AutoCell — An Intelligent Cellular Mobile Network Management System

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Abstract

AutoCell is a system developed to assist in the operation and management of cellular mobile networks operated by Singapore Telecom (ST). Its deployment is in line with ST's strategic move to introduce intelligent software into its operations. With the help of AI concepts and techniques, the system has enhanced the operational efficiency, network capacity and level of customer service of the network.

Introduction

The use of mobile phones in Singapore has been increasing rapidly since it was introduced by Singapore Telecom (ST) in 1988. To meet this ever-rising demand and to maintain high-quality service, ST has to continually expand and improve the cellular networks it operates.

AutoCell is an intelligent operations management system that allows ST to better manage the AMPS & ETACS cellular networks through the provision of on-line monitoring, planning and control facilities. The system is jointly developed by ST and the Information Technology Institute (ITI), the applied R&D arm of the National Computer Board. The AutoCell system for the AMPS network has been completed and deployed since Oct 94, while work on porting the system to the ETACS network is currently underway.

In this paper, we will describe how the integration and synergy of data, human expertise and computer technology has generated value for ST. In particular, we focus on how and where AI concepts and techniques have proven valuable in this endeavour.

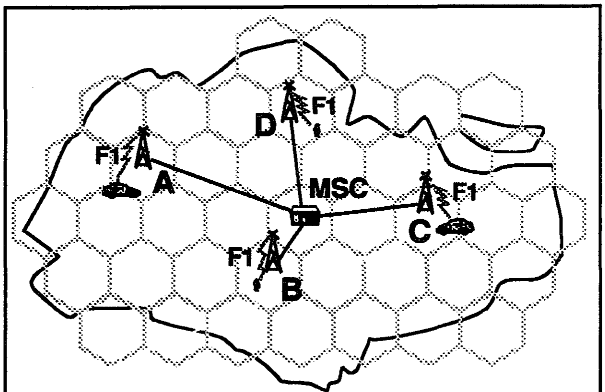
Background on Cellular Communications

A cellular mobile network[1] (Figure 1) divides the service area into a number of *cells*, each of which offers a set of *voice channels* to carry calls to/from mobile phone users in the cell's *coverage* area. Each cell contains a *base station* where the transceiver hardware for voice channels is installed. The base stations are linked via line circuits to a central control unit called the *Mobile Switching Center* (MSC), which performs various control and administrative functions, such as the activation of voice channels and the reporting of network alarms and traffic data.

Each call to/from a mobile phone takes place over radio waves, at the preset frequency of a voice channel, between the mobile phone and the base station of the cell. The number of concurrent mobile calls that can be supported in any one cell is therefore constrained by the number of voice channels available in the cell. Each voice channel is associated with a specific *frequency channel* taken from the frequency band allocated to ST. As the total number of frequencies available in the band is limited, they are therefore a scarce resource that must be efficiently utilized.

Cellular networks achieve efficient utilization of the allocated frequencies by allowing the same set of frequencies to be *re-used* at several non-adjacent cells. This allows calls to be carried by voice channels of the same frequency at several places in the network at the same time, thereby increasing the effective call-handling capacity. Figure 1 shows an example where the same frequency F1 is re-used at 4 separate cells in the network. Such a group of cells is called a *cell group*.

1. We shall restrict our scope to FDMA (frequency-division multiple access) analog cellular networks only. A good source for more detailed description of mobile cellular networks is (Lee 1990).



Hypothetical cellular network over the island of Singapore — Here, frequency F1 is re-used in cells A, B, C and D. This allows 4 concurrent calls carried by F1 to take place simultaneously, assuming that there is no *co-channel interference* between any pair among the 4 cells.

Figure 1: Frequency Re-use in a cellular network

Although the coverage of the cells is presented as non-overlapping hexagons in Figure 1, in reality, the coverage areas are irregularly-shaped and overlapping due to the irregularities of terrain and radio-wave propagation. As a result, the coverage of any one cell will overlap with that of another. Should the same frequency be used simultaneously in these cells, interference would occur, resulting in cross-talk or dropped calls. This phenomenon is called *co-channel interference*. To avoid co-channel interference, the network staff must ensure that the same frequency cannot be in use at any two mutually-interfering cells over the same time period. This involves *blocking* (i.e. disabling) the frequency channel in one cell so that it can be used freely in the other. The act of changing the availability of a frequency channel amongst cells by blocking it in one cell and unblocking it in another is called *frequency re-assignment*.

A well-managed cellular network is one which has no interference, a high utilization of base station equipment, and a good *grade of service* (GOS) in all its cells. The GOS represents the probability of a call attempt being blocked. A *congested* cell will therefore have a poor GOS, which is manifested in the form of a high number of failed call attempts and dropped calls. Typically, a GOS of 2% or less is considered desirable while a GOS above 5% is considered as unacceptable.

