

QoS-Factor Transmission Control Mechanism for Voice over IP Network based on RTCP-XR Scheme

Jinsul Kim, Seung Ho Han, Hyun-Woo Lee, Won Ryu, and Minsoo Hahn

Abstract — *With the increasing demand for Internet telephony services by using the Voice over IP (VoIP) technology, techniques for QoS-factor monitoring over IP networks are required to manage the speech quality of VoIP services constantly. This paper presents an end-to-end bidirectional transmission control mechanism to manage QoS-factors such as jitter, delay, packet loss rate, etc., based on the RTCP-XR scheme. Also, we propose and modify the standard RTCP-XR scheme defined by IETF to perform better quality monitoring of VoIP service. In order to evaluate the newly proposed RTCP-XR scheme for VoIP services, we measure in real-time the quality degree of the received speech signal while applying our improved Packet Loss Concealment (PLC) algorithms in a G.729A codec using an implemented Session Initiation Protocol (SIP)-based SoftPhone and a 1-port gateway. And then, for the accurate QoS delivering evaluation of the RTCP-XR Scheme we applied calls through the PSTN to SIP gateways, SIP gateways to the PSTN, and SIP gateways to SIP gateways. The experimental results confirm that the applied VoIP service in real environments with the QoS-factor transmission control mechanism achieve a sufficient accuracy for quality monitoring of VoIP services¹.*

Index Terms — VoIP, QoS, Speech Quality, RTCP-XR, PLC, PESQ, E-Model

I. INTRODUCTION

As the interests in supporting IP communication tremendously increase, a variety of IP-based real time multimedia application services such as the VoIP and the MMoIP have been developed rapidly in residential and enterprise communication markets because of their attractive service enhancements and cost savings. Moreover, according to the discovery of available and suitable audiovisual services over IP, researches on the Quality of Service (QoS) for various multimedia application services are required. An important factor for VoIP QoS control technique involves the rate control, which is based largely only on network impairments such as the packet loss rate or the delay due to the network congestions [1], [2]. The

second important factor is based on the factor that different parts of speech have different perceptual importance and each part of speech does not contribute equally to the overall voice quality [3]. Hence, in our approach, voice packets that are perceptually more important are marked, i.e. acquire priority. If there is any congestion, the packets are less likely to be dropped than packets that are of less perceptual importance. The priority marking based QoS schemes are open loop ones and do not make use of changes in the network impairments. To measure the speech quality we adopt the well-known PESQ (Perceptual Evaluation of Speech Quality) algorithm, which is one of objective perceptual voice quality measurement techniques, based on the ITU-T speech quality evaluation standards [4]. Non-intrusive methods do not need a reference signal and are appropriate for monitoring the real traffic. The ITU-T E-model [5] is the most widely used non-intrusive voice quality measurement method and may be used to predict the conversational MOS (Mean Opinion Score) directly from the IP network and the terminal parameters [6].

The Real-time Transport Protocol (RTP) and RTP Control Protocol (RTCP) communications use the RTCP-Receiver Report to feedback IP network conditions from RTP receivers to RTP senders. However, the original RTCP provides overall feedback on the quality of end-to-end networks as a whole [7]. The RTP Control Protocol Extended Reports (RTCP-XR) is a new VoIP management protocol which defines a set of metrics that contains information for assessing the VoIP call quality by the IETF [8]. The RTCP-XR can be implemented as software integrated into IP phones and gateways inexpensively and then, messages containing key call-quality-related metrics are exchanged periodically between IP phones and gateways. However, in order for monitoring the QoS-factor on end-to-end VoIP networks, the RTCP-XR is insufficient to estimate the speech quality because it doesn't have any speech quality monitoring functionality. To solve this problem we propose the update of some components in RTCP-XR scheme.

