IMAGE PROCESSING, PATTERN RECOGNITION

Cross-layer optimization technology for wireless network multimedia video

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Abstract

With the development of communication technology, wireless Internet has become more and more popular. The traditional network layered protocols cannot meet the increasingly rich network services, especially video. This paper briefly introduced the cross-layer transmission of video in wireless network and the cross-layer optimization algorithm used for improving video transmission quality and improved the traditional cross-layer algorithm. Then, the two cross-layer algorithms were simulated and analyzed on MATLAB software. The results showed that the packet delivery rate, peak signal to noise ratio and downlink throughput of the improved cross-layer algorithm were significantly higher than those of the traditional cross-layer algorithm under the same signal to interference plus noise ratio of receiving users in wireless network; meanwhile, with the increase of signal to interference plus noise ratio of the receiving user, the packet delivery rate and peak signal to noise ratio of the two algorithms increased, and tended to be stable after some signal to interference plus noise ratio, while the throughput of the two algorithms increased linearly. In the established real wireless network, the package delivery rate, peak signal to noise ratio and throughput of video after application of cross-layer algorithm were significantly improved, and the wireless network applying the improved cross-layer algorithm improved more. In summary, compared with the traditional cross-layer algorithm, the improved cross-layer algorithm can better improve the transmission quality of video in wireless network.

Keywords: wireless network, video transmission, cross-layer optimization, quality of service.

Citation: Xia W. Cross-layer optimization technology for wireless network multimedia video. Computer Optics 2020; 44(4): 582-588. DOI: 10.18287/2412-6179-CO-620.

Acknowledgments: This paper is one of the periodic achievements of the 2017 provincial major fund teaching and research project of Anhui province, "research on education teaching support function of informatization and digitization campus construction" (project number: 2017jyxm0542).

Introduction

With the process of the Internet and wireless communication technology, people can use mobile phones, PAD and other mobile terminals to watch multimedia video. At the same time, due to the convenience of wireless networks, people are gradually more inclined to use wireless network to acquire multimedia resources [1]. The traditional Internet is based on wired connection. In addition, in the early days of the Internet, the data transmission technology is relatively backward, the transmission speed is slow and unstable, which basically does not support large-volume multimedia file transmission [2]. Under the background of Internet technology at the time, the layered protocol in the Internet paid more attention to the transmission of file data without losing packet, but paid no attention to whether the transmission was delayed or not [3]. However, with the rapid development of wireless communication technology, the data transmission speed of the Internet has increased rapidly, and it is sufficient to support the transmission speed requirements of multimedia video. However, the traditional layered protocol cannot meet the low delay requirements of video transmission, so wireless network must be optimized across layers. Related studies are as follows. Jia et al. [4] proposed an effective cross-layer optimization framework based on genetic algorithm, which could find the optimal power control, channel allocation and routing in polynomial time, and a large number of simulation experiments showed that the throughput of the network was effectively improved. Yang et al. [5] proposed a mathematical optimization problem that comprehensively considered the network topology design and cross-layer optimization in wireless somatosensory network and used a fast convergence algorithm based on binary search to solve the problem. The simulation results showed that this method can save the cross-layer optimization problem quickly and effectively. She et al. [6] proposed a cross-layer optimization framework to guarantee ultra-high reliability and ultra-low latency in the consideration of transmission delay and queuing delay in wireless access network. In this framework, the active packet loss mechanism was adopted to ensure the service quality under limited transmission power. The simulation results showed that this cross-layer optimization framework can effectively improve the transmission quality of wireless network. Based on the Multiple Input Multiple Output (MIMO) system of 4G communication network, this paper briefly introduced the cross-layer transmission of video in wireless network and the cross-layer optimization algorithm used for improving video transmission quality and improved the traditional cross-layer algorithm. Then, the two cross-layer algorithms were simulated and analyzed on MATLAB software.

