Activity-Based User Modeling in Service-Oriented Ad-hoc-Networks*

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Abstract. Wireless network research still lacks methods to integratively evaluate the performance that can be expected from application layer protocols. The user behavior is predominantly affecting network performance and shows itself in two parts: its mobility and its network usage. However, it is often reduced to analytical mobility models and network traffic models separating otherwise intertwined parameters. This paper demonstrates that the use of an integrated view based on the users' real-world activity can explain network-relevant parameters both with respect to mobility and to network usage and thereby allows a more natural and realistic modeling of user behavior. The benefits are presented with the help of our graph-based mobility model and its accompanying network usage model.

1 Introduction

Wireless mobile ad hoc networks (MANETs) are a fascinating alternative to infrastructure-based cellular wireless networks. Consequently, they have been a popular research topic for the last few years. In the beginning, most of this research was focussed on making MANETs technically feasible. The major prerequisite for this was the development of appropriate routing protocols. In order to evaluate these protocols all that was needed were some more or less straightforward adaptations of existing network simulation software. Recently, however, more and more research has been dedicated to application level usability of MANETs [1–3]. Here, the main challenge is to enable users to access the heterogeneous resources spread across the network. To evaluate these approaches, again, a simulation is needed. However, it is not so important to find a realistic model of the underlying network. Rather, the decisive factor for the performance evaluation of application level approaches is a realistic model of the user. Unfortunately, up to now, no realistic user model exists, making it virtually impossible

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to reliably evaluate application level approaches. Of course, users and their behaviour have been modeled in the past, however, these models have a number of drawbacks which make them unusable for the simulations needed here:

Many models assume a basically random movement of the user. While this is sufficient to simulate the performance of network level protocols, this assumption is not suitable for application level evaluation. Here, it is important to take into consideration that, usually, users do not wander around aimlessly but move in order to accomplish a certain task or a number of tasks. This implies also, that the movement of the users and their usage of the network resources are not unrelated but in the contrary highly correlated. Users will perform certain activities at certain locations exhibiting certain movement patterns. For instance, while a user may check his mail while walking from one location to another, he will most probably not edit a paper while doing so. A student may participate in an online game while relaxing in the cafeteria, but he will (hopefully) not do so while attending a class in a lecture hall. Existing models do not allow to capture this relationship, virtually all of them regard movement and network usage as two separate, independent factors.

To overcome the limitations of existing models, in this paper, we present a user-centered, integrated approach to mobility and network usage modeling which adapts to the requirements of ad hoc networks, thus facilitating a meaningful evaluation of new application protocols. Notice that our approach is applicable for other types of wireless networks, too. However, the benefits of a realistic user modeling are most obvious in the area of mobile ad hoc networks. Our activity-based approach derives an integrated view on mobility and network usage from a user's real-world activity and thereby obtains mobility patterns and service usage preferences in a natural way. Therefore, mobility is considered a secondary need that a user derives from his activities. Additionally, the needs modeled through an activity induce the service types and thereby the network usage in the mobile ad hoc network.

The paper is structured as follows: Section 2 sets the scope of the considered modeling. In Section 3 an overview of related approaches to user modeling is given, before Section 4 introduces our integrated, activity-based approach. Section 5 presents implementation issues of our user model. The paper ends with a conclusion and an outlook to future work in Section 6.

2 Scope of the considered modeling

In this section, we present the class of networks which is the object of our modeling: service-oriented ad hoc networks. By this means, the requirements and basic constraints of the modeling become apparent. In addition, we introduce an example from our research project DIANE: a campus scenario where students cooperate by using services with the help of mobile devices. This helps to illustrate the approach more vividly.

Service Oriented Ad hoc Networks. As introduced above, we will concentrate on modeling users in service-oriented mobile ad hoc networks. Typically, these networks combine mobility and spontaneous membership with generic mechanisms for management and usage. For example, mobility occurs whenever people cannot accomplish their tasks at the same place during the day: Workers need to drive or walk to their workplace, to the shopping mall or to lunch, or students walk to school or move between class rooms. Mobility leads to spontaneous meetings of people where ad hoc networks allow the communication with previously known or unknown network users and the usage of the services. Other drivers may provide news about traffic, shops may provide information about their products or restaurants may inform about the meals offered. Previously known network users (co-workers or students of the same class) may provide services that are of common use.