Packet loss occurs inherently in an IP network due to the network characteristics such as the delay, the jitter, and network congestions. The packet loss stands missing speech samples for a time interval at receiver and brings about the degradation of the received speech quality. Since transmission is a real-time process, it is impossible to re-transmit the missed data when the data is missed. A concealment technique is required for the missed packet reconstruction. Speech codecs have their own PLC mechanisms against the packet loss. At the receiver, a new

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speech signal is generated to reduce the effect of packet loss by utilizing the PLC mechanism [9].

In this paper, for the QoS management and monitoring of the speech quality during mutual conversations over IP networks, we proposed an end-to-end bidirectional transmission control mechanism to manage the QoS-factors such as the jitter, the delay, and the packet loss rate on a modified RTCP-XR scheme. The newly presented QoS-factor transmission control mechanism is assessed with the performance analysis of the proposed PLC algorithms in VoIP speech coders. Various types of packet losses are generated by the Error Insertion Device (EID) and then the PESQ is used to evaluate both the original and the proposed PLC algorithm in G.729. Also, to measure and report the R-factors, our experiments specify the QoS performance with the objective measurement method over the IP network, i.e., E-Model.

II. VOIP NETWORK ARCHITECTURE AND PROCEDURE FOR QoS-FACTOR MANAGEMENT

A. VoIP System Architecture

Historically, voice has been delivered, either wireless or wired, in a dedicated, one-to-one circuit switched manner. This is because of the unique requirements voice traffic places on a network. It requires the low latency and jitter performance of a voice call, but places high demands on the data capacity at the same time. To guarantee the QoS for VoIP services we proposed a new architecture with a QoS measuring server.

Our proposed architecture, Fig. 1 is designed with a SoftPhone and a 1-port gateway as the main User Agent (UA) which carries QoS measurement components. Our network also includes SIP servers and a QoS-factor monitoring server for the call and QoS control.

B. Real-time QoS-Factor Measurement and Transmission

Because present IP networks are not designed to support the QoS, the quality measurement becomes more important and urgent for more reliable higher quality multimedia services over IP networks. We explore the impact of the individual packet loss, the delay, and the jitter on the perceptual speech quality in VoIP systems. The VoIP service quality evaluation is carried out by firstly encoding the input speech pre-modified with given network parameter values and then decoded to generate degraded output speech signals. In order to obtain an end-to-end (E2E) MOS between the caller-UA and the callee-UA, we apply the PESQ and the E-Model method. In detail, to obtain the R factors for E2E measurement over the IP network we need to get I_d , I_e , I_s and I_j . Here, I_j is newly defined as in equation (1) to represent the E2E jitter parameter.

