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Uncertainty and Management of Cellular Telephone Networks

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Abstract

This article discusses some aspects of the development of the management system for the Cellular telephone networks. The system is intended to analyze and optimize cellular network performance. Networks are considered as loosely coupled heterogeneous distributed nonstationary nonlinear statistics systems. Fuzzy sets terminology is used for the network analysis.

1. Introduction

The first articles addressing cellular network performance analysis and optimization were published long before actual full-scale cellular networks were created. For instance see [1,2]. Publication of such articles continues. For example, see[3,4] However, the cellular network management problem is so complex that is still very far from resolution. This article does not pretend to answer all questions but shell tried to discuss some problems, directions and suggestions that can bring to us close to the solution.

Optimal design and measurement of the cellular radio network is a very complicated tesk. This complexity is caused by a number of different factors. Major of which are:

1. Traffic varies from region to region and depends on the sizes and shapes of service zones, the covered roads and the density of car traffic on them, the penetration of the cellular service and so on.
2. In turn, the service zones of the cell sites depend on power levels of the transmitters, the terrain, access thresholds, and other parameters.
3. Telephone traffic in the same region can fluctuate widely, depending on the time of day the day, the day of the week, the seasons of the year, car traffic conditions, unusual events and so forth.
4. Channel assignment and hand-off algorithms are designed to provide improved and reliable service. However, they create such a complicated call migration pattern that a mathematical model that is adequate to real cellular networks has not yet been developed.
5. Distribution of telephone traffic in the system depends not only on size and shape of the services zones, but also on the values of the different network attributes, such as hand-off thresholds, directed retry assignments, biases and so on.
6. The results of cellular network analysis are valid only for a short period of time because real networks are in state of constant change.

7. Cause-and-effect trials that are made at the same time but in different regions can show different relationships between the same parameters.
8. Linear increments of the control attributes produce non-linear affects.
9. Cellular network is loosely couplet distributed system. Of of this unwise is shows that only company hence if management system that considers all the above.

This analysis shows that only comprehensive management system that considers all the above described features can provide efficient management. To create a classical control loop the management system should be composed of three interrelated subsystems Monitoring, Decision Support and Executive. However, in this article we will only discuss problems relevant to the Decision Support Subsystem design.

1. Decision Support System

This subsystem is an intelligent module or the Management system. It should study cellular network behavior, analyze its performance and provide a system engineer with the information and tools that are necessary for the decision making.
The size and complexity of real cellular networks is the reason that neither adequate hard (precise) models nor comprehensive hard management methodology based on precise methods have yet been developed. This situation exists because the traditional modeling approach requires significant simplification of real networks to allow the use of available theories. As a result models, proposed in the literature are inadequate to actual management tasks.
To resolve these difficulties and keep simplification to the minimum, we suggest the use of soft (imprecise) models and soft management methodologies hat mimic a human reasoning for study, modeling, and optimization. As an object for study we intend to use real networks. To avoid analysis of whole network we shall try to create a network decomposition technique that take advantage of network looseness.

For the following discussion, let's introduce some definitions.

By sell side controlled attributes we mean attributes that can be changed by an operator. They are, for example, access and hand-off thresholds, neighbor lists and transmitted power levels.
Attributes that that changing as a result of changes made to control attributes, we will call sell site (network) controlled attributes. This attributes are: percent of successfully processed calls, blocking ratio, percent of dropped calls, percent of covered area with sufficient SNR, and so on.
We should consider that the change of the control attribute can produce changes of more than one controlled attributes. The same change of controlled attribute can be a result of changes of different control attributes. To achieve a desired change of a controlled attribute sometimes a set of control attributes of a number of cell sites have to be changed.
For the network modeling, decomposition, management and optimization we need to know how changes of control attributes are mapped to changes of controlled attributes. This mapping reflects all the complexities and uncertainties cellular network behavior and constitute a major problem in the whole management task. As a possible solution to

the problem of mapping analysis we propose to use a cause-and-effect approach. It can be executed either via preplanned changes of control attributes in the real network or by a monitoring disturbances created in network by external sources with simultaneous evaluation of hollow controlled attribute became affected. (An example of disturbance is a cell site equipment failure.)

