BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

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THE EFFECTS OF USER MOBILITY ON THE PERFORMANCE OF WIRELESS NETWORKS

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Summary of the Ph.D. Dissertation

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1. Introduction

Mobile communication is an integrated part of our daily lives. It surrounds us, and provides a ubiquitous communication channel even for the most demanding multimedia services. The focus of mobile communication shifts from voice to mobile broadband data services – at least the traffic load and the popularity of mobile data services are greater than the conventional circuit-switch voice service.

Mobile operators are introducing novel techniques, such as High Speed Packet Data (HSXPA) and UMTS LTE (Long Term Evolution), to serve more traffic on the radio interface [1]. Radio cells are also getting smaller, so mobile operators can achieve higher level of spatial reuse of the radio channels, too. Besides transmission speed, the quality of the connection is also a very important aspect, which might turn the balance in the competition among operators. The topic of my dissertation is finding the right balance between the quantity and the quality in mobile networks, by focusing on three main aspects:

- Tracking mobile user movements in cellular mobile wireless networks
- Ring based Call Admission Control algorithm and Ring Based Mobility management algorithm
- Performance Evaluation of Anycast Based Micro-mobility Management

1 Research Objectives

The objectives of my research is to enhance the Quality of Service in wireless mobile networks by efficient Call Admission Control algorithms supported by appropriate mobility modeling schemes, and to reveal the possible application of IPv6's novel, anycast addressing methods in mobility management schemes.

In particular, my goals are

- to enhance the effectiveness of CAC algorithms by examining the accuracy of the underlying mobility models, and by taking into consideration the dynamic nature of users' mobility patterns and behaviors.

- to provide efficient mobility management methods for IPv6 networks by analyzing the performance of the novel anycast based mobility management proposal.

2 Methodology

To be able to compare the efficiency of my new methods and the ones can be found in the literature, I have relied on the same performance analysis methodology and terminology that was used by the authors of significant papers of the field. To use the analytical approach, first I had to construct the underlying mathematical models of my new methods. These mathematical models are based on Markov-chains and graph theory, and enabled the performance comparison of the proposed methods and the ones present in literature. Besides the analytical approach, I have used simulation to verify the results. I have relied on a well-known discrete time simulation framework, the open source OMNet++ simulator [2].

3 New Results

3.1 Tracking mobile user movements in cellular mobile wireless networks

Thesis 1.1. *I have introduced an extension to Random Walk model (HOV) and a three stage Markovian mobility model (M3), thus created more accurate, yet analytically tractable mobility models. The accuracy of the models is compared to other mobility models. The new models provide 50% to 80% accuracy gain depending on the cell dwell times compared to the Random Walk model [J2, J3, J4, C6, C7, C11, C18] .*

In the first chapter I have compared different mobility models from the viewpoint of accurate modeling of mobile user movements in wireless cellular networks. I have proposed a Handover Vector (HOV) based enhancement to the Random Walk model, and a three state Markov mobility model (M3). My goal is to define a simple yet appropriate model; therefore I have extended a one-dimensional Markov model to twodimensions retaining its simplicity, by limiting the possible states of the mobile user. The main idea of my model is separating the neighbouring cells into two groups according to the typical user movement's direction (left side, right side and stationery). I have investigated the accuracy of the models by simulation. The simulation was written in the open source OMNet++ simulator (Figure 1.) [2].

The results show, that the new models perform better than the Random Walk model for the purpose of accurate user motion prediction in cellular mobile networks (Figure 2.).

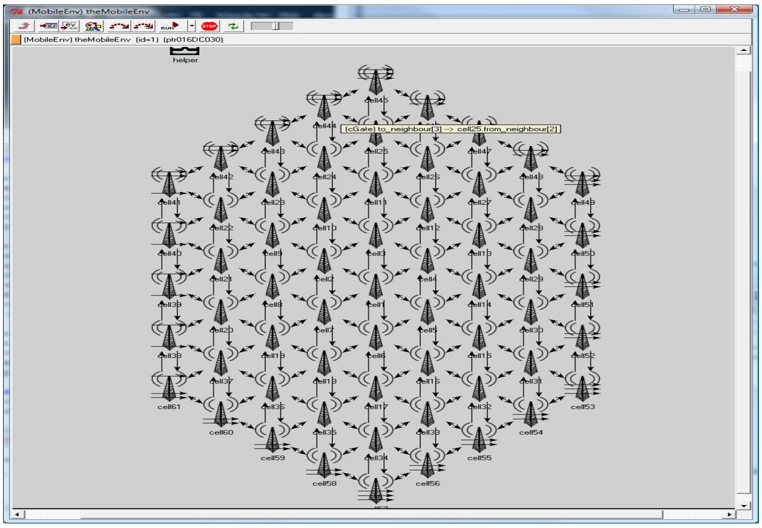

Figure1. A screenshot of the mobility simulation environment in OMNet++ framework

