

# START: Status and Region Aware Taxi Mobility Model for Urban Vehicular Networks

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## Abstract

Using a realistic mobility model will enhance the validity of simulations. However, the difficulty lies in discovering laws from large amounts of data and applying those rules. Researchers have been working on mobility model extracting from real data set, whereas the taxi behavior differences between different taxi statuses have been ignored in previous works. Two assumptions related to the taxi status, that one is the behavior of taxi will be influenced by the statuses and the other one is the macroscopic movement is related with different geographic feathers in corresponding status, are introduced and estimated by actual data. Based on the two assumptions, a novel taxi movement model START is proposed with respect to taxi statuses. The simulation results illustrate that the proposed movement model has a good approximation with reality in trace samples, distribution of nodes and the contact characteristics.

## keyword

movement model, taxi status,region regnition

## I. Introduction

In vehicle ad hoc networks (VANETs) [?], realistic movement model is an important way to improve route planning, control traffic situations, or solve the vehicle-to-vehicle communication problems. However, movement models will influence simulation performance, since movement model defines the nodal movement

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pattern including speed and direction. Whereas, large amounts of data are difficult to utilized directly. It is necessary to work on realistic mobility models. Some researchers [?], [?] modeled the vehicular movement, extracting different feathers from real data sets. But taxi status is ignored in the previous works. In this work, a STatus and Region Aware Taxi mobility model, START, is proposed based on the real taxi GPS data. Two assumptions are introduced in section ???. We assume that the taxi behavior and geographic feathers are related with different status. They are validated to be reasonable by the statistical analysis of the data set. START is modeled based on these assumptions. In the macro scope, instead of simply dividing the area into coarse-grain regions, we divide the area into two set of regions according to the two event (means status changes, include on-event and off-event) density. Note that the union of each set of regions is the whole area. When a taxi take a passenger, the current region will be selected in the region set of on-event and the destination region, where the off-event happens, will be selected in the region set of off-event. We investigate the relationship between on-event regions and off-event regions. Pathes from the sources to destinations will be found by Dijkstra algorithm. For microscope, the *speed* for the two taxi statuses are discussed respectively. Simulations are carried out to compare the similarity of node trace characteristics and contact characteristics. The results show that our mobility model has a good approximation with the real scenario. The rest of our paper is organized as follows: Section ?? provides an overview of related works on mobility models. Section ?? proposes two assumptions which are further validated by statistical results of real data. Section ?? presents the modeling process. Simulation results are demonstrated in Section ???. Finally, Section ?? concludes this paper.

## II. Related Works

We briefly review the mobility models below. Mobility model can be classified into free space and constrained models[?], [?] based on the degree of randomness. For the free space scenario, the random way point (RWP)[?] movement model is the most commonly used. The movement model identified a pause time, speed range from zero to the maximum, and movement area where the model select a random destination. Amit Kumar Saha, et al. [?] found that RWP in many cases the Random Waypoint mobility model is a good approximation of the vehicular mobility model based on real street maps. The constrained mobility models show closer relevance to the realistic. Literature [?] demonstrated that graph structure is close related with inter-contact time distribution in both random and social mobility on grid-based graphs. Some models [?], [?], [?], [?], [?] take the geographic structure into consideration. Manhattan model (MM) models the city as a Manhattan style grid, with a uniform block size across the simulation area, while all streets are two-way with a lane in each direction which constrained car movements [?]. In 2007, Atulya Mahajan, et al. [?] accounted for the street layout, traffic rules, multi-lane roads, acceleration-deceleration, and radio frequent (RF) attenuation due to obstacles, and further evaluated the synthetic maps by comparing with real maps. In 2008, David R. Choffnes, et al.[?] developed their movement model based on a realistic vehicular traffic model on road defined by real street map data. In 2010 and 2012, Huang H, et al. [?], [?] proposed mobility models based on taxi trace data in Shanghai, China. They designed three parameters, i.e., turn probability, road section speed and travel pattern, which can be estimated by analyzing the data statistically. But it is complicated to re-implement this model, for the model is strongly related to the map they simplified from the real map. To the best of our knowledge, our work is original to develop mobility models by investigating taxi behavior and geographic feathers of different statuses.

## III. Assumptions and Statical analysis of Taxi Trace

In this section, we mainly focus on statistical analysis on the speed and duration characteristics on the data set. Firstly, the data set will be introduced in section ???. Then, two assumptions are proposed and validated in the following sections.

