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A QoE Evaluation Method for RT-HDMV Based on Multipath Relay Service

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Received: 31 July 2019; Accepted: 28 August 2019; Published: 5 September 2019

Abstract: Multipath diversity leads to a possible higher performance for real-time high definition video, especially for medical video transmission, which would improve the stability of multiple transmission paths in the symmetrical state, and avoid the potential losses of imaging information in the communication process. Most of the previous works are always based on the single-path end-to-end transmission, although the service had been demonstrated that it is unable to meet the rigorous demand for the RT-HDMV. In the paper, a multipath relay service based on the QoE (quality of experience) evaluation method is proposed for the RT-HDMV (real-time high definition medical video). The method eliminates several of the limitations in the existing methods for some conventional single-path transmission. It can fully utilize the finite network resources and transmission bandwidth to meet the users' demands of the RT-HDMV to get a better score of the QoE. We use a four-stage framework to evaluate the QoE, which consists of constructing the multipath relay transmission for the RT-HDMV, calculating the weights of diversified QoS parameters in the multipath, designing the load distribution strategy by the mapping between the QoS (quality of service) and QoE, and redefining the rule of the QoE evaluation. Many experiments show that the proposed design scheme achieves weighting of the transmission sub-paths and computes the QoE score. Compared with the state-of-art methods in the single path transmission scene, our framework mainly gains the excellent performance for the RT-HDMV.

Keywords: multipath diversity; multipath relay service; QoS; RT-HDMV; AHP; QoE evaluation

1. Introduction

In the e-health service, the RT-HDMV has been widely used. It provides convenience for sharing medical resources and diagnosis by establishing efficient communication between various medical organizations or doctors and patients [1]. As a real-time bidirectional video streaming service, RT-HDMV usually uses QoE to evaluate the quality of service. QoE is the description of the users' satisfaction with the network services used [2]. The mainstream QoE evaluation methods for video streaming media services contains subjective evaluation methods, objective evaluation methods, and pseudo subjective evaluation methods.

The subjective evaluation method is a direct test by the observer subjective response to the measurement video image to determine the performance of the system from the perspective of the users' perceptions evaluation of the service [3–5]. The objective evaluation method is to compare the uncompressed original video data and the compressed original video data to obtain the evaluation index value, and then according to the index value to evaluate the video quality [6–9]. The pseudo-subjective evaluation method absorbs the advantages of the first two methods, it prepares a test environment for the test samples and integrates the effective methods of statistical science and artificial intelligence to obtain a more reliable QoE evaluation [10–12].

The above research work mainly focuses on the quality evaluation of single-path scenarios. Although it has contributed to the improvement of the QoE of video streaming services, the RT-HDMV has higher requirements for the stability and effect of transmission. When the random background traffic is added to the network, resulting in random congestion or disconnection of transmission paths due to insufficient bandwidth, the traditional single-path transmission mode cannot meet the QoE requirements of services. So, in order to overcome these problems, the highlights for our contributions could be summarized into the following points:

- (1) We use the technology of P2P and SDN for reference [13,14], build an overlapping network defined by the software without changing the existing network structure, and realize the relay transmission function of the application layer. This transmission scenario is mainly built for media relay services, rather than content distribution services like P2P. We use the relay controller deployed in the backbone network to realize the separation of the service transmission and control, and use the relay server to execute the storage and forwarding of the media service. On the premise that the link of the service terminal access network is not the transmission bottleneck, the transmission path between real-time service terminals is in addition to the default routing path provided by the network layer. It can also choose and adopt an application relay path, which can provide the QoE a guaranteed transmission for the RT-HDMV service under the premise of effectively expanding the transmission bandwidth and cooperating with the appropriate QoE evaluation method;
- (2) We adopt the pseudo-subjective evaluation method, which is widely used at present. Through the design of input and output conditions in the QoE scoring calculation of the RT-HDMV service, the evaluation rules of the service QoE in the multipath relay transmission scenario are formulated. Among them, the input conditions mainly include the weights of diversified QoS parameters and load distribution. It closely combines the coupling relationship between multiple sub-paths in the process of the service transmission, and objectively obtains the quantitative index of the service QoE. The output condition is the QoE score obtained after each service transmission. It establishes the corresponding relationship between the calculation of the QoE score and the user's subjective feelings from the perspective of the subjective evaluation, combining the user's expectation of service QoE;
- (3) By improving the existing QoE evaluation algorithm, we design a new QoE score calculation method based on the RT-HDMV service. We use the AHP (analytic hierarchy process) method to select the main parameter information from the acquired diversity path QoS parameter information as the judgment condition, establish the judgment matrix, and get the weight of the QoS parameter through normalization. Then, we use the second-order judgment matrix to calculate the load distribution ratio of the path and obtain the load distribution strategy of the traffic transmission. Finally, the parameters are substituted into the improved QoE evaluation formula to get the final QoE score.

