HYBRID MODEL OF HUMAN MOBILITY FOR DTN NETWORK SIMULATION

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KEYWORDS
Human mobility models, wireless ad-hoc networks modeling.

ABSTRACT

A hybrid model of human mobility is presented. It combines features of the SLAW–type models and the Levy walk models to preserve advantages of the SLAW-type model in simulation of real human mobility and decrease computational time.

INTRODUCTION

An adequate model of node mobility in ad-hoc networks is very important for correct estimation of the network performance by simulation of the real networks' behaviour. Especially it is important for such class of ad-hoc networks as delay-tolerated networks (DTN). The DTN networks are characterized by small connectivity, so at some moment of time a connection between message sender and receiver may not exist and will appear only because of the nodes' positions changing. Therefore, adequateness of the mobility model to the real mobility is a key to the correct estimation of such fundamental characteristics of DTN networks protocols like probability of message delivery and probability distribution of transmission delay. It is the reason, why during the last decade a lot of efforts of research community were devoted to an investigation of real human mobility and to a development of adequate models of it.

Modern researches of human mobility reveal important features, like waypoint clustering and Levy-type distribution between consecutive waypoints (see, for example, (Brockmann et al. 2006; Gonzalez et al. 2008; Rhee et al. 2008; Rhee et al. 2011)). These features should be taken into account for correct modeling of user mobility in DTN networks. There are many modern well-known mobility models, like TLW (Rhee et al. 2011), CMM (Lim et al. 2006), ORBIT (Ghosh et al. 2007) and so on, which are able to catch some of the features of real human mobility, but not all of them.

Recently in (Lee et al. 2012; Lee et al. 2008) a new type of models was presented, which can be referred to as SLAW-type models (Self-Similar Least Action Walk) and are able simultaneously to catch several important features of real human mobility. Comparisons made in (Lee et al. 2012) show that these models outperform models from (Rhee et al. 2011; Lim et al. 2006; Ghosh et al. 2007) in catching real mobility features. However, as we demonstrate in this report, SLAW-type models can take much computational time. This circumstance could be important, if these models are used for simulation of DTN networks with large number of nodes.

In this report we propose a hybrid model of human mobility, which combines features of the random Levy walks with some features of SLAW. This presented model keeps useful features of SLAW, but is more effective in terms of computational time.

SHORT DESCRIPTION OF SLAW-TYPE MODELS

SLAW-type models consider human mobility as transitions between so-called waypoints, where the human stops for a noticeable amount of time. It is well-known (see, for example (Rhee et al. 2011)), that the distance between consecutive waypoints has probability distribution close to the Levy distribution. Time stopped in waypoint has probability distribution close to the Levy distribution too. These features are captured well by the random Levy walk model (see, for example (Rhee et al. 2011)), but the clustering of waypoints is not captured by this model.

In the SLAW-type models, clusters can be taken from a real mobility traces. For this purpose, the real trace is processed for finding waypoints, and then for grouping these waypoints into clusters. By definition, the waypoint is the center of a circle with radius r of several meters (usually r = 5m) where a human spends inside more than T seconds (usually T=30sec). A cluster of waypoints is a rectangle that include transitive closure of waypoints which are not further from each other then the distance R (usually R=100m, also 50m and 250m are used). Also, SLAW-type models use self-similar parameter (variance) from the real trace (Lee et al. 2008).

When simulated trace is generated, its waypoints are randomly distributed inside clusters with the same self-similar parameter (variance), as in the real trace. As showed in (Lee et al. 2012), to provide Levy distribution of distances between consecutive waypoints, waypoints inside a cluster should be visited according LATP (Least Action Trip Principle), and after visiting all waypoints inside the current cluster, the

