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A Space-filling Visualization Technique for Cellular Network Data

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Abstract: The widespread use of cellular devices has resulted in an increased demand for proper and continuous functioning of cellular services. For this reason, cellular service providers require better and more sophisticated tools to analyze customer usage data. They are constantly seeking new approaches for fine tuning and optimizing the performance of their networks. In this paper, we describe the design and implementation of a new space-filling visualization technique that is capable of displaying multi-dimensional attributes of a cellular network data. We illustrate the value of the technique through an example.

Keywords: Visualization, cellular data, network optimization, space-filling visualization, protocol analysis.
Categories: H.5.2 [Information Interfaces and Presentation]: User Interfaces, C.2.3 [Computer Communication Networks] Network Operations - *network management, network monitoring.*

1 Introduction

The number of cellular users has grown exponentially over the last decade. This growth will continue as service providers increase the range and quality of services they offer. To meet the demands and provide high-quality service, stakeholders in the cellular industry are building the necessary infrastructures. However, the complexity of cellular networks requires constant surveillance, analysis of behavioral patterns in a system, and tuning of equipment parameters. The issue of providing high-quality services is particularly acute in regions where the demand for real-time and continuous services of cellular data is mission critical.

At the core of all the data transmission within cellular networks are base stations [Sandag 1995]. These are physically installed units with pre-configured hardware and software. Each base station represents a cell-site (or cell) that administers all the communication processes and parameters within a specific geographical region. Cell-sites are responsible for handling calls on different channels and communicating with a central unit to assist the handing-off of calls from one cell to another as a user travels through the system. At the most elementary level, a cell is a hexagonally shaped region with a base station at its center.

Despite the existence of well-formulated algorithms that manage all data communication within cellular networks, configuring and fine-tuning a cellular network still remains an area requiring a high level of data analysis. Performance engineers need to find an optimum solution for monitoring conflicting characteristics such as coverage area, signal strength, number of blocked and lost calls, and voice quality. The lack of precise solutions and the evolving nature of cellular content make cellular network performance analysis an ideal application for new visualization methods. The remainder of this paper describes a visualization technique that can be used for the analysis of cellular network performance.

2 Prior Cell Visualizations

Visualization techniques for cell-site performance optimization and planning have been integrated into commercial tools that facilitate a range of data analysis activities. Tools such as PERFEX [Tan et al. 1996] have been implemented for facilitating intelligent performance optimization of cellular networks. PERFEX uses pie charts to display the proportion of variability of any given parameter at a base station in the network. While pie charts are well suited at displaying proportions, they lack in their expressivity for displaying the relation between multiple parameters at the same time, and therefore do not facilitate within-parameter comparison that can be critical for properly performing optimization and planning tasks. Another visualization tool was built to investigate the real-time survivability metrics of cellular networks [Dahlberg et al. 2000]. Its visualization technique is a 3D line graph and can only display up to two variables at a time.

In general, visualization techniques for cell-site data are limited at displaying only a small number of variables at a time, and do not make efficient use of the display space available. In order to analyze data for optimizing a cellular network, it is important that the visualization technique be capable of displaying several variables at a time so that the human operator can perform proper comparisons of variables within cells.

3 Vin-Wang: A Method for Visualizing Cell Site Data

To address the problem of visualizing multiple attributes of a cell-site we have implemented a space-filling visualization technique. Space-filling techniques attempt to make use of 100% of the space provided and facilitate the relative comparison of objects within the structure that is being represented. For example, tree-maps [Johnson and Schneiderman 1991] divide the display into regions based on the relative sizes of objects in the hierarchy. SeeSys [Baker and Eick 1995] displays statistics associated with program source code by dividing the display region into files or directories and mapping statistical attributes onto sub-regions of the display. Sunburst [Stasko 1998] and Information Slices [Andrews and Heidegger 1998] are radial space-filling techniques that map each level of a hierarchy onto concentric circles. The area of each disc is proportional to the size of the sub-hierarchy.