Problem Description

Due to the increasing number of cellular mobile subscribers, changes in physical terrain (e.g. due to new buildings and highways) and changes in demographic profile at various areas (e.g. due to new housing estates), there is a need for ST to continually monitor the performance of the network to avoid performance deficiencies (e.g. interference between cells, or shortfall of available channels at a cell). This can be done by adjusting the coverage of cells (i.e. adjusting the base station antenna), cell-splitting, adding new cells, or installing additional channels at existing cells, etc.

The above task is performed through the combined efforts of a team of network planners, field engineers and O&M (operations & management) staff. The O&M staff are responsible for acquiring and collecting various traffic and network status data from the MSC. The field engineers will conduct field measurements to detect inter-cell interference. The network planners will then analyze the data provided by the above mentioned parties and work out the appropriate near-term and long-term solutions towards improving network performance.

However, the work flow prior to the introduction of AutoCell suffered from 3 major drawbacks. Firstly, the acquisition of network and traffic data was a tedious and labour-intensive task. The O&M staff had to interface with the MSC via a command-line interface which accepts mnemonic commands and outputs raw data in a fairly cryptic format. Typically, an experienced O&M staff would devote one man-day to collect a few days' worth of data and to generate reports, with the help of a spreadsheet tool. Due to the time and effort required for this task, the O&M staff would typically only generate such reports on a few selected days each month.

Secondly, as the cellular network expands and evolves, the network planners were finding it increasingly difficult to cope with the sheer number of network elements (cells, channels, etc.) involved. Since network data was not captured regularly nor available on-line, the planners were unable to perform any extensive or compute-intensive studies based on past network behavior, such as computing the required channel capacity of each cell over the past few months under various performance targets (say, 2% or 5% GOS). This in turn hampered their long-term network planning efforts.

Thirdly, it was laborious for the O&M staff and the planners to monitor each and every network element closely, due to the frequent fluctuations in network and traffic conditions. This made it difficult for them to quickly invoke corrective action to alleviate temporary network performance deficiencies due to causes like faulty equipment, or abnormally high traffic demand in some cells.

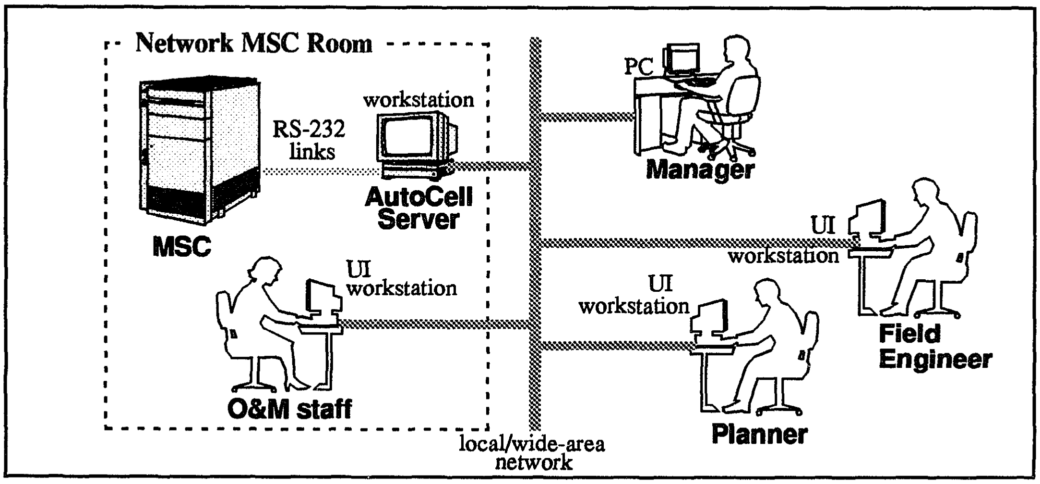


Figure 2: The AutoCell System Overview

Objectives of AutoCell

The AutoCell project was initiated with 3 main objectives. The first objective is to provide easy access to useful past and present information about the network. This is to be achieved by automatically acquiring network and traffic data from the MSC, storing the data into the database and presenting value-added information via a user-friendly GUI to the O&M staff, planners, field engineers and managers.

The second objective is to provide assistance and recommendations to network planners in monitoring and improving overall network performance. AutoCell is to apply frequency planning expertise on the database of historical network data to assist the planners in deriving actions that would improve the performance of the network.

The third objective is to perform automatic frequency re-assignment to alleviate temporary network congestion. AutoCell is to dynamically track the network status and traffic conditions at various cells throughout the day and automatically re-assign channels from less congested cells to more congested cells.

AutoCell System Overview

AutoCell is a distributed client-server system composed of the AutoCell Server that runs round-the-clock on one workstation, and User Interface (UI) clients running on several (possibly remote) workstations (Figure 2).

The AutoCell Server is connected via RS-232 links to the MSC, from which it periodically acquires network status and traffic data. The collected data is processed and stored into a central database. The Server will, at regular intervals, generate traffic forecasts for all cells and perform automatic frequency re-assignment to make available more channels (if possible) at cells that are congested due to unexpected high demands or faulty channels. The Server will also accept requests from any of the UIs to generate traffic forecasts and to optimize frequency assignments for some future time period.