Proceedings 30th European Conference on Modelling and Simulation ©ECMS Thorsten Claus, Frank Herrmann, Michael Manitz, Oliver Rose (Editors)
ISBN: 978-0-9932440-2-5 / ISBN: 978-0-9932440-3-2 (CD)

next cluster should be selected according LATP again (using distance between clusters).
According LATP, the next location to visit (as waypoint as cluster) is selected with probability, inversely to the distance to it in some power (parameter of the model). I.e. while the current location (waypoint or cluster) is i and the set of all locations is V, then the probability of selecting the next location with number j is calculated as follows:

$$\Pr\{i \to j\} = \frac{\left(\frac{1}{d_{ij}} \right)^p}{\sum_{k \in \{V - V'\}} \left(\frac{1}{d_{ik}} \right)^p} \qquad (1)$$

where d_{ij} is the Euclidean distance from the location i to j, parameter p is a fixed real variable with values in the range [0; +∞), and V' is a set of locations from V, that have already been visited. Parameters p (there are two different parameters – one for waypoints selection, another one for clusters selection) can be used to fit the distribution of transition distances in simulated trace to the distribution in real trace.
In fact, for calculations according LATP, if there are N waypoints in cluster, it is necessary to calculate $N(N-1)/2$ distances between waypoints, i.e. $O(N^2)$ operations. This could require a large computational time, which the presented hybrid model can decrease.

HYBRID MODEL DESCRIPTION

As in SLAW-type models, proposed model uses clusters, which were found by the processing real traces data. At the beginning of the simulation run, each user gets a general information about its trace in the form of a set of clusters to be visited during the trip. User chooses first cluster and takes random points inside the cluster as a start position. Then it moves inside the cluster, making Levy steps and pauses after each step for Levy distributed time (the point of pause is the waypoint). Probability density of one Levy step is

$$f_X(x) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \exp\left(-itx - |ct|^\alpha \right) dt \qquad (2)$$

Usually the direction of simple Levy walk is uniformly distributed, but in our model, it is not the case. Instead of uniform distribution of the direction of next Levy step, the direction of the step is selected to prevent exit from the cluster as long as possible. If the next step in random direction is going to be outside of the cluster, this direction is changed directly toward the most distant corner of the cluster. Such change has maximal chance to keep the moving node (human) inside the cluster. If after the direction change the step is still outside the cluster, it means that it is time to change the cluster and to select the next cluster. Transitions between clusters, like in SLAW-type models, go on according LATP. From the set of given at the beginning of simulation and still unvisited clusters, the user chooses the next cluster with the probability (1), and takes a random point inside it as end point for inter-cluster step. After transition to the new cluster user starts movement inside cluster as described above.
It is obvious, that calculation time of movement inside the cluster is proportional to the number of waypoints inside the cluster, i.e. $O(N)$. Therefore, for large N we can expect that this model will be faster then the SLAW-type model.

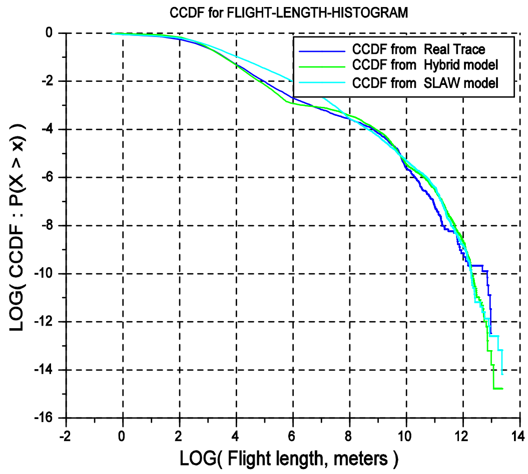
EXPERIMENTAL RESULTS

For comparison the results of real traces simulation by hybrid and SLAW-type models, both of them were implemented in the OMNET++ simulation system (Varga András 2001) with INET framework (Steinbach Till et al. 2011). Real traces of human mobility were taken from (Kotz D. 2015). These traces are the files with records of movement of one person (moving node). Each record is the time stamp with 30 sec step and two coordinates of the node at this time. Therefore, before using this data in our experiments, traces are processed for waypoints and clusters finding. A set of points from the file of real trace, which will join to the one waypoint, is determined as follow: at the beginning this set is empty, and then each point being successively read from the trace file is tested for possibility to be added to the set; if the new point and all members of the set are inside the circle of radius r, then the point is added to the set. If the point can't be placed in the circle with member of the set, then the current waypoint is complete, its coordinates are coordinates of the covering circle, and the new point is the first member of a set for new waypoint. After the transformation of the real trace into sequence of waypoints, the cluster bounds are detected according above cluster definition. Also the self-similar parameters (variances) necessary for SLAW-type model are calculated according formulas from (Lee et al. 2008).
To compare the simulated mobility with the real one the complementary cumulative distribution function (CCDF) of a distance between consecutive waypoints (including transitions between clusters) is used. By definition, CCDF is

