Dual Probability Selection Mapping Algorithm for Video Transmission over Wireless Sensor Networks

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Abstract —The video stream transmission over wireless sensor networks is specially required to consider the Quality of Service (QoS), such as low packet loss, low latency and high Peak Signal-to-Noise Ratio (PSNR). In order to improve the performance above, we propose a novel video transmission solution, named Dual Probability Selection Mapping Algorithm (DPSMA). In this solution, by analyzing different video frames for the importance of decoding and combining with the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) mechanism, the DPSMA allocates different mapping probabilities for different video frames. In addition, the DPSMA could be able to perceive the congestion of the queue and could be able to ensure the transmission of high priority data. By simulating with the NS2 tool, the DPSMA shows better performance than the 802.11e and other mapping algorithms.

Index Terms—Video stream transmission, QoS, PSNR, wireless sensor networks

I. INTRODUCTION

Nowadays, more and more multimedia application appears with the development of wireless sensor networks. Not exactly the same as other transmission in wireless sensor networks, the video stream transmission should meet the varying QoS requirements. In order to solve the problem above, the IEEE 802 working group develops the 802.11e protocol. This protocol effectively improves the QoS by providing differentiated classes of service at the Medium Access Control (MAC) layer to enhance the ability of physical (PHY) layer to deliver time-critical traffic in the presence of traditional data packets. In the 802.11e protocol, a new MAC layer access mechanism named Enhanced Distributed Channel Access (EDCA) is put forward [1]. The EDCA classifies video traffic into four different access categories (ACs), just as AC_VO (for voice traffic), AC_VI (for video traffic), AC_BE (for best effort traffic) and AC_BK (for background traffic). Based on the 802.11e EDCA, more and more researches on video stream transmission appear to improve the QoS by putting forward methods concerning with application layer [2], transport layer [3], MAC layer [4], [5], PHY layer [6], and cross-layer design [7]-[9]. In MAC layer, researchers could improve the network performance and preserve the fairness to satisfy higher priority traffic by adjusting the EDCA parameter set, including Arbitration Inter Frame Space Number (AIFS), minimum Contention Window size (CWmin), maximum Contention Window size (CWmax), and Transmission Opportunity limit (TXOPlimit). In PHY layer, error control techniques and joint source-channel coding technology are primarily used. In cross-layer design, some approaches optimize the existing protocol stack and jointly consider the MAC layer parameter set and the PHY layer situation.

Based on the above description, the video stream transmission analysis and a new cross-layer mapping algorithm are proposed. Starting with characteristic of the wireless network and feature of scalable video coding, this approach uses the cross-layer design idea to fulfill the QoS requirements. In particular, because of using twice probability selection, the proposed mechanism shows better performance than others when network is congested.

The remainder of this paper is organized as follows. 802.11e EDCA, the video encoding mechanism, and the study on cross-layer design are introduced in Section II. Then, DPSMA algorithm is proposed and the simulation process is presented in Section III. Section IV provides the extensive simulation results under different network environments. Finally, conclusions are drawn in Section V.

II. BACKGROUND AND RELATED WORK

In this section, the 802.11e EDCA scheme, video encoding mechanism and researches on QoS are introduced. And we also analyze defects existed in other algorithms.

A. 802.11e EDCA Scheme

Since 802.11b standard just works for best-effort traffic and it performs badly for real-time business, the 802.11e standard is formulated to enhance the MAC layer by providing a distributed access method that can support service differentiation among different classes of traffic called EDCA. As shown in Fig. 1, different from the 802.11b standard, the 802.11e standard classifies traffic into four ACs. The advantages of four ACs are considered in two aspects. On one hand, it could provide

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differentiated service for real-time traffic. On the other hand, this structure is controllable when the network is congested.