The space-filling techniques described above are primarily suited at displaying hierarchical data. They facilitate the perception of relative sizes, which are mapped onto an area of the display. Color and other surface attributes then portray other non-primary dimensions of the data, such as file type and modification date. By contrast, we have designed a space-filling visualization technique based on similar concepts as those just described, but with the important difference that the visualization is based on a technique that uses the entire space available within the logical structure of the cell-site being analyzed. Despite the limitation on the number of displayable cell attributes, our technique can depict more variables than other cell-site visualization techniques.

Our space-filling technique, referred to as Vin-Wang (Visualization of Wireless cell-sites), optimizes the display space available within a cell by filling each hexagon with the familiar Chinese Yin-Yang pictogram. Vin-Wang is characterized by an outer circle composed of two inner circles A and B [See Fig. 1]. A and B in turn contain each one inner circle a and b, respectively. Finally the lower segment of circle A and the upper segment of circle B are erased to give the final image.

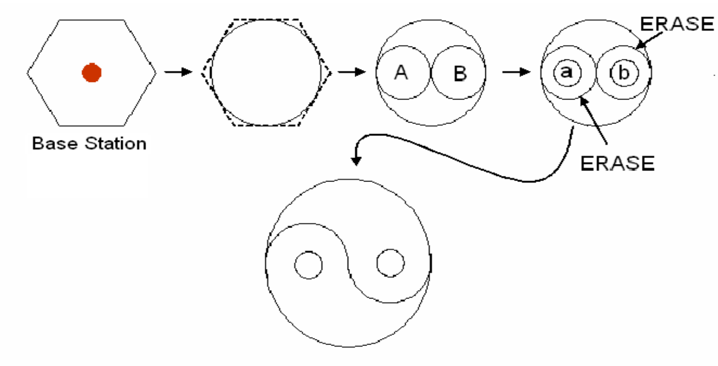

Figure 1. Structural components in Vin-Wang

Our technique maps data variables onto each element of Vin-Wang [See Fig. 2]. The technique can display a minimum of five variables (two of which are tightly related as described below). Additional variables can be added by increasing the number of concentric circles inside circles A and B. Variable V5 is displayed by rotating the image in a clockwise manner. Human perceptual ability is sensitive to a limited set of variations and rotations of about 30º or more to create clear distinctions [Kosslyn 1993]. In Vin-Wang we initially provide rotations of exactly 60º to separate each adjacent value in the range of the variable V5. This variable is primarily reserved for suggesting the direction of growth of the cellular network (the choice of 60º is based on the fact that there are six faces in a hexagon and network growth would follow along one of these faces).

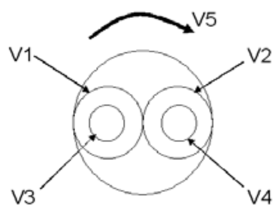

Figure 2. V1-V4 in Vin-Wang represent the diameter of each respective circle.

The relative size of an object is well suited at encoding strong or weak relationships in a display [Irani et al. 2001]. This visual cue is used for depicting the variations in variables V1-V4 by enlarging/shrinking their respective area. Figure 3 shows the modification of several variables and their effect on the Vin-Wang representation.

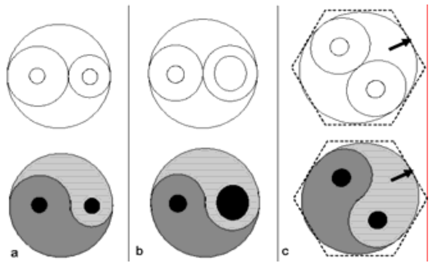

Figure 3. Variations in elementary units and their corresponding Vin-Wang representation. (a) increase in variable V1 (b) increase in variable V4 (c) clockwise change in variable V5. Since the Yin-Yang representation is rotationally symmetric modulo color, an arrow is used for explicitly indicating the direction of the rotation.

We use color to map additional variables. The chosen colors are separated in the color spectrum based on hue and are used for mapping the range of frequencies or the number of users in a cell [See Fig. 4]. To encode a variable in the qualitative domain, we vary only one psychophysical variable, such as brightness. We have adopted the isomorphic colormap suggested in [Rogowitz and Treinish 1996] to encode variables of this type. For example, good voice quality is represented with a darker hue while poorer quality is mapped onto a brighter hue.

