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A Bayesian NetworkBased MethodforService Quality Optimization

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Abstract

Video conference, as an application of Internet streaming media, has attracted wide attention from both academic and industrial sectors. However, usersmay encounter many problemsindailyuse, such as poor video quality, playback delay, and lack of adjustable context, whichcausenegative impactson customers'usage experience. Existing end-to-end service quality assurance method mainly analyzes the relationship between the target service quality parameters and the context in a "single" manner. In this paper, we propose a Bayesian network-based service quality assurance method (named as Comprehensively Context-Aware approach, CCA), which combines Bayesian network and fuzzy set theoryand obtainsrandomrelationshipsamongdifferent service quality parameters through contextual awareness. Comprehensive experimentsclearly validate the superiority of CCA against other well-established methods.

Keywords: video conference, servicequality, Bayesian network, contextual awareness

1. Introduction

In recent years, web-based communication service has become a research hotspot (Cheng, 2012, pp.696-705; Chou, 2007). It closely combines the upper application service with the underlying communication platform to effectively support transaction processing under the service-oriented architecture. Service Oriented Communication (SOC) is apromising research direction of service-oriented architecture in the future (Chou, 2008, pp. 136-143).

As an important application of Internet streaming media, video conference has attracted wide attention from both academic and industrial sectors. Due to fact that existing service-oriented architecture are unable to provide effective support for streaming media transmission, users may meet a great many of problems in their actual use, such as low video quality and playdelay(Yan, 2012; Lin, 2010, pp. 2132-2144).

End-to-end service quality management has proven to be an effective solution in existing research work. According to (Yan, 2012), existing methods can be divided into two categories: active probing and passive monitoring. However, a common problem with respect to these two kinds of methods is that they analyze the relationship between service quality parameters and the context in an "isolated" manner, which may cause many problems and have a bad effect on the service quality. For example, context adjustment method based on network bandwidth awareness aims to maximize the throughput of the upper application, which fails to work when the type of the upper application is Constant Bit Rate (CBR).

In this paper, we comprehensively analyze and utilize the relationship between the service quality parameters and the context, and propose an end-to-end service quality assurance method for video conference. Experimental results show that the proposed method can effectively reduce the playback delay and increase the throughput.

2. MethodDesign

In this section, we introduce thecontext comprehensive awarenessbasedservice quality assurance method. The overall design of this method is shown in Fig. 1. Since the service quality parameters and the context need to be fed back from the client, the monitoring software is installed on the client. Specific contexts corresponding to different users, e.g., available bandwidth and buffer length, are obtained through establishing communication protocols between the server and the client.

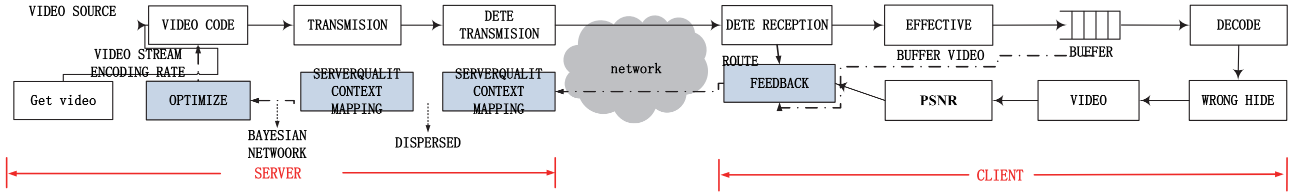

Figure 1. Overall design of our method

2.1 Information Feedback and Learning

The "information" described in this section includes the context and service quality parameters. In order to mine the random relationship between the service quality parameters and the context, we take advantage of fuzzy logic so as to map inaccurate values to explicit values and present an adaptive context/service quality parameters discretization method. The approximated Gaussian probability density function can be expressed as:

$$f(x)=\sum_{i=1}^{n} a_i \exp\left(-\left(\frac{x-b_i}{c_i}\right)^2\right),$$

Where$n$ represents the total number of examples, a_i denotes the coefficient of the i-th element, and b_i, c_i are the expected value and standard deviation of the i-th element, respectively. Algorithm 1 shows the procedure of learning service quality parameters and context.