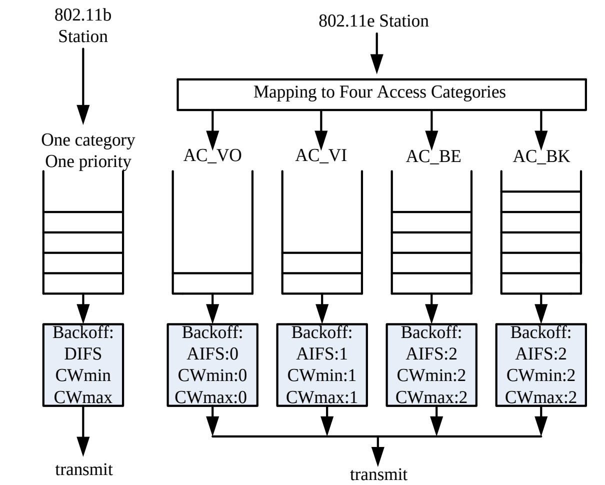

Fig. 1. Queue mechanism of 802.11b and 802.11e.

In the 802.11e EDCA scheme, every AC is independent with its own parameter set (such as AIFS, CWmin and CWmax). Corresponding to different priority, the parameter set is different as shown in Table I.

TABLE I: 802.11E EDCA PARAMETER SET

AC(priority)	Designation	AIFS	CWmin	CWmax
AC-VO (3)	Voice	2	7	15
AC-VI (2)	Video	2	15	31
AC-BE (1)	Best Effort	3	31	1023
AC-BK (0)	Background	7	31	1023

Based on the parameter set, Fig. 2 shows the way of channel competition in detail. Higher priority AC is more easily to obtain access to communication channel, because it possesses smaller AIFS, which stands for the number of slot needed to wait before starting the backoff process.

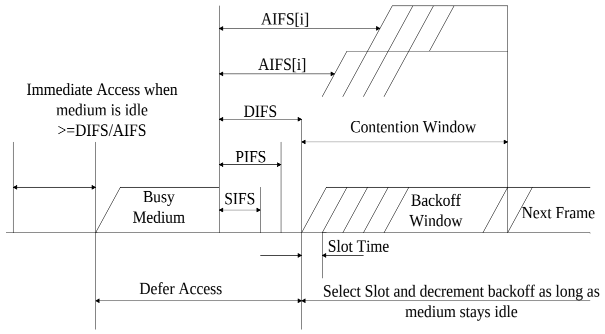

Fig. 2. Channel competition in 802.11e.

B. *Video Encoding Mechanism*

For video stream transmission, MPEG-4 is a standard adapted to deformation-based key points. This standard is proposed by Moving Picture Experts Group (MPEG) to reduce the flow of information required in files and multimedia communications. In addition, MPEG-4 standard has three advantages, including interactive performance, high compression ratio, and unified storage.

MPEG-4 standard uses hierarchical design to enhance its own performance. The compression layer, synchronization layer, and deliveries multimedia integration framework layer cooperate to ensure the coding efficiency and network services. The former two layers are mainly responsible for motion compensation, transform coding of coefficients, and entropy coding. And the latter layer is in charge of sending data packets to the network.

As shown in Fig. 3, the Group of Picture (GOP) is the smallest unit of data in encoding and decoding of MPEG-4. Generally, one GOP is made up of three different types of frame, which including intra-coded frame (I-frame), predictive-coded frame (P-frame), and bi-directionally predictive-coded frame (B-frame) [10]. I-frame is coded independently of all other pictures and it can be decoded without the need for any other frames. Each GOP begins (in decoding order) with this type of picture. While P-frame contains motion-compensated difference information relative to previously decoded pictures and it should be encoded/decoded according to previous I-frame and/or P-frame. B-frame can only reference two pictures, one of which must precede the B picture in display order and the other must follow the B picture in display order.

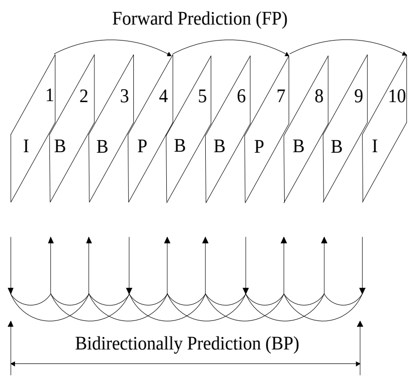

Fig. 3. The GOP of MPEG-4.