For RT-HDMV, a reasonable QoE security mechanism is the key to innovation. The proposed QoE evaluation method is based on the combination of the multipath transmission technology and service QoE evaluation method. From the viewpoint of the network transmission optimization, we prove that it can bring a better experience than that of the traditional single path transmission.

In the rest part of the paper, Section 2 summarizes the related works. Section 3 introduces the multipath relay transmission scene. The load distribution strategy, QoE scoring rules, and computing methods are presented in Section 4. Our results are shown in the experiment in Section 5. Our discussion and contribution are shown in Sections 6 and 7.

2. Related Works

When the subjective evaluation method is used to evaluate the service quality of video streaming media, it mainly chooses the specific test group to complete the evaluation statistics of the service

quality from the aspects of the video broadcast form, content, and duration. The method DSCQS (double stimulus continuous quality scale) is proposed in [3]. This method replays the image sequence to be evaluated and the corresponding reference sequence alternately to the evaluators according to the set playback time, and completes the statistical work of the average video score in the two-second playback interval. An improved UFQ (user feedback quality) method is proposed in [4]. In this method, the observers can interactively select a preferred video clip from a set of alternative options (The video clips can be long or short video sequences), and then use the input control devices to evaluate any specific location in the video image sequence. An improved VQA (video quality assessment) method is proposed in [5]. The method explores the impact of reducing the sequence length upon the perceptual accuracy when identifying compression artifacts. A group of four reference sequences, together with five levels of distortion, are used to compare the subjective ratings of viewers watching videos between 1.5 and 10 s long. By setting a smoothing function, it shows that the accuracy increases linearly with the sequence length from 1.5 s to 7 s, and achieves a satisfactory accuracy level between 5 s and 10 s.

When using the objective evaluation method to evaluate the service quality of video streaming media, it mainly combines specific service types to analyze the influencing factors of the service QoE, and uses numerical calculation to complete the quantification of the service QoE. A coding video quality evaluation method considering the video quality time conversion is proposed in [6]. In this method, according to the short-term characteristics of the human memory, the weighted average of the frame quality is obtained by the weighted function calculation, and the genetic algorithm is used to calculate the optimal weighted function of each coded video. A novel multicast service for the IEEE 802.11 WLAN standard is proposed in [7]. The method combines a novel MAC scheme and layered video, guaranteeing a minimum acceptable video quality to all the members of the multicast group through the base layer. A multi-factor QoE evaluation method is proposed in [8]. This method establishes a video content classification mechanism, and then synthetically evaluates the video QoE according to the content type of the H.264/AVC coded video, the target parameters of the bit stream layer and application layer. An alternative architecture for improving the video quality in networks is proposed in [9]. In the new architecture, an algorithm to dynamically compute the MBR (maximum bit rate) for each streaming user based on the media buffer feedback is designed, it solves the problem of the video-aware multi-user resource management in modern wireless networks.