### A. Trace Dataset: Beijing Taxi Traces

A real-world GPS data set is used in this paper, which was generated by 12,455 taxis in Beijing, China

TABLE I  
EXPLANATION OF EVENTS AND STATUS

Event	Explanation
0(off)	A taxi's status change to vacant.
1(on)	A taxi's status change to occupied.
2	Set up defense.
3	Cancel defense.
4	No event happened.
Status	Explanation
0(vacant)	A taxi is vacant.
1(occupied)	A taxi is occupied.
2	A taxi is setting up defense.
3	Stop running.

within 5 days from March 3rd,2011 to March 7th,2011. This data set has been used by several key researches and application programs of Intelligent Transportation Systems (ITS) in Beijing, China. The number of participated taxis (12,455 taxi node) is 18% of the total taxis in the city. Each taxi is equipped with a GPS device and upload its information (including location, speed, direction ) about every 60 seconds. There are about  $1.22 \times 10^8$  records in total. Each row includes a base station ID, company name, taxi ID (*id*), timestamp (*t*), current location (*l*, including longitude and latitude), location of 54 format, speed, acceleration, status of the taxi, event, and height. Of all the fields, taxi ID, timestamp, and current location, status and Event are used in this paper. Note that GPS traces from taxis have been used recently for inferring human mobility [?] and modeling city-scale traffics [?]. Therefore, we believe that they are suitable to characterize the contact patterns among vehicles in large-scale urban scenario.

Especially, there are five types of events and four types of status. The explanations are as table ???. We only discuss the vacant status and occupied status in this paper. Accordingly we utilize the on-event and off-event as well.

### B. Assumptions

According to the experience in daily life, the following two assumptions are given:

- **Assumption 1:**The behavior of a taxi will change when its status changes. When a taxi is taking passengers, its destination is fixed, and the speed of it is relatively faster. In contrast, when a taxi is vacant, it will slow down or even stop to search for potential passengers along the road. Thus, taxi behavior characteristics, such as speed and the status duration varies consequently.
- **Assumption 2:** The movement behavior of taxies associates with geographic feathers.
  - 1) The destination selection will be influenced by different regions.

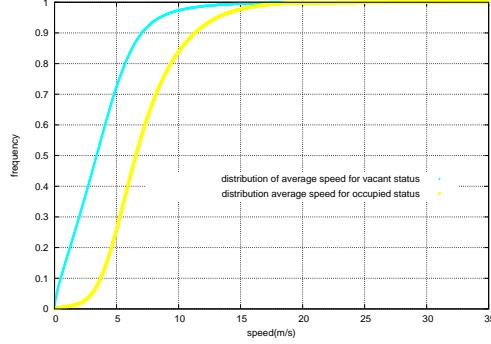


Fig. 1. Speed Distribution for vacant and occupied status.

- 2) events occurs in different regions un-evenly, passenger off and on events are distinct.

Therefore, we analysis the speed,duration and passenger on/off events distribution to estimate our assumptions.

### C. Speed analysis

In this section, we investigate the average speed  $\bar{speed}$  in each status. For example, taxi  $i$  drives in occupied status for a distance  $d$  using time  $t$ , then the average speed in this status is  $d/t$ . From March 3th to 7th, 2011, the  $\bar{speed}_{empty} = 3.627m/s$ , while that for occupied status is  $\bar{speed}_{occupied} = 7.083m/s$ .

To further investigate the speed distribution, proportion for every  $\bar{speed}$  section is calculated, in fig. ?? . For example, dot(x,y) means 2.45% records fall in the speed range [0,20]km/h. Fig. ?? shows that  $\bar{speed}$  distribution differs for each status. For vacant status, the  $\bar{speed}$  gather together at ?? also demonstrates that the speed distribution is with strong regularity for each status.

### D. Status duration analysis

The duration distribution for each status are shown in fig.. Status duration represents the time length of a taxi staying in a certain status. The red line presents the duration time distribution for vacant status, and the green one is for status 1. A dot of the line means the proportion of the duration. A peak exists in each line, and it is obvious that the peak of the red line is earlier than that of the other line. And the value of duration for status 0 trends to be smaller. It accords to the realistic situation, because drivers tend to shorten the waiting time to raise their income.

The statistical results are consistent with the *assumption 1*, that is, the behaviors of taxis are similar within each status while it differs between the two statuses.

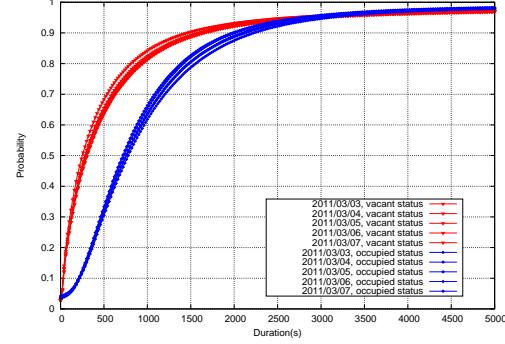


Fig. 2. Status duration distribution.

