Impact Analysis of Realistic Human Mobility over Wireless Network

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Abstract. Mobility management is crucial for mobile Internet services. Mobile IPv6 and many subsequent variants aim to provide network layer mobility support for mobile nodes or mobile networks, whose performance is highly dependent on user mobility model, network topology and traffic model. Several previous researches have evaluated their performance by simulations, analytical models, and experiments. However, most of them adopt classic mobility models such as RWP without considering more realistic human mobility characteristics since most of mobile devices are carried by human being. Therefore, the performance evaluation of these solutions under realistic human mobility models becomes an important issue. In this paper we investigate human mobility characteristics and evaluates their impacts on existing mobility management protocols based on a unified simulation platform which abstracts movement parameters from realistic traces and uses them to tune other mobility models. The final results show: (1) The mobility model has an important impact on performance evaluation, and the delivery costs of RD and RWP models are different from the realistic trace which may mislead the protocols design; (2) The current mobility management protocols little consider the human mobility characteristics which cannot benefit the positive of human mobility characteristics, and they should consider the impacts of human mobility and absorb human mobility characteristics in future.

Keywords: Mobility models · Mobility management · Human mobility

1 Introduction

The development of wireless and mobile technologies spurs the booming of various mobile services, and providing Internet services is becoming a big challenge. Especially, with the rapidly increasing of various IoT devices, the limitations in terms of network resource and energy consumption require the protocol design for continuous accessing for huge mobile devices to satisfy the upper service requirements and underly network characteristics. Among these protocols, many mobility management solutions have been proposed under different layers [4,9]

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in which network layer mobility management (also called as IP mobility management) is a crucial and promising solution for global roaming of Mobile Nodes (MNs).

As a basic mobility support solution, MIPv6 [17,34] introduces Home Agent (HA) to perform the handover management and location management, and the data forwarding for each registered MNs. By extending corresponding node to maintain latest locations of MNs, it can also support optimal routing. The subsequently enhanced solutions such as Hierarchical MIPv6 (HMIPv6) [36,37] and Fast handover for MIPv6 (FMIPv6) [21–23] were proposed to optimize handover performance in terms of signaling cost and handover delay, respectively. However, all of them require the involvements of energy-limited MNs, which may aggravate the energy consumption and therefore restrict their deployment. To solve these problems, Proxy MIPv6 (PMIPv6) [11] was proposed which introduces Mobility Access Gateway (MAG) to deal with the mobility-related signaling exchange instead of MNs. It has been testified that PMIPv6 can reduce handover delay and signaling cost [10]. After that, F-PMIPv6 [42] combines fast handover with PMIPv6 to further improve its performance. The recent Distributed Mobility Management (DMM) [5] aims to make mobility management more scalable and flat to get rid of the restriction of single point failure such as HA in MIPv6 or Local Mobility Anchor (LMA) in PMIPv6.

These mobility management protocols have different characters and application scenarios [2,3,14,16,29,41]. However, how to evaluate their performance becomes an important issue before deployment. Several works have adopted simulation [6], theoretical analysis [40] and experiments [7] methods to evaluate them under different mobility models, topology models and traffic models in terms of handover latency, packet loss, signaling cost and so on. However, most of them adopt Random Walk (RW), Random WayPoint (RWP) or Random Direction (RD) due to their simplicity and tractability to model MNs' movement, while little consider the impacts of realistic human mobility characteristics. It has been verified that these traditional mobility models cannot capture human mobility characteristics [24]. Furthermore, some researches only study the performance under given topology setting by assigning the predefined distances among different mobility entities, which is difficult to emulate real application scenarios.