Measurement of controlled attributes is a difficult task sense they are non-0stationery and noisy. For the filtration of a noise, we can recommend using seasonal time series analysis forecasting algorithm because variations of majority of attributes contain a periodical component of the. In this approach, noise can be a partially filtered when real data are substituted with forecasted values. Good results can be achieved via model developed in corporation with Dr. A. Pankratz. In this model a one-hour-ahead forecast of a value of attribute z at hour t is calculated as:

$$z_t = z_{t-24} + \Phi_1 w_{t-1} - \Theta_{24} a_{t-24} \qquad (1)$$

where:
Φ and Θ are weight coefficients. They are recalculated each time when new data are received. Calculations are made via an optimization procedure aimed to minimize

$$s = \sum_{t=1}^{240} a_t^2 \qquad (2)$$

One-step-ahead backward forecasts

$$w_t = e_t + F_1 w_{t+1} - Q_{24} e_{t+24} \qquad (3)$$

One-step-ahead forward errors

$$a_t = w_t - F_1 w_{t-1} + Q_{24} a_{t-24} \qquad (4)$$

One-step-ahead backward errors

$$e_t = w_t - F_1 w_{t+1} - Q_{24} e_{t+24} \qquad (5)$$

Our experience shows there for forecasting, a history of constantly moving 240 hours values can be considered sufficient. Even though some noise can be filtrated, the results of measurements of controlled attributes will still be uncertain. Mapping and measuring problems are a justification (from our point of view) for using soft methods for network analysis. As a descriptive and analytical tool we have chosen a Fuzzy Sets theory [5].

Network studies should start with preliminary self-educational phase, during which sufficient cause-and-effect data have been accumulated. After this phase we can start our analysis with *decomposition* problem. Assume S is a set of all cell sites in the network;

X_{iz} is a value of a control attribute $i (i \in I)$ of cell site $z \in S$; Y_{jd} - is a value of a controlled attribute $j (j \in J)$ of a cell site $d \in S$; and $a(X_{iz}), b(Y_{jd})$ are corresponding membership functions. (Using membership functions instead of precise values will provide the necessary “softness” in our studies.

Decomposition can be based on the concept of an *affected* zone. For simplicity, let’s from now on consider X_{iz} as a value of a change of a control attribute *I* of cell site *z* (it is a cause) and Y_{jd} as a value of a change of a controlled attribute *j* of a cell site *d* (effect). We also will consider $a(X_{iz}), b(Y_{jd})$ as corresponding cause-and-effect membership functions.

Because of looseness, effects die out when they propagate. Let’s assume that d_j is a tolerated threshold value of an attribute *j*. Then a subset $P_{j/iz} \subseteq S$ of cell sites (z_{ji} -affected zone) producing effect *j* in response to the cause *i* created on *z*, can be defined as follows:

$$P_{j/iz} = \{d_{j/iz} \mid \min[a(X_{iz}), b(Y_{jd/iz})] \geq \mathrm{d}_j) \qquad (6)$$

where $b(Y_{jd/iz})$ is a membership function of an effect *j* generated on *d* by cause *I* created on *z*.

When one cause can generate multiple effects, then z_i -affected zone is defined as

$$P_{iz} = \bigcup_{j \in J} P_{j/iz} \qquad (7)$$

If a number of causes ($I' \subseteq I$ are generated simultaneously on *z* (system engineers of cellular networks often make multiple changes) then *z*’-affected zone is:

$$P'_z = \bigcup_{j \in J} P'_{j/z} = \{d'_{j/z} \mid \min[A'_z, b(Y_{jd/A'z'})] \geq \mathrm{d}_j \} \qquad (8)$$

where $A'_z = A(a'_z(X))$ is a second order membership function of causes created simultaneously on *z*; $a'_z(X) = \{a(X_{iz}) \mid i \in I'\}$ is a set of membership functions of causes created simultaneously on *z*; $b(Y_{jd/A'_z})$ is a membership function of *j* effect generated on *d* by causes *I*’ and created on *z*. Both membership functions in (8) consider the fact, that since networks are non-linear, resulting *j*-type effect can be equal to, more than or less than a sum of partial effects of *j*-type generated on d by different causes and are created on z.

The maximal size of the affected zone P_z will be when *I'=I*.
In this case

$$P_z^{'} = P_z \quad (9)$$

To evaluate and optimize network performance and also to organize adaptability properties for the management system, a soft criterion ("goodness") for the affected zone is proposed. (We do not discuss an adaptability issue in this article.)

Goodness value $G_{dz}^{'}$ generated on cell site *d* by *I'* causes created on z. is as follows:

$$G_{dz}^{'} = \sum_{j\in J} K_j(\min[A_z^{'}, b(Y_{jd/A_z^{'}})]) \quad (10)$$

When $K_j (K_j \neq 0)$ is a weight coefficient of the j-th parameter. Coefficients of this kind are usually the result of surveys made in cellular telephone company and they represent subjective of imprecise collective opinion of different company representatives. This fact also justifies use of soft methods in the network optimization.