The AutoCell UI provides the network O&M staff a user-friendly interface for monitoring the current status and traffic conditions of the network. The UI panels include maps, graphs and tables that are color-coded to quickly draw the attention of operational staff to abnormal conditions. These panels will refresh automatically whenever new traffic or status data becomes available.

The AutoCell UI also provides network planners with an intuitive interface for network analysis and planning, including panels that allow one to review past and present traffic demand graphs and to evaluate the impact of adding/removing channels to/from one or more cells. More importantly, the UI workstation can be run from the planner's own desktop, allowing him instant access to information about the network.

AutoCell also provides a reporting facility where regular or ad-hoc reports on traffic demand and network performance can be generated on-screen or printed out. This report module can be invoked from any workstation or PC that has access to the AutoCell database.

The overall data and information flow of the AutoCell work environment is illustrated in Figure 3, while sample screen panels of the UI are shown in Figure 7.

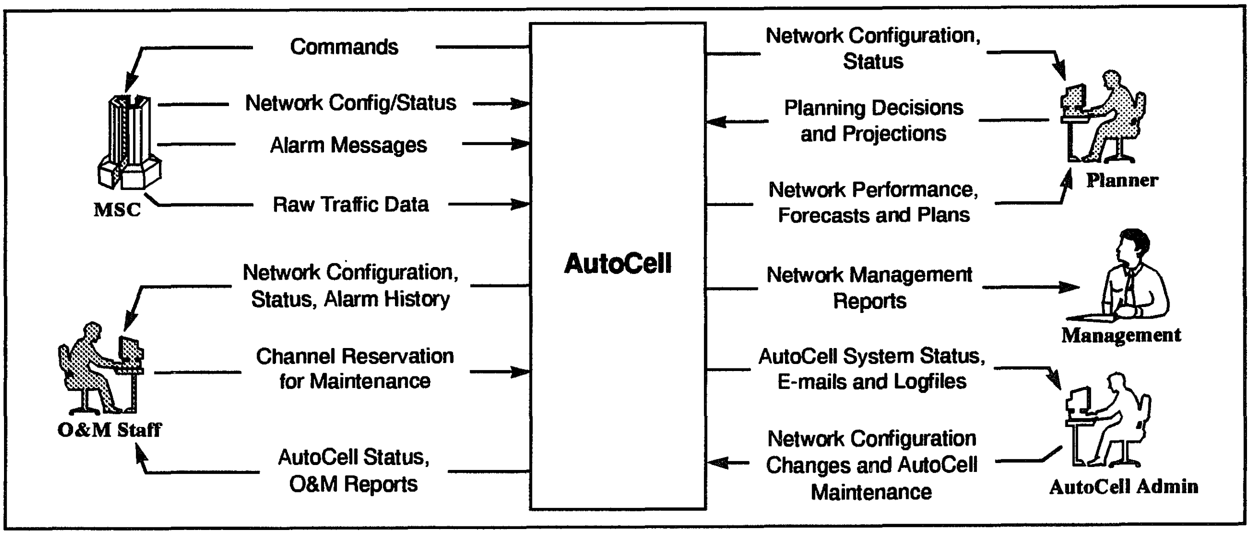


Figure 3: AutoCell Information Flow

Technical Challenges

The team identified three aspects of AutoCell that were technically challenging. These are elaborated below.

Interfacing with the MSC

The MSC provides a set of serial ports from which traffic data and alarm messages can be output autonomously, and commands issued by AutoCell to query for status or configuration data or to invoke changes in the network can be accepted. However, the MSC can only process one command at a time and the time taken for the reply can vary from 10 seconds to 30 minutes, depending on the command type, parameters and the current processing load at the MSC. Furthermore, sending too many commands to the MSC can potentially affect its processing throughput on its other (perhaps more important) tasks. Thus, AutoCell can only send commands sparingly to the MSC, and yet be able to maintain up-to-date status information and perform periodic channel re-assignments.

A careful strategy must therefore be formulated so that commands are sent to the switch only when necessary. For example, a "poll-channel-status" command should be sent upon a "cell-down-alarm" message. Commands can also be scheduled to be executed at appropriate intervals (e.g. hourly or daily). Furthermore, should the MSC be late in delivering a reply to the current command, lower-priority commands due for execution should be dropped so as not to affect the timeliness of the more important commands. Such a strategy was formulated with the help of a few expert O&M staff, who were able to provide much strategic expertise (when to do what?) to go with the procedural knowledge (how to parse MSC data?) that can be gleaned from the MSC manuals.

The challenge for the AutoCell team is therefore to devise a suitable architecture where multiple data streams can be handled concurrently, where time and event-driven commands to the MSC can be sent, and where procedural and strategic knowledge can be encoded in a modular fashion. In particular, this architecture must facilitate the evolution of AutoCell to handle additional data streams, additional traffic data types, or changes to the MSC's processing capabilities.

