Performance Analysis of Cellular Mobile Communication Networks Supporting Multimedia Services

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Abstract

This paper shows that the development of an analytical model for a communication network provides integrated services to apopulation of mobile users, and presents performance results to both validate the analytical approach, and assess the quality of theservices offered to the end users. The analytical model is based on continuous-time multidimensional birth–death processes, and isfocused on just one of the cells in the network. The cellular system is considered to provide three classes of service: the basic voiceservice, a data service with bit rate higher than the voice service, and a multimedia service with one voice and one data component.

In order to improve all the network performance, some channels can be reserved for handovers, and multimedia calls that cannotcomplete a handover are decoupled, by transferring to the target cell only the voice component and suspending the data connectionuntil a sufficient number of channels become free. Numerical results demonstrate the accuracy of the approximate model, as well as theeffectiveness of the newly proposed multimedia call decoupling approach

1. Introduction

The ever-increasing popularity of cellular and cordless telephone services is making wireless access and mobility two major components in the evolution of telecommunication networks.

In the design of the first and second generation cellular mobile telephony systems (such as ETACS and GSM in Europe), the technical approach mainly focused on increasing the capacity available for voice services, so as to cope with the explosive growth in the number of subscribers. Today, the need for an increased system capacity is combined with the request for a wider spectrum of telecommunication services, in order to be able to offer data services in addition to plain telephony; this will pave the way to the introduction of wireless multimedia services for mobile users, including voice, data and images. While the performance of cellular telecommunication networks offering mobile telephony services was investigated by many authors under several different operating conditions, the same cannot be said of networks offering a variety of services to mobile users.

The performance of cellular telecommunication networks can be investigated by using either simulation or analytical models (or a combination of both). Though simulation is often preferred when aiming at the detailed study of the behavior of a specific cellular system covering a given area, in recent years a number of analytical frameworks were developed to obtain more general results. Some examples of analytical approaches to the performance analysis of cellular telecommunication networks are found in [1–9]. In [8] the performance of a personal communication network based on microcells covering city streets is analyzed to determine some important teletraffic parameters, such as the blocking probabilities of new calls and handovers, the carried traffic and the spectrum efficiency. The fluid model in [4] describes a wireless system fed with traffic scenarios based on Poisson time dependent processes. Techniques to reduce forced terminations of calls in progress due to handover failures are proposed and evaluated in [2], where several priority schemes are defined, which reserve channels to handovers. In [1] the performance of a hierarchical cellular system based on microcells and overlaying macrocells is analyzed, and the benefit of introducing "tier handovers", i.e., handovers between cells belonging to different hierarchical levels, is discussed. This research is extended in [6], where the performance of a more complex network, comprising *n* hierarchical cell levels, is evaluated. In [9] a model of a circuit switched cellular network with *m* classes of traffic sources is presented. Each class is defined by different resource and performance requirements, and therefore has a different blocking behavior.

2. Model description

The analytical model is based on a continuous-time multidimensional birth–death process, as we already mentioned; the model illustration is organized in four stages:

1. Discussion of the main assumptions and of the modelparameters.
2. State definition and identification of the model drivingprocesses.
3. Derivation of the flow balance equations and computationof the equilibrium state probabilities.
4. Evaluation of aggregate performance measure.

2.1. Assumptions and parameters

The cellular telecommunication system comprises alarge number of cells, and provides three classes of serviceto satisfy different kinds of users requests:

_ *Class A* service is intended to support basic voice callswhich require narrowband connections.

_ *Class B* service satisfies the requirements of data calls(or slow video calls) with (moderately) wideband connections.

_ *Class C* service is intended to support multimedia callscomposed of a data component and a voice component,which are set up and terminated at the same time, andmust be managed together.

Denoting with *N* the number of radio channels availablein a given cell of the cellular telecommunication system,we assume that the establishment of connections of class *A*requires just one channel, that connections of class *B* require*C*d channels and, finally, that connections of class *C*require *C*d + 1 channels.

2.2. State definition and driving processes

The cell state, in any instant, is determined by the number of currently active connections for each class of traffic, and it is, therefore, given by the vector:

$s = (v, d, m, r)$,

where

_ *v* is the number of active voice calls in the cell;

_ *d* is the number of active data calls;

_ m is the number of multimedia calls, with both components
(voice and data) active;
_ r is the number of active voice components of decoupledmultimedia calls; if $r > 0$, some suspended data callsare waiting to be resumed as soon as a sufficient numberof channels becomes available.
We denote with $n(s)$ the function giving the total number of channels allocated to active connections when the cell is in state s:

$n(s) = v + dCd + m(Cd + 1) + r:$
We shall simply write n instead of $n(s)$ when no ambiguity
arises. Since the number of channels available in the cell is N, the maximum values of v, d and m are respectively N, $bN=Cdc$ and $bN=(Cd + 1)c$. Whereas these values are determined by the cell configuration, the maximum number of decoupled calls that can be active at the same time, r, is limited by a threshold $r$max, that must be fixed by the operator of the cellular system; if no threshold is defined, r can grow up to N. Let S be the state space of the model we just described; it is convenient to order and number states from 0 to Smax. The model dynamics is determined by a number of *driving stochastic processes* which cause state transitions at random instants.

