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Automatic diagnosis of mobile communication networks under imprecise parameters

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Abstract

In the last years, self-organization of cellular networks is becoming a crucial aspect of network management due to the increasing complexity of the networks. Automatic fault identification, i.e. diagnosis, is the most difficult task in self-healing. In this paper, a model based on discrete bayesian networks (BNs) is proposed for diagnosis of radio access networks of cellular systems. Normally, inaccuracies are unavoidable in the parameters of the model (interval limits for discretized symptoms and probabilities in the BN). In order to enhance the performance of BNs, a methodology to model the "continuity" in the human reasoning is presented, named smooth bayesian networks (SBNs). SBNs are intended to decrease the sensitivity of diagnosis accuracy to imprecision in the definition of the model parameters. An empirical research campaign has been carried out in a live GSM/GPRS network in order to assess the performance of the proposed techniques. Results have shown that SBNs outperform traditional BNs when there is inaccuracy in the model parameters.

Keywords: Automated management; Expert systems; Network operation; Diagnosis; Mobile communications; Bayesian networks; Probabilistic reasoning; Wireless networks; Self-healing; Fault management; Troubleshooting; Self-optimizing networks

1. Introduction

The mobile telecommunication industry has experienced significant changes in the recent past and it will continue evolving in the foreseeable future. In the years to come, the scenario will comprise a heterogeneous Radio Access Network (RAN) (GSM, UMTS, WLAN, etc.), applications which will require increasing bandwidth and users who will demand high quality of service at low cost, all with a limited spectrum. As a result, the operation of the RAN will be a tough challenge that the operators will have to tackle. In addition, cellular network operators will have to find ways to reduce the cost of their services and improve their quality to counter the threat posed by emerging technologies and services, such as the wide availability of WLAN-based broadband access and the launch of telephony based on WLAN.

As networks consist of a high number of pieces of equipment that are distributed across the entire country, maintaining and operating this large and technically complicated system is a difficult task that requires operator personnel around the clock in several regional offices. In a system of this size, even with reliable hardware and software there are always faults which have to be rectified as otherwise the end-user will either experience sub-optimal service levels or no service at all. As in most countries several operators are competing for subscribers, it is imperative to rectify such occurrences because otherwise users will naturally switch to competing network operators. Hence, fault management, also called troubleshooting (TS), is a key aspect of the operation of a cellular system in a competitive environment. As the RAN of cellular systems is by far the biggest part of the network, most of the TS activities are focused on this area. Faults typically include wrong installation of the hardware, incorrect parameterisation of the software, wear and tear of the installed equipment, to name just a few.

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TS comprises the isolation of faulty cells (fault detection), the identification of the fault causes (diagnosis) and the proposal and deployment of healing actions (solution deployment). Nowadays, highly experienced and, thus, expensive personnel have to be involved in the troubleshooting process. Thus, automating TS tasks would highly diminish operational expenditure.

Among troubleshooting tasks, diagnosis of the cause of faults is the most complex and time-consuming one. Surprisingly, very few references can be found on automatic diagnosis in the RAN of cellular networks, in spite of the increasing interest in this type of research shown by mobile network operators and manufacturers (Altman et al., 2006). In (Barco, Nielsen, Guerrero, Hylander, & Patel, 2002), an expert system based on discrete bayesian networks (BNs) (Pearl, 1988) was proposed for the automatic diagnosis in cellular networks. BNs were chosen because they provide a modelling approach suitable to cater for the uncertainty inherent in human reasoning. BNs have been previously applied to automatic diagnosis in other application domains, such as diagnosis of diseases in medicine (Andreassen, Woldbye, Falck, & Andersen, 1987; Ng & Ong, 2000), the troubleshooting of printer failures (Heckerman, Breese, & Rommelse, 1995; Jensen et al., 2001) and fault identification in the core network (CN) part of communication networks (Katzela & Schwartz, 1995; Steinder & Sethi, 2004). However, the techniques used in these domains cannot be directly applied to the RAN of cellular networks, due to their peculiarities, such as the inherent continuous nature of the symptoms and the existence of configuration faults.