Based on Fig. 3, three conclusions are obtained. Firstly, the loss of one I-frame can lead to loss of some sequent frames. Then, some other P-frame and B-frame will be affected by the loss of one P-frame. Thirdly, the importance of three frames is different with the descending order I>P>B.

C. *Reality Work of QoS Study*

Owing to the service differentiation of 802.11e EDCA and the frame differentiation of video stream, a few studies jointly consider these two characteristics to optimize the network performance by different methods, such as rate adaptive algorithm [11], primary automatic repeat-request [12], and QoS parameter adaptive algorithm [5]. In particular, cross-layer design methods through the optimal prioritized packet fragmentation show better performance than other algorithms, e.g. a slice discard scheme using frame importance [7] and adaptive cross-layer mapping algorithm [9]. The adaptive cross-layer mapping algorithm is mainly introduced and compared in this paper.

For adaptive cross-layer mapping algorithm, the author introduces a cross-layer architecture based on both the significance of the video data and the network traffic load. The improvement in the quality of the video delivered by exploiting the hierarchical characteristic of video frames and passing the significance information of video data from application layer to MAC layer in a cross-layer design architecture. The MAC layer makes use of the significance information to provide differentiated service to different types of video packets accordingly.

The above method shows good performances in most situations, but it also has its limitations. For the adaptive cross-layer mapping algorithm, although it improves faultiness for occupying one AC even though there is no any packet in the AC, it cannot fully guarantee the importance of packets. So we propose Dual Probability Selection Mapping Algorithm (DPSMA) to assure both AC efficiency and packet priority. The DPSMA includes two selection processes, the first of which guarantees the importance of frames by providing different mapping probabilities and the second of which ensures the utilization of ACs through offering dynamic mapping.

III. System Structure Diagram and Proposed Method

For explaining the experiment comprehensively, we firstly introduce the simulation process and then we propose the DPSMA.

A. *System Structure Diagram*

For this paper, the experiments are done on the NS2 by using NS2 tool set [13], and the system structure diagram is shown in Fig. 4. In the effort to test and evaluate the correctness and the performance of network applications, the original YUV video files, video codec and NS2 simulation tool are mainly used in this experiment. Firstly, by encoding and converting the original YUV video files, we could get the video sender trace file, which including detail information of every single frame. Then, by NS2 simulation tool we obtain the receiver trace file, which could be compared with the sender trace file to generate frame loss rate, frame jitter. Next we could get the reconstructed video file by decoding and converting the video format. Through analyzing the raw YUV video files and the reconstructed fixed YUV video files, we can finally obtain the PSNR. The PSNR can be expressed as

$$\text{PSNR}=10\lg\frac{D^2}{\frac{1}{MN}\sum_M\sum_N\left[f(m,n)-g(m,n)\right]^2} \tag{1}$$

where $f(m,n)$ and $g(m,n)$ are the pixel gray value of original image and reconstructed image, M and N are the pixel numbers on horizontal direction and vertical direction, D is maximum gray scale value of continuous tone image. So the PSNR could objectively reflect the whole characteristics of original image and reconstructed image. Through these measures, we finally get the packet delivery fraction, packet delay, PSNR, and reconstructed video, which is used to analysis the network performance.

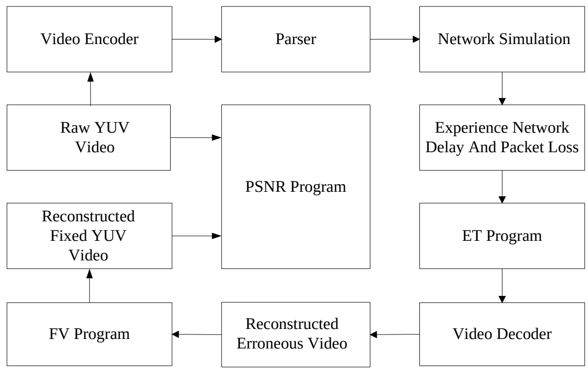

Fig. 4. The system structure diagram.

