Performance Evaluation of Network Systems
Accounting for User Behaviors

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Abstract—Considering user behaviors in the performance evaluation of mobile networks is crucial as traffic generation in such networks is highly dependent on mobility and communication activities of mobile users. This paper presents a simulator that can faithfully simulate user behaviors together with the target network system. The following three components have been implemented in a network simulator in order to model realistic user behaviors: (i) a function of loading geographical data for the target area, (ii) a pedestrian mobility model in which users walk along streets based on the given geographical data, and (iii) a communication behavioral model, which accounts for correlations between user profiles and their communication activities. Simulation of a mobile network system is performed and shown that the simulator replicates realistic behaviors of individual users, and also that the user behaviors do influence the predicted overall system performance. This indicates the importance of accounting for user behaviors in mobile network system evaluation.

Keywords—mobile communication; mobility model; simulation; user behavior

I. INTRODUCTION

In mobile networks, users always carry their mobile terminals, and make or receive calls anytime and anywhere. Therefore, the generation of communication traffic is heavily dependent on user behaviors such as mobility and communication behaviors. These behaviors also are strongly influenced by environmental factors associated with the user (street layout, weather, and special events, such as fireworks displays or football matches). For instance, when a user walks in the crowded area like a fireworks display, he or she may not take the shortest route to the destination, but rather may select a less busy route to avoid the crowds. In the case where many people are gathered in a small area, which causes network congestion, they may reattempt calls repeatedly at short intervals until they are successful. Moreover, even if some people are in the same environmental situation, their communication behavior, such as interval between retries, differs according to certain attributes (gender, age and so on). Therefore, in mobile networks, we can state two issues: 1) the traffic that flows into a mobile network is heavily dependent on user behaviors, and the quality of service resulting from the network condition greatly influences user behaviors, 2) individual users may behave differently according to certain attributes, such as age.

In order to evaluate the performance of mobile networks, network simulation is widely used. For example, we have proposed a traffic control method that guides users, to alleviate congestion by giving them information about the network [1]. In this method, the network sends users one of three guidance messages according to the state of the network congestion. These messages are A) to encourage users to wait calling, to achieve time balancing, B) to encourage user to change communication medium (for instance, from phone call to text messaging), and C) to encourage users to move for calling, to achieve geographical balance. This traffic control method aims to improve not only network performance but also the quality of service users perceive, and so ultimately to increase customer satisfaction. It is quite difficult to evaluate the performance of such a method in the field and therefore evaluation by means of simulation is useful. To evaluate such a control method through simulation, it is necessary for the simulator to represent both individual user behaviors and the degree of customer satisfaction with the network service provided.

Recently there have been some studies on simulation techniques which consider user mobility for mobile networks, such as the verification of the random waypoint model, which is often used to evaluate network performance, and the development of realistic mobility models [3]-[6]. However, there have been few reports that consider detailed network simulation to deal with both issues 1) and 2) mentioned above. For the performance evaluation of mobile networks, we have proposed the concept of a user and network integrated simulation capable of dealing with both issues 1) and 2) and showed the importance of such a simulation [2].

This paper presents a simulator as a platform for performance evaluation corresponding to various applications and services. We have developed a large-scale simulator which
can more faithfully simulate the network (which offers communication services), users (who are the source of traffic), and the environment (which influences user behavior). We also evaluate the network systems by using the developed simulator with parameters based on communication logs and a survey of cellular phone customers. The simulation results show that the developed simulator has high functionality and it is able to represent detailed individual user behaviors (mobility and communication). The rest of this paper is organized as follows. First, the concept and the requirements of the proposed simulator are described in Chapter II. The components of the developed simulator are then explained in Chapter III. The results of performance evaluation of network systems are shown in Chapter IV. Finally, we discuss our conclusions in Chapter V.

II. PRELIMINARY

A. User and Network Simulator: Concept

The proposed user and network integrated simulation can represent individual user behaviors (mobility and communication behavior) and customer satisfaction with the quality of service provided, in addition to providing the functionality of a conventional network simulator. Therefore, it also has a mechanism to incorporate feedback from user behaviors to traffic, from traffic to quality of service, and from quality of service to user behaviors [2].

Fig. 1 shows the simulation targets of conventional network simulators and the proposed simulator. Conventional simulators cover only network elements and mobile terminals. In contrast, our simulator covers not only the network per se (which provides network services), but also users (who are the source of traffic) and the environment (which influences users and the network). Here, the environment includes the geographical situation, such as streets and traffic lights, the weather, and events, such as football matches and fireworks displays.

