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E-Diophantine estimating peak allocated capacity in wireless networks

Xavier Costa-Pérez [a,*], Zhendong Wu [a], Marco Mezzavilla [a], J. Roberto B. de Marca [b], Julio Aráuz [c]

[a] NEC Laboratories Europe, Heidelberg, Germany
[b] Catholic University, Rio de Janeiro, Brazil
[c] School of Information and Telecommunication Systems, Ohio University, USA

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ABSTRACT

Wireless networks providing QoS guarantees need to estimate the increase in peak allocated capacity when considering admitting a new resource reservation in the system. In this paper we analyze different available approaches to compute this capacity increase and, based on their limitations, propose the *E-Diophantine* solution along with two heuristics of polynomial complexity: *E-Diophantine-W* and *E-Diophantine-UW*. The properties of the designed algorithms are derived through a mathematical analysis and their accuracy and computational load characteristics evaluated in a generic scenario. Complementary to the generic study, a network performance evaluation comparing the different approaches is conducted using OPNET's simulator and considering a realistic wireless network.

Based on our results, the main conclusions that can be drawn are: (i) the larger the degree of flexibility allowed for defining the resource reservations characteristics, the larger the potential benefit of the *E-Diophantine* solutions both in accuracy and computational load terms and (ii) for systems supporting a large number of reservations, the *E-Diophantine* heuristics can be used to reduce the computational load from exponential to polynomial (cubic) at a low estimation error probability cost.

1. Introduction

Wireless networks are a key element of today's society to communicate, access and share information. The ever increasing wide range of services and applications building on wireless network capabilities results in a diverse range of Quality of Service (QoS) requirements that needs to be fulfilled to ensure user satisfaction. Third (3G) and Fourth-generation (4G) broadband wireless technologies such as 3GPP Long Term Evolution (LTE) [1], LTE-Advanced [2], IEEE 802.16 [3] and IEEE 802.16m [4] have already defined flexible mechanisms to be able to support a large number of different QoS requirements. In the Wireless Local Area Network (WLAN) domain, a similar path was followed with the standardization of IEEE 802.11e [5] and IEEE 802.11-2012 [6]. Complying with the QoS requirements of granted service demands is mandatory for service providers and requires accurately estimating the available system capacity when deciding whether new service requests can be accepted. Precise capacity estimation techniques allow for the design of efficient admission control algorithms in order to maximize the utilization of networks while ensuring a satisfactory Quality of Experience (QoE) for users.

In this paper we propose a peak allocated capacity estimation algorithm, *E-Diophantine*, and evaluate its performance. This new algorithm improves the accuracy of prediction versus complexity trade off when compared with currently available approaches. The results here presented extend our previous work in [7] and [8] by: (i) analyzing the *E-Diophantine* complexity as compared to competing approaches and (ii) designing and evaluating two heuristics, *E-diophantine-W* and *E-diophantine-UW*, that reduce the *E-Diophantine* computational load from exponential to polynomial (cubic) at a low estimation error probability cost.

This article is structured as follows. In Section 2 we review the standardized QoS resource reservation specifications for wireless networks, propose a common modeling and describe solutions available in the literature to estimate peak allocated capacity. Our proposed *E-Diophantine* approaches are explained in Sections 3 and 4 along with their mathematical foundations and corresponding complexity analysis. The allocated capacity estimation accuracy and computational load of the different solutions is compared and a realistic wireless system evaluation performed in Section 5. Finally, Section 6 contains a summary of our findings and concludes the paper.

* Corresponding author.
E-mail addresses: perez@neclab.eu (X. Costa-Pérez), wu@neclab.eu (Z. Wu), mezzavilla@neclab.eu (M. Mezzavilla), r.demarca@comsoc.org (J. Roberto B. de Marca), arauz@ohio.edu (J. Aráuz).

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2. Estimation of peak allocated capacity

Wireless networks support QoS reservation of resources by allowing new flows to apply for admittance in the system through request messages indicating their specific requirements. Such requests contain a set of QoS parameters which include different information depending on the service type. In the following we review different QoS reservation schemes as defined by the predominant wireless technologies in order to find out their commonalities. We take here an industry-driven top-down approach where, rather than considering the information we would ideally like to have for our modeling, we analyze which information is actually available based on the standardized specifications of the wireless technologies under consideration. Note that the focus here is not on performing a comprehensive review of all available wireless standards but rather on providing some major relevant examples of diverse wireless technologies with a wide acceptance in the marketplace.

2.1. Reservation information available based on standardized specifications

2.1.1. 3GPP LTE

We start our analysis considering 3GPP's LTE, the wireless cellular technology becoming predominant worldwide. QoS reservations in LTE's evolved packet system (EPS) are based on bearers which correspond to packet flows established between the packet data network gateway (PDN-GW) and the mobile stations. The bearer management and control follows the network-initiated QoS control paradigm and defines two types of bearers: Guaranteed bit rate (GBR) and Non-Guaranteed bit rate (Non-GBR). Bearers are assigned a scalar value referred to as a QoS class identifier (QCI). Several standardized QCI values with specific characteristics have been defined to allow for successful multivendor deployment and roaming. Table 1 summarizes these standardized QCIs as described in [9].

