2

The pseudo code of mapping policy is shown in Figure 2. When a video packet arrives, the queue length of AC2 ($Qlen_{\mathrm{AC[2]}}$) is checked. If the queue length is lower than the lower threshold value, $Threshold_{low}$ (light load), the video data is mapped into AC[2]. However, if the queue length is greater than the upper threshold value, $Threshold_{high}$ (heavy video traffic load) the video data is straightforwardly mapped to lower priority queues, AC[1] or AC[0]. However, when the queue length of AC[2] decreases between $Threshold_{high}$ and $Threshold_{low}$, the mapping decision is made based on both mapping probability (*P(Type)*) and the current buffering size of the queue as given by (1). Hence, based on the estimated downward mapping probability, the video data packet will be mapped to either AC[2], AC[1] or AC[0]. By exploiting such a priority scheme and queue length management strategy of MDCA MAC, the video transmission is prioritized and the drop rate of video can be minimized to enable efficient utilization of network resources.

```
When a video data slice arrives:
If (Qlen AC[2]  < Threshold low )
     Video packet → AC[2];
Else if (Qlen AC[2]  < Threshold high ) {
          $P(New) = P(Type) \times \frac{Qlen_{AC[2]} - Threshol_{low}}{Threshold_{high} - Threshold_{low}}$
RN = a random number generated from Uniform function (0.0, 1.0);
If (RN > P(New) )
                Video slice → AC[2];
Else
                Video slice → AC[1];
}
Else If(Qlen AC[2]  > Threshold high ) {
                If(RN > P(Type) ) {
                Video slice → AC[1];
                Else
                Video slice → AC[0]; }
```

Fig. 2. The Proposed Adaptive Cross-Layer Mapping Strategy

2.2 GEDSR Model for Adaptive FEC

To characterize and estimate the dependence and sensitivity of video streams, we adopt the GEDSR model. This is a network-level metric and is defined as the fraction of decodable slice rate, which is the total number of decodable slices over the total number of slices transmitted by the sender as follows:

$$GEDSR = N_{dec}/(N_I + N_P + N_B) \tag{2}$$

where N_{dec} is the summation of $N_{I\text{-slice dec}}$, $N_{P\text{-slice dec}}$ and $N_{B\text{-slice dec}}$. It is clear that, the larger the GEDSR value, the better the video quality as received by the receiver. If we denote the probability that a slice α is regarded as decodable by $P(\alpha)$, then, the probability $P(I)$ that the I-slice in GOP_i is decodable is simply as follows:

$$P(I) = (1 - \xi I)^{Avgpacket_I} \tag{3}$$

$$N_{I\text{-slide dec}} = P(I) \times N_{GOPi} \tag{4}$$

where ξI stands for packet loss rate, $Avgpacket_I$ is the average number of packets to carry the data of each type of I-slice and N_{GOPi} represents total number of GOPs. The probability of the P-slice can be obtained as:

$$P(P_{Np}) = (1 - \xi I)^{Avgpacket_I} \quad (1 - \xi P)^{Avgpacket_P * Np} \tag{5}$$

With all these derivations, the expected number of decodable P-slices for the entire video will be:

$$N_{P-slice\ dec} = P(I) \times \sum_{j=1}^{Np} (1 - \xi\mathrm{P})^{j \times Avgpacket_P} \times N_{GOPi} \tag{6}$$

where ξP represents packet loss rate, $Avgpacket_P$ is the average number of packets to carry the data of each type of P-slice. It can be observed that the channel state feedback and adaptive FEC can be incorporated with GEDSR. Especially, as shown in Figure. 3, with CSE information, we can design adaptive FEC that allows N_{dec} to achieve higher value in order to improve the GEDSR parameter and the received video quality. The channel state estimation algorithm was illustrated in [1] in detail.

$$\alpha = 1 - \frac{queue_{high\_threshold\_of\_retry} - retry}{queue_{high\_threshold\_of\_retry} - queue_{low\_threshold\_of\_retry}} \tag{7}$$

