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Teletraffic approach to design and planning of GSM network employing the hierarchical cell structure

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Abstract

Due to increasing user demand and rapid growth of mobile cellular networks, the need for systematic planning methodology of networks has become essential. This paper presents a simple traffic model of a microcell in a GSM network that employs the hierarchical cell structure. The analytic model is used to estimate the number of traffic channels to be activated within the microcells for acceptable performance measures.

Keywords: Traffic model; Hierarchical cell structure; GSM; Microcell

1. Introduction

Basically, the algorithm used in conventional cellular network planning consists of four phases, see Fig.1 (Wojciech and Leibtiz, 2000).

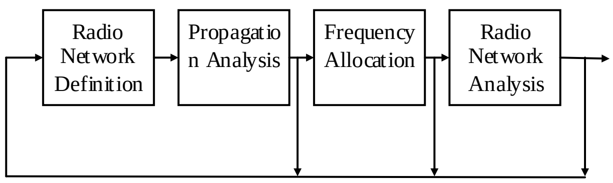

Fig.1. Network planning phases.

i. Radio Network Definition Phase: In this phase, an experienced radio-planning engineer chooses cell site locations based on his knowledge and planning experience.
ii. Propagation Analysis: The Radio coverage of the area using field strength prediction method is then evaluated.
iii. Frequency Allocation Phase: If the coverage requirements are met, the number of traffic channels is calculated and a frequency allocation is performed.
iv. Radio Network Analysis Phase: If the frequency plan can be computed, the network performance is evaluated in the radio network analysis phase by computing some quality of service (QoS) parameters in the cells.

From the above description, it is apparent that the conventional cellular network planning problem is driven by radio coverage considerations i.e. selection of cell site location, frequency planning, antenna design, etc.

The major disadvantage of this approach is that the teletraffic issues and customer behavior aspects are left out of focus in the network planning. Thus, an approach to performing a truly traffic-based cellular network planning for a given area is necessary.

The aim of this paper is to present analytic approach to the computation of the number of channels to be activated in cells, so as to obtain acceptable performance. This model can be used in the design and planning of GSM networks employing the hierarchical cell structure (HCS).

2. System description

A GSM network employing the hierarchical cell structure is considered. The HCS scheme provides coverage for high traffic areas with as many microcells as required. Overlaying macrocells cover low-traffic areas and provide overflow channels for the microcells. In HCS system, channels that are allocated to an overlaying macrocell act as the shared channel pool for subordinate microcells (Rappaport and Hu, 1994).

The system is operated such that a call served at a given hierarchical level will not request handoff to a cell that is lower in hierarchy. The structure is that of a hierarchical overflow system in which the microcells receive input streams of new and handoff calls, whereas overlaying macrocells receive input streams of new and handoff calls as well as overflow traffic from subordinate microcells (Rappaport and Hu, 1994).

The Dual – Band GSM network is based on the use of two separate frequency bands, around 900MHz and 1800MHz, respectively.

3. Mathematical models

The focus is on a macro-area covered by one macrocell and two microcells cf Fig. 2.

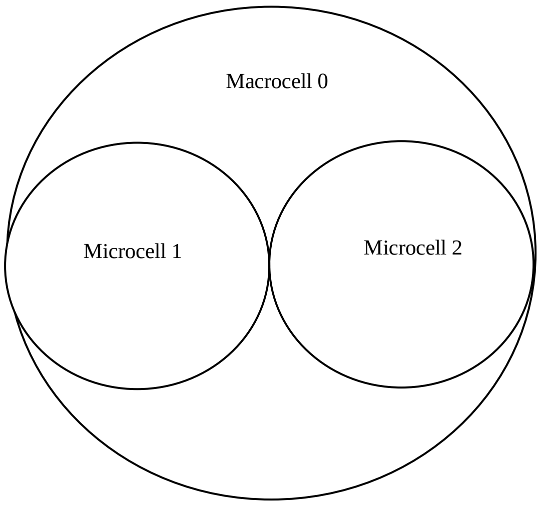

Fig. 2. A macro-area covered by an overlaying macrocell and two overlaid microcell.

To develop analytic model of traffic operation in the system, the following assumptions are made:

(a) Each macro-area is contiguous to at least several other macro-areas; the combined handoff arrival process from neighboring macro-areas follows Poison distribution.
(b) The new call and handoff arrival processes in any cell follow Poison distribution with mean rates denoted by λ_o, λ_h respectively.
(c) The dwell time, T_d of a communicating MS in a cell is a random variable having negative exponential Probability density function (pdf). The mean of T_d is $1/\mu_d$
(d) The unencumbered session duration of a call T is a random variable having negative exponential pdf mean of T is = $1/\mu$ (Stojmenovic, 2002).

