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Quality management in GPRS networks with fuzzy case-based reasoning

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Mobile networks pose challenges to quality management because of the limited capacity of the air interface and the mobility of the users. GPRS is the prevailing system for mobile connectivity at the moment. This paper approaches quality management in GPRS networks with a two-phase system, where a detector block first culls quality disturbances and a fuzzy case-based reasoning engine then proposes a solution to the problem. The main advantage of the concept is model maintenance: the experienced network operator can take part in the decision-making and his or her knowledge thus accumulates in the case base. We also present simulated examples of GPRS network data classified with the detector and inserted into the case base.

1. Introduction

The rapid growth of telecommunications has resulted in an ongoing trend towards more complicated network systems. The growth is not always controlled; expanding and connecting subsystems of latest technology as well as legacy networks brings along management problems.

Problems in the network give rise to a need of fault management. A *fault* is a disorder occurring in the hardware or software of the managed network [1]. *Fault management* in turn is defined as a five-step process [2]: fault detection, fault location, service restoration, identification of the problem's root cause and problem resolution.

The above definition of fault management involves fault detection and location. Fault isolation and localization are further terms used in the context of fault management with more or less different shades of meaning [3]. Reported approaches to these tasks include neural networks [4], belief networks [5] and graph theory [6], just to name some of the recent ones. An extensive review is provided in [3].

In addition to faults, we address *performance management* in this paper. Performance management [2] entails problems that are not actual faults in hardware or software but may appear as faults to the user, such as excessive amount of users in a certain network segment. As these problems often pertain to the conception of quality, we use the term *quality disturbance* in this paper to denote all quality degradations originating from different causes.

Quality of Service (QoS) relates to performance management in the sense that QoS attempts to rescue the quality of the connection by dividing it into different quality classes, such as gold, silver and bronze. One of the main problems of QoS is measuring quality, particularly the quality perceived by the end user [7]. A variety of QoS parameters [8] can be measured from the network to describe the quality. We use statistical parameters to define acceptable QoS for the quality management system.

General Packet Radio Service (GPRS) is a service enabling mobile access to the Internet. In contrast to circuit-switched mobile communications, GPRS uses packet-switching, which results in effective use of radio bandwidth. This has made GPRS a system affordable to a mass market. Whether or not third generation networks will truncate the life cycle of GPRS, remains to be seen [9].

Inherent problems with mobile network QoS include link quality, mobility of the user and limitations of the portable device [10]. Combining these with the complexity of the wired network poses challenges to the quality management of GPRS networks. While some problems in the wired world can be solved simply by adding bandwidth at moderate expense, the air interface has a physical limit.

Steinder and Sethi [3] declare fault localization in mobile networks an open research problem. Indeed, very few publications cover the particular problem of GPRS networks and fault management. Yoneki and Bacon [11] introduce semantics for event correlation in complex mobile networks. In this context, event correlation is a term closely related to fault localization. Kant [12] discusses self-healing properties of wireless networks and proposes a restoration mechanism combined with QoS policies for GPRS network. Lewis has published a book on network management and case-based reasoning in 1995 [13] but at that time there were no mobile packet data networks. Thus, our fuzzy case-based reasoning approach to GPRS network quality management can be termed novel.

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The results presented here are a part of a larger research project [14]. The focus of the project was on analysis and management of networked systems by means of intelligent data analysis. Complex and changing networks call for sophisticated methods combined with the traditional tools of the very application. This paper concentrates on one such application, GPRS network, and combines an adaptive performance management system with the existing GPRS network management.

We introduce a two-phase quality management concept that consists of a detector and a fuzzy case-based reasoning (FCBR) block (Fig. 1). The detector observes measurements collected from the network and separates disturbances from normal operation. As soon as the detector detects a disturbance, it creates a *trouble ticket* [15] and passes it to the FCBR block. The trouble ticket contains all measurements at the moment as well as a number identifying the disturbance class.

When the fuzzy CBR engine gets a trouble ticket, it checks its case base to see whether an existing case matches the current one. This is where fuzziness comes in: the operator gets proposals with different membership grades that indicate the degree of match. The final decision of which case to choose is up to the operator. Most importantly, the operator also has the possibility to give feedback to the FCBR engine. Hence the case base evolves to fit the changing needs of the whole system.

