QoE-Based Adaptive Control of Speech Quality in a VoIP Call

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***Abstract*—This study presents the idea of building a robust controller for a codec in charge of a two-way audio stream bringing together the contributions of the areas of Voice over IP (VoIP) and adaptive systems. Such a controller will be possible with the application of a solution based on the Quality of Experience (QoE) for the control problem real-time speech quality of VoIP calls for the future applications and services.**

Keywords-Quality of Experience (QoE); Voice over Internet Protocol (VoIP); Adaptive control system; speech quality; Codec Switching.

I. INTRODUCTION

Speech transmission over computer networks is liable to several impairments from both application and network layer, such as codec compression, end-to-end delay, and packet loss. In the last years, Quality of Service (QoS) control mechanisms have been developed to make optimum use of network and terminal resources in order to minimize the effects of network impairments on speech quality. Some of these mechanisms seek to adapt the voice flow or other VoIP-related parameters in accordance with significant changes in the network, end user's preferences, or service provider's requirements.

Adaptive systems in general respond to changes in their internal state or external environment with the guidance of an underlying control system. VoIP systems are particularly likely to require a dynamic adaptation solution for dealing with the complex trade-off between speech quality and impairments, due to the decentralized control nature of IP networks and the stochastic nature of data packet delivery. Although the existing adaptive solutions for QoS control of VoIP show some performance improvement and exhibit some feedback, they do not provide explicit focus on the control loop [1].

In this paper, we aim to develop a robust controller for a codec in charge of a bidirectional audio flow. This controller will take some observation variables as input, such as latency and packet loss, and map them into adjustable variables, such as packetization, bitrates, sampling frequency, redundancy level, among others. The control objective will be initially set towards speech quality performance, in terms of QoE. It can also be extended to other issues, such as energy consumption, resource optimization, security aspects, and so on.

Figure 1 and Figure 2 give an overview of the controller to be developed. Figure 1 shows the feedback loop that lies at the core of any self-adaptive system. The feedback loop, also known as adaptation or autonomic loop, typically involves four key activities: monitoring, analysis, planning, and execution [2][3].

As depicted in Figure 1, sensors collect data from the managed system. The feedback cycle starts with the monitoring of relevant data that reflect the current state of the system. Next, the system analyzes the collected data, structuring and reasoning about the raw data. Upon completing this step, decisions must be planned about how to adapt the system to reach a desirable state. Finally, to implement the decision, the system must execute it by means of available effectors. Central to this loop, there will be a knowledge base that keeps the necessary information about the managed entities and their operations.

Current VoIP solutions for QoS control of speech quality lack of this view. Bringing the control loop to surface can improve the efficiency of such solutions.

Whereas Figure 1 shows the agents that compose the control loop, Figure 2 shows the information flow among these agents. Usually, a system converts input signals into output signals by performing operations on the inputs and intermediate products. The values of measurable properties of system's states are called variables [4]. A first step in designing an adaptive mechanism is to identify the key variables of the managed system:

- Observation parameters. They are measurable variables from which the adaptive mechanism can infer the status of the managed system.
- Decision metrics. They characterize the system performance over a sampling period and that the planning agent tries to optimize. They can be equivalent to a single observation parameter, such as delay and packet loss, or a synthesis of a set of observation parameters, such as Mean Opinion Score (MOS).
- Performance references. They represent the desired system performance in terms of observation parameters.
- Adjustable parameters. They correspond to the effectors in the feedback loop (Figure 1), an attribute of the managed system that can be manipulated to apply the necessary adaptations.

Essentially, adaptive systems implement a transfer function that takes decision metrics as input and gives the amount of change (if needed) in the adjustable parameters as output.

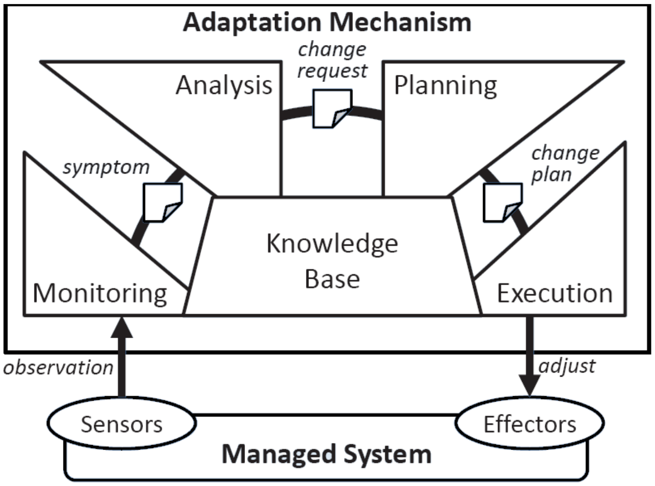

Figure 1. The feedback loop.

This project will be a follow-up of the work of Carvalho [5], in the sense of exploring newer codecs, such as Opus [6], and making use of a larger set of adjustable parameters in order to adapt the audio flow to monitored network conditions.

A. *Experimental Techniques*

The four classes of agents of the feedback control loop (Monitoring, Analysis, Planning and Execution) in Figure 1 can be arranged in different ways in order to control an audio flow between two endpoints (sender and receiver). Some of these arrangements will be implemented as candidate controllers. Hence, some comparative tests will be performed to select the best arrangement of the control loop agents.

The validation of the adaptive controller will be based on measurements over both simulated and real Internet scenarios. The audio flow will be systematically submitted to some network impairments, and its performance will be measured in terms of latency, packet loss, and MOS. Those measurements will support the researcher to check the candidate codec controllers against the following self-adaptive properties [7]: stability, accuracy, short settling time, small overshoot, robustness, and scalability.

The collected data will be analyzed by statistical tools like Akaroa [8][9] and R [10], based on statistical hypothesis testing, longitudinal data analysis, among other techniques.

B. *Work organization*

The project execution is divided into two basic steps: controller implementation and experimentation. During the controller implementation step, the researchers will design and implement an adaptive controller for an audio codec. During the experimentation phase, the controller candidates will have their performance compared in order to determine which arrangement of the control loop agents is more robust against network impairments.

The software development steps will be conducted by a PhD candidate and a student. The PhD candidate will specify the audio flow parameters that should be monitored and adjusted by the controller, and the arrangements of control loop agents that will be tested.

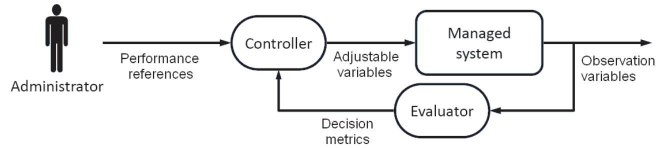

Figure 2. Variables related to a generic adaptive system.

Also, he or she will plan the experimental setup, conduct the statistical analysis of the collected data and look for improvements in controller design, code writing or experimental procedures.

The student will be responsible for writing the code of the controller candidates, and executing and automating the experimental apparatus.

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