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Empirical Modeling and Simulation of Temporal Based Adaptive Mobility Model for MANET

Gurusamy Prema[1,3], Chandrabose Aravindan[2], Kirthivasan Kannan[1], Rathinam Maheswaran[3]
[1]*SASTRA University, Thanjavur, India*
[2]*SSN College of Engineering, Chennai, India*
[3]*Mepco Schlenk Engineering College, Sivakasi, India*
E-mail: {*gprema, rmahes*}*@mepcoeng.ac.in, aravindanc@ssn.edu.in, kkannan@maths.sastra.edu*
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Abstract

Mobile Ad Hoc network (MANET) is a collection of wireless mobile nodes forming a temporary network without the aid of any established infrastructure. To conduct meaningful performance analysis of MANETs, it is essential that the simulation of mobility model should reflect the realistic mobility pattern of mobile nodes *i.e*. placement of mobile nodes at different intervals of time. The formation of spontaneous network depends heavily on the movement of different nodes in a particular practical scenario. This research focuses on the modeling and simulation of a temporal Adaptive Mobility Model which can be adapted to any dynamic practical scenario. The mobility in the realistic environment is simulated based on a Probability Transition Matrix named as Personal Behavior Model (PBM) and validated for a practical Health Care Environment. The formation of MANET is assumed to be based on the movement of the patient i.e. mobile nodes in the health care environment. Patients waiting in front of each service point for different time intervals are taken as results and compared with the actual data.

Keywords: MANET, Mobility Model, Probability Transition Matrix, System Dynamics

1. Introduction

A Mobile Ad Hoc Network (MANET) is a spontaneous, self-organizing network of mobile computing devices, having no fixed infrastructure or administrative support, where each mobile node also acts as a router of network packets. The primary function of the MANET is to facilitate communication between its constituent nodes. So, each node on the network may be either sender or receiver of packets, and all nodes works as router as discussed in [1]. MANET's performance is validated by simulation with the help of mobility models that describe and dictate the mobility pattern of the mobile nodes that take part in forming MANET. Mobility model mimic the movement of mobile nodes in MANET simulation and is a representation of a certain real or abstract world that contains moving entities. The mobility model describes the movement pattern of mobile user and how their location, change over time. The movement pattern of mobile nodes plays an important role in the performance analysis of wireless networks [2,3]. The mobility of the nodes affects the number of average connected paths, which in turn affect the performance of the routing algorithm [4]. In [5], S.Ray discussed some of the mobility models are realistic and they reflect as close as possible those real world scenarios.

Due to the dynamic nature of users in a MANET, a key challenge in the evaluation of mobility pattern is to conduct the performance analysis, with realistic mobility models that accurately reflect the mobile users' movement [6]. In their work, S.Gowrishankar et al. discussed about MANET environment, where mobile nodes are free to join or leave the network at any point of time, resulting in a highly dynamic network environment compare to wired network [7]. The advantage and importance of simulation of mobility model for MANET is discussed in [8]. Several mobility models have been developed for MANET simulations and mostly they are unrealistic mobility models. In the unrealistic mobility model, the node can move towards a randomly chosen destination with a randomly chosen speed and direction [9]. They are not suitable for real environment. In realistic mobility models, the node can move towards proper destination instead of randomly choosing the destination. An adaptive mobility model is developed in this work can be used to simulate various practical environments [10,11]. The dynamic MANET formulation in any environment [12] with its realistic movement of nodes at different time intervals can also be simulated by using the developed adaptive model.

The developed model is validated for a Health Care Environment having five Service Points/ Attraction Points and working from 9 am to 10 pm with a maximum average of 106 patients per day by conducting a survey and observing the patients movement [13,14].

The paper is organized as follows: Development of Temporal Adaptive Mobility Model is discussed in Section 2 and Health care environment for which the model is developed is described in Section 3. Numerical example showing the simulation setup is given in Section 4. Simulation results are explained in Section 5. Finally Conclusion is given in Section 6.

