

ERCIM “Alain Bensoussan” Fellowship Scientific Report

Fellow: Georgios Paschos
Visited Location : VTT, Finland.
Duration of Visit: 12 months

I spent my 12 month stay with the “Network Performance” team, VTT, Finland, with Prof. Ilkka Norros as team leader. I studied and got in touch with peer to peer networking, random graph models, statistics and wireless networking which are main topics of the team. Finally, I focused on the last field, and I cooperated closely with Dr. Petteri Mannersalo (VTT, “Network Performance” team).

During my 12 month stay, I also cooperated with Ioannis Papapanagiotou (North Carolina State University, U.S.A.), Prof. Michael Devetsikiotis (NCSU), Prof. Stavros Kotsopoulos (University of Patras), Efstathios Vagenas (UoP), Thomas Bohnert (Siemens, Germany), Prof. Patrick Thiran (EPFL, Switzerland), Dr. Pasi Lassila (Helsinki University of Technology) and Prof. Rudesindo Nunez Queija (CWI).

I worked in the field of performance analysis of Wireless Local Area Networks (WLANs) and Wireless Metropolitan Area Networks (WMANs). I also worked in investigating scaling laws for large wireless ad hoc networks and developing mobility models for cellular networks.

I - Scientific activity

• WLANs

In this part, I cooperated with Ioannis Papapanagiotou, Prof. Michael Devetsikiotis and Prof. Stavros Kotsopoulos. We worked in improving the performance analysis of IEEE 802.11 protocol, [1]. Specifically, in [J.1] we add the arbitrary interframe spacing effect, the error prone channel analysis

and yield the solution for multiple class case of IEEE 802.11e differentiation scheme, [2].

In [C.1], we provide further extensions to all known approaches for performance analysis ([3],[4] and [5]) and we compare them in terms of complexity, efficiency, accuracy and expandability. This paper received the Best paper award in IEEE Globecom 2007 / PMQRS Symposium.

- **WMANs**

- part 1: Multihop cellular WiMAX

Together with Dr. Petteri Mannersalo, we investigated the case of extending the coverage of WiMAX cell by using the protocol extension IEEE 802.16j, [6], for multihop operation. Specifically we found that moving the customers away from the cell has a negative effect in the capacity of the cell. This can be partially alleviated by spatial reuse of the resources, enabled by the scarce topology of the network. The most important idea rising from our paper [C.3], is that the network operator can use cheap relay devices in order to expand the network infrastructure in a smooth way.

- part 2: Sleep Mode algorithms

WiMAX networks are expected to operate in mobile mode and the protocol extension 802.16e, [7], defines the power saving algorithms that are proposed for this operation. An overview of research on this matter can be found in [BCR.1] which is a joint work with Ioannis Papapanagiotou and Thomas Bohnert.

Next, together with Petteri Mannersalo, we are interested to derive the statistics of these algorithms for cases when more than one instance of sleep mode is running in the terminal. This undergoing work is an extension of [8].

- **Scaling laws for large wireless ad hoc networks**

Connectivity in wireless networks can be studied using percolation theory, a technique borrowed from physics that studies the existence of an infinite connected component among the particles. We are particularly interested in examining percolation phenomena in the Signal to Interference Ratio Graph (STIRG) connectivity model with power management. More specifically, assuming that all nodes use the same power, the STIRG is known to percolate under suitable parameter values. On the other hand, a

simple distributed algorithm can be used to optimize the powers of a STIRG. We are now extending the percolation analysis to the case of heterogeneous powers. Our first, non-surprising, result shows that a system with constant transmission powers has strictly smaller super-critical region than a system with optimized heterogeneous powers with same mean power. In dense networks, a simple thinning argument implies that this holds true also if we keep the maximum power fixed. Next, with Dr. Petteri Mannersalo and Prof. Patrick Thiran, we are aiming for more detailed gains resulting from power management. An intuitive reference in this field can be found in [9].

