Framework for Wireless Networks Management based on Network and Traffic Modeling with QoS Objectives

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I. Introduction

The highly erratic and unpredictable behavior of wireless network traffic can be attributed to the combination of different factors: the variable number of users, the capacity of the access links/points, traffic matrices, users' mobility, background traffic and the diversity of applications, services and user behaviors. These issues, together with the increasing demand for bandwidth and the every day appearance of new applications and QoS requirements, have been driving a strong need for tools that can aid in the global management of mobile networks.

This extended abstract proposes a management framework for wireless networks that integrates a wireless network model and a set of procedures allowing (i) to predict network Quality of Service (QoS) evolution for varying number of users and user characteristics and (ii) to assess the need for network upgrades.

The availability of this framework can help network managers and service providers to plan short-term or long-term network reconfigurations and upgrades or design new strategies for network management, traffic routing, service provisioning and other critical network operational issues. The correct planning and location of network resources can greatly increase network operation efficiency and optimize network QoS parameter values.

The framework's inherent wireless network model [1], [2] incorporates all network important functional characteristics and is able to predict QoS parameters based only on traffic that enters and leaves the network at its different access points (APs) (the inputs of the model), without requiring any *a priori* information on the network structure, traffic routing or users mobility profiles. The network model is built from a set of (past) measurements of the APs inbound/outbound traffic and the corresponding network QoS metrics. After being inferred, the model can predict the network QoS parameters based on traffic predictions obtained from previously inferred traffic source models and based on an estimation on the future number of users (and their respective profiles). Besides, the network model parameters can be mapped to real network parameters: traffic flows between network users and APs, users' mobility characteristics, background traffic, network operational characteristics and inherent fixed QoS.

The extended abstract is organized as follows: section II presents the framework wireless network model, including the main steps of its inference procedure; section III presents the proposed network management framework and section IV presents the network and simulation scenarios that will be used to demonstrate the usefulness and accuracy of the proposed framework.

II. Wireless network model

The wireless network model is the key component of the management framework. The network model is built from a set of (past) measurements of the access points inbound/outbound traffic and the corresponding network QoS metrics; then, the constructed model can be used to predict the QoS metrics based only on the inbound/outbound traffic. That is, the proposed network model receives as inputs the bi-directional traffic in all its access points and outputs the wireless network's QoS parameters. The model inputs used to predict QoS can be obtained directly from traffic measurements or indirectly through the application of traffic models. The usage of traffic models allows the characterization of a particular source and the posterior extrapolation of the generated traffic for users with different profiles. The synthetic traffic obtained from the traffic models can then feed the network model in order to estimate the network behavior for the new scenario. In this extended abstract it is assumed that the average percentage of users (with a common profile) using one particular network access point is stationary. This is a realistic assumption in networks with a high number of users and considering a limited period of the day. Non-stationarity of the average percentage of users using one particular AP requires the introduction of one additional modeling block, but this issue goes beyond the scope of this extended abstract.

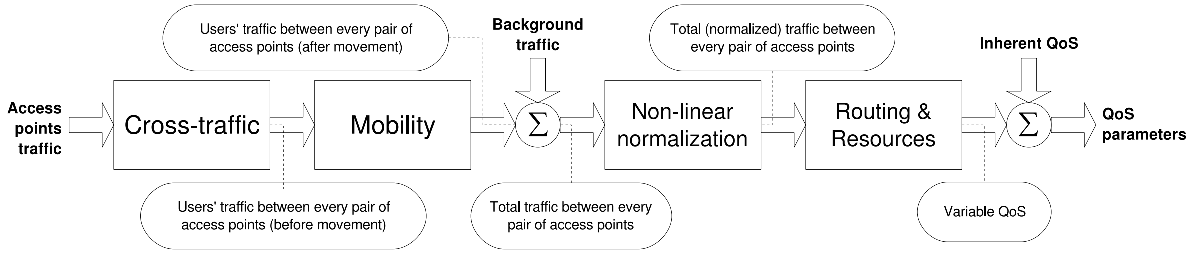

Fig. 1. Wireless network model concept.