### E. Taxi event distribution

To validate *assumption2*, we quantitatively analyze vehicles density in one hour. By dividing the whole network into  $100 * 100$  grids, taxi density distributions for event 0, 1 are computed in each cell.

Figure.?? shows the on/off events distribution in three time sections. In the morning, people begin to get out. so the on-event distribute is more even than that of off-event. this phenomenon may be caused by the on-event spots are mainly at the homes of the citizens, while the off-event spots tend to gather together at workplaces, railway stations or scenic spots. Besides, in the evening, the dispersion of on-event is of lower degree than that of off-event, for people coming home at that time.

The amount of loading passengers in each cell shows geographic feathers:the distribution is uneven, and the difference between on/off-event distributions illustrates the on/off-event regions are different which support the *assumption 2*.

## IV. Modeling

Movement model defines the mobility pattern of nodes, which can be represented as a collection of paths  $Paths : \langle p_1, p_2, \dots, p_n \rangle$ , so dose START. A  $p_i$  includes two steps, destination selection and moving process from source location to destination.

**Destination selection:** In START, to select a destination of a node is closely related to note only its current location but also its current status. Dividing the area into regions by the density of passenger on/off events or loading passenger events respectively, two transition probability matrixes are calculated, one is the probability from passenger off event regions  $\{REGION_{m,off}\}$  to passenger on events regions  $\{REGION_{n,on}\}$ . Note that  $\bigcup\{REGION_{m,off}\} = \bigcup\{REGION_{n,on}\} = AREA$ . If the status of a taxi changes to vacant, its current location determine a  $REGION_{i,off}$ . Consequently, a destination region in  $\{REGION_{n,on}\}$  will be selected

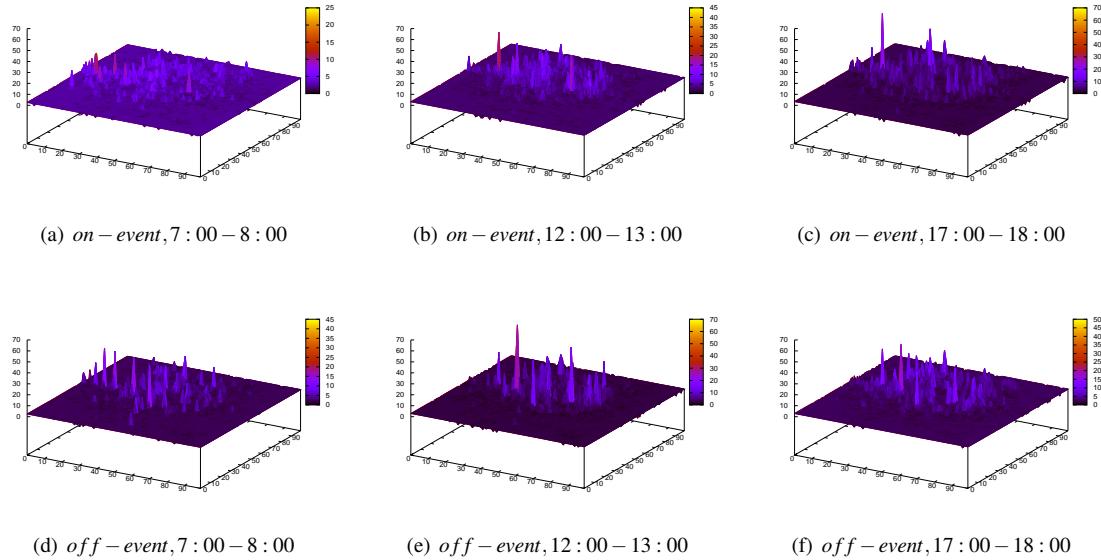


Fig. 3. Taxi density for on-event and off-event in one hour

by querying the transition matrix from  $\{Region_{m,off}\}$  to  $\{Region_{n,on}\}$ . Then, START will randomly select a map node in the region as the destination. As to the status of a taxi changing to Occupied, the destination selection process is similar. During this process, the region transition matrix will be utilized according to the current status.

**Moving process:** When the source location (current location) and destination location is given, next step is to find a path and set the speed. To simplify, we adopt the Dijkstra algorithm ,which will find a shortest path from source to the destination, to route on map. The speed is assigned by the average speed distribution of the corresponding status.

