

Supporting Performance and Configuration Management of GTE Cellular Networks

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Abstract

GTE Laboratories, in cooperation with GTE Mobilnet, has developed and deployed PERFEX (PERformance Expert), an intelligent system for performance and configuration management of cellular networks. PERFEX assists cellular network performance and radio engineers in the analysis of large volumes of cellular network performance and configuration data. It helps them locate and determine the probable causes of performance problems, and provides intelligent suggestions about how to correct them. The system combines an expert cellular network performance tuning capability with a map-based graphical user interface, data visualization programs, and a set of special cellular engineering tools. PERFEX is in daily use at more than 25 GTE Mobile Switching Centers. Since the first deployment of the system in late 1993, PERFEX has become a major GTE cellular network performance optimization tool.

Introduction

During the last 5–6 years, the number of cellular service customers in the United States has increased by 30% to 40% annually. In order to meet the demand and provide high-quality service at this growth rate, the cellular industry is making huge capital investments to build the required cellular infrastructures. However, this rapid build-up of cellular networks is not sufficient to solve all of the capacity and service quality problems. Cellular networks are extremely complex hardware and software systems. There is a need for constant surveillance, analysis of hundreds of system behavioral parameters, and tuning of tens of network configuration and radio equipment parameters.

Despite the existence of mathematical models of radio wave propagation, the process of configuring and tuning a cellular system remains an area requiring significant experience and experimentation. The task facing the performance engineers is to find an optimum solution in adjusting multiple conflicting characteristics such as coverage, signal strength, number of lost calls, and voice

quality. The heuristic nature of the performance tuning process, the lack of precise solutions, and the incomplete and evolving content of the knowledge make cellular network performance analysis and tuning an ideal candidate for application of AI techniques.

PERFEX is an intelligent system for performance and configuration management of GTE cellular networks. PERFEX assists cellular network performance engineers in analyzing large volumes of cellular network performance and configuration data. It helps to locate performance violations, determines the potential causes of the violations, and provides intelligent suggestions about how to correct the occurring performance problems. The system combines expert cellular network performance tuning capability with data, network, and geographic map visualization. We found that data visualization and knowledge-based processing are complementary techniques of managing complex cellular networks. PERFEX is in daily use at more than 25 GTE Mobile Switching Centers (MCS).

Cellular network performance tuning is an integral part of the larger effort of operations support of cellular networks. These efforts include alarm/fault management, call traffic management, capacity planning, RF (radio frequency) propagation modeling, and others. Two systems in this category were described at the previous IAAI Conference: IMPACT (Jakobson, Weissman, and Goyal 1995) and AutoCell (Low et al. 1995). IMPACT is a knowledge-based network event correlation system used for real-time network surveillance and fault management. AutoCell is similar to PERFEX in its collection and display of network status and traffic data, but differs in its objectives and the methods used to implement those objectives. AutoCell collects cellular traffic data and uses heuristics to reassign channels among cells during unexpected high traffic demand or when there are faulty channels. PERFEX collects cellular network traffic and configuration data and uses a neural net to discover performance problems in the network, and then uses rules to generate expert advice on

how to fine-tune the system parameters to improve performance.

The paper first introduces the cellular domain and the problems associated with cellular network performance optimization. It then describes the method that we have adopted for performance tuning, the PERFEX system itself, the system development and deployment experience, and the benefits of using PERFEX. It concludes with lessons learned and future enhancements. A more detailed description of the PERFEX approach can be found in (Tan and Lafond 1995, 1996).

Cellular Domain

A cellular network consists of a number of radio base stations, each responsible for covering a geographical service area called a cell. A mobile unit (portable or hand-held) communicates with the base station via a separate duplex voice channel. All base stations are linked by microwave, copper, or fiber transmission facilities to an MSC. The MSC coordinates the operation of the entire system, and serves as a connection point to the public switched telephone network. A set of control (setup) channels are reserved at each base station to help the mobile unit establish and monitor the quality of the voice communication.

