Mobile Information Systems 4 (2008) 219–235
IOS Press

WIT: A wireless integrated traffic model

Arta Doci[a] and Fatos Xhafa[b]
[a]*Department of Mathematical & Computer Sciences, Colorado School of Mines, Golden, CO 80401-1887, USA*
E-mail: adoci@mines.edu
[b]*Department of Languages and Informatics Systems, Technical University of Catalonia, Barcelona, Spain*
E-mail: fatos@lsi.upc.edu

Abstract. Simulation is a common approach for designing ad hoc network applications, due to the slow deployment of these networks. The main building blocks of ad hoc network applications are the routing protocols, mobility, and traffic models. Several studies, which use synthetic models, show that mobility and traffic have a significant effect on protocol performance. Synthetic models do not realistically reflect the environment where the ad hoc networks will be deployed. In addition, mobility and traffic tools are designed independently of each other, however real trace data challenge that assumption. Indeed, recent protocol performance evaluation using real testbeds show that performance evaluations under real testbeds and simulations that use synthetic models differ significantly. In this paper we consider jointly both real mobility and traffic for protocol performance evaluation. The contributions of this work are as follows: (1) demonstrates that real mobility and traffic are interconnected; (2) announces the design and implementation of WIT –Wireless Integrated Traffic–, which includes the design of a real traffic generator; (3) shows that under real mobility and integrated traffic the performance metrics need to be re-thought, thus we propose availability as a new ad hoc network protocol performance metric; and, finally, (4) evaluates protocol performance under synthetic and real mobility models with integrated traffic. We believe that the results of our work constitute a step forward toward benchmarking of ad hoc network performance evaluations.

1. Introduction

Ad hoc networks, which are usually referred to as the art of networking without a network, are networks of wireless devices that form a network without an existing infrastructure. The unique characteristics of these networks are battery, bandwidth, and security constraints. In addition, another feature is that they are multi-hop, since to send a packet from source to destination, due to limited transmission ranges of the wireless devices, it will require that the packet must be relayed by intermediary nodes. The principal applications of these networks have been military driven, thus “the solutions so far proposed are suitable for battlefields and for large scale civilian defense and emergency operations. Commercial applications are finally beginning to emerge” [9].

Camp et al. [5] presented an in-depth study of the synthetic mobility models and demonstrate how the performance of mobile network protocols can vary significantly with different mobility models. Their contribution was the identification of factors, such as mobility, that have an effect into protocol performance. On the other hand, authors of [4,7,8] address the question: Given a number of factors that affect the protocol performance, i.e., traffic and mobility, how to separately analyze the effect of the individual factors? Specifically, the authors showed that the two main parameters of the mobility models, such as speed and pause time, have a significant effect on routing performance. They demonstrated that as

1574-017X/08/$17.00

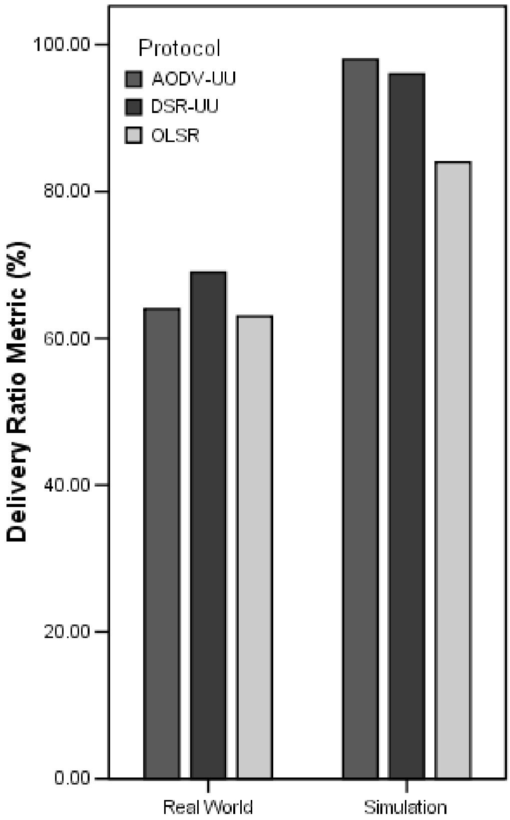


Fig. 1. Protocol performance in simulation and real world environments.

the pause time increases at low speeds, an almost perfect delivery ratio is obtained. In addition, the authors showed that the parameter *number of sources* from the traffic model affects the performance. Specifically, as the number of sources increases, the performance drops for all protocols due to congestions in the network.