All applications of service-oriented mobile ad hoc networks have several properties in common which lead to basic constraints and requirements of a possible modeling:

- Provision of a **diverse set of services**. This results from their mobility and the generic service paradigm in these networks. So, users with different incentives participate in the network, which leads to a high number of services.
- **Mobility and network usage are highly interwoven.** This is obvious with regard to services that are unlikely to be used in highly mobile situations, but holds true for other services as well.
- The provision and consumption of services **highly depends on the time, location and the user's need for certain services.**

Campus Scenario. To illustrate our approach, we present a university campus scenario that is characterized by a schedule-dependent mobility between locations and a wide range of possible services and network users. Here, people and institutions are able to cooperate with the help of mobile ad hoc networks. The cafeteria might be offering information about its meals to customers coming near, and co-workers or fellow students could provide useful bookmark lists. Common institutions such as libraries might be offering information about recently acquired literature. Especially on university campuses, the students' incentive to help each other by sharing knowledge with fellow students is high and thereby includes a wide range of possible ways to cooperate[1]. For example, their cooperation consists of collaboratively solving open questions with the help of discussion forum services or providing useful related or summarized information about their lectures through document sharing services.

Also, mobility is an important issue on such a university campus. On university campuses, students move between lecture halls, dormitories, the cafeteria or other common institutions. Employees move between meeting halls, workplaces, the car park or the cafeteria on corporate campuses. Besides the movement between those locations, there is also motion during the stay at one of them. For example, customers in a canteen move to receive the components of their meals and finally to one of the tables.

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[1] Compare with the *collective pattern* in [4, 5].

In general, the set of members of a given ad hoc subnetwork constantly changes due to the movement and the different daily schedules of the people moving. However, the schedule of lectures resp. meetings leads to time periods with high mobility (lecture breaks) followed by periods with low mobility (lectures, meetings). Therefore, a highly varying network topology is followed by a rather constant one.

3 Related Work

In the literature, different user models have been proposed. Apart from user models for wireless networking, it seems promising to take a closer look at user models for travel demand modeling. This stems from the relative matureness of travel demand models. Therefore, in this section, we give a short overview of both domains of user models and conclude by pointing out the need for activity-based modeling.

3.1 User Models in Wireless Networking

We distinguish three types of user model in wireless networking. The most basic is the type of analytical mobility models that describe the movements of network users. The second type of user model adds a simple, independent network usage model and thereby represents user behavior by two separate models. The third type of user model increases the semantics of its underlying mobility model and therefore allows the integration of more sophisticated network usage models. In the following, we will analyze these types in more detail.

Analytical Mobility Models. In most user models for wireless networks, user behavior is described in terms of mobility models. Research has created a wide range of mainly analytical mobility models such as the Random Walk, the Random Waypoint [6] or the Gauss-Markov [7] model. However, their analytical properties are hindering their use for application-level performance evaluations. Mobile nodes move without actual incentive and without environmental constraints. Therefore, the oversimplified assumptions of unconstrained, erratic movement largely differ from reality.

Combined Mobility and Usage Models. The second type of user models adds simple network usage models to their mostly analytical mobility models. Such simple network usage models are typically traffic models that describe how users interact in terms of the amounts of data sent through the network. With regard to wireless telecommunication networks, this task has been achieved through the use of call models [8] by LAM ET AL. However, they introduced a network usage model that limits the set of services to phone calls and that is separated from the mobility model. Thus, the correlation of mobility and calling activities is modeled with the help of time-dependent call distributions. In service-oriented ad hoc networks, however, service usage strongly depends on location (which services are available), network topology (which users are near) and mobility (which services are usable). Therefore, service usage is constantly changing with respect to the users' movement, distribution and service needs.

User-Centered Mobility Models. The third type of user model integrates realistic mobility models that approach mobility from a user-centered point of view. Therefore, they provide semantic information to network usage models that are built upon them. One example is the realistic mobility model presented by TAN ET AL. in [9]. In this model, mobility is the result of the users' interaction with each other. The perception of the environment and the general behavior is modeled after the principles to which animal herds or swarms adhere. This interaction principle couples the network usage model with the user mobility. However, the mobility model focuses on movements that are opposite to spontaneous and independent membership. However, the interaction principle would facilitate the coupling of the dependencies of the network usage models and the user mobility.

