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Performance analysis of a mobile communication network: the tandem case

Attahiru Sule Alfa[a,*], Bin Liu[b]

[a]Department of Electrical and Computer Engineering, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V6
[b]Institute of Applied Mathematics, AMSS, Chinese Academy of Sciences, Beijing 100080, P.R. China

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Abstract

This paper investigates mobile communication networks consisting of N-cells in tandem. Two models with fixed channel assignment are considered, which correspond to (A) a uni-directional traffic flow and (B) bi-directional traffic flows, respectively. We develop an approximate method to obtain main performance measures of systems such as the loss probabilities of handover calls and fresh calls, and the expected number of occupied channels in each cell. Our approximation is based on decomposing the N-cells in tandem network into $N-1$ pairs of cells with overlaps. The stochastic correlation among neighboring pairs are captured by appropriately selecting the state-dependent Poisson processes as the approximation of handover processes. Some numerical examples are given to demonstrate the accuracy and the convergence of the proposed approach.

Keywords: Tandem network; Mobile communication networks; Performance; Corridor movements; Fixed channel allocations; Call loss probabilities

1. Introduction

The rapid development of personal communication services (PCS) has stimulated increasing interests in studying the performance measures of *cellular* mobile communication networks with various control mechanisms. Specifically, this trend has called for better and more efficient analysis of such systems in order to improve the quality of the service. One of the common features in these networks is that the whole service area is divided into cells (Fig. 1), which are served by cell transceivers. However, the number of transceivers (Fig. 2) in each cell is severely limited. This is due to the fact that the number of frequencies available to carry mobile calls is limited. The second feature of these networks is that there are usually two or more classes of calls, e.g. *fresh* calls and *handover* calls. The fresh calls are ones which are just starting, and the handover calls are ones which are already ongoing but have moved out of the original cell and need to connect to a transceiver in a new cell.

Because of the limited number of channels available for each cell, one of the crucial performance measures for cellular mobile communication networks is the loss probability, i.e. the probability that a call cannot be connected. There are two types of common call losses. One is called *fresh call loss* due to lack of available channels to accommodate a fresh call. The other is called *handover call loss*. If a mobile terminal moves from the radio coverage of one cell to the radio coverage of another cell, the call is handed over from one transceiver to another. However, if there is no channel available in the new cell, the call is lost. In the perspective of communication company, the latter incurs greater loss than the former.

Most models for the analysis of PCS and mobile communication systems have focused only on a single cell. They assume that all the cells in the network are homogeneous (see Refs. [13,14] and the reference therein). Such an assumption is only a matter of convenience for computational tractability, but is not quite realistic. For example, the input of new calls in each cell could be very different and thus immediately contradicts the assumption of homogeneity, especially if the differences are significant. Besides, depending on the designs, the number of channels in each cell are not necessarily the same and the number of channels reserved for handoff calls may also be different. Some researchers recently have considered non-homogeneous cells in the mobile network

* Corresponding author. Tel.: +1-204-474-8789; fax: +1-204-261-4639.
E-mail addresses: alfa@ee.umanitoba.ca (A.S. Alfa), bliu@mail.amt.ac.cn (B. Liu).

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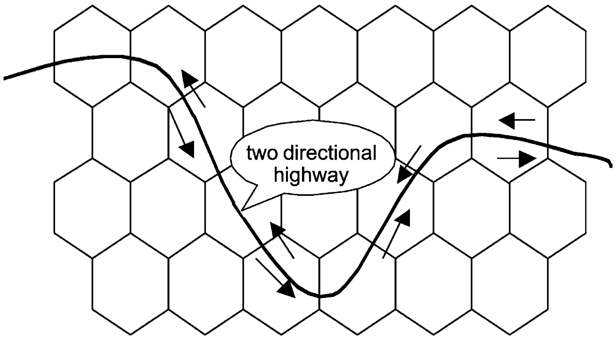

Fig. 1. A two-directional highway covered by a cellular mobile communication network.

