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A Behavior Pattern Based Mobility Simulation Framework for Office Environments

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Abstract—**Modeling movements in office is useful for smart indoor ad hoc networks. People carrying PDA or cell phones can encounter others and in some cases are able to establish connections and transfer data between them. Currently, commonly used mobility models, such as Random Walk and Random Waypoint Model, do not capture the real movements in real life scenarios, especially in office environments where three typical patterns of heterogeneous behavior, i.e., entity movements, group movements and regular movements, often occur.**

In this paper we propose a novel mobility simulation framework based on behavior patterns for office environments. The base part is Simulation Time Controller, on which we model the structure of offices and define behavior patterns. In this paper we define three typical patterns of behavior to simulate the heterogeneous movements mentioned above.To simulate more real movements, people can add more patterns of behavior to this framework, which is the main motivation of our framework. We also derive theoretic results of hitting time, which determines the packet delivery delay in Delay Tolerant Networks. Simulation studies show our expressions have error always under 10%. And the staying ratio of our simulation, i.e., the ratio between the time people spend in main place and the total time, is close to the MIT real traces.

I. Introduction

There has been an exponential growth in the popularity of portable devices used in office environments, such as PDA, cell phone and so on. In offices, portable devices can form ad hoc networks when people meet together, then people can share files or play online games for fun. Also sensors can be embedded in these mobile devices to monitor environments in offices and guide people to survive in emergency cases [1]. Mobility models in office environments are important for researches in mobile ad hoc networks and delay tolerant networks(DTN). Though there have been testbeds deployed to get real traces of mobile devices, such as [2], [3], [4]. Both Balazinska et al. [2] and Kim et al. [3] get traces of mobile devices through access points deployed in campus, while Rhee et al. [4] get traces of people by GPS devices carried by volunteers. These mobility models are related to very specific scenarios. Movements are different in different circumstances. For example, movements of trucks on roads differ from movements of people shopping in markets. There have been a lot of mobility models for outdoor environments, however few models have been proposed for people in office, where people are well organized in the form of departments.There are three typical patterns of movements , i.e., entity movements, group movements and regular movements. These movements are heterogeneous, for example, people in some departments may move more often than people in others; people in the same department may meet together more often than people in different departments; and different people have different favorite places to go periodically. To the best of our knowledge, there has been no simulation framework proposed to simulate all such heterogeneous behavior.

Our main contribution in this paper is the proposal of a mobility simulation framework based on behavior pattern for office environments. This framework captures the heterogeneous movements mentioned above. First we use a tree-based structure to model departments, then we define a behavior-pattern module to simulate different behavior. In this paper we describe three typical patterns of behavior, i.e., talk behavior, meeting behavior and regular behavior, in order to simulate entity movement, group movement and regular movement respectively. People can extend this module by adding other behavior patterns. Moreover, the proposed model can be mathematically analyzed to get the theoretical expression of the hitting time, which is an important qualities to determine the performance of the packet delivering in Delay Tolerant Networks, which are Ad Hoc Networks whose connectivity changes frequently. Hitting time is the average time for two randomly chosen persons to meet each other. And the comparison of staying ratio shows our model can be tuned to match MIT real traces.

The rest of this paper is organized as follows. In Section II we discuss the related work. Section III and IV describe our Mobility Simulation Framework for Office Environments and detailed modular design. Then in Section V we give the theoretic analysis of hitting time in different cases. We give a comparison between theoretic results and experimental results in Section VI. We conclude our work in Section VII.

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II. Related work

Camp et al. [17] classified mobility models into two categories, entity mobility models and group mobility models. However there have been new mobility models trying to characterize the real world movements more precisely recently.

1) Entity model: Large wireless networks have been deployed [2], [3], through which people get logging information, which are used as indicators for mobile nodes' locations and then derive the statistical characteristics of movements. For outdoor environments, Rhee et al. [4] get real traces by using GPS devices carried by volunteers. They found that human walks resemble Levy Walk in both flight length and pause length. These models can produce similar statistical characteristics to the many real world traces. However these models do not capture group mobility, heterogeneity among nodes, or other relationships between nodes.