2. Development of Temporal Adaptive Mobility Model

The proposed Temporal Adaptive Mobility Model is developed based on the following assumptions:

1) Nodes which are entering into the environment are assumed to carry a mobile device capable of forming MANET [9].
2) Each node has its own RF transmission range of coverage as per IEEE 802.11b standards [15].
3) A node may visit an attraction point only once to complete all the services performed at that attraction point.

When a mobile node enters into the region where other nodes transmission range overlaps with its own transmission range, the connectivity is established between the nodes and the MANET structure is formed [16]. The block diagram of the proposed temporal adaptive mobility model is given as shown in **Figure 1**.

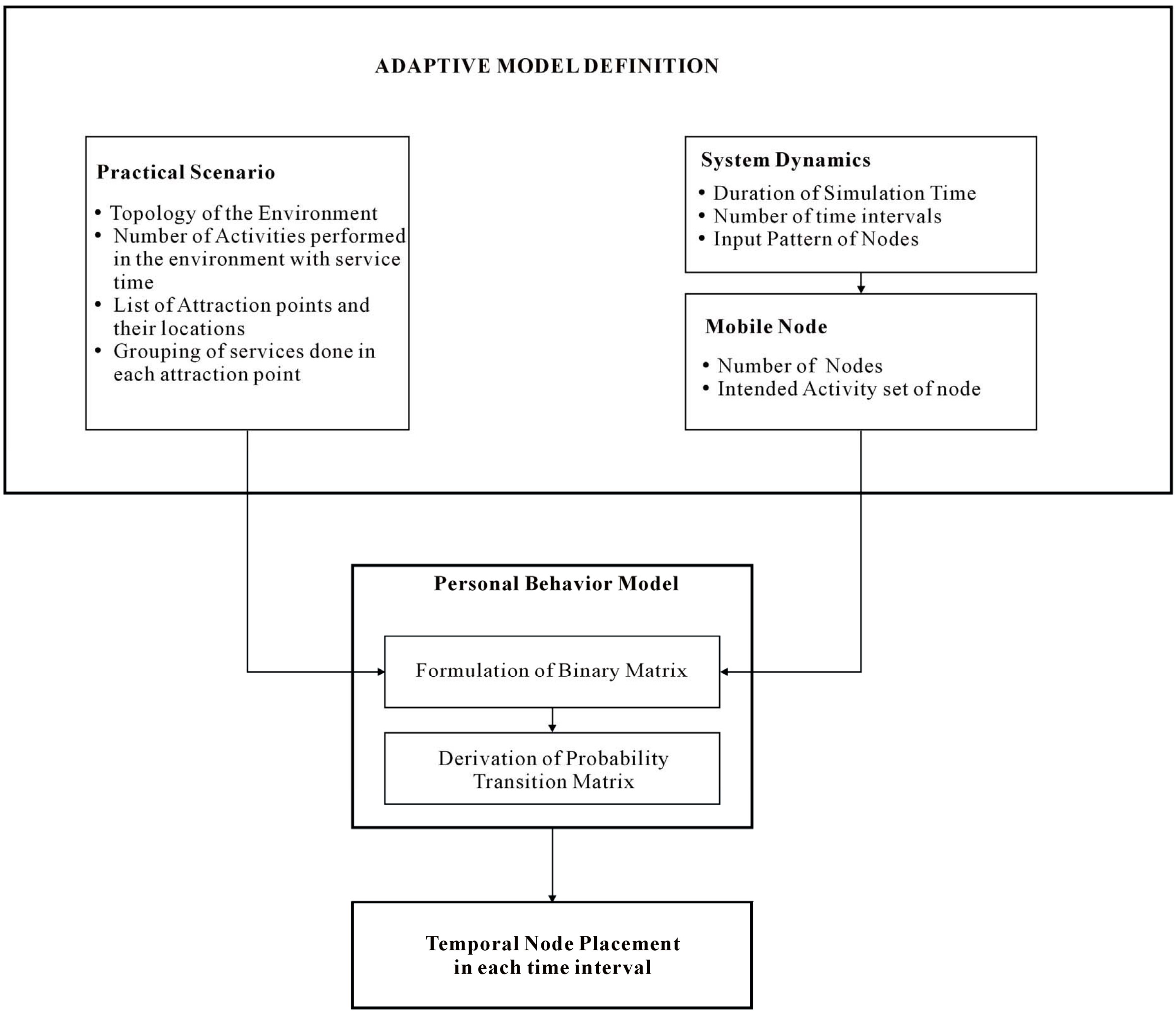

Figure 1. Adaptive temporal mobility model.