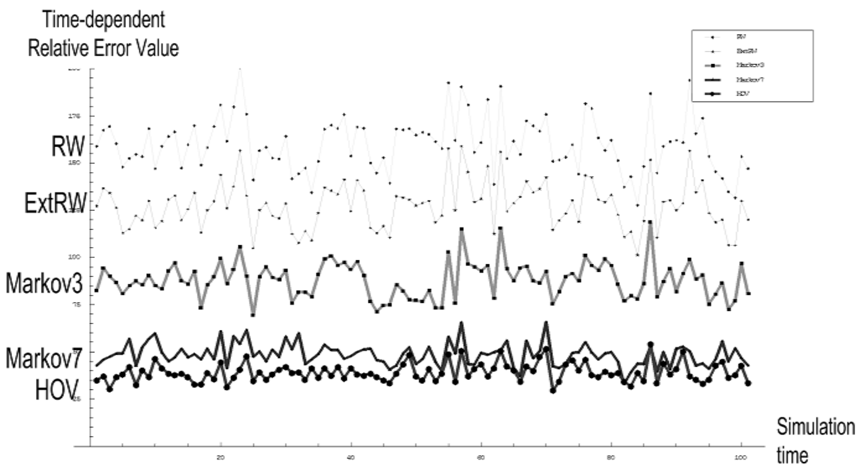

Figure2. Accuracy comparison of different mobility models.

3.2 Ring based Call Admission Control algorithm

I have proposed a novel CAC algorithm (Ring based CAC) and analyzed its performance in the second chapter.

Thesis 2.1. *I have invented a new call admission algorithm called RCAC. RCAC is the mosaic for Ring based CAC. The idea is that the expected leaving/arriving users in a ring around the given cell should also be taken into consideration when making a CAC decision [J1, C1, C2, C3].*

The basic idea behind foreseeing resource reservation based CAC algorithms is the following. When a new call arrives or initiated at a mobile node and requires admission to a radio cell the CAC algorithm first checks if the current free bandwidth of the given cell can support the call. The call is rejected if the cell does not have enough free bandwidth. Otherwise, the CAC algorithm will check the availability of free bandwidth in the Most Likely Cell-Time (MLCT) of this mobile [3]. The MLCT of a mobile is a cluster of time units at a cluster of cells when and where a mobile will most likely visit in the future. In order to guarantee the handoff dropping probability, an amount of bandwidth is reserved based on the mobility prediction to guarantee some target handoff dropping probability. To achieve a better balance between guaranteeing handoff dropping probability and maximizing resource utilization, the admission threshold is adaptively controlled. My approach is based on the concept of defining rings around the radio cells in the network, and these rings are used to calculate the MLCT.

Thesis 2.2. *I have provided a sophisticated analytical model for RCAC. This model enables the determination of optimal size of the ring [J1, C1, C2, C3].*

I gave an upper bound on the probability of a user from ring no. 1, 2, etc. moving toward the center of the ring. The worst-case scenario is an undirected, random movement, when all the elements in the handover vector are equal. Based on the results, the optimal depth (the number of rings) can be calculated for RCAC algorithm.

The probability P_N of a user from ring no. 1, 2, etc. reaching the center of the ring in case of uniform user movement directions is given by

$$P_N = 6\mathrm{N} \cdot \prod_{i=0}^{N} \frac{2\mathrm{i}-1}{6\mathrm{i}}. \quad (1)$$

As it can be concluded, the probability of a user from ring no. 1, 2, etc. reaching the center decreases as the number of rings (parameter *N*) increases. The results of my analysis can be utilized in optimizing the RCAC algorithm; according to Equation (1), it is sufficient to rely only on the first two levels of rings, which simplifies the application of the RCAC method in real life scenarios. However, if user movement directions are not evenly distributed, then the RCAC algorithm can provide even better performance.