$$R \text{ factor} = R0 - I_s - I_d - I_j - I_e + A \quad (1)$$

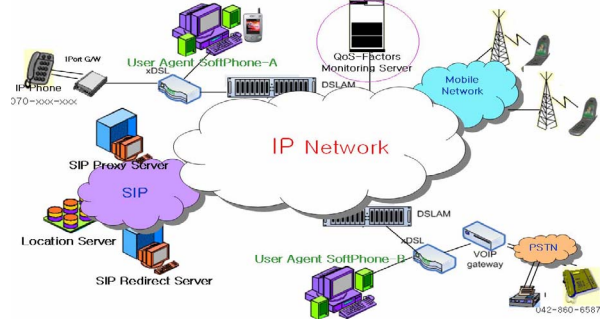


Fig. 1. VoIP network architecture

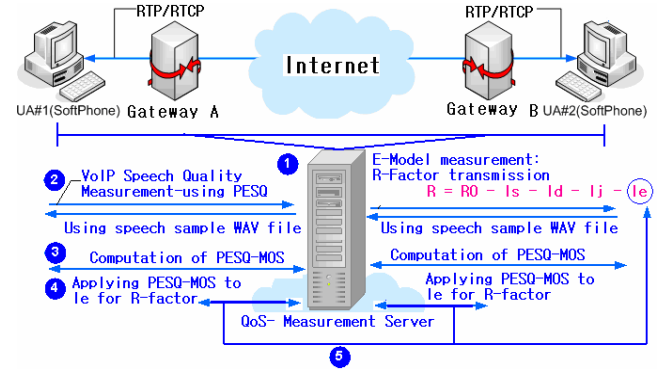


Fig. 2. Procedure of QoS-Factor measurement and transmission

The ITU-T Recommendation provides most of the values and methods to get parameter values except I_e for the G.729A codec, I_d and I_j . First, we obtain I_e value after the PESQ algorithm applied. Second, we apply the PESQ values to I_e value of R-factor as shown in Fig.2. We measure the E2E I_d and I_j from our current network environment. By combining I_e , I_d and I_j , the final R factor could be computed for the E2E QoS performance results. Finally, obtained R factor is reconverted to MOS by using equation (2), which is redefined by the ITU-T SG12.

$$\begin{cases} R \leq 6.5: MOS = 1 \\ 6.5 \leq R \leq 100: MOS = 1 - \frac{7}{1000}R + \frac{7}{6250}R^2 - \frac{7}{1000000}R^3 \\ R \geq 100: MOS = 4.5 \end{cases} \quad (2)$$

III. QoS-FACTOR TRANSMISSION CONTROL MECHANISM BASED IN RTCP-XR SCHEME

A. Operation Procedure with Voice Packet Transmission

The RTP protocol is used for transmitting real-time data information and the RTCP, for sending the control information. The main function of the RTCP is to provide a detailed representation of the voice packets exchanged during an RTP session. Its structure includes the sender report (SR) and the receiver report (RR) transmitted periodically to all participants in the session. It aims at providing a feedback on the quality of the transmission (e.g., delay jitter, average packet loss, etc.), where transmitters

send “sender reports” and receivers send “receiver reports” using the RTCP-XR. While the SR includes transmission and reception information for active senders in the session, the RR would also contain the reception information for non-active senders. The QoS measurement server receives the QoS-factor and reports them to the QoS-monitoring interface every 2-second. Fig. 2 also shows that the procedure of the RTP/RTCP/RTCP-XR packet transmission with the QoS measurement procedure.

B. Conversational Speech Quality Monitoring with Modified RTCP-XR Scheme

For the conversational speech quality we have developed an RTCP-based packet structure to provide an end-to-end bidirectional transmission control that can report the delay, the jitter, and the packet losses in a timely manner. Our packet structure is similar to the RTCP-XR, which is primarily defined to provide more detailed statistics, particularly for multicast applications [8]. In our case, the RTCP-XR scheme was specifically designed to report the delay, the jitter, and the packet losses for every frame of voice signal. Also, the loss and the discard rates are designed to be calculated for each session at the end-receiver in order to get real-time measured values. The original RTCP-XR packet type defined can be used for speech quality monitoring. However, it is not familiar with real-time speech quality reporting for bidirectional conversation through VoIP networks. We modified the RTCP-XR packet scheme in order for conversational speech quality reporting and monitoring because communication services like the VoIP must be recognized as the mutual conversation one.

For the delay monitoring as one of the significant QoS-factor BT-5 is formatted with both sub-block 1 and sub-block 2. SSRC_1 and SRRC_2 are for the sender and the receiver numbers which is defined randomly. The DLRR in sub-block 1 reports the one way delay between the sender and the receiver. The DLRR in sub-block 2 reports the round trip delay which is measured using the one way delay information from DLLR in sub-block 1. Fig. 3 shows the message format-II of BT-5 for delay monitoring. In Fig. 4, information of the jitter and the packets is controlled in BT-6. At first, in order to manage the jitter, we categorize it into three levels of min_jitter, max_jitter, and mean-jitter. Those are reported as the cumulative effects of jitter values obtained through the jitter buffer in our cases. Second, to get the real-time mutual communication speech quality monitoring field of packet count information of the RTP/RTCP is included in the report block. The Tx/Rx RTP Packets format in BT-6 is designed for monitoring sender/receiver RTP. The Rx RTCP Packets are the RTCP XR packets which are received at the QoS measurement server, and the Tx RTCP Packets are the RTCP XR packets which are sent from the SoftPhone (or Iport Gateway) to the QoS measurement server. The bidirectional QoS-factor is also measured in real-time and reported to the QoS-Monitoring device. The final result value of the cumulative packet loss is also included in our BT-6 scheme. The format