2) Group model: Blakely et al. [11] define a reference point to every group. By specifying distance and angle distribution between the node and the reference point, this model can simulate different scenarios. Zhou et al. [12] especially models group merge and split, which are often seen before the traffic lights. Rossi et al. [18] concentrate on aggregating terminals whose links remain stable over the time. And Minder et al. in [5] propose a meeting model for office environments, on which our model is partially based . Meeting is the typical group movement in office environments.

3) Community based model: The community based mobility models [9] are based on the idea that people like to get together with their family, or their friends. Musolesi et al. [9] use social network to model relationships between people, and people tend to go to places where their friends are. Similar ideas are also proposed in [7], [8], however, both Hsu et al. [7] and Ekman et al. [8] model node's regular behavior, i.e., nodes move to different places at different times of day in a periodic manner, by defining the people's preferences for places. In office people also have favorite place to go, that's the typical pattern of regular movements.

4) Others: Recently, there are more papers [13], [14], [15], [16] concentrating on analyzing the distribution derived from real traces or the key characteristics of the mobility models. Chaintreau et al. [13] study how the parameters of the distribution , i.e., power-law distribution, impact the delay performance of forwarding algorithms. Karagiannis et al. [14] show that the CCDF of the interconnect time follows a power-law decay up to half a day and then it follows an exponential decay. Cai et al. [15] prove that a finite domain, in which most of the current mobility models are defined, plays an important role in creating the exponential tail of the inter-meeting time. La et al. [16] show that given they are in the same cell, when the probability that two nodes can communicate directly with each other is small, the distribution of inter-meeting times can be well approximated using an exponential distribution under the Hybrid Random Walk mobility model. In our model, the duration of talk are set to follow an exponential distribution. Other models such as [6] proposes a generic mobility simulation framework largely for vehicular ad-hoc networks, and [10] proposes a model associated with the disaster scenario.

III. Description of Mobility Simulation Framework for Office Environments

In this section, First we use a tree-based structure to model departments, then we describe mobility characteristics observed from real traces in previous work, lastly we elaborate on design issues in Mobility Simulation Framework for Office Environments.

A. Modeling the Structure of Departments

As in office environments, people are usually organized in the form of departments. Department is an important factor influencing movements of people in offices. For example, some Departments are more mobile than others, and people in the same departments connect with each other more often.

Department is a recursively defined structure. At the lowest level, i.e., level-0, a single person constitute a department called atomic department. A level-$(i+1)$ department is constructed by level-i departments and an atomic department acting as leader of the level-$(i+1)$ department, however the level of the leader is promoted to i. We also define level-i co-worker relationship as follows: for subordinates, i.e., people who are not leaders, if person A and B in the same level-i department, they are level-i co-workers, and that's the same for people acting as leader of level-1 department. But for people acting as leaders of level-i, $i > 1$, their level-i co-workers are people in the same level-i department acting as leaders of the level-$(i-1)$ departments. If person A and B are level-i co-workers, while A and C are just level-$(i+1)$ co-workers, A connects with B more often than with C. Fig. 1 shows an example of level-2 departments. Person A, B and E are level-1 co-workers, person B, C and D are level-1 co-workers, while B and F are level-2 co-workers, not level-1 co-workers.

Then we talk about how to place departments in a grid and get locations of atomic departments. Because people in the same department usually work near each other, we construct the top department from lower departments logically. In level-1 department, level-0 departments are deployed randomly in a square whose size is 1 in logical construction. The location of an atomic department is represented by (x, y), which is the logical location of the square. From the view of level-$(i+1)$ department, level-i departments are squares of the same size S_i. After placing these level-i squares randomly with (X_i, Y_i) denoted as their logical location in level-$(i+1)$ department and the

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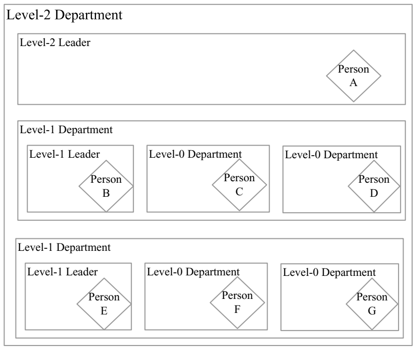

Fig. 1. An Example of Department.