Algorithm 1 Service Quality Parameters and Context Learning

Input: Service quality parameters/context samples set S

Output: Discrete set DS of samples S

1. $\{D, M\} \Leftarrow \text{Dis-Mem}(S)$; // Call function Dis-Men
2. **FOR ALL** *sample* $s \in S$ **DO**
3. $\quad s \Leftrightarrow D$;
4. $\quad s \Leftarrow D$;
5. **END FOR**
6. **RETURN** DS;

Procedure Dis-Mem(S):

1. $ProbDens \Leftarrow \text{K-DENSITY}(S)$; //Usekerneldensity method to estimate probability density
2. $\{GF, MSRM\} \Leftarrow \text{GUASSIAN-FITTING}(ProbDens)$; // Call Gaussian method to correct $ProbDens$
3. $a_{\max} \Leftarrow 0$;
4. $temp \Leftarrow 0$;
5. **FOR EACH** $t \in G$ **DO**
6. $\quad temp \Leftarrow temp + 1$;
7. $\quad M[temp] \Leftarrow t$;
8. $\quad D[temp] \Leftarrow cnt$;
9. **END FOR**

2.2 Service Quality-Context Mapping

After learning and discretizing context/service quality parameters, we apply Bayesian network (Cooper, 1992, pp. 309-347) during the modeling process. Concretely, targetservice quality parameters are regarded as child nodes, and contexts are treated as parent nodes. In order to reflect the impact of context on service quality, Bayesian network structure learning algorithm is exploited to construct directed graph. The Bayesian network consists of directed graphs and conditional probability tables. Assume that the Bayesian network is denoted as $G=(V,E)$, where V is the set of all nodes and E is the set of all edges in the directed graph. If node v_a is the parent node of v_b, then there is a directed edge from v_a to v_b, which represents the random relationship between the service quality and the context. Since we only need to store the condition probabilities of parent nodes, the space occupied by condition probability table can be reduced dramatically.

We take service quality parameters and context into account, and apply Bayesian network to obtain a directed graph, which is shown in Fig. 2.

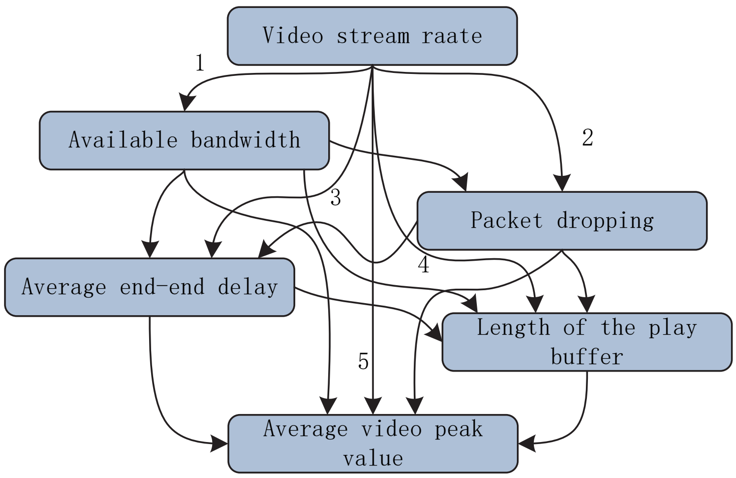

Figure 2. Bayesian network directed graph

Algorithm 2 gives the process of service quality-context Mapping.

Algorithm 2 Service QualityParameters-Context Mapping

1. Use the method discussed in this section to sort the context/service quality parameters in the order required bythealgorithm K2;

2. Applyalgorithm K2to construct a Bayesian network directed graph and a conditional probability table;

3. Employtraversal algorithm of the Bayesian network directed graph to map the service quality parameters and their contexts.

2.3 Context Adjustment Optimization

The Bayesian network directed graph and the conditional probability table are constructed in the previous section. In this section, we update the Bayesian network parameters based on context and service quality parameters, and a complete Bayesian network is obtained when relevant structures and parameters are specified. Given the data observations, Bayesian network inference can be employed to calculate the boundary values for the specified query nodes.

The purpose of the context adjustment is to optimize the targetservice quality parameters, such as maximizing video PSNR or minimizing playback delay. In order to take multiple service quality parameters into account, let the set of service quality parameters and contexts be QM and C, respectively. Algorithm 3 summarizes the procedure of context adjustment optimization.