of our BT-7 scheme is similar to the standard RTCP-XR. However, the loss and the discard rates are computed as soon as the call session stats by using the cumulative packets controlled by BT-6. The accuracy of each packet counting in real-time is important. Especially, for time synchronization we set our execution time of both the SoftPhone and the 1-port gateway to the NTP (National Time Protocol). That is, the host system time is synchronized with the national standard time. Finally, by applying the QoS-factor obtained from the bidirectional speech quality measurement MOS-LQ and MOS-CQ is defined separately for the listening quality and the conversational quality. Other factors in BT-7 are just added to the standard format scheme as shown in Fig. 5.

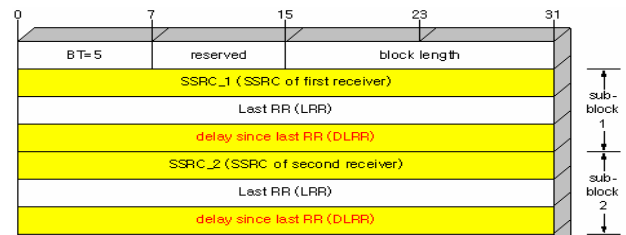


Fig. 3. QoS-factor: BT=5 delay monitoring for transmission control

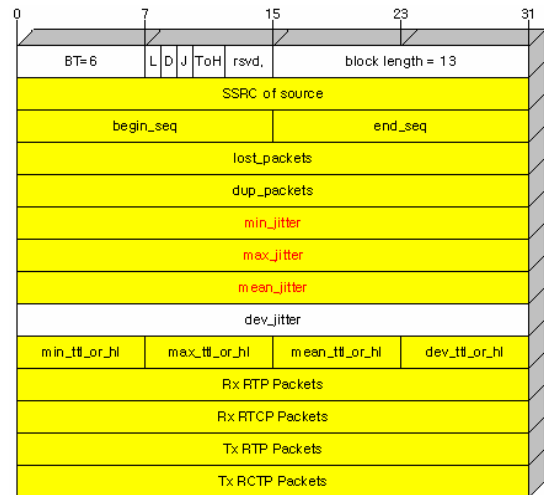


Fig. 4. QoS-factor: BT=6 jitter, packets for transmission control

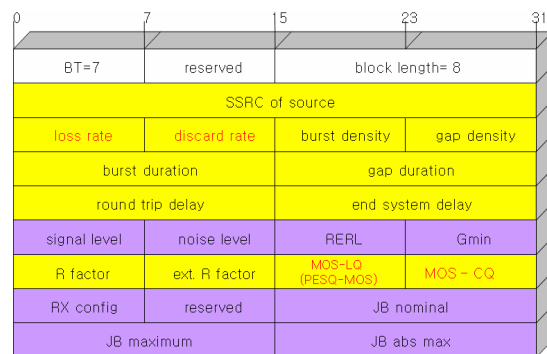


Fig. 5. QoS-factor: BT=7 loss & discard late, MOS-LQ, & -CQ for transmission control

IV. PROPOSED PLC ALGORITHMS

When packet losses occur over IP networks, the PLC algorithm employed in G.729A reconstructs lost speech frames based on the previously received speech information [9]. In this paper, two techniques are proposed to construct a new PLC algorithm for G.729A. One adaptively utilizes both-side information for lost frames based on the class classification. The other is the adaptive gain control according to the average magnitude variation across the frames. We apply the algorithm to our system to prove packets loss compensation in both off-line test environment in which the decoder is modified by our PLC algorithm and real-time environment, by the transmission control mechanism based on the RTCP-XR scheme with given QoS-factors.