Cross-layer transmission of video in wireless network

As shown in Fig. 1, the nodes used by multimedia video in wireless network transmission process could be simply divided into the transmitting node and the receiving node. Data transmission between transmitting and receiving nodes was carried out through wireless channels. The two types of nodes in the wireless network included three layers: the application layer, the media access control (MAC) layer and the physical layer. The application layer was the user-oriented structure layer, and the main function of the application layer of the transmitting node was to generate data that could be transmitted. Taking video as an example, the code rate of video files is compressed, recoded and error screened. The compression technology used in the application layer can directly affect the transmission quality of the video; the main function of the application layer of the receiving node is to reverse operation of the transmitting node and decompress the video [7]. In this paper, the mean square error was used to describe the distortion characteristics in the video compression and decompression process. The equation is:

$$D_k = D_k^{enc} + D_k^{loss} \approx D_{0,k} + \frac{\theta_k}{R_k - R_{0,k}} + v_k (P_e + P_k^{dly}), \quad (1)$$

where D_k is the overall distortion of video received by user k; D_k^{enc} represents the distortion caused by video compression; D_k^{loss} represents the distortion caused by packet loss in video transmission; $D_{0,k}$ represents the initial distortion degree; θ_k represents the video code rate; R_k, $R_{0,k}$ represent the coding rate and initial coding rate, respectively; v_k is the sensitivity of the video to packet loss; P_e is the probability of packet loss caused by transmission error in wireless channel; P_k^{dly} represents the probability of packet loss caused by transmission waiting time exceeding the maximum delay threshold.

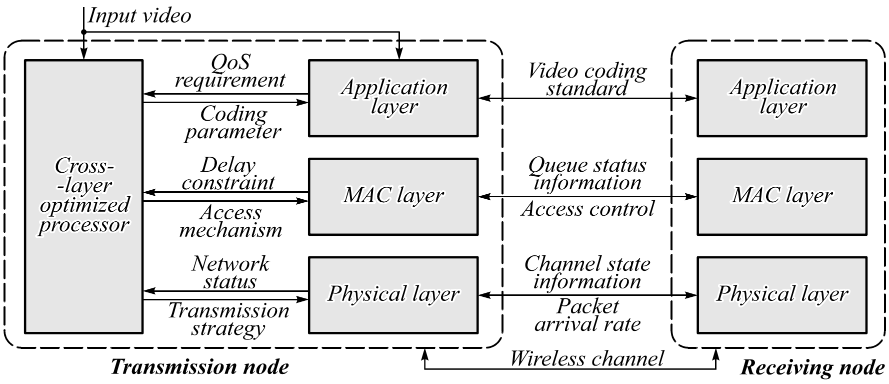

Fig. 1. The framework of multimedia video cross-layer transmission

The MAC layer is a sublayer of the data link layer [8], and its main function is to coordinate the user's allocation of wireless spectrum resources. The protocol in this layer can directly affect the probability of the user's access to network port and the delay of data transmission. When the video packets enter the MAC layer, they will be queued for transmission in a first-come-first-served order, and the equation of the queue model is:

$$\begin{cases} \lambda_k = \dfrac{R_k}{L_k}, \\ t_k = \dfrac{L_k}{C_k}, \\ \Pr(S_k = mt_k) = P_e^{m-1}(1-P_e), \\ W_k = \dfrac{\lambda_k S_k^2}{2(1-\lambda_k S_k)}, \\ P_k^{dly} = \lambda_k S_k \cdot \exp\left(-\dfrac{T_k^{th} \lambda_k S_k}{W_k}\right), \end{cases} \quad (2)$$

where λ_k is the average arrival rate of user k's video packet in this layer; L_k is the average length of the video data; C_k is the effective transmission rate of the actual available route; t_k is the time required to transmit one video at a time; S_k is the time required to successfully transmit a video; Pr(•) represents the probability density function; m represents that a video is successfully received or timeout after the m-th transmission; W_k is the time of video data waiting to be processed in this layer; T_k^{th} is the maximum delay time for video.

The physical layer [9] generally refers to the wireless channel between the transmitting node and the receiving node in the wireless network. In this layer structure, the allocation strategy of channel spectrum and the adaptation mechanism of link route, etc. affect the transmission rate and packet loss rate of video packets. The equation of the physical layer transmission model is:

$$\begin{cases} \gamma_k = \dfrac{\chi_k P_k G_k}{\sigma_k^2 + \sum_{j \neq k} P_j G_j}, \\ C_k = B \log_2(1+\gamma_k), \end{cases} \quad (3)$$

where γ_k is the receive signal to noise ratio of the user k; χ_k is the spread spectrum gain of wireless network; P_k, P_j

represent the transmission power of user k and other users respectively; G_k, G_j represent the channel gain of user k and other users including large and small scale fading, respectively; σ_k^2 represents the noise power received by user k; C_k is the physical layer link capacity of user k; B is the channel bandwidth.