B. *Dual Probability Selection Mapping Algorithm (DPSMA)*

As described in Section II, we use the same cross-layer structure as the adaptive mapping algorithm [9]. A more insightful interlamination communication is given in Fig. 5.

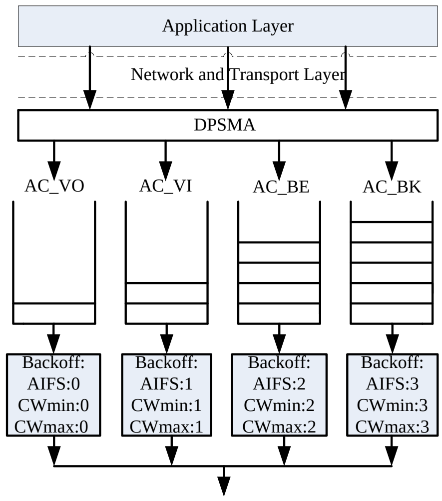

Fig. 5. The cross-layer structure.

The interaction is initiated by application layer and reacted by MAC layer. Firstly, application layer extracts code information, which including types of video frames, frame number, frame length and time stamp. Then the MAC layer provides a different probability for each packet, which is the first probability selection. In this step, the more important the video frame is, the greater probability it has to map to higher priority AC. Based on the significance of video frames and suffering to [9], the initial mapping probability of different frames are set as

$$p_\text{I}=\frac{T_\text{I}}{T} \tag{2}$$

$$p_\text{P}=\frac{T_\text{P}}{T} \tag{3}$$

$$p_\text{B}=\frac{T_\text{B}}{T} \tag{4}$$

where T_{I}, T_{P} and T_{B} are the total packets of different frames, T is the total packets of all frames.

Then mapping probability will constantly change along with the packets coming as

$$p_{time} = p_i \times \frac{qlen_{ac} - AC_{low}}{AC_{high} - AC_{low}} \quad (5)$$

where $i \in \{\mathrm{I}, \mathrm{P}, \mathrm{B}\}$, p_{time} is the real time mapping probability, $qlen_{ac}$ is the average length of different ACs, and AC_{high} / AC_{low} is the maximum/minimum queue value.

In order to improve the faultiness of the adaptive mapping algorithm, we set different AC_{high} / AC_{low} for different frame. The basic AC_{high} is 40 and the basic AC_{low} is 20, based on which the different AC_{high} / AC_{low} can be given by

$$AC_{high} / AC_{low} = p_{selection} \times basic\ AC_{high} / basic\ AC_{low} \quad (6)$$

where $p_{selection}$ =1.2/1/0.8 for I/P/B frame. This is the second probability selection and the algorithm is shown in Fig. 6.

When a video data frame arrives:
① Judging the type of frame;
② Assigning different AC_{high} / AC_{low}.
③ if ($qlen_{AC\_VI} < AC_{low}$)
video frame → AC_VI;
else if ($qlen_{AC\_VI} < AC_{high}$){
$p_{time} = p_{\mathrm{i}} \times \frac{qlen_{ac} - AC_{low}}{AC_{high} - AC_{low}}$
if(*Random Number* > p_{time})
video frame → AC_VI;
else
video frame → AC_BE;}
else if($qlen_{AC\_VI} > AC_{high}$) {
if(*Random Number* > p_{time})
video frame → AC_BE;
else
video frame → AC_BK; }
*Where *Random Number* $\in (0.0, 1.0)$ and it is generated randomly by NS2.

Fig. 6. DPSMA algorithm.

The main difference of the presented work and that in [9] is the mapping mode that is considered. Besides the specific characteristics of ACs, the problems considered in our manuscript are the queue length of ACs and the specific characteristics of frames. The interval of ACs in [9] are static, while those in our algorithm are adaptive, e.g. the minimum of queue interval is bigger when one I-frame packet comes, so the I-frame packet has a better opportunity mapping to the AC_VI (important frame → high priority AC). Our work is particularly stable for multi-video transmissions problems.