The proposed simulator can model traffic based on realistic user behaviors and the user environment rather than assuming simple traffic based on Poisson distribution and so on. This simulator makes it possible to:

1) analyze the mechanism of traffic generation for modeling mobile traffic in both usual and unusual conditions such as congestions or equipment failures,

2) evaluate new traffic control methods which take account of individual user satisfaction, including “traffic control by influencing user behavior” [1], and

3) improve the simulation accuracy by using realistic traffic inputs.

B. Functional Requirements

This section describes the key functions required to realize the concept described in Section II.A. The user and network simulator needs to represent realistic individual user mobility and communication behaviors. For modeling realistic user mobility, users in the simulation should walk along streets laid out according to real geographical information. In order to utilize real geographical information in simulations, the function of loading real map data into the simulator is required. For modeling realistic user communication behavior, it is necessary to use not just a uniform models but detailed models which can be defined by user profiles. Thus, the main functional requirements for the simulator to meet these conditions are as follows:

- Real map loading function
- Pedestrian mobility model
- User behavior model.

III. IMPLEMENTED FUNCTIONS

A variety of commercial and non-commercial network simulators are used for network research, such as ns-2 [7], OPNET [8] and QualNet [9]. In developing our simulator, we chose to make use of an existing network simulator, and selected QualNet for our simulation engine on account of its scalability and high simulation speed. To build the proposed simulator, we added the required components described in Section II.B to QualNet as add-ons and also made some customization. Each component is explained in the following sections.

A. Real Map Loading Function

The real map loading function loads the map information of a specified area for use in simulation scenarios.

We adopted digital maps that conform to the Japan Profile for Geographic Information Standards (JPGIS) issued by Japan Geographical Survey Institute (JGSI). We developed a converter, which extracts the required information relating to a specified area and converts it into an XML format suitable for simulation scenarios. Although the maps issued by JGSI include information about streets, intersections, and park areas, they do not include all the information needed for our simulation. We therefore developed a mechanism to add the necessary information which is absent from these maps. In the default setting, train station areas, connections between station areas and streets, entrances to parks, street widths, and traffic lights are added from the other geographic information. We also developed an add-on function for loading the XML-format maps required for simulation scenarios. The XML format which we defined allows an easy description of streets, intersections, parks, train stations etc. By basing geographic data on this format, it is possible to use original geographic feature data in simulation scenarios.
B. Pedestrian Mobility Model

The pedestrian mobility model represents users walking along the streets on the maps loaded by the real map loading function. This model assumes that each user has an individual destination and walks independently of others. It allows users to change their walking speed and destination dynamically depending on the state of the surrounding environment, such as a crowded street.

We divided the mobility model into three parts (streets, intersections, and parks). Each part is explained below.

1) Mobility Model for Streets

It would be more realistic to consider how users adjust their walking speed to the conditions in the street. When there are a large number of people in the street, the walking speed is generally reduced. From the observed data in [10], [11], the walking speed can be determined as

$$v = v_0 - a \times d \quad (d \leq d_C)$$

where $v_0$ is usual walking speed, $a$ is a constant, and $d$ is population density as shown in Fig. 2. Also, when a population density $d$ exceeds certain point $d_C$ in Fig. 2, the walking speed becomes flat $v_L$. Here, the population density is defined as the number of users divided by the street area (street width $\times$ street length), as shown in Fig. 3. The street length is divided into segments: $\Delta$ (Fig. 3), and users move segment by segment. The population density of a street is calculated every time a user moves, and is reflected in the walking speed. This model provides for more realistic mobility whereby users reduce their walking speed when the street gets crowded and increase it when the situation is alleviated.

