PERFORMANCE ANALYSIS OF MULTI-CHANNEL AND MULTI-TRAFFIC ON WIRELESS COMMUNICATION NETWORKS

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Wuyi Yue
Konan University, Japan

and

Yutaka Matsumoto
I.T.S., Inc., Japan

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The book will prove useful to a post-graduate course in computer science or engineering. It is often a pre-requisite to some other more advanced courses like network design and management based on queueing modeling with examples of their applications to multimedia communication networks and computer networks. It can also be used for a course on stochastic models in mathematics and operations research departments.

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Preface

With the rapidly increasing penetration of laptop computers and mobile phones, which are primarily used by mobile users to access Internet services like e-mail and World Wide Web (WWW) access, support of Internet services in a mobile environment is an emerging requirement. Wireless networks have been used for communication among fully distributed users in a multimedia environment that has the needs to provide real-time bursty traffic (such as voice or video) and data traffic with excellent reliability and service quality.

To satisfy the huge wireless multimedia service demand and improve the system performance, efficient channel access methods and analytical methods must be provided. In this way very accurate models, that faithfully reproduce the stochastic behavior of multimedia wireless communication and computer networks, can be constructed. Most of these system models are discrete-time queueing systems.

Queueing networks and Markov chains are commonly used for the performance and reliability evaluation of computer, communication, and manufacturing systems. Although there are quite a few books on the individual topics of queueing networks and Markov chains, we have found none that covers the topics of discrete-time and continuous-time multichannel multitraffic queueing networks.

On the other hand, the design and development of multichannel multihop network systems and interconnected network systems or integrated networks of multimedia traffic require not only such average performance measures as the throughput or packet delay but also higher moments of traffic departures and transmission delay.

The purpose of this book, therefore, is to offer detailed exact and approximate analytical solution methods and techniques using queueing theory to model the complex multichannel and multi-hop network systems with procedures of multiple access schemes and reliably evaluate the performance of the systems. In particular, this book presents methods of approximating the system performance of discrete-time and continuous-time multimedia networks, the probability distribution of the interarrival time of internetwork transmissions at the adjacent network and the higher moments of the transmission departure distribution and delay distribution in wireless multimedia communication environment.

The generally accepted view is that discrete-time multimedia communication systems can be more complex to analyze than equivalent continuous-time ones, because of the finite size of a time-unit, multiple state changes can occur from one time-unit to the next. This complicates the resulting analysis of the model. In this book, numerical results that illustrate the applications of the theory and various properties are also discussed.

We organize the book to three parts. In Part I, we discuss wireless communication networks with the multiple random access slotted ALOHA protocol with several system performance analyses for multichannel, multi-hop and multi-traffic network systems. Part I includes 4 chapters, Chapters 2-5.

In Chapter 2, we consider packet radio communication systems that employ a set of M parallel channels under the slotted ALOHA protocol and exactly derive the moment generating functions of the packet interdeparture time, number of packet departures and packet delay for both IFT and DFT protocols.

In Chapter 3, we present an exact analysis to evaluate the effect of capture on the multichannel slotted ALOHA protocol and give the improved system performance such as the channel utilization and average packet delay.

In Chapter 4, we propose two different procedures of multichannel multiple random access schemes with slotted ALOHA operation for integrated voice and data traffic and present exact analyses to numerically evaluate the average performance measures and high moments of these systems. In scheme I, there is no limitation on access between voice transmission and data transmission, i.e., all channels can be accessed by all transmissions. In scheme II, a channel reservation policy is applied where a number of channels are used exclusively by voice packets, while the remaining channels are used by both voice and data packets, and voice packets select the reserved channels with a given probability.

In Chapter 5, we analyze a multi-hop packet radio communication network which consists of a finite number of hops with infinite buffer capacities. In this chapter, two major results are presented. First, through an exact analysis, the average queue length and packet delay of the system are explicitly derived, and performance of the system with and without transmission error is compared. Then, an approximate analytic method, based on a decomposition approach in which the total system is divided into subnetworks of the generalized M/G/1 type, is proposed to simplify the analysis of the queue length and packet delay in packet radio communication networks with a large number of hops.

In Part II, we provide the analyses and various properties for local area networks (LANs) and wireless LANs (WLANs) with the multiple random access CSMA/CD and CSMA/CA protocols for multichannel and multitraffic. There are 3 chapters, Chapters 6-8, in Part II.

In Chapter 6, we present the system performance analysis of slotted multichannel non-persistent CSMA/CD local area networks with a finite number of users. Channel utilization, delay performance and higher moments of the packet interdeparture time, number of packet departures and packet delay are then calculated in the terms of the number of network users, the number of network channels and the channel access rate.