It should be noted that all the studies mentioned so far, used synthetic mobility and traffic models to evaluate the protocol performance. Most of the studies used Ad-hoc On-demand Distance Vector Routing (AODV) [21] and Dynamic Source Routing (DSR) [12] routing protocols in the routing layer, where different implementations exist, including the Uppsala University (UU) implementations. Recent studies, for example the authors of [20], used real test beds in their performance evaluations. They showed that there were observed significant differences between the performance evaluations into simulations and real testbeds, by demonstrating that the delivery ratio of the protocols drops by 30% when using real test beds versus simulation (see Fig. 1). The same conclusion is reported in [16], exemplified by the case of mobility scenarios of multicast protocols.

The main assumption in synthetic mobility models is that wireless nodes start and remain into the simulation for the duration of the simulation, which is a user specified variable. On the other hand, real user traces (e.g. [14]) challenge this assumption and suggest that wireless nodes posses dynamic membership, meaning that they join and leave the network at different times and are withdrawn from exponential distributions. In addition, another unrealistic assumption in simulation models, is that the traffic and mobility have been implemented as two independent tools. We show in this paper that when using real mobility tools that support dynamic membership *traffic and mobility models are interconnected*.

To achieve the goal, we designed and implemented WIT (Wireless Integrated Traffic), which to the best of our knowledge, is the first tool that integrates a real mobility model (RealMobGen [23]), with traffic. First, the tool learns the dynamic membership of the nodes from the mobility tool, then by using the knowledge gained it generates the necessary traffic. The traffic generated can be the Poisson, Exponential, Pareto, or CBR models, which are extended to take into account the dynamic membership of the nodes.

Furthermore, a unique feature of WIT is the correlation of real traffic with the main characteristic of RealMobGen that is the wireless nodes cluster around the hotspots. The authors of [19] show that traffic is location dependent. For example, they show that traffic generated depends on the hotspots and the subnet they belong to, which at a fine grain level can be characterized by a Weinbull distribution. In order to account that traffic is location dependent, WIT introduces the `HotspotTrafficArray` array, which stores the parameters of the Weibull distributions that are extracted from the same real dataset that RealMobGen was extracted from. In addition, the real data sets show that almost 80% of the traffic is TCP flows (not CBR as used by most of the studies, so far).

In addition, as indicated in [18], a simulation model should be validated relative to those measures of performance that actually be representative of those cases. However, we realized that none of the current performance metrics can be used, due to the dynamic membership of the nodes; this actually revealed the need for the introduction of new performance metrics. Therefore, we introduce here a new metric, namely *availability*.

The contributions of this paper could be summarized as follows: (1) we present WIT (Wireless Integrated Traffic), an integrated Traffic and Real Mobility tool; (2) extend current traffic tools, as well as, implement a new realistic traffic tool, which generates 80% TCP traffic flows and generates traffic that is dependent on wireless nodes location and the type of the node; (3) define *Availability*, which is a new performance metric that takes into account the dynamic membership of the nodes; and finally, (4) evaluate protocol performance using real mobility model and integrated traffic, thus make a step forward toward benchmarking of performance evaluations in wireless networks, which has been left behindhand.

WIT is implemented under the NS 2 [10] network simulator, since it is the most utilized simulator for ad hoc networks [3]; as a matter of fact, “NS is an ideal virtual test bed for comparing protocols because it offers a publicly available simulator with a large protocol library.” The reminder of the paper is structured as follows. Section 2 discusses the synthetic and real mobility model used in this paper. In Section 3, we survey the current traffic tools and propose to extend current traffic models to interconnect traffic and mobility. The architecture of WIT tool is presented in Section 4. We show in Section 5 some simulation results of the performance analysis under integrated traffic model with real mobility. We end in Section 6 with some conclusions and future research on the field.