On the basis of the former two methods, when using the pseudo-subjective evaluation method to evaluate the service quality of video streaming media, it mainly designs complex training models, seeks the rules of service evaluation through large data processing, and establishes a perfect service QoE evaluation mechanism. An improved two-phase rate adaptive strategy for the user real-time video QoE is proposed in [10]. Considering the relationship among the video quality, video buffer, and video transmission rate, this strategy measures and evaluates the video QoE based on the RNN recurrent neural network. A method of evaluating the impact of network conditions on the video traffic quality based on the fuzzy expert system is presented in [11]. This method establishes the mapping relationship between the network's QoS index and user's QoE perception, deduces the membership function of the fuzzy system by using the normalized probability distribution associated with the QoS index and QoE, and designs a fuzzy reasoning rule for the video QoE evaluation. A method of QoE evaluation using idealized data clustering for the OTT video is proposed in [12]. This method uses clustering processing to divide the reliability of the video QoE evaluation subjects. By adding unreliable pseudo-participants, it provides differentiated evaluation data for the service QoE evaluation according to the level of the video transmission damage.

Through the summary of the three methods mentioned above, we can see that although the subjective evaluation method can be closer to users' perception of service quality, the implementation steps are more complicated and the cost is too high due to various factors that need to be considered in the specific implementation; the objective evaluation method has the characteristics of simplicity and practicability, but this method needs to be based on the human perception model, which requires a high accuracy of the algorithm and increases the difficulty of design. Therefore, combined with

the characteristics of the transmission demand and service content of the RT-HDMV, we choose the pseudo-subjective evaluation method to evaluate the service quality in our research work.

3. Transmission Scene of RT-HDMV

3.1. Multipath Relay Transmission Scene

We propose the multipath relay service for the RT-HDMV based on the overlay network by separating the control plane and the forwarding plane by deploying the relay server and the relay controller at the application layer without changing the existing network architecture. The relay controller performs a relay service management and control functions, and the relay server performs a media relay service [15]. The multipath relay transmission network topology is shown in Figure 1.

Figure 1. The network topology of the multipath relay transmission based on the overlay network.

As shown in Figure 1, RTs are deployed in the network layer, but they belong to the different autonomous domain (AS). UA is short for user agent located in an access network. RS and RC denote as the relay server and relay controller. They transplant the function from the network layer to the application layer [16].

Without considering the intersection of the paths, we can set up the session link of RT-HDMV between the service terminal of Alice and Bob with the default route for the network layer [17]. If the access network of the terminal is not in the transmission bottleneck, the multipath relay service can provide application relay paths for the service transmission in addition to the default path [18]. In this way, it can be used to provide real-time service to the user when the bandwidth is effectively extended.

3.2. The QoE Evaluation Scene

In order to realize the QoE evaluation of the RT-HDMV in the multipath relay transmission, we add the QoE server for performing the QoE monitoring, evaluation, and management in the application layer. The QoE evaluation scene of the RT-HDMV is shown in Figure 2.

Figure 2. The quality of experience (QoE) evaluation scene of the real-time high definition medical video (RT-HDMV) based on the overlay network.

As shown in Figure 2, after the multipath discovery and selection, we construct three incompletely intersecting paths between the service terminals without considering the redundant transmission (path 1 is the default path). The network elements involved in the QoE evaluation of RT-HDMV mainly include the service terminal, relay controller, relay servers, and QoE server.

- (1) Relay controller: It mainly performs the function of sending the session quality evaluation subscription request message to the QoE monitoring server, and the information includes the service type, service source address, service destination address, all the relay node address, and the QoS parameters of the multipath, it also sends the IP address of the own node location, and is responsible for the maintenance of the media relay node information, including the relay server registration, allocation or revocation;
- (2) Relay server: It receives the node location monitoring request sent by the QoE monitoring server and sends the relay node IP address message along with its own QoS parameter information to the QoE monitoring server. At the same time, it can receive the service information of other relay nodes and the QoE evaluation parameter information, and processes the information extraction, parameter conversion, storage, and forwarding;
- (3) QoE server: As the core of the QoE evaluation mechanism, the QoE server is responsible for the centralized QoE evaluation. After receiving all the service parameters, the QoE server performs the parameters extraction and QoE evaluation. The QoE server mainly includes four modules:
 - A. Acquisition module: Getting service transfer parameters from the service terminal, relay server and relay controller;
 - B. Analysis module: Using the measurable QoE evaluation algorithm for the service QoE score;
 - C. Decision module: Taking an appropriate control mechanism according to the service QoE score, including the sender path selection, and data load distribution ratio adjustment;
 - D. Implementation module: Guiding the service transmission according to the control mechanism.