The recent work [39] shows that these simple mobility models are sufficient for initial testing of new schemes but insufficient for proving their viability in real-world conditions. In addition, the recent development of 5G suggests that the future mobility should support the mobility on-demand, ranging from very high mobility such as high-speed trains to low mobility or stationary devices such as smart meters. In this perspective, the mobility management should also consider the mobility characteristics of the mobility entities. Considering that many mobile device especially IoT devices move with wearable devices with humans and vehicles, and the previous work has found that the IoT devices have different characteristics in mobility from traditional mobile devices such as cellular phones [15]. Therefore, we evaluate mobility management protocols under different mobility models, and compare their performance with the realistic human mobility trace. The contributions of this paper are shown as follows: (1) we investigate the recent performance evaluation methods of mobility management protocols, and conclude their shortcomings; (2) we compare the performance of mobility management protocols under realistic trace and different mobility models; (3) we summarize the future directions of mobility management to improve its intelligence.

The organization of this paper is shown as follows. Section 2 describes typical performance evaluation methods of mobility management protocols. Section 3 summarizes the recent work of human mobility models and analyzes its features. Section 4 construct a unified simulation platform and compare performance of typical mobility management protocols under different mobility models, and analyzes their differences. Section 5 summarizes this paper.

2 Related Work

2.1 Mobility Evaluation Method

The early stage performance evaluation methods of mobility management is generally derived from the personal communication system in terms of cost and delay via analytical analysis or simulations.

Christian Makaya and Samuel Pierre [30] proposed an analytical framework to assess the performance of IPv6-based mobility management protocols under different packet arrival rates, wireless link delays, and Session-to-Mobility Ratios (SMRs). This analytical framework deduces the binding update cost, binding refresh cost, packet delivery cost, required buffer space, handoff latency and packet loss. To facilitate network design, the potential pros and cons of MIPv6, HMIPv6, FMIPv6 and F-HMIPv6 are analyzed under the given network topology and pre-defined parameters. This model, however, does not consider the message sizes and their scalability problem, and it adopts the fluid flow model which does not consider the human mobility characteristics. Besides, J-H Lee et al. evaluated the cost and handover delay in [25], respectively, which also adopts the fluid flow model. They adopted bytes*hops per second to evaluate signaling cost, and based on given topology to compare their registration delay, signaling cost and traffic intensity. More recently, Vasu et al. [40] proposed a comprehensive framework to evaluate IPv6 mobility management protocols including MIPv6, FMIPv6, HMIPv6, PMIPv6 and DMM in terms of signaling overhead, handover delay and packet loss. This framework applies transport engineering principles to derive the relation between handover delay and number of hops, and adopts the analytic results from [28] to deduce the signaling cost.

In addition to the analytical method, Guan et al. [10] studied the network-based mobility management protocols and demonstrated the experimental results of MIPv6, FMIPv6, HMIPv6 and PMIPv6 under the given test-bed, and analyzed their signaling cost and packet delivery cost under random walk model without considering the human mobility. More recently, Giust et al. [24] mainly focused on DMM especially network-based DMM, and implemented them in a

Linux-based test-bed to evaluate their handover delay in a real IEEE 802.11 scenario. Additional, they adopted the fluid flow model to derive the analytic model of signaling cost, packet delivery cost and handover latency. The above analyses show that most of existing researches adopt the fluid flow model or random walk model to capture the users' mobility. Fluid flow model can be applied when users have high mobility, while random walk is suitable for users moving in a limited area. However, both of them cannot comprehensively capture the human movement characteristics. Therefore, modeling human mobility and evaluating its impact on related network protocols have been got more concerns recently. However, there is lack of a comprehensive performance evaluation of mobility management protocols under realistic mobility models.