The temporal adaptive mobility model is defined by the various inputs viz. 1) System dynamics based inputs, 2) Practical scenario based inputs and 3) Mobile node based inputs and they are used to formulate a Personal Behavior Model (PBM) which is a probability transition matrix and temporal node placement in different time interval to form spontaneous dynamic MANET within the environment.

2.1. Temporal Adaptive Model Definition

The temporal adaptive model suitable for any practical environment is defined by the following three inputs.

1) System dynamics based inputs.
2) Practical scenario based inputs.
3) Mobile node based inputs.

2.1.1. System Dynamics Based Input

The system dynamics of the adaptive mobility model is governed by two dynamic inputs namely 1) Duration of Simulation which is the time for which the environment is simulated and 2) Number of time intervals. The input pattern of nodes may follow a Probability Distribution Function over the simulation time. The total simulation period is the total period of observation in which the environment is simulated and duration of time interval can be calculated according to the number of time interval. At the start of each time interval the personal behavior model is updated.

2.1.2. Practical Scenario Based Inputs

The practical scenario based inputs [17] are environment specific inputs that specify the simulation environment according to the practical scenario. This consists of topology of the scenario which indicates the dimensions of the environment; various activities performed in the environment are listed out with their service time and given as total number of activities. Services are grouped and performed in particular service points. Various service points are listed out and given as inputs to the model with their locations.

2.1.3. Mobile Node Based Inputs

Any entity needing services from the practical scenario can be taken as nodes. These entities will enter into the practical scenario with an intended set of activities named as activity set and fulfilling their activities by the services performed at different service points and leave the system. So, any entity entering into the system has to move within the dimensions of environment and create individual mobility pattern within the environment during the simulation time. These will be given as mobile node based inputs. It is assumed that each entity is having a mobile device to formulate MANET at different time instances.

2.2. Personal Behavior Model (PBM)

Personal behavior model represents the intended real movement pattern of individual nodes in the environment based on the activities to be performed in the different attraction points. PBM is formulated by means of a binary matrix formed based upon the practical scenario and node based inputs at a particular time interval.

2.2.1. Formulation of Binary Matrix

Binary matrix is represented as a $M \times N$ matrix where M is the number of nodes entering at a particular time interval and N is the number of activities performed in the environment as shown in **Table 1**.

The Binary matrix is formulated as follows: Elements C_{ij} in the matrix represent whether i^{th} Node performs j^{th} activity or not. C_{ij} is assigned as 'one'; if the i^{th} node performs j^{th} activity. Else C_{ij} is assigned as 'zero'; i.e., the i^{th} node does not perform j^{th} activity.

For example, four nodes, C_1, C_2, C_3 and C_4 are entering into the environment with four different activity sets AS_1, AS_2, AS_3 and AS_4 respectively at a particular time interval. C_1 is entering with an activity set consists of activities A_1 & A_5; C_2 is entering with an activity set consists of activities A_2 & A_3; C_3 is entering with an activity set consists of activities A_1, A_4 & A_5 and C_4 is entering with an activity set consists of activity A_2. The corresponding entries in binary matrix are shown in the **Table 2.**

The binary matrix given in **Table 2** will be the input for the derivation of PBM.