4 Implementation

A prototype of the Vin-Wang visualization technique has been developed using OpenGL. We have constructed a sample dataset for the purpose of illustrating the visualization technique described in this paper. We have included several parameters used in optimizing and analyzing cell-site performance metrics as suggested in [Sandag 1995]. These include: Usage Load (UL), Cell Signal Strength (CSS), Forced Termination Rate (FTR), New Call Blockage Rate (NCBR), Direction of Growth (DOG), Predominant Frequency (PF), Number of Users (NU), and Voice Quality (VQ). We used the following mappings: UL → V1, CSS → V2, FTR → V3, NCBR → V4, DOG → V5. PF and NU are encoded with color hue, VQ is encoded using color brightness [See Fig. 4]. Variables used for analyzing the performance of a cellular network are generally related. In this example, cell signal strength is inversely proportional to the load of the cell-site. The variables in our dataset are related as follows: $V1 \propto 1/V2$, $V3 << V1$, $V4 << V2$, $V5 = k*60^{o}$ where k is a constant greater than 0. Figure 4 depicts a sample Vin-Wang representation of a cellular network's properties with the given dataset.

The Vin-Wang representation facilitates the comparisons of variables between and within cells. For example, cells 1, 2 and 3 cover commercial zones, while cells 4, 5, and 6 cover residential zones. In 4.b, we notice that the system is suggesting the addition of a new cell between cells 1 and 3 and above cell 2 (shown using rotation on cells 1 and 3). We also observe that cells 1, 2 and 3 are overloaded with users, and cells 1 and 3 have a high rate of terminating calls (i.e. high FTR). In 4.c, (i.e. at noon) the system is relatively stable, with the exception of cell 4 having a high rate of forced terminations (FTR). In the evening, we notice an overload in the residential zone (Figure 4.d). In addition, we observe a decrease in Voice Quality (VQ) depicted by the brighter hues on cells 4 and 6, and an increase in new calls being blocked in cell 4. We can also quickly notice that the most predominant frequency in the morning and at noon is at the 1900 MHz level (shown as the right-half in primarily red), while in the evening the most predominant frequency is at 900 MHz.

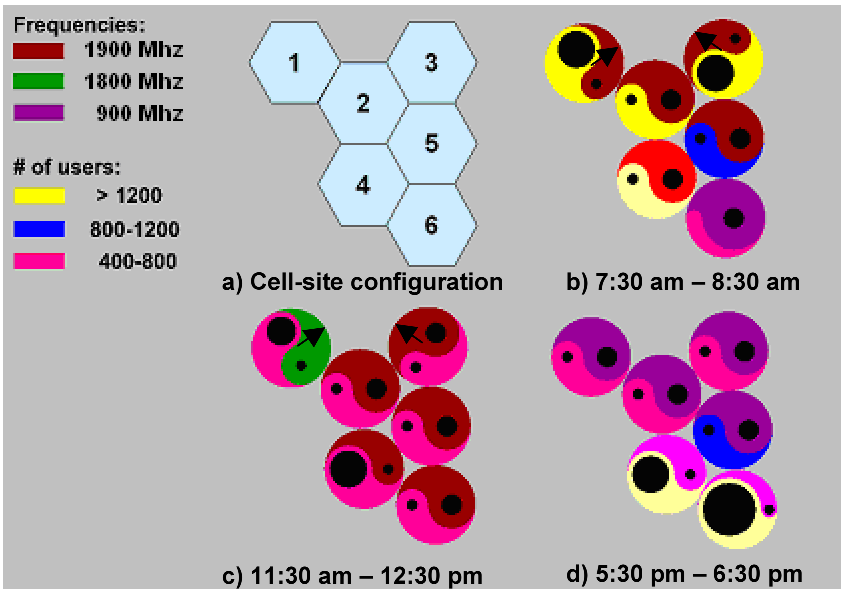

Figure 4. Representation of cell-sites in a cellular network that has a configuration as depicted in (a). The equivalent Vin-Wang representations for given time intervals: (b) in the morning (c) at noon, and (d) in the evening.