2.2 Human Mobility Characteristics

Different from traditional mobility models, human mobility is generally derived from realistic traces [32], and it has following statistic characteristics [33]:

- (1) Heterogeneously Bounded Mobility Area:
  Humans usually spend most of their time in several specific areas (also called as hubs) and move among them, which results in a high degree of temporal and spatial regularity of trajectories, and different people may have widely different move areas [35].
- (2) Heavy-tail Flights Length and pause times Distribution:
  Human is more likely to travel for long distances which results in that the flight distribution follows the truncated heavy-tail distribution, and the pause-time distribution follows the truncated power-law distribution [20].
- (3) Dichotomy of Inter-contact Time Distribution:
  Inter-contact time is the time elapsed between two successive meetings of the same persons. The complementary cumulative distribution function of inter-contact time of humans illustrates a dichotomy which consists of a truncated power-law head followed by an exponential tail [18].
- (4) Location Preference:
  Humans always follow simple reproducible movement patterns [13], and they spend most of time in small part of locations and repeat the same movement periodically.
- (5) Self-similar:
  The self-similar is observed at different scales such as space or time, which means that humans are always attracted to more popular places and therefore their visiting destinations tend to be heavily clustered [26]. In addition, humans like to visit destinations nearer to their current places when visiting multiple destinations in succession.
- (6) Irregular Inter-hub Movement:
  Humans do not move in a straight line from one hub to another due to the unexpected obstacles during the movement, which means humans do not take the shortest path but take a long path [27].

Due to these human mobility characteristics, the existing mobile models are not suitable to evaluate the performance of network protocols in realistic applications. In contrast, absorbing the human mobility characteristics such as predictability can benefit the protocol design. The prominent work in [8] shows that human mobility has high degree of spatial and temporal regularities. When applying the prediction into the handover [31], it can reduce the signaling cost if the prediction accuracy is higher than 40%.

2.3 Human Mobility Models

To capture these human mobility characteristics, several human mobility models have been proposed. Truncated Levy Walk (TLW) [35] is a kind of random walk which uses the truncated Pareto distributions for flight and pause-time distributions to capture the property of heavy-tail flight length distribution. In TLW model, a mobile node travels short distances in most of the time and sometimes long distances. TLW is a simple model but cannot capture the human spatial, temporal and social contexts. After that, Time-Variant Community (TVC) Model [12] captures the location visiting preferences and periodical reappearance (or spatial preference and temporal preference) by observing mobility characteristics from the traces, and sets up a time-variant community mobility model for in-depth theoretical analysis. Subsequently, SWIM [?] captures the feature that human always go to the places not very far from their home and where they can meet a lot of other people. Later on, SLAW mobility model [26] modifies Levy walk-based model and models the human waypoints as fractals. SLAW not only captures the heavy-tail flight and pause-time distributions, heterogeneously bounded mobility area of individuals and the truncated power-law inter-contact times, but also captures the additional features that the human destinations are dispersed in a self-similar manner and human more likely to choose a destination closer to its current locations. Therefore, SLAW can be viewed as a representative realistic mobility model which will be used in the following analysis.

The impacts of human mobility have been studied in term of delay torrent networks routing [19] and mobile ad hoc networks routing [38], which find out that the performance of some routing protocols becomes serious and discrepancy with the real scenarios, and they suggest to revisit mobility modeling to incorporate accurate behavioral models in future. Therefore, in this paper, we study the impact of human mobility on mobility management protocols.

3 Performance Evaluation over MM

In our performance evaluation, we first analyze realistic human mobility trace to acquire its parameters, and then tune the other mobility models to unify the simulation setting to compare them. Second, we analyze signaling and delivery costs of MIPv6, HMIPv6, PMIPv6 and DMM (including Host-DMM and Network-DMM) under different mobility models and realistic trace, and analyze their differences.

3.1 Realistic Human Mobility Trace

We select the NCSU realistic dataset [1] which records the locations of 35 nodes moving around the NCSU campuses. This realistic dataset can be viewed as a typical human mobility scenario to capture the mobility characters in campus. Its record interval is 30 seconds and the duration of each node is different. So we select a part of this dataset, which includes 34 nodes, and moves in the range of 12 * 8 km^2. The total moving duration is 6150 s.