Network Analysis and Planning

The network planners have observed that there exists recurring *traffic demand patterns* at various cells at various hours of a day over various days of a week. In other words, the traffic demand at a cell for a particular day, say a Tuesday, will not vary significantly from that of the few Tuesdays immediately before or after it. Such traffic patterns, if computed, succinctly represent the expected traffic demand at each cell and facilitate the planning for enough capacity to cater to the expected demands at each cell. What the planners need is therefore for AutoCell to automatically compute the traffic patterns for all cells using traffic data collected over the recent few months. However, there exists no obvious formula for computing a traffic pattern based on past traffic demand samples. Hence, an algorithm needs to be developed that would make use of the expertise of the experts, in particular, on how to weigh traffic data samples of different recency, how to judge whether a generated pattern is representative of samples that it is

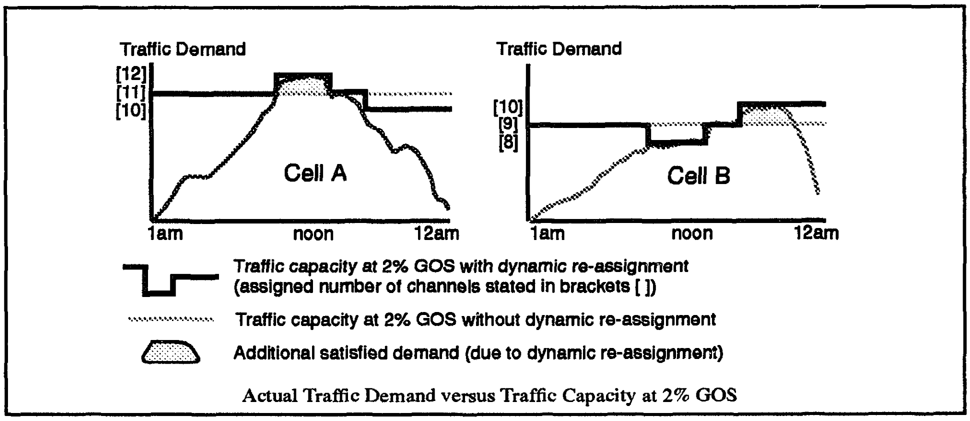


Figure 4: Dynamic re-assignment between two interfering cells

generated from, and to detect and handle data samples that are incomplete, erroneous or abnormal.

Dynamic Frequency Re-assignment

The network planners also observed that the shape of the traffic demand curve of a given day do vary for different cells. For example, the traffic demand at a cell in the urban area may peak at noon, while the demand of another cell in the sub-urban area may peak in the evening. This gives rise to the opportunity of sharing the same frequency at any two or more mutually-interfering cells that peak at different hours, by dynamically re-assigning a frequency from one cell to another based on where the demand for it is higher (see Figure 4). This concept is called dynamic frequency re-assignment, which is aptly described by Calhoun in (Calhoun 1988):

> *This would allow the network to "breathe" with the flow of traffic, shifting channels back and forth between cell sites as necessary, putting the spectrum resource where the need is greatest.*

To be able to apply dynamic re-assignment effectively, AutoCell must be able to accurately forecast the traffic demands at each cell for each time period (e.g. quarter-hour), and then be able to optimize the frequency assignments with respect to the expected demands and performance criteria of each cell. It must also minimize the number of channels to be re-assigned so as not to overload the MSC.

How is AI applied in AutoCell

In the above mentioned technical challenges, the team looked towards AI to provide the solutions. However, the team discovered that the nature of the human expertise acquired is broad but shallow, and not particularly amenable for representation in any single AI representation. There exist AI tools that do address some of AutoCell's requirements, but the payoff from using each of these tools was deemed not commensurable with the costs/risks involved in procurement, training, integration, support and maintenance. The team and user management therefore decided to adopt a more customized approach that would borrow heavily from existing AI concepts if appropriate, and that would not preclude the future inclusion of AI tools should the need arises.

In the case of generation of traffic patterns and forecasts, the team decided to adopt conventional statistical algorithms to perform the tasks. Human expertise is either encoded directly either into the algorithms used or in the form of parameters that can be adjusted from the AutoCell UI. In addition, as the team and the experts were unable to formalize a general strategy for predicting traffic demand due to special events (when a higher than expected demand in some cells is anticipated), some means are provided for the user to manually edit the forecasts to reflect the expected demand (if predictable) of these special events.

In the case of providing flexible event-driven control in AutoCell, as well as the optimization of frequency assignments, AI principles and techniques proved to be valuable. This is elaborated in the following subsections.