The conceptual details of the proposed network model are depicted in figure 1. The network model relies on the assumption that the network QoS parameters can be inferred as a function of the access points' inbound/outbound traffic, users' traffic flows between network access points, background traffic, inherent network QoS (i.e. transmission times, network equipments processing time, etc) and a model of the wireless network routing and resources. With the exception of the access points inbound/outbound traffic, all other parameters are inferred by the network model inference procedure. The model functionality can be divided in three main building blocks: one that models the network cross-traffic, a second one that models the users' mobility and, finally, a block that models the network routing and resources. The first building block transforms the network inputs (inbound/outbound traffic at the different access points) into the users' traffic flow between every pair of network ingress and egress points. Each traffic flow between any pair of network access points is modeled by a linear combination of all model inputs. The second building block adjusts the traffic flows in order to reflect the users movement during one time interval. After this operation, the background traffic is added in order to obtain the total flow traffic between every pair of network access points. The next step normalizes the total flow traffic data by using a sigmoid function, and this operation has two main objectives: (i) to introduce non-linearity in the model and (ii) to eliminate outliers that may bias the model. The third main building block models each one of the chosen network QoS parameters as a function of the amount of traffic that flows between each one of the network access points. The inputs of this block are the total flow traffic data and the outputs are the variable components of the QoS parameters that depend on the traffic throughput. The observed QoS parameters results from the variable QoS component added to the network fixed QoS, which is independent from the network traffic throughput.

The proposed wireless network model is a system with $2N$ inputs and Q outputs, where N represents the number of network access points and Q is the number of QoS parameters of interest. The model inputs are the network inbound and outbound traffic in each one of the N access points, at time instant k, and are denoted by data vector $\mathbf{t}_k$.

The data vector of the effective QoS network parameters (at time interval k) outputted by the network model can be express by the following equation :

$$\delta_k = \zeta\left(\mathbf{t}_k \mathbf{X}\mathbf{M} + \mathbf{b}\right)\mathbf{S} + \mathbf{z}. \tag{1}$$

where:

- $\mathbf{X} = \{x_{i,j}, i, j = 1, \ldots 2N\}$ and $x_{i,j}$ represents the percentage of the traffic flowing between the j^{th} pair of access points that ingressed (or egressed) the network through the i^{th} network access point.
- $\mathbf{M} = \{m_{i,j}, i, j = 1, \ldots N^2\}$ and $m_{i,j}$ represents the percentage of traffic flowing between the i^{th} pair of access points that, during time interval k, started flowing between the j^{th} pair of access points due to users movement. This transformation adjusts the users' traffic flow between every pair of network ingress and egress points to reflect the users' movement during time interval k and the probabilistic redistribution of the traffic among every access point.
- $\mathbf{b} = \{b_i, i = 1, \ldots, 2N\}$ and b_i represents the background traffic amount existing between the i^{th} pair of ingress (egress) network access points.
- $\mathbf{S} = \{s_{i,j}, i = 1, \ldots, 2N, j = 1, \ldots, Q\}$ and $s_{i,j}$ represents the relative weight that the (transformed) traffic flowing between the i^{th} pair of network access points has in the determination of the j^{th} QoS parameter.
- $\mathbf{z} = \{z_i, i = 1, \ldots, Q\}$ and z_i represents the inherent i^{th} QoS parameter, i.e., the QoS component independent of the traffic amount flowing the network.
- $\zeta(.)$ represents a non-linear transformation defined by sigmoid function, $\zeta(x) = (1 + e^{-x})^{-1}$.

The inference procedure builds the network model, i.e., matrices $\mathbf{X}$, $\mathbf{M}$ and $\mathbf{S}$ and vectors $\mathbf{b}$ and $\mathbf{z}$ based on the inbound and outbound measured throughput and on the measured QoS values. The fitting process must find the best solution to equation (1) that, for a particular input set, minimizes the difference between the measured ($\hat{d}_{k,m}$) and the outputted ($\hat{\delta}_{k,m}$) normalized QoS values. The proposed inference procedure proposed relies on solving a minimization process with a cost function $C(\mathbf{p})$ defined by

$$C(\mathbf{p}) = \frac{1}{2}\sum_{k=1}^{K}\sum_{m=1}^{M}\left(c_{k,m}(\mathbf{p})\right)^2 \text{ with } c_{k,m}(\mathbf{p}) = \hat{d}_{k,m} - \hat{\delta}_{k,m}.$$

This minimization process is a non-linear least squares problem that can be solved using several methods [3], [4]. We choose the Levenberg-Marquardt algorithm [5], [6] due to it's versatility and fast convergence. The Levenberg-Marquardt algorithm requires the knowledge of the Jacobian matrix $\mathbf{J}$ of the cost function (II) which is given by:

$$(\mathbf{J})_{(q-1)K+k,u} = \frac{\partial c_{k,q}(\mathbf{p})}{\partial p_u}, \tag{2}$$