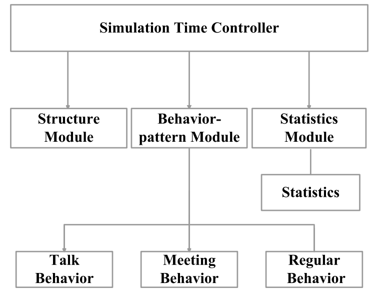

Fig. 2. The Modular Design of Mobility Simulation Framework for Office Environments.

level-(i+1) leader is placed in one of these level-i squares, level-(i+1) department has been constructed successfully. We denote (x_i, y_i) as an atomic department's location in level-i department whose logical location is (X_i, Y_i) in level-($i+1$) department. The atomic department's location in level-($i+1$) department is calculated as:

$$(x_{(i+1)}, y_{(i+1)}) = (x_i + S_i \cdot X_i,\ \ y_i + Si \cdot Y_i) \tag{1}$$

Then the distance between A(x_A, y_A) and B(x_B, y_B) is $S \cdot (|x_A - x_B| + |y_A - y_B|)$, where S is the real size of the level-0 department, whose logical size is 1.

B. Mobility Characteristics Observed In Real Traces

There are three typical characteristics observed in real indoor traces and we need to support simulating all these behavior in our framework, which is our main motivation to propose the framework. The first characteristic is the differences in user mobility as shown in [2]. In [2], access points are deployed in three buildings, and Balazinska et al. find that most wireless users stay within one building, but a significant fraction(20% to 45%) move between two or more buildings, and only a small fraction(up to 11%) of users visit all three buildings. Meeting with other people is the second characteristic observed in [5]. Minder et al. [5] deploy access points in rooms and when people log in the same access point for at least 30 seconds, a meeting is considered to be held. They show the heterogeneity in the number of people involved in a meeting and the duration of meetings. The last characteristic, skewed location visiting preferences, is mentioned in [2], [7], [8], i.e., nodes like to visit some areas more often than other areas and nodes may visit some areas regularly.

C. Mobility Simulation Framework for Office Environments

The mobility simulation framework is designed as an extensible framework for office environments. It should support simulating heterogeneous behavior mentioned above. Fig. 2 shows the modules of our framework.

The base part of the framework is Simulation Time Controller, which captures movements generated by Behavior-pattern Module and calls relevant functions to deal with them. The base modular of the framework is Structure Module, whose detail is presented in Section III-A. The core part of the framework is Behavior-pattern Module. In this paper, we define three patterns of behavior, i.e., talk behavior, meeting behavior, regular behavior. Talk behavior is used to capture heterogeneity of user mobility in entity movements. Most people spend their time just working busily in their atomic department, while only a small part of people keep moving. However, the movements are not aimless. People move to a selected co-worker and talk about business. Meeting behavior is used to capture group mobility in offices, i.e., people in offices often gather together for business or something else. Like user mobility, group mobility is also heterogeneous reflected by the frequency of meeting, the duration of meeting and the number of attenders, observed by [5]. Regular Behavior is used to capture periodical re-appearance at the same place. In offices people may move to rest room to get a cup of tea or coffee at a regular time. And also people may have their location preferences, such as a friend's department.

Statistics are collected in Statistical Module. All these modules are controlled by Simulation Time Controller, which generates different patterns of behavior defined in Behavior-pattern Module to simulate movements in office environments. People can define their own structure of offices, extend the Behavior-pattern Module, and get the statistics they are concerning.

IV. Description of modules

A. Behavior-pattern Module

To capture different heterogeneous behavior simultaneously in offices, we define three patterns of behavior and states associated with former.

