Mobility Models-Based Performance Evaluation of the History Based Prediction for Routing Protocol for Infrastructure-Less Opportunistic Networks

Sanjay K. Dhurandher[1], Deepak Kumar Sharma[2],
and Isaac Woungang[3](✉)

[1] CAITFS, Division of Information Technology, NSIT,
University of Delhi, New Delhi, India
dhurandher@rediffmail.com
[2] Division of Computer Engineering, NSIT,
University of Delhi, New Delhi, India
dk.sharma1982@yahoo.com
[3] Department of Computer Science, Ryerson University,
Toronto, ON, Canada
iwoungan@scs.ryerson.ca

Abstract. In Opportunistic Networks (OppNets), the sender and receiver of a packet are not assumed to be connected with each other through an end-to-end continuous path. They exploit the contact opportunity that arises between the nodes due to their mobility to pass the messages from one place to another in the network. They do not rely on any pre-existing topology; rather they belong to a dynamic network topology. In this paper, the performance of our recently proposed History-Based Prediction for Routing protocol for infrastructure-less OppNets (so-called HBPR) is evaluated on two different mobility models – the Random Waypoint (RWP) and the Custom Human Mobility Model (CHMM). The HBPR protocol is evaluated against four performance metrics, namely, the number of messages delivered, the overhead ratio, the average hop count, and the average latency. Simulation results show a significant decline in the performance of HBPR for the RWP model compared to the CHMM model.

Keywords: OppNets · Opportunistic routing · Infrastructure-less protocol · Delay tolerant networks · The ONE (Opportunistic Network) simulator · Mobility models

1 Introduction

Opportunistic Networks [1] are considered as the sub-class of Delay Tolerant Networks (DTNs) [2]. They are the recent extensions of MANETs [3] that have become very popular among the researchers working in the area of wireless networking and mobile communication. In contrast to MANETs, nodes in OppNets are not aware about the network configuration and the route construction is not static but dynamic in nature due to the ever changing network topology. Due to the transient and un-connected nature of

I. Stojmenovic et al. (Eds.): MOBIQUITOUS 2013, LNICST 131, pp. 757–767, 2014.
DOI: 10.1007/978-3-319-11569-6_66

the nodes, routing and forwarding of messages becomes a challenging task in such type of networks. The source node or intermediate node can choose any node as next hop from a group of potential neighbors, which promises to take the message closer to the destination or to the destination node itself. Thus, traditional MANET routing protocols such as AODV [4], DSR [5] and internet routing protocols such as TCP/IP do not work in OppNet scenarios. However, their utility and potential for scalability make them a huge success. A few typical characteristics of OppNets are described as follows [6, 7]:

(a) *Highly mobile nodes:* The network nodes are highly mobile in nature making this type of network quite dynamic and ever-changing. These networks can originate from one node that acts as seed and dynamically adds neighboring nodes to the network as and when required.
(b) *Sparse connectivity:* Because of their high mobility it is likely that nodes that have recently met do not encounter each other for a long period of time and network partitions can occur. As such, the connectivity is sparse, intermittent and usually unpredictable.
(c) *Store-carry and forward method:* The routing and forwarding in OppNets is based on the store-carry and forward technique. The nodes can store messages with themselves until they find the destination or find a node that is a better carrier for the message than itself.
(d) *No end-to-end path:* OppNets can deliver messages even though there might be no knowledge of a previous path. The nodes do not have to worry about finding or creating an end-to-end connected path. They study and utilize other aspects such as, behavior and characteristics of nodes to deliver messages.

The routing protocols used by OppNets can be classified into two major categories: *Infrastructure-less protocols* and *Infrastructure-based protocols* [8]. The *Infrastructure-less protocols* make no previous assumptions regarding the nodes and the network topology. No infrastructure existence is assumed which can help in the forwarding of messages. On the other hand, the *Infrastructure-based Protocols* make use of some form of infrastructure to deliver the messages effectively; e.g. base stations and access points. The base stations can either guide other nodes or serve as intermediaries for storing the messages. Their presence helps in modeling a structure of the network, and thus effectively decreases the complexity of the message delivery.

The rest of the paper is organized as follows. Section 2 presents some related works. Section 3 describes the simulation setup. Section 4 is devoted to the simulation results, where we discuss and compare the performance of our recently proposed HBPR protocol [9] using two different mobility models. Finally, Sect. 5 concludes our work.

2 Related Work

In this section, a brief overview of the HBPR protocol [9] is provided, along with the a description of the Random Waypoint [10] and the Custom Human Mobility [9] Models.