A more advanced user-centered mobility model is presented in [10] by SCOURIAS and KUNZ. The daily movements of users are used to evaluate the distribution of subscribers of a cellular phone network. In this regard, daily activity patterns are modeled with the help of an activity transition matrix and an activity duration matrix. Their network usage model is based on time-dependent call arrival probabilities. Thus, the increased level of semantics in the mobility model is not used. In [11], STEPANOV describes a similar approach of implementing an activity-based mobility model. The network usage model uses constant bitrate connections and therefore does not use the semantics provided by the mobility model either.

3.2 User Models in Travel Demand Modeling

Travel demand modeling is a more mature domain of user modeling than user models in wireless networks. This research topic from civil engineering uses information on population, employment, roads, public transport systems and travel behavior in order to forecast traffic on transportation systems. In the following, we discuss the two predominant types of travel demand modeling.

Trip-based modeling. Conventional traffic simulation in civil engineering uses trip-based models of travel demand [12]. The simplicity of these models implicates several drawbacks. On the one hand, trip-based models feature a step-wise procedure of generating immutable and independent trips. This prevents the implementation of complex human behavior and cooperation schemes. On the other hand, these models typically do not incorporate the time of day. Therefore, it is difficult to describe time-dependent phenomenons such as congestions during rush hours.

Activity-based modeling. Activity-based approaches towards user modeling have become popular in transportation research. Thus, a number of activity-based approaches have been developed that differ in the way how activity patterns are modeled. KITAMURA categorizes them in [13]. TIMMERMANS focuses on the scheduling of activities in the daily course of people's life and gives an overview in [14].

Activity-based modeling typically describes daily user behavior as sequences of activities derived from a set of parameters. The respective models can be distinguished by the way they model the user's decision of when and how an activity is carried out. One type of model describes decisions with the help of linear structure equations of a set of parameters whose dependencies are well understood. Another type imitates the cognitive processes of human decision-making by examining the activities to choose from and scheduling them according to the decision models.

These so-called activity scheduling models describe decision-making in a more natural way. One widely used type of activity scheduling models represents the human decision process as the application of a sequence of prioritized production rules. This method does not necessarily optimize the utility of an activity sequence, but allows for a dynamic and application-dependent way of determining activity patterns.

3.3 Summary

The use of analytical mobility models in wireless network research has shown similar problems as in travel demand modeling. The complexity of human behavior has been reduced to the selection of only mathematically connected movement parameters. Similarly to the trip-based models in transportation research, analytical mobility models neglect the effects of time-dependent behavior. Especially in our campus scenario, where mobility increases during lecture breaks, this is a severe drawback. The independent modeling of trips is similar to the memoryless nature of most analytical mobility models that cannot support saturation effects and sequence-dependent behavior.

In analogy to the recent developments of travel demand modeling, we conjecture the necessity of activity-based modeling in wireless networks.

4 Activity-Based Approach

Our approach to user modeling is structured in four main parts (cf. Figure 1): The **activity model** determines which activities users are performing. The **motion model** calculates the movement of the users with the help of a multigraph[2] -based mobility model. The **service model** realizes the network usage model. Both the motion model and the service model derive their respective parameters from the activity model. The **environment model** provides the paths that are available to the motion model and the locations where activities take place. In the following sections, we will describe these models in more detail.

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[2] A multigraph is a graph in which every pair of nodes may be connected by several edges. In this paper, we assume that these edges are ordered.

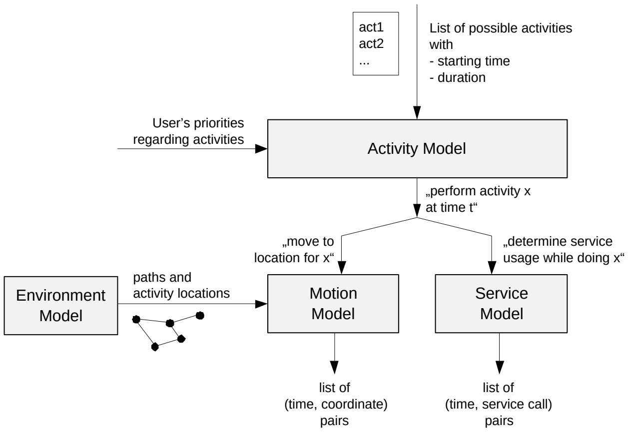

Fig. 1. The four parts of our activity-based approach. The *activity model* calculates a user's timetable of non-networking activities. This is used within the *motion* and the *service model*, which derive the necessary movements as well as useful services during this activity. The *environment model* provides the necessary information about the paths and activity location of the simulation area.