2. Mobility models

In this section we briefly overview the synthetic and real mobility models. We selected one representative each from synthetic and real mobility models. First, we selected the Random Waypoint Mobility (RWM) [4] synthetic model, since it is the most used synthetic mobility model in ad hoc network simulations. Second, we selected RealMobGen [23] as a realistic mobility model representative because it is the only mobility model which implements the dynamic membership of the nodes.

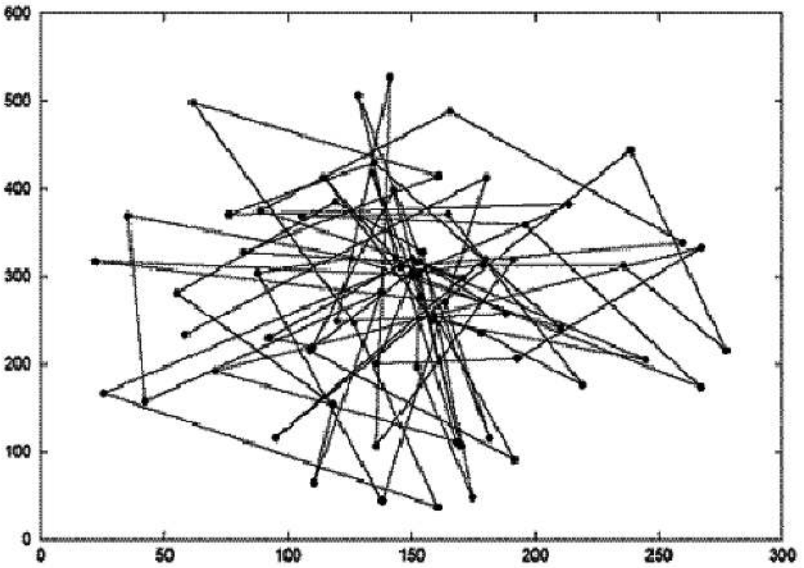


Fig. 2. Snapshot of RWM.

2.1. Random Waypoint Mobility model

The main characteristics of a synthetic mobility model are speed, pause distribution, and direction of movement. In this model, each node is assigned a randomly distributed initial location $(x0; y0)$. Then, each node randomly picks up a destination independent of its initial position and moves toward it with speed chosen uniformly on the interval $(v_0; v_1)$. Nodes pause upon reaching each destination and repeat the process until the allotted simulation time. We show in Algorithm 1 the pseudo-code for RWM. A snapshot of the RWM model is given in Fig. 2.

Algorithm 1. RWM Algorithm

```
Input: Number of nodes; Pause time; Maximum speed; Area; Simulation time

Pick a random initial position for each node.
repeat
    Select a destination node, independent of the initial position of the node.
    Select speed $v$ from a uniform distribution $(v_0; v_1)$.
    Move the node with speed $v$ to the destination through a straight line.
    Pause for the pause time.
until Allotted simulation time
```

2.2. RealMobGen model

RealMobGen is based on Dartmouth's model of mobile network traces [14] and University of Southern California's Weighted Way Point (WWP) [11] model. The model mimics the environments where ad hoc networks will likely be deployed closer, since it borrows its characteristics from models derived from real user traces. In RealMobGen, nodes are classified as stationary (46% of the nodes) or mobile (54% of the nodes). Mobile nodes select the next location not independently of the current location, but rather withdraw it from a time-dependent transition matrix. In addition, the direction of movement from one