The above application layer, MAC layer and physical layer are the structures of both the transmitting node and receiving node. The transmitting node also has a cross-layer optimization processor in order to improve the transmission quality of multimedia video in wireless network. When the video data packet enters the transmitting node, the relevant parameters of the video sequence will not only enter the application layer, but also enter the cross-layer optimization processor at the same time to allocate resources reasonably according to the collected parameters of the relevant structure layer, so as to coordinate the cooperation of different structure layers and achieve cross-layer optimization.

Cross-layer optimization

In traditional wireless internet transmission model, the data transmission follows the inherent mode that transmits data only between adjacent layers. Although the lower packet loss rate is guaranteed as mentioned above, the delay is serious. Especially nowadays when the wireless network is speed up, it will aggravate the congestion of layer and layer transmission, indirectly increase packet loss rate [10], and reduce user experience. Cross-layer optimization technology considers all structural layers in the network as a whole and uses specific parameters in cross-layer shared channel to make the information interaction between layers not limited to adjacent layers, but to coordinate all layers to achieve global optimization.

In cross-layer optimization, the main structural layers involved are described above: the physical layer, the MAC layer, and the application layer. In this paper, the application layer and MAC layer were used as objects, and the cross-layer optimization algorithm was used for coordinating different structural layers to achieve the effect of optimizing the user experience.

As shown in Fig. 2, in the traditional cross-layer optimization algorithm, when video was transmitted into the application layer, the encoder in the application layer conducted data separation operation on video when it is compressed, and divided the data in video according to the importance. Then, the divided data was given corresponding marking parameters, which are packaged, compressed and transmitted to the MAC layer. In the MAC layer, the tag parameters in video compression package were identified, and different data units were processed accordingly. There were different queue channels in the MAC layer, including AC_VI (video queue), AC_BE (the best effort queue), and AC_BK (background service queue) [11]. The priority of queue channel was VI>BE>BK, that is, the data in video queue was allocated to better communication channel first. The traditional cross-layer optimization algorithm mapped the segmented video to the corresponding queue according to the marking parameters of the segmented video data in the MAC layer. The more important the segmented video data was, the more priority it was mapped to the queue. The wireless network coordinated by the traditional cross-layer optimization algorithm could fully utilize two queues except video and improve the transmission effect of video according to the data of different importance in video. However, the traditional cross-layer optimization algorithm did not consider the dynamic change of the queue but mechanically allocated the segmented video according to the specified parameters. Even if the allocated queue is already crowded, it will not be allocated to another idle queue, which eventually leads to data loss.

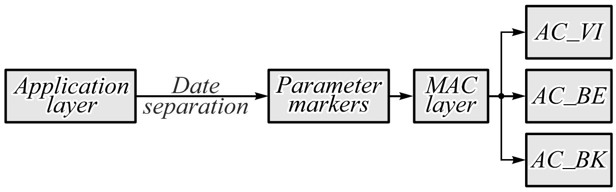

Fig. 2. The flow of the traditional cross-layer optimization algorithm

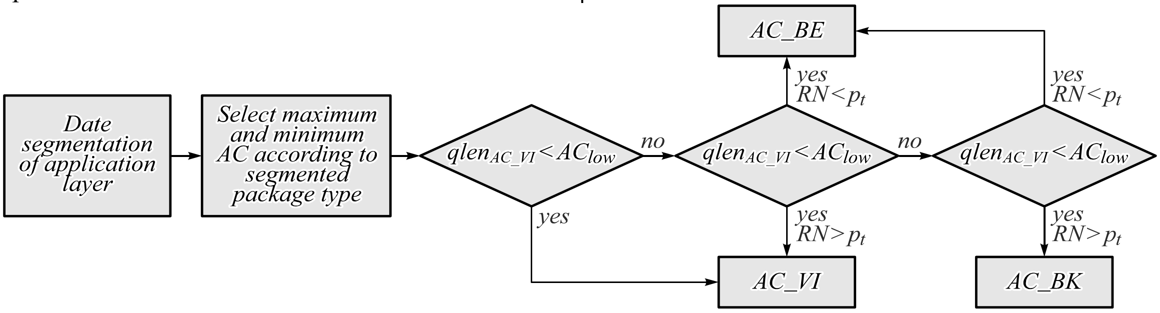

Fig. 3. The flow of the improved cross-layer optimization algorithm

In order to solve the problem of solidification allocation of traditional cross-layer optimization algorithm, it was improved, as shown in Fig. 3:

1. Firstly, the same as the traditional algorithm, the video data was divided by encoder at the application layer according to the frame type of video. In this paper, the MP4 format video was selected as the research object. The video frame types of MP4 format were divided into internal frame (frame I), predictive frame (frame P) and bidirectional predictive frame (frame B) [12]. After dividing, the data was transmitted to the MAC layer.