Thesis 2.3. *I introduced a ring-based mobility management protocol, called RBMM (Ring-Based Mobility Management). I have made simulations on the performance of RBMM mobility management protocol to back up the analysis. The results show the efficiency of my RCAC algorithm and have provided a way to examine how changes in various parameters affect the performance of my algorithm.*

The proposed RBMM mobility management protocol (Figure 3.) is similar to HMIPv6 protocol [4], however its performance is better. The proposed RBMM model uses the MAP - Mobility Anchor Point, which was originally introduced in HMIPv6. The MAP is integrated into RBMM as a proxy for HA. In the RBMM mobility management, if a user moves into a network domain, it needs to register with the HA and CN.

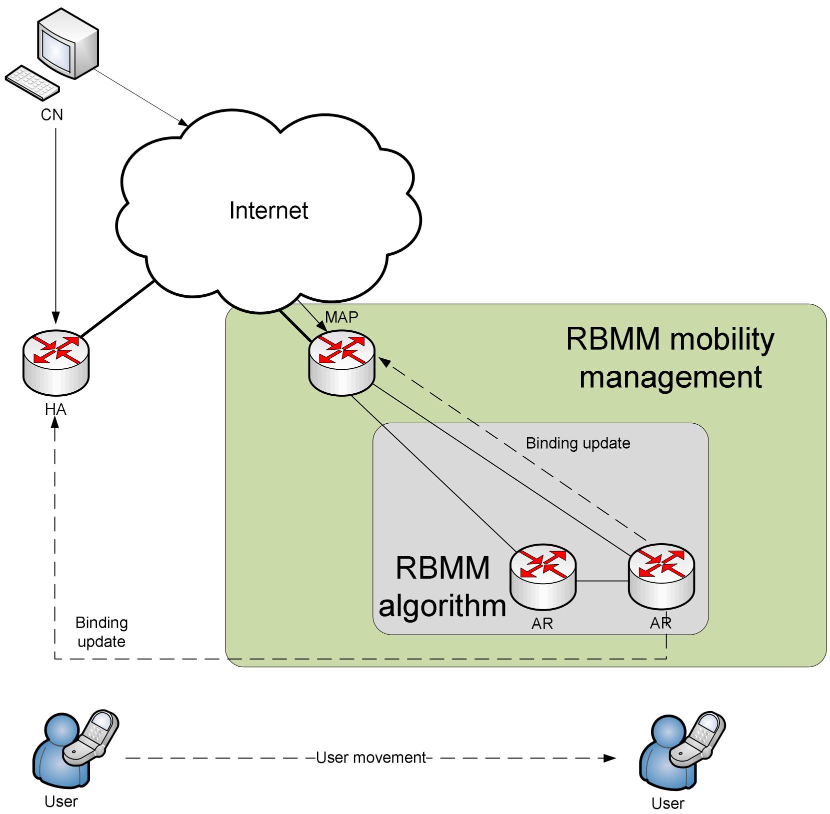

Figure 3. The ring-based RBMM mobility management protocol

If a user moves into a new subnet in the same domain, then only the MAP has to be informed, similarly to HMIPv6. In this solution, the user's movement within the domain are hidden from the HA and the CN, and the user can send the periodic binding update message to the MAP. The RBMM mobility management scheme is similar to classical HMIPv6 architecture; however RBMM scheme accommodates to frequent mobility and reduces the signaling load in the Internet. The RBMM mobility management protocol uses a ring based algorithm, and I used an analytical model to analyze the performance of the proposed RBMM mobility management protocol. I have investigated the following performance parameters of RBMM: location update cost and relative signaling cost compared to MIPv6 (RBMM /MIPv6), using Equation (2),

$$C_g = 2\left(\tau_1 + \tau_2\left(d_{AR-MAP} + d_{MAP-HA}\right)\right) + 2N_{CN}\left(\tau_1 + \tau_2\left(d_{AR-MAP} + d_{MAP-CN}\right)\right) + P_{HA} + P_{MAP} + N_{CN}P_{CN}, \quad (2)$$

where τ_1 and τ_2 are unit transmission costs in wireless and wired environment, N_{CN} is the average number of corresponding nodes which are communicating with mobile node [5]. There are many distances in the model denoted by *d* with a sub-index in the model, which distances are measured in the number of average hops between the network elements:

- d_{AR-MAP}: Average number of hops between AR and MAP,
- d_{MAP-HA}: Average number of hops between MAP and HA,
- d_{MAP-CN}: Average number of hops between MAP and CN,
- d_{HA-CN}: Average number of hops between HA and CN.

The location update cost as a function of the average cell residence time can be seen in Figure 4.