A Multi-agent Event-driven Architecture

As AutoCell is required to handle multiple MSC data streams in a event-driven manner, it requires an architecture that allows concurrent processing of the MSC data and flexible control of processing activities that were triggered by various events. The team decided to adopt a multi-agent event-driven architecture based on

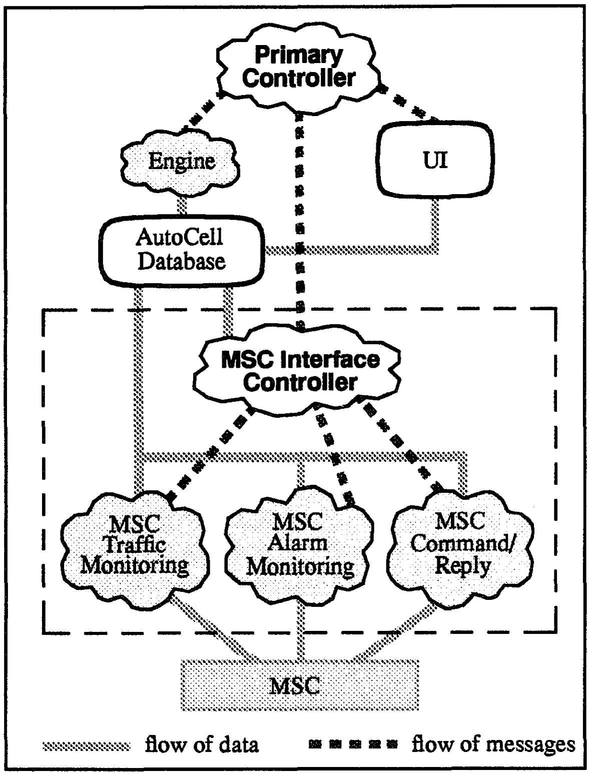


Figure 5: The AutoCell Multi-Agent Architecture

AI/OO (Artificial Intelligence/Object Oriented) techniques.

Each MSC port is handled by an Agent program (running as a individual Unix process), each of which specializes in handling the input/outputs with the specific MSC port (see enclosed sub-box in Figure 5). Within each Agent program, expertise on how to parse and store the collected MSC data is encapsulated as separate objects in the program. As new data arrives from the MSC port, the appropriate object will be invoked to parse and process (e.g. store into database) the data items. Each Agent will also monitor its port for problems such as corrupted data or non-arrival of data.

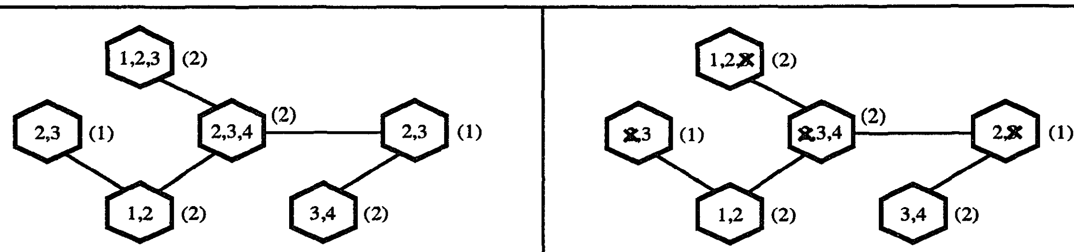
All of these agents are in turn controlled and monitored by a Controller program called the MSC Interface Controller. This Controller program communicates with the Agents via the exchange of messages. The messages can be in the form of requests from the Controller to an Agent (e.g. "start-collecting-traffic") or notifications from an Agent to the Controller (e.g. "cell-down-alarm"). The Controller program is therefore where the strategy for interacting with the MSC can be implemented — we encode the appropriate actions in response to different events within separate task classes, use a message interpretation loop to map incoming messages to new or existing tasks, and maintain a task agenda to hold ready and pending task instances of various expiry times and priorities. For example, a "cell-down-alarm" notification from the MSC Alarm Agent to the Controller will invoke a "handle-cell-down-event" task in the Controller. This task will in turn send a "poll-channel-status" request to the MSC Command/Reply Agent. The latter program will then dispatch the appropriate MSC command to the MSC, collect the reply and update the status database.

This architectural scheme turns out to be useful beyond the scope of interfacing with the MSC and is in fact replicated at the highest level of the AutoCell Server architecture (Figure 5). In this case, there is an overall Controller module called the Primary Controller that communicates with its 2 Agent programs — the MSC Interface Controller described above and an Engine program that specializes in various value-adding data-processing tasks (e.g. derivation of traffic patterns, optimization of frequency assignments, etc.).

The role of the Primary Controller is to invoke various processing tasks in response to events. An event can be a pre-programmed notification based on time (e.g.; every Monday at 0130 hours), a notification due to some MSC event (e.g. arrival of new traffic data) or a user request from one of the UI clients (e.g. to pre-generate optimized frequency assignments for some future time period). The Primary Controller is also responsible for reporting various events to all the active UI clients (e.g. arrival of traffic data) so that each UI can refresh its respective panels.

This scheme allows one to schedule various processing activities in a way that maximizes the use of the AutoCell Server, which, like the MSC, is a resource with processing throughput constraints. For example, heavy processing tasks, such as the generation of traffic patterns, can be scheduled to be performed during off-peak hours.