4.1 Activity Model

The general assumption of activity-based models in transportation research is that motion is not a primary need in daily life. It rather enables the execution of activities by connecting the locations of two consecutive activities. This assumption is valid in scenarios where people are not moving as an end in itself. This is typically the case in the campus scenario from Section 2.

The main task of the activity model is to transform an abstract list of possible non-networking activities into a concrete schedule of these activities. This becomes possible when activities are described with at least two characteristics: a more or less restrictive **starting time** and a typical **duration**. Additionally, each user or class of similar users weights these activities by a set of **priorities**, which helps to decide in case of conflicts. This process is described in more detail below.

The first step of creating an activity model is the identification of non-networking actions that are typical in the scenario to be considered. However, this results in an overly detailed list of actions. Therefore, actions of users are collected into classes of actions. Generally, actions from a class can be treated equally, if the desired level of detail requires no further distinction and the actions' parameters allow for a common treatment. The concept of an action class leads to the collective term of an activity. It represents the entirety of parameter sets for an action class. For example, in the university campus scenario, attending lectures and seminars, preparing for an exam, but also pursuing social activities like recreating or eating can be identified as typical actions. If a rather low level of detail is required, lectures and seminars can be generalized to an activity of a *course*. These actions typically share common locations and are both regular, recurring events. Therefore, the subsumption of these actions is possible.

In the next step, the starting time of each activity has to be determined. Typically, we can differentiate between activities with a fixed starting time such as attending some lectures and free-floating activities like borrowing a book which can be scheduled at will except for possible constraints like opening hours.

Furthermore, the duration of an activity is important. In general, it can be fixed or variable within a certain range. Typically, free-floating activities have durations that adhere to random distributions. Therefore, the distributions and their respective parameters have to be identified.

Having identified time and duration, activities often will overlap in time. Therefore, we choose a priority scheduling technique. Hence, each user or class of users classifies the activities in pre-planned, high priority activities and spontaneous activities of lower priority. In our scenario, compulsory events such as lectures and seminars are of high priority, while free-floating activities such as the borrowing of books at the library are of lower priority. Furthermore, people are also carrying out standard activities that use up their time in between these special activities. For example, with regard to employees on a corporate campus, these non-special activities could be the steady work at their office desks. These standard activities are of lowest priority and are performed in the remaining time. As a rule, activities of higher priority take precedence over activities of lower priority when there are conflicting starting or ending times.

To summarize, activities are described by the following characteristics:

- **Starting time:** Activities either start at a fixed point in time or are freely schedulable in time.
- **Duration:** Activities last either for a fixed time or their duration is described by a random distribution.
- **Priority:** Activities are scheduled in the order of their priority when time conflicts arise. Notice that each user or each class of users defines its own set of priorities.

With all these information, the activity model is able to calculate concrete activity schedules for a user. To do that, the model tries to develop an optimal plan by placing freely schedulable activities around the ones with fixed starting time. In case of conflicts, it prefers activities with a higher priority.

4.2 Environment Model

Environment models are constraining the movements in realistic mobility models. Therefore, mobile nodes described in such mobility models can no longer move arbitrarily, but have to adhere to the constraints given by buildings, vegetation or route sections.

In our campus scenario, people are typically moving around on foot. Pedestrians' movements mostly follow common paths which exist in different widths. Therefore, our environment model describes the entirety of paths as edges in

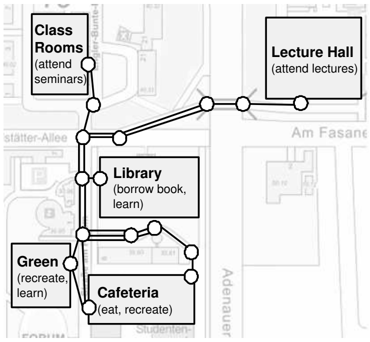

Fig. 2. Environment model of our campus scenario as multigraph. Activity locations like the library or the cafeteria (depicted by rectangles with location name and possible activities) are connected via a multigraph representing walkable paths of the real world. The width of a path is represented by the edge multiplicity.

an undirected multigraph (see Figure 2). The vertices of the graph typically represent places where several trails meet. By varying the number of vertices, the level of detail is adaptable to the needs of the application. The vertices are connected by (possibly multiple) edges that stand for the paths on the campus. The number of edges connecting a certain pair of vertices represents the width of a path. With the help of these widths, a realistic group movement where several people are moving together can be modeled. Therefore, individuals are able to move side by side on one of these parallel paths.