2.2.2. Derivation of Personal Behavior Model

Personal behavior model is a Probability Transition Matrix,

Table 1. *Binary matrix.*

NODES	ACTIVITIES							
	C_i/A_j	A_1	A_2	A_3	A_4	A_5	…	A_N
	C_1	C_{ij}						

Table 2. Formulation of *binary matrix.*

NODES	ACTIVITIES					
	C_i/A_j	A_1	A_2	A_3	A_4	A_5
	C_1	1	0	0	0	1
	C_2	0	1	1	0	0
	C_3	1	0	0	1	1
	C_4	0	1	0	0	0

which indicates the probable movement of the nodes to fulfill the intended activities towards various service points in the environment. The matrix is having dynamic rows based upon the nodes available in the system other than waiting in front of the attraction points and number of attraction points as columns and updated at the starting of each time interval. This behavior model is used to denote the Probability of the nodes moving towards each attraction point. The Personal behavior model is derived as follows: Let T_i be the total number of activities in the intended activity set of the i^{th} node and T_{ik} be the number of activities serviced in k^{th} attraction point for i^{th} node. Probability $P(C_i, AP_k)$ represents the probability of i^{th} node in the system intended to move to the k^{th} attraction point and given by the Equation (1).

$$P\left(C_i, AP_k\right) = \frac{T_{ik}}{T_i} \tag{1}$$

For a particular time interval, having the binary matrix as shown in **Table 2**, the PBM is derived as shown in **Table 3**.

Consider a practical environment, where there are three attraction points located and activities A_1 and A_2 are performed in AP_1, activities A_3 and A_5 are performed in AP_2 and activity A_4 is performed in AP_3. For the binary matrix shown in **Table 3**, the entries in the PBM are as shown in **Table 4**.

After completion of all the activities, a node will move to next attraction point if it is having activity to do and after completing all the intended activities a node will leave the system.

Table 3. Formulation of personal behavior model.

	Attraction Points				
NODES	C_i/AP_k	AP_1	AP_3	…	AP_P
	C_1				
	⋮	$P(C_i,AP_k)$			
	C_N				

Table 4. Personal behavior model.

	Attraction Points			
NODES	C_i/AP_k	AP_1	AP_2	AP_3
	C_1	0.5	0.5	0
	C_2	0	1	0
	C_3	0.33	0.33	0.33
	C_4	1	0	0

2.3. Temporal Node Placement

For a given simulation time, different nodes are entering into the system and move according to their intended activity set. For any discrete time interval of the simulation, the nodes will be distributed over the entire dimensions of the environment. This distribution is purely based upon purpose of entering the system and leaving the system after the services are completed. So, the connectivity of the nodes will be spontaneous and it will form a self organizing network *i.e.* MANET. So, the node placement during the entire simulation time is taken as the mobility pattern of the system to formulate the MANET structure.

3. Health Care Environment

The Temporal adaptive mobility model developed is tested for a practical health care environment, where 31 different activities are performed at 5 different service points namely, Doctor's Room, Injection/Dressing Room, Pharmacy, Laboratory and Physiotherapy centre and is working from 9 a.m to 10 p.m. After making a pilot survey for a period of one month, it is observed that a maximum average of 106 patients is entering into the system to avail different services.

Health care environment is defined by having the system dynamic based inputs, the total simulation period 780 minutes is divided into 26 numbers of equal intervals, each of 30 minutes duration. First interval is from 9.00 am to 9.30 am, second interval is from 9.30 am to 10.00 am, etc. up to 26th interval is from 9.30 pm to 10 pm. It is assumed that Personal Behavior Matrix is updated at the start of each time interval. For the first time interval it is updated at 9.00 am, second time at 9.30 am etc. The Arrival pattern of the nodes into the system may follow a probability distribution and observed during the different time intervals is plotted as shown in **Figure 2**.

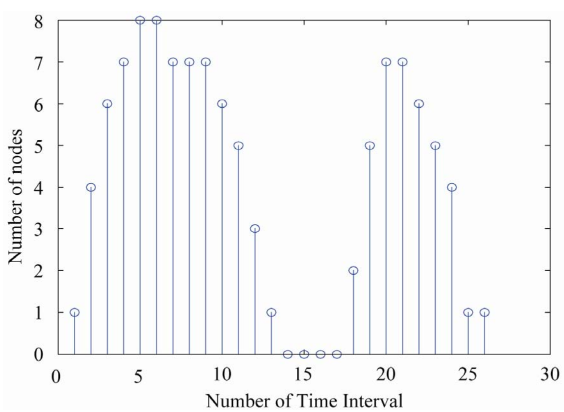

Figure 2. Number of nodes entered into the system in each time interval.