2. After receiving the divided data packet, the MAC layer first determined the type of packet frame and then selected the mapping threshold required for mapping. The AC_{low} of frame I was 24, the AC_{high} was 48; the AC_{low} of frame P was 20, the AC_{high} was 40; the AC_{low} of the frame B WAS 16, and the AC_{high} was 32.
3. When the queue length of *AC_VI* in the MAC layer was smaller than the AC_{low} of corresponding frame, the frame data packet of that kind was mapped to *AC_VI*.
4. If not, whether the queue length of *AC_VI* was smaller than the AC_{high} was continued to determine; if so, the packets of such frame was mapped to *AC_VI* when the random parameter was greater than the real-time mapping probability p_t; when the random parameter was smaller than the real-time mapping probability p_t, this packet of such frame was mapped to *AC_BE*.
5. If not, whether the queue length of *AC_VI* was larger than the AC_{high} was continued to determine; if so, the packets of such frame was mapped to *AC_BK* when the random parameter was greater than the real-time mapping probability p_t; when the random parameter was smaller than the real-time mapping probability p_t, the frame data packet of that kind was mapped to *AC_BE*.

The calculation equation of the real-time mapping probability is:

$$p_t = \begin{cases} \dfrac{T_I}{T} \cdot \dfrac{qlen_{ac} - AC_{low}}{AC_{high} - AC_{low}} & \text{data packets of frame I}, \\ \dfrac{T_P}{T} \cdot \dfrac{qlen_{ac} - AC_{low}}{AC_{high} - AC_{low}} & \text{data packets of frame P}, \\ \dfrac{T_B}{T} \cdot \dfrac{qlen_{ac} - AC_{low}}{AC_{high} - AC_{low}} & \text{data packets of frame B}, \end{cases}$$

where p_t is the real-time mapping probability; T_I, N_P, T_B are the number of data packets of frame *I*, *P* and *B*, respectively; *T* is the total number of packets; $qlen_{ac}$ is the average length of all queues.

Simulation analysis

1. Experimental environment

In this paper, MATLAB software [13] was used for simulation analysis of two cross-layer optimization algorithms. The simulation experiment was carried out in a laboratory server. The server configuration were: Windows7 system, i7 processor and 16G memory.

2. Relevant parameters

In the MATLAB software, the parameters of the simulated wireless network can be set arbitrarily, but in the actual wireless network, different parameters have an impact on the transmission quality of video, so it is necessary to select appropriate parameters. The relevant parameters affecting the quality of video transmission mainly include packet length, compression quantification parameters and group of picture (GOP) [14]. The packet length is the number of data bytes that each segmented data packet can hold when the video is divided; the compression quantification parameter is the quantification standard on which the video is compressed; GOP is the type of group of picture.

To ensure the objectivity of the comparison results of the two cross-layer optimization algorithms, the same simulation network and transmission video were used, and the relevant parameters are shown in Table 1. 3GPP SVM wireless channel model was used. Then to simulate the movement state of receiving users, different user SINRs were set, which were 10, 11, 12 ... 19 and 20 respectively. The packet delivery rate, peak signal to noise ratio and throughput of the cross-layer optimization algorithms under different SINRs were detected.

Tab. 1. Relevant parameters of the simulation networks in which the cross-layer algorithms are located

Relevant parameters	Values
Packet length	1024B
Compression quantization parameter	10
GOP type	GOP9
Channel width	10MHz
Subchannel frequency	10.94kHz
Effective sign time	91.4 μ*s*
Maintenance time	11.4 μ*s*
Number of frames of Video I	45
Number of frames of Video P	89
Number of frames of Video B	266

3. Simulation settings of practical application

After simulation using MATLAB software above, 20 wireless sensor nodes were set in an 30*m*×30*m* experimental area. Every sensor node was connected with a server. The cross-layer optimization algorithm used in this study operated in server. In the actual simulation experiment, the wireless network composed of wireless sensors adopted point-to-point transmission in video transmission, and the transmission protocol of the wireless network was 802.11 protocol. Video parameters used in the transmission and the processing parameters for video transmission were consistent with the simulation parameters mentioned above. After the start of the experiment, every server randomly selected other server in the wireless network via wireless node for point-to-point transmission. The experiment was carried out under the condition when the cross-layer algorithm was not used, the traditional cross-layer algorithm was used, and the improved cross-layer algorithm was used. Every experiment lasted for three hours.