Central to the whole scheme is the AutoCell Database, to which all Controllers and Agents have access to. This allows one Agent to work on top of information produced by another Agent. For example, the MSC Traffic Monitoring Agent will first record collected traffic demand data into the Database. The Engine program will then perform some additional error-checking and computation on the data and later use it to generate traffic demand patterns and frequency assignment plans. The assignment plans are in turn read by the MSC Interface Controller to carry out channel re-assignments.



Problem: To select frequencies to de-activate so that no 2 interfering cells (linked by edges above) have any activated frequencies in common and so as to minimize the worst-case shortfall in active channel supply with respect to the expected demand (specified within brackets).

Solution: De-activate the frequencies that are crossed out. In this case, the minimum worst-case shortfall is zero.

Figure 6: A hypothetical frequency assignment optimization problem and solution

The architecture also allows some form of fault-tolerance to be built in. The Primary Controller will, for example continually monitor the state of its Agent programs. Should any of them crash, the Primary Controller will immediately re-start the crashed Agent.

Heuristic Search

A *frequency assignment plan* is one which assigns frequencies to be activated in each cell in a cell group for a specific time period. A feasible assignment plan must respect constraints imposed by the set of installed frequencies at each cell and the co-channel interference constraints between cells. In AutoCell, the frequency assignments must be re-generated every 15 minutes so that re-assignments can take place every quarter-hour.

The objective of the frequency assignment optimization is to find a set of feasible assignments to each cell that is optimal with respect to some specified criteria, for example, minimizing the shortfall in channels assigned with respect to the forecasted traffic demand at some target GOS. This represents a graph-coloring problem, as illustrated in Figure 6, where the vertices (hexagons) represent cells, colors (depicted as integers within each hexagon) represent frequencies installed at each cell, and edges represent co-channel interference relationships.

In addition, AutoCell's optimization algorithm should:

- achieve a near-optimal solution under 2 minutes
- always generate a feasible solution
- minimize perturbation from the current (or some default) channel assignments.

With these in mind, a heuristic incremental refinement algorithm (Low 1994) was developed for AutoCell. The algorithm is a 2-level search where the first level involves a steepest-ascent hill climbing search that repeatedly seeks the most needy cell whose interferers can donate a frequency to; while the second level involves a simple search that employs a heuristic penalty-scoring scheme and branch-and-bound pruning to select the best frequency to be re-assigned to the identified needy cell.

The basic goal of this algorithm is to continually seek to improve on the more needy cells by re-assigning frequencies to it from less needy cells. Each successful iteration through the search therefore improves the overall performance (predicted) of the cell group a little better, until a local optimum or the given iteration limit is reached. In this way, the algorithm will always produce a solution that is no worse than the initial solution.

The various decision points in the search where heuristics can be applied are captured as decision functions. This allows the team to tweak the performance or the optimization criteria of the algorithm by modifying just the decision functions. For example, the functions currently implement the following set of criteria, listed in descending order of priority:

- minimize the worst-case GOS of cells whose GOS is worse than 5%;
- minimize the number of cells whose GOS are worse than 5%;
- maximize the number of cells at or better than 2% GOS;
- prefer assignment plans that are aesthetically pleasing when displayed (i.e. where blocked and unblocked channels are grouped into contiguous bands).

Development, Deployment and Maintenance

Development Schedule, Costs and Resources

A team of 5 developers (2 from ITI, 3 from ST) took about 2 years to complete the AutoCell system on the AMPS network. The time spent included domain study, technical training and hardware/software acquisition time. The total project cost, inclusive of hardware, software, training and development was estimated at about S$1.3 million.

AutoCell is developed and deployed on a network of SUN Sparcstations running on Solaris 1. The AutoCell Server is developed in C++ using the GNU suite of C++ tools. The AutoCell UI is developed using the ILOG suite of UI tools. The database is implemented on Informix Online.

Development and Deployment Plan

The development and deployment of AutoCell was broken into Phase I (15 months) and II (9 months).

The aim of Phase I was to develop a system that is able to interface with the MSC so that sufficient traffic data can be collected by the end of the phase for use in traffic analysis and forecasting, and so that enough experience could be gained for use in deriving a reliable MSC control strategy. The team also spent time exploring various forecasting and optimization algorithms and was able to quickly implement a few UI displays that allowed the users to visually inspect and feedback on the quality of the generated traffic forecasts and assignment plans.

The team realized that the confidence of the users in the system cannot be assumed, hence several manual checkpoints and overrides were implemented into AutoCell to assure the users that the system will not cause undue degradation to the network's operations. For example, the users were required to pre-generate and approve (via the UI) each frequency assignment plan before any re-assignments is to take place.

AutoCell was deployed at the end of Phase I with the ability to capture traffic data, perform traffic pattern generation and perform pre-planned frequency re-assignment, with access given to a few selected users. This deployed Phase I system would continue to operate while Phase II development carried on. Within one month of deployment, the users had gained sufficient confidence in AutoCell to request that some of the manual controls be removed so that channel re-assignment can be executed in a less supervised manner.