4. Service QoE Evaluation Method

4.1. Service QoE Scoring Rules

The service QoE scoring rules of the RT-HDMV depends on the design of input and output conditions of the service QoE scoring calculation. The input conditions we designed mainly include the weights of the diversified QoS parameters and load distribution:

- (1) The QoE server chooses the diversified QoS parameters information as the judgment condition after obtaining the multipath QoS information from the relay controller, and establishes the judgment matrix by using AHP, the matrix eigenvector obtained by the normalization processing is the weight of the diversified QoS;
- (2) By solving out the feature vector of the judgment matrix and weight vector of the level-two judgment matrix, we use the linear weighting method to calculate the load distribution weight, the QoE server chooses the service load distribution optimization scheme coordinated with the relay controller.

According to the currently widely used MOS (mean opinion score), which is suggested by ITU (the international telecommunication union) [19], the user's subjective perception of the quality of service can be divided into five levels, as shown in Table 1.

Table 1. User's subjective expectation setting.

MOS Grade	QoE Score Interval	Subjective Feeling	Degree of Damage
5	0.8~1.0	Excellent	No perceiving
4	0.6~0.8	Good	Can be perceived but not serious
3	0.4~0.6	Common	Slight
2	0.2~0.4	Bad	Serious
1	0~0.2	Very bad	Very serious

As shown in Table 1, according to different MOS levels, we choose the QoE score as the output condition and correspond the QoE score with the MOS level.

4.2. Service QoS Weight and Load Distribution Weight

In the multipath relay transmission scene, the QoE of the RT-HDMV depends on the coupling of the service media data and multipath QoS parameters, which has many differences from the conventional single-path transmission, such as delay, jitter, packet loss, and bandwidth, they determine the final score of QoE [20–22]. In order to guarantee the QoE of the multipath relay service, we put the complex problem into a number of levels and elements of the method, use AHP to calculate the weight of the QoS parameters and sub-paths, and then get the load distribution strategy. The implementation steps are as follows:

- (1) Building judgment matrix: We choose the QoE as the judging criterion from the technical level, and establish the judgment matrix through the comparison of the multipath QoS parameters. The established judgment matrix is:

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1i} \\ q_{21} & q_{22} & \ddots & q_{2i} \\ \vdots & \vdots & & \vdots \\ q_{j1} & q_{j2} & \cdots & q_{ji} \end{bmatrix} \quad i, j = 1, 2, \dots, 5 \quad (1)$$

Based on the expert experience and the previous discussion of the relationship between the QoE and QoS, we set the QoS including the delay (q_1), jitter (q_2), packet loss rate (q_3), bandwidth (q_4), and burstiness (q_5).

- (2) Setting the judgment range: The value range of the judgment matrix is shown in Table 2.

Table 2. The scope definition table.

Criteria Scale	Definition	Criteria Scale	Definition
1	For Q, q_i and q_j are equally important	7	For Q, q_i is much more important than q_j
3	For Q, q_i is slightly more important than q_j	9	For Q, q_i is absolutely more important than q_j
5	For Q, q_i is more important than q_j	2, 4, 6, 8	Between the two judgment scale above

As shown in Table 2, we can determine the value of the judgment matrix by using the judgment range, and then get the weight of the diversified QoS by solving the matrix eigenvector:

$$W = (q_1, q_2, q_3, q_4, q_5)^T \quad (2)$$

(3) Calculation path weight: We choose the diversified QoS as the judging criteria based on formulas (1) and (2), then use the AHP to build the level-two judgment matrix according to the data of the transmission sub-paths. The level-two judgment matrix is:

$$q_x = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1i} \\ p_{21} & p_{22} & \ddots & p_{2i} \\ \vdots & \vdots & & \vdots \\ p_{j1} & p_{j2} & \cdots & p_{ji} \end{bmatrix} \quad i, j = 1, 2, \dots, 5. \quad (3)$$

As shown in formula (3), $p_{11} = 1$, p_{ij} and p_{ji} are reciprocals of each other, p_{ij} represents the comparison of the importance of the same QoS on different sub-paths, which reflects the influence of the sub-paths QoS on the overall QoS. The weights of the diversified QoS on the different sub-paths are:

$$q_x^w = (P1_{q_x}^w, P2_{q_x}^w, \dots, Pn_{q_x}^w) \quad i = 1, 2, \dots, n \quad (4)$$

As shown in formula (4), q_x^w represents the weight set of the diversified QoS parameters on the different sub-paths, $Pi_{q_x}^w$ represents the weights of the diversified QoS parameters on a particular path.