2.1 HBPR Protocol

The History Based Prediction Routing (HBPR) protocol [9] predicts a node's future location based on the past information about its movement in the network. This prediction is then used for message passing in the network. The HBPR maintains two tables, namely the *Home Location* table and the *History* table. The *Home Location* table stores the location of a node which it visits more frequently. On the other hand, the *History* table is used to maintain a list of various locations visited by a node in the past. The next hop selection in HBPR is based on the calculation of a *Utility Metric*. This *Utility Metric* is obtained as a function of three parameters. The first parameter is the *Stability of node's movements*. For this parameter, a list of a node's average speeds over a period of time is maintained. Using this list, it can be observed whether the change in the average speeds is very large or nominal. A nominal change accounts for a stable node whereas a large change signifies an unstable movement. The second parameter is *Prediction of the direction of future movement using Markov Predictors*. For this parameter, Markov models [11] are used to predict the next location based on the past histories. A table is maintained with the frequencies of visits for every location for the given pattern of visits. This is then used to predict the next location. The third parameter is *the perpendicular distance of the neighboring nodes from the line of sight of source and destination (SD line)*. This metric is used to select those nodes which are closer to the *SD* line as they have to travel a lesser distance as compared to those which are away from it. The message is then forwarded to those nodes that have their *Utility Metric* value greater than the *Threshold (T)*. The HBPR protocol is described in-depth in [9].

2.2 Random Waypoint Model

In the Random Waypoint model [10], nodes in the network move randomly in any direction within the simulation area. It includes the pause time between any changes in the direction or speed of the nodes. A mobile node stays at a location for a certain period of time and then moves to the new destination by choosing a random speed from the maximum and minimum range already defined.

2.3 Custom Human Mobility Model

In OppNets, the movements of devices mimic the movements of the human subjects carrying them. It is very likely that nodes will have a predictable fashion in which they move and there are always a few places (*Home Location)* that they will visit more frequently than others. Thus, it can be assumed that devices display a Human Mobility pattern [12]. Keeping this in mind, the *Custom Human Mobility Model* [9] movement model is designed, with the aim to simulate the community relationships among the nodes. The nodes might travel to their *Home Location* more frequently as compared to other locations. The whole world size is divided into cells of 100 m × 100 m. The nodes are then grouped into six communities. Each community has a *Home Location* cell. At the start of the simulation, every node is present in its *Home Location*, which it disseminates through the network using its own *Home Location table*. The node travels to its *Home Location* with a probability *p* and to all other locations with probability *1* − *p*.

3 Simulation Setup

The performance of HBPR protocol is evaluated using the ONE simulator [13]. The nodes are mobile and have been divided into six groups, where each group has 15 nodes. The first and third group nodes are of pedestrians with speed between 0.5 and 1.5 m/s. The second group is of cyclists with speed varying between 2.7 and 13.9 m/s. The fourth, fifth and sixth group nodes are cars with speeds varying in the range 7–10 m/s. The first, second and third groups have the same *Home Location* while the fourth, fifth and sixth groups have different *Home Locations.* The mobile nodes have a transmission range of 10 m and transmit at a speed of 2 Mbps. Each simulation is run for 43000 s. The total simulation area is taken to be 4500 m × 3400 m. A new message is generated at every 25–35 s and the message size varies from 500 KB to 1 MB. A constant bit-rate (CBR) traffic is generated between the nodes. The value of *p* is taken as 0.25 in this work.

The following settings and configurations have been used in our simulations:

(1) *Varying the number of nodes:* The total number of nodes in the simulation are varied as 90, 120, 150, 180, 210, 240, and 300. The number of nodes is kept fixed to 240 wherever it is not varied.
(2) *Varying the message Time-to-live (TTL):* The messages have their Time-to-live varied as 60, 90, 120, 150 & 180 s. The message TTL is kept fixed to150 s wherever it is not varied.
(3) *Varying the speed of nodes:* In order to evaluate the effect of node speed on the performance of HBPR, 3 sets of different speeds for different groups of nodes have been considered. In *Set 1,* the speed of nodes in group 1 and group 2 is fixed between 0.5 m/s and 1.5 m/s. Nodes in groups 4, 5 and 6 have their speed between 7 m/s and 10 m/s. Nodes in group 3 have their speed between 2.7 m/s and 13.9 m/s. In *Set 2*, the speed of nodes in groups 1 and 2 is fixed between 2.5 m/s and 4.5 m/s. Nodes in groups 4, 5 and 6 have their speed between 9 m/s and 12 m/s. Nodes in group 3 have their speed between 4.7 m/s and 19.9 m/s. In *Set 3,* the speed of nodes in groups 1 and 3 is fixed between 2.5 m/s and 4.5 m/s. Nodes in groups 4, 5 and 6 have speed between 7 m/s and 10 m/s. Nodes in group 2 have their speed between 2.7 m/s and 13.9 m/s. All nodes move according to their respective group speed wherever speed is not varied.