The aim of Phase II was to further enhance the data capture, forecasting and optimization capabilities of AutoCell, and to complete the UI displays. In particular, the team focused on implementing quarter-hourly dynamic forecasting and frequency re-assignment to cope with unexpected traffic surges and down channels.

The full AutoCell system was deployed in Oct 94 after the completion of Phase II implementation, user training and acceptance testing.

A new team has been formed and trained to port the application to the ETACS network. This new project started in Jul 94 and is expected to take a year to complete. The implementation effort is estimated to be about 44% of that spent on the original system.

Maintenance Plan

The users are not expected to perform any software maintenance on AutoCell. However, network planners are allowed to tweak certain aspects of AutoCell's forecasting and optimization algorithms by adjusting certain global or cell-based parameters (e.g. target GOS of a cell).

New requirements and changes in control strategy, however, is expected to be implemented by software engineers from ST. The maintenance effort will be facilitated by the modularity, object oriented-ness and the separation of data-processing logic from control logic in AutoCell's design.

Application Use and Payoff

AutoCell was deployed as a network monitoring system in Oct 93 and began performing automatic dynamic channel re-assignment in Mar 94. The benefits accrued from its deployment so far are described below.

Increased Revenue

With the help of AutoCell-generated recommendations, ST has been able to identify and transfer 97 voice channels (with its associated hardware) from un-congested cells over to cells which are congested or which are exhibiting rapid growth in demand. This has helped increase the overall capacity of the network without requiring any purchase of additional hardware, while maintaining the same level of service. ST estimates that the additional traffic demand carried to be worth about S$1.27 million in revenue in the first year alone. Such re-configuration exercises are expected to be conducted on a regular basis with the help of AutoCell.

Since Mar 94, AutoCell has been applying dynamic channel re-assignment to a pilot group of 8 cells. The monthly gains in traffic revenue has varied between S$500 to S$2000 a month from these 8 cells alone. The gains are expected to become more substantial as further demand and subscription growth strain the capacity of individual cells and create more situations where time-sharing of channels becomes necessary.

Improved Level of Service

With improved network monitoring and planning capabilities, the network planners have been able to react quickly to potential network deficiencies by implementing the necessary medium-term (e.g. adding new channels) or long-term (e.g. adding new cells) solutions.

The application of dynamic channel re-assignment has significantly improved the worst-case performance of cells it is applied on. In particular, AutoCell has successfully alleviated traffic congestion in situations where there is an extended surge in traffic demands or an occurrence of multiple faulty channels in a cell.

As a result, the number of occurrences of high congestion (i.e. where GOS exceeds 5%) has been reduced to no more than 2 cells per month since Mar 94.

Improved Operational Efficiency

The amount of time spent by a O&M staff to collect data and generate reports has been reduced from 1 man-day per month to approximately 1 hour. Moreover, the generated reports contain data collected over every day of the month instead of just a few selected days, and contain more types of data than was collected before.

The amount of time needed by the O&M staff to check the status of certain network elements (e.g. voice channels) has been reduced from 2 hours to 5 minutes. With the tedious and time-consuming task of data acquisition, management and processing automated by AutoCell, the O&M staff can thus devote their time and effort on more important operational tasks (such as diagnosis).

With the easy access to a rich set of data and information, the planners have been able to perform network planning efficiently. Recently, the network planners conducted a study on how to further improve the channel utilization of the AMPS spectrum. According to one planner, AutoCell enabled him to complete his task, which previously would take no less than 3 days, in about 4 hours.

Framework for Continual Improvement

It is conceivable that a network engineer might formulate new hypotheses relating certain traffic or network data items while browsing through the various UI panels and reports. He can then proceed to verify the hypothesis against past records of traffic/network data. Once this hypothesis is certified, it may be codified into a future release of AutoCell, making it a bit more intelligent than before. In fact, it is this feedback loop between AutoCell and the engineers that holds the most promise, as we envision a scenario where AutoCell and the engineers form a partnership that continually learn from each other, with the continual improvement of network performance (better service, higher capacity, lower costs) being the outcome of this partnership.

Concluding Remarks

The application of AI principles and techniques at both high-level (i.e. agents, agenda-based control) and low-level (i.e. heuristic search) aspects of AutoCell has helped create a system which, to the users, exhibited intelligence. In particular, the users have been impressed with AutoCell's ability to smoothly gather information from the MSC, to react actively to network congestion, to provide value-added information and recommendations, and to operate autonomously round-the-clock without requiring human supervision.

More importantly, the use of AutoCell has brought both tangible and intangible benefits to ST. The team believed that the success of the application has been due to the *synergy* of abundant data (from the MSC), computer technology (GUI, database, networking, intelligent techniques and algorithms) and the collective expertise from various O&M and network planning experts.