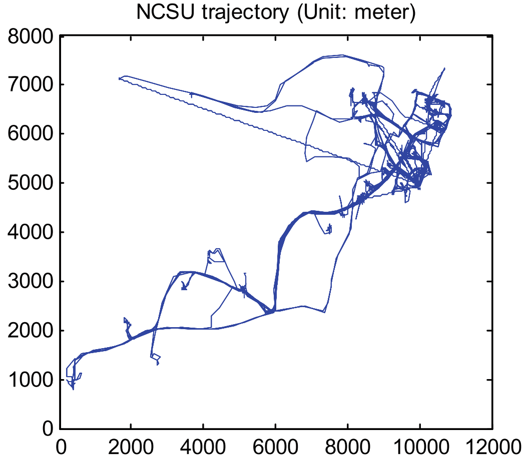


Fig. 1. The movement trajectories of NCSU.

Figure 1 shows a nodes movement trajectory (unit: meters). We can find that the trajectory is relative concentrated, and node only moves around some locations, and most moving path is not straight, which reflects the human mobility characteristics of heterogeneously bounded mobility area, location preference and irregular inter-hub movement.

Figure 2 shows the speed probability distribution. We can find out these speeds are from 0 m/s to 23 m/s, and most of speeds are below 5 m/s which are different from the traditional mobility models whose speed is generally uniform distribution between minimal speed and maximum speed. To tune the speed of other mobility models, we set the speed as [0, 21] m/s.

To simulate access networks such as MAG and domains such as LMA domain, we adopt the m * n mesh structure for the topology as shown in Fig. 3.

Each small square represents a subnet with a mobility anchor (such as AR or MAG) inside. Moreover, the topology is divided into different domains to simulate MAP domain or LMA domain where a MAP or a LMA is inside. In our simulation, we divide the topology into 24 domains which are marked as square as shown in Fig. 3. Besides, the HA is located in the center of the topology, and CMD of DMM is also located in the same location of HA.

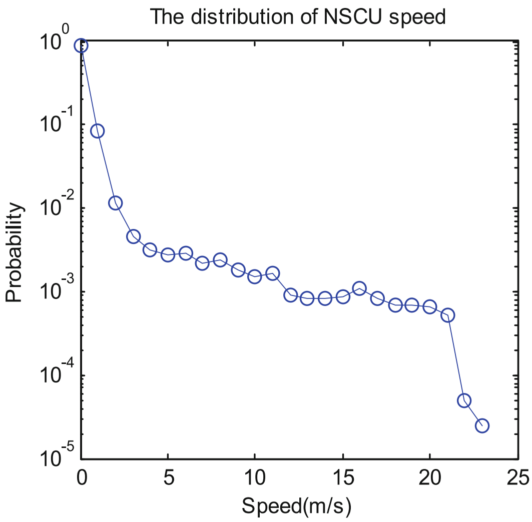


Fig. 2. Probability distribution of speed in NCSU.

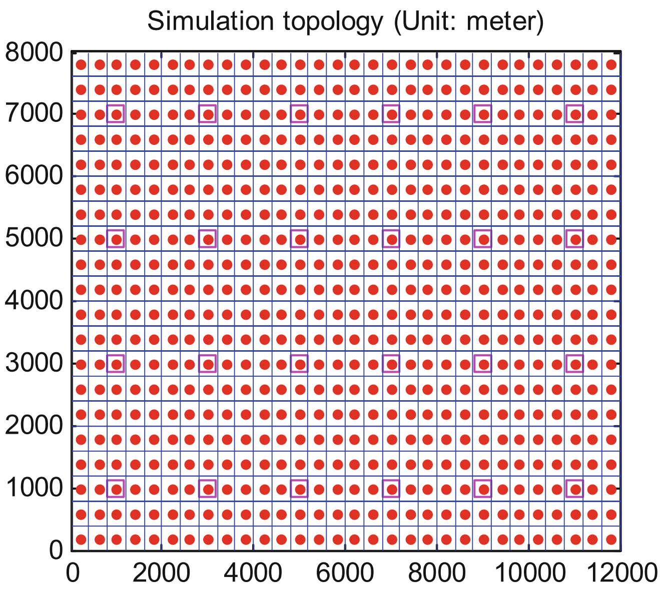


Fig. 3. The simulation topology (unit: meter).