The considered performance metrics are:

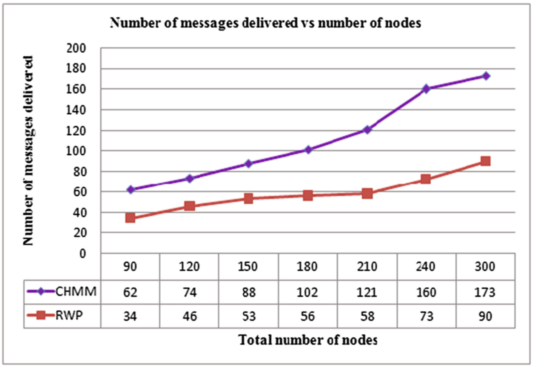
(1) *Total number of messages delivered:* This is the count of the total number of messages successfully delivered to the destination node.
(2) *Average Hop Count:* This is the average of the number of intermediate nodes travelled by a message to reach the destination.
(3) *Overhead Ratio:* This is the average number of forwarded copies per message.
(4) *Average Latency:* This is the average of the difference between the message delivery time and message creation time.

4 Simulation Results

In this work, we have simulated the HBPR with only two mobility models namely the Random Waypoint (RWP) model and the Custom Human Mobility Model (CHMM). However, it can also be simulated on other mobility models such as Map Based Movement model [13], Shortest Path Map Based Movement model [13] etc. The results comparing the RWP model and the CHMM model are captured in Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12. From these figures, it can be observed that the number of nodes, the message TTL, and the speed of nodes, do impact the performance of the HBPR routing protocol.

4.1 Performance of HBPR Under Varying Number of Nodes

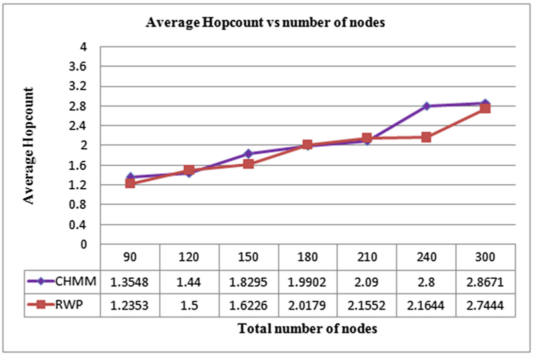
In Fig. 1, it can be observed that when the number of nodes increases, the number of messages delivered also increases. The CHMM has more number of messages delivered compared to the RWP. Also, the rate of increment is more pronounced in case of CHMM. This is attributed to the fact that nodes in CHMM come to their home locations more frequently, and thus follow some pattern in their movement in the network. This is not the case with RWP. Figure 2 shows that the average hop count for a message remains comparable for both CHMM and RWP. In Fig. 3, the overhead ratio increases with the increase in the number of nodes. This is attributed to the fact that a node now has more number of potentially good neighbor nodes at its disposal that can forward or deliver the message towards the destination. However, the overhead ratio of HBPR remains much less for CHMM compared to RWP.



	90	120	150	180	210	240	300
CHMM	62	74	88	102	121	160	173
RWP	34	46	53	56	58	73	90

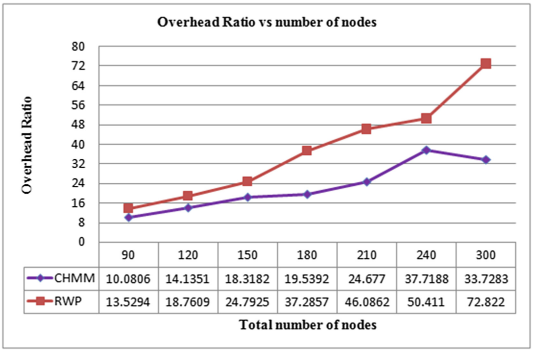
Fig. 1. Number of messages delivered vs. Total number of nodes.

