Prediction Based Handovers for Wireless Networks Resources Management

Piotr Rygielski, Paweł Świątek, Krzysztof Juszczyszyn, and Adam Grzech

Institute of Computer Science, Wrocław University of Technology,
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
{piotr.rygielski,pawel.swiatek,krzysiek,adam.grzech}@pwr.wroc.pl

Abstract. The paper is devoted to the problem of mobility and resources management in heterogeneous wireless networks. It is assumed that in certain area covered by multiple overlapping wireless networks there is certain number of mobile client which consume networks resources by use of available communication services (e.g.: voice or data transmission) delivered by network providers. Moreover it is assumed, that communication services continuity may be assured with use of common handover techniques supporting clients mobility (e.g: MIPv6, IEEE 802.21, etc.). The task of mobility and resources management consists of making decisions concerning the moment and the network to which particular clients should be handed over in order to optimize certain quality criterion (e.g. utilization of network resources). In this paper we show that gathering knowledge about clients movement and prediction of their future position may significantly improve the overall quality of delivered services and network resources utilization.

Keywords: network-assisted handover, user mobility prediction, wireless network management.

1 Introduction

Wireless networking is becoming more and more popular. Personal devices manufacturers equip their laptops, PDAs and smartphones with each and every wireless networking technology available, beginning with short-range bluetooth radios, through mid-range WLAN interfaces, ending on long-range 3G and WiMAX cards. As a result, the network services provider can deliver its services to mobile users ‘anywhere and anytime’.

Providing high level of the quality of services (QoS) in mobile wireless environment raises a number of technical problems, which have to be overcome. The main issues here are: a) mobility management in heterogeneous wireless environment which allows for seamless handover between different data transmission technologies, and b) security and trust between different administrative domains allowing for secure transfer of credentials of a mobile device roaming through different networks.

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A lot of research effort has been already made to address aforementioned problems. Intra-technology data link layer handovers are handled with use of media specific signaling procedures introduced as extensions to particular wireless transmission standards, e.g.: 802.11r for WLAN [8], 802.16e for WiMAX [7], etc. Currently a new standard is being developed to manage inter-technology layer 2 handovers. This proposal, 802.21 – Media Independent Handover [9], provides a set of mechanisms which allows to trigger higher layer media independent handover procedures based on unified set of commands and media specific events. Network layer handover is managed by mobility extensions of the IP protocol, i.e. MIPv4 [5] and MIPv6 [11]. In order to provide service continuity and guarantee required quality of service during handovers additional modifications to mobility management protocols has been made, e.g. FMIPv6 [12] and HMIPv6 [2]. However, a breakthrough in mobility management has been made by introduction of Media-Independent Pre-Authentication (MPA) mechanism [4], which allows for seamless and secure handovers between different administrative domains.

Application of above mechanisms in heterogeneous wireless environment allows to provide truly mobile services on *anywhere and anytime* basis. In such scenarios, where users are not bound to use particular wireless network, network selection and handovers do not affect users application performance, a number of network management and optimization tasks can be performed using network-assisted (network-enforced) handovers. These tasks include among others: network load balancing, user allocation, resources allocation, network resources utilization optimization and quality of service provisioning.

In this paper a general concept of network resource assignment optimization assisted by network-enforced handover is proposed. Network optimization tasks which utilize proposed concept are introduced. Moreover, it is shown that application of even simple methods of prediction of user's movement may significantly improve the efficiency of network management and optimization tasks. The influence of the proposed network optimization concept on the network performance is evaluated by means of computer simulation.

The paper is organized as follows. In section 2 we present assumed models of wireless networks and user-mobility. In section 3 we formulate the problem of assignment users to networks and propose the solution. Section 4 is devoted for experiment description and result analysis. Finally in section 5 we summarize the presented work.