3.2 Mobility Models Settings

In the evaluation, we adopt RW, RWP, RD to represent the typical mobility model, and SLAW to represent the human mobility model. The relevant parameters setting is based on the NCSU dataset. Table 1 shows the related parameters for each mobility models, and all simulation time is 6150 s which is same to the realistic trace.

Table 1. Simulation parameter setting.

Parameter	RW	RWP	RD	SLAW
Size (km^2)	12 * 8	12 * 8	12 * 8	12 * 8
Simulation time (s)	6150	6150	6150	6150
Velocity (m/s)	[0, 21]	[0, 21]	[0, 21]	[0, 21]
Pause time (s)	[0, 60]	[0, 60]	[0, 60]	[0, 60]
Cluster range (m)	N/A	N/A	N/A	200

First, we demonstrate the movement traces of different mobility models in the pre-defined network topology. Figure 4 shows the typical movement traces. We can get that the movement trajectories are greatly different. To be specific, RWP and RD are more diffused which are random without regularity. In contrast, RW and SLAW are more tenacious. This difference will influence the performance evaluation of mobility management protocols.

3.3 Mobility Management Analysis

Considering that handover times and location preferences are important for mobility management, we first compute the number of intra-domain and inter-domain handovers, and location distribution.

(1) The number of intra-domain and inter-domain handovers
Figure 5 shows the numbers of intra-domain and inter-domain handover during the simulation (X axis is the simulation time). It is obvious that the number of handover is increased with simulation time. The handover numbers of RD and RWP are significantly larger than others for that their movement trajectories are more diffusible. SLAW is more close to realistic trace for that it captures some human mobility characteristics such as heterogeneously bounded mobility area of individuals and self-similar to choose destination.
In perspective of mobility management, the more handover happens, the more signaling and delivery cost is generated. The reduction of handover derives from the glutinousness of human mobility, which reduces the handover probability.

(2) Location distribution
Figure 6 shows the normalized location distribution of different models, where X axis is the rank of locations and Y axis is the probability of the corresponding locations. It is obvious that the realistic trace is more concentrated, and MNs only move among several locations, while other models are

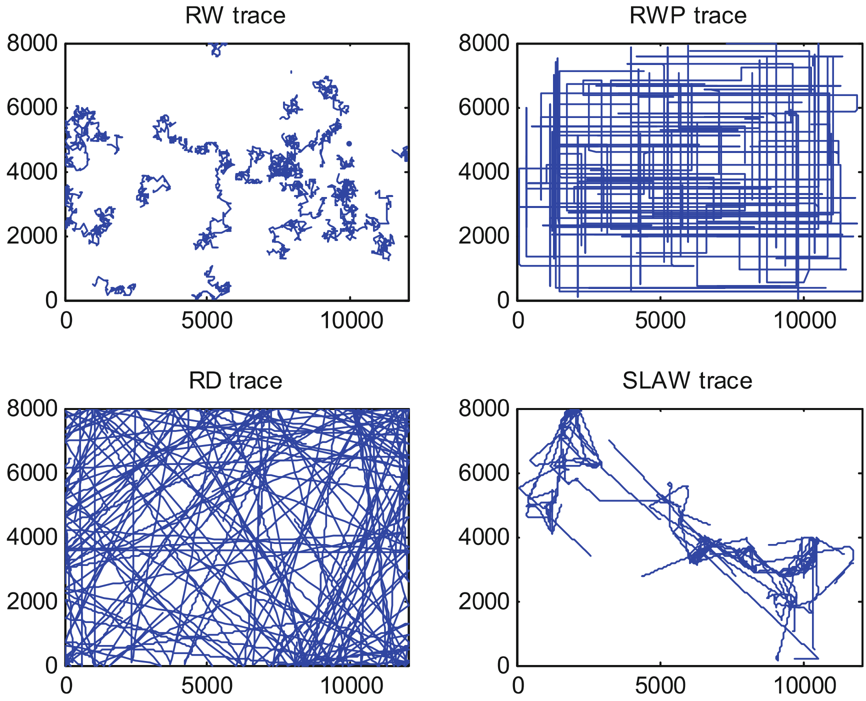


Fig. 4. Snapshot of movement traces (unit: meter).