Practical scenario based inputs showing area of the environment having the dimension 25 m (Length) and 16.5 m (width) and locations of service points are given in **Figure 3**.
15 different significant activities are selected by neglecting the rarely occurring activities performed in the environment with their service time are listed in **Table 5**.

The activities are grouped and serviced in the five different service points as shown in **Table 6**.

Node based inputs are the number of nodes entering into the environment for a particular time interval and the arrival pattern. For any interval of time, activity set is assigned to each node randomly following the Probability Distribution. Nodes which are entering will be assigned with any one of the intended activity set as shown in **Table 7**.

The formulation of binary matrix and derivation of PBM are explained using a numerical example.

4. Numerical Example

The development of the PBM for the above defined Health care environment explained in the previous section is illustrated as follows:

4.1. System Dynamic Based Inputs

Simulation time: 780 minutes
Number of time interval: 26
Duration: 30 minutes

4.2. Practical Scenario Based Inputs

Area of the environment: 25 m* 16.5 m
Number of Activities performed: 15

Table 5. The list of activities and their service time.

Activity Set	List of Activities	Activity Set	List of activities
AS_1	$A_1\&A_4$	AS_{18}	$A_1,A_2, A_4, A_7\&A_{10}$
AS_2	$A_1, A_2\&A_4$	AS_{19}	$A_1\&A_3$
AS_3	A_1	AS_{20}	$A_1\&A_6$
AS_4	$A_1\&A_2$	AS_{21}	$A_1, A_4\&A_{11}$
AS_5	$A_1,A_4\&A_7$	AS_{22}	$A_1, A_2, A_4, A_7\&A_{12}$
AS_6	$A_1\&A_7$	AS_{23}	A_3
AS_7	$A_1, A_4\&A_{13}$	AS_{24}	$A_1, A_4\&A_8$
AS_8	$A_1, A_2, A_4\&A_7$	AS_{25}	$A_1, A_4\&A_{10}$
AS_9	$A_1, A_2\&A_7$	AS_{26}	$A_1, A_{12}\&A_{13}$
AS_{10}	A_5	AS_{27}	$A_1, A_2, A_3\&A_4$
AS_{11}	$A_1, A_4\&A_{12}$	AS_{28}	$A_1, A_2, A_4\&A_8$
AS_{12}	$A_1, A_2, A_4\&A_{13}$	AS_{29}	$A_1, A_7\&A_{12}$
AS_{13}	$A_1\&A_{13}$	AS_{30}	$A1, A_4\&A_9$
AS_{14}	$A_1\&A_{12}$	AS_{31}	$A_1, A_4\&A_{14}$
AS_{15}	$A_1,A_4,A_7\&A_{10}$	AS_{32}	$A_1, A_4\&A_{15}$
AS_{16}	$A_1,A_3\&A_4$	AS_{33}	$A_1, A_7\&A_{10}$
AS_{17}	$A_1,A_2\&A_{13}$	AS_{34}	$A_1, A_2, A_4\&A_{12}$