2 Network and Mobility Model

2.1 Network Model

Assume that there are N wireless networks net_n $(n = 1, ..., N)$ covering certain area A. Exemplary area A is depicted in figure 1. We assume that each network net_n covers a circular area with a center $(net_n(x), net_n(y))$ and radius r_n. Each network net_n is characterized by maximal amount of available resources U_n. Depending on the amount of free network resources u_n a client may receive certain amount of network capacity c_n calculated by function $c_n = f_n(u_n, r_n)$ which is specific to each access network net_n.

Assume that area A is divided into $I \times J$ identical square cells. Integers I and J are chosen in such a way, that cells are small enough for the characteristics of each network to be constant across the area of single cell. Each cell $cell_{ij}$ $(i = 1, \ldots, I; j = 1, \ldots, J)$ may contain any number of users and network access points. Coordinates of users and access points lying within particular cell $cell_{ij}$ are assumed to be equal to the coordinates of the cell. Moreover, we assume that the distance between certain user and certain access point is equal to the distance between cells containing user and access point.

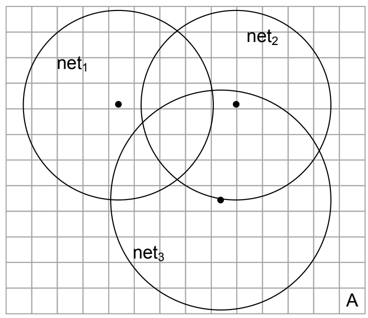

Fig. 1. The exemplary area A divided into 168 cells with networks coverage

The service of the network which can be delivered to multiple clients may have various interpretations in different access networks. In networks based on time-division multiplexing (TDM) medium sharing technique, allocated resource is interpreted as number of time slots in which a client is allowed to transmit data. On the other hand, in networks based on frequency-division multiplexing (FDM) certain amount of bandwidth is allocated to each user.

The form of function $f_n(u_n, r_n)$ depends among others on the type of network it is associated with. Another important factor is the ISO/OSI layer at which network capacity is measured. At the physical layer capacity c_n measured as number of bits send per second is roughly proportional to the amount of allocated resources and does not depend on the distance from the network access point. At the data link layer, where due to transmission errors datagram retransmission may occur, user's distance from the antenna plays important role. At higher layers of the ISO/OSI model protocol specific mechanisms requiring data retransmissions may further decrease delivered network capacity. In general it may be assumed that effective network capacity c assigned to a user is proportional to the amount of allocated resource u and inversely proportional to the distance r from the network access point:

$$c_n = f_n(u_n, r_n) = C_n \cdot \frac{u_n}{U_n} \cdot \frac{r_n - r}{r_n}, \tag{1}$$

where C_n is the maximal achievable effective capacity under assumption that a user is assigned with all available resources $u_n = U_n$ in a near zero distance from the network access point. For such a general model we add some assumptions and formulate mobility management tasks which are presented in section 3.

2.2 User's Mobility Models

The quality of services and performance of wireless networks highly depend on the position and movement trails humans which operate the various types of communication devices. Most of these devices are small, handheld equipment attached to their operators. It is rather difficult to deploy large-scale wireless networks for testing purposes, so various mobility models are used for simulations and performance evaluations. Mobility models, which reproduce the movement patterns of humans, are applied to make their behavior predictable, and support the algorithms used for network management [3]. We consider three mobility models, reflecting various statistical features observed in human activity patterns: Random Walk, Truncated Levy Flight (TLF) and Self-Similar Least Action Walk (SLAW).

The Random Walk model does not require much explanation — we assume stochastic movement with the maximum distance limit. The Truncated Levy Flight (TLF) model was based on the proposal discussed in the work [10], where the applicability of Levy walk model was proved for human mobility patterns. In particular — this result is especially interesting because the model verification in [10] was carried out on the data gathered in mobile telecommunication networks. Typically in experiments Levy exponent for flight length distribution and pause time distribution are equal to 1.5.

