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Performance analysis of a PCS network with state dependent calls arrival processes and impatient calls

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Abstract

This paper studies the behavior of performance evaluation for a personal communication services (PCS) network, in which the calls' arrival process may depend on the number of calls in the target cells. Each cell of the PCS network consists of a finite channel and a buffer (with finite or infinite size) for handoff calls. The handoff calls having to wait in the buffer for further communication may become impatient and leave the system if their waiting time exceeds their own patience. The mobilities of the portables are characterized by the random cell residence times of the portables. For insight into the effect of dependent calls arrival processes and the impatient calls on PCS network performance, we propose an analytical model and obtain the expressions for the following interesting conventional and new performance measures: the new call blocking probability, handoff call failure probability and the forced termination probability of a handoff call; the quasi and actual waiting time of a handoff call in the buffer; the actual call holding time of a new call; and the blocking period of time of the new calls and the handoff calls etc. We also provide an algorithm to compare these blocking probabilities and the arrival rates for handoff calls. Some special cases of our model used in previous traffic models of wireless and/or wireline communications are discussed. The results presented in this paper can provide guidelines for field data processing on updated PCS network design and performance evaluation.

Keywords: Dependent calls arrival processes; PCS network with impatient call; Mobility

1. Introduction

A convergence of personal communication services network has led to the emergence of networks poised to provide integrated services such as voice and data to mobile users anywhere, anytime [6,20] in an uninterrupted and seamless way, using advanced micro-cellular and handoff concepts [17]. Due to the growing importance of PCS, it is necessary to study their behavior for performance evaluation and optimization under more realistic conditions. When a portable user initiates or receives a call, he/she may roam around in the convergence of the PCS network. If the portable moves from one cell to another, and the call from/to the portable has not finished, the network has to handoff the call from one cell to another at the cell boundary. Because the number of channels available in a cell is limited, the handoff call may not be successful. Similarly, when a portable makes a new call, the new call may be blocked. Since handoff calls have been in the network already, these calls should have a higher possibility of completion in order to maximize customers' satisfaction. The practical ways to keep this include designing a buffer for temporary queue of the handoff call and/or giving priority for channels to handoff attempts over new calls attempts [16,30,33]. In Refs. [11,32,33] both new call rate and handoff call rate are given as input parameters. In Refs. [12,16,24], the net handoff call arrival rate is derived by using the net new call rate and some mobility parameters. However, for the sake of convenience and tractability, most previous traffic analysis made the assumption that the handoff call rate is a constant, which is usually obtained in terms of the depart rate of calls from a cell. This assumption is unrealistic because it is obvious that the depart rate of calls from a cell is closely dependent on the new call arrival processes, the channel capacity, the average call numbers in the cell and other mobility input parameters. The authors in Refs. [15,31] used a Markov modulated Poisson process to describe superposition packet streams whose interarrival times are known to be correlated. The authors in Ref. [21] model the total calls arrival process in a PCS network as a general Markov arrival process, which allows the correlation of the

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interarrival times among new calls, among handoff calls and between the handoff calls and the new calls. Most recently, the authors in Refs. [4,5] analyzed a wireline system with state dependent arrival and impatient calls and proposed an application in Automatic Call Distributor (ACD) system of finite capacity with outbound calls and impatient inbound calls.

For insight into the effect of the dependent calls arrival processes and the impatient calls on PCS network, we present an analytical model with a set of reasonable assumptions which enable us to give analytical results for the performance of PCS networks. More precisely, the PCS network we consider here possesses the following characteristics.

- The PCS network consists of homogeneous cells [28], i.e. the underlying processes and parameters for all cells within the PCS networks are the same, so that all cells are statistically identical. Each cell consists of K channels for both new and handoff calls and a buffer with size of N ($0 \le N \le \infty$) for handoff calls only.
- The arrival of calls, i.e. new calls and handoff calls, to the network are modeled as Poisson processes depending on the number of calls in the cell. Specifically, when the total calls in the cell are n ($n = 0, \ldots, K + N$), the new call arrival process is considered as a Poisson process with arrival rate λ_n. The handoff calls arrival process is also assumed to be a Poisson process with general rate η_n, the value of which will be derived in later discussion. The reasons for this handoff assumption include: (1) if $\eta_n = \eta$, our model will specially reduce to the constant handoff rate, which is more intuitive that the handoff rate will be independent of the calls in the target cell; and (2) the handoff calls per unit time from the undergoing cell to the target cell will depend on the average number of calls in the undergoing calls and, therefore, the handoff rate will be dependent on the numbers in the previous cells.
- Each handoff call arriving to the cell and having to wait for in the buffer has a patience time. If the virtual waiting time (i.e. the time which the handoff call would have to wait until service) exceeds the patience time, the handoff call departs from the system and gets lost by impatience. The patience times of the handoff calls are assumed to be i.i.d. with exponential distribution and with an expectation $1/\alpha$. There are a lot of papers dealing with impatience phenomena. For some related literature please refer to Refs. [2,13,14,34] etc.
- The requested call holding of new calls, each of which is defined as the duration of the requested call connection to a PCS network for a new call (also called the unencumbered call holding time [9] or the unencumbered session time [27]) on the channels, are i.i.d. with exponential distribution and with an expectation $1/h$.
- The cell residence times of portables, each of which is defined as the intervals that a portable stays in the cells and are usually a function of system parameters such as cell size, speed and direction of the portables, are i.i.d. with exponential distribution and with an expectation $1/r$.

This traffic model could cover many special cases which have been previously investigated for the PCS networks. A special case is that the calls are all patient (i.e. $\alpha = 0$) and both the new call and the handoff calls form stationary Poisson processes, which are independent of the numbers in the cell and which have been widely used in the current literature for the tractability of the mathematics [9,13] etc. Some other special cases previously studied for general wireless and/or wireline networks include: (1) if $\eta_n = \eta$, and there exists an integer m between 0 and K such that $\lambda_n = \lambda$ if $0 \le n \le K - m$ and zero otherwise, the traffic model reduces to the channel reservation scheme [16] (or queuing priority scheme [19]), which reserved m channels for handoff calls and which scheme has been widely used in wireless communications [27]; and (2) if $\eta_n = r = d = 0$, $N = \infty$, and $\lambda_n = \lambda$ if $0 \le n < K$ and $\lambda_n = \theta\lambda$ if $n \ge K$ (where θ is a probability), the traffic model reduces to *loss–delay hybrid model* [25]. Some other related models can be found in Refs. [1,14] etc. With the dependent call arrival model and the mobility model for the cell residence time as well as the patience time that we present in this paper, it is possible to generalize many classic analytic results in the current traffic theory for PCS network to a more realistic status. This paper takes the first step towards this goal.

The other parts of the paper are organized as follows. In Section 2, we investigate the three interesting probabilities of the traffic model, i.e. new call's blocking probability, handoff call failure probability and the forced termination probability of the handoff calls. We also provide an algorithm to compute these blocking probabilities and the arrival rates for handoff calls. In Section 3, the concepts of the quasi waiting time and the actual waiting time of a handoff call are introduced and the closed expressions are obtained. In Section 4, the actual call holding time of a new call is proved to be exponential. Finally, in Section 5, the new call blocking period of time and the handoff call blocking period of time are introduced and the closed expressions are derived.

2. Model analysis

In this section, by constructing a general birth and death process based on the input parameters of the traffic model, we find the stationary probability of n calls in the cell first. Then, we investigate the three interesting probabilities of the traffic model, i.e. new call's blocking probability, handoff call failure probability and the forced termination probability of the handoff calls. An algorithm to compute these probabilities and the arrival rates for handoff calls is also proposed.