MobiCom Poster Abstract: Super-diffusive Behavior of Mobile Nodes from GPS Traces

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1. INTRODUCTION

Mobility is the most important factor in mobile ad-hoc networks (MANETs) and delay-tolerant networks (DTNs). Mobility models that fail to capture real movement pattern of mobile nodes will result in misleading guidelines on the design of new protocols and their performance evaluations and thus prevent us from making judicious decisions.

Two different approaches – synthetic modeling and trace-based modeling – have been put forth for sound mobility models. Synthetic mobility models [7] have been developed mainly for the purpose of simplicity and the ease of analysis, but subsequently been criticized for their unrealistic behaviors. On the other hand, the trace-based approach suffers from lack of the amount of available traces on a fine time/space scale, and are applicable only for the particular setting under consideration and highly sensitive on the choice of the reconstruction algorithm.

In this work, we take a different approach from the above two. We first investigate numerous GPS-based mobility traces for various mobile nodes. In view of Data MULEs or Message Ferrying based approaches, we consider different kinds of human movement patterns such as walking, running, inline skating and bicycling as well as zebra and bus movement. We then find out that all those traces show *super diffusive movement pattern*, which is characterized by 'faster-than-linear' growth curve of the mean square displacement (MSD), i.e., $\mathbb{E}\{\|Z_t - Z_0\|^2\} \sim t^{\gamma}$ with $\gamma > 1$, where $Z_t \in \mathbb{R}^2$ is the position of the mobile node at time t.

Based on the observed super-diffusive behavior, we propose to use a set of Lévy walk model as simple, easy-to-generate, yet realistic mobility models. The Lévy walk models allow us to directly control the super-diffusive behavior of generated trajectories[1] and can be easily incorporated into performance evaluation of protocols of MANETs and DTNs.

[1]Typical random walks or Brownian motion show 'normal' diffusive patterns (linear growth of MSD with $\gamma = 1$), while Lévy walk models show super-diffusive ones.

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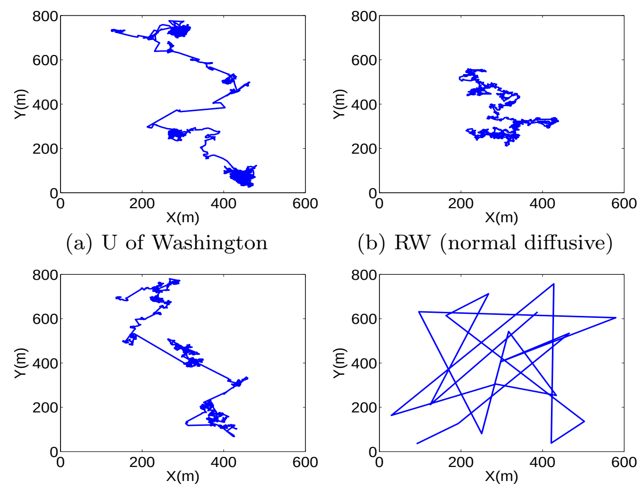
2. MOTIVATING EXAMPLE



(a) U of Washington (b) RW (normal diffusive)

(c) LW (super-diffusive) (d) RWP

Figure 1: Sample trajectories of a mobile user from (a) a real trace (U of Washington); (b) Random Walk (RW); (c) Lévy Walk (LW); (d) Random waypoint model (RWP). (b)-(d) are generated with the same speed $v = 1.34m/s$ over the same time duration as (a).

source	duration	sample	# nodes
Web-Walking [2]	19 hours	3–60sec	11
Web-Running [2]	27 hours	3–60sec	22
Web-Inline Skating [2]	42 hours	3–60sec	17
Web-Bicycling [2]	36 hours	3–60sec	13
UW-Walking [1]	2 hours	1 sec	1
NCSU-Walking [3]	3 weeks	1 sec	1
Zebra [1]	10 days	4–8 min	4
Bus [4]	3 months	100 sec	1200

Table 1: Summary of GPS-based traces

Figure 1(b) shows an isotropic two-dimensional random walk (RW) whose step-length distribution has finite variance, while it is heavy-tailed with infinite variance for Lévy walk. Figure 1 manifests the statistical similarity between the real trace and Lévy walk model with super-diffusive behavior. The power-law step-length distribution used in Figure 1(c) creates occasional very-long jumps[2] followed by many small steps with random orientations.

[2]It takes longer to finish those very long steps as the speed of the node is fixed to $1.34m/s$ (or could be a well-defined random variable).

3. MEAN SQUARE DISPLACEMENT FROM GPS TRACES

Available GPS Traces: Table 1 shows the available GPS traces in detail. Most data are gathered from the GPS user's community website [2], where they share mobility traces of numerous activities. In addition, zebra [1] and bus traces [4] are also included as they can be used as mobile nodes in other applications.

Mean Square Displacement (MSD) and Super Diffusive Behavior: The movement of a mobile node can be characterized by measuring how quickly it 'spreads out' from its current position after time t. For example, the trajectories in Figures 1(b) and (c) are generated over the same duration and with the same speed, but are clearly different in how the nodes spread out. This 'diffusive' behavior or the rate at which the mobile node spreads out can be described by the mean square displacement (MSD) [6], defined by $M(t) \triangleq \|Z_t - Z_0\|$, and $\sqrt{M(t)}$ gives typical amount of displacement of the mobile node after time t.