(4) Getting the load distribution policy: After the calculation of the above formulas (1)–(3), we can use the linear weighted method to calculate the load distribution weights V_{Pn} of the different sub-paths by multiplying the different QoS weights W_{q_x} and sub-paths corresponding to the weight $Pn_{q_x}^w$:

$$\begin{aligned} V_{P1} &= W_{q1} * P1_{q1}^w + W_{q2} * P1_{q2}^w + W_{q3} * P1_{q3}^w + W_{q4} * P1_{q4}^w + W_{q5} * P1_{q5}^w \\ V_{P2} &= W_{q1} * P2_{q1}^w + W_{q2} * P2_{q2}^w + W_{q3} * P2_{q3}^w + W_{q4} * P2_{q4}^w + W_{q5} * P2_{q5}^w \\ &\dots \dots \dots \dots \dots \dots \\ V_{Pn} &= W_{q1} * Pn_{q1}^w + W_{q2} * Pn_{q2}^w + W_{q3} * Pn_{q3}^w + W_{q4} * Pn_{q4}^w + W_{q5} * Pn_{q5}^w \end{aligned} \quad (5)$$

As shown in formula (5), according to the weight of the load distribution, the QoE server will be used as the load distribution strategy to guide the service transmission.

4.3. Service QoE Scoring Calculation

The service QoE score calculation process we designed includes two steps:

(1) Design the service QoE evaluation message flow: According to the multipath relay transmission scene service, the QoE evaluation message flow is shown in Figure 3.

Figure 3. The service QoE evaluation message flow.

As shown in Figure 3, after the RT-HDMV established link, the QoE server completes the service QoE score calculation work according to the input conditions, which is designed in the service QoE evaluation rules.

(2) Calculation of the service QoE score: At present, many researchers calculate the service QoE score by establishing the correlation model of the service QoE and QoS [23,24]. Through the summary and analysis of these research results, the video service QoE evaluation model can be expressed as:

$$QoE = \frac{Q_r}{10^3} (1 - QoS(X))^{\frac{RQoS(X)}{M}} \quad (6)$$

As shown in formula (6), Q_r is the video resolution, in order to guarantee the effect of the video image, it is usually 1080P; R is the correlation coefficient of the video image, it can reflect the degree of change between the images. For the medical video, because of less scene switching and higher correlation parameters of image content, according to the expression of the image correlation coefficient in the image quality evaluation, it can be set to a constant between zero and one; M is the refresh rate of the intra-frame macroblocks when the quality of the video image decreases due to the error diffusion in the process of video coding and decoding. According to the user's tolerance of the packet loss, the refresh rate is $1/p$, usually no more than 0.1; $QoS(X)$ is the normalized QoS value, it can be expressed as:

$$QoS(X) = K\{D * W_d + J * W_j + L * W_l + B * W_b + U * W_u + \dots\} \quad (7)$$

As shown in formula (7), K is the overall QoS determinant factor in different types of medical video services; D and W_d are respectively the delay and delay weight; J and W_j for the jitter and jitter weight; L and W_l for the packet loss rate and packet loss rate weight; B and W_b for the bandwidth and bandwidth weight; U and W_u for the suddenness and suddenness weight.