Self-Similar Least Action Walk was based on the model proposed in [13]. It is the most advanced approach, which covers several distinctive features observed in human mobility patters. First, it gives truncated scale-free distributions of flights (elementary movement actions) and pause times (time intervals between movements). This is the same feature which is also addressed by the TLF model. Moreover, the SLAW simulates the influence of individual mobility areas, typical for each user. The individual character of movement patterns was confirmed in [1]. The next feature modeled by SLAW are intercontact times. It is assumed, that the movements of individuals are correlated, and people tend to move in spontaneously formed groups which have truncated power law time distribution. The last feature are characteristic movement destination points which have fractal-type geographical distribution — this is used to simulate that some destinations are preferred and visited more often than the others. Following the results from [16] it is a characteristic feature observed in many scenarios, especially in an urban and industrial environments. The geographical space (area A) in our experiments is a 30×30 mesh with reflection boundary (points crossing the boundary turn back instead of returning on the other side of the mesh which is wrap-around boundary). According to the state-of-art we use the SLAW model in our experiments.

3 Problem Formulation

There is a number of mobility management tasks which can be performed to improve delivered quality of service in wireless networks. Each mobility management task can be formulated as an optimization problem which in general is NP-hard. In this section we focus on the problem of maximization of connected users number. Then we consider the simple prediction mechanism in order to minimize the overall handovers number.

3.1 Maximization of the Number of Connected Users

It is assumed that there are M users in the area A, each accessing one of the wireless networks. The task is to find such an assignment of M users to N networks for which the maximum number of users is connected with network.

Let matrix $R_{N \times M}$ ($R_{n,m} \in \{0, 1\}$) models the possibilities of connecting users to the networks in the moment t. Value $R_{n,m} = 1$ means that m-th user is located within the range of n-th network, while $R_{n,m} = 0$ means that such a connection is impossible at t-th moment of time. Assuming that all variables are considered in the moment t we can formulate the following optimization problem.

$$\text{Maximize} \qquad \sum_{n=1}^{N} \sum_{m=1}^{M} P_{n,m} \tag{2}$$

$$\text{subject to :} \quad \underset{n=1\ldots N}{\forall} \; \underset{m=1\ldots m}{\forall} \; P_{n,m} \in \{0, 1\} \tag{3}$$

$$R \cdot P = P \tag{4}$$

$$\underset{m=1\ldots M}{\forall} \; \exists! P_{n,m} = 1 \tag{5}$$

$$\underset{n=1\ldots N}{\forall} \; \sum_{m=1}^{M} P_{n,m} \le c_n. \tag{6}$$

It can be shown that the problem formulated above is in general a NP-hard optimization problem. The proof can be shown by transformation to *Multidimensional Multiple-choice Knapsack Problem* (MMKP) [14]. Therefore above formulation cannot be utilized in real-life applications where the number of users and networks may be large. In the next section we simplify the problem by assuming that each user requests the same amount of network resources. For such an assumption we present polynomial time exact algorithm.

3.2 Minimization of Resource Assignment Errors Number

The situation when user is not assigned with desired amount of resources we call the resource assignment error. The method presented in this subsection works if and only if all the users in the considered area requests the same amount of resources (e.g. the same maximum bandwidth). We can identify this with situation, when the mobile operator guarantees the equal throughput say 1Mbps for each mobile device with a contract.

Solution for this task is obtained by transformation of the original problem to the classic assignment task. Assuming that each user demands equal network capacity $c = c_n$ (for $n = 1, \ldots, N$) we create virtual wireless networks in the following way. Each n-th real network with total capacity U_n is divided into $\lfloor \frac{U_n}{c} \rfloor$ virtual networks. After such transformation we know that each of $K = \sum_{n=1}^{N} \lfloor \frac{U_n}{c} \rfloor$ virtual networks can handle exactly one user.

In the next step we build square binary matrix R' of size $max\{K, M\}$ in the following way. If m-th user can be connected (is located within the range) to virtual network k then $R'_{mk} = 1$, otherwise $R'_{mk} = 0$. If $K > M$ we add $K - M$ artificial users with possibility to connect each network. If $M > K$ we add $M - K$ artificial virtual networks where each virtual network can be accessed by any user in the area A.