IV. Simulation Results and Analysis

In this section, some simulations are presented to prove the theoretical analysis presented in the previous section. We conduct two sets of simulation and every simulation consists of two parts which include sole video traffic flow and four different traffic flows.

The video source used in the simulation is YUV QCIF Foreman, which is one video sequence of commonly used in video test. QCIF defines a video sequence with a resolution of 176×144.

In Foreman used in our simulation, the total frame number is 400 (I→45, P→89, B→266) and the total packet number is 659 (I→237, P→149, B→273). Each video frame is fragmented into packets before transmission, and the maximum transmission packet size over the simulated network is 1024 bytes.

A. Two Nodes Communication

As shown in Fig. 7, in this experiment, one node is video sender and the other is video receiver. The simulation parameters for the proposed solution are shown in Table II.

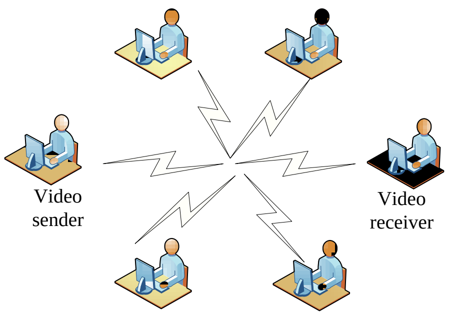

Fig. 7. Two nodes communication.

Table II: Simulation Parameter Set (Two Nodes)

Parameter	Value
NS2 Version	NS-2.29
Propagation	TwoRay Ground
Video Traffic	YUV QCIF (Foreman)
Voice Traffic	VoIP
Best Effort Traffic	CBR
Background Traffic	TCP
Routing Protocol	AODV
MAC Layer Protocol	802.11e
Allowed Queue Length	50
Data Rate	11Mbps
Max Fragmented Size	1024B
Topology Range	500m*500m

Firstly, we observe the mapping of video packets in MAC layer under sole video traffic situation, and there are three mapping algorithms, including IEEE 802.11e, adaptive mapping algorithm, and DPSMA.

According to Fig. 8, the DPSMA performs better than the 802.11e and the adaptive mapping algorithm. The reasons are as follows. Firstly, only AC_VI used in 802.11e results in the waste of ACs and affects the efficiency of packet transmission. Owing to using AC_BE and AC_BK, adaptive mapping algorithm performs better than 802.11e. For it could adapt to the changes of network and utilize the ACs effectively.

Meanwhile, as a result of the AC_{low} is fixed, the video packet will randomly map to ACs when the $qlen_{ac}$ is larger than the AC_{low}. So it is likely to occupy the congested AC queue and reduce the simulation performance. So the packet delivery fraction is still unsatisfactory. By adjusting the AC_{high} / AC_{low}, the DPSMA algorithm ensures the mapping of important packets and reduces the side effects of conditions emerging in the adaptive mapping algorithm.

Corresponding to Fig. 8, the average PSNR of video transmission for different methods is shown in Fig. 9. Owing to the packet delivery fraction directly affects the PSNR of every frame, so the average PSNR performs the same trend to the packet delivery fraction. One optimal reference PSNR value tested under no packet losing simulation environment is given out as 34.887196. By comparing with this reference PSNR value, we could analysis the performance in a better way.

In order to illustrate the performance of DPSMA, we further analysis the packet delay. As shown in Fig.10, the packet delay of DPSMA still keeps in a good level.

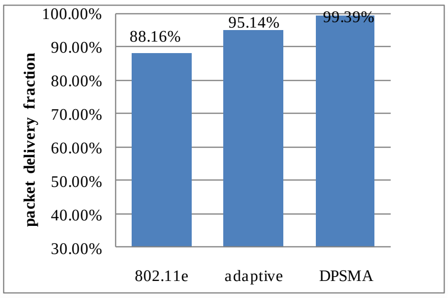

Fig. 8. Packet delivery fraction under sole video flow for two nodes.