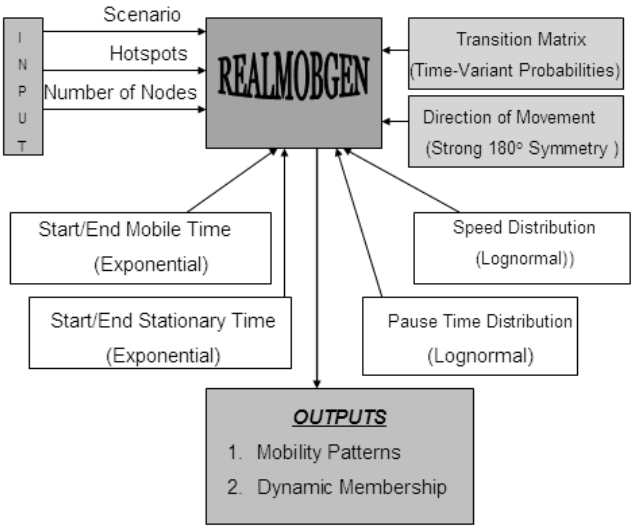


Fig. 3. REALMOBGEN building blocks.

location to another one follow a 180° node symmetry. The distributions of the extracted variables are log-normal for the pause time, exponential for the start/end times, and log-normal for speed (se Fig. 3 for the main building blocks).

Specifically, the generator works as follows:

Stationary Nodes: select a location based on a transition matrix that defines the probabilities for moving from one point to another. Once a location is selected a node is turned on for a time drawn from the exponential distribution of start time for the stationary nodes. Stationary node stays at the selected location until the allotted stationary end time.

Mobile Nodes: select a start location based on the transition matrix. The mobile node enters the simulation at a time drawn from the mobile node start time. The node pauses at the selected location until the allotted pause time from mobile pause time exponential distribution. After the pause time is up, the mobile node selects the next location based on the transition matrix and moves there not in straight line but following data that supports movements along popular roads and turns. The mobile node repeats the pattern '*pause–select next location–move there*' until allotted mobile simulation end time.

RealMobGen shows that wireless nodes tend to cluster around popular locations, i.e., cafeteria, gym, classes, and library (see Fig. 4 for a snapshot of RealMobGen on 40 wireless nodes distributed onto a campus map). To the best of our knowledge, RealMobGen is the first mobility model that implements the dynamic characteristic of wireless devices in NS 2, that is, devices join and leave the network at different times, as shown in Fig. 5.

3. Traffic models

NS 2 views traffic as a two layer approach (as shown in Fig. 6). The first layer implements transport protocols, Transmission Control Protocol (TCP) and User Datagram Protocol (UDP), while the second

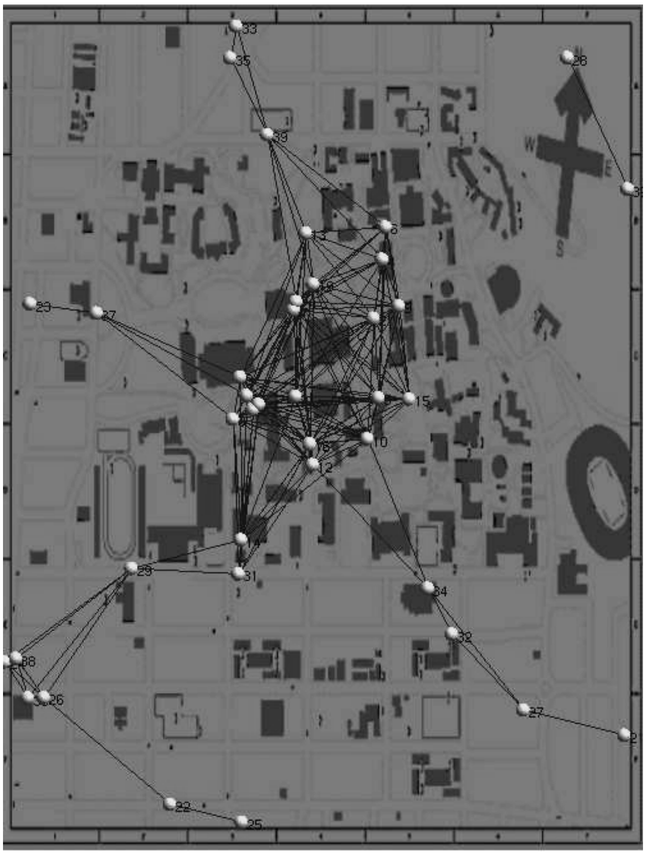


Fig. 4. RealMobGen on 40 nodes distributed onto a campus map.