Due to the multipath relay transmission environment, the sub-paths service transmission is in a coupling relationship, the service QoE evaluation does not depend on single-path QoS conditions. Combining with the multipath relay transmission load distribution strategy research in the previous section, we set up the QoE evaluation model of the RT-HDMV, and make improvements for formula (7):

$$QoS(X) = \{(\sum_{i=1}^n q_1^{p_i} * V_{p_i}) * W_{q_1} + (\sum_{i=1}^n q_2^{p_i} * V_{p_i}) * W_{q_2} + (\sum_{i=1}^n q_3^{p_i} * V_{p_i}) * W_{q_3} + (\sum_{i=1}^n q_4^{p_i} * V_{p_i}) * W_{q_4} + (\sum_{i=1}^n q_5^{p_i} * V_{p_i}) * W_{q_5}\} \quad (8)$$

As shown in formula (8), $q_x^{p_i}$ represents various QoS parameters obtained from the sub-paths; V_{p_i} represents the load distribution weights for each sub-path, we can get the whole of the QoS with the method of the linear weighted sum.

5. Experiment

5.1. Building Simulation Environment

We use the discrete event simulation software OMNeT++ (Objective Modular Network Testbed in C++) to simulate the real network. By loading the INET packets, the QoE servers, relay servers, relay controllers, and service terminals are configured under the “network” and “application” files in “omnet/inet/resource” [25]. The test network topology is shown in Figure 4.

Figure 4. The test network topology based on the OMNeT++

As shown in Figure 4, the controller is the relay controller, router1 to router5 is the router that actually performs the service data transmission in the network, relays1 to relays3 is the relay server deployed on the router, qoeser is the service QoE evaluation server, which provides the guidance strategy for the service data transmission by collecting the location information of the network nodes and the status information of the network links. In the simulation environment, when the user agent sender sends the RT-HDMV requests, three incomplete intersecting transmission sub-paths are constructed between the sender and receiver by the relay controller through discovery and selection of transmission paths:

- A. Path 1 (the default path): Sender-> router1-> router4-> router3-> receiver
- B. Path 2: Sender-> router1-> router2-> router3-> receiver
- C. Path 3: Sender-> router1-> router5-> router3-> receiver

5.2. Calculating QoE Score

According to the simulation environment, we randomly initialized the link state and measured the path's QoS index when establishing the session. The QoS information of the three sub-paths in the initial state is shown in Table 3.

Table 3. The path quality of service (QoS) parameter extraction.

Path	Delay	Jitter	Packet Loss Rate	Bandwidth	Suddenness
path1	69 ms	50 ms	3%	10 Mbit/s	0.93 ms
path2	121 ms	60 ms	5%	11 Mbit/s	0.59 ms
path3	61 ms	40 ms	2%	12 Mbit/s	1.64 ms

As shown in Table 3, we assign the parameters in formula (1) based on the expert experience and user perception, and calculate the impact of the current path QoS parameters on the service QoE:

$$X = \begin{bmatrix} 1 & 5 & 4 & 6 & 2 \\ 1/5 & 1 & 1/3 & 2 & 1/4 \\ 1/4 & 3 & 1 & 3 & 1/2 \\ 1/6 & 1/2 & 1/3 & 1 & 1/5 \\ 1/2 & 4 & 2 & 5 & 1 \end{bmatrix} \quad (9)$$

After normalizing the column vectors of the judgment matrix, the matrix A is obtained:

$$A = \begin{bmatrix} 0.472 & 0.371 & 0.521 & 0.353 & 0.506 \\ 0.095 & 0.074 & 0.044 & 0.118 & 0.063 \\ 0.118 & 0.222 & 0.130 & 0.176 & 0.127 \\ 0.079 & 0.037 & 0.044 & 0.059 & 0.051 \\ 0.236 & 0.296 & 0.261 & 0.294 & 0.253 \end{bmatrix} \quad (10)$$

The weights of the diversified QoS parameters are obtained respectively:

$$W = (0.4446, 0.0788, 0.1546, 0.054, 0.268)^T \quad (11)$$

We can further calculate the weight vectors of the different QoS parameters for three disjoint paths by hierarchical sorting based on formula (3):

$$\begin{aligned} W_1^v &= (0.164, 0.298, 0.538); \\ W_2^v &= (0.32, 0.123, 0.557); \\ W_3^v &= (0.286, 0.571, 0.143); \\ W_4^v &= (0.571, 0.286, 0.143); \\ W_5^v &= (0.222, 0.667, 0.111); \end{aligned} \quad (12)$$