with $u = 1, \ldots, U, k = 1, \ldots, K, q = 1, \ldots, Q$, where

$$\frac{\partial c_{k,q}(\mathbf{p})}{\partial p_u} = \begin{cases} \frac{\partial c_{k,q}(\mathbf{p})}{\partial x_{i,j}} & u \le L_X \\ \frac{\partial c_{k,q}(\mathbf{p})}{\partial m_{r,v}} & L_X < u \le L_X + L_M \\ \frac{\partial c_{k,q}(\mathbf{p})}{\partial s_{l,w}} & L_X + L_M < u \le L_X + L_M L_S \\ \frac{\partial c_{k,q}(\mathbf{p})}{\partial b_\alpha} & L_X + L_M + L_S < u \le U - L_z \\ \frac{\partial c_{k,q}(\mathbf{p})}{\partial z_\beta} & u > U - L_z \end{cases} \tag{3}$$

with

$$\frac{\partial c_{k,q}(\mathbf{p})}{\partial x_{i,j}} = \\ -\hat{t}_{k,i} \sum_{a=1}^{N^2} \left[m_{j,a} s_{a,q} \Psi \left(\sum_{\eta=1}^{N^2} \sum_{n=1}^{2N} t_{k,n} x_{n,\eta} m_{\eta,a} + b_a \right) \right], \tag{4}$$

$$\frac{\partial c_{k,q}(\mathbf{p})}{\partial m_{r,v}} = \\ -\sum_{a=1}^{2N} \left(\hat{t}_{k,a} x_{a,r} \right) s_{v,q} \Psi \left(\sum_{\eta=1}^{N^2} \sum_{n=1}^{2N} t_{k,n} x_{n,\eta} m_{\eta,v} + b_v \right), \tag{5}$$

$$\frac{\partial c_{k,q}(\mathbf{p})}{\partial s_{l,w}} = \begin{cases} -\zeta \left(\sum_{\eta=1}^{N^2} \sum_{n=1}^{2N} t_{k,n} x_{n,\eta} m_{\eta,l} + b_l \right) & q = w \\ 0 & q \ne w \end{cases}, \tag{6}$$

$$\frac{\partial c_{k,q}(\mathbf{p})}{\partial b_\alpha} = -s_{\alpha,q} \Psi \left(\sum_{\eta=1}^{N^2} \sum_{n=1}^{2N} t_{k,n} x_{n,\eta} m_{\eta,\alpha} + b_\alpha \right) \tag{7}$$

and

$$\frac{\partial c_{k,q}(\mathbf{p})}{\partial z_\beta} = \begin{cases} -1 & q = \beta \\ 0 & q \ne \beta \end{cases}, \tag{8}$$

where $\Psi(x)$ represents the first derivative of the sigmoid function $\zeta(x)$ and is defined by $\Psi(x) = e^{-x}(1 + e^{-x})^{-2}$.

A more detailed presentation of the network model and its associated inference procedure can be found on [1], [2].

III. Management framework

The management framework proposed in this extended abstract defines a set of methodologies in order to assess the future resource requirements of a wireless network. The framework concept is depicted in Figure 2.

The QoS prediction is obtained from the wireless network model and an estimation of the network inbound/outbound traffic. Distributed and periodic measurements of the network's access points inbound and outbound traffic and relevant QoS network parameters are the base to construct/infer the wireless network model (see Section II) and to obtain an estimation of the future network traffic.

Based on measurements, it is possible to infer a set of source traffic models. The traffic models characterize different applications, individual users or groups of users. The models should have additive properties, i.e., a traffic model characterizing n sources should allow the determination of the traffic model equivalent to $N \times n$ sources, with N and n integers. There are several mathematical traffic models available in the literature with these characteristics and being able to reproduce the more relevant traffic characteristics [7], [8], [9]. Alternatively, it is possible to use simulators to generate traffic streams of pre-identified and characterized traffic applications. Therefore, a set of traffic models in conjunction with an estimation of the future number of users (and their profiles) will allow to obtain an estimation of the future network inbound and outbound traffic.

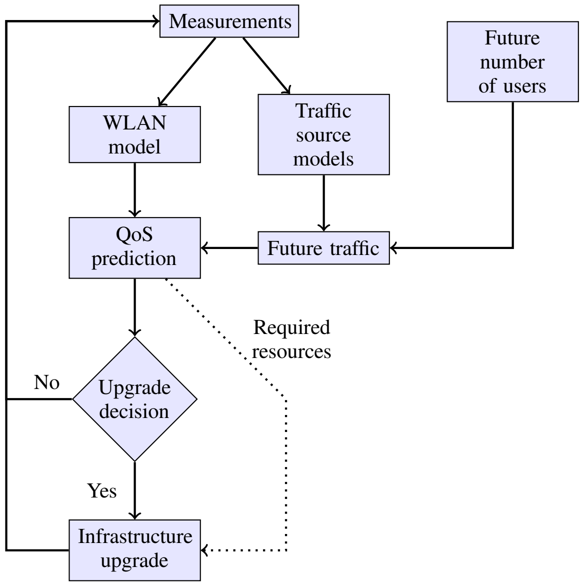

Fig. 2. Management framework concept.

