

# ERCIM “Alain Bensoussan” Fellowship Scientific Report

Fellow: Ash Mohammad Abbas

Visited Location: Norwegian University of Science and Technology (NTNU)

Duration of Visit: 12 months, 28/12/08 – 27/12/09

## **I - Scientific activity**

During the period of the fellowship, I focussed on the provision of *quality of service* (QoS) in mobile ad hoc networks. To support some applications, it is desirable that an ad hoc network has a provision of QoS. However, devising a scheme or a protocol for the provision of QoS in an ad hoc network is a challenging task. The challenge comes from the inherent characteristics of the network. The dynamically varying topology hinders in making any hard guarantees about the QoS provided by the network. There are many other issues in providing the QoS in mobile ad hoc networks. To gain an insight about the issues related to the provision of QoS in mobile ad hoc networks, I carried out a survey of the research reported in the literature in [3]. Due to the varying conditions at every node along a multihop path from a given source to the destination, it is probabilistic that a packet flowing along the path can satisfy the QoS requirements in terms of end-to-end delays. In [1], I proposed a protocol that is based on the probability whether a packet would be able to meet its delay deadline.

I emphasized the need to use multiple paths to satisfy the QoS requirements of an application. As the resources of devices used to form an ad hoc network are limited, therefore, a single path between a given source and the destination may not be able to satisfy the bandwidth requirements of a flow of packets. In such a case, the source may use multiple paths to the destination, and bandwidth may be reserved in parts along each path so that the combined bandwidth along the multiple paths used is equal to the bandwidth requirements of the flow of packets. On the other hand, if a single path is able to provide enough resources to satisfy the QoS requirements of the flow of packets, then other paths can be used as backup paths in case of failure of currently used paths.

The type of multiple paths, the source is equipped with, are node-disjoint. However, node-disjoint paths might be *correlated* i.e. nodes lying along a path may have their neighbors lying along other node-disjoint paths. To use a number of multiple paths simultaneously, the paths should ideally be uncorrelated. Finding uncorrelated node-disjoint paths in an ad hoc network is a challenging task. More specifically, identification of node-disjoint paths that are uncorrelated is an NP complete problem. I suggested the use of node-disjoint paths in such a fashion so that the source is aware of the correlation. Based on the extent of correlation, the source may take remedial steps so that the bandwidth requirements of the flow of packets are satisfied. In other words, we proposed that let the node-disjoint paths be correlated, one can identify node-disjoint paths and reserve the bandwidth along them so that the effect of correlation is taken care of by over-allocating the bandwidth. A protocol to identify node-disjoint paths that are able to satisfy the bandwidth requirements and the source is aware of the correlation is described in [2]. The criteria for awareness about the extent of correlation and the computational complexities involved therein may suggest a tradeoff and are addressed in [5].

## II- Publication(s) during your fellowship

- [1] A.M. Abbas, Ø. Kure, "A Probabilistic Quality of Service Routing for Mobile Ad hoc Networks", In *Proceedings of 1<sup>st</sup> IEEE International Conference on Networked Digital Technologies (NDT)*, Ostrava, Czech Republic, pp. 269-273, July 29-31, 2009.

**Abstract-** Provision of quality of service (QoS) in an ad hoc network is a challenging task due to their inherent characteristics. In this paper, we present a routing protocol for QoS provisioning in mobile ad hoc networks. Our protocol tries to discover multiple node-disjoint paths between a given source and a destination that are able to satisfy QoS requirements. We discuss the probabilistic QoS guarantees using a protocol in which each intermediate node decides whether the packet will be able to reach the destination before its deadline. The decision is based on the delay incurred by the packet upstream and the remaining delay that the packet may incur till the destination so as not to miss the deadline. We analyze the probability that the packets arrive at the destination before their respective deadlines.

- [2] A.M. Abbas, Ø. Kure, "CQSR: A Correlation-Aware Quality of Service Routing for Mobile Ad hoc Networks", In *Proceedings of 3<sup>rd</sup> IEEE International Conference and Exhibition on Next Generation Mobile Applications, Services and Technologies (NGMAST)*, Cardiff, Wales, UK, pp. 363-368, September 15-18, 2009.

**Abstract-** Devising a solution for the provision of quality of service (QoS) in a mobile ad hoc network is a challenging task. In this paper, we propose a routing protocol with a provision of QoS. Our protocol tries to discover multiple node-disjoint paths between a given source and a destination and tries to utilize them for a desired level of QoS. In our protocol, nodes along paths are aware of the correlation among different node-disjoint paths. We study the effect of correlation, node mobility, and the number of QoS flows on the probability of successfully meeting the QoS requirements. Further, we analyze the overheads incurred in the route discovery phase of the proposed protocol.