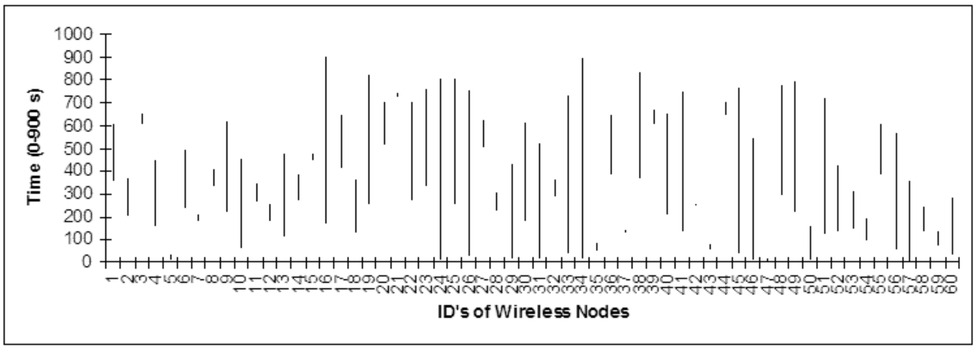


Fig. 5. Dynamic membership graph on 60 nodes.

layer transmits application level data. For example, FTP and Telnet are two applications that generate traffic over TCP. On the other hand, Constant Bit Rate (CBR), Exponential, Pareto, and Poisson are applications that can be used to generate traffic over UDP.

Traffic modelling can be classified under two main groups. The first group is that of applications that generate continuous traffic, namely the CBR that is the most used traffic model in ad hoc network

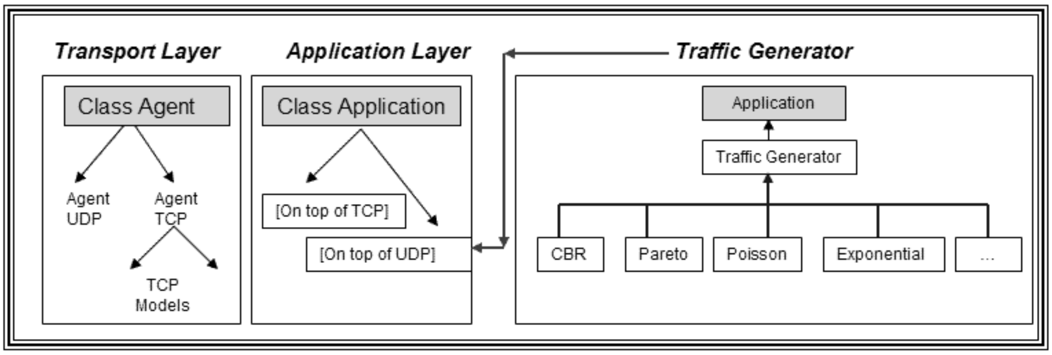


Fig. 6. Traffic generation process in NS 2.

simulation studies [4,7]. In the second group, there are applications that model packet arrivals under Pareto, Exponential and Poisson Distribution [15,13]. The latter, can be considered as applications that generate bursty traffic. We briefly describe these models next.

Constant Bit Rate traffic model. In this model source nodes generate traffic at a constant rate that are sent every interval ΔT seconds, which is defined by the user. For example, many sensor network applications generate constant bit rate traffic. In most ad hoc network applications wireless nodes do not send traffic continuously.

Exponential and Poisson traffic models. The exponential traffic model sends traffic during an '*on*' state and does not send any traffic during the '*idle*' state. The traffic is generated during the '*on*' state with the following parameters: the packet size, the traffic rate, and the burst time.[1]

The exponential distribution can be viewed as a Poisson process when setting the variable burst time to zero and the variable traffic rate to a large value. In general, the packet inter-arrival times in the Poisson process are exponentially distributed. The probability distribution function is given by Eq. (1) and the density function is given by Eq. (2).