The wireless network model, in conjunction with the estimation of the future network traffic, are used to predict the evolution of the network QoS parameters. A network manager should then evaluate the need to perform upgrades to the network. Moreover, the framework will allow managers to identify the exact resources requirements. This evaluation (and all related steps) should be a periodic procedure. Measurements and model updates must be made periodically in order to obtain more precise models and, consequently, more reliable and accurate predictions.

This framework allows relating the predictions on the number of users (and their profiles) to the network perceived QoS, allowing network managers to make conveniently supported management decisions and mid-term network planning.

IV. Network and simulation scenarios

We will apply our framework to the wireless network of the University of Aveiro (UA) campus, which is illustrated in Figure 3. This scenario represents a multiple infrastructure BSS, where stations can access services located at several different servers through multiple APs (located at the different University departments). The roaming capability is

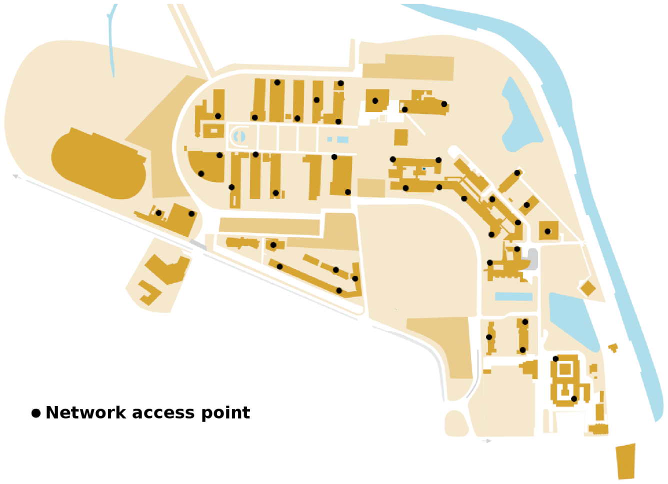

Fig. 3. Network scenario: wireless network of the UA campus.

enabled, letting WLAN nodes connect to a better AP when the connection quality with their current AP drops below an acceptable level. Mobile nodes change their positions through random vector-based trajectories, consisting of a direction and a velocity that can be changed at run time. Random mobility requires the definition of a rectangular region in which a node will move during a simulation. During simulation, the site randomly selects a destination in the region and moves toward it at a specified or randomly chosen speed. Upon reaching its destination, the site pauses for a configurable length of time before it repeats the process by selecting another random destination. The mobility profile is characterized by the following parameters: the moving speed is uniformly distributed, the pause time is constant and movement begins at the start of the simulation and stops at the end of the simulation.

There are two types of clients: laptop and handheld clients. Laptop clients are mobile but can only access the network when stopped and use Web-browsing, e-mail, FTP and VoIP services. Handheld clients are mobile, can access the network at any time and use Web-browsing, e-mail, FTP and VoIP services when stopped but use only e-mail and VoIP services while moving.

The detailed profiles for the different services are characterised by the following parameters:

- Web-browsing - Uses HTTP 1.1, the interval between page clicks is exponentially distributed with mean 60 seconds and each page has 5 images, with sizes uniformly distributed between 500 and 2000 bytes, and 1000 bytes of text;
- E-mail - The interval between sending actions is exponentially distributed with mean 360 seconds, the interval between receiving actions is exponentially distributed with mean 360 seconds and in each action the user always sends or receives 3 e-mails with a constant size of 2000 bytes each;
- FTP - The user performs 50% of GET commands and 50% of PUT commands; the interval between requests is exponentially distributed with mean 360 seconds and the file size is exponentially distributed with mean 500 Kbytes.
- Voice over IP - Incoming and outgoing silence lengths are exponential distributed with mean 65 seconds. Incoming and outgoing talk spurt lengths are exponential distributed with mean 0.352 seconds. Call interval is exponential distributed with mean 1200 seconds. Call duration is exponential distributed with mean 180 seconds.

Several simulation scenarios will be defined, based on the previous client and services profiles, differing basically in the number of wireless users considered. All scenarios will be simulated using the OPNET network simulator.

The results obtained from the application of our framework to all simulation scenarios will be analyzed, evaluating how accurately the proposed network model predicts network QoS parameters even when there are significant changes in the number of users.

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