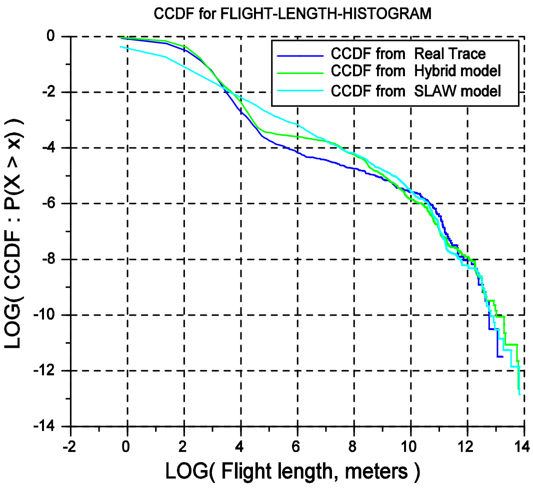
$$\overline{F}(x) = \Pr\{X \geq x\} = 1 - F(x) \qquad (3)$$

and after waypoint finding for the real trace, appropriate data are collected.
Then hybrid model with the same clusters as in the real trace run several times to find parameters c and α and parameter p of LATP cluster selection procedure, that provide closeness of CCDF for the trace simulated by hybrid model to CCDF of the real trace. In the

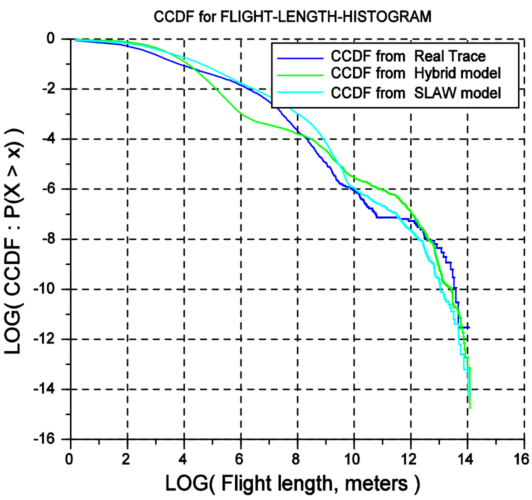
simulated trace, there are many small Levy steps, which are less then r, therefore described above procedure of