Having the matrix R' filled with proper values we produce the assignment cost matrix denoted CR which defines the apparent cost of assignment the users to the virtual networks. The size of CR matrix is the same as the size of R'. The cost matrix CR is calculated in the following way. If $R'_{mk} = 1$ then $CR_{mk} = 0$; if $R'_{mk} = 0$ and $m < M$, $k < K$ then $CR_{mk} = b_1$; otherwise $CR_{mk} = b_2$. The b_1 and b_2 are any high numbers such that $b_1 > b_2$. In our experiments we take $b_1 = 1000$ and $b_2 = 500$. Such a cost matrix puts preference of connection of users that are within the range of any real wireless network. If user is not within the range of any network, the assignment cost is very high so the connection is unlikely to be preferred. The cost of assignment of artificial user or the assignment to the artificial network is also high, but lower than in the case when no network is available. This does not impact the overall solution because the artificial users are not going to be connected in real. The connection of real user to artificial network will cause the resource assignment error (in real the user will remain not connected) but will satisfy the general problem constraints (eq. 3–6).

Such a cost matrix is the only parameter of an algorithm solving the stated assignment problem. As the algorithm we use the Hungarian method [15] with cost minimization objective.

3.3 Minimization of Movement Prediction Errors Number

In this subsection we consider the minimization of prediction errors number problem which is a further extension of the resource assignment errors number minimization problem (eq. 2). We assume that the user location can be predicted for the next step thus we want to minimize the overall handovers number over the experiment time.

As the movement prediction error we understand the situation when handover of user occurred when it was not necessary — there existed such an assignment earlier that the handover would not occur now. The handover operation is not costless so we want to minimize handovers number in order to manage the wireless system resources properly.

In order to consider the prediction in the assignment algorithm we introduce the following changes to the cost matrix CR. Consider t-th moment of time. If

m-th user is within the range of k-th virtual network and will remain in the range of this network in the moment $t + 1$, the cost equals $CR_{mk} = 5$. The cost equals $CR_{mk} = 10$ if the k-th network will be unavailable in the moment $t + 1$ but is available in t. Moreover, if the m-th user is connected to the k-th network in the moment t and this network will be available in the moment $t + 1$ the cost is $CR_{mk} = 0$. As the prediction algorithm we use the geometric mean. The solution is obtained again using Hungarian algorithm with cost minimization objective.

4 Experiment and Results Discussion

In order to evaluate the efficiency of proposed methods there has been a simulation environment developed in C++ with use of Qt library. Developed simulator simulates the set of users moving over a square area covered with wireless networks. The area A has been split into 900 (30×30) square cells where defined number of wireless radio stations and users were placed. Each user located within the area A behaves in the following way. Every step the user makes a movement from one cell to another one according to the mobility model. When user changes a cell the decision is being made which network should be connected. After each step the number of unconnected users was counted.

The experiments executed in the simulation study consist of running proper number of simulation runs, each with constant number of networks but with increasing number of users and using various assignment algorithms. The results for each simulation run contain statistics about the following parameters values: connection errors — how many times user's requirements were not satisfied (user was not connected); prediction errors — how many times the handover occurred even if there was earlier such an assignment possible that the handover would not occur.

We examined four algorithms of assignment: $USR1$ — the user makes decision which network to connect depending on the signal strength; $USR2$ — the user chooses network with lowest ping; $HEU1$ — the heuristic algorithm presented in [17]; $OPT1$ — the optimal assignment solution for problem given with equations 2–6.

The results of the first experiment are presented in the figure 2. Each simulation run was executed with different number of users in the area A. There was 600 steps of simulation. In each step every user made a movement according to the mobility model. The heuristic algorithms $USR1$ and $USR2$, where user makes assignment decision, caused the largest number of connection errors. Both USR algorithms were used to show the waste of wireless networks resources when the user is making the decision — the way that is mostly used in practice nowadays. In the heuristic $HEU1$ the networks were making decision which user to connect. This method outperforms the methods $USR1$ and $USR2$. The optimal method $OPT1$ presented in this paper maximizes the number of users which have connectivity to the network.