Based on the design above, we model the movement on the speed, duration and region transition matrix respectively.

#### A. Region transition probability

A travel path of a taxi can be simplified as a multi-hop process, in which a hop indicates an on/off event happened. Seeing that, we define a *region transition probability* to figure out the probability of the next hop falling in a definite region  $j$  from the current region  $i$ . Particularly, two successive events are different. Likewise, the region  $i$  and  $j$  are recognized by different metrics, that is, off or on event distribution. It is more reasonable. For an instance, if the taxi is occupied, the next hop event is the off one. Hence, choosing a target region from a region set divided by off event distribution is more logical.

To calculate the region transition probability, the **region recognition process** should be executed in advance.

Firstly, we divide the area into  $100 \times 100$  grids, and define cells in it as equation ???. Then, we consider region as adjacent cells as equation ??.

$$CELL_{x,y} := \{(lon, lat) | x \leq \frac{lon}{len_x} < x + 1, y \leq \frac{lat}{len_y} < y + 1\} \quad (1)$$

$$\begin{aligned} REGION_m := \{ &CELL_{x,y} | \exists CELL_{i,j} \in REGION_m \\ &\Rightarrow \|x - i\| \leq 1, \|y - j\| \leq 1 \} \end{aligned} \quad (2)$$

By clustering cells into regions, two set of region  $\{REGION_m^{on}\}$  and  $\{REGION_n^{off}\}$  can be recognized. The clustering idea is to put adjacent cells with event density larger than the event threshold  $\eta$  into one cluster. To avoid the size of the region become too large or too small, we set a *CLUSTERSIZE* to restrict a region, say  $\|REGION_i\| \leq CLUSTERSIZE$ , and only limit the top 200 regions, in which  $CELL_{x,y}.events \geq \eta$ . After that, the other cells not belong to the top 200 regions, will be cluster into regions, while  $\|REGION_j\| \leq CLUSTERSIZE$ . We sort the cells by event density in descending order, and begin with the first cell to search its neighbors whether to join the same region using breadth traversal. The region recognition results for on/off events are shown in figure ???. The detail clustering algorithm is presented in the appendix. In addition, the  $CLUSTERSIZE = 200$ ,  $\eta = 121$  for on

event and  $\eta = 141$  for off event set by the average event density of the top 5000 cells order by its event density.

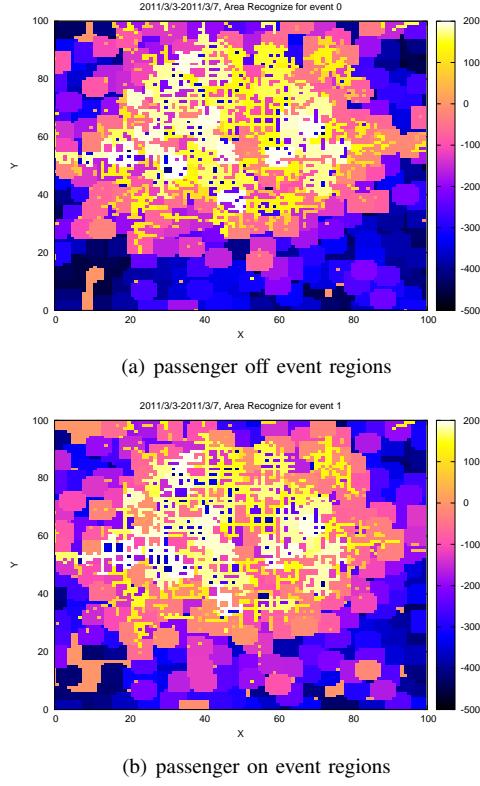


Fig. 4. Region recognition

**The calculate process of the region transition probability:** After clustering cells into regions, the transition probability from  $REGION_i^{on/off}$  to  $REGION_j^{off/on}$ , donated as  $p_{i \rightarrow j}^{on \rightarrow off/off \rightarrow on}$ . To substantiate, the calculate process of  $p_{i \rightarrow j}^{on \rightarrow off}$  will be introduced in detail. Clearly, the records in  $REGION_i^{on}$  can be required from the data set easily. the record amount is donated as  $\|RECORDS_i^{on}\| = \{record | record.location \in REGION_i^{on} \cap record.event = on\}$ . For  $record \in RECORD_i^{on}$ , the next event and location can be easily required. Therefore, the record can be associated with its next hop information to  $(taxiid, location_{current}, event, event_{next}, location_{next})$ . The  $RECORDS_{i \rightarrow j}^{on \rightarrow off} = \{record | event = on \cap event_{next} = off \cap location_{current} \in REGION_i^{on} \cap location_{next} \in REGION_j^{off}\}$  will be obtain.