In Fig. 4, it can be observed that the average latency for HBPR is lesser for RWP at smaller number of nodes and more pronounced at higher number of nodes as compared to the CHMM. This is justified by the fact that with the increase in number of nodes, there may be more nodes present in the network that have common home locations. This favors HBPR to deliver the messages to the destination in lesser time using CHMM.



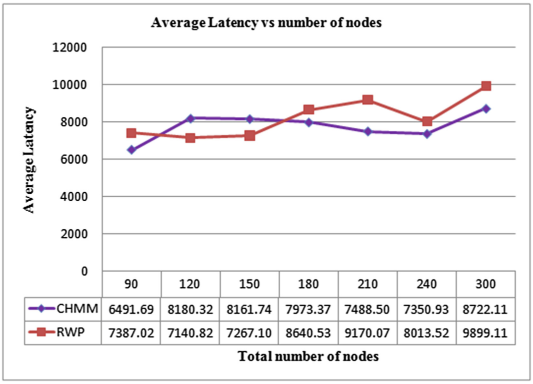
	90	120	150	180	210	240	300
CHMM	1.3548	1.44	1.8295	1.9902	2.09	2.8	2.8671
RWP	1.2353	1.5	1.6226	2.0179	2.1552	2.1644	2.7444

Fig. 2. Average hop count vs. Total number of nodes.



	90	120	150	180	210	240	300
CHMM	10.0806	14.1351	18.3182	19.5392	24.677	37.7188	33.7283
RWP	13.5294	18.7609	24.7925	37.2857	46.0862	50.411	72.822

Fig. 3. Overhead ratio vs. Total number of nodes.



	90	120	150	180	210	240	300
CHMM	6491.69	8180.32	8161.74	7973.37	7488.50	7350.93	8722.11
RWP	7387.02	7140.82	7267.10	8640.53	9170.07	8013.52	9899.11

Fig. 4. Average latency vs. Total number of nodes.

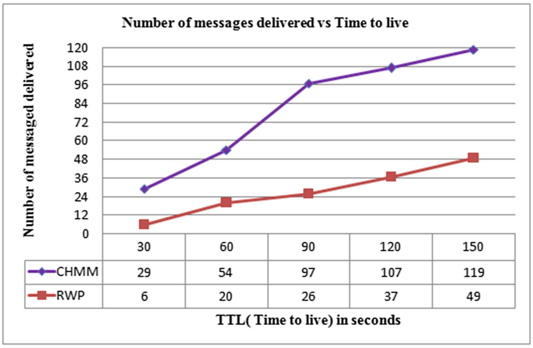


Fig. 5. Number of messages delivered vs. Time-to-live.

4.2 Performance of HBPR Under Varying Time-To-Live (TTL) Field Values

In Fig. 5, it can be observed that the number of messages delivered increases with the increase in the Time-to-live. This is attributed to the fact that with the increase in a message's TTL, a message can remain active in the network for a longer period of time, resulting in more messages getting delivered to the destination. The rate of increment and the total number of messages delivered is higher in CHMM as compared to RWP.

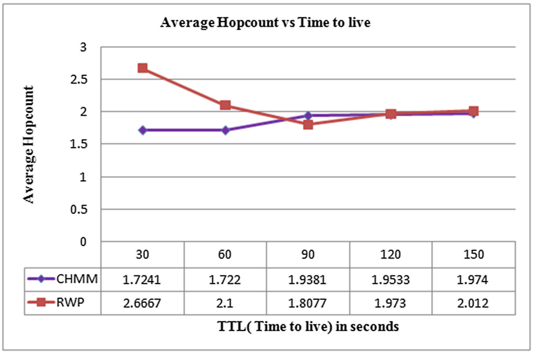


Fig. 6. Average hop count vs. Time-to-live.

In Fig. 6, it can be observed that the average hop count for a message is lesser for CHMM at smaller values of TTL. However, it remains comparable for both CHMM and RWP at higher values of TTL. In Fig. 7, it can be observed that the overhead ratio decreases with the increase in message TTL. This is attributed to the fact that with the increase in message TTL, the messages are given enough time to reach the destination and are not dropped on the way. This results in a limited number of copies of a particular message flowing in the network, and thus lowers the overhead ratio.