2) Mobility Model for Intersection

We developed a model for selecting a street at an intersection as follows. When a user arrives at an intersection, he or she selects one of the streets connected to the intersection. In general, the user selects the street that leads to the shortest path to the destination. This would uniquely determine which street the user will select. However, in a real situation, users may avoid a crowded street even if it is the shortest route to the destination. In our model, the user selects a street connected to the intersection on the basis of parameter value $w$, which is defined by (2).

$$w = (\cos\theta + 1)^2 \times f(d)$$

When a user arrives at an intersection, $w$ is calculated for every street connected to it. Here, $\theta$ is an angle between the direction to the destination and the direction of the street in question, as shown in Fig. 4. $f(d)$ is a function of population density $d$. We defined this function as shown in Fig. 5. We assumed four situations on population density $d$: 1) no crowded ($0 \sim d_1$), 2) a little crowded ($d_1 \sim d_2$), 3) very crowded ($d_2 \sim d_3$), and 4) extremely crowded ($d_3 \sim \infty$). In no crowded situation, $f(d)$ takes a maximum value $f_1$. Also, in a little, very, and extremely crowded situations, $f(d)$ becomes lower value. In extremely crowded situation, $f(d)$ is set to 0 so that a user can avoid going to such a street. When this algorithm is applied to the selection of the street to take, users tend to select a street which is less crowded but still provides a reasonably short path to the destination. In this model, a route can easily be determined by using current location, destination, and surrounding population density. Moreover, it is unnecessary to hold route information during simulations.

3) Mobility Model for Parks

In a park, user movement is not constrained by streets, and users can move in any direction. They tend to move in a direction which is not too crowded but still provides a
reasonably short route to the destination. In order to simulate such behavior, we defined a model similar to the mobility model for intersections.

We assumed that a park area is divided into a grid pattern, and a user can move in one of the four directions: north, south, east, and west, as shown in Fig. 6. The user selects the direction based on \( w \) in (2). The population density \( d \) is calculated for four each directions from the number of users in the area in front of the user. The area size is \( n \times 2n + 1 \) as shown in Fig. 6, where we assume \( n \) to be two meters. \( \theta \) is the angle formed between one of the four directions and the direction to the destination, as shown in Fig. 7. As in the mobility model for intersections, we use \( f(d) \), as shown in Fig. 5. As in the mobility model for streets, the walking speed is assumed to change dynamically depending on the population density. Thus, the mobility model for parks can represent the case where users in the park move to a place which is less crowded but is still on a reasonably short route to the destination.

C. User Behavior Model

User behaviors (mobility and communication behavior) are strongly influenced by the surrounding environment and the time of day. For example, many calls are generated in downtown regions and near train stations in the evening, and users move slowly in a crowded street. In addition, people with different attributes (age, gender etc.) behave differently [12]. Therefore, we developed a mechanism representing that communication patterns change dynamically depending on the user attributes and the user environment. Specifically, we introduced a “User Layer” as a layer above the “Application Layer”, as shown in Fig. 8. User layer contains user attributes and profiles for characterizing user behaviors. User layer dynamically sends a message to the application layer for initiating calls and receives a message about status of calling.

Fig. 9 shows a part of the structure of user layer which provides the communication behavior description. The communication behavior description is defined by “User”, “Profile”, and “Traffic pattern”. \( N \) in “User” is number of users in simulations, and \( M \) in “Profile” is number of profiles (1 \( \leq M \leq N \)). Each user is assigned attributes such as gender and age, and a profile which characterizes his or her communication behavior. We can also configure the traffic pattern according to the required situation as part of the profile. A profile can be applied not only to an individual user but also to a group of users who exhibit similar user behavior. For example, one profile can be defined for younger persons, another for middle-aged persons and yet another for elderly persons. Specifically, the traffic pattern in the profile defines the following items, some of which are expressed in the form of distributions.

Traffic Patterns

- Communication interval
- Communication methods
- Probability of selecting each communication method
- Probability of making repeated attempts (retries) for each communication method
- Interval between retries for each communication method
• Maximum number of retries for each communication method
• Means of selecting a call destination
• Communication duration for each communication method

Using these parameters, it is possible to specify a variety of service applications (voice calls, text mail, and videophone etc.) in detail. Traffic patterns can be changed flexibly depending on the time of day or the specific user environment. This way, a variety in user behavior resulting from changes in the user environment can be well represented.

IV. Evaluation and Validation of the Simulator

We implemented the three components described in Chapter III, and conducted two experiments to evaluate the network systems from the perspectives of mobility and communication behavior.

A. Evaluation of the Mobility Models

First, we demonstrated the functionality and the effectiveness of the real map loading function and the pedestrian mobility model described in Sections III.A and III.B, respectively. To confirm the influence of the pedestrian mobility model on the simulation result, we compared our model with the random waypoint model, which is used widely for the performance evaluation of mobile communication networks.