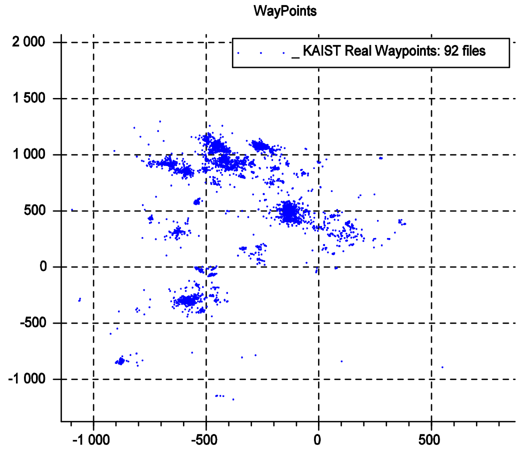
Figures 1: CCDF for KAIST



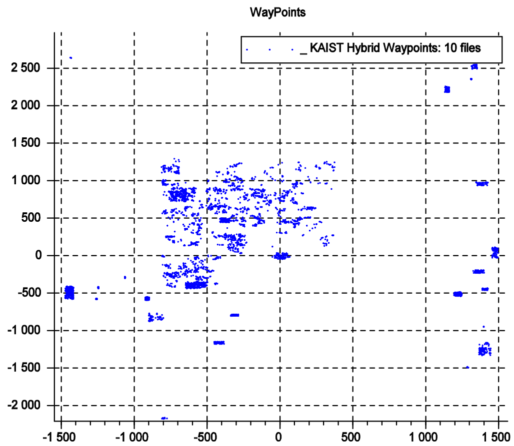
Figures 2: CCDF for NCSU



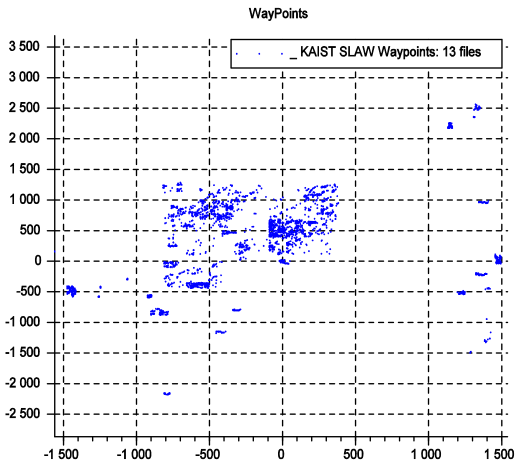
Figures 3: CCDF for Disney World



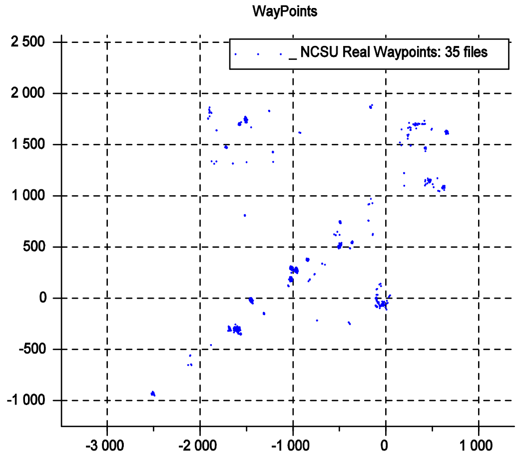
Figures 4: Waypoints for KAIST real trace



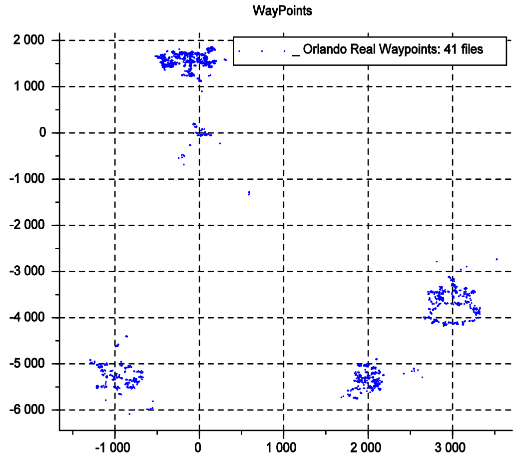
Figures 5: Waypoints for KAIST Hybrid model



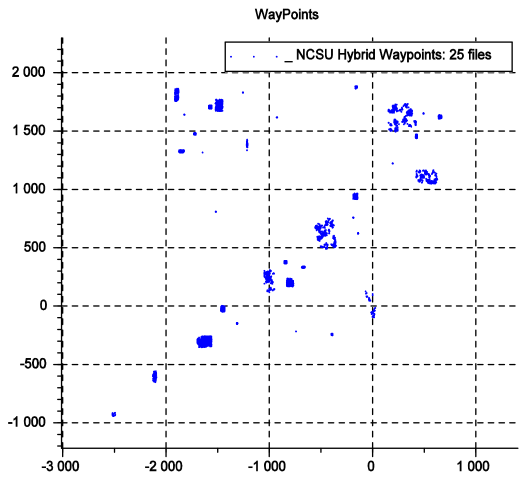
Figures 6: Waypoints for KAIST SLAW model



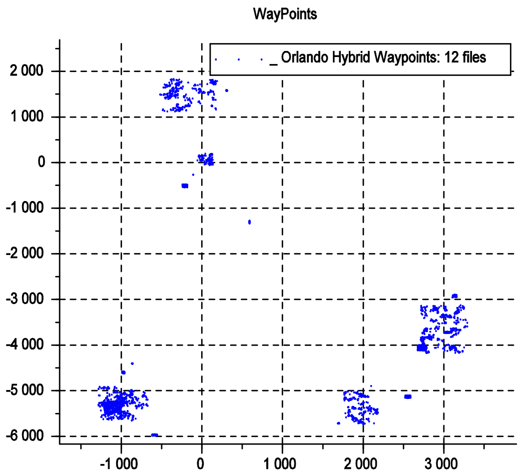
Figures 7: Waypoints for NCSU real trace