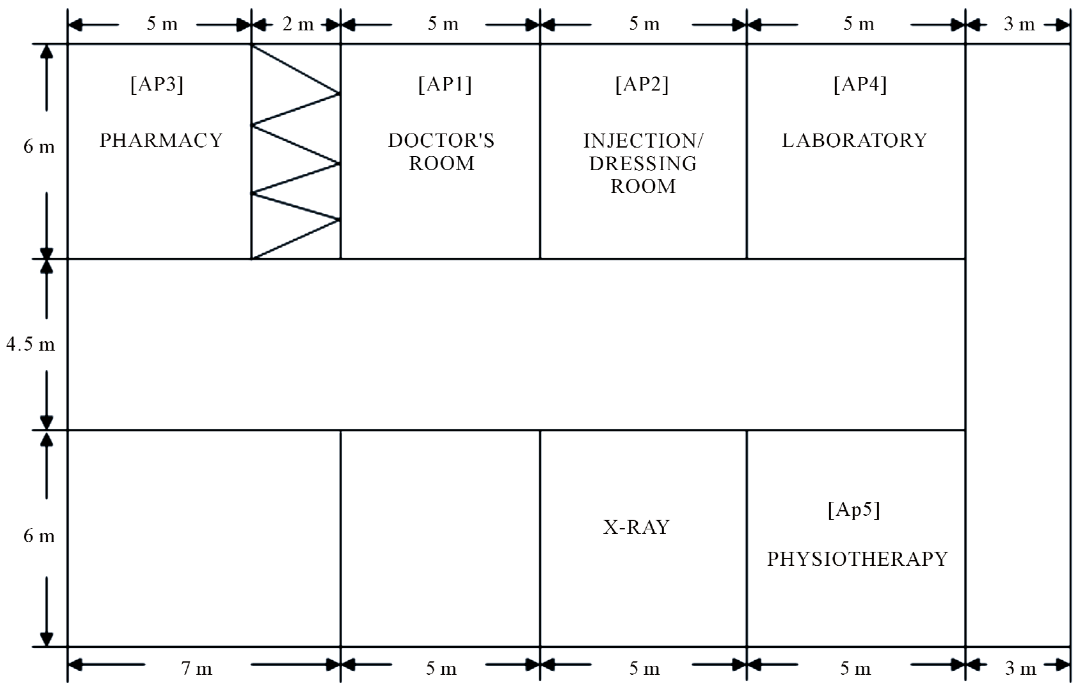

Figure 3. Topology of the environment showing the locations of Service points.

Table 6. Attraction point and activities performed in them.

Attraction Point	Name	Activities
AP_1	Doctor's Room	A_1
AP_2	Injection/Dressing Room	A_2 & A_3
AP_3	Pharmacy	A_4 & A_5
AP_4	Laboratory	A_6, A_7, A_8, A_9, A_{10}, A_{11}, A_{12} & A_{13}
AP_5	Physiotherapy centre	A_{14} & A_{15}

Table 7. Activity set.

Activity Set	List of Activities	Activity Set	List of Activities
AS_1	A_1&A_4	AS_{18}	A_1, A_2, A_4, A_7&A_{10}
AS_2	A_1, A_2&A_4	AS_{19}	A_1&A_3
AS_3	A_1	AS_{20}	A_1&A_6
AS_4	A_1&A_2	AS_{21}	A_1, A_4&A_{11}
AS_5	A_1, A_4&A_7	AS_{22}	A_1, A_2, A_4, A_7&A_{12}
AS_6	A_1&A_7	AS_{23}	A_3
AS_7	A_1, A_4&A_{13}	AS_{24}	A_1, A_4&A_8
AS_8	A_1, A_2, A_4&A_7	AS_{25}	A_1, A_4&A_{10}
AS_9	A_1, A_2&A_7	AS_{26}	A_1, A_{12}&A_{13}
AS_{10}	A_5	AS_{27}	A_1, A_2, A_3&A_4
AS_{11}	A_1, A_4&A_{12}	AS_{28}	A_1, A_2, A_4&A_8
AS_{12}	A_1, A_2, A_4&A_{13}	AS_{29}	A_1, A_7&A_{12}
AS_{13}	A_1&A_{13}	AS_{30}	$A1$, A_4&A_9
AS_{14}	A_1&A_{12}	AS_{31}	A_1, A_4&A_{14}
AS_{15}	A_1, A_4, A_7&A_{10}	AS_{32}	A_1, A_4&A_{15}
AS_{16}	A_1, A_3&A_4	AS_{33}	A_1, A_7&A_{10}
AS_{17}	A_1, A_2&A_{13}	AS_{34}	A_1, A_2, A_4&A_{12}

Number of Attraction points: 5

No. of Activities performed in AP_1: 1
No. of Activities performed in AP_2: 2
No. of Activities performed in AP_3: 2
No. of Activities performed in AP_4: 8
No. of Activities performed in AP_5: 2

4.3. Node Based Inputs at the First Time Interval t_1 From 9.00 Am to 9.30 Am

The number of nodes entering in first time interval from 9.00 am to 9.30 am is one and the intended activity set assigned to this node among 34 activity set is AS_1, which consists of two activities A_1 and A_4. Binary matrix formulated at the start of first time interval is as shown in **Table 8**.