We measured the amount of the resource used at each base station in two models: one where the random waypoint model was applied and the other where the pedestrian mobility model was applied. In the latter case, users chose the route they walked along based on the geographical information. We used the map shown in Fig. 10, which represents a part of one of the largest cities in Japan and covers an area of 1.5 kilometers square. The shaded areas on the map represent parks, and “S” marked on the map means train stations where users start to move. The simulation conditions are as follows.

Simulation conditions
• Simulation area: 1.5 km × 1.5 km, as shown in Fig. 10
• Number of users: 500
• Number of base stations: 6
• Number of sectors in each base station: 6
• Channel bandwidth in each sector: 1024Kbps
• Mobility model: random waypoint model (maximum speed: 1.5m/s, minimum speed: 0.5m/s, waiting time: 0s), pedestrian mobility model (usual walking speed \( v_0 \): 1.0m/s, minimum speed \( v_1 \): 0.5m/s).
• Communication model: One call occupies a bandwidth of 64 kbps. The average call origination interval is 1,800 seconds, and the average communication duration is 90 seconds.
• Call destination: a randomly selected user in the simulation
• Simulation duration: 3,600 seconds.

We assumed a situation of fireworks as a simulation scenario and considered five cases for the mobility scenario as shown in Table I. Case 1 uses the random way point model and the other cases use the pedestrian mobility model described in Section III.B. “Random intersection” in Initial location of Table I means that each user starts from a randomly selected intersection and “Station” means that each user starts from a station selected randomly from the four train stations on the map. “Random intersection” in Destination of Table I means that the destination of each user is a randomly selected intersection, and when a user arrives at the destination, he or she heads toward the next destination which is again selected randomly. “Park” in Destination means that users first move to a station selected randomly from the four train stations on the map. Therefore, in Cases 2-5 which use the pedestrian mobility model, Case 2 has the highest randomness and is the most similar to the random waypoint of Case 1. In contrast, Case 5 represents the most realistic situation of a fireworks display.

![Figure 10. Map of area used in simulation.](image)

**TABLE I. MOBILITY SCENARIOS**

<table>
<thead>
<tr>
<th>Mobility model</th>
<th>Initial location</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Random waypoint</td>
<td>Random</td>
</tr>
<tr>
<td>Case 2</td>
<td>Pedestrian</td>
<td>Random intersection</td>
</tr>
<tr>
<td>Case 3</td>
<td>Pedestrian</td>
<td>Station</td>
</tr>
<tr>
<td>Case 4</td>
<td>Pedestrian</td>
<td>Random intersection</td>
</tr>
<tr>
<td>Case 5</td>
<td>Pedestrian</td>
<td>Station</td>
</tr>
</tbody>
</table>
First, we ran 20 simulations under these conditions and measured the average resource usage in each case. Fig. 11 shows the average amount of bandwidth used at each base station. The horizontal axis identifies the base stations, and the vertical axis indicates the average usage of bandwidth. In Case 1, the bandwidth usage of base stations 2 and 5, which are located nearest the center of the area, is higher than that of other base stations, and the others all used more or less the same amount of bandwidth because the users with random waypoint mobility tend to congregate in the center of the area [4]. In Cases 2, 3, 4 and 5 where the pedestrian mobility model is used, the differences in bandwidth usage among base stations are larger that those in Case 1 where the random waypoint model is used. The bandwidth usage of base station 3 in Cases 2-5 is rather small because there are few roads around it and so users rarely used this base station. Moreover, the initial locations and the destinations are the key factors in the mobility model and strongly influenced the simulation results. In Case 4 and 5, as there is a park near base station 5, users gathered in the areas covered by this base station, resulting in higher bandwidth usages than those in Cases 1, 2 and 3. The simulation results quantitatively show that when we set realistic parameters for the mobility model, initial locations and destinations, the results are closer to the result reflecting the most realistic situation of Case 5. Conversely, when the randomness of the parameters increases, the results are closer to those in Case 1, the random waypoint model.

Next, we investigated how the resource usage changed during simulation time. We examined base station 5 where there is a significant difference of the average resource usage among mobility models. Fig.12 shows the time-series changes of the bandwidth used at base station 5 in Case 1 and Case 5, which were obtained from one of the simulations results described above. In Case 1 applying the random waypoint model, the bandwidth usage is almost constant because number of users covered by a base station hardly varies. On the other hand, in Case 5 applying the pedestrian mobility model, the bandwidth usage significantly changes according to the simulation time, and the peak of the usage is about three times as high as that in Case 1. This means that a significant difference of the resource usage is occurred by the variety of mobility models. Therefore, using the pedestrian mobility model can reduce risk of overestimation and underestimation in performance evaluations of network systems.