1) Talk Behavior: In our framework, talk scenario is described as follows: when people keep staying in their atomic departments, they select a co-worker to talk to

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with probability of $P_{i,j}$, subscripts i and j indicate levels of departments. When the person begins to move, he should also decide to move inside or outside department . We denote P_{ti} as probability of inside movement and P_{to} as probability of outside movement. At the same time, he changes his state from staying to move and the co-worker changes its state from staying to being picked for a talk. When he arrives at the selected co-worker, if the co-worker is still waiting in its atomic department, the talk will begin with their states changed to talking or he will wait with his state changed to waiting for a talk until the co-worker comes back with their states changed to talking. After the talk, he will return to his own atomic department with the state of move while the state of the co-worker is changed back to staying. Arriving at his own atomic department, his state is also changed back to staying.

2) Meeting Behavior: In our framework, meeting scenario is depicted as follows: conferences are usually held by leaders of departments, however, different leaders have different probability of calling conferences indicated by P_m. Similarly we denote P_{mi} and P_{mo} as probability of calling conferences inside department and outside department respectively. N_{mi} and N_{mo} indicates the number of contenders. The leader picks people who are staying or picked for a walk to meet. And these people's states are changed to move, while the leader's state is changed to waiting for a meeting.The leader's state is changed to meeting until all these attenders arrive. Then the meet begin. After the meeting ends, the leader's state is changed back to staying, while other attenders' states are changed to move. Arriving at their own atomic departments, attenders change back to staying state.

3) Regular Behavior: In this framework, people go to a favorite department periodically with a high probability. And researchers can specify this according to relationships between people in offices.

B. Statistics Module

The Statistics Module is used to gather metrics we are interested in, such as hitting time, ratio of staying and duration of a talk or a meeting. This module has access to all attributes of atomic department, which is the base of our office structure. As simulation runs, this module gathers and analyzes metrics, and at the end of simulation prints results or exports to files.

V. Derivation of theoretic expression

Hitting time and contact time, i.e., the duration of a talk or a meeting, are two critical metrics determining the packet delivery delay in DTN. Here we only talk about hitting time. With the existence of department, whether the chosen target is inside the department changes the expected hitting time value significantly. The hitting times for people in the same level department and one in level-i department while another in level-$(i+1)$ department are hence calculated separately. In the following, the first and second subscripts in $HT_{i,j}$, where $i < j$, mean that these two people are not in the same level-i department, but they are in the same level-j department, and if $i = j$, these two people are in the same level-i department.

Corollary 5.1:

$$H\bar{T}_{i,i} = \frac{2}{3} \cdot S_{(i-1)} k/\bar{v}, \tag{2}$$

where level-i department is constructed by $k \times k$ level-$(i-1)$ departments, whose sizes are $S_{(i-1)}$, and $\bar{v}$ indicates mean velocity of people.

Proof: First we choose two nodes from a $k \times k$ grid randomly, we denote (x, y), (x', y') as their locations, and their distance is $(|x - x'| + |y - y'|)$. Their mean distance $\bar{D}$ is calculated as following:

$$\begin{aligned}
\bar{D} &= \frac{1}{k^2}\frac{1}{k^2-1}[\sum_{x=1}^{k}\sum_{y=k}^{k}\sum_{x'=1}^{k}\sum_{y'=1}^{k}(|x-x'|+|y-y'|)] \\
&= \frac{1}{k^2-1}\cdot 2[\frac{k^2(k-1)}{2} - \sum_{i=2}^{k}[k-(i-1)][2(i-1)-k]] \\
&= \frac{1}{k^2-1}\cdot 2[\frac{k^2(k-1)}{2} + \frac{-k^3+3k^2-2k}{6}] \\
&= \frac{2}{3}k
\end{aligned}$$

So $H\bar{T}_{i,i} = S_{i-1}\bar{D}/\bar{v} = S_{(i-1)} \cdot \frac{2}{3}k/\bar{v}$

■

Corollary 5.2:

$$H\bar{T}_{i,(i+1)} = (\frac{2}{3}k + \frac{1}{3})S_i/\bar{v}, \tag{3}$$

where level-$(i+1)$ department is constructed by $k \times k$ level-i departments, whose sizes are $S_{(i)}$, and $\bar{v}$ indicates mean velocity of people.