Additionally, the environment model describes activity locations. Besides the representation as vertices of the graph, these locations are modeled as rectangles. Each of these locations is suitable for certain activities and is characterized by its own mobility profile. Typically, analytical mobility models are suitable to describe the motion within the activity area described by the rectangles. Their use is facilitated by the rectangular shape of these areas. Generally, reaching a vertex connected to an activity location is equivalent to beginning the execution of an activity. Moreover, this involves a different type of mobility than the one connecting two consecutive activity locations.

4.3 Motion Model

The main task of the motion model is to break down the high-level movement commands ("move to a location which enables activity x") to fine-grained micro-movements. This can be done in three steps so that the motion model is split up in three layers: the location determination layer, the route calculation layer and the path selection layer (see Figure 3). To do its work, each layer receives certain information from the environment model. In the following, we will describe these three layers in more detail.

The highest layer is the **location determination** layer. It transforms semantic movement commands like "move to a location for activity *eating*" into

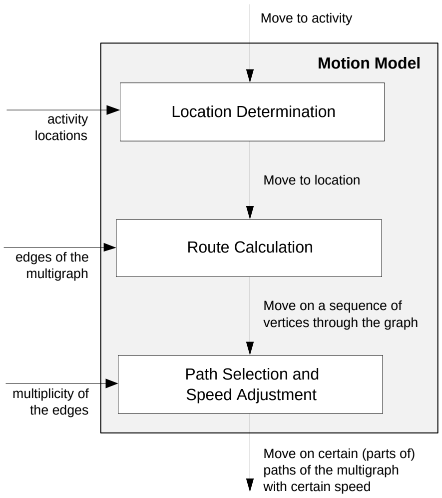

Fig. 3. The three layers of the motion model. In the *location determination layer*, a suitable location for a given activity is selected. After that, the *route calculation* determines a sequence of intermediate vertices to reach that location. Finally, the lowest layer performs a *path selection and speed adjustment* step to handle effects of crowded paths and slower moving pedestrians.

physical movement commands like "move to the cafeteria". This becomes possible by the information about the possible activity locations, which is provided by the environment model. Generally, in this step, a random (or the nearest) possible location for that activity is chosen, but special user preferences ("For learning, I prefer going to the library") can change this behavior.

The second layer performs the **route calculation**. It has to determine the sequence of nodes between the actual and the desired activity location. As we assume that pedestrians optimize their movements more or less, we calculate the shortest path between these two nodes. Again, the information about the graph is offered by the environment layer.

Finally, the lowest layer executes the **path selection** and the **speed adjustment**. This is necessary as pedestrians are not alone but have to deal with overcrowded paths. Therefore, users are selecting one of the parallel neighbored paths distributing themselves over the width of the available walking space. Nonetheless, this can lead to paths being overcrowded. Therefore, in our model, the speed of a user depends on the number of users walking on a path. Thus, if a lot of users have chosen to use a certain path, this will reduce their walking speed on this overcrowded path. To reduce complexity, this speed adjustment affects all current users of a certain path.

As a final result, the motion layer provides a way through the multigraph together with the according speed. According to the needed simulation granularity, the bypassed coordinates can be calculated as a list of (time, coordinate) pairs. These can be used directly to determine the movement of the user.

Notice that the motion model only calculates the movements *between* activity locations. When the desired location is reached, the activity is carried out resulting in an activity-specific movement (like wandering through the shelves of a library), which is described by a specific, mostly analytical motion model.

4.4 Service Model

The service model represents the implementation of a network usage model. With the help of the semantic information available from the activity model (i.e. which activity is to be performed at what time), the service model can derive the type of service that is most useful during this activity.

We have identified four types of services that are typical in a campus scenario. These are as follows:

- **Document Services:** Static documents that are downloadable from other users in the ad hoc network. This type of service is typically provided by most users. Using this service leads to a few simple interactions.
- **Cooperative Work Services:** Services that facilitate cooperative work and induce complex interactions. Due to transactional requirements, this type of service is not available all the time or is not provided redundantly.
- **Interactive Services:** Services that induce a high number of simple interactions. As an example, chat services (instant messaging, IRC) are considered interactive services. Due to their simplicity, they are often available.
- **Dependent Services:** Services that are used only in connection with other services. For example, services that allow the printing of documents and therefore require the prior usage of a document service are considered dependent services.