- **Mobility models for cellular networks**

Mobility prediction in wireless cellular networks is very important for managing the resources. I worked together with E. Vagenas towards developing a mobility model for prediction of sojourn time characteristics in wireless cellular networks. The model assumes Gaussian distributed velocity, street length and crossing delay and combines these cell characteristics. Finally, we derive the distribution of remaining sojourn time in closed form. This work can be found in [JR.1] and is currently under review. It can be seen as an extension to [10] and [11].

In [J.2], we propose another mobility model which is based in similar assumptions. In this case, it is proposed that mobility characteristics in urban environments can be predicted using empirical formulas from simulations. The results are compared to real measurements in the city of Patras, and are found to have satisfactory matching.

II- Publication(s) during your fellowship

[J.1] "A Comparison Performance Analysis of QoS WLANs: Approaches with Enhanced Features" I. Papapanagiotou, **G. S. Paschos** and M. Devetsikiotis – Hindawi Journal of Advances in Multimedia, Special issue on Multimedia Transmissions over emerging Wireless Technologies, no. 2, April 2007.

[J.2] "A Deterministic Simulation Model for Sojourn Time in Urban Cells with rectangular geometry", **G. S. Paschos**, I. G. Tsoulos, E. D. Vagenas, S. A. Kotsopoulos and G. Karagiannidis – International Journal of Vehicular Technology, under review.

[C.1] "Extensions and Comparison of QoS-enabled WiFi models in the presence of errors", I. Papapanagiotou, **G. S. Paschos** and S. A. Kotsopoulos, IEEE Globecom 2007, 26-30 November 2007, Washington DC, USA, **Best Paper Award in PMQRS symposium.**

[C.2] "Performance Evaluation of IEEE 802.11e based on ON-OFF Traffic", I. Papapanagiotou, I. Vardakas, **G. S. Paschos**, M. D. Logothetis and S. A. Kotsopoulos, to appear in proc. of ACM Mobimedia 2007, Aug 2007.

[C.3] "Cell Capacity for IEEE 802.16 Coverage extension", **G. S. Paschos**, P. Mannersalo and T. M. Bohnert, 2nd IEEE Broadband Wireless Access Workshop, co-located with IEEE CCNC Las Vegas 2008.

[JR.1] "An Analytical study of remaining Sojourn Time in Cellular Mobile Networks" E. D. Vagenas, **G. S. Paschos**, S. A. Kotsopoulos – IEEE Vehicular Technology Transactions, under review.

[BCR.1] "Power Saving Mechanisms in 802.16e Wireless Networks", **G. S. Paschos**, I. Papapanagiotou and T. M. Bohnert, WiMax Networks, Planning and Optimization (under review).

[BCR.2] "Energy Consumption and Mobility of QoS-aware Wireless Terminals" , I. Papapanagiotou and **G. S. Paschos**, chapter of

Heterogeneous Next Generation Networking: Innovations and Platform, Idea Group Inc. (to be published).

* (J=journals, C=conferences, JR=journals under review and BCR=book chapters under review)

III -Attended Seminars, Workshops, and Conferences

Part of my work was entwined with the European project IST NetRefound (<http://www.netrefound.org/>) and the ABI project (<http://abi.vtt.fi/>) in the meetings of which I took actively part. In the context of these projects, I cooperated with Dr. Petteri Mannersalo and Prof. Patrick Thiran.

I presented my work in workshop : E-Quality workshop, Performance Analysis of Mobile and Wireless Communications, November 15 & 16, 2007, EURANDOM, Eindhoven. NL. I also post my work in ACM Mobicom 2007, IEEE CCNC 2008, Las Vegas and IEEE Globecom 2007, Washington DC, but I didn't attend these conferences. The work there was presented by colleagues. Finally I also attended WiOpt 2008, Berlin and several workshops in Helsinki.

IV – Research Exchange Programme (12 month scheme)

Thanks to ERCIM fellowship programme, I visited Prof. Rudesindo Nunez Queija (CWI, Amsterdam), Prof. Patrick Thiran (EPFL, Lausanne) and Prof. Slawomir Stanczak (FrG, Berlin). In these visits, I had the chance to meet many important researchers working on my field, exchange ideas with them and set up cooperations.