Proof: This is the case when node a and b are not in the same level-i department, but they are in the same level-$(i+1)$ department.A and B indicate the level-i department they belong to respectively. First we calculate mean distance when a and b are in the adjacent level-i department. We divide the distance into two parts, the distance from a to the nearest node $c$in department B and the distance from the nearest node to b. $D_{(a,b)} = D_{(a,c)} + D_{(c,b)}$. If department A is above B, all these nearest nodes are in the first row nodes of department B, and for nodes in department A, which are in the same column, they have the same second parts of the above-mentioned distance expression. We denote $\bar{D}_i$ as the mean distance from $(1, i)$ in department B to other nodes in department B.

$$\bar{D}_{(a,b)} = \frac{1}{k_i^2} S_{i-1}[\sum_{i=1}^{k_i} ik_i + k_i(\sum_{i=1}^{k_i} \bar{D}_i)],$$

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level-i is constructed by $k_i \cdot k_i$ squares.

No matter k_i is even or odd, we get following results:

$$\bar{D}_{(a,b)} = \frac{4}{3}k_i S_{i-1} = \frac{4}{3}S_i$$

From the view of level-$(i+1)$ department, we need $\frac{2}{3}k$ steps from A to B according to Corollary 5.1. We create an image node of b in an department B' adjacent to A and on the path from A to B, named b', which is in the same place in department B' as b in department B. $\bar{D}_{a,b'} = \frac{4}{3}S_i$, and $\bar{D}_{b',b} = (\frac{2}{3}k-1)S_i$ because b' is an image of b. so $\bar{HT}_{i,(i+1)} = (\bar{D}_{a,b'} + \bar{D}_{b',b})/\bar{v} = (\frac{2}{3}k + \frac{1}{3})S_i/\bar{v}$. ∎

Theorem 5.1:

$$\bar{HT}_i = P_{i,i}\bar{HT}_{i,i} + P_{i,(i+1)}\bar{HT}_{i,i+1} + P_{i,(i+2)}\bar{HT}_{i,i+2} + \cdots, \quad (4)$$

here $P_{i,i}$ is the probability of talking between two people in the same level-i department, while $P_{i,j}$, $j > i$, indicates the probability of talking between two people in the same level-j department and not in the same level-$(j-1)$ department. $P_{i,i} + P_{i,i+1} + P_{i,i+2} + \cdots = 1$.

Proof: This is easily conducted from corollary 5.1 and Corollary 5.2. ∎

Theorem 5.2:

$$\begin{aligned} HT_{meet} =& T[1-(1-P_{meet}))^{t_m}] + \frac{(1-P_{meet})^{t_m}-1}{-P_{meet}} \\ &- (t_m-1)(1-P_{meet})^{t_m} + t_m(1-P_m)^{t_m}, \end{aligned} \quad (5)$$

this is the case when person a begin to move to a chosen target, which may be choose to a meeting during the period of moving. P_{meet} indicates the probability of being picked to attend a meeting, t_m indicates the time spent moving from a to the target, and $T = \bar{T}_s + \bar{T}_m$, where T_s is the time from picking attenders to all attenders arriving and T_m is the duration of a meeting.

Proof: Since the target is chosen to attend a meeting randomly, each time unite can be considered as an independent Bernoulli trial with success probability P_{meet}.

$$\begin{aligned} \bar{HT}_m =& \sum_{i=0}^{t_m-1}[i + \max(t_m - i, T_s + T_m)](1-P_{meet})^i P_{meet} \\ &+ t_m(1-P_{meet})^{t_m} \end{aligned}$$

usually $T_s + T_m > t_m$, in the following we use $T = T_s + T_m$ to substitute $\max(t_m - i, T_s + T_m)$.

$$\begin{aligned} \bar{HT}_m =& \sum_{i=0}^{t_m-1}[i+T](1-P_{meet})^i P_{meet} + t_m(1-P_{meet})^{t_m} \\ =& T[1-(1-P_{meet}))^{t_m}] + \frac{(1-P_{meet})^{t_m}-1}{-P_{meet}} \\ &- (t_m-1)(1-P_{meet})^{t_m} + t_m(1-P_{meet})^{t_m} \end{aligned}$$

∎

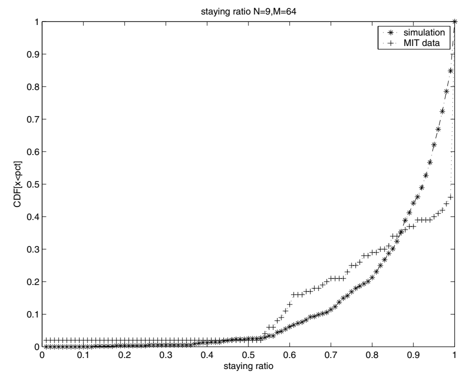

Fig. 3. Staying Ratio (N = 9, M=64).