A. Adaptive Utilization of Both-side Information

Our improved PLC algorithm uses adaptively both-side information for lost frames with the buffer to store a succeeding frame. When both-side information is available, the proposed PLC algorithm modifies the LSP (Line Spectrum Pairs) interpolation coefficients for first subframe based on the class of the last good frame. The last good frame is classified into either the class A or the class B by the decision tree. To make out decision tree, we use the CART (Classification And Regression Tree) [10] and analyze 1000 Korean dialogue speech. The ZCR (Zero Crossing Rate) [11], the ratio between the average magnitude [11] of the current frame and that of the adjacent frame, the average magnitude ratio between the subframes in current frame, and ratio between the first value and the second value of the autocorrelation function [11] are evaluated as the feature parameters.

In the class A, the modified LSP interpolation is given as

$$q_i = 0.48q_i^{(\text{previous})} + 0.52q_i^{(\text{future})}, \quad i = 1, \dots, 10 \quad (3)$$

where q_i is the i -th LSP coefficient for the current lost frame, $q_i^{(\text{previous})}$, for the previous frame, and $q_i^{(\text{future})}$, for the future frame. And, in the class B, the modified LSP interpolation is given as

$$q_i = 0.52q_i^{(\text{previous})} + 0.48q_i^{(\text{future})}, \quad i = 1, \dots, 10. \quad (4)$$

B. Adaptive Gain Control

The PLC algorithm employed in G.729A attenuates the adaptive and fixed codebook gains as follows.

$$g_c^m = 0.98g_c^{(m-1)}, \quad g_p^m = 0.9g_p^{(m-1)} \quad (5)$$

where m is the subframe index, g_c is the fixed codebook gain, and g_p is the adaptive codebook gain.

The proposed PLC algorithm modifies the attenuation

factor based on the variation of average magnitudes between previous two frames. The variation is evaluated by G . G_I in increasing case and G_D in decreasing case are respectively calculated by

$$G_I = \frac{2E_{i-1} - E_{i-2}}{E_{i-1}}, \quad G_D = 2 - \frac{2E_{i-2} - E_{i-1}}{E_{i-1}} \quad (6)$$

where E is the average magnitude, and i is the frame index.

The adaptive and fixed codebook gains are attenuated by the new factors as follows.

$$\begin{cases} G_I > 1: g_c^m = 0.988g_c^{(m-1)}, g_p^m = 0.92g_p^{(m-1)} \\ 0.7 \leq G_D \leq 1: g_c^m = 0.98g_c^{(m-1)}, g_p^m = 0.9g_p^{(m-1)} \\ G_D < 0.7: g_c^m = 0.977g_c^{(m-1)}, g_p^m = 0.88g_p^{(m-1)} \end{cases} \quad (7)$$

V. SIMULATION SURROUNDINGS

This paper evaluates the performance of the QoS-factor transmission control mechanism with the proposed PLC algorithm under different packet loss simulating conditions. The PLC algorithm is tested in both in off-line environment and real-time environment with G.729A.

In the off-line environment, Fig. 6 shows the experimental procedure. First, speech data are encoded in the encoder. Second, packet losses are generated by the EID. Third, encoding files are decoded with and without packet losses. Finally, decoding files with packet losses are evaluated with the reference speech decoded without a packet loss in the speech quality evaluation module.

In real-time environment, our VoIP system applies the QoS-factor transmission control mechanism based on the RTCP-XR scheme for the QoS-factor management and monitoring. Fig. 7 outlines the configuration for the VoIP system test environment under test. Both the original and proposed PLC algorithms are tested each other interactively using the SoftPhone and Iport gateway.