Algorithm 3 Context Adjustment Optimization

1. The Bayesian network directed graph constructed by the method described in Section 2.2 is used to find the parent node of the context/service quality parameters through the directed graph traversal algorithm;

2. Remove the unadjustable context set from the context set $C$to get an adjustable context set; $C' = C - C_p$

3. Calculate query nodes' edge values, context parameters, given observations, and adjustable contexts;

4. For the target service quality parameter set QM, target valuesare selected from different discrete values, andcorresponding adjustment value is selected from the context for each target value;

5. Adjustelements in the adjustable context set C' to target values, so that the service quality parameter qm_i can be adjusted to q_i with probability p.

3. Method Implementation

This section discusses the realization of the proposed comprehensive awareness method. First, we introduce the architecture design and core components of the conference system, and then giverelevant implementation details.

The overall architecture of the conference system is shown in Fig. 3. The conference system includes some real-time communication services, such as video and audio conference, short message service, and some non-real-time communication services, such as user authentication and charging services. Therefore, the design and implementation of the system must take into account the requirementsofthese services. The core part of this system, Enterprise Service Bus (ESB), is based on the open source project Servicemix(ServiceMix, 2017). The purpose of introducing the service bus is to modularize the entire system. Major modules in the figureare responsible for different functions, and theyare tightly coupled via the bus.

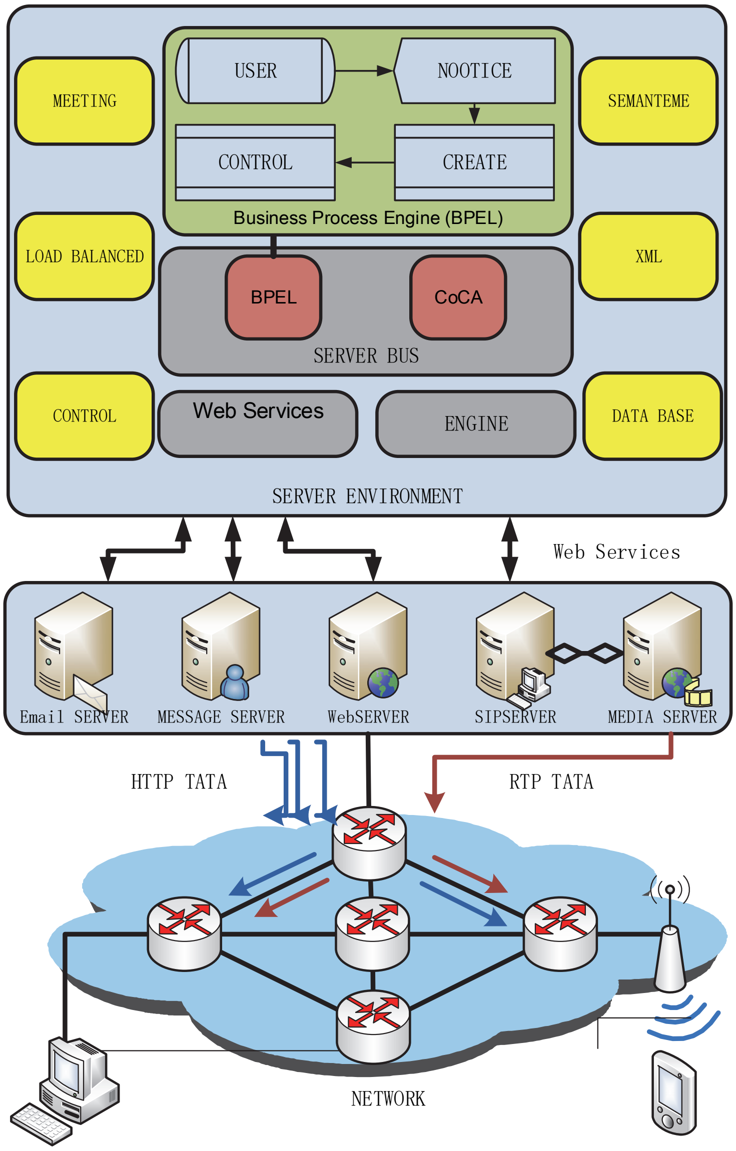

Figure 3. Overall architecture of the conference system

In the enterprise service bus, the Business Process Execution Language (BPEL) engine is responsible for processing the various processes of the conference, such as user login, conference notification, conference creation, and conference process monitoring. In order to ensure the high efficiency of streaming media transmission, the media server and the client communicate in real time through the RTP protocolafter the conference is successfully created. The reason for using BPEL is that the system needs to meet the needs of different typesof users, such as enterprises, governments, and individuals. We observe that BPEL engine can efficiently deal with the concurrent conference requests with a number of 1000 or more.