$$F(t) = 1 - \exp^{-\lambda t}, \text{ where } \lambda \text{ is arrival rate} \tag{1}$$

$$f(t) = \lambda \exp^{-\lambda t}. \tag{2}$$

Pareto traffic model. The Pareto traffic model also has the 'on' and 'idle' states, as the exponential traffic model. The packet arrival times of the Pareto distribution are independent and identically distributed, which means that each arrival time has the same probability distribution as the other arrival times and all are mutually independent. The two main parameters of the Pareto process are the shape and the scale parameter. The probability distribution function is given by Eq. (3) and the density function is given by Eq. (4).

$$F(t) = 1 - (\frac{b}{t})^a, \text{ where } a, b \geqslant 0 \text{ and } t \geqslant 0 \tag{3}$$

$$f(t) = \frac{ab^a}{t^{a+1}} \text{ for } t \geqslant b, \tag{4}$$

where a is the shape parameter and b is the scale parameter.

---

[1] The mean of the '*on*' time that is withdrawn from an exponential distribution.

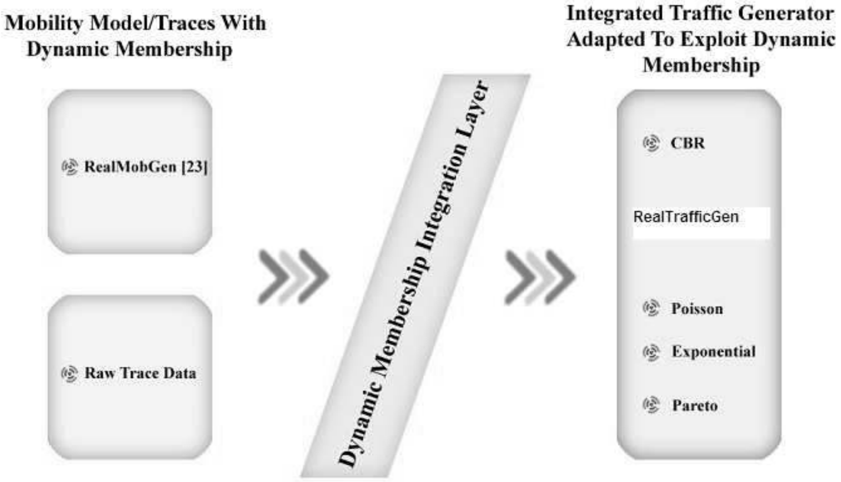


Fig. 7. WIT architecture.

4. WIT: Wireless Integrated Traffic model

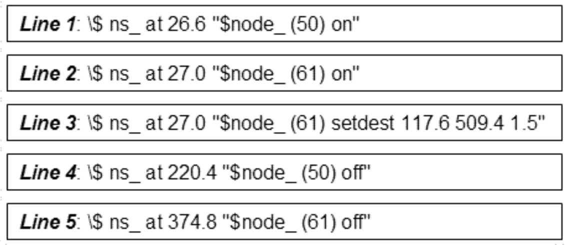
We extended the current traffic models in NS 2 to take into account the dynamic membership of the wireless nodes. In addition, we implemented RealTrafficGenerator that is extracted from real user data [19] previously used to design RealMobGen tool. Traffic generation is designed to be dependent on the hotspots and is modelled to follow Weibull distributions. In this section, we first discuss the architecture of WIT and then, we show the design choices of the new traffic RealTrafficGen tool.

4.1. WIT architecture

The main building blocks of WIT (see Fig. 7) are the output of RealMobGen or the real user trace data (raw), the dynamic membership layer, and the integrated traffic models. The dynamic membership layer parses the mobility information in an understandable and useful format for any traffic tool.

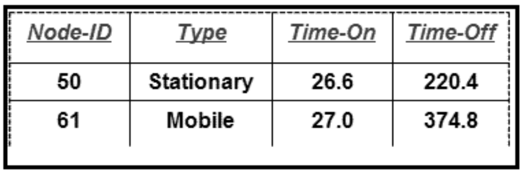
For example, in Fig. 8 we provide a snapshot of a mobility file generated from RealMobGen. Let's look at the snapshot to see what useful information can we gather. There are two nodes in this snapshot, node number 50 and 61. Node number 50 turns on at time *26.6 seconds* while node 61 turns on at time *27.0 seconds*, as shown in Line 1 and