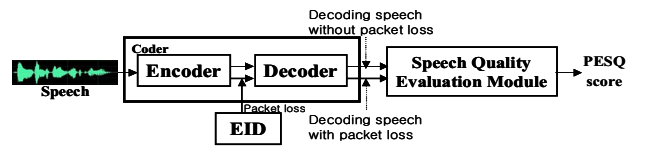


Fig. 6. Experimental procedure



Fig. 7. Configuration of simulation environment applying proposed QoS-factor scheme and improved PLC algorithm

A. Packet Loss Design

A communication channel can be modeled by the Gilbert-Elliott model [12] or the Bellcore model [13]. In the simulation, we use the STL (Software Tool Library) included in ITU-T Recommendation G.191 [14] to model packet losses. The STL provides the EID which generates losses based on the Gilbert-Elliott model and the Bellcore model. A various patterns of losses can be generated by the modification of parameters in the EID.

To model various packet loss environments, we design burst and random packet losses with 1%, 3%, 5%, 10%, and 15% loss rates and it is considered that a packet contains 1 speech frame, 2 speech frames, or 3 speech frames.

B. Performance Evaluation

For PLC algorithm performance evaluation, we use the systemic evaluation method which is PESQ defined by ITU-T Recommendation P.862 for objective assessment of quality. After comparing an original signal with a degraded one, the output of PESQ provides a score from -0.5 to 4.5 as a MOS-like score. The reference speech for the real-time environment simulation and the off-line environment simulation is the original speech and the decoded speech without any packet loss, respectively. In the real-time environment, after getting the PESQ, it is used for E-Model evaluation method as we mention above. Finally, the MOS is acquired.

We use 200 Korean dialogue speech utterances from 2 male and 2 female speakers as test data. The duration of each utterance is about 10 seconds.

VI. SIMULATION RESULTS

The simulation results show that the proposed PLC algorithm outperforms that employed in G.729A for both off-line and real-time environments. The simulation shows that the proposed QoS-factor transmission control mechanism based on the modified RTCP-XR scheme achieves much better result for speech quality than other VoIP systems which use standard scheme during bidirectional talk in IP network environment.

TABLE I
PESQ RESULT FOR OFF-LINE ENVIRONMENT

Loss type \ PLC	Original			Proposed			
	1fpp	2fpp	3fpp	1fpp	2fpp	3fpp	
Random	1%	3.952	3.912	3.939	3.976	4.003	4.005
	3%	3.569	3.488	3.500	3.615	3.637	3.605
	5%	3.319	3.239	3.234	3.386	3.417	3.359
	10%	2.936	2.818	2.776	3.038	3.030	2.932
	15%	2.658	2.537	2.475	2.787	2.751	2.642
Burst	1%	3.953	4.031	4.019	3.991	4.049	4.039
	3%	3.531	3.634	3.698	3.587	3.663	3.717
	5%	3.275	3.347	3.406	3.352	3.393	3.434
	10%	2.808	2.896	2.936	2.901	2.953	2.974
	15%	2.478	2.543	2.585	2.586	2.604	2.674

TABLE II
RESULT FOR REAL-TIME ENVIRONMENT

Loss type \ PLC	Original			Proposed			
	PESQ	R	MOS	PESQ	R	MOS	
Random	0%	3.5	72	3.7	3.5	72	3.7
	3%	3.2	63	3.4	3.3	68	3.5
	5%	3.1	62	3.2	3.2	65	3.4
	10%	2.9	57	2.9	3	58	3.0
Burst	0%	3.5	72	3.7	3.5	72	3.7
	3%	3.2	64	3.3	3.3	67	3.5
	5%	3.1	61	3.2	3.2	64	3.2
	10%	2.9	56	2.9	3.0	57	2.9