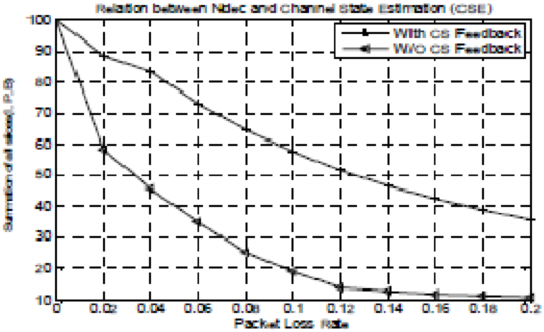

Fig. 3. Relation between N_{dec} and CSE

MP reduces the number of redundant FEC packets based on the current retry time: *retry (weighted moving average retry time)* = (1- rweight) * current_*retry* (*current retry time*) + rweight * *retry*. Note that $queue_{low\_threshold\_of\text{-}retry}$ and $queue_{high\_threshold\_of\text{-}retry}$ are 5 and 15, respectively. Consequently, the number of adaptive FEC is implemented as shown in Figure 4.

```
If ( retry < queue low_ threshold of retry )
    FEC no (number of redundant FEC) = 0;
Else if ( retry < queue high _ threshold of retry )
    FEC no = FEC no ×α (adaptive factor) ;
Else
    FEC no = FEC no ;
```

Fig. 4. Pseudo code of adaptive FEC Algorithm

3 Experimental Results

In this research, simulations have been carried out to compare the performance of static cross-layer and adaptive cross-layer mapping algorithm for video streaming over wireless mesh networks. Specifically, we implement the hybrid mesh mode simulation topology that consists of 14 mobile stations with 4 mesh clients, 4 conventional clients, and 6 mesh points. The bit rate is at 1Mbps, and several system parameters are based on physical layer parameters used in the 802.11b standard. In addition, in order to implement more complicated channel model that is close to practical network setting, we adopt the Rayleigh fading statistical channel in combination with the Finite-state Markov chain channel models [13]. This is more realistic than existing approaches in which they have not considered the impact of wireless fading channel on video transmission quality over wireless mesh networks. Figure 5(a) illustrates the performance of the throughput in destination nodes based on the simulation topology described above using NS-2. Both static and adaptive cross-layer mechanism have the similar throughput improvements. Figure 5(b) shows the dropping rate performance comparison. As expected, adaptive cross-layer algorithm outperforms static cross-layer scheme resulting because of full CSE information feedback and higher total number of decodable slices as shown in Figure 3.

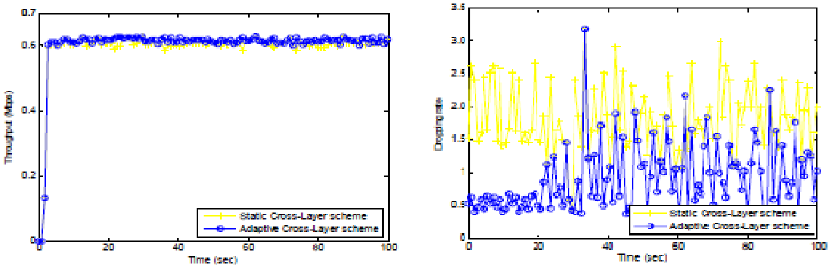

Fig. 5. Throughput and dropping rate comparison

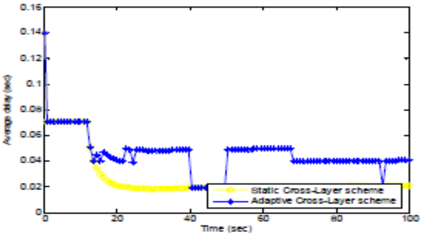

Fig. 6. Delay comparison

Figure 6 shows the average delay performance comparisons. The static cross-layer mechanism actually outperforms the proposed adaptive cross-layer scheme. With CSE, adaptive cross-layer scheme needs additional time to accommodate the feedback. However, the delay is well under the acceptable range. Overall, we can observe that the performance of our proposed model is significantly better than that of static cross-layer mapping, especially in terms of packet drop rate. In addition to the simulation results of relevant QoS metrics, we have also estimated the subjective quality of this H.264 video transmission for both static cross-layer and adaptive cross-layer mapping schemes as shown in Figure 7. It is clear that the overall subjective quality of the proposed adaptive scheme is noticeably better than that of the static scheme.