3.1. Microcell model

With the above listed assumptions, a microcell can be modeled as a continuous time Markov chain and in particular Birth-Death process. At any time instant the state of the microcell is determined by the number of communicating MS_S. Assuming uniform subscriber density throughout the cell and a user is equally likely to move in any direction with respect to cell border, then a microcell can be modeled by a typical M/M/N/N queuing model. For nonpriority handoff access scheme and single traffic system the behavior of a cell can be described as a (N+1) states Markov process (Stojmenovic, 2002). Each state is labeled by an integer n (n= 0, 1, N) representing the number of channels is use. The state transition diagram is shown in Fig. 3.

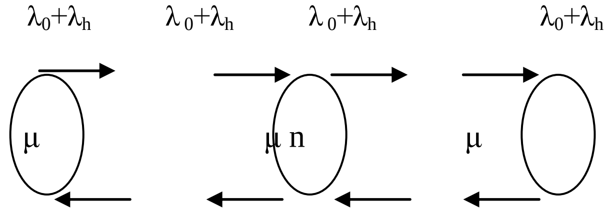

Fig. 3. State transition diagram for M/M/N/N queue model.

Let P (n) be the steady–state probability that n channels are busy in the microcell, from the state transition diagram, the state balance equation is

$$(\lambda_o + \lambda_h)P(n-1) = n\mu P(n) \quad 0 \le n \le N \tag{1}$$

Using equation (1) recursively, with the normalization equation

$$\sum_{n=0}^{N} P(n) = 1 \tag{2}$$

Then the steady –state equation is as follow:

$$P(n) = \frac{(\lambda_o + \lambda_h)}{n!(\mu)^n} P(0), \qquad 1 \le n \le N \tag{3}$$

where

$$P(0) = \frac{1}{\sum_{n=0}^{N} \frac{(\lambda_o + \lambda_h)^n}{n!(u)^n}} \tag{4}$$

The blocking probability for new call arrival is

$$Pb = P(N) = \frac{\frac{(\lambda_o + \lambda_h)^N}{N!(\mu)^n}}{\sum_{n=0}^{N} \frac{(\lambda o + \lambda h)n}{n!(\mu)^n}} \tag{5}$$

The blocking probability for a hand off call, is P_h = P_b because of the nonpriority hand off access scheme (Stojmenovic, 2002). In the above derivation of loss formula, the hand off calls arrival rate, λ_h is assumed. In practice, the value of λ_h is determined as a function of λ_o, μ_d, μ_d and N.

The probability that all channels in the microcell are busy, P(N) is given by equation. (5)

When a new call or handoff arrival finds all the microcell channels busy, it tries to access a channel in the macrocell. In order to model accurately the

macrocell, we need to characterize this overflow process at the macrocell. The behavior of the macrocell is more complex than that of the microcell.
The carried traffic in the microcell, A_c is simply the average of occupied channels in the cell [2] and is given by

$$Ac = \sum_{n=0}^{N} nP(n) \tag{6}$$

3.2. Implementation

This section presents the design and working of the model developed in section 3.1.
Table 1 summarizes the default values for the parameters used in the study.

Table 1
Default values of parameters. Source: Mtel (Nig) Ltd, (Area V)

Parameter	Value
Total No of channels in a micro cell	44TCH$_s$ 900MH$_z$: 14 channels 1800MH$_z$: 30channels
No of MSs per cell (estimate)	500
New call origination rate (λ_0)	2Calls/Hour(5.55x10^{-4}calls/sec)
Mean call duration, $1/\mu$	100s
Mean dwell time, $T_d = 1/\mu_d$	120s
Offered load to each cell	33.33 Erlangs

The new call origination rate, λ_0 from any MS regardless of its position in the cell was varied from 0.5 calls/ Hr to 2.0 calls /Hr (13.8x10^{-5} to 55.5x15^{-5} calls/sec) The mean unencumbered call duration is 100seconds. For this study the handoff call arrival rate, λ_h is taken to be 0. 2λ_0 and the out going rate of mobile users μ_h is, 0.2μ_d. Thus the offered traffic per mobile subscriber (MS) ranges from 0.01667 to 0.06667 Erlangs and the total traffic as seen by a microcell range from 8.333 to 33.33 Erlangs for the 500 estimated MS$_S$.
The performance indices considered in this study are the call blocking probability, the handoff failure probability and the carried traffic.
Two different channels allocation are considered
(i) Pattern – I: 30 channels are allocated to a microcell,
(ii) Pattern – II: 44 channels are allocated to the microcell.