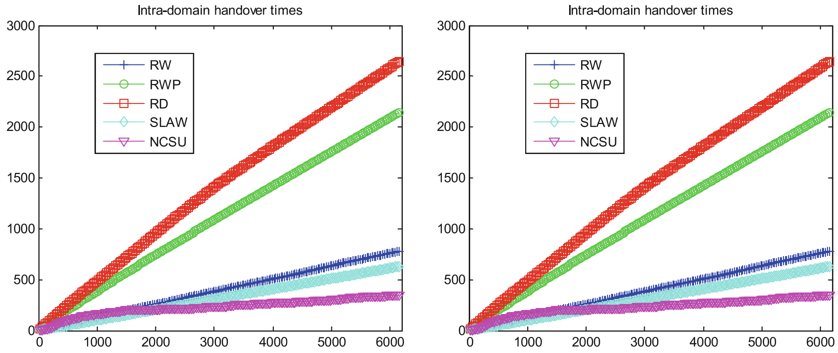
more distributed among the total movement area. This is consistent with the fact that human beings always spend most of time in only small part of locations. Therefore, it is important to optimize mobility management in term of binding cache for that MNs are generally located in limited places.

(3) Cost analysis under different mobility models

Based on the above analyses, we compare the performance of mobility management under different mobility models. The cost analysis is based on bytes * distance and Table 2 shows the related parameters. We run each simulation for 20 times, and average them to compare with the NCSU.

Figure 7(a) shows the signaling cost of different mobility management protocols under RW, RWP, RD, SLAW and NCSU. It can get that the signaling cost under different mobility models is different, and NCSU is less than the others. And the RD has largest signaling cost, while SLAW has similar signaling cost to that of NCSU. For different mobility management protocols, their relationship of size is same under different models.

Figure 7(b) shows the delivery cost, and it is obvious that mobility model has an important impact on delivery cost. More specifically, RWP and RD have large delivery cost due to their unrealistic movements. Both RW and SLAW are similar to NCSU. More important, the size relationship of different mobility management protocols under RD and RWP is different from



(a) Intra-domain handover (b) Inter-domain handover

Fig. 5. The number of total handovers.

Table 2. Parameters of cost analysis.

Name	Value(s)	Description
RS	16 byte	Router solicitation
RA	64 byte	Router advertisement
BU	56 byte	Binding update, used for MIPv6
BA	40 byte	Binding acknowledgement, used for MIPv6
LBU	56 byte	Local binding update, used for HMIPv6
LBA	40 byte	Local binding acknowledgement
PBU	56 byte	Proxy binding update, used for PMIPv6
PBA	40 byte	Proxy binding acknowledgement
RtSolPr	88 byte	Proxy router solicitation, used for FMIPv6
PrRtAdv	104 byte	Proxy router advertisement, used for FMIPv6
FBU	72 byte	Fast binding update, used for FMIPv6
FBack	32 byte	Fast binding acknowledgement
HI	72 byte	Handover initiate, used for FMIPv6
HAck	32 byte	Handover acknowledgement
FNA	24 byte	Fast neighbor advertisement
ABU	56 byte	Access binding update, used for HDMM
ABA	40 byte	Access binding acknowledgement, used for HDMM
MBU	56 byte	Mobility capable access router (MAR) binding update for DMM
MBA	40 byte	MAR binding acknowledgement
MCreq	76 byte	Mobility context request, used for NDMM
MCRes	76 byte	Mobility context response, used for NDMM
Plen	500 byte	Packet length
λ	0.5	Sessions arrival rate with Poisson process
μ	30 s	Session length with exponential distribution