Acknowledgments

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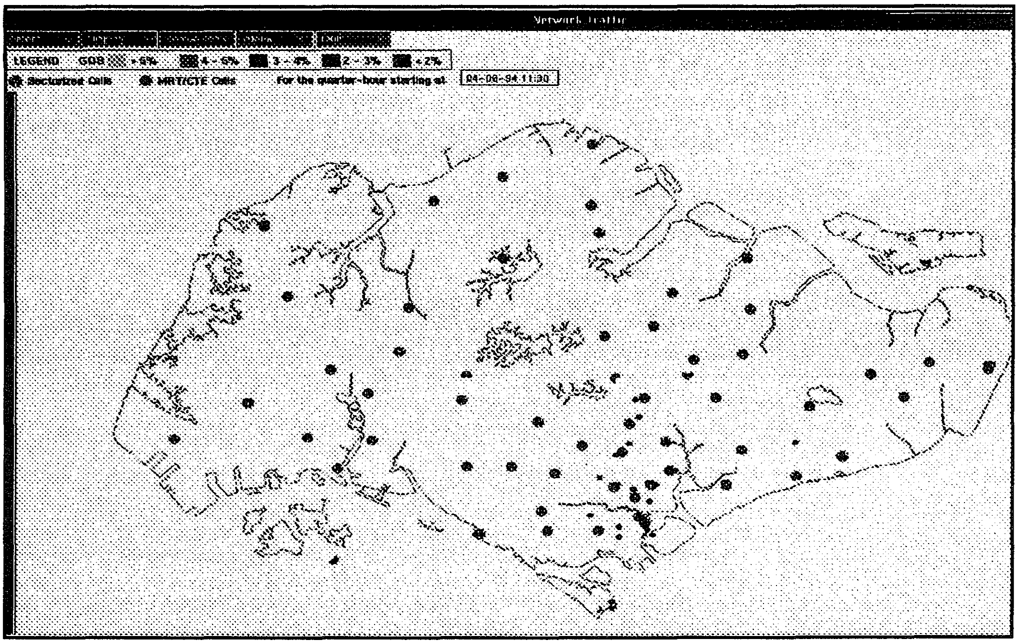
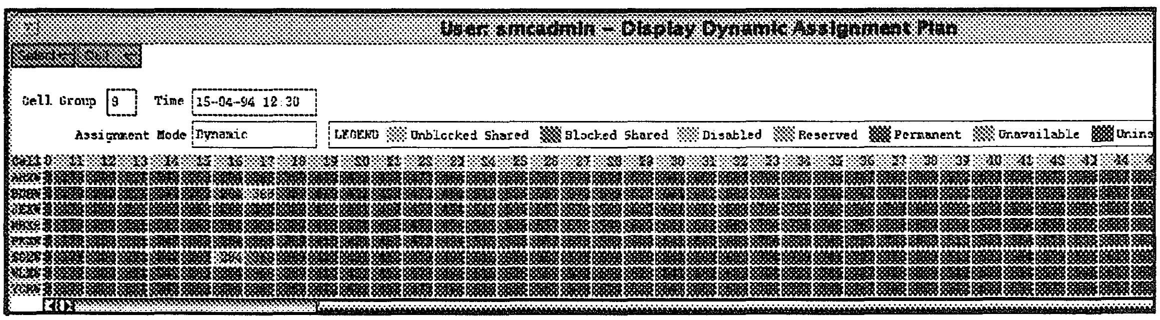
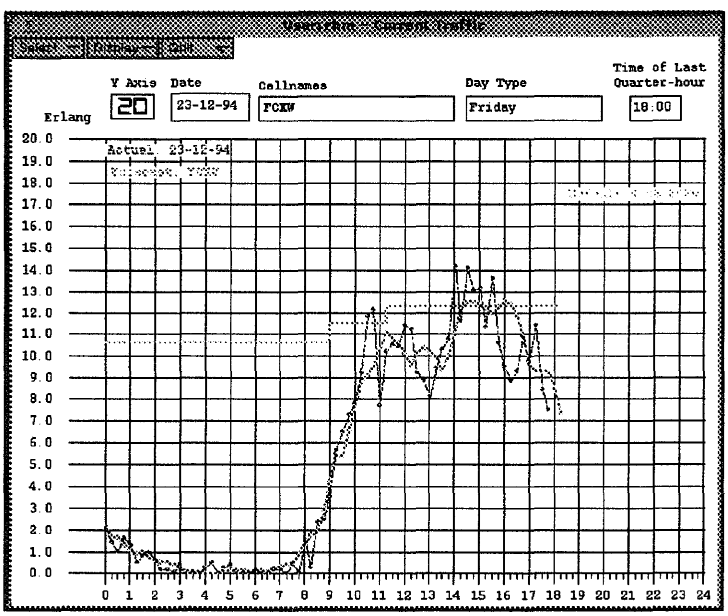


(a) Network GOS



(b) Dynamic Frequency Assignment Plan



(c) Cell Actual, Forecasted and Supported Traffic

Figure 7: Sample screen panels of the AutoCell UI

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