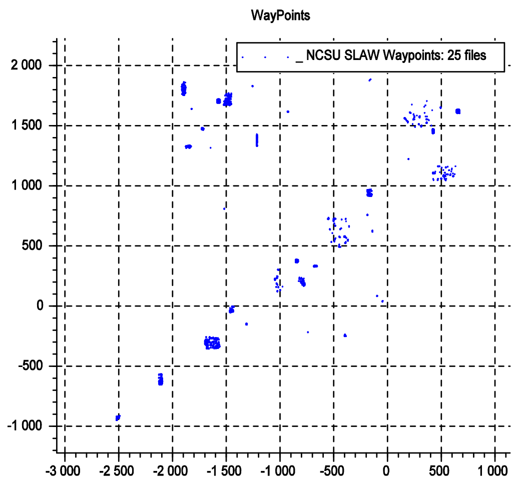
Figures 10: Waypoints for Disney real trace



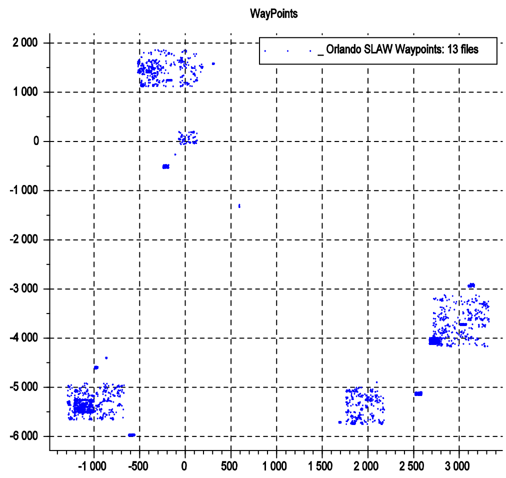
Figures 8: Waypoints for NCSU Hybrid model



Figures 11: Waypoints for Disney Hybrid model



Figures 9: Waypoints for NCSU SLAW model



Figures 12: Waypoints for Disney SLAW model

waypoints finding performs on simulated trace before the CCDF calculation.

The numbers of waypoints in each cluster of hybrid model trace are saved to use for SLAW-type model runs. According to description of SLAW model in (Lee et al. 2008), our version of SLAW model was developed. It intended just for comparison with hybrid model in computational complexity (computational speed). Our version of the SLAW model uses clusters and self-similar parameters from real trace and numbers of waypoints in each cluster from hybrid model. Given number of waypoints are distributed inside appropriate cluster in self-similar manner and then these points are visited in sequence according LATP with some parameter p_1. After visiting the last waypoint inside the cluster, next cluster is chosen according to LATP with parameter p_2. Just to complete the picture we run SLAW model several times to find appropriate p_1 and p_2 that provide closeness of the SLAW model CCDF to the CCDF of the real trace.

Our purpose in fitting CCDF of our version of SLAW model is just to demonstrate that this version is able to work. Real ability with deep details of SLAW-type models see in (Lee et al. 2012; Lee et al. 2008).

Here we present the results for three data sets from collection in (Kotz D. 2015): from KAIST (Korea Advanced Institute of Science and Technology), from NCSU (*North Carolina State University*) and from Disney World in Orlando. All these data sets were obtained by the same way: 50 volunteers (university students) during the day (or during the visit to the park) carried in the pocket GPS navigator, which recorded its position every 30 sec. We used these data to find real waypoints, real clusters of waypoints and other parameters for SLAW-type and Hybrid models.

Both models run for 50 mobile nodes, for model time of 5 days. The computational time is presented in Table I.

On the figures 1-3, CCDF of the distance between consecutive waypoints are presented for all places. It is shown that CCDF of both models have about the same closeness to the CCDF of the real trace.

In addition, we present a set of pictures of waypoints positions for real trace and for both models to show clustering ability (figures 4-12). All pictures have approximately the same number of waypoints. For each dataset an only part of the whole area of simulation is presented to show clustering ability more clearly. It is clear, that waypoint distribution patterns for both models have about the same closeness to the pattern of the real trace.

Table 1: Computational time (sec)

Data Set	SLAW model	Hybrid model	Ratio
KAIST	391.4	167.4	2.34
NCSU	323.8	85.5	3.79
Disney	476.4	179.6	2.65

CONCLUSIONS

The hybrid model of human mobility is presented. This model captures such important features of real mobility as Levy steps between waypoints and waypoints clustering and is faster in simulation then the SLAW model. Therefore, the hybrid model can have advantages in simulation of DTN networks with large number of nodes.

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