2.3. Flow balance equations and equilibrium probabilities

Since the Markovian model is homogeneous and irreducible, with finite state space, an equilibrium (or steadystate) distribution $\mathbf{p} = \{p(i)\}$, with $i = 0, : : : , S$max exists, and can be computed through the matrix equation $\mathbf{p}$ _ $\mathbf{Q} = \mathbf{0}$, where $\mathbf{Q}$ is the infinitesimal generator matrix, together with the normalization condition PSmax i=0 $p(i) = 1$. The transition rates, i.e., the elements $q(i, j)$ of matrix $\mathbf{Q}$, are obtained from the analysis of the system driving processes. For each driving process, it is possible to determine what state transitions can happen, i.e., what are the possible *successor states* of a generic state $s = (v, d,m, r)$. This is what we discuss next.

New call requests

A new call is accepted in the cell if the number of free channels, excluding those reserved to handovers, is such that the call can be accommodated. Furthermore, new calls are refused if some class D connections are active, (i.e., if $r > 0$), in order to favor recombination of decoupled multimedia calls. Table 1 shows, for each type of new call, the conditions on the model state for a transition to be possible, the rate associated with the transition, and the successor state.

2.4. Model complexity

The transition rate from a state s to a state k is computed by summing the contributions resulting from the driving processes that were just described. The state space size S (hence, the dimension of matrix $\mathbf{Q}$, which is S _S) depends on the values of Cd, $r$max, and, most important, on the number of radio channels available in the cell, N. Let the maximum number of active voice, data and multimedia calls be respectively $V = N$, $D = bN=Cdc$ and $M = bN=(Cd + 1)c$. The state space size S is upper bounded by $(V + 1)(D + 1)(M + 1)(r\text{max} + 1)$ (due to the restriction that the total number of busy channels is smaller than or equal to N, the expression above is not exact, but gives a close upper bound for S). S can be rather large, so that in the computation of the equilibrium probability distribution it is essential to use a numerical algorithm that exploits the sparseness of the infinitesimal generator; choosing the best representation of $\mathbf{Q}$, in order to minimize computation time and memory requirements, is not a minor task. For the results presented in section 3 we used an iterative solution technique which requires for each iteration step a number of multiplications equal to the number of elements of **Q** which are different from 0, that in our case is about *S*max _ 10.

3. Results

This section consists of two parts. First we present some comparisons between analytical and simulation results in order to validate our approximate modeling approach; then we explore some alternate system configurations to assess their effectiveness. As a basic scenario we refer to a configuration similar to the one being considered by ETSI (the European Telecommunications Standards Institute) for the introduction of (moderately) high speed data services within the European wireless telephony network. We, thus, consider two classes of service only: class *A* (voice call) and class *B* (data call). Each data call requires the allocation of *C*d = 4 channels. The mean dwell time of voice or data calls is set to 80 s, while the mean unencumbered session duration is taken to be 100 s. The fraction of voice calls is assumed to be 75% of the total, the remaining 25% being data calls. The number of channels in the cell is taken to be 64. The number of users in the cell under investigation is taken to be 500. The performance indices will be presented as curves plotted versus the input load in terms of total call rate.

3.1. Model validation

As we already mentioned, validating the analytical model by comparison with the results produced by a very detailed simulation of the wireless network is a necessity, because of the numerous simplifying assumptions adopted in the model development, in order to keep complexity under control. Recall that the major simplification stems from the choice of studying just one cell in isolation, instead of developing a detailed model of the entire network with the description of the interactions among adjacent cells. This also requires assuming that the average incoming handover flow is equal to the average outgoing handover flow. The simulator provides the description of a whole network comprising several cells. In each cell the stochastic representation of the new call request traffic and of the user mobility is the same as in the model: new calls are generated according to Poisson processes and call durations and dwell times are random variables with negative exponential distributions. The differences between the two approaches are due to the representation of the handover flow. While in the analytical model the handover flow entering a cell is assumed to be Poisson and its rate is derived by balancing the average flows of incoming and outgoing handovers, in the simulator the handovers are described in detail. Once a user issues a handover request towards a neighboring cell, a procedure starts which releases resources in the current cell, checks for available resources in the target cell and possibly allocates resources to the incoming handover. The correlation between the behaviors of two adjacent cells involved in a handover procedure is in this way accurately described. Simulation results will be presented for a network comprising seven hexagonal cells, comparing the performance estimates referring to the central cell against analytical results.

4. Conclusions

In this paper we have illustrated the development of an approximate Markovian model for a communication network providing integrated services to a population of mobile users, and we have presented performance results to both validate the approximate analytical approach, and assess the quality of the services offered to the end users.

The cellular system is assumed to provide three classes of service: the basic voice service, a data service with bit rate higher than the voice service, and a multimedia service with one voice and one data component. In order to improve the overall network performance,

some channels can be reserved to handovers, and multimedia calls that cannot complete a handover are decoupled, by transferring to the target cell only the voice component and suspending the data connection until a sufficient number of channels becomes free. The analytical model is based on continuous-time multidimensional birth–death processes, and it is focused on one of the cells in the network only. The model solution

is obtained with standard approaches for the solution of large Markovian systems, exploiting the sparseness of the infinitesimal generator. Numerical results demonstrate the accuracy of the approximate model, as well as the effectiveness of the multimedia call decoupling approach, that is a novel contribution of this work.

References

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