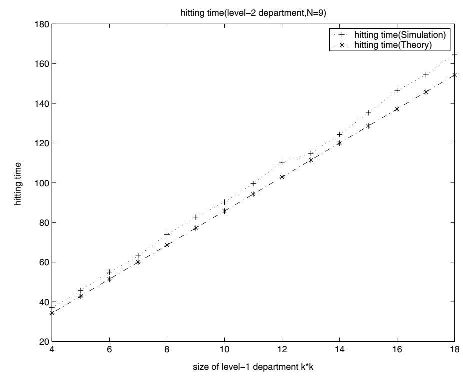

Fig. 4. Hitting Time with Level-2 Department (N = 9).

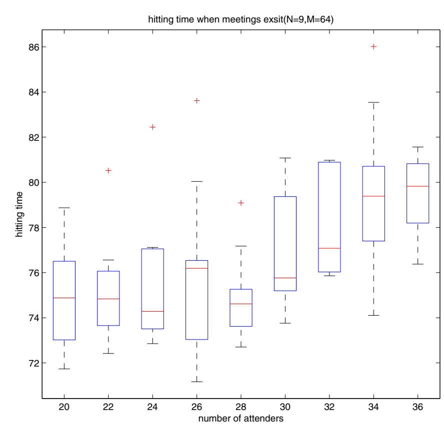

Fig. 5. Hitting Time When Meetings Exist (N = 9, M=64).

VI. Validation of theory with simulation

We implement our framework using C++. First we construct a level-2 office scenario with N indicating the number of level-1 departments in a level-2 department and M indicating the number of level-0 departments in a level-1 department. Fig. 3 shows the staying ratio of our simulation and MIT real trace [2]. We set different mobile probability to different department following an exponential distribution with $\lambda = 1$. The duration of

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talks, which is also the contact time, is simulated by an exponential distribution with $\lambda = 2$, not Lévy fight found by [4] because of its complexity. The probability of talk inside a department, i.e., P_{ti}, is 0.8. And the velocity of people is following a normal distribution with $\mu = 0.7, \sigma = 0.1$. From Fig. 3 we can see that exponential distribution is close to the real trace. We have observed that a large part of IPs logs in a AP all the time, so their staying ratio is 100%, the $CDF[x < pct]$ spikes in the end of staying ratio. This is because laptops are commonly used wireless devices which always stay in one room all the day. However, exponential distribution can be used to approximate the phenomenon in real traces.

The duration of meetings follows a lognormal distribution found by [5] with $\mu = 3, \sigma = 1$. The probability of a meeting inside level-1 department is set to 0. 7. Fig. 4 we compare theoretic hitting time derived from Theorem 5.1 and hitting time in simulation with different M without meeting. As shown in Fig. 4, our expressions have error always under 10%. Theorem 5.2 is hard to calculate, however its numerical result is shown in Fig. 5, we repeat the experiment for each configuration ten times and we can see when the numbers of attenders in a meeting increases, the average hitting time increases longer in a slow way.

VII. Conclusion and future work

We have proposed a behavior pattern based mobility simulation framework for office environments. In this framework, we simulate heterogeneous entity movements, group movements and regular movements through defining three patterns of behavior. Researchers can extend this framework to simulate other scenarios in offices. We also derive the theoretic expression of hitting time, which is close to the simulation results.

In future we would like to apply social relationship to our framework in order to describe the movements in real scenarios more precisely. And we would like to get more accurate indoor traces not just those derived from logging information. More accurate traces will help us tune the parameters of our framework. We believe such a framework is helping to simulate heterogeneous behavior in office environments.

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