Since there are a fixed number of RF frequencies allocated by the FCC (Federal Communications Commission) to cellular companies, there are a limited number of calls that one base station can support simultaneously. In order to provide greater capacity, the RF channels are reused by assigning the same frequencies to nonadjacent cells. Because the location of the base stations may not be evenly spaced (especially in urban areas) and the terrain covered may vary, these reused channels may overlap each other, causing interference or even dropped calls. For example, in order to decrease the interference factor, one can lower the power of the base station radios. However, this in turn reduces the coverage footprint, and the system may lose coverage in some portion of its service area. Therefore, voice quality has to be balanced with the need for coverage and capacity. When resources such as channels and trunks are limited, performance engineers must also take traffic patterns into consideration in order to optimize the distribution of these resources. These can be done only with a great deal of knowledge and expertise by adjusting system parameters at the cell sites.

As the cellular traffic grows and new cell sites are added or sectorized, adjustments must be made to neighboring sites, and the affected sites must be monitored for performance

quality and tuned accordingly. For instance, a moving mobile unit's call should be handed over from one base station to another without dropping the call or losing the quality of the call. The candidate base stations for handoff are stored in a neighbor list. Performance tuning in this case involves updating neighbor lists and handoff thresholds so that calls are handed off smoothly between existing and new sites.

For these reasons, performance engineers continuously examine a large number of performance reports, check detailed handoff patterns, record power level measurements, and examine call processing failure messages to decide if there are problems in the network and how to solve them.

Problem Description

Monitoring system performance and tuning configuration parameters is a challenging task for most performance engineers. There are four major problems associated with the task: system dimension, incomplete knowledge, interdependency of parameters, and delayed feedback.

Practically, the system dimension problem translates into a data problem. There is a huge amount of data that performance engineers have to follow and understand. For example, a medium-size cellular network contains about 80–120 cell sites with about 200–300 antenna faces. It generates hourly more than one hundred megabytes of data per face. This data, combined with other megabytes of trunk and switch data, produces a constant flow of information which is very hard to follow and interpret. Consequently, it is not uncommon for network performance and radio field personnel to be unable to fine-tune the system in a timely manner.

The incomplete knowledge problem is due to the fact that cellular network performance optimization is a young and evolving domain. The performance data analysis and performance tuning knowledge is an evolving collection of heuristic rules, rules of thumb, and solutions often based on the intuition of performance engineers. Existing analytical relationships between the quality of service, such as the percentage of blocked calls, the system capacity, and signal strengths are sensitive to specific geographic, demographic, terrain, and other “nonanalytical” conditions. As a result, performance engineers often change system parameters on a “trial and error” basis.

Many configuration parameters are interdependent and have certain domain-specific constraints. Because of errors, ignorance, or improper use of tuning procedures, the

performance engineers may fail to maintain these interdependencies and constraints. Yet, manual discovery of incorrectly set configuration parameters is a time-consuming task. This poses a serious threat to the system performance.

The delayed feedback problem is related to the fact that the cellular network, from the standpoint of performance tuning, is a "slow" system." The effects of the application of performance tuning actions may become apparent only after analyzing several hours of performance data. Therefore, incorrect tuning actions may have a long-lasting adverse effect on system performance before they can be discovered.

Performance Tuning Method

To address the problems mentioned above, PERFEX mimics the way a human expert performs the network performance tuning task. It also automates data preprocessing and configuration checking (see Figure 1).

Initially, hundreds of performance data counts describing the functioning of all cells, faces, links, and the different call processing components of the cellular switch are collected hourly and used to calculate a limited number, usually 20–25, of performance indicators. The performance

indicators give an aggregated and quantifiable view of the state of the cellular network. Performance violations, such as call processing failures, incomplete handoffs, and blocked calls, are determined by comparing the performance indicators against performance quality thresholds. The performance quality thresholds, such as "the number of blocked calls should be less than two percent," can be changed by performance engineers.