$$P_{i \rightarrow j}^{on \rightarrow off} = \frac{\|RECORDS_{i \rightarrow j}^{on \rightarrow off}\|}{\|RECORDS_i^{on}\|} \quad (3)$$

$$P^{on \rightarrow off} = (p_{i \rightarrow j}^{on \rightarrow off})_{m \times n} \quad (4)$$

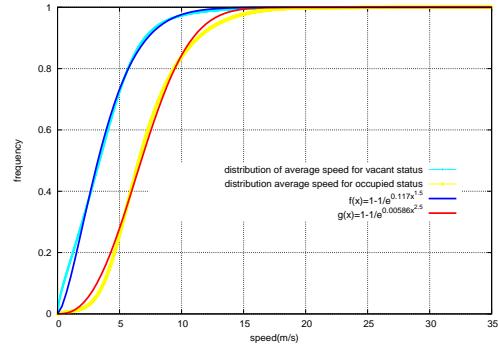


Fig. 5. The fit result of the cumulative speed distributions.

TABLE II  
THE PARAMETER AND THE RMS OF RESIDUALS OF FITTING CURVES

Categories	rms of residuals	
$f(x)$	$a1 = 0.117$	0.0113159
$g(x)$	$a2 = 0.0586$	0.0137029

$$P^{off \rightarrow on} = (p_{i \rightarrow j}^{off \rightarrow on})_{n \times m} \quad (5)$$

### B. Parameter estimation of speed distribution

In this section, we modeling the speed distribution. we fit the cumulative status average speed distribution to get the cumulative probability distribution function, and then take a derivative with it to obtain the speed probability distribution.

From figure. ??, the average speed distribution shows exponential law. Given that, we set the function form as follows:

$$\begin{cases} f(x) = 1 - e^{-a_1 x^{1.5}} \\ g(x) = 1 - e^{-a_2 x^{2.5}} \end{cases} \quad (6)$$

The fit formulas are given as formulas ???.  $f(x)$  is the function form for the average speed distribution of vacant status, and the other one  $g(x)$  is for that of occupied status.

Fig. ?? also plots the fit results.

The rms of residuals for each fit are as table ???. The smaller rms of residuals means better fitting. In the table, the values are all less than 0.02, showing good similarity.

## V. Model Verification

In this section, START mobility model is validated on the aspects of node distribution and contact characteristics. All movement models are implemented on Opportunistic Networking Environment (ONE)[?].

Shortest Path (SP) movement model based on the map in Beijing is another comparison, which is implemented by ONE. It also moves along the map roads by Dijkstra algorithm. The RWP model is another comparison, because it is proved to be an efficient model modeling the nodal movement in VANETs. But it takes no consideration of the node statuses and geographical distribution.

The START, SP and RWP mobility model are compared with the real trace. In simulations, Node number is set as 4000 and scenario in area  $24445 * 23584m^2$  (a sub-map of the whole area), including fourth ring roads in Beijing. The simulation time is three hours and the warm up time for reports is one hour, so that the nodal movement and position will not be affected by its initial position. The communication range is 200m.

#### A. Traces and distribution of nodes

Trace samples and their snapshots are demonstrated in this section, shown as fig. ?? and fig.??.

Fig.?? shows the trace in one day. The trace of the real data and START only cover some part of the area, while the trace of SP and RWP almost go through the whole area. Because SP and RWP will select a destination randomly, while START takes the associations between current region and destinations into consideration which satisfies the movement rules of taxies.

From fig.??, Real trace START and SP movement model exhibit the road structure. However, the node distribution of RWP is much uniform.

To further explore the node distribution feathers, by dividing areas into  $10 * 10$  grids, (length of each cell is about 2400 meters), the node density distributions are investigated. An interpolation process is conducted on RWP traces, because it will not generate a position data until it changes its direction. Under this condition, middle point in the straight line created by two original points of continues time stamp is inserted for every 5 seconds. In each cell of grids in 20 seconds, the distinct nodes occurring are counted, that is, if a node prints its location in a cell twice, it will not add up to the node density in this square. Consequently, the interpolation process on RWP trace will not influence the results. Moreover, the upper limit of speed is 33.3 m/s, so that for every node, it can occur in no more than 3 cells in 20 seconds. In table. ??, the average of node densities for models and real traces are close. Whereas, the variances change a lot from 4848 of RWP to 107423.3 of START. The variance of Real trace is large, because nodes in reality during a short time is not evenly distributed. Although, Shortest Path movement model takes the geographic characteristics