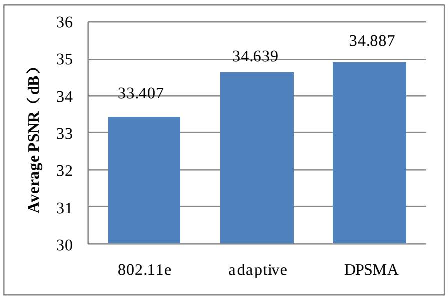

Fig. 9. Average PSNR under sole video flow for two nodes.

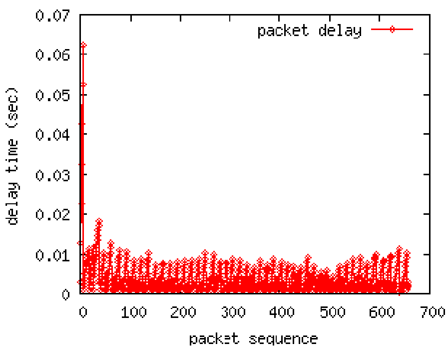

Fig. 10. Packet delay of DPSMA under sole video flow for two nodes.

Next, we observe the mapping of video packets in MAC layer under four traffic flows including audio stream, video stream, CBR stream, and TCP stream.

As shown in Fig. 11 and Fig. 12, the DPSMA still performs better than the other two algorithms. In addition, all of three methods show little worse performance than previous experiments. This is because the wireless network load is increased under four traffic flows.

For Fig. 13, although the packet delay of DPSMA performs not so good as Fig. 10, the average packet delay is perfectly acceptable, for the average packet delay is 0.0082 seconds.

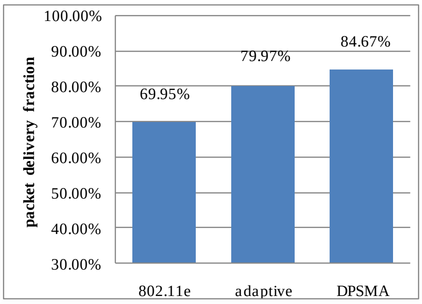

Fig. 11. Packet delivery fraction under four flows for two nodes.

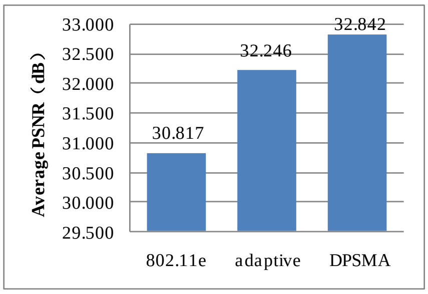

Fig. 12. Average PSNR under four flows for two nodes.

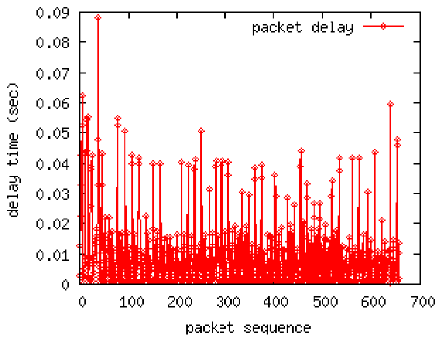

Fig. 13. Packet delay of DPSMA under four flows for two nodes.

In fact, PSNR could reflect the packet delivery fraction and packet delay in one way, because PSNR is related to both the raw YUV video files and the reconstructed fixed YUV video files. In addition, both the packet delivery fraction and packet delay have an influence on the reconstructed fixed YUV video files. Fig. 8 – Fig. 10 and Fig. 11 – Fig. 13 could reflect the expression above.

B. Six Nodes Communication

As shown in Fig. 14, in this experiment, three nodes are video senders and the other three are the video receivers. The simulation parameters for the proposed solution are shown in Table III.

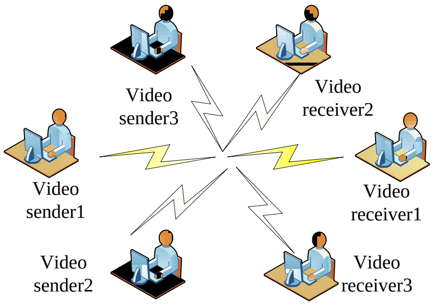

Fig. 14. Six nodes communication.

