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Closing the gap between traffic workload and channel occupancy models for 802.11 networks

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ABSTRACT

The modeling of wireless network traffic is necessary to evaluate the possible gains of spectrum sharing and to support the design of new cognitive protocols that can use spectrum efficiently in network environments where diverse technologies coexist. In this paper we focus on IEEE 802.11 wireless local area networks and close the gap between two popular levels of modeling, macroscopic traffic workload modeling and microscopic channel occupancy modeling. We consider traffic streams generated by established traffic workload models and characterize the networking scenarios where a simple, semi-Markovian channel occupancy model accurately predicts the wireless channel usage. Our results demonstrate that the proposed channel occupancy model can capture the channel idle time distribution in most of the scenarios, while the Markovian assumption cannot be validated in all cases.

1. Introduction

Spectrum sharing among diverse network technologies has been introduced as a promising solution to increase the efficiency of spectrum utilization in wireless environments, and thus ease the problem of spectrum scarcity. One of the key components of efficient spectrum sharing is cognitive medium access control, building on the knowledge of the channel usage patterns of the coexisting networks [1]. Therefore, traffic workload and channel occupancy models, either considered to be known [2] or derived on-line [3], are necessary for protocol design and channel access optimization. The issue of network coexistence in the open ISM band is particularly relevant due to the proliferation of diverse low-power wireless technologies, all sharing the ISM spectrum with the high-power Wireless Local Area Networks (WLANs). Accurate WLAN modeling enables these low-power technologies to alleviate harmful WLAN interference [4] and to ensure an effective use of the shared open spectrum [5,6].

WLAN modeling can be classified in two main categories, based on the considered time scale, *traffic workload* modeling and *channel occupancy* modeling. *Traffic workload* studies involve stochastic analysis and modeling of high-layer traffic statistics, such as user arrival and departure process [9] and client-generated flow statistics [10–12], the characterization of user traffic [8,13] or the user mobility [14,15]. In these studies WLAN measurement data is collected via active probing or passive network monitoring, followed by the statistical processing of the collected data, when analytic probability distributions are fitted to the empirical traces. Traffic workload models are often specific to a given networking scenario, for example [16] considers a campus-wide WLAN and provides detailed multi-level, campus-wide WLAN traffic modeling where both session

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and flow statistics are collected and fitted to analytic distributions. Although sufficiently realistic, these approaches capture the behavior of WLANs only at a macroscopic level.

Contrary to traffic workload modeling, *channel occupancy* studies aim at modeling directly the short term temporal behavior of the channel status in WLAN networks. They characterize the periods when the channel is either *active* due to a WLAN packet transmission, or *idle*. Clearly, the distribution of the active times is determined by the packet sizes used by the applications, while the distribution of the idle periods depends on both the process of packet generation and the medium access control. We can distinguish between *analytic* and *measurement-based* studies, depending on whether the spectrum occupancy model is developed based on analytic modeling of user behavior and network protocols, or it is extracted from channel occupancy measurements. The seminal work in [17] gives an analytic model for the impact of the IEEE 802.11 MAC protocol on channel occupancy, and derives the network throughput of a single Access Point (AP) WLAN assuming saturated user traffic, i.e. users always have packets to transmit. The case of a non-saturated single WLAN AP is studied in [18], modeling the packet arrivals at the users as a Bernoulli process. In [19] WLAN output buffers are modeled as M/G/1 queues, resulting in sub-geometric idle period distribution. The generality of these analytic channel occupancy models, is, however, limited, since they are based on specific, simple traffic workload models.

As far as measurement-based approaches are concerned, in [20] a hyper–exponential distribution is fitted to the empirical idle period distribution derived by traffic traces from an area with heterogeneous wireless devices. In [21] a Markovian channel occupancy model is developed based on channel measurements extracted from controlled laboratory environments in the 2.4 GHz ISM band. In [22,23] the heavy-tailed behavior of the idle channel periods is demonstrated and a mixture distribution is proposed to capture the two basic sources of channel inactivity, the short, almost uniformly distributed contention windows and the long, heavy-tailed white space periods, when the WLAN users are inactive. The simplicity of the resulting semi-Markovian model makes it attractive for analytic performance studies and cognitive protocol design [5,23,24]. This model considers an idle period length distribution with a high number of degrees of freedom and, potentially, good fitting quality, therefore we select it as the candidate channel occupancy model. In [22,23] it has been validated for a limited set of scenarios, under perfect channel conditions and considering constant UDP payload traffic with exponential packet inter-arrival times. In this paper we evaluate it for a wide range of traffic patterns and network scenarios and define the key factors that affect its accuracy. As traffic traces cannot provide the diversity we are looking for, we build our evaluation on synthetic traces based on validated traffic workload models. To investigate the generality of the model, we select three scenarios with significantly different traffic workload characteristics, namely, university campus, conference-hall, and industrial-plant WLANs.

Specifically, we validate the proposed heavy-tail idle period distribution and the Markovian *assumption*, that is, the assumption that consecutive idle periods have independent durations. We focus on the idle periods, as the active period distribution is not significantly affected by the medium access control, instead, it is directly determined by the packet sizes in the application mix. The model validation is completed with an evaluation of its accuracy considering a restricted dataset of real WLAN traces.

The main contributions of the paper are summarized as follows:

(1) *Traffic workload and channel occupancy modeling.* We define detailed traffic workload models for the three networking scenarios, and parameterize the related semi-Markovian channel occupancy model using extensive simulations of an IEEE 802.11 AP.
(2) *Evaluation of the idle period distribution.* We evaluate the fitting quality of the channel occupancy model, specifically considering the distribution of the idle times. Our results indicate that the mixture distribution proposed in [22,23] is valid in a wide range of networking scenarios.
(3) *Evaluation of the Markovian assumption.* We evaluate the validity of the Markovian assumption considering the correlation of the consecutive idle time period lengths. We conclude that the idle period lengths may be correlated at low or very high load and when the traffic is highly heterogeneous. Therefore the Markovian assumption has to be applied with care.
(4) *Model validation with real WLAN traces.* We evaluate the fitting accuracy of the semi-Markovian model as well as the validity of the Markovian assumption, considering a set of real 802.11 channel occupancy traces captured in diverse WLAN environments. The results are similar to the ones with the synthetic traces, however, they show as well that real occupancy traces can reflect unexpected traffic characteristics.

The remainder of the paper is structured as follows. In Section 2 we review the considered traffic workload and channel occupancy models. In Section 3 we introduce the networking scenarios under study, along with a detailed description of the multi-layer traffic models. The simulation setup, as well as the employed statistical validation tools are presented in Section 4. Section 5 presents the results of the channel occupancy model validation using synthetic WLAN channel occupancy traces, while Section 6 includes the validation over the real WLAN traceset. Section 7 concludes the paper.

2. Traffic workload and channel occupancy models

In this section we define the structure of the multi-layer WLAN traffic workload model and the analytic model for WLAN channel occupancy that is considered in the paper.

2.1. Multi-layer WLAN traffic workload model

Fig. 1 depicts the structure of the multi-layer traffic workload model. As suggested by [16], the *sessions*