The telecom service engine is based on the open source projectMobicents(Mobicents, 2017), which is a highly scalable, event-driven middleware platform. The specific procedure for implementing the CCA method based on this SOA architecture will be described later.

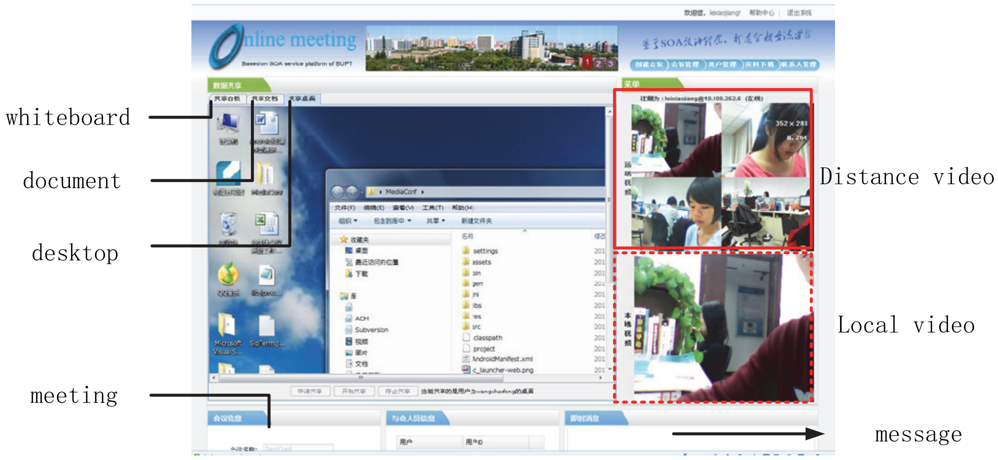

Figure 4. Userinterface of the conference system

The user interface of the conference system is shown in Fig. 4. The implementation of the CCA method proposed in this paper requires both the server and the client to modify and extend theirsoftware. The main function module is implemented in the enterprise service bus (ESB), andthe video traffic (coding rate) control function is implemented by a JAVA interface provided by a media processing server manufacturer. In the main program, this function interface is invoked to adjust the video traffic in real time.

4. Experiment

Inthis section, weconduct a plenty of experimentsto validate the effectiveness of our method.

4.1 Experimental Method

4.1.1 Experimental Environment

In order to simulatethe actual network, weestablish the host and the simulated network environment using the simulation server. Fig. 5 showsthe network topology, wherethe media server and the receivers are respectively mapped to specific nodes in the simulated network.

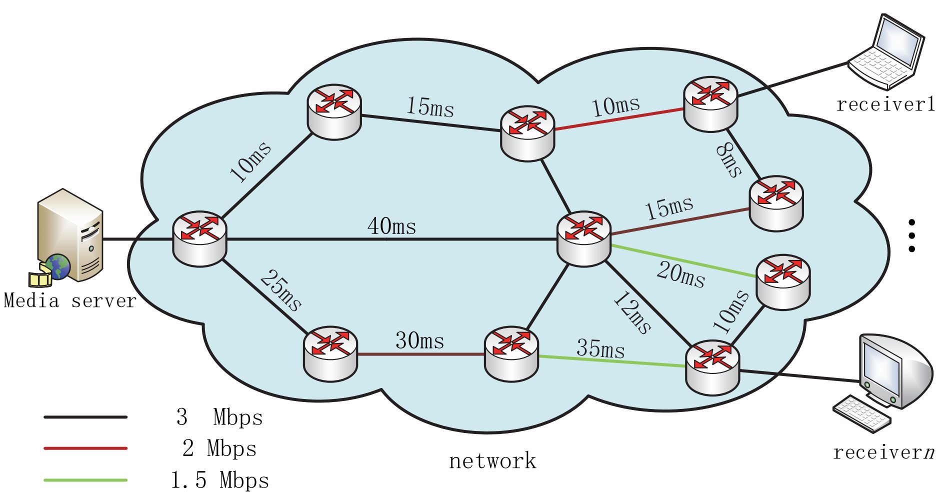

Figure 5. Network topology

In the actual network, background traffic is a factor that must be takenintoconsideration, and we adopt three background traffics, namely FTP, CBR, and Pareto. The parameter settings are shown in Table 1.