While the system can adapt to conform to many kinds of fault management problems, here we refine and apply it with a GPRS network in mind. The main advantage of the concept is model maintenance: the knowledge of an experienced user inherently helps in adapting to new and changing situations. Additionally, keeping the detector and FCBR blocks separate lets one train the detector off-line and adapt the FCBR during online use. The operator needs no knowledge on the underlying algorithms or programming, he or she just provides the expertise.

The system has two major modes, off-line training and online operation. Section 2 concentrates on the off-line mode, that is, training a supervised algorithm. After the detector has been trained, Section 3 describes how detector and FCBR blocks work together online. We also present some test cases for the concept with a fluid flow model for the GPRS network in Section 4.

2. Off-line training

Clearly, the measurements available regularly from the network are not alone sufficient to distinguish between normal and disturbance states. The quality management system therefore needs a detector that is able to cull a disturbance during online operation.

The detector is trained off-line with predefined fault cases. Fig. 2 presents the arrangement in which the detector gets the same input measurements as in online operation (Fig. 1) and, additionally, disturbance classes that it is presumed to learn.

Nelles [16] divides learning methods into three categories: unsupervised, supervised and reinforcement learning methods. In managing QoS of a telecommunication network, it is possible to predefine disturbance classes and teach them to the detector off-line. In the online phase then, the class numbers are not available but the detector infers them itself. Thus, we need a supervised learning method for the task. Section 2.2 discusses the choice of the method.

A simpler approach would be to design a binary detector, that is, a subsystem that only informs the FCBR engine that a disturbance has occurred. However, distinguishing different disturbances does not differ much from distinguishing just between right and wrong, so inferring and delivering the class number is more profitable for the FCBR engine (see Section 3).

2.1. Defining quality disturbances

Defining the disturbances is a process of its own. While some of them are consequences of clear hardware failures, many disturbances may be visible only through a deterioration in some QoS parameters. As this deterioration is of statistical nature, we have to address the problem from a statistical point of view.

Suppose we have some knowledge of acceptable values of a QoS parameter. This knowledge may have come from an experienced operator, as in [17], or it may be stated in a service level agreement (SLA). As the parameter always is a random variable, it varies inside the acceptable region and, unfortunately, also outside it. All we need is a statistic, describing the distribution of the parameter, and a limit for the statistic.

Mean, median, variance and quantities are examples of useful statistics for defining quality disturbances. Fig. 3 shows an example of a statistically defined disturbance where the round-trip time between a mobile terminal and a host is significantly prolonged. The operator of the network has set a limit to "95% quantile of the round-trip time does not exceed 5000 ms". The figure presents two empirical cumulative distribution functions (CDFs), one for a normal state and one for a disturbance. The 95% quantile in the

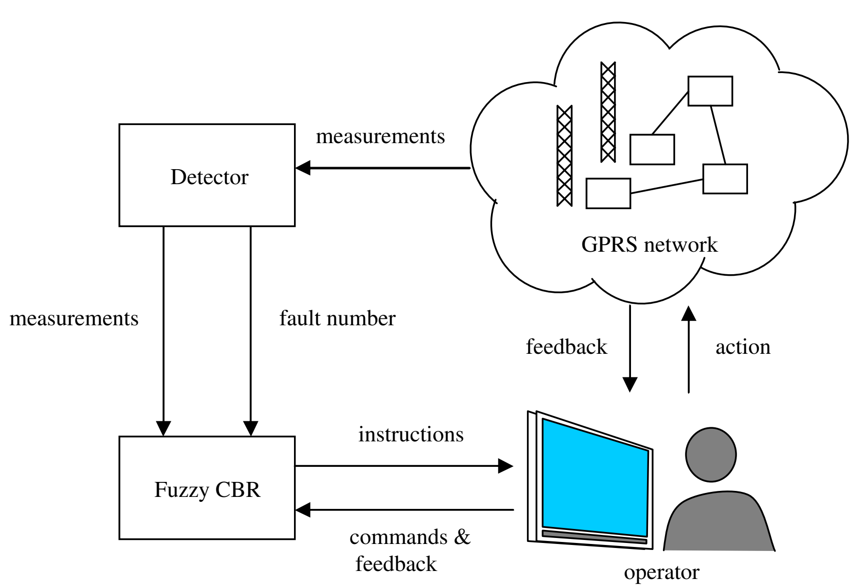

Fig. 1. Structure of the quality management system.