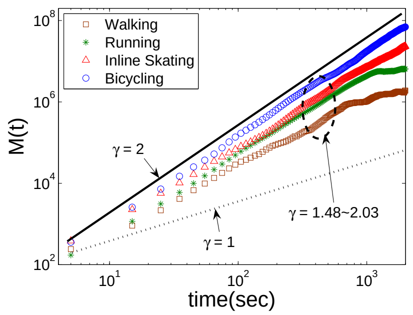
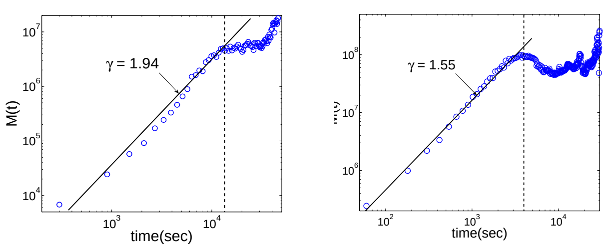


Figure 2: MSD of human mobile nodes. In all cases, MSD increases faster than linear ($\gamma > 1$), which shows super-diffusive behavior.



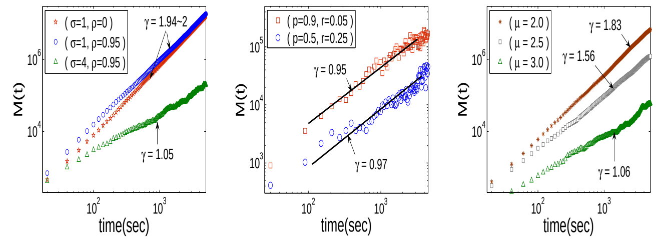
(a) zebra (b) bus

Figure 3: MSD of zebra and bus movement. Super-diffusive patterns ($\gamma > 1$) are also observed.

Figures 2 and 3 show the MSD of various mobile nodes from GPS traces on a log-log scale. In all cases (including zebra and bus traces), MSD increases faster than linear, which implies the super-diffusive behavior of mobile nodes. In addition, the slope of $M(t)$ in a log-log scale (γ) characterizes how fast it spreads out. For example, a mobile node with inline skating ($\gamma = 1.88$) tends to spread out quicker than the one with walking ($\gamma = 1.48$).

4. EXISTING MOBILITY MODELS

Figures 4(a) and (b) show the MSD of Gauss-Markov (GM) model [7] and Correlated Random Walk on Grid (CRWG) [5]. We consider these two models as they can control the degree of correlations in the direction of the movement at each



(a) GM (b) CRWG (c) LW

Figure 4: MSD of GM, CRWG and LW models on a log-log scale

time step and thus may potentially create super-diffusive patterns. For GM model, we test under various angle correlation parameter (ρ) as well as the shape of the marginal angle distribution (σ). As Figure 4(a) shows, the GM model is likely to generate 'ballistic' trajectory ($\gamma = 2$) where the marginal angle distribution is 'pointed' with small σ (the mobile node has its favorite direction and remembers this forever), or normal diffusion ($\gamma = 1$) for larger σ (even with very strong correlations in angle ($\rho = 0.95$)). For CRWG, we vary the probability of moving along the same direction as the previous one (p) and the probability of turning either to right or left (r). Even with $p = 0.9$ (strong directional tendency), Figure 4(b) shows that the MSD grows linearly overall. On the other hand, in Lévy walk models, we set the angle distributions uniform and *i.i.d.* over time, and then choose the probability density of the step-lengths as

$$f_L(l) \sim l^{-\mu}, \quad 1 < \mu < 3. \tag{1}$$

Note that the super-diffusive behavior is easily captured by the exponent μ in (1), whereas for other correlated walk models one would have to tweak the distribution and correlations of the angles very carefully. As Figure 4 shows, however, this approach would typically result in either $\gamma \approx 1$ or $\gamma \approx 2$, thereby making it unwieldy or practically infeasible to generate various mobility patterns with different degrees of diffusive behavior.

5. CONCLUSIONS AND FUTURE WORK

We have investigated numerous GPS traces and found that super-diffusive behavior is common in all those traces. We also suggest to use a class of Lévy walk models, as an easy yet effective way to generate realistic mobility trajectories. Our future works include (i) thorough investigation of the impact of this newly observed super-diffusive behavior on the network performance, and (ii) validation of the super-diffusive behavior in access-point (AP) limited traces [1].

6. REFERENCES

[1] CRAWDAD. In *http://crawdad.cs.dartmouth.edu/*.
[2] GPS traces. In *http://www.gps-info.com/*.
[3] NCSU trace. In *http://www4.ncsu.edu/∼skim8/trace/*.
[4] Seattle Bus trace. In *http://www.monarch.cs.cmu.edu/*.
[5] Bandyopadhyay, S., and Coyle, E. Stochastic properties of mobility models in mobile ad hoc networks. In *Conference on Information Sciences and System(CISS)* (2006).
[6] Berg, H. *Random Walks in Biology*. Princeton University Press, 1983.
[7] Camp, T., Boleng, J., and Davies, V. A survey of mobility models for ad hoc network research. *Wireless Communications and Mobile Computing 2*, 5 (2002), 483–502.