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Survey

Performance models for wireless channels

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ABSTRACT

Performance modeling of wireless access technologies is useful to understand their limitations in various operational conditions and find a way to improve their performance. In the past two decades a number of models have been proposed. These models are often more complicated compared to those developed for wired networks. The reason is that in wireless networks performance degradation is caused by both incorrect reception of channel symbols at the physical layer and queuing at higher layers. Various error control mechanisms used to hide the effect of error-prone channel behavior complicate performance analysis and often require restrictive assumptions to retain analytical tractability. The aim of this paper is to review performance evaluation models proposed for wireless channels, highlighting their basic ideas, shortcomings, and advantages. We consider models developed for both centralized and distributed access technologies. Potential applications and extensions are also discussed. We believe that this study may provide a starting point for those looking for a suitable modeling framework and allow time to be saved in developing new performance models.

1. Introduction

Wireless access technologies are becoming widespread in our everyday life providing a fast and convenient way to access various Internet services "anytime and anywhere". In response to the constantly growing need for more bandwidth at the air interface, vendors and standardization bodies continue to improve existing technologies and develop new ones. These new technologies include many parameters that are not necessarily optimized for specific environments. To evaluate the efficiency of new wireless access technologies and optimize the performance of existing ones, performance models are required.

The aim of this paper is to provide an in-depth review of analytical models proposed so far for performance evaluation of wireless access technologies. The motivation behind this work is manifold. First of all, performance modeling of wireless channels is an extensively studied research area nowadays. Although the literature on this topic has exploded over the past two decades, to the best of the author's knowledge, there have been no studies trying to sort the performance evaluation models proposed to date and explain their basic approaches and ideas. Given the existing database of these models it is difficult for a newcomer to the field to choose a point to start from. Secondly, performance modeling of wireless systems brings a number of unique challenges that have never been an issue in wired networks. This includes the error-prone nature of wireless channels, channel access methods, various channel adaptation mechanisms, etc. As a result, performance models are often complex

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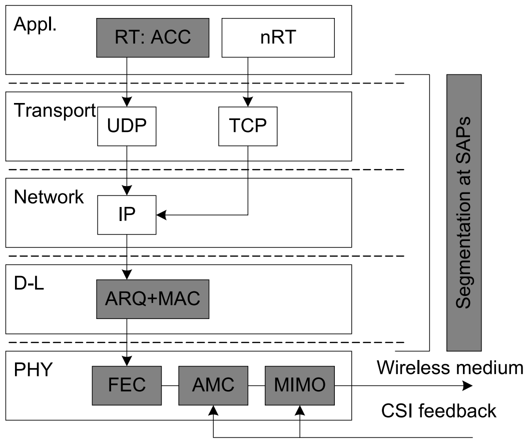

Fig. 1 – Channel adaptation mechanisms in the protocol stack.

as their construction and interpretation require extensive background knowledge of various fields in communications engineering. Finally, in spite of significant past research efforts there are no models that are versatile enough to apply to any wireless technology. The choice of a model depends on the specific purposes of a performance analyst and particular configuration of the protocol stack. However, as wireless access technologies differ in many aspects of their operation, including operating frequency, modulation and coding schemes, multiple access schemes, error mitigation principles, etc. many performance evaluation models already include certain combinations of these mechanisms. As a result, for wireless access technologies that may appear in the future there is already a large set of approaches to apply directly or to start from.

We divide the process of performance modeling into three major steps, namely, wireless channel modeling, traffic modeling, and performance modeling, and consider each of these steps in detail. We concentrate on major ideas rather than on particular details of different models. Whenever appropriate we also discuss specific performance insights and trade-offs revealed by performance models proposed to be of interest. Although this manuscript was initially conceived as a review of the work that has been done so far we realized that some models need to be considered in more detail. As a result, this work can also serve as a tutorial introducing those models that have provided most impact on the community. This, however, does not imply that our study is self-contained, and interested reader is expected to browse through the referenced studies to gain a deeper insight. We believe that our work will be helpful for both newcomers to the field looking for a point to start from and experienced analysts looking for the best possible model for their specific purposes.

The rest of the paper is organized as follows. Specific details related to performance modeling of wireless systems are discussed in Section 2. There we consider the specifics of wireless channels and the metrics conventionally used to estimate their performance. The importance of wireless channel characteristics, protocols used for communication, and traffic arrival statistics is also highlighted. In Section 3 we review and discuss models used to capture wireless channel characteristics. We distinguish between signal strength models and PDU error models, discussing their applicability and shortcomings for various performance modeling studies. We also briefly address applications of performance evaluation models considered in this paper to cross-layer modeling studies. Next, in Section 4, we consider arrival traffic models for both real-time and non-real-time applications, highlighting that the TCP protocol alone poses many challenges to a performance analyst. We also discuss why batch arrival models are better suited for accurate performance modeling of real-time applications in a wireless environment. Performance models for centralized and distributed access mechanisms and their applications are reviewed in Sections 5 and 6, respectively. In both sections we distinguish between models developed for real-time and non-real-time applications. Conclusions are drawn in the last section.

2. Basic notes on performance models

2.1. *Wireless channel specifics*

There are a number of factors affecting the performance experienced by applications running over wireless channels. These are the traffic characteristics of a given application, time-varying characteristics of wireless channels, and protocols with a set of their parameters. It is known from teletraffic theory that each application is characterized by its own traffic characteristics that may significantly affect the performance provided by a particular networking technology. Environmental characteristics of a landscape and movement of a user are stochastic factors affecting the propagation characteristics of a wireless channel. Protocols and their parameters determine how given traffic is handled in the protocol stack. The performance that a given application achieves is then a complex function of the properties and interactions between these components.

To optimize the performance of applications in a wireless environment, state-of-the-art technologies incorporate a number of advanced channel adaptation mechanisms at different layers of the protocol stack. These are error correction techniques including both forward error correction (FEC) and automatic repeat request (ARQ), adaptive size of protocol data units (PDU) at different layers, automatic modulation and coding (AMC) schemes, multiple-in multiple-out (MIMO) antenna design, power control mechanisms, etc. At the application layer adaptive compression and coding (ACC) can be used to reduce the rate required from the network. These mechanisms are implemented at different layers of the protocol stack and affect the performance provided to applications differently [1]. Various channel adaptation mechanisms and their places in the protocol stack are marked by a grey color in Fig. 1, where nRT stands for non-real-time applications and RT refers to real-time applications. To effectively deal with the error-prone nature of wireless channels, a particular wireless access technology implements one or more of these mechanisms. To understand what performance level can be provided to applications under different wireless channel and traffic conditions, studies on the operation of these mechanisms are required.