The affected zone goodness value that is gained via *I*' causes created on z is:

$$G_z = \sum_{d\in P_z} G_{dz}^{'} \quad (11)$$

A set of the affected controlled attributes contains all cellular service quality attributes. Part of them can be considered as constrains.

The optimization task for *d* when *I'* controlled attributes are changing on *z* is formulated as:

$$\underset{I'}{optG_{zd}} = \max \sum_{j\in J} K_j(\min[A_z^{'}, b(Y_{jd/A'z})]) \quad (12)$$

The optimization of the affected zone, which is made by varying the cell site z control attributes, is governed by the following:

$$\underset{I'}{optG_z} = \max \sum_{d\in P_z} \sum_{j\in J} K_j(\min[A_z^{'}, b(Y_{jd/A'z})]) \quad (13)$$

Whole network decomposition can be achieved via a set M cell sites selected in such a way that:

$$M = \{z \mid ((\bigcup_{z\in M} P_z = S) \vee (\bigcap_{z\in M} P_z = \otimes \quad (14)$$

When |M|=1 then decomposition is impossible.

Total optimal network "goodness" value can be calculated as:

$$opt\ G = \sum_{z \in M} opt\ G_z \tag{15}$$

It is possible that the network can be decomposed in several different ways. In this case we can define $r \in D$ as an *r*-attempt of decomposition, M^r as a set of cell sites used in this attempt, and $opt\ G^r$ as corresponding total network "goodness" value. It is a logical to try to find

$$opt\ \overline{G} = \max_{r \in D} opt\ G^r \tag{16}$$

where $opt\ \overline{G}$ is a best total network optimal "goodness" value found during all decompositions. Because |*D*| can be significant, we shell limit our self to a reasonable number of attempts.

Sometimes management task is reduced to the adjustment of only one controlled attribute. Let's consider this: to create an necessary effect Ψ_j on *d* (for example, to decrease a percent of dropped calls on cell site) often a combination of changes made on a group of cell sites $P_d^{'} \subseteq P_z$ is needed. We should consider that in this case quality attributes of cell sites that are outside of an affected zone can also be affected. A set B_{jd} of possible solutions $b_{jd} = (P_d^{'}, A^{'})$ can be defined as:

$$B_{jd} = \{b_{jd} \mid \{(\min_{P_d^{'} A^{'}}[A^{'}, b(Y_{jd/A^{'}})]) \geq \Psi_j) \wedge ((\min_{P_d^{'} A^{'}}[A^{'}, r(R_{tn/A^{'}})]) \leq \Theta_t))\} \tag{17}$$

where $A^{'} = A(A^{'}z)$ is a third order membership function of causes that are simultaneously created on cell sites in the affected zone. This membership function shall reflect the non-linear nature of cellular networks; $r(R_{tn/A^{'}})$ is a *t* constrain of a membership function of cell site $n \in S; \Theta_t$ is a tolerance threshold of quality attribute *t*.

It is possible that $B_{jd} = \otimes$. However, if $B_{jd} \neq \otimes$ and it contains more then one solution, then a "goodness" value for every solution can be calculated as:

$$G^j = \sum_{d \in P} \sum_{j \in J} K_j (\min[A\ , b(Y_{jd/A^{'}})]) \tag{18}$$

(For the simplicity in this a equation we use K_j to present weight coefficient for that desired effects and constraints, and $b(Y_{jd/A^{'}})$ to represent membership functions for the desired effects and constrains.) The solution that provides a maximum value of G^j is a candidate for implementation.

We should note that multiple causes created on a set of cells sites represent a general case. When only one control attribute of a cell site is changing, then formulas need to be modified, cause membership functions A' and $A_z^{'}$ should be replaced by $a(X_{iz})$, and effect membership function should be represented by $b(Y_{jd/iz})$.

Causes that produced a desired result on the consider cell site or in the effected zone should be used for creating reasoning rule(s) in the Decision Support Subsystem.

3. Conclusion

The soft approach is emerging now as a most promising direction in analysis and development of complex and non-stationary systems. Designed soft methodologies often have a generic nature and can be reused for application in areas other then for which they were developed. The decomposition and decision-making methodology proposed in this article can be used in such different system as data communications, electrical and oil pipe networks, car traffic flows in major cities and so on.

4.**References**

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