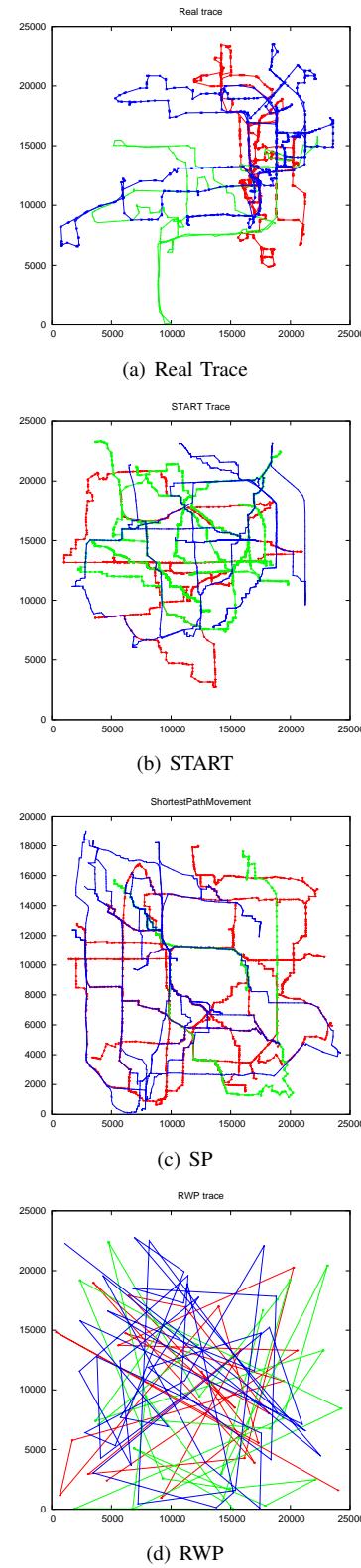


Fig. 6. Trace samples

TABLE III  
AVERAGE AND VARIANCE OF NODE DENSITY

type	average	variance
Real Trace	41.39175	107401.1
START	44.28421	107423.3
S-START	45.3	86084.9
ShortestPath	43.41414	52820
RWP	43.2	4848

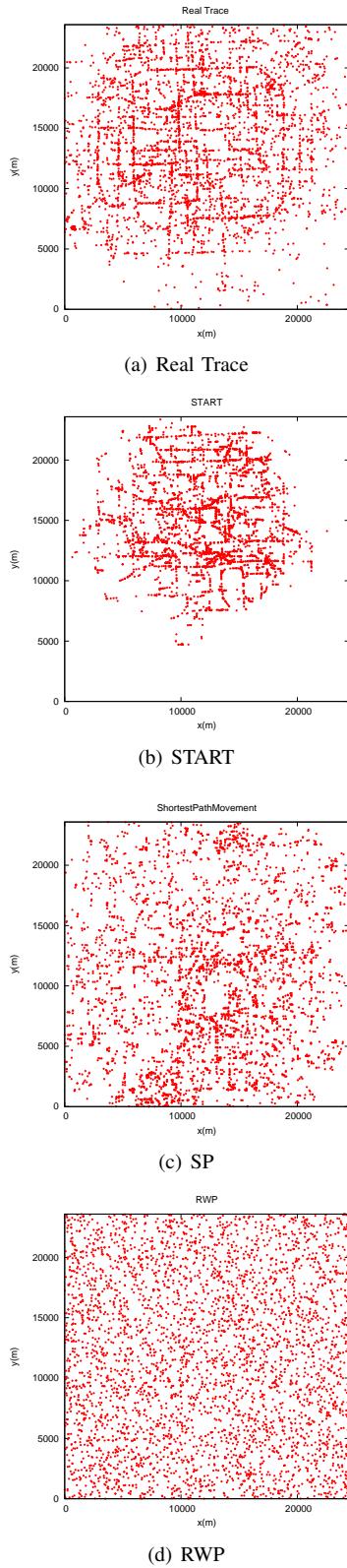


Fig. 7. Trace snapshots

into consideration, the difference from different road segments is disregarded.

### B. Contacts characteristics

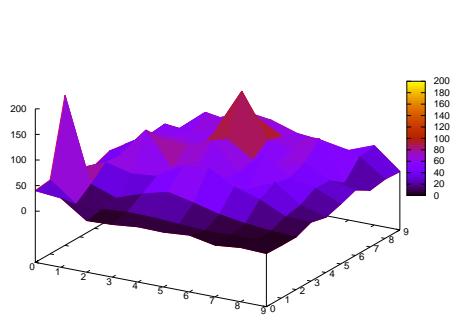
The contact time and inter contact time are evaluated as the indicators to validate the similarity. The speed range of RWP and SP need to be configured. To ensure the accuracy, we choose three speed range  $[0, 44.4]m/s$ ,  $[0, 33.3]m/s$  and  $[0, 22.2]m/s$ , that is, the upper bounds of speed are  $80, 120, 160 km/h$ .