- [3] A.M. Abbas, Ø. Kure, "Quality of Service in Mobile Ad hoc Networks: A Survey", *International Journal of Ad Hoc and Ubiquitous Computing (IJAHUC)*, InderScience, In Press.

**Abstract-** To support multimedia applications, it is desirable that an ad hoc network has a provision of Quality of Service (QoS). However, the provision of QoS in a mobile ad hoc network is a challenging task. In this paper, we present a review of the current research related to the provision of QoS in an ad hoc environment. We examine issues and challenges involved in providing QoS in an ad hoc network. We discuss methods of QoS provisioning at different levels including those at the levels of routing, Medium Access Control (MAC), and cross layer. Also, we discuss schemes for admission control and scheduling that are proposed in the literature for the provision of QoS. We compare salient features of various solutions and approaches and point out directions for future work.

- [4] A.M. Abbas, Ø. Kure, "A Deadline-Driven Quality of Service Routing for Mobile Ad hoc Networks", *Journal of Digital Information Management (JDIM)*, Digital Information Research Foundation, Accepted for publication.

This is an extended version of the paper mentioned in [1]. Additionally, an intermediate node along a path reserves the right to increase or decrease the downstream priority of a

packet based on the service received upstream, the number of packets forwarded for the same priority class, and the utilization of the link. The algorithms together with other necessary details which were omitted in the conference version due to space limitations are described in the journal version.

- [5] A.M. Abbas, Ø. Kure, “A Correlation Aware Quality of Service Routing for Mobile Ad hoc Networks”, *International Journal of Ad Hoc and Ubiquitous Computing (IJAHUC)*, InderScience, Submitted for review.

This is an extended version of the paper mentioned in [2]. In addition to the protocol, it contains details about the extent of awareness about the correlation among node-disjoint paths defined in different manners. Further, it contains how one can select a definition of the extent of correlation awareness based on the computational complexities involved and may suggest a tradeoff.

### **III -Attended Seminars, Workshops, and Conferences**

The events in which I participated during the period of the fellowship are as follows.

1. 1<sup>st</sup> IEEE International Conference on Networked Digital Technologies (NDT), Ostrava, Czech Republic, July 29-31, 2009.
2. Norwegian Academy of Technological Sciences (NTVA) Seminar on Internet: Global Market – National Opportunities, Trondheim, Norway, September 9, 2009.

### **IV – Research Exchange Programme (12 month scheme)**

*First Period: One week at INRIA Sophia Antipolis, France (March 30 - April 5, 2009)*

*Project Team: MAESTRO*

*Contact Person: Dr. Philippe Nain (E-mail: [Philippe.Nain@sophia.inria.fr](mailto:Philippe.Nain@sophia.inria.fr))*

During my research exchange program at INRIA Sophia-Antipolis, I visited the MAESTRO project team. The project focuses on the models for performance analysis and control of communication networks with an emphasis to develop mathematical and software tools for evaluating the performance, optimizing and controlling discrete event systems including networks and their applications. I interacted with the members of the MAESTRO project team individually and in groups. They explained me about the research activities carried out by them in the past and the areas that they are focussing currently. I discussed with them some of the issues related to the current area of my research. On April 1, 2009, I gave a seminar presentation on my research in the area of multipath routing in mobile ad hoc networks. The feedback given by the audience was relevant and fruitful.

*Second Period: One week at CWI, Amsterdam, Netherlands (June 08 - June 13, 2009)*

*Project Team: PNA2 (Probability and Stochastic Networks)*

*Contact Person: Prof. R.D. van der Mei (E-mail: [R.D.van.der.Mei@cwi.nl](mailto:R.D.van.der.Mei@cwi.nl))*

During my research exchange program at CWI, Amsterdam, I visited the Probability and Stochastic Networks (PNA2) research group. The focus of PNA2 is to develop and study models for control and optimization of stochastic systems. The group is divided into three main research areas: performance analysis of information and communication systems, probability

and spatial stochastics, and stochastic geometry. I interacted with the members of the research group individually and discussed with them some of the issues related to my area of research. The members of the group explained me about the research carried out in the recent past and the current areas of their focus. On June 10, 2009, I gave a seminar presentation on my research work related to the provision of quality of service using multipath routing in mobile ad hoc networks. The presentation was covering ideas and results published in [2]. I received a very good feedback on the work presented, and their suggestions helped me to concentrate on some of the issues more closely.