The above indicates that the simulation results using the pedestrian mobility model match what we would normally expect from the geographical information. In other words, the simulation using the pedestrian mobility model replicates the real world better than the simulation using the random waypoint model. When evaluating traffic control techniques and design methods of a real network, it is necessary to consider user mobility that takes account of the actual geography. Our pedestrian mobility model is effective for such an evaluation.

### B. Evaluation of Communication Behavioral Model

We show an example of the simulation applying the communication behavioral model described in Section III.C and demonstrate the effectiveness and significance of the function. First, we indicate correlations in real traffic between users with different attribute values. Figs. 13 and 14 show the differences in the communication patterns for twelve combinations of attributes (gender and age). Figs. 13 shows the mean values of the number of phone calls per day and the holding time per call for users with different attributes based on the communication logs of about 16 million cellular phone customers. Fig. 14 shows the mean value of the interval between retries and maximum number of retries during network congestion. The values result from the survey of 2339 cellular phone customers because these values can not be obtained from the communication logs. The numbers of survey respondents for each combination of attribute values are shown in Table II. All values in Figs. 13 and 14 show the normalized values when the mean value for a male in his teens is one. We can see that there are significant differences and correlations in the communication trends according to age and gender. The communication behavioral model we developed can take into account such a difference in the communication behavior among users with different attributes in the simulation.
Then, we ran more simulations in order to clarify whether there is a difference in the simulation results between the conventional case in which the simulation parameters are set by using only the average value of the total set of users (scenario A) and the case in which parameters are set using the values which account for the differences between users with different attributes (scenario B). We generated the following two simulation scenarios applicable to the communication behavior model described in Section III.C.

1) Scenario A (using 1 profile)
   - All users are assigned the same profile.
   - Traffic pattern (number of phone calls, holding time, interval between retries, and maximum number of retries): mean value of all simulation users (exponential distribution).

2) Scenario B (using 12 profiles)
   - Each user is assigned a profile corresponding to his or her attributes (gender and age).
   - Traffic pattern: mean value of the users grouped by their attributes (refer to Figs. 13 and 14).

We assumed the number of simulation users to be 2339, which is same as the number of respondents to the survey. Also, we utilized the same attribute distribution as existed for the respondents, as shown in Table II. Other simulation parameters were the same as those of the experiment described in Section IV.A and the mobility model was assumed to be that of Case 5, which applies to the pedestrian mobility model in the situation of a fireworks display.

Fig. 15 shows the mean values of the number of retries per call for users with different attributes. The number of retries is one of the evaluation metrics resulting from a variety of types of communication behavior by the user, and is influenced by the various parameters, that is the number of phone calls, holding time, interval between retries, and maximum number of retries, defined in the simulation scenarios. The horizontal axis of the figure indicates age and the vertical axis indicates mean value of number of retries.

Fig. 15(a) shows the results of scenario A, using the common profile, while Fig. 15(b) shows the results of scenario B, using the twelve profiles which depended on the attributes of gender and age. The results in scenario A show that there is

<table>
<thead>
<tr>
<th>Age</th>
<th>10s</th>
<th>20s</th>
<th>30s</th>
<th>40s</th>
<th>50s</th>
<th>60s+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>149</td>
<td>266</td>
<td>232</td>
<td>221</td>
<td>210</td>
<td>112</td>
</tr>
<tr>
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<td>151</td>
<td>227</td>
<td>216</td>
<td>225</td>
<td>220</td>
<td>110</td>
</tr>
</tbody>
</table>

**TABLE II.** NUMBER OF SURVEY RESPONDENTS.
We have investigated the functional requirements for achieving an evaluation platform based on our proposed concept of a user and network integrated simulation which can faithfully simulate individual user behaviors in a realistic situation. We also have implemented a real map loading function, pedestrian mobility, and a user behavior model to meet the requirements. In addition, we have performed simulations of mobile networks by using implemented components. The simulation results have shown that the user behaviors do influence the predicted overall system performance. This indicates that our pedestrian mobility model can replicate realistic mobility and our user behavior model can account for individual communication behavior with different attributes. This means that it is important to take realistic and detailed user mobility and communication behavior into consideration in mobile network system evaluation.

**REFERENCES**