Based on formulas (11) and (12), we can calculate the load distribution weights of the three paths as follows:

$$\begin{aligned} V_1 &= 0.164 * 0.4446 + 0.32 * 0.0788 + 0.286 * 0.1546 + \\ &\quad 0.571 * 0.054 + 0.22 * 0.268 = 0.232 \\ V_2 &= 0.298 * 0.4446 + 0.123 * 0.0788 + 0.571 * 0.1546 + \\ &\quad 0.286 * 0.054 + 0.667 * 0.268 = 0.425 \\ V_3 &= 0.538 * 0.4446 + 0.557 * 0.0788 + 0.143 * 0.1546 + \\ &\quad 0.143 * 0.054 + 0.111 * 0.268 = 0.343 \end{aligned} \quad (13)$$

By substituting the diversified QoS parameters and the weights of the three paths into formula (8), we can get the following score of the QoS in the current transmission environment:

$$QoS(X) = 0.8468 \quad (14)$$

Due to the reason that the core area of the RT-HDMV video image is mainly the content of medical diagnosis, the *R* value can be set to 0.5 under the premise of a high image correlation. At the same

time, when the amount of the packet loss does not exceed the user's acceptable range, the M value can be set to the maximum value of 0.1. The $QoS(X)$ value is substituted for (6) to get the QoE score:

$$QoE = \frac{1080 * 1920}{10^3} (1 - 0.8468)^{\frac{0.5 * 0.8468}{0.1}} \approx 0.7364 \quad (15)$$

As shown in formula (15), according to the diversified QoS of each transmission sub-path in the current simulation environment, it can be seen from the calculation that the quality evaluation method of the RT-HDMV designed by us can obtain the score that meets the user's QoE expectation.

5.3. Test Sample Analysis

In order to verify the practical application effect of the QoE evaluation method designed in this paper, the RT-HDMV test of the terminal equipment (terminal equipment can be a telephone or a PC, etc.) is carried out without considering the coding and decoding ability of the terminal. The test scenario we selected was the remote lung cancer CT consultation (The CT scans from the LUNA16 challenge are available on the website (<https://luna16.grand-challenge.org/>)), during the video session of 1080P, the session duration was 15 min, the frame rate was 25f/s, and the video clips of 1 s were randomly intercepted as test samples, the total number of the samples was 500. The test results are shown in Figure 5.

Figure 5. Comparison of the sample transmission effect between the single and multiple transmission scene.

As shown in Figure 5, in the simulation environment shown in Table 3, we take the random test samples as an example, and take four frames as sampling intervals according to human visual characteristics. The first line is the original video frame sequence, the second line is the frame sequence of the single-path transmission (based on the default router), and the third line is the frame sequence of the multipath relay transmission. By comparing the transmission effect, we can see that the 1st frame/5th frame/17th frame in the frame sequence are less distorted after the single-path and multipath transmission, respectively, which will not affect the diagnosis results of the case. However, when transmitting the 9th frame and 13th frame, local noise appears in the video image transmitted by the single path, and the quality of the video image decreases, while the multipath transmission can still maintain a high image quality.

In order to ensure the objectivity of the test results, we reconfigured the simulation environment and tested the samples under different path conditions. The test results are shown in Figure 6.

Figure 6. Comparison of sample test results between the single and multiple transmission scene. (a,b) are comparison of the QoE results between single-path transmission and multipath relay transmission when the path conditions satisfy service transmission requirements. (c,d) are comparison of the QoE results between single-path transmission and multipath relay transmission when the path conditions can not satisfy service transmission requirements.

As shown in Figure 6, when the network is idle and the available bandwidth of the transmission path can satisfy the transmission requirements of the RT-HDMV (as shown in (a,b)), the QoE scores of the single-path transmission and multipath transmission are similar, which can achieve the desired transmission effect. However, when random background traffic is added to the network, the resulting bandwidth shortage or random congestion has a greater impact on the single-path transmission, the service QoE score decreases significantly (as shown in (c,d)). Due to the increase of the parallel transmission bandwidth, the multipath transmission obtains the corresponding load distribution through the path weight calculation, then the policies are used to guide the service transmission, which can still provide a guaranteed QoE transmission for the service.