After careful observation of the data, cell-site engineers can take measures to enhance the performance of the network. Additional cells could be added, or alternatively, neighboring cells can be optimized to share their resources. In this example, the performance can be compared at various time intervals in a day by observing the changes between the multiple representations. More detailed results about our technique can be found in [Irani et al. 2002].

5 Conclusions and Future Work

To analyze and enhance the performance of cellular networks, large amounts of multi-dimensional data need to be investigated. In this paper we briefly describe a space-filing visualization technique, Vin-Wang, for displaying various cell-site parameters. The technique facilitates the comparison of parameters between and within cells. It is also well-suited at inspecting data at different time intervals by presenting small multiples [Tufte 1983].

We are in the process of collecting actual usage data and evaluating the visualization system with cellular network engineers at a local cellular service provider. We hypothesize that this visualization technique will simplify the task of performance engineers in fine tuning and improving cellular network operations. To enhance and evaluate the practicality of the tool, several additional features will be implemented. The tool will support what-if scenarios such as adding new cells, increasing the usage load, modifying the parameter mappings, and adjusting behavioral parameters to observe the effect on the network. Using dynamic queries, users will also be able to select any cross-section of a time interval to observe the utilization of resources at the cellular level in the network. Finally, the tool is reasonably generic to be used by researchers interested in low-level protocol analysis and by managers involved in decisions concerning the expansion and functioning of cellular networks.

References

[Andrews and Heidegger 1998] Andrews, K. and Heidegger, H.: “Information Slices: Visualizing and Exploring Large Hierarchies using Cascading Semi-Circular Discs”; Proc. of the IEEE Symposium on Information Visualization, Late Breaking Hot Topics (1998), 9-12.

[Baker and Eick 1995] Baker, M. J. and Eick, S. G.: “Space-filling Software Visualization”; J.VLC (Journal of Visual Languages and Computing), 6, (1995), 119–133.

[Dahlberg and Subramanian 2000] Dahlberg. T. A. and Subramanian, K. R.: “Visualization of Real-time Survivability Metrics for Mobile Networks;” Proc. of Workshop on Modeling and Simulation of Wireless and Mobile Systems (2000), 113-118.

[Irani et al. 2001] Irani, P., Ware, C. and Tingley, M. “Using Perceptual Syntax to Enhance Semantic Content in Diagrams"; IEEE Computer Graphics & Applications, 21:5, (2001), 76-85.

[Irani et al. 2002] Irani, P., Eskicioglu, R. and Wu, J. “Vin-Wang: Visualizing Cellular Network Data"; University of Manitoba, Department of Computer Science Technical Report TR-02-07, December 2002.

[Johnson and Schneiderman 1991] Johnson, B. and Schneiderman,, B.: “Tree-Maps: A Space Filling Approach to the Visualization of Hierarchical Information Structures”; Proc. of the 1991 IEEE Symposium on Visualization, (1991), 284-291.

[Kosslyn 1993] Kosslyn, S. M.: “Elements of Graph Design”; W. H. Freeman & Company, New York (1993).

[Rogowitz and Treinish 1996] Rogowitz, B. and Treinish, L., “How NOT to Lie with Visualization”; Computers in Physics, (1996), pp. 268-274.

[Sandag 1995] San Diego Association of Governments; “Wireless Communications Facilities Issues”,1995.

[Stasko and Zhang 2000] Stasko, J. and Zhang, E.: “Focus+Context Display and Navigation Techniques for Enhancing Radial, Space-Filling Hierarchy Visualizations”; Proc. of the IEEE Symposium on Information Visualization (2000), 57-65.

[Tan et al. 1996] Tan M., Lafond, M. C., G. Jakobson, G., and Young, G.: “Supporting Performance and Configuration Management of GTE Cellular Networks”; Proc. of National Conference on Artificial Intelligence (1996), 1556-1563.

[Tufte 1983] Tufte, E.R. “The Visual Display of Quantitative Information”; Graphics Press, Cheshire, CT (1983).