The node has to visit two attraction points namely, AP_1 to fulfill the activity A_1 and AP_3 to fulfill the activity A_4. The probability of visit to different attraction points are calculated by using equation (1). Therefore, $P(C_1, AP_1) = 0.5$, $P(C_1, AP_2) = 0$, $P(C_1, AP_3) = 0.5$, $P(C_1, AP_4) = 0$ and $P(C_1, AP_5) = 0$. Personal behavior matrix derived for the first time interval is given in **Table 9**.

This PBM will be updated according to the entry of nodes in time interval 2, time interval 3 etc. For a middle interval, *i.e.* at the start of seventh time interval t_7, from 12 pm to 12.30 pm, the number of nodes arrived during this interval are 7 (from C_{35} to C_{41}). Up to the 6th interval, 34 nodes entered into the environment. 8 Nodes fulfilled the services and left the system and at the start of 6th interval, 26 nodes are present in the system at the start of the interval. At the end of 6th interval, one node left the system. The corresponding Binary matrix formulated at the start of seventh time interval is shown in **Table 10**.

Personal behavior matrix derived for this time interval is given in **Table 11**.

Table 8. Binary matrix formulated at first time interval.

C_i/A_j	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
C_1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Table 9. Personal behavior matrix derived atfirst time interval.

C_i/AP_k	AP_1	AP_2	AP_3	AP_4	AP_5
C_1	0.5	0	0.5	0	0

Table 10. Binary matrix formulated at seventh time interval.

C_i/A_j	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
C_{35}	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_{36}	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
C_{37}	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
C_{38}	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
C_{39}	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
C_{40}	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
C_{41}	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Table 11. Personal behavior matrix at time interval t_7.

C_i/AP_k	AP_1	AP_2	AP_3	AP_4	AP_5
C_{35}	1	0	0	0	0
C_{36}	0.333	0.333	0.333	0	0
C_{37}	0.5	0	0.5	0	0
C_{38}	0.5	0	0.5	0	0
C_{39}	0.5	0	0.5	0	0
C_{40}	0.5	0	0.5	0	0
C_{41}	0.5	0	0.5	0	0

For each time interval, if there is any entity waiting for service at attraction points, node has to join in the queue for their service. This placement of different nodes in the environment will create a dynamic MANET topology and connectivity among the nodes for the entire simulation period.

5. Simulation Results

The temporal adaptive model is defined and simulated with VC++ in a Pentium IV computer with 1 GB RAM working in Windows XP Professional O.S platform version 2. The arrival of nodes into the health care environment, their movement patterns i.e. the placement of nodes at different time interval is simulated. The results of simulation viz. mobile nodes placement in different attraction points for each time interval, number of nodes arrived, total number of nodes present in the system at the start of the interval, number of nodes which are waiting in front of APs at the start of the interval and the number of nodes left the system at the end of the interval are tabulated and shown in **Table 12**.

Table 12. Mobile nodes details in front of all APs in each time interval.

Time Interval	No. of nodes arrived	Total no. of nodes in the system	No. of nodes in APs at the start of the interval					No. of nodes left the system at the end of the interval
			AP_1	AP_2	AP_3	AP_4	AP_5	
1	1	1	1	-	-	-	-	1
2	4	4	2	-	2	-	-	1
3	6	9	3	2	4	-	-	2
4	7	14	5	3	6	-	-	1
5	8	21	8	4	9	-	-	3
6	8	26	10	5	11	-	-	1
7	7	32	11	6	15	-	-	3
8	7	36	13	5	17	1	-	3
9	7	40	14	7	19	-	-	4
10	6	42	15	7	20	-	-	1
11	5	46	15	8	23	-	-	1
12	3	48	15	6	27	-	-	3
13	1	46	10	6	30	-	-	4
14	0	42	5	4	33	-	-	2
15	0	40	-	5	35	-	-	2
16	0	38	1	3	34	-	-	2
17	0	36	-	3	33	-	-	2
18	2	36	2	1	33	-	-	2
19	5	39	4	1	34	-	-	2
20	7	44	5	2	36	1	-	3
21	7	48	8	1	39	-	-	3
22	6	51	11	2	38	-	-	2
23	5	54	9	2	43	-	-	3
24	4	55	9	1	45	-	-	3
25	1	53	4	3	46	-	-	3
26	1	51	1	1	49	-	-	2