In Chapter 7, we present an exact analysis to numerically evaluate the performance of high-speed and realizing fully distributed WLAN systems with a multiple random access method named non-persistent CSMA/CA protocol. The collision avoidance portion of CSMA/CA in this system model is performed with a random pulse transmission procedure, in which a user with a packet ready to transmit initially sends some pulse signals with random intervals within a collision avoidance period before transmitting the packet to verify a clear channel.

WLANs as in Chapter 7 have been used for communication among fully distributed users in a multimedia environment that has the needs to provide real-time bursty traffic (such as voice or video) and data traffic. In Chapter 8, we present a detailed system model and an effective analysis for the performance of WLANs which support multimedia communication with the non-persistent CSMA/CA protocol. In this chapter, we also present an exact analysis to derive the moment generating function of the packet interdeparture time for the output process.

In Part III, we present performance analyses and evaluations for personal communication networks and cellular mobile networks with various chan-

nel access process methods as the CDMA protocol, fixed and hybrid channel assignment schemes for supporting multi-traffic transmission and hand-off. Part III has 3 chapters, Chapters 9-11.

In Chapter 9, we present the output and delay process analysis of integrated voice and data slotted CDMA network systems with a multiple random access protocol for personal wireless communications. In the system, the allocation of codes to voice calls is given priority over that to data packets, while an admission control, which restricts the maximum number of codes available to voice sources, is considered for voice traffic so as not to monopolize the resource. In addition, the system monitoring can distinguish between silent and talkspurt periods of voice sources, so that users with data packets can use the voice codes for transmission if the voice sources are silent.

In Chapter 10, we provide two approximate techniques to evaluate the performance of large scale cellular mobile wireless network systems using a hybrid channel assignment scheme. The two approximate analyses give the steady-state probability distributions of the system which are used to obtain expressions for the blocking probabilities. Analytical results are compared with simulation results and good agreements are observed for both fixed and hybrid channel assignment schemes.

In Chapter 11, we present an exact analysis and an efficient matrix-analytic procedure to numerically evaluate the performance of the large scale cellular mobile wireless network systems with hand-off. This chapter considers such a priority scheme that some channels and buffers are reserved for hand-off calls to reduce the forced termination of calls in progress. Performance characteristics included blocking probability, channel utilization, average queue length, average waiting time and high moments.

Finally, in Chapter 12 we offer a summary of our conclusions in this book and suggest topics for future research.

We classify the performance models analyzed in each chapter in Table 0.1 with regard to whether the analysis is exact or approximate, what types of communication network and protocol are considered, and whether the performance measure obtained is with respect to average or distribution. In Table 0.1, we use some abbreviated signs as follows: "Ch." for "Chapter", "M.C." for "Multichannel", "M.T." for "Multi-Traffic", "M.H." for "Multi-Hop", and "Perf.M." for "Performance Measure".

Furthermore, we point out that Chapters 2-9 analyze discrete-time networks operating on the basis of time slotting, and transmitting information

Table 0.1. Classification of performance model in each chapter

	Analysis	M.C.	M.T.	M.H.	Protocol	Perf.M.	Note
Ch. 2	Exact	○	×	×	ALOHA	Distribution	
Ch. 3	Exact	○	×	×	ALOHA	Average	Capture
Ch. 4	Exact	○	○	×	ALOHA	Distribution	
Ch. 5	Exact & Approx.	×	×	○	ALOHA	Distribution	
Ch. 6	Exact	○	×	×	CSMA	Distribution	
Ch. 7	Exact	×	×	×	CSMA	Average	
Ch. 8	Exact	×	○	×	CSMA	Distribution	
Ch. 9	Exact	×	○	×	CDMA	Distribution	
Ch. 10	Approx.	○	×	○	-	Average	Cellular
Ch. 11	Exact	○	×	○	-	Distribution	Hand-Off

in fixed length units such as packets (but in Chapter 5, arrivals of packets can possibly occur at any given time instant on the time axis). Chapters 10 and 11 analyze continuous-time networks at which arrivals and departures can possibly occur at any given time instant on the time axis.

The analysis offered in each chapter is independent of that offered in other chapters, although, depending on the class of queueing system involved, there is some common ground between the techniques employed. Each chapter contains its own system model and offers important equations and specific numerical results. The reader will find it helpful to refer to Chapter 1 initially, but after that the remaining chapters are stand-alone units which can be read in any order.

The book should prove useful to a post-graduate course in computer science or engineering. It is often a pre-requisite to some other more advanced courses like network design and management based on queueing modeling with examples of their applications to multimedia communication and computer networks. It can also be used for a course on stochastic models in mathematics and operations research departments.

WUYI YUE
YUTAKA MATSUMOTO
Kobe, Japan

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