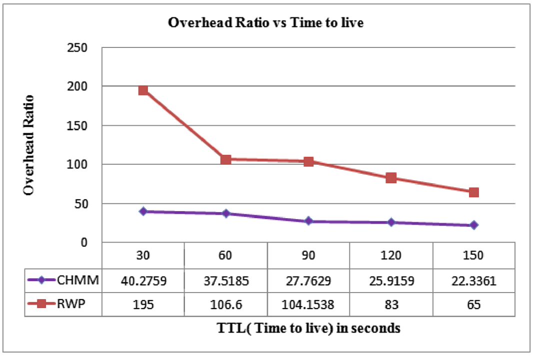


Fig. 7. Overhead ratio vs. Time-to-live.

In Fig. 8, it can be observed that the average latency for HBPR increases with the increase in message TTL. This is justified by the fact that with the increase in the value of TTL, a message will take more time for getting delivered. This may increase the overall value of the average latency/delay for all the messages in the network. However, it remains comparable for both CHMM and RWP.

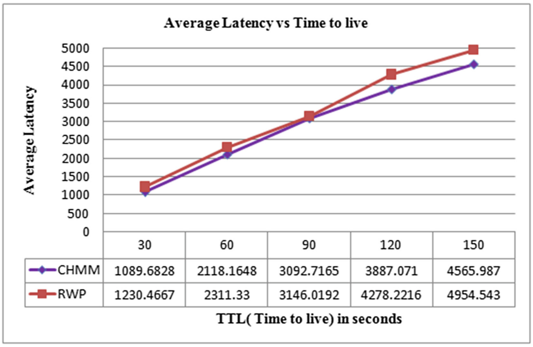


Fig. 8. Average latency vs. Time-to-live.

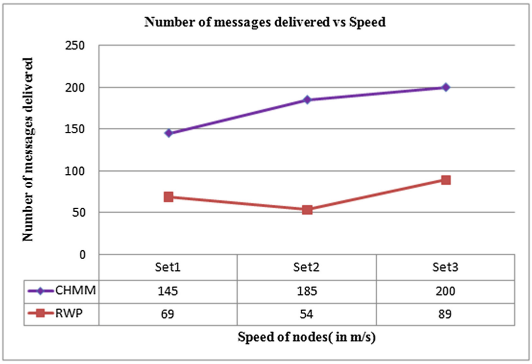


Fig. 9. Number of messages delivered vs. Speed of nodes.

4.3 Performance of HBPR Under Varying Node Speeds

In Fig. 9, it can be observed that the number of messages delivered is maximum for Set 3. This number is higher in case of CHMM as compared to RWP. Figure 10 shows that the average hop count for a message is higher for CHMM (compared to RWP) at all the three Speed Sets. Its value is lowest at Set 2 for both CHMM and RWP. From Fig. 11 (resp. Fig. 12), it can be observed that the overhead ratio (resp. the average latency) for HBPR is less in case of CHMM as compared to RWP in all the three Sets. These values are minimum for CHMM at Set 2 and for RWP at Set 3.

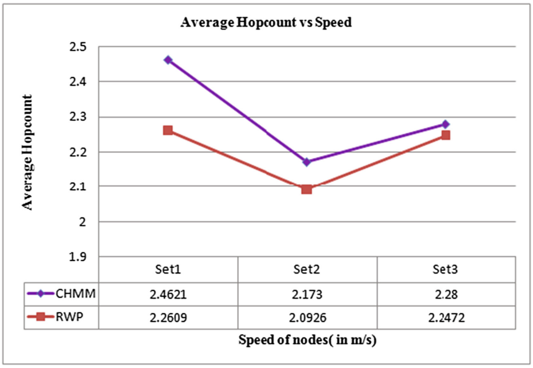


Fig. 10. Average hop count vs. Speed of nodes.

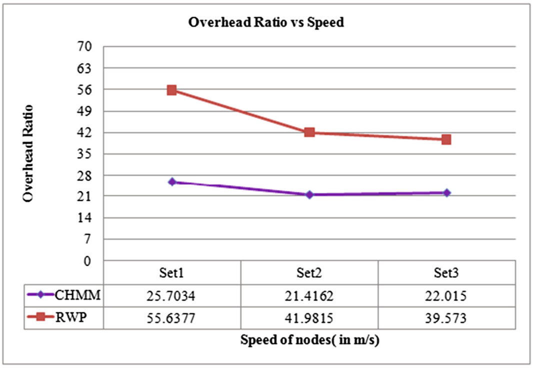


Fig. 11. Overhead ratio vs. Speed of nodes.

