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AFTER: Algorithmic Framework for Throughput EstimatoRs for IEEE 802.11 networks

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ABSTRACT

Predicting performance in real-time in multihop wireless networks is still a challenge. This problem arises, for example, in routing decisions and QoS provisioning. The literature includes a number of prediction techniques, but usually they are based on simplifications or information that lowly correlates with actual performance. More complex mathematical models exist, but they are computationally expensive and not as accurate as one might expect. An alternative is the usage of network simulation. However, traditional stochastic network simulators require high levels of user intervention and long execution times for reliable results due to their randomized nature. Thus, they are not suitable for autonomic applications that demand real-time responses. This work proposes AFTER (Algorithmic Framework for Throughput EstimatoRs), an on-the-fly algorithm for real-time throughput estimation for multihop IEEE 802.11 based networks. Instead of mathematical models that are either too complex or overly simplified, AFTER uses a simulation-based approach. Differently from stochastic network simulators, AFTER replaces random events for their expected outcome. This procedure continues until AFTER is able to determine the long term average throughput for all network flows. We evaluate AFTER using a number of multihop wireless scenarios and results show that it accomplishes its goals. In comparison to stochastic network simulators, AFTER is able to greatly reduce the time needed for predicting throughput and completely eliminates the need for user intervention. On the other hand, in comparison to mathematical models, AFTER achieves better accuracy and correlation with the actual throughput. Moreover, due to its simulation-based nature, AFTER can be extended to incorporate complex network interactions.

1. Introduction

Wireless devices are now ubiquitous in everyday life. Given the performance of current wireless networks, they lend themselves well to a number of applications while allowing systems to be more practical and easier to use and deploy.

Due to this popularity, for the past several years, wireless communication systems and, in particular, multihop wireless networks have been a very active area of research. While substantial progress has been achieved on numerous research fronts, one fundamental problem that remains open is on-the-fly performance prediction. In other words, how to accurately predict performance parameters of a given multihop wireless network in real-time remains an open issue.

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Multihop wireless networks are complex systems, which explains the difficulty in predicting their performance. In isolation, the performance of a single wireless link can vary due to the used transmission rate, its SNR (Signal to Noise Ratio), and complex propagation phenomena, such as fading and multipath [1]. When we consider the full network topology, there are also factors that hinder performance, such as inter and intra-flow interference, medium access contention, and collisions. In summary, the actual link or network throughput can greatly deviate from the nominal transmission rates, as repeatedly shown in the literature [2,3].

Despite its complexity, this problem arises in a number of contexts. One such example is routing. Routing protocols usually choose the “best” path under certain performance criteria. To this end, they use some kind of routing metric [3]. A routing metric assigns weights to wireless links and combines these weights into a path cost, *i.e.*, a single number that, hopefully, represents well the performance of that path. Another example is traffic admission control for quality of service (QoS) provisioning [4]. In this case, the network must assess whether the requirements of all flows would still be guaranteed if a new flow is accepted. As one last example, there is the network planning problem [5]. Generally speaking, the goal of this problem is to choose several installation related parameters | that may include node placement, antenna alignment, and transmission power | such that the network installation cost is minimized, while guaranteeing certain performance requirements.

While solutions have been proposed for the performance prediction problem under those contexts [3], the accuracy of those proposals is negatively affected by a number of factors. First, the general complexity of wireless systems causes most proposals to infer performance based on oversimplified models and/or lowly correlated variables. Moreover, most of the literature includes only indirect evaluation of those solutions, because they are usually proposed within the context of other large-scale problems, such as routing or network planning. For instance, routing metrics are not normally evaluated on how well their assigned costs correlate with actual performance. Instead, they are usually evaluated by simply applying them to a routing protocol, running a large number of experiments with diverse network flows, and comparing statistics regarding performance parameters measured during those experiments to those obtained with other routing metrics. While useful for comparing the end performance of different routing metrics, this approach does not guarantee that the evaluated metric is actually good at modeling the performance of paths. As a consequence, mechanisms that rely on this kind of method, such as routing protocols, QoS provisioning techniques, network planning algorithms, may exhibit suboptimal performance or fail to enforce required constraints.

There are also more complex proposals targeted specifically at analyzing network performance for wireless communications [6–13]. Those proposals evaluate the steady state behavior of CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) and, thus, can be used to estimate or infer network throughput. Those works present closed-form formulas or numerical methods for computing certain network parameters by employing a number of assumptions, simplifications and probabilistic models . While this kind of proposal is a very interesting analytical tool to understand the behavior and inefficiencies of CSMA/CA (and, thus, of several wireless networks), the simplifications and assumptions used to guarantee the tractability of the problem lower their accuracy. At the same time, the application of those models to practical real-sized networks is computationally expensive, especially when dealing with more than one network flow. This last characteristic makes using those models prohibitive in real-time applications.

Given those factors, simulation is a valuable tool for assessing network performance. There is a variety of good network simulators available and many are widely considered to be reliable, such as NS-2 [14], NS-3 [15], and OMNeT++ [16].[1] Such simulators can be considered *stochastic network simulators* in the sense that they use pseudo-random number generators to simulate random network events, such as a transmitter choosing the value for a backoff counter. They are capable of modeling multihop wireless networks to a high level of detail and, assuming the simulation is run for a long enough period, it is possible to obtain statistically accurate predictions about network performance. Moreover, stochastic simulators are capable of accurately representing transient network states, which can be important for certain analyses. However, the use of stochastic network simulators has certain downsides. One example is the time required for a simulation to provide statistically significant data. This time can range from several seconds to hours or even days, which makes its application on problems that require real-time responses, such as routing and QoS provisioning, unfeasible. Moreover, it is common for the same network simulation to be executed multiple times, varying the seed for random number generation, which further increases simulation execution time and often requires user intervention for determining a suitable number of repetitions.

In this paper we tackle the performance prediction problem by combining the accuracy of simulations with the efficiency and automation of more direct methods, such as routing metrics and mathematical models. Specifically, we propose AFTER (Algorithmic Framework for Throughput EstimatoRs), a simulation-based algorithm for predicting the throughput of each flow in an IEEE 802.11 [19] multihop wireless network for a given set of data flows and corresponding routes. Differently from stochastic network simulators, however, AFTER simulates the behavior of the link and network layers replacing probabilistic events, such as the value of a backoff counter in CSMA/CA for example, with their long term expected outcomes. By replacing random events with deterministic counterparts, we argue that AFTER is able to rapidly and autonomically determine the long term network behavior and compute the long term network throughput, *i.e.*, the average throughput assuming an infinitely long network life-time. Moreover, by using a simulation-based method instead of complex mathe-

[1] For more information on network simulators, please refer to [17,18].