Table 1. Background traffic parameter settings

Parameter	FTP	CBR	Pareto
Start time (seconds)	Rand[0,100]	Rand[0,50]	Rand[50,150]
Duration (seconds)	Rand[0,300]	Rand[50, 200]	Rand[50, 150]
Packet length (bytes)	1500	500	1000
Data size	Rand[0,300]KB	Rand[5,50]MB	N/A

4.1.2 Experimental Parameters

In this paper,twowidely-usedparametersare employed to evaluate the performance of different methods.

(1) Playback delay. Playback delay is the sustained play time of the video stored in the playback buffer. This parameter can reflect the delay performance of various methods. In the real-time video application, the delay is an important parameterthat directly influence user’s experience. Long delaywill cause a series of problems, such asvideo intermittent, frame dropping, andframe skipping.

(2) Throughput. The throughput refers to the actual network bandwidth occupied by the video stream. As discussed in the previous section, too much or too little video streaming throughput may engender video quality degradation. Weuse a data analysis tool called Analyzer to obtain itsvalue.

4.1.3 Comparative Approach

In the experiment, the CCA method proposed in this paper is compared withtwostate-of-the-artmethodsto validate its performance:

(1) Bandwidth Aware (BA) method (Xiang, 2012, pp. 167-172; Miller, 2012, pp. 173-178). Itsmain principle is to dynamically adjust the video stream rate according to the network bandwidth, aiming at maximizing video streaming rate within bandwidth tolerance so as to reduce video source distortion and enhance video quality. However, the main problem with this method is that as the video stream rate increases, end-to-end delay of the stream alsoincreases, which may cause more video frames to reach the client beyond their decoding time and reducethevideo quality.

(2) Playback Buffer Aware (PBA) method (De Cicco, 2011, pp. 145-156; Mok, 2012, pp. 11-22). Themain principleis to adjust the video traffic according to the remaining play time of the videoin the playback buffer. Generally, when the playtime ofthebuffered video is lower than a certain threshold, we can reduce the video traffic in order to avoid buffer starvation, and when the playtime is higher than the threshold, we can increase the video traffic in order to avoid buffer overflow. In both cases,users’ experiencewill be seriously affected. In our experiments, the upper and lower thresholds are set to 1.5 and 0.5 seconds, respectively.

4.1.4 ExperimentalScene

The number of participants is an important factor which influences the performance ofthemethod. Weset the number of participants as4, 8, 12, and 16, respectively. Each experiment is repeated morethan5 times so as to obtain the results with a 95% confidence interval. For the time series analysisresults, typical value of the minimum noise interference is selected in multiple iterations.

In reality, the increase of video traffic will not only increase the network load, but also give rise to the corresponding network cost. Therefore, the purpose of the CCA method is to maximize the video PSNR according to the lower limit of the discrete value thatwehaveobtained.

4.2 Experimental Results

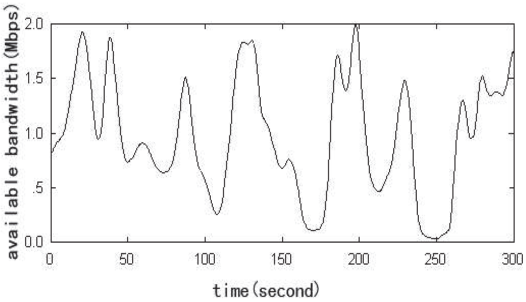

Figure 6. User's actual available bandwidth

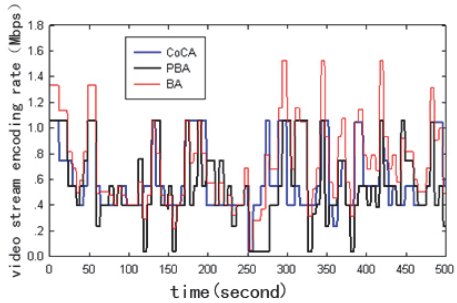

Figure 7. Adjustment values under real-time video stream encoding rate

Before presenting and discussing the results of the main experimental parameters, we first depict howthe network bandwidth changesduring the experiment. It can be seen from Fig. 6 that within [0,300] seconds, user's available network bandwidth fluctuates frequently, which mainlydue to the changesin background traffic.Fig. 7 shows the real-time video streaming rates for the three comparison methods in [0,500] seconds. We can see that the BA method can adjust the video traffic in real time according to the actual available bandwidth and in most cases the adjustment valuesare greater than the other two comparison methods. In addition, the CCA method proposed in this paper not only hasbetter real-time performancebut alsogivesbetter adjustment valuesthan the PBA method.