3.3. Computational algorithm

The mathematical model of the microcell is implemented in Visual Excel with the following notation adopted for the program design

Variable	Description
N	The state of a cell (defined as the number of calls in program in the cell or the number of channels in use)
N	Maximum number of channels in the cell
A	Offered traffic to a microcell
P(0)	The initial steady-state probability.
P(n)	The steady-state probability for state n.
P_b (n = 30)	The blocking probability when maximum 30 channels are in use.
P_b (N = 44)	The blocking probability when maximum 44 channels are in use.
Ac	The carried traffic.

3. Results and discussions

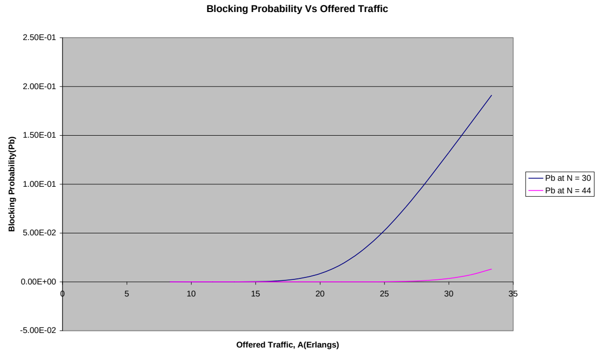

Fig. 4. Variation of blocking probability with offered traffic.

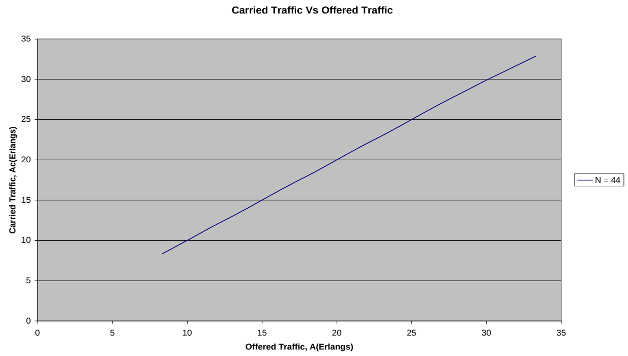

Fig. 5. Variation of carried traffic with offered traffic.

Figures 4 and 5 show traffic performance characteristics of a microcell in a dual-band GSM network implementing hierarchical cell structure. Two different channel allocations to the microcell are considered: Pattern – I, 30 channels are allocated to the cell, while in Pattern – II, 44 channels were allocated to the cell. P_b denotes the blocking probabilities.

From Fig. 4, it is seen that the blocking probability in a cell is significantly decreased as the number of channels allocated to the cell is increased. Since the total number of channels is fixed, one would expect that this improvement in a cell is at the expense of blocking probability performance degradation in another cell.
However, because channels in the macrocell level in a hierarchical network also functions as overflow channels for the microcells, this intuitive ordering is true at high traffic while under low offered traffic, the channels of the macrocell can sufficiently accommodate the new call origination from macrocell and the overflow calls from the microcells. Thus for low offered traffic, Pattern-II results in the lowest blocking probabilities in the microcell. Fig 5 shows the predictable variation of carried traffic with offered traffic in a microcell for non-priority handoff access scheme.

The results of this analysis can be used in resource planning of GSM network implementing hierarchical cell structure.

The most valuable resource in a cellular mobile system is the allocated channels. Assuming the network planner has N channels for a given cell, he can easily compare the blocking probability performance for the different configurations. The system parameter values are chosen, such that a specified call blocking probability can be guaranteed.

4. Conclusion

This paper has considered a GSM network employing the hierarchical cellular structure. We have presented the performance analysis of a microcell using a simple analytic model of the microcell.

We have also presented resource planning techniques for dual-band GSM networks, where service is offered to users moving over an area covered with overlaying macrocell and overlaid microcell.

The behaviour of the macrocell is more complex than that of the microcell, due to the presence of two classes of sessions: microcell to macrocell handovers and macrocell to macrocell handovers. Future research will consider the modeling and performance evaluation of the macrocell.

References

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