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Neural-based downlink scheduling algorithm for broadband wireless networks

Pasquale Fiengo, Giovanni Giambene *, Edmondo Trentin

Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Siena, Via Roma, 56, 53100 Siena, Italy

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Abstract

Wireless local area networks are becoming very popular in many scenarios because they are very simple, convenient and cheap. This paper focuses on multimedia traffic management in wireless networks, where we consider to provide differentiated *Quality of Service* (QoS) levels. We address the complex task of traffic scheduling with multi-objective requirements in the presence of errors introduced by the radio channel. In particular, we focus on managing downlink traffic in both wireless ATM and WiFi scenarios, referring to an infrastructure wireless access network where a central coordinator takes scheduling decisions for the mobile users in its cell. Our scheduler is based on an *Artificial Neural Network* (ANN) with reinforcement learning. The ANN is trained from examples to behave as an "optimal" scheduler, according to an Actor-Critic model. The results obtained in scheduling concomitant voice, video and Web traffic classes permit to show the significant capacity improvement that can be achieved by our scheme with respect to other techniques previously proposed in the literature.

Keywords: Wireless communications; Traffic scheduling; Reinforcement learning

1. Introduction

In recent years there has been a growing diffusion of multimedia applications and, at the same time, of telecommunication technologies. Furthermore, mobility has become a new essential requirement in order to access telecommunication services for an increasing number of users. Hence, wireless networks are expected to play a crucial role by allowing Internet access, real-time transactional services and multimedia applications while on the move. This wide range of services calls for the support of a differentiated and complex set of *Quality of Service* (QoS) requirements. Moreover, it is important to achieve an efficient multiplexing of diverse traffic classes on the air interface in order to attain a high utilization of the scarce radio resources. In addition to this, a fair sharing of resources has to be grated among the users. Radio resource management techniques are then needed to schedule appropriately the different transmission flows according to their QoS characteristics.

In wireline networks, fair queuing has been a popular scheduling paradigm providing some QoS requirements, throughput and bounded delay [1]. However, adapting fair queuing to wireless networks is a non-trivial task due to the typical characteristics of the radio medium (i.e., unpredictable and bursty channel errors). Consequently, a number of scheduling algorithms has been proposed to provide fairness in the service of mobile users in wireless environments. In general, these algorithms approximate fair queuing when the channel is assumed to be ideal [2,3]. Many other scheduling algorithms have been proposed taking into account only a limited number of QoS requirements. Among them, the technique proposed in [4] deals with channel losses, while [5] focuses on fairness. All these schemes provide delay bounds and throughput guarantees.

* Corresponding author. Tel.: +39 0577 234603; fax: +39 0577 233602.
E-mail address: giambene@unisi.it (G. Giambene).

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In this paper, we focus on scheduling downlink transmissions in a wireless network of the infrastructure type [6], where a central coordinator, named *Access Point* (AP), schedules the transmission of packets for different traffic flows to the mobile users in its cell of radio coverage. We envisage a hot-spot of traffic load (for example University campuses, shopping malls or airport halls) where the satisfaction of the traffic demand is very challenging. Downlink can be the system bottleneck due to asymmetric user traffic (i.e., the AP-to-mobile user traffic is typically heavier than the mobile user-to-AP traffic). This is particularly true considering for instance downloading video streaming traffic from the Web.

Scheduling of packets sent in downlink to the users must be performed effectively, so that the QoS of each traffic flow is maintained while channel utilization is maximized. The realization of a scheduling algorithm that fulfills all QoS requirements needed by multimedia applications is a very complex task. This is due to the fact that some QoS requirements entail conflicting requests that need to find a right trade-off (for instance fairness among different traffic classes and latency for real-time applications).

In [7], the *Cyclic & Dynamic Resource Assignment* (CDRA) protocol has been proposed to manage multimedia traffic. It uses a token-bucket-based scheme to adapt dynamically the transmission rights of the different traffic flows depending on their short-term traffic load conditions and the experienced radio channel state. Different QoS parameters are considered in [7], but the scheduling scheme is not conceived to guarantee them. This is the reason why this paper proposes a multi-objective scheduling algorithm that aims to meet a wide range of QoS requirements.

In order to realize our scheduling algorithm we have taken advantage of *Artificial Intelligence* (AI) paradigms, namely *Artificial Neural Networks* (ANNs) [8], and considered the design of a scheduler as an intelligent agent. With such approach, we have developed a learning algorithm that is able to support many QoS requirements. The final implementation of the obtained scheduler uses feed-forward ANNs [8] that can achieve good performance in terms of response time, flexibility and scalability. The ANN is expected to be adaptive, i.e., it can learn from examples to fit the requirements of an optimal scheduler according to given multi-criteria and relying on an Actor-Critic scheme for reinforcement learning [9]. Our ANN-based scheduler has been named *Multimedia Neural Scheduler* (MNS).

Two series of experimental results are presented in this paper. The first one considers a *Wireless Asynchronous Transfer Mode* (WATM) scenario for the comparison with CDRA [7]; the second one refers to the WiFi scenario [10]. The obtained results highlight the significant performance of our MNS scheme as follows: high capacity of real-time traffic sources; good behavior in the presence of errors introduced by the radio channel; fairness in the service of distinct traffic flows.

2. Downlink radio resource management

Management of multimedia communication services in wireless local area networks imposes to find the right trade-off among competing QoS requirements, such as: *throughput, fairness, delay, delay jitter* and *packet loss*. In particular [11]:

- *Throughput* represents the bit-rate capacity needed for a traffic flow. It is one of the most critical QoS requirements in wireless networks, due to the reduced wireless channel bandwidth and the frequent errors.
- *Fairness* requires the fair sharing of the total bandwidth among competing flows and the protection of applications from more aggressive applications as well.
- *Delay* is a very important QoS constraint in real-time applications, which may tolerate some packet losses, but cannot have large transmission delays.
- *Delay jitter* is a significant QoS parameter in real-time applications too, even though, in practice, receivers maintain buffers to reduce the variations of inter-packet arrival times.
- *Packet losses* may have a significant impact (and be potentially harmful) in wireless networks: failure of this QoS requirement may degrade the *Transport Control Protocol* (TCP) goodput [12].

In the previous section, we have outlined the complexity of designing a scheduler that fulfills those QoS requirements that tend to compete each other. The nature of such complexity emerges, first of all, because of the differences between QoS parameters such as packet loss and delay bounds between real-time and non-real-time traffic classes. Second, it emerges due to the heterogeneity of the QoS requirements and their numeric values. Many of these problems are still far from having found an adequate solution. For all these reasons, we consider a different approach relying on AI methods. The MNS algorithm proposed in this paper uses feedforward ANNs and adopts the *Reinforcement Learning* (RL) theory [13]. The rationale behind such choice is discussed in the next Section. Before presenting the details about the proposed algorithm, we describe below our system assumptions.

Three different traffic classes are here considered[1]:

- Real-time video sources,
- Real-time voice sources,
- Non-real-time Web sources.

In this paper, we focus on the downlink direction, where an AP sends multimedia traffic to mobile terminals. N wireless terminals are present in the range of the AP. Each wireless terminal corresponds to a pedestrian user with a speed $v = 3$ km/h (constant speed).

[1] Further details are given in the Appendix.