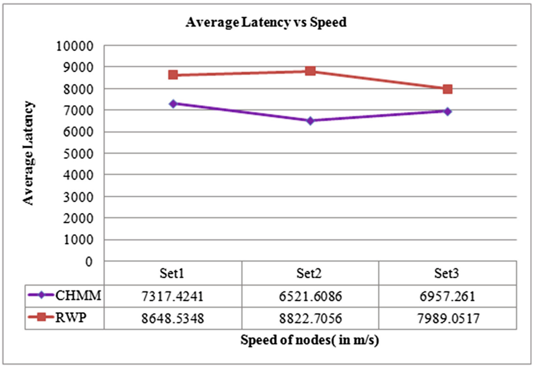


Fig. 12. Average latency vs. Speed of nodes.

5 Conclusion

In this work, the performance of HBPR is evaluated against various performance metrics using two movement models: the Random Waypoint model and the Custom Human Mobility model. Simulations results show that HBPR performs significantly well in terms of number of messages delivered when CHMM is used. The overhead ratio and average latency is also lesser in case of CHMM as compared to RWP. From these, it can be concluded that CHMM is best suited for the HBPR protocol. The use of CHMM can be attributed to the fact that HBPR is designed to perform best with human scenarios. It works on the existence of community such as structures and a recurring pattern. Hence, its performance will surely decrease in a movement model where the nodes move randomly rather than with a predetermined destination. As future work, we intend to study the performance of the HBPR protocol under other realistic mobility models.

Acknowledgment. This work was supported in part by a grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) held by the third author, under Ref# RGPIN/ 293233-2011.

References

1. Lilien, L., Kamal, Z.H., Bhuse, V., Gupta, A.: Opportunistic networks: the concept and research challenges in privacy and security. In: Proceedings of NSF International Workshop on Research Challenges in Security and Privacy for Mobile and Wireless Networks (WSPWN 2006), Miami, pp. 134–147, March 2006
2. Fall, K.: A delay-tolerant network architecture for challenged internets. In: Proceedings of ACM SIGCOMM 2003, Karlsruhe, Germany, pp. 27–34, 25–29 August 2003
3. Toh, C.-K.: Ad Hoc Mobile Wireless Networks: Protocols and Systems. Prentice Hall PTR, Englewood Cliffs, ISBN: 0-13-007817-4 (2002)
4. Perkins, C.E., Belding-Royer, E.M., Das, S.: Ad hoc on demand distance vector (AODV) routing. IETF, RFC 3561, July 2003

5. Johnson, D., Maltz, D.: Dynamic source routing. In: Imielinski, T., Korth, H. (eds.) Mobile Computing, vol. 353, Chap. 5, pp. 153–181. Kluwer Academic Publishers, Dordrecht (1996)
6. Dhurandher, S.K., Sharma, D.K., Woungang, I., Chao, H.-C.: Performance evaluation of various routing protocols in opportunistic networks. In: Proceedings of IEEE GLOBECOM Workshop 2011, Houston, TX, USA, pp. 1067–1071, 5–9 December 2011
7. Huang, C.-M., Lan, K.-C., Tsai, C.-Z.: A survey of opportunistic networks. In: Proceedings of the 22nd International Conference on Advanced Information Networking and Applications Workshops (AINAW 2008), Okinawa, Japan, pp. 1672–1677, 25–28 March 2008
8. Pelusi, L., Passarella, A., Conti, M.: Opportunistic networking: data forwarding in disconnected mobile ad hoc networks. IEEE Commun. Mag. **44**(11), 134–141 (2006)
9. Dhurandher, S.K., Sharma, D.K., Woungang, I., Bhati, S.: HBPR: history based prediction for routing in infrastructure-less opportunistic networks. In: Proceedings of 27th IEEE International Conference on Advanced Information Networking and Applications (AINA-2013), Barcelona, Spain, pp. 931–936, 25–28 March 2013
10. Camp, T., Boleng, J., Davies, V.: A survey of mobility models for ad hoc network research. Wirel. Commun. Mob. Comput. (WCMC) (Special Issue on Mobile Ad Hoc Networking: Research, Trends and Applications) **2**(5), 483–502 (2002)
11. Ross, S.M.: Introduction to Probability Models. Academic Press, New York, ISBN-10: 0123756863 (1985)
12. Song, C., Qu, Z., Blumm, N., Barabasi, A.: Limits of predictability in human mobility. Science **327**(5968), 1018–1021 (2010). doi:10.1126/science.1177170
13. Keranen, A.: Opportunistic network environment simulator. Special Assignment Report, Helsinki University of Technology, Department of Communications and Networking, May 2008