6. Discussion

Our purpose is to establish a multipath relay service based on the overlay network. The system provides the RT-HDMV transmission service, which meets the needs of the service on the basis of breaking through the inherent single-path transmission mode. However, the QoE evaluation method of the RT-HDMV based on the multipath relay service is still in the research and development stage at present and the studies of the relevant references and technical documentations are relatively difficult to get. Therefore, we have carried out the establishment and traffic from the multipath relay scene load distribution strategy to explore the problem. There are still some defects on constructing a set of the RT-HDMV optimized transmission solutions to the practical application.

- (1) The establishment of the application layer relay transmission service involves many problems, such as the network resource scheduling, relay node deployment, and path management rules. In our research, we deploy controllers at the relay nodes to schedule network resources, without considering the balance of network resources and the design of the scheduling algorithm. For the

generation and maintenance of the relay path, we assume that the transmission process is stable (no relay node joins or exits). At this time, the QoE server cooperates with the relay controller to determine the number of parallel transmission paths and the path QoS information. In addition, through simulation experiments, we can see that the application of the multipath relay service is to better avoid the impact of the random network congestion on the service QoE, but in the idle state of the network, the advantages of the multipath relay service are not more obvious. Therefore, we need to discuss the preconditions for the application of the multipath relay service in future research work.

- (2) The load allocation strategy of the multipath relay service depends on the path condition and service type. In the real network, the path of executing the service data transmission needs a multi-hop selection, we regard the path state of each link as a whole without considering the impact of the path conditions of different segments on the strategy results. When designing the strategy, we limit the transmission path to incompletely intersecting paths. Even if the transmission quality of the single-path decreases, the specific load distribution ratio can be re-determined by calculating the weight of the QoS parameters of each sub-path without performing redundant transmission. In addition, our research work has a good application effect for RT-HDMV. In the future, we will consider expanding the research scope to the general real-time HD video services, such as IP telephony or video conferencing.
- (3) The essential purpose of the QoE calculation of the RT-HDMV is to complete the predicting function of the service transmission combining the path coupling relation and the diversified QoS information. The establishment of the expert database based on big data processing can provide the QoE of the RT-HDMV while obtaining the evaluation results of the service. Our research work pays more attention to the real-time evaluation of the service QoE, and does not involve the establishment and maintenance of the database in the process of the RT-HDMV QoE calculation. We plan to establish a perfect evaluation mechanism of the service QoE through the accumulation of historical data in future work.

7. Conclusions

The main contributions of the paper include using the SDN design idea to design the overlay definition software, and establish the multipath relay transmission scenarios through the network resource scheduling and application layer relay node deployment. In the scenario, in order to meet the QoE requirements of the RT-HDMV service, we establish the QoE evaluation rules and processes based on the characteristics of the multipath diversity and the coupling relationship of the multipath transmission. On the basis of calculating the weight of diversified QoS parameters and sub-paths using AHP, we get the load distribution strategy and QoE score of the service. The simulation results show that the scheme can make better use of network resources and expand the transmission bandwidth, and effectively avoid the impact of the random network congestion on the quality of the RT-HDMV service under a single-path transmission mode from the perspective of the transmission optimization. Through a real-time load distribution strategy selection and QoE score calculation, it can provide reliable transmission of the QoE guarantee for RT-HDMV.

Author Contributions: Conceptualization, Y.Z., W.L., W.Z., Y.G.; Data Curation, Y.Z.; Formal Analysis, Y.Z.; Investigation, Y.Z., Y.G.; Methodology, Y.Z., W.L. and W.Z.; Supervision, W.L. and W.Z.; Validation, Y.Z.; Writing—Original Draft Preparation, Y.Z.; Writing—Review and Editing, Y.Z., W.L. and W.Z.

Funding: This work was supported by the National Key Research and Development Program of China Grant No. 2018YFB1702000, the National Natural Science Foundation of China Grant No. 61671141, and the Liaoning Provincial Natural Science Foundation of China Grant No. 20180551007.

Conflicts of Interest: The authors declare no conflict of interest.

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