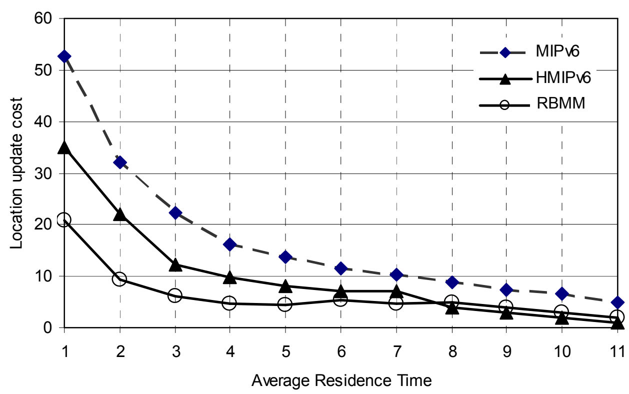

Figure 4. Location update cost as function of average cell residence time

3.3 Performance Evaluation of Anycast Based Micro-mobility Management

The common goal of micro-mobility proposals is to minimize delay, signaling load and packet loss during handover. Most of the existing mobility management protocols rely on hierarchical architecture, to reduce routing update latency. The main drawbacks of hierarchical architectures are the vulnerability to failures at the higher levels of hierarchy, and the increasing load of network nodes at these levels. Together with my coauthors, we propose a novel method, based on the IPv6 anycast addresses [C14]. I do not claim the invention of the proposed protocol, however the performance analysis and optimization are my results. The anycast based micro-mobility protocol is not sensitive for node or link failure, since it contains no centralized database, the routing information is distributed among the network nodes. Our solution is highly decentralized, according to the philosophy of IP, and uses an enhanced IP based mobility detection method. The proposed method is independent of the radio layer, and does not introduce extra signaling load on the wireless interface. The signaling load introduced by the routing information updates is proportional to the number and the speed of mobile nodes in the network. I have focused on analyzing the performance of the proposed method.

Thesis 3.1. *I have provided an analytical model for the Anycast based micro-mobility management scheme. This model enables the direct comparison with other micro-mobility solutions, and the computation of performance indicators such as maximum user speed and stability criterion. I have provided an optimization scheme in order to minimize the delay of the Anycast Based Micro-mobility Management method [J8, C15, C16, C17].*

I have used an analytical approach to perform a topology and load analysis, and evaluate different delays during handover events; for this reason I have calculated the number of different type of handovers, routing information updating speed, and the signaling load.

The number of possible handovers of *j*-depth in a *k*-depth binary tree (Figure 5.) can be given by the number of access routers of level-*k* and the sum of *previous layers* for $j = 1,\ldots,k-1$ as

$$HO_{No}(k) = AR_{No}(k) \times \sum_{j=1}^{k-1} 2^j. \quad (3)$$

As one can conclude, the number of handovers is increasing exponentially, therefore it is appropriate to minimize the handovers of great depths in the tree.

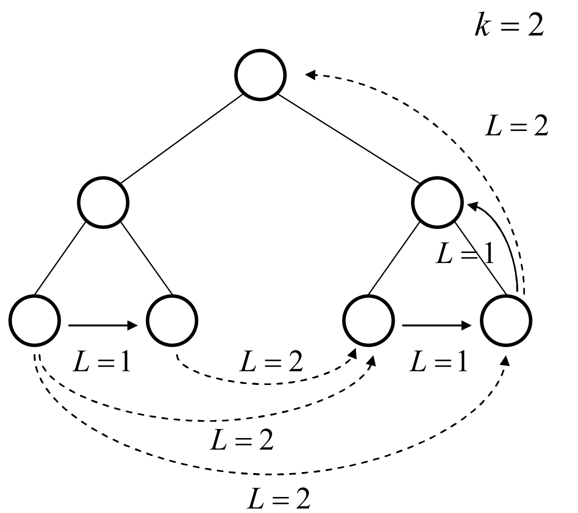

Figure 5. The handover distribution on different levels in the Anycast based model

The number of updated routers of the tree (Figure 6.) in *uplink* direction during the handover of a *k*-depth binary tree can be given as the sum of previous levels for $k = 1, \ldots, n$ and the level number n of the tree, as

$$UR_{No}^{uplink} = \left(\sum_{k=1}^{n} 2^k - 1\right) + 1 = \sum_{k=0}^{n} 2^k - (n+1) = \sum_{k=1}^{n} 2^k - n. \quad (4)$$