TABLE III: SIMULATION PARAMETER SET (SIX NODES)

Parameter	Value
NS2 version	NS2.29
Propagation	TwoRay Ground
Video Traffic	YUV QCIF (Foreman)
Voice Traffic	VoIP
Best Effort Traffic	CBR
Background Traffic	TCP
Routing Protocol	AODV
MAC Layer Protocol	802.11e
Allowed Queue Length	50
Data Rate	11Mbps
Max Fragmented Size	1024B
Topology Range	500m*500m

The same as experiments in part A, we firstly observe the mapping of video packets in MAC layer under only video traffics. According to Fig. 15 and Fig. 16, we summarized results of three video streams. The variation trend of those three methods is similar to the first experiments in part A, and the three video transmissions perform stably to each other. Foreman images of reconstructed video are shown in Fig. 17, and DPSMA also shows better performance than other algorithms. For both the queue length of ACs and the specific characteristics of frames are concerned in DPSMA.

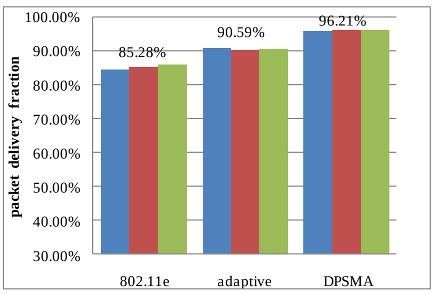

Fig. 15. Packet delivery fraction under sole video flow for six nodes.

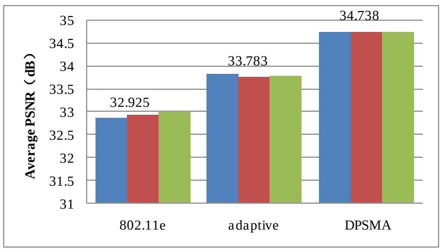

Fig. 16. Average PSNR under sole video flow for six nodes.

(a) (b) (c)

Fig. 17. Foreman images of reconstructed video under sole video flow for six nodes: (a) 802.11e, (b) adaptive, (c) DPSMA.

Next, we observe the mapping of video packets in MAC layer under four video traffic flows including audio stream, video stream, CBR stream, and FTP stream. As shown in Fig. 18 and Fig. 19, the DPSMA performs best among the four algorithms. Foreman images of reconstructed video are shown in Fig. 20, we can clearly distinguish the performance under high network load.

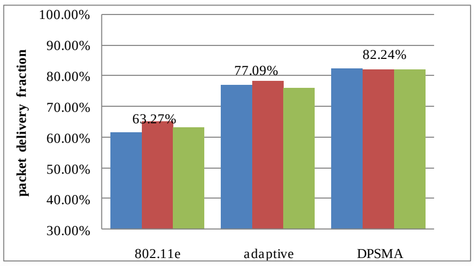

Fig. 18. Packet delivery fraction under four flows for six nodes.

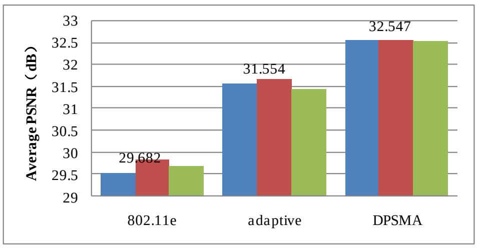

Fig. 19. Average PSNR under four flows for six nodes.

(a) (b) (c)

Fig. 20. Foreman images of reconstructed video under four flows for six nodes: (a) 802.11e, (b) adaptive, (c) DPSMA.

In the experiment of part B, we could not only prove the better performance of DPSMA by comparison of four algorithms but also verify the stability of DPSMA through little changes of performances for three communication lines.

V. CONCLUSIONS

In this paper, the video transmission performances of 802.11e, adaptive algorithm and DPSMA algorithm are compared in two different network topologies. The numerical results including sole video traffic flow and four traffic flows show that the DPSMA algorithm performs better than the other methods as a result of solving faultinesses existed in queue allocation and priority protection.

The next step of our work will focus on H.264 video codec and more complex network topology.

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