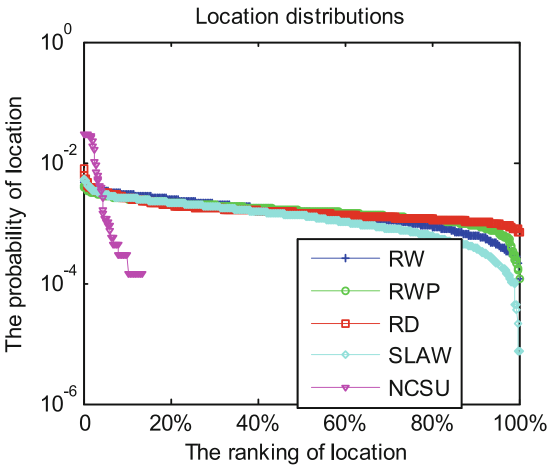


Fig. 6. Locations distribution of different models.

that of RW, SLAW and NCSU. This finding shows that using RD or RWP as the mobility model to evaluate the mobility management may get the wrong conclusion. Besides, we can also get that relative performance of each protocols follows the similar tendency, which shows that the simple mobility model can only get the qualitative results, but cannot provide the accurate quantitative results.

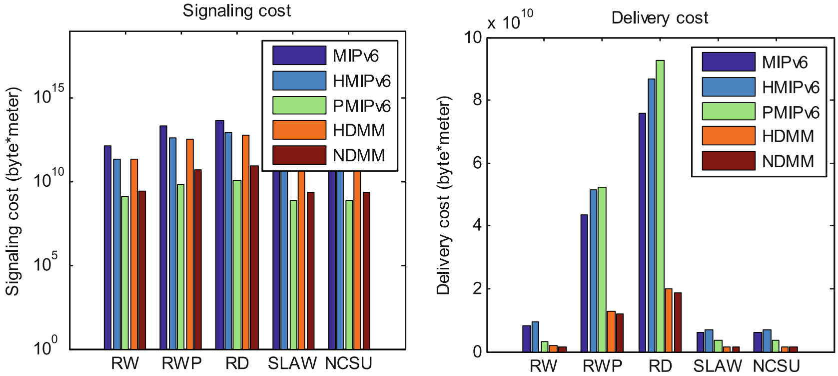
These evaluation results show that the performance of mobility management protocols is deeply dependent on the mobility models. However, due to the little consideration of special design for human mobility characteristics, mobility management protocols cannot absorb the positive affect of human mobility characteristics.

3.4 Discussions

Based on the above analytical results, the future mobility management design should consider the following aspects:

(1) Model the user behavior patterns and predict their future behaviors such as movement trajectory. The analytical results demonstrate that the mobile users always have the regular patterns in terms of time and space. Therefore, their movement trajectory can be predictive in advance especially in the scenarios such as high trains. Based on these findings, the mobility management protocols can be provided on-demand.

(2) Mine the social relationship among user and optimize the caching strategy. The location preference is derived from the social relationship of mobile users, which means that the mobile users only communicate with a small of part of the others. This finding can be used to optimize the binding



(a) Signaling cost (b) Delivery cost

Fig. 7. The cost under different mobility models.

caching design. To improve the intelligence of mobility management, the future directions should also consider the service characteristics and social relationship to optimize design.

4 Conclusion

In this paper, we investigate the related work in term of human mobility models, and analyze their impacts on the mobility management performance evaluation. From analytical results, we can observe that although the mobility models have an important impact of performance evaluation, the compared mobility management protocols don't get the benefits from the human mobility. The future design of mobility management should absorb the human mobility characteristics such as periodic reparation and social contract relationships to further improve their performance. In this work, the domain design is simple and ideal, so the further work is to combine the real network topology and traces to analyze their performance.

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