Fig. ???. (a)(b) is the contact time and inter-contact distribution, which shows the probability of the contact or inter-contact time smaller than certain time length. To substantiate, a point  $(200, 0.5)$  in these figures means the probability is 0.5 when contact or inter-contact time is shorter than 200s. In addition, a point  $(x, y)$  in ???.(c) means the sum of contact time is  $y$  when the simulation time is  $x$ . In this figure, the three green lines of SP and the three blue lines of RWP are coincide with each other. To recognize the differences, we set  $y$  axis as log-scale in fig.???.(d). The curves of the total contact time vs. time presents a liner law. For SP and RWP, the differences of speed ranges show little influence on these curves. Clearly, the rank of the contact characteristic similarity with the real data is  $START > SP > RWP$ .

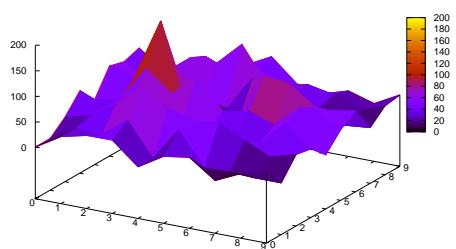
To conclude, by comparing the node distribution and contact characteristics, the START mobility model performs good similarity with the real data. The evaluation results conform to our expectations. Because START takes use of speed and geographic feathers related with status, While SP employs the map information and RWP is a random model taking use of no realistic data.

## VI. Conclusion

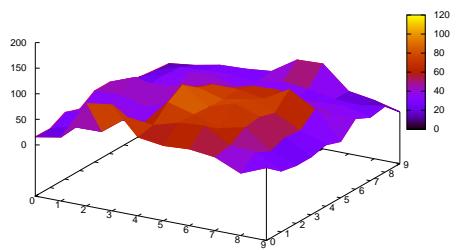
Since the mobility model is essential for mobile network, a novel mobility model START based on real GPS trace data is proposed. By assuming the taxi behavior is related with its statuses and geographic feathers, statistical experiments are conducted to verify those assumptions using the real trace data. Further, its parameter—average speed of each status are estimated respectively, and the region transition probability is