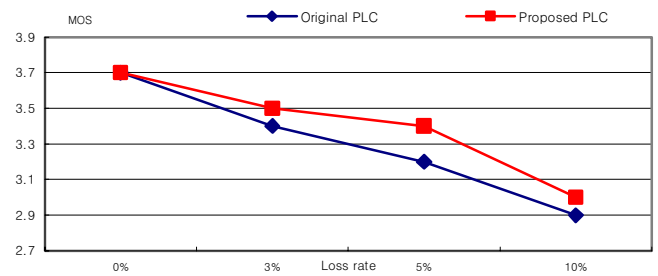


Fig. 8. MOS results for random losses in the real-time environment

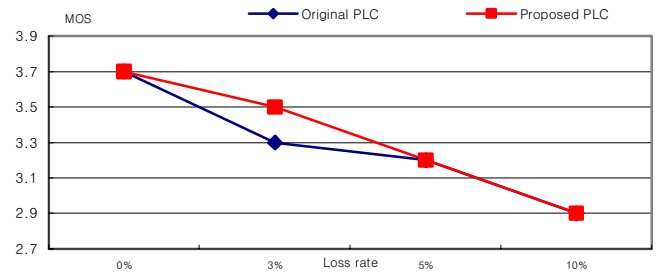


Fig. 9. MOS results for burst losses in the real-time environment

A. PESQ Measurement in Off-line Test Environment

Table I shows the results of the PLC performance evaluation in PESQ scores. In the table, 'fpp' refers to frame per packet. As the proposed PLC algorithm is applied, the PLC performance is improved. At 1fpp, the difference of the degree of improvement score between random losses and burst losses is not large. PESQ scores are increased by 0.074 on the average. On the other hands, at 2fpp and 3fpp, the degree of improvement for random losses is higher than that for burst losses because of the packetization effect. At 2fpp, the degree of the improvement for random losses is 0.169 while that for burst losses is 0.042 on the average. At 3fpp, the degree of the improvement is 0.124 for random losses and 0.0389 for burst losses, respectively.

B. PESQ, R-factor and MOS Measurement in the Real-time Environment

In Table II, the PLC performance evaluation results for the real-time environment are summarized as the PESQ, the R-factor, and the MOS. The proposed PLC achieves the

PESQ gain of 0.1 for all types of loss. The corresponding gains for the R-factors and the MOSs are achieved by this PESQ gains. Finally, even though the MOS is not improved for burst losses at high loss rates, the MOS gain of 0.1 is generally achieved as shown in Fig. 8 and Fig. 9. Thus, the improvement of the performance in the real-time environment is also confirmed.

VII. CONCLUSION

In this paper we have proposed an end-to-end bidirectional QoS-factor transmission control mechanism to manage the speech quality in real-time on modified RTCP-XR scheme for QoS monitoring of mutual conversations over IP networks. The newly presented QoS-factor transmission control mechanism is assessed with the performance analysis of the proposed PLC algorithms in off-line and real-time environment. The speech quality performance evaluation confirms that our proposed PLC algorithm outperforms the one in the G.729A speech codec. The future direction of this research will be further evaluations and verifications of the modified RTCP-XR in more complex converged networks.

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Minsoo Hahn was born in Seoul, South Korea, in 1956. He received the B.S. and the M.S. degrees in electrical engineering from Seoul National University, Seoul, South Korea, in 1979 and 1981, respectively, and the Ph.D. degree in electrical and electronics engineering from University of Florida, Florida, USA, in 1989. From 1982 to 1985, he was with Korea Research Institute of Standards and Science (KRISS), Deajeon, South Korea. From 1990 to 1997, and he was with Electronics and Telecommunications Research Institute (ETRI), Deajeon, South Korea. In 1998, he has been a faculty member of the School of Engineering, Information and Communications University (ICU). Currently, he is a Full Professor in School of Engineering, ICU and a Director in Digital Media Laboratory, ICU. His research interests include speech and audio coding, speech synthesis, noise reduction and VoIP. Recently, he is located general chair for Speech Engineering Community, South Korea.