4.2.1 Playback Delay

As shown in Fig. 8, the PBA has the lowest average playback delay among all the comparison methods, and the CCA's delay is lower than the BA. Thisis mainly becausethe video stream rate adjustment value of BA is higher than the other two methods, which further brings about greater end-to-end delay of thevideo streaming. Fig. 9givesuser's average playback delay within [0,500] seconds, which shows thatthe PBA method can effectively adjust the video traffic in real time according to the length of the play buffer, makingthe video play time in most cases within [0.5, 1.5] seconds. Furthermore, although the performance of CCAis inferior to the PBA, CCA is able to effectively avoidbuffer starvation, i.e., the playback delay is greater than 0.5 seconds. Compared to PBA and CCA, BA adjusts video streaming with a fasterrate, resulting in larger end-to-end delay.

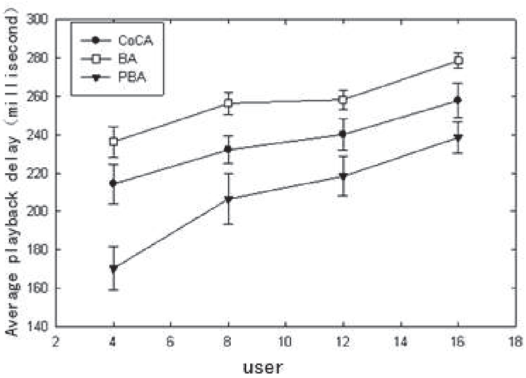

Figure 8. Average playback delay

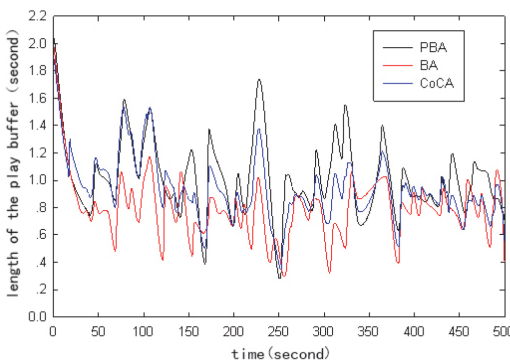

Figure 9. Instantaneous values of user's play back delay

4.2.2 Throughput

Fig. 10 shows the instantaneous values of the throughput in [0,300] seconds. Wecan observe thatBA and PBA'sthroughputvaluesfluctuatemore wildlythan CCA, which impliesthat userexperience of CCA is much better that the other two.

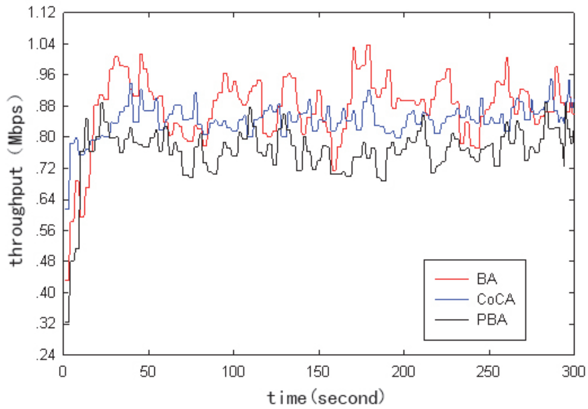

Figure 10. Instantaneous values of the throughput in [0,300] seconds

5. Conclusion

This paper proposes an end-to-end service quality assurance method for video conference based on Bayesian network. We comprehensively analyze and utilize the relationship between theservice quality parameters and the context, and combine Bayesian network and fuzzy set theory to obtain random relationships among different service quality parameters through contextual awareness. Experimental results show that the proposed method can effectively reduce the playback delay and increase the throughput. In the future,weplan to develop the system running on mobile devicesandinvestigate the performance of our method on mobile devices.

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