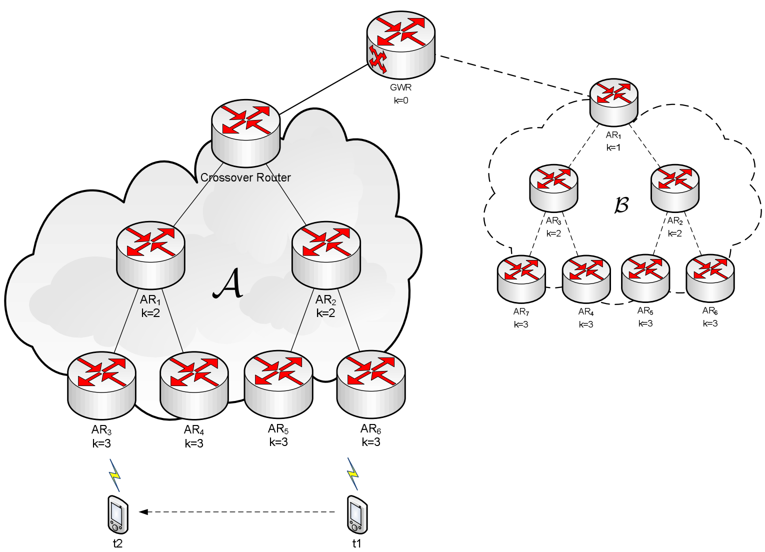

Figure 6. The involved subset of nodes in intra domain traffic

My goal is to optimize the access network topology based on the information derived from the handover vector (H), with respect to the handover delay in order to minimize convergence time of the anycast based micro-mobility approach. I propose to group radio cells with high values of mutual handover probabilities (according to the Handover vectors) to the same router at the lowest level possible. This way, the number of handovers of great depth is reduced. Many possible hierarchical radio cell combinations exist, in which the optimal configuration satisfies the requirements for minimal delay. In hierarchical radio cell systems, the handover time can be minimized by Equation (5).

$$\min \sum_{k} (HO_{No}(k)). \quad (5)$$

The *cumulative delay* $d_{cummulative}$ of a *k*-level tree can be calculated as the sum of the number of handovers of *k*-depth $HO_{No}(k)$, multiplied by the delay *D* for a *k*-level tree, in the following way

$$d_{cummulative} = \sum \frac{HO_{No}(k) \times (d_p + d_l)}{\sum AR_{No}(k)} = \sum \frac{HO_{No}(k)}{\sum AR_{No}(k)} \times D, \quad (6)$$

where $D = (d_l + d_p) \times k = \prod_{i=0}^{k} (c-1)c^i.$, and d_l denotes the link delay, d_p is the process delay, and the number of access routers is $AR_{No}(k)$ of *k*-depth.

4 Application of the Results

The results of the first chapter related to mobility modelling were utilized indirectly in the framework of the BIOlogically inspired NETwork and Services (BIONETS) [6] EU FP6 project, during the analysis and simulation of different data spreading algorithms [C4, C5, C9, C10]. The results are also beneficial for mobile operators and mobile network vendors in the field of self-configuration and self-healing. In case of self-healing a base station runs a prediction of the most likely user numbers, and if it experiences significcantly less connected users, a problem with the radio unit is presumed. The results of mobility modelling can ser vas an input data for self-configuration, for example to reconfigure the radio interface if a higher level of traffic is expected during rush hours.

The RCAC method provides a method to enhance the network performance meanwhile maintain the desired QoS level by foreseeing administration of resources. Mobile network operators might benefit from the proposed methods; by appling the RCAC method, better resource usage in the network can be achieved. Mobile network operators can optimize their service by means of quality (user satisfaction, less dropped calls) versus network utilization. Currently I'm working on to validate the theoretical and simulation results based on real-life operator traces.

The proposed anycast based mobility management method, and its performance analysis represents an effective technique for mobile operators during the ongoing IPv4 – Ipv6 transition. As the IPv6 transition emerges, the analysis can be extended to examine other IPv6 mobility management system's performance, too. To my knowledge, there is no such work published in the literature related to anycast performance evolution, which can give a correspondence between the number of routers in the network topology and the delay related stability issues in anycast. In my present work, I have investigated the performance of the novel anycast based micro-mobility method, to validate the application of anycast technology in mobility management.

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Number of publications:	44
Number of citations:	17
Number of independent citations:	17
Number of self citations:	0
Citations not classified:	0
Cumulated impact factor:	1,387

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