Markov analysis of the PRMA protocol for local wireless networks *

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PRMA (packet reservation multiple access) is a reservation-ALOHA access protocol specifically designed for wireless microcellular networks that handle both real-time and non-real-time traffic. We present a thorough analysis of this protocol, considering real-time traffic only, based on a suitable Markov model. The size of the model is such that it can be directly used for an exact quantitative analysis of the system. In particular, we are able to analyze the packet dropping process, by evaluating both average and distribution measures. The latter are particularly useful to characterize the degradation caused to real-time traffic (e.g., voice) by the loss of consecutive packets. Besides, we also derive from the Markov model a qualitative analysis of the system stability, based on the equilibrium point analysis (EPA) technique. By this technique, we characterize the system stability and analyze the effect on it of several system parameters (e.g., load, permission probability).

1. Introduction

The growing availability of mobile tools for personal computing and communication is stimulating an intense interest in wireless communication networks. Among the topics of interest there is the definition of access protocols that can efficiently handle both real-time (e.g., voice) and non-real-time (e.g., data) traffic. These protocols must be designed taking into account the expectation of large mobile users densities in the near future, and the limitation in the available radio spectrum. Microcellular networks are a possible solution, thanks to a higher frequency reuse but, in turn, they imply an increasing complexity of mobility management. Hence, access protocols within each microcell should require little or no central coordination, to free up network resources for mobility management [3].

The packet reservation multiple access (PRMA) protocol has been recently proposed as a viable solution for wireless microcellular networks [3]. PRMA is basically a modification of the R-ALOHA protocol [2] for microcellular applications designed for transmission of voice and data. As R-ALOHA, PRMA shares both the advantages of decentralized packet contention protocols and of reservation protocols, better suited for real-time traffic [3].

In a PRMA system, voice terminals are statistically multiplexed to achieve efficient use of the channel resource. To this end, terminals employ speech activity detectors and transmit only during voice active periods (talkspurts). The resulting contending mechanism causes packet delay and, since speech packets require prompt delivery, voice terminals are designed to drop those delayed beyond the maximum delay limit. Dropped packets affect speech quality and hence packet dropping measures are important for assessing the PRMA system performance and the achievable statistical multiplexing gain.

The PRMA voice protocol was first analyzed by simulation in [3]. Successively, in [8,9], Markov models for the PRMA voice and voice-data system were developed. In both papers, though, the system performance was evaluated only approximately by means of equilibrium point analysis (EPA) [11,12], owing to the models complexity. Models that allow direct and exact analysis have also been considered. In [13], the voice-data system is studied under the assumptions the voice terminals do not drop packets. In [6], the PRMA voice system is studied and compared with other random access protocols. The packet dropping probability and the packet loss distribution are evaluated under the assumption that the maximum packet delay is equal to the frame duration.

In this paper we analyze the performance of a PRMA system with emphasis on real-time, delay constrained traffic. We develop a Markov model of the PRMA voice system, the size of which allows direct evaluation of the system performance. We also derive from the Markov model a qualitative analysis of the system stability, based on EPA. The study of the dynamics of a single terminal enables us to analyze the packet dropping process, by evaluating both average and distribution measures. The latter are particularly useful to characterize the degradation caused to real-time traffic (e.g., voice) by the loss of consecutive packets [1]. Differently from [6], in our analysis the maximum packet delay is not constrained to the frame duration. Therefore, our model can be used to study the impact of different delay constraints on system performance.

The rest of the paper is organized as follows. In section 2 we briefly describe the PRMA protocol. In section 3 we present the PRMA model: first, the voice model is described; then, the overall PRMA model is presented. In section 4 we evaluate the packet loss performance measures

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A detailed description of the protocol can be found in [4,9]. We concentrate on the real-time (voice) system aspects only.

3. The model

In this section we develop a Markov model for a PRMA voice system. We begin our study by describing the voice source model.

3.1. The voice model

During speech, talkspurt and silent periods alternate. A simple model for voice sources is provided by a two state Markov process: exponentially distributed talking (active) periods alternate with exponentially distributed silent (idle) periods. For the analysis of slotted systems, a discrete time version of the above process is preferable. Denote \( t_1 \) and \( t_2 \) the mean length of a talking and of a silence period, respectively, and \( \tau \) the slot duration. The probability \( \gamma (\sigma) \) that a talkspurt (silent) period of mean \( t_1 \) (\( t_2 \)) ends within a slot of duration \( \tau \) is

\[
\gamma = 1 - \exp(-r/t_1) \quad \text{and} \quad \sigma = 1 - \exp(-r/t_2).
\]

A discrete time model for a voice source is given in figure 1, where the time unit corresponds to one slot duration. The transition from the Talk (talking) to the Sil (silent) state occurs with a fixed probability \( \gamma_1 \), and the transition from the silent to the talking state occurs with a fixed probability \( \sigma \). The silent and the talking periods are geometrically distributed with means \( 1/\sigma \) and \( 1/\gamma \), respectively. The fraction of time spent in each state is

\[
\pi_{\text{Sil}} = \frac{\gamma}{\sigma + \gamma} \quad \text{and} \quad \pi_{\text{Tal}} = \frac{\sigma}{\sigma + \gamma},
\]

respectively. Observe that because PRMA voice packets are generated at frame rate, a talkspurt of length \( L \) slots in the model of figure 1 corresponds to the generation of \( L_p = \lceil L/N \rceil \) packets, where \( N \) denotes the number of slots per frame.

3.2. The PRMA model

Consider a PRMA system with \( M \) homogeneous independent voice terminals. Let \( N \) denote the number of slots per frame and \( p \) the permission probability, that we assume

\[
B = \left\lceil \frac{D_{\text{max}}}{N} \right\rceil,
\]

where \( D_{\text{max}} \) is measured in slot, \( N \) denotes the number of slots per frame and \( \lceil x \rceil \) denotes the smallest integer larger or equal to \( x \).