(see Refs. [1,2,4–12]). However, most results were obtained only for those networks with product form solutions.

Pallant and Taylor [10] studied a cellular mobile network with dynamic channel allocation (maximum packing strategy proposed by Everitt and Macfadyen [4]), and proved that its product form solution exists under certain reversibility conditions. Their model was further extended to allow directed retry for handover calls after being blocked.

In Ref. [2], Boucherie and Van Dijk presented a stochastic model for cellular mobile communications networks by taking into account phase-type distributed call-length and phase-type distributed channel holding time. They formulated a stochastically equivalent queueing network with age-dependent routing for their model. For some special networks having product form solutions, they obtained two results on insensitivity of distributions, i.e. the stationary distribution of system depends on the call-length distribution only through its mean, and also depends on the distribution of the time a call spends in cells only through its mean.

Boucherie and Mandjes [1] introduced a simulation algorithm to evaluate performance measures (blocking probabilities) from the product form equilibrium distribution. Their numerical method is based on importance sampling in conjunction with large deviation techniques. The necessary condition for using their method is the existence of a product form equilibrium distribution. For some important networks with different protocols such as redial, soft capacity and push-out policy, the authors studied the conditions to ensure the equilibrium distributions to be of the product form.

In general, the conditions which ensure a product form equilibrium distribution are quite restrictive and are unlikely to be satisfied in practical. In fact, for the vast majority of networks, the solutions cannot be obtained in closed form. Therefore, it is very important to develop effective approximate methods to obtain their solutions.

Massey and Whitt [8] and Leung et al. [7] studied a so-called highway Poisson-arrival-location models (PALM) for a wireless network along a highway, which is closely related to our models. In their model, vehicles were classified as non-calling or calling. Basic model is for traffic on a one-way, semi-infinite highway, with movement specified by a deterministic location function. Two-way model and other more general movements in R^2 and R^3 were treated as superpositions of independent one-way traffic along paths in these spaces. Under assumption of no capacity constraints, they derived the partial differential equations (PDEs) or the ordinary differential equations (ODEs) to describe the evolution of the system. The call density and call handoff rate were calculated by solving these equations numerically. For models with capacity restrictions, the blocking probabilities of calls were approximated by applying the results on infinite capacity models. No discussion on the accuracy of approximation is provided in their papers.

In this paper we consider a network of N-cells in tandem which are prevalent in mobile communication services on highways and railways during the morning and afternoon rush hours. We study two different models with fixed channel allocation, which correspond to (A) a uni-directional mobile traffic flow, and (B) bi-directional mobile traffic flows, respectively. There are two different types of call (handover call and fresh call) arrivals for each cell. To ensure that handover calls gain a higher priority than fresh calls, we always reserve some channels in each cell for possible arriving handover calls (see Refs. [13,14]). An approximation approach is developed to calculate some important performance measures such as the loss probabilities of fresh calls and handover calls and the expected number of occupied channels in each cell. The approximation is based on decomposing the N-cells in tandem to $N-1$ pairs of cells with overlaps. The approximation performs reasonably well in a wide range of data based on the numerical examples. This method has been used

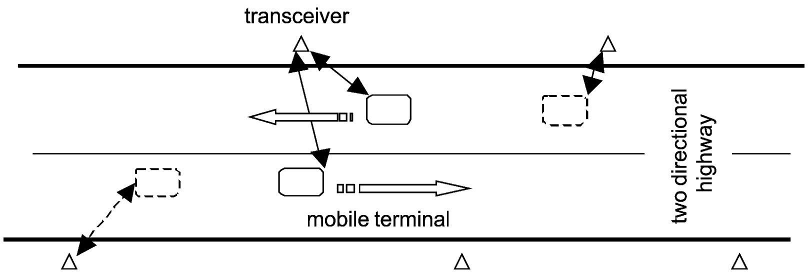

Fig. 2. Communication between mobile PC terminals and transceivers.