After determining the performance violations, human experts typically examine all of the violations at one cell site and identify a problem category. The mapping from violations to problem categories varies depending on the cellular network configuration, the surrounding terrain, the nature of calling patterns, and other factors. PERFEX emulates this expert behavior by using neural networks. It identifies problem categories by using the trained neural network that maps multiple violations to categories. Currently, there are five problem categories: Interference, Coverage, Parameters, Resources, and Hardware. Each training case for the neural network contains a set of the values of violations and its associated problem categories. The training cases come from two sources: (1) expert-labeled specialized cases and (2) generic cases collected from field. For the expert-labeled cases, the problem categories are determined by the experts who take into account some nonquantifiable knowledge. The problem categories for the field collected cases are determined by

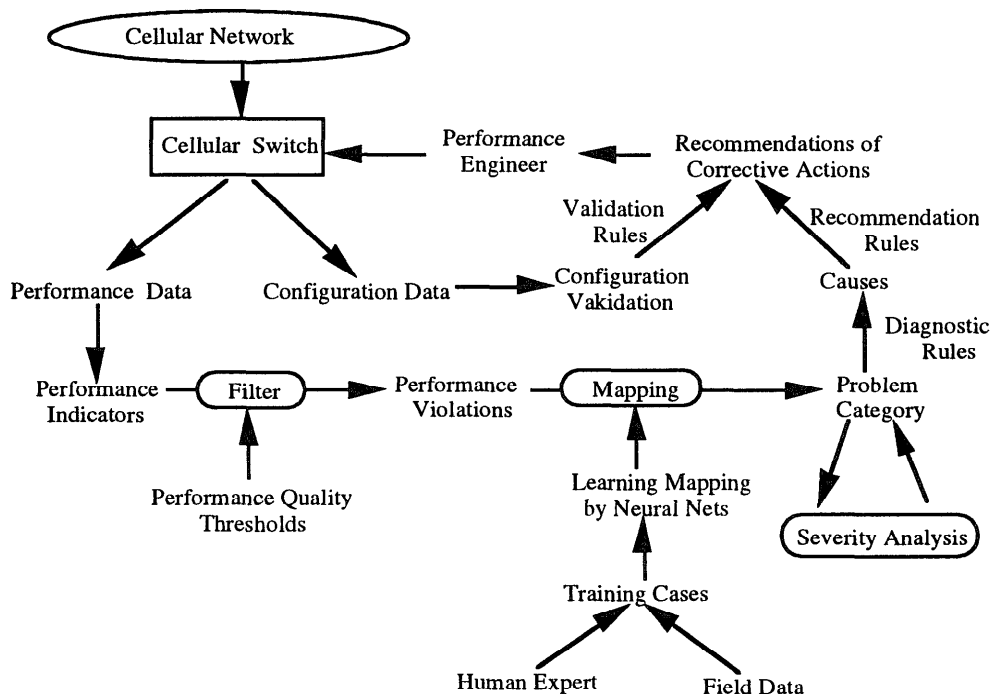


Figure 1. Performance Tuning Model

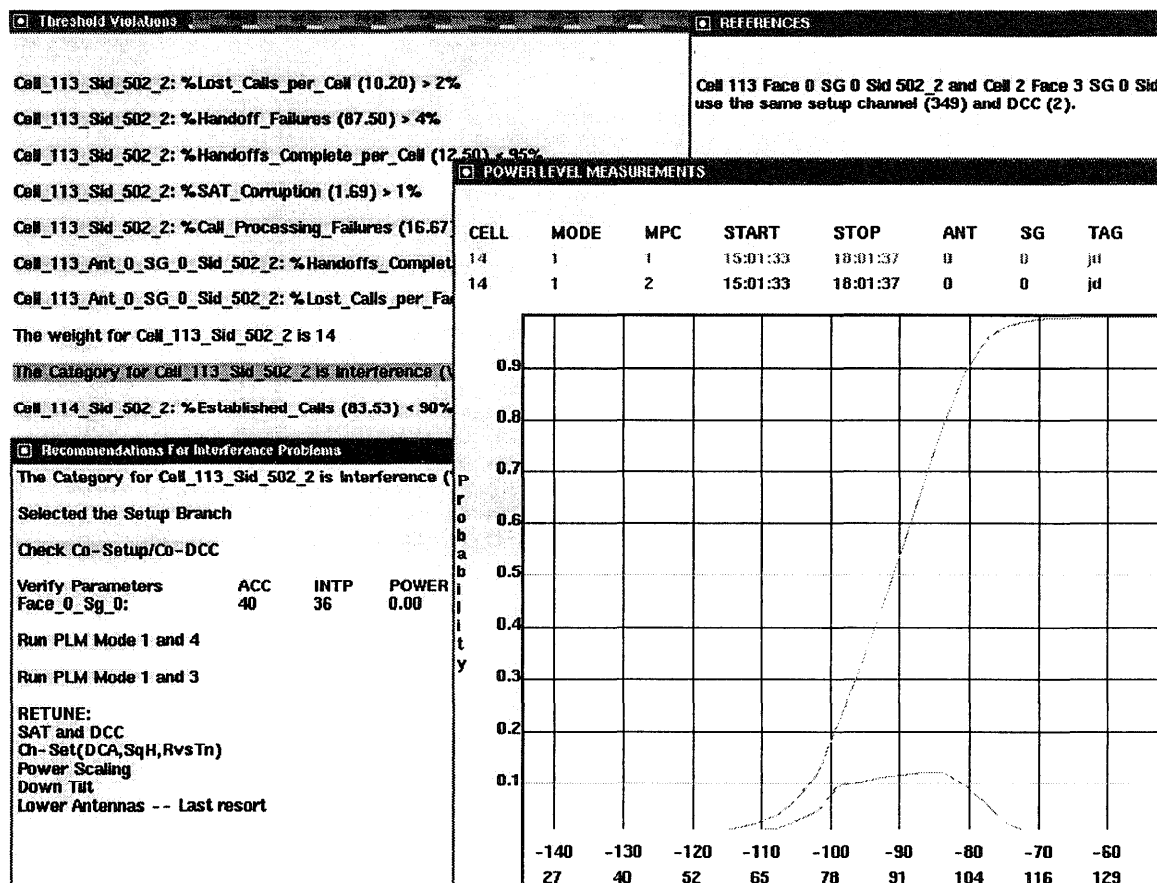


Figure 2. Multiple Violation Performance Tuning

using generic heuristics provided by human experts, which exclude any nonquantifiable knowledge. When running the neural network on new field cases, the correctness is about 90%, as judged against the generic heuristics. Results may be improved if the experts judge the correctness. The next step should be to add more specialized cases to the training set.

After the problem categories have been identified, a problem severity analysis is conducted to identify the cells with the most critical problems. For each cell and its corresponding problem category, PERFEX executes the corresponding diagnostic rules to further identify the causes. These rules can check additional performance data, scrub configuration data, verify handoff patterns, or execute special engineering tools to further analyze the problem. Finally, for the probable causes identified, PERFEX makes recommendations of corrective actions using recommendation rules. Examples of corrective actions include modifying dynamic power control parameters, reassigning handoff neighbors, scaling antenna power, down tilting the antenna, and adjusting access parameters. After corrective actions have been taken, the

performance data must be closely monitored to recognize new problems and possible side effects of the actions.

Figure 2 illustrates the performance tuning process of PERFEX. The Threshold Violations window displays a list of violations associated with cell 113. Cell 113, with the highest calculated weight of 14 for the severity of violations, is ordered first. The predicted problem category for cell 113 is Interference. The Recommendations window displays several suggestions on how to fix the Interference problem:

- Check Co-Setup/Co-DCC
- Verify Parameters ACC (Access Threshold), etc.
- Run PLM (Power Level Measurements)
- Retune SAT (Supervisory Audio Tone), etc.