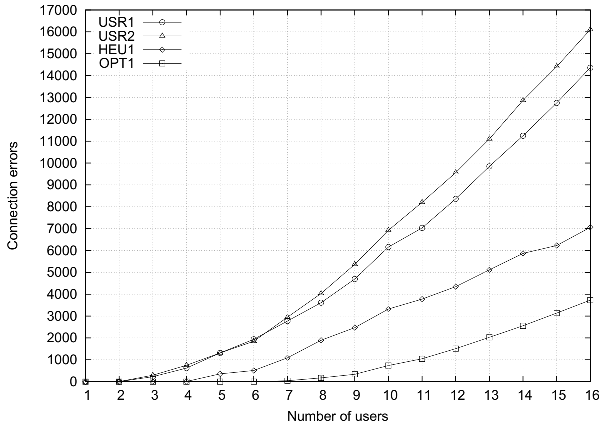

Fig. 2. Number of network resource assignment errors under control of various assignment algorithms for increasing number of users present in the area A

In the second experiment we investigate the quality of exact method by comparing the number of prediction errors when using the following prediction assumptions (in all cases the geometric mean is used as a predictor):

– no prediction of user location,
– low quality predictor — only partial information about user's past movements was available,
– hi quality predictor — only some data about past movements were missing,
– ideal predictor 1 step — we assume that we know exact position of user in the next step
– ideal predictor 2 step — we assume that we know exact position of user in the next two steps.

The results of the second experiment are presented in the figure 3. Each simulation run in this experiment gives equal connection errors number — same as in the first experiment for algorithm $OPT1$. This means that the modifications of algorithm does not change the optimality in sense of optimization criterion (eq. 2) chosen as minimization of connection errors. In this experiment we change the optimization criterion and compare number of prediction errors for the optimal algorithm.

The results show that prediction of future user location is worth the effort. Even the low quality prediction gives the satisfying improvement in the prediction errors number. Using more sophisticated methods of prediction improves the wireless network resources usage, assuming that each handover impacts the load of the network. In this case the high quality predictor gives satisfying results. More interesting observation is that using ideal predictor with longer prediction horizon does not improve significantly the results comparing to ideal predictor with shorter horizon.

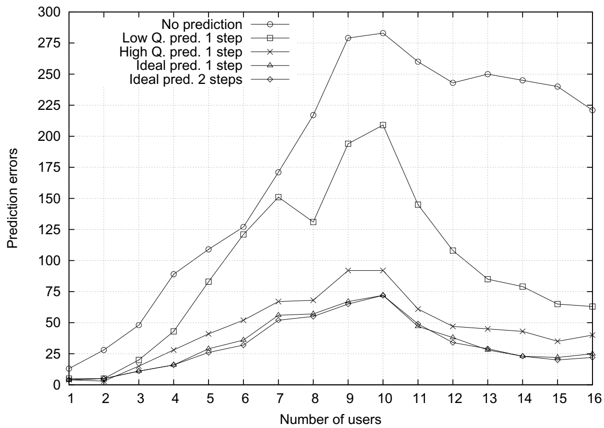

Fig. 3. Number of prediction errors under control of predictors with various quality using exact assignment algorithm for increasing number of users present in the area A

5 Final Remarks

The general problem formulated in this paper concerns a situation when the users are moving through area covered by many wireless networks. Every user uses the network but can be connected to any particular wireless station that is within the range. We have formulated the general problem of assignment users to the networks and the simplify it in order to show that prediction of user's location in the future causes less handovers. Moreover, we point out that sophisticated methods of prediction will rather not improve much the performance of the wireless system. In the future we plan to discard the simplifications introduced in this paper and propose efficient heuristic algorithm for general problem formulated in section 3. Moreover, we plan an application of such a methods in service-oriented [6] sensor data acquisition system.

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