4. Judgment index

The indicators used for measuring the cross-layer optimization algorithm in this study were: packet delivery rate, peak signal to noise ratio, and throughput [15]. The packet delivery rate is the ratio of the effective data packet received by the receiving node to the data packet transmitted by the transmitting node, and this data reflects the packet loss degree of video data in wireless network transmission. The larger the data is, the smaller the packet loss degree is. Peak signal to noise ratio is a parameter used for measuring the image quality of video after wireless transmission; throughput is the amount of data successfully transmitted per unit of time in the network.

5. Simulation results

As shown in Fig. 4, video in wireless network was under the two cross-layer optimization algorithms. With the increase of SINR of the receiving node users in wireless networks, the packet delivery rate in the video transmission process showed an upward trend and gradually tended to be flat after the SINR of 16 dB. It could be clearly seen from Fig. 4 that under the same SINR of the receiving node user, the improved cross-layer algorithm made the packet delivery rate of video in the transmission process higher. Taking the packet delivery rate under the SINR of 20 dB at the time of basic stability as an example, the package delivery rate of the traditional cross-layer algorithm was 98.66 %, and the package delivery rate of the improved cross-layer algorithm was 99.98 %, which increases by 1.34 %.

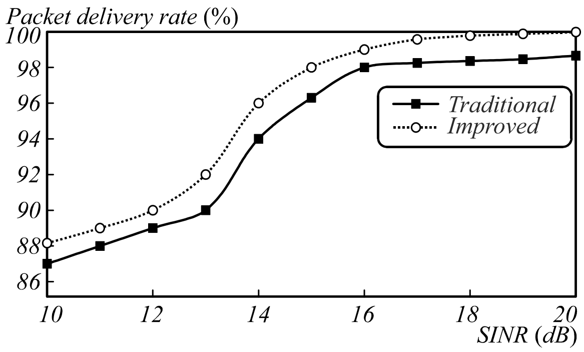

Fig. 4. The packet delivery rate of video with different SINR under two cross-layer optimization algorithms

As shown in Fig. 5, video in wireless network was under the two cross-layer optimization algorithms. With the increase of SINR of the receiving node users in wireless networks, peak signal to noise ratio of received video after decompression and decoding showed an upward trend and gradually tended to be flat after the SINR of 18 dB. It could be clearly seen from Fig. 5 that under the same SINR of the receiving node user, the improved cross-layer algorithm made the peak signal to noise ratio of video after transmission, decompression and decoding higher, that is, video image quality was lost less in the transmission process. Taking the peak signal to noise ratio of video under the SINR of 20 dB at the time of basic stability as an example, the peak signal to noise ratio of video of the traditional cross-layer algorithm was 39.76, and the peak signal to noise ratio of video of the improved cross-layer algorithm was 40.76, which increases by 2.52 %.

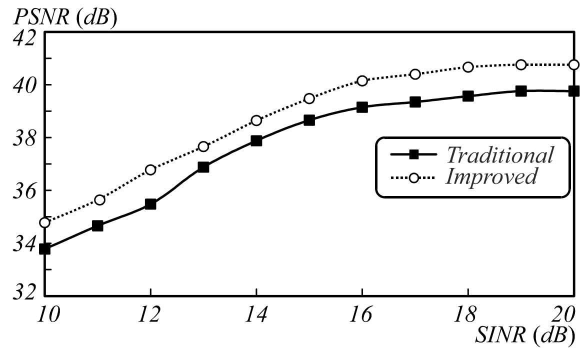

Fig. 5. Peak signal to noise ratio of video with different SINR under two cross-layer optimization algorithms

As shown in Fig. 6, video in wireless network was under the two cross-layer optimization algorithms. With the increase of SINR of receiving node users in wireless network, the throughput of downlink of receiving node users receiving video basically increased linearly. By comparing the two cross-layer algorithms, it could be clearly seen from Fig. 6 that under the same SINR of the receiving node user, the throughput of the downlink of video received by users under the improved cross-layer algorithm was higher, which was about 8.93 % higher than that of the traditional cross-layer algorithm. It indicated that the improved cross-layer algorithm improved the transmission efficiency of video frames in wireless network.