For example, the first recommendation suggests checking whether there are cells which have the same setup channel and digital color code (DCC) as cell 113 and whose signal strength is strong enough to interfere with cell 113. PERFEX finds that cell 2 meets those criteria and displays it on the References window. Therefore, either the setup

channel or the digital color code of cell 113 should be modified to reduce the interference. The Power Level Measurement window shows the results of power level measurements performed as the second recommendation.

In parallel to the above-described main performance tuning loop, the network configuration data is collected daily and validated against incompleteness and inconsistency through a library of configuration scrub routines. The routines also flag configuration assignments that can potentially cause interference. The above performance tuning example actually calls one of those scrub routines to find a specific Co-Setup/Co-DCC offender.

It was clear from the beginning that traditional procedural approaches alone were insufficient to solve the problems facing the performance engineers. The mapping between performance problems and tuning recommendations is a nontrivial task of multiparameter optimization. No analytical methods existed to describe it. Initially we thought that PERFEX could be implemented exclusively as an expert system with tuning knowledge encoded as rules. As the system evolved, we realized that collecting cases for dynamic matching from performance violations to problem categories would be easier to update, and the lack of complete knowledge of how to map from multiple violations to problem categories could be compensated for by introducing a neural-net-based classification algorithm.

On the other hand, the mapping from problem categories to recommendations is relatively static and has a standard procedure to follow. This knowledge is encoded as rules.

System Description

As a central process in PERFEX, performance tuning is supported by a variety of tools grouped into the following categories: Cellular Engineering Tools, Customization Tools, and Visualization Tools (see Figure 3).

Cellular Engineering Tools are used to examine the network in finer detail. They include PLM Graph, which displays histograms of the power levels measured from selected frequencies; Interference Measurement, which gives a quick estimate of the interference experienced by a certain mobile from multiple frequencies; Handoff Matrix, which displays all of the handoffs occurring between a selected set of cells and antennas; Call Processing Failure, which displays individual call failures in greater detail; and Configuration Scrub, which is used to detect the constraint and interdependency violations between multiple configuration parameters.

Typically, a user will run the performance tuning module on the most recent performance data and look at the cells with the most critical problems in the network. Sometimes