(a) Static Cross-Layer Mapping

(b) Adaptive Cross-Layer Mapping

Fig. 7. Evaluation of Video Streaming Transmissions

4 Conclusions

We have described in this paper a novel adaptive cross-layer mapping strategy for MAC protocol to achieve reliable delivery of the H.264 video streaming over wireless mesh networks. Based on the unique dynamic characteristic of wireless mesh networks, we developed an adaptive cross-layer mapping based MDCA MAC, making full use of the GEDSR model for the adaptation and application of adaptive FEC to combat wireless channel impairments. We adopt both network-level QoS metrics as well as received video quality at the receiving node to evaluate the proposed adaptive cross-layer mapping scheme against the static cross-layer mapping scheme for H.264 video over WMNs. The simulation results have confirmed that the proposed scheme is able to substantially outperform the static cross-layer mapping scheme with an average of 1.5dB in reconstructed video quality. Future extension of the proposed research include the adaptation of H.264 scalable video coding standard in order to meet the desired scalability requirements for a wider range of MAC configurations.

Acknowledgments. This work was supported by the University of Incheon Research Grant in 2010.

References

1. Oh, B.J., Hua, G., Chen, C.W.: Seamless Video Transmission over Wireless LANs based on an effective QoS Model and Channel State Estimation. In: Proc. of IEEE ICCCN, pp. 1–6 (2008)
2. Oh, B.J., Chen, C.W.: An Opportunistic Multi Rate MAC for Reliable H.264/AVC Video Streaming over Wireless Mesh Networks. In: Proc. of IEEE ISCAS, pp. 1241–1244 (May 2009)

3. Mobile Digital Video Recorder (MDVR) of Link Communications, Ltd., `http://www.lnkcom.com`
4. Athanasiou, G., Korakis, T., Ercetin, O., Tassiulas, L.: A Cross-Layer Framework for Association Control in Wireless Mesh Networks. IEEE Trans. on Mobile Computing 8, 65–80 (2009)
5. Shen, Q., Fang, X., Li, P., Fang, Y.: Admission Control Based on Available Bandwidth Estimation for Wireless Mesh Networks. IEEE Trans. on VT 58, 2519–2528 (2009)
6. Mogre, P.S., Hollick, M., Steinmetz, R.: QoS in Wireless Mesh Networks: Challenges, Pitfalls, and Roadmap to its Realization. In: Proc. of ACM NOSSDAV (June 2007)
7. Hamidian, A., Korner, U.: QoS Provisioning in Wireless Mesh Networks. In: Proc. of EuroN-GI/FGI Workshop on Wireless and Mobility, Barcelona, Spain (January 2008)
8. Moleme, N.H., Odhiambo, M.O., Kurien, A.M.: Improving Video Streaming Over IEEE 802.11 Mesh Networks through a Cross-Layer Design Technique. In: Proc. of IEEE BroadCom, Pretoria, South Africa, pp. 50–57 (November 2008)
9. Oh, B.J., Chen, C.W.: A Cross-Layer Oriented Multi-Channel MAC Protocol Design for QoS-Centric Video Streaming over Wireless Ad Hoc Networks. In: Proc. of IEEE ICME, New York, USA, pp. 774–777 (June 2009)
10. Oh, B.J., Chen, C.W.: A Cross-Layer Approach to Multi-Channel MAC Protocol Design for Video Streaming over Wireless Ad Hoc Networks. IEEE Trans. Multimedia 11, 1052–1061 (2009)
11. Oh, B.J., Chen, C.W.: Energy Efficient H.264 Video Transmission over Wireless Ad Hoc Networks based on Adaptive 802.11e EDCA MAC Protocol. In: Proc. of IEEE ICME, Hanover, Germany, pp. 1389–1392 (June 2008)
12. Hiertz, G., Max, S., Zhao, R., Denteneer, D., Berlemann, L.: Principles of IEEE 802.11s. In: Proc. of IEEE ICCCN, Honolulu, Hawaii, USA, pp. 1002–1007 (August 2007)
13. Oh, B.J.: Supporting Multimedia Quality of Service (QoS) in Wireless Networks. Ph. D. Dissertation, Dept. of ECE, Florida Institute of Technology, Melbourne, FL (December 2008)