2.1.2. WiMAX

Second, we consider WiMAX networks as the major LTE competing technology. WiMAX supports QoS reservation of resources by allowing a new flow to apply for admittance in the system through a Dynamic Service Addition REQuest message (DSA-REQ). Such requests contain a QoS parameter set which includes different mandatory information depending on the data delivery service requested in the downlink direction (DL), Base Station (BS) to Subscriber Station (SS), or the scheduling service requested in the uplink direction (UL). Five different QoS services are supported: Unsolicited Grant Service (UGS), Extended Real-Time Variable Rate Service (ERT-VR), Real-Time Variable Rate Service (RT-VR) and Best Effort Service (BE). Table 2 summarizes the required QoS parameter set per Data Delivery Service according to the IEEE 802.16 standard [3]. A similar set of parameters is required in the uplink direction.

Table 1
3GPP LTE standardized QCI parameters.

3GPP LTE standardized QCI parameters					
Res. type	QCI	Min. rate	Delay (ms)	Loss rate	Service example
GBR	1	•	100	10^{-2}	Conv. voice
GBR	2	•	150	10^{-3}	Live streaming
GBR	3	•	50	10^{-3}	Real-time gaming
GBR	4	•	300	10^{-6}	Buffered streaming
Non-GBR	5		100	10^{-6}	IMS signaling
Non-GBR	6		300	10^{-6}	TCP-based apps

Table 2
WiMAX QoS parameters per data delivery service.

IEEE 802.16 QoS parameters per data delivery service					
Data delivery services	UGS	ERT-VR	RT-VR	NRT-VR	BE
Min. Resv. Tr. Rate (MRTR)	•	•	•	•	
Max. Sust. Tr. Rate (MSTR)		•	•	•	•
SDU size	•				
Maximum latency	•	•	•		
Tolerated jitter	•	•			
Traffic priority		•		•	•
Req./trans. policy	•	•	•	•	•

2.1.3. Wireless LAN

Finally, we consider the Wireless LAN technology as the most popular wireless technology in homes and hotspots nowadays. In Wireless LAN QoS reservation of resources has been also enabled as defined by IEEE 802.11e [5] and 802.11-2012 [6]. These standards introduce the Traffic Specification (TSPEC) mechanism which defines a set of mandatory QoS parameters in admissible TSPECs for different service types. In Table 3 we summarize a subset of these admissible TSPECs. Note that we focused in this case in the baseline IEEE 802.11 standard given that it is the mandatory default specification to be implemented by any wireless LAN device. Relevant extensions of the baseline standard as IEEE 802.11aa could be further considered for specific use cases or when widely adopted by the market.

2.2. Model for peak allocated capacity estimation

Based on the aforementioned set of parameterized QoS guarantees for 3GPP LTE, WiMAX and Wireless LAN, we identify a minimum common subset of QoS parameters available based on the standardized specifications composed by (i) starting time of granted QoS reservation request, (ii) required data rate and (iii) periodicity at which the guaranteed data rate should be fulfilled (delay bound). Based on this minimum common subset of information available in the QoS reservations, in the following we define a reservation model which will be used for estimating the peak of allocated capacity when considering admitting a new reservation.

Let us consider an arbitrary reservation r_i for which a minimum set of requirements can be defined for services with QoS guarantees as:

- Reservation start time: t_i (ms)
- Reservation required capacity: B_i (bits)
- Periodicity of reserved resources: T_i (ms)

Then, based on these requirements, our QoS reservation model can be described as follows: given a reservation starting time t_i, a certain amount of capacity B_i (bits) is reserved periodically for transmitting reservation r_i data within a time interval T_i. Based on this reservation model, a resource reservation request r_i can be expressed as a periodic discrete sequence of Kronecker deltas with amplitude B_i in the following way

$$r_i(t) = B_i \cdot \delta_{t,t_i+n\cdot T_i} = \begin{cases} B_i & \text{if } t = t_i + n \cdot T_i; \quad n \in \mathbb{Z}_{\geqslant 0} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Once a new reservation request is received, an allocated capacity estimation algorithm needs to evaluate the impact of accepting it on the currently existing aggregated allocated capacity peak. Assuming a wireless system with N reservations already granted, we define $A(t)$ as the aggregation (as a function of time) of the N flows already in the system plus the one requesting admittance. See Fig. 1 for a graphical representation of the model for a 5 reservations example.

The objective of our estimation algorithm is thus, starting from a given point of time, t_0, find the allocated capacity peak, $max(A(t))$,