We assume that service usage is dependent on a set of parameters: First, service usage depends on the **ongoing activity**. For example, the usage of document services such as additional lecture material is more useful during lectures than during lunch. Second, service usage depends on the general situation or **state of the service user**. For example, students preparing for their exams might rather use document services than interactive services. Third, service usage depends on the **level of attention** that a user can give to the usage. Therefore, we assume that faster-moving users will reduce service usage with respect to services that require a high level of attention.

We are modeling these dependencies by mapping parameter ranges to a set of service profiles. These service profiles abstract from the usage intensity of a service. The usage intensity is based on the number of interactions per unit of time and the duration of a single interaction.

4.5 Discussion

Our activity-based approach was designed with the goal to meet the new requirements of user modeling in service-oriented mobile ad hoc networks. In the following, we will examine whether these requirements have been met.

High-Level Semantics: The needs of application-level simulations in MANETs with regard to semantic information are broadly supported. Therefore, our activity-based user modeling introduces an incentive to otherwise aimless behavior. Finding simulation representations of real world scenarios is facilitated as the semantic information of a behavior's incentive is available. With respect to application-level protocols, this allows to build performance evaluations that closely fit their anticipated application scenarios and give more accurate results.

Diverse Set of Services: The spontaneous arrival, mobility and membership of users in ad hoc networks induces a potentially diverse set of available services. Therefore, our approach to user modeling handles network resources in their diversity. Thus, the activity concept allows to distinguish service usage in a natural way by an activity's main parameters, i. e. location and time. Service diversity often results from the diversity of users.

Interwoven Mobility and Network Usage: Our activity-based approach allows dependencies between mobility and network usage. Therefore, it derives both mobility and service usage from user activity. Our approach maps parameters concerning mobility, activity and personal situation to appropriate usage profiles. Hence, it is possible to examine the effects of mobility on service usage and thereby network performance.

Dependencies on Time, Location and User's Needs: Our approach captures these dependencies by correlating the user's current activity and his service usage in the service model.

5 Realization and Evaluation

Our user model has been realized as a set of meta protocols using our high-level network simulator DIANEmu [15] (see screenshot in Figure 4). With the help of a layered protocol approach, the visualization and protocol implementation have been facilitated. In addition to the protocols implemented for the activity, motion and service models, the implementation of our approach features a user model. While the former models are implemented as protocols that are interacting locally, the user model allows the cooperation of nodes in the network. Therefore, conjointly planned activities are possible.

In spite of the integration into our simulator tool, the mobility and service usage data is not bound to it. We are separating this data from its application to network protocol performance evaluation. This allows for reproducible results when used in other simulation environments.

Realistic user models need input data to imitate actual users in the scenario evaluated by simulation. Therefore, the environment model is based on the university campus in Karlsruhe. For the activity data, we use actual lecture

Fig. 4. Simulator DIANEmu View. Left: Visualization of users moving on campus. Right: Message view of the underlying meta protocols.

schedules, opening hours of campus institutions and survey data. Therefore, we conducted a survey [16] about students' activities and service usage on the campus. The data used in our model is based on the answers of about 80 first-year students in computer science. The survey provides us with data about the students' activity and service priorities as well as their activities' frequency and duration. Additionally, it gives us data about the dependencies of the service usage and its parameters such as mobility or personal situation.

For evaluation, we are comparing the mobility from our activity model with the motion of students as stated in our survey. Therefore, our survey featured questions about the students' daily course of activities. This included information about the students' location at several points of time during the day.

The survey data is currently being used to evaluate the level of reality of our model. Therefore, we compute the deviation of the users' positions derived from our model with the reference positions given by the survey data. A user's activity motion is then matched to that survey participant's data giving the smallest error sum of squares. For comparison, this matching is also done for a graph-based Random Waypoint implementation using appropriate wait times.

6 Conclusion and Future Work

In this paper, we have motivated the need for realistic, semantically rich user models for service-oriented ad hoc networks. Then, we have presented an activity-based approach from transportation research that derives user mobility from the basic human need to carry out activities. With the help of this semantic model, we have presented our integrative approach of a graph-based mobility model and a semantic network usage model.

Currently, we are refining the modeling of free-floating activities and sequence-dependent services. In the future, we will evaluate our application level protocols with the help of the mobility and network usage data derived from the activity model.

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