It is observed from the results that more number of mobile nodes is waiting for service at AP_1 & AP_2 than AP_3, AP_4 & AP_5 since in most of the activity sets, activities to be done at AP_3, AP_4 & AP_5 are rarely occurring when compared to other activities done in this particular simulated Health care environment. Therefore, nodes get services in these attraction points without waiting in the queue. It is also observed that size of the queue in front of AP_1, *i.e*. at Doctor's Room is having a peak from 12 pm to 3 pm and around 7 pm. Number of nodes in AP_3, *i.e*. at Pharmacy is increasing up to last time interval since most of the patients has to visit Pharmacy in the health care environment. The number of nodes waiting in front of the various service points is shown in **Figure 4**.

From the **Figure 4**, it is observed that the nodes waiting in front of Laboratory and Physiotherapy centre are minimum. Maximum numbers of nodes are waiting in front of Doctors room and Pharmacy. It is also verified from the observed data that always Pharmacy is overcrowded. The number of nodes present in the system for various time intervals is given in **Figure 5**.

The simulation results showing nodes leaving pattern is shown in **Figure 6**.

In the simulation it is assumed that all the nodes will the system only after fulfilling the intended activities. Therefore the nodes present in the system have to wait in the queue for long time as the number of nodes entered as per the arrival pattern. But the real time data observed

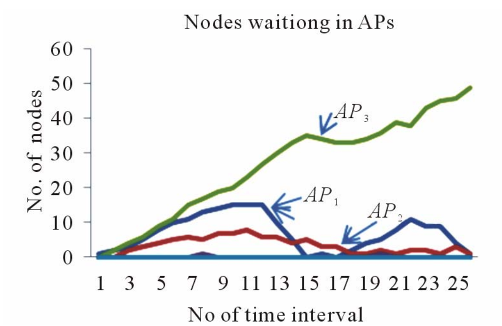

Figure 4. Nodes in attraction points at different time intervals.

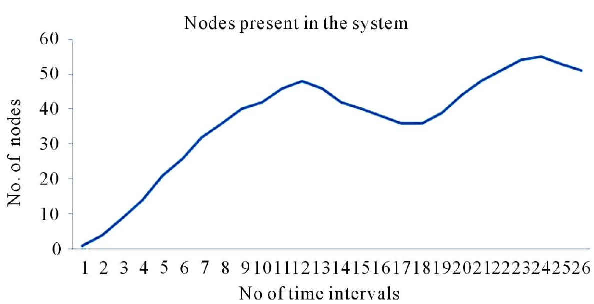

Figure 5. Nodes present in the system at different time intervals.

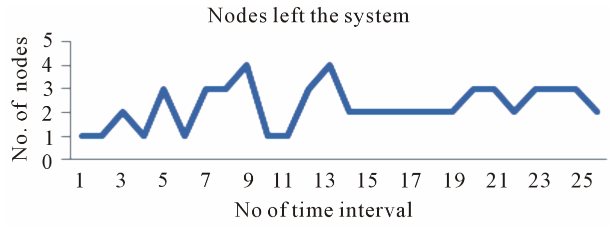

Figure 6. Nodes left the system at different time intervals.

in the environment during survey is having the leaving pattern of the nodes that some of the nodes left the system after consultation without getting medicine from the pharmacy.

6. Conclusions

A temporal adaptive mobility model is developed which can be used to simulate any practical scenario by giving the appropriate inputs. The model is simulated for a health care environment by assuming patients as nodes which moves towards various service points like Doctor's Room, Injection/Dressing Room, Pharmacy etc. and the mobility patterns are analyzed. The output of the simulated model reflects exactly the dynamic movement pattern of the mobile entities as observed in the environment. The simulated results are similar to the practical environment but the number of nodes queue in front of pharmacy is not correlated because of dejected leaving patients from the system.

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