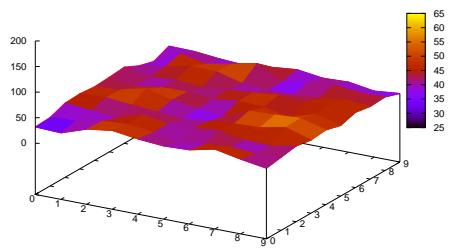
(a) Real Trace



(b) START

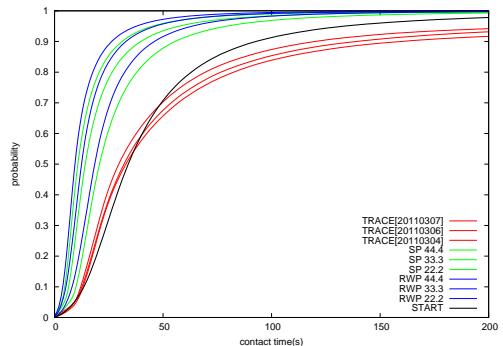


(c) SP

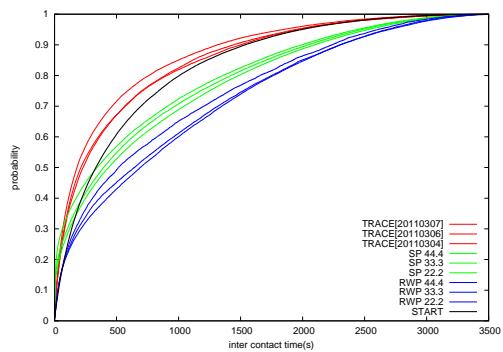


(d) RWP

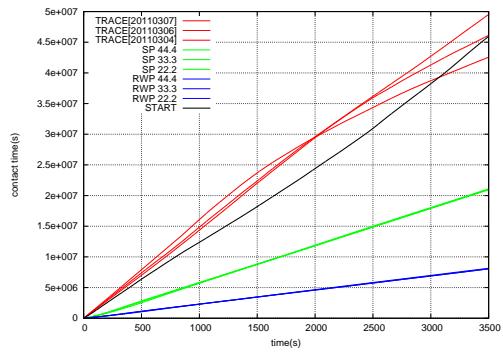
Fig. 8. Node density in 20 seconds



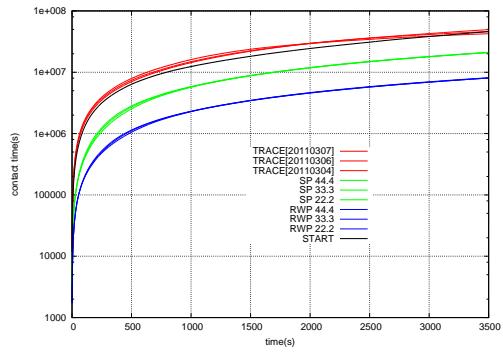
(a) cumulative contact time distribution



(b) cumulative inter contact time distribution



(c) time vs total contact time



(d) time vs total contact time in logscale

Fig. 9. Contact times distribution and Cumulative ICT distribution

calculated. In this case, macroscopic movement, a node moves switch between on-event regions and off-event regions, and microscopic movement(speed for each status) can be defined. Finally, the START is implemented on ONE simulator and estimate it by comparing with the real trace, RWP and Shortest Path movement Model. Comparing the node distribution and contact feathers, START shows better performance. Simulation results demonstrate that START has a good approximation with reality.

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## Appendix

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### Algorithm 1 Clustering

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Require:  $Cells = \{CELL\}$ 
 $\eta$  ##events threshold
 $CLUSTERSCALE$ 
 $REGIONSEED = 200$ 
 $ClusterQueue = \emptyset$ 
 $UsedCells = \emptyset$ 
Sort  $Cells$  by events DESC
for  $CELL_{x,y} \in Cells$  do
    if  $CELL_{x,y} \notin UsedCells$  then
         $CELL_{x,y}.region = REGIONSEED$ 
         $size = 1$ 
         $CLUSTERSEED = CLUSTERSEED - 1$ 
         $ClusterQueue.enqueue(CELL_{x,y})$ 
         $UsedCells.add(CELL_{x,y})$ 
        while  $ClusterQueue \neq \emptyset$  do
             $CELL_{x,y} = ClusterQueue.dequeue()$ 
            if  $REGIONSEED \geq 0$  and  $CELL_{x,y}.events \geq \eta$  then
                enqueueNeighbor( $CELL_{x-1,y}$ )
                enqueueNeighbor( $CELL_{x-1,y-1}$ )
                enqueueNeighbor( $CELL_{x-1,y+1}$ )
                enqueueNeighbor( $CELL_{x+1,y}$ )
                enqueueNeighbor( $CELL_{x+1,y-1}$ )
                enqueueNeighbor( $CELL_{x+1,y+1}$ )
                enqueueNeighbor( $CELL_{x,y-1}$ )
                enqueueNeighbor( $CELL_{x,y+1}$ )
            else
                enqueueNeighborOthers( $CELL_{x-1,y}$ )
                enqueueNeighborOthers( $CELL_{x-1,y+1}$ )
                enqueueNeighborOthers( $CELL_{x-1,y-1}$ )
                enqueueNeighborOthers( $CELL_{x+1,y}$ )
                enqueueNeighborOthers( $CELL_{x+1,y-1}$ )
                enqueueNeighborOthers( $CELL_{x+1,y+1}$ )
                enqueueNeighborOthers( $CELL_{x,y-1}$ )
                enqueueNeighborOthers( $CELL_{x,y+1}$ )

```

---



---

### Algorithm 2 enqueueNeighbor( $CELL_{x,y}$ )

---

```

if  $CELL_{x,y}.events \geq \eta$  and  $size < CLUSTERSCALE$ 
and  $CELL_{x,y} \notin UsedCells$  then
     $ClusterQueue.enqueue(CELL_{x,y})$ 
     $CELL_{x,y}.region = REGIONSEED$ 
     $UsedCells.add(CELL_{x,y})$ 
     $size = size + 1$ 

```

---



---

### Algorithm 3 enqueueNeighborOthers( $CELL_{x,y}$ )

---

```

if  $size < CLUSTERSCALE$  and  $CELL_{x,y} \notin UsedCells$ 
then
     $ClusterQueue.enqueue(CELL_{x,y})$ 
     $CELL_{x,y}.region = REGIONSEED$ 
     $UsedCells.add(CELL_{x,y})$ 
     $size = size + 1$ 

```

---