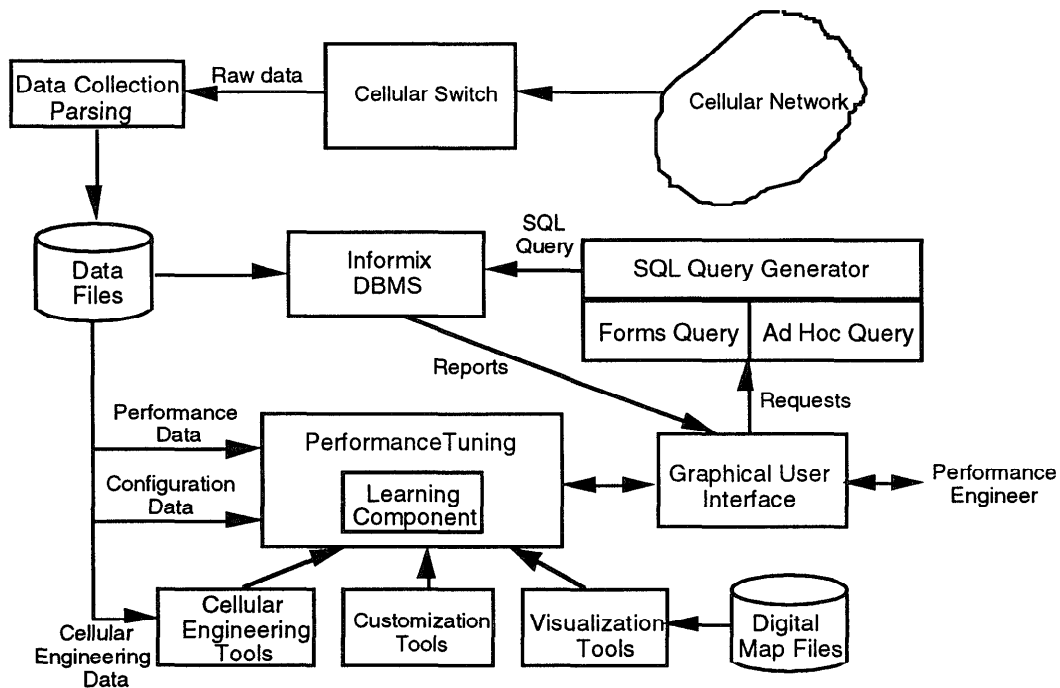


Figure 3. PERFEX Architecture

the advice includes a suggestion to run one of the Cellular Engineering Tools to get more corroborating evidence or to eliminate a possible cause. For example, the call processing failure tool can be used to isolate faulty radios at a specific cell site.

Customization Tools are used to adapt PERFEX for different regional installations and equipment. PERFEX provides domain specific editors to update cell site antenna and location information, and to modify thresholds for configuration data scrubs and performance calculations. The performance engineers can create their own performance reports, tables, and graphs with an easy graphical database interface. This interface includes a graphical query builder for ad hoc queries and a forms query interface for specializing previously defined ad hoc queries.

Visualization Tools are used to graph performance data, visualize data patterns, and picture cell sites overlaid on geographic maps. The PERFEX user interface contains a map of the cellular region with a graphical representation of each cell's antenna faces and server groups. Users can access historical data as well as the current day's data displayed as tables or graphs. A performance data trending graph allows users to examine the change of data over a period of time such as days, weeks, months, or years.

During the performance tuning process, a user can examine the individual performance counts supporting the conclusions, or bring up a trending graph to check for the duration and severity of the problem. Also a display of actual call handoff data patterns on the map can be used to update the neighbor lists of the problem cell. Figure 4 illustrates visualization of the handoff percentage data between a selected face (colored red on a color-monitor) and neighboring faces (colored yellow). The simultaneous display of a cellular network and color-coded patterns of network data help users to recognize performance and configuration problems.

PERFEX tools can also be used independently of the performance tuning process. For instance, they can be used to generate and print hardcopy reports for management, or create maps and tables for performance engineers for road testing the network.

A distinctive feature of the PERFEX design is the tight integration between its different information presentation forms, such as the map, tools, graphs, reports, and cell sites. Tight integration creates a uniform information space so users can easily navigate through the interface from one information presentation form to another.

All data in PERFEX is automatically collected, parsed, and stored in a uniform format so the most recent data, as well as the data from the previous days, weeks, or months, is available to the user and to all functional modules of the system. This dramatically reduces the time and knowledge required to manually gather this information from the switch.

Development, Deployment, and Maintenance Development Schedule

Initial development of the PERFEX concept began in November 1992, and a proof of concept demonstration system was conceived by July 1993. During 1993, extensive knowledge acquisition sessions were conducted to collect and formalize performance tuning rules. By the end of the year, the first prototype system was completed, and in March 1994, PERFEX 1.0 was deployed for testing and evaluation in two GTE cellular markets. The prototype was well received by performance engineers. Several functional enhancements were suggested by the users, including additional data scrubs, cellular engineering tools, tools for performance trend analysis, and editors to customize the system violation thresholds, configuration, and data parsing routines. All changes were included in PERFEX 2.4, which was released by the end of 1994. By the middle of 1995, the system was operational at 12 GTE MSCs. In September 1995, a high-performance PERFEX system 2.9 was released, which significantly reduced raw performance data processing time. By the end of 1995, PERFEX 2.9 was installed at 25 centers, which covers the majority of GTE cellular service areas.