In the RAN of cellular networks, the symptoms that may help to identify the fault cause are alarms and Key Performance Indicators (KPIs). As KPIs have values in a continuous range, they should be discretized before using them as inputs to a discrete BN. Therefore, the parameters of a model based on BNs are the thresholds for the discretization and the probabilities in the BN. Those parameters may be either elicited by experts in the RAN or calculated based on statistics from the cellular network.

Contrary to other application domains, in cellular systems there are no databases of classified cases. This is the reason why the model has to be based on knowledge, i.e. experts define the model parameters. When the number of parameters to be set is large, which is normally the case, inaccuracy in setting these parameters is unavoidable. The result is that the time required to fine-tune the model is extremely large if acceptable diagnosis accuracy is pursued. In addition, once the model is fitted for a particular situation, the performance of the diagnosis system would degrade with any small change in the cellular network. The aim of this paper is to propose a method, namely smooth bayesian networks, which overcomes the effects of inaccurate model parameters in order to enhance the diagnosis accuracy.

This paper is organized as follows: Section 2 briefly reviews concepts involved in diagnosis of cellular networks. Section 3 introduces BNs and explains how to use them for diagnosis in mobile communication networks. In Section 4, smooth bayesian networks are presented. In Section 5, the experimental setup and the results are detailed. Related work is discussed in Section 6. Finally, Section 7 presents some conclusions and future work.

2. Diagnosis in cellular networks

A *problem* is defined as a situation in a cell which has a degrading impact on the service offered by that cell. Every operator uses a different method to identify the problematic cells, which can be based on different performance indicators, e.g. dropped calls, access failures, congestion, etc. The most severe problem for mobile network operators are cells experiencing a high number of dropped calls, because a dropped call has a very negative impact on the service offered to the end user. In that sense, the dropped call rate (DCR) is a good indicator about the quality of the cell. A DCR between 1 and 2% is common for well performing cells. Once the cells with problems are isolated (e.g. DCR $\gg$ 2%), a diagnosis of the cause of the problems should be done separately for each problematic cell. A *cause* or *fault* is the defective behaviour of some logical or physical component in the cell that generates problems, e.g. interference, hardware fault, etc. A *symptom* is a KPI or an alarm whose value can be a manifestation of a fault, e.g. the number of handovers due to interference. On the one hand, KPIs are collected daily by the network management system (NMS) with the help of counters situated at different points of the network. On the other hand, the NMS provides thousands of alarms from network elements, which may help to identify the cause of the problem. When one of the faults is causing problems in a cell, the values of some KPIs change from their nominal values and some alarms may also be triggered. The aim of the automatic diagnosis system is to identify the cause of a problem based on the values of some symptoms. Details about the main causes and symptoms in the RAN of cellular networks can be found in (Barco, Wille, & Díez, 2005) for GSM/GPRS networks and in (Khanafer, Moltsen, Dubreil, Altman, & Barco, 2006) for UMTS networks.

Research studies in automation of diagnosis in the RAN of cellular networks have been focused on alarm correlation (Frohlich, Nejdl, Jobmann, & Wietgrefe, 1997; Wietgrefe, 2002; Wietgrefe et al., 1997). In current cellular networks, most systems are semi-intelligent and generate alarm messages when errors occur. The abstraction level of these alarm messages is normally very low, leading to a high number of alarms for any single cause. Alarm correlation consists in the conceptual interpretation of multiple alarms, so that new meanings are assigned to the original alarms. Although alarm correlation can be considered a first step in the diagnosis of faults, alarms do not provide enough information to identify the cause of problems, especially if the possible causes are not only faults in pieces of equipment. Even after alarm correlation, the number of