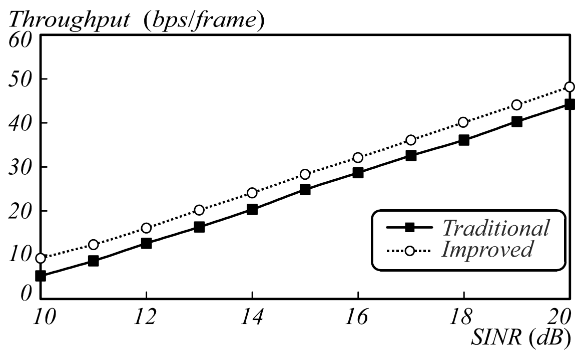

Fig. 6. Throughput of video with different SINR under two cross-layer optimization algorithms

Limited by the length of paper, only the effect of one video under the condition when the cross-layer algorithm was not used, the traditional cross-layer algorithm was used, and the improved cross-layer algorithm was used was displayed, as shown in Fig. 7–9. Subjectively, the video which did not apply the cross-layer algorithm had severe loss of image quality through wireless network transmission, and besides fuzzy picture, there was also a lot of mixed color in pixels, which further intensified the ambiguity of video; the video which applied the traditional cross-layer algorithm had significantly improved picture quality than the video which did not apply the cross-layer algorithm after wireless network transmission, and there was no obvious interference of mixed color, although the picture was fuzzy; the video which applied the improved cross-layer algorithm had further improvement of picture quality, clear picture and no interference of mixed color compared with the other two videos.

Fig. 7. The effect of videos transmitted under the conditions when the cross-layer algorithm was not used

Fig. 8. The effect of videos transmitted when the traditional cross-layer algorithm was used

Fig. 9. The effect of videos transmitted when the improved cross-layer algorithm was used

The experiment of each algorithm was carried out for 3 hours, and the corresponding video data was recorded and averaged. The results are shown in Table 2. In the established real wireless simulation network, the cross-layer algorithm was not used, only relying on 802.11 protocol, the packet delivery rate of video transmission was 85.4 %, peak signal to noise ratio was 24.6db, and the throughput was 33.2 bps/frame; when the traditional cross layer algorithm was used based on 802.11 protocol, the packet delivery rate of video transmission was 95.3 %, packet delivery rate was 39.7 db, and throughput was 44.5 bps/frame; when the improved cross-layer algorithm was used based on 802.11 protocol, the packet delivery rate of video transmission was 98.9 %, the packet delivery rate was 40.8db, and throughput was 48.2 bps/frame. It was seen from Table 2 that the packet delivery rate, peak signal to noise ratio and throughput of video which applied the cross-layer algorithm under the same transmission protocol were significantly improved in the wireless network, and the wireless network which applied the improved cross-layer algorithm.

Tab. 2. The average evaluation indicators of video transmission under the conditions when the cross-layer algorithm was not used, the traditional cross-layer algorithm was used, and the improved cross-layer algorithm was used

Evaluation indicator	The cross-layer algorithm was not used	The traditional cross-layer algorithm was used	The improved cross-layer algorithm was used
Package delivery rate %	85.4	95.3	98.9
Peak Signal to Noise Ratio/dB	24.6	39.7	40.8
Throughput bps/frame	33.2	44.5	48.2

Conclusion

This paper briefly introduced the cross-layer transmission of video in wireless network and the cross-layer optimization algorithm used for improving video transmission quality and improved the traditional cross-layer algorithm. Then, the two cross-layer algorithms are simulated and analyzed on MATLAB software. The results are as follows: (1) in wireless network, with the increase of the SINR of receiving user, the packet delivery rate of video transmission under the two cross-layer optimization algorithms showed an upward trend and tended to be stable after 16 dB; the packet delivery rate under the improved cross-layer algorithm was significantly higher than that of the traditional cross-layer algorithm, which was 1.34 % higher when it was basically stable; (2) with the increase of the SINR of the receiving user, the peak signal to noise ratio of video transmission under two cross-layer optimization algorithms showed an upward trend and tended to be stable after 18 dB; the peak signal to noise ratio of the improved cross-layer algorithm was obviously higher than that of the traditional cross-layer algorithm, which was 2.52 % higher when it was basically stable; (3) with the increase of the SINR of the receiving user, the downlink throughput of the video transmission under the two cross-layer optimization algorithms showed a linear growth trend; the throughput of the improved cross-layer algorithm was significantly higher than that of the traditional cross-layer algorithm, with an increase of about 8.93 %; (4) in the established real wireless network, the package delivery rate, peak signal to noise ratio and throughput of the video which applied the cross-layer algorithm was significantly improved, and the wireless network which applied the improved cross-layer algorithm improved more.

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Received August 20, 2019. The final version – December 02, 2019.