Implementation

The system is mainly written in Tcl/Tk (Ousterhout 1994), including the GUI, data processing routines, and some data visualization routines. Computationally intensive and time-critical components such as raw data parsers and digital map data processing routines are written in C. The database management system is Informix. The graphical query builder was initially developed by GTE Telecommunication Services, Inc., and modified by GTE Laboratories for PERFEX. PERFEX uses the Xerion Neural Network Simulator Version 3.1 (Van Camp 1993) for its neural network training and test. This simulator is also implemented in Tcl/Tk. The training cases and thresholds are stored in files, while recommendation rules are embedded in code. Training cases from the field are automatically generated, while the expert cases have to be collected by developers. The map information system uses U.S. Census Bureau data for generating geographic maps. PERFEX runs on a variety of UNIX platforms, including

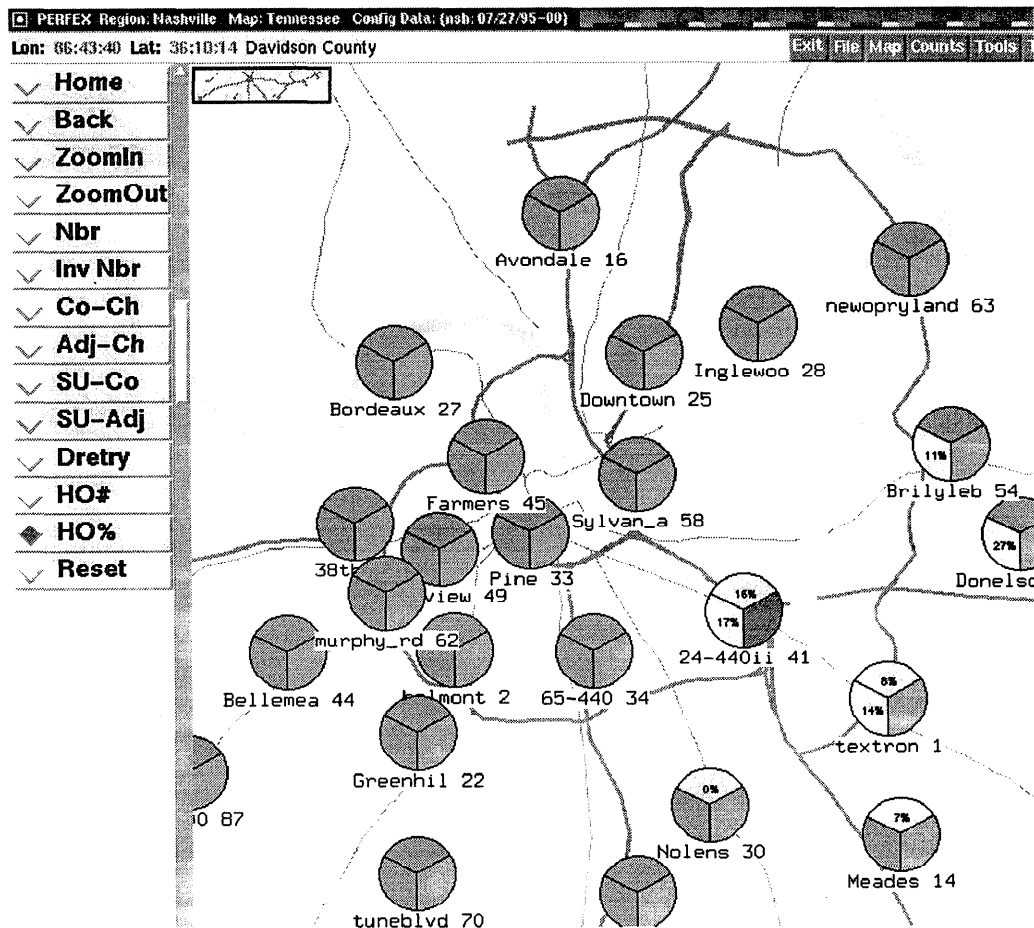


Figure 4. Display of Handoff Percentage Patterns

SUN, SGI, and Data General. The size of the code, including both Tcl/Tk and C, is about 90,000 lines.

Development Effort and Cost

At different stages of the project, 3-4 technical staff members from GTE Laboratories and 4-5 performance engineers from various GTE Mobilnet mobile switching centers took part in the system specification, knowledge acquisition, development, and deployment. The total project cost (including, hardware, software, and development) for the three-year effort was calculated at approximately \$1.35M.

Maintenance

PERFEX is maintained by technical personnel from a GTE Mobilnet central office. This includes the tasks of maintaining the code, reporting bugs, installing new system releases, setting up data collection environments, and configuring hardware and software. PERFEX was designed to be easily maintainable. It accommodates changes in network configuration and tuning knowledge via format

files and smart editors. GTE Laboratories is responsible for bug fixes and system enhancements. User training is currently provided by GTE Laboratories; in the near future, however, training will be provided by the GTE Mobilnet central office. So far, about 40 engineers have been trained to use the system.

Payoff

The five-year financial projection for PERFEX's payoff, a reflection of cost savings and revenue generation, totals over \$12 million. The economic significance of PERFEX is a direct result of the technological benefits of PERFEX over the existing methods of cellular network configuration and performance management. The potential for increased revenues is derived from improved cellular system performance, increased customer base, and reduced customer turnover. The direct cost savings potential of PERFEX derives from several different sources: replacement of currently used third-party software,

reductions in capital investment and user training, and reduced operational headcount. For the development and deployment of innovative technical solutions in support of GTE cellular services and for the cost savings and revenue generation, the PERFEX team won the highest GTE technical achievement award in 1995.

Lessons Learned and Future Enhancements

Initially, we underestimated the efforts needed to develop data collection, preprocessing, and other support functions needed in PERFEX. It gradually became apparent that many other components, such as cellular engineering tools, graphics, and DBMS-based reporting, would be necessary for the success of performance tuning. Particularly, the visual information presentation tools played an important role in creating the network management information space. Visualization significantly enhances the way performance engineers understand network configuration, recognize potential problems from performance data patterns, and undertake performance tuning actions. The tight seamless integration of different components was critical for our task because these components would not be used by performance engineers if access was inconvenient or required a separate process.

Future changes to the cellular networks include the addition of digital technology and the introduction of a different class of cellular switches. Both of these changes will require modifications to data formats, data interpretation, and network performance tuning and configuration knowledge.

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References

- Jakobson, G., Weissman, M., and Goyal, S. 1995. IMPACT: Development and Deployment Experience of Network Event Correlation Applications. In *Proceedings of the 7th Innovative Applications of Artificial Intelligence Conference*, 70–76, Montreal, Quebec.
- Low, C., Tan, Y., Choo, S., Lau, S., and Tay, S. 1995. AutoCell — An Intelligent Cellular Mobile Network Management System. In *Proceedings of the 7th Innovative Applications of Artificial Intelligence Conference*, 114–124, Montreal, Quebec.
- Ousterhout, J. 1994. *Tcl and the Tk Toolkit*. Reading, Mass.: Addison-Wesley.
- Tan, M., and Lafond, C. 1995. PERFEX: An Intelligent Performance Tuning System for Cellular Networks. In *Proceedings of the 7th International Conference on Wireless Communications*, 299–307, Calgary, Canada.
- Tan, M., and Lafond, C. 1996. PERFEX: A Cellular Performance Support Expert. In *Proceedings of the 3rd World Congress on Expert Systems*, 413–420, Seoul, Korea.
- Van Camp, D. 1993. A Users Guide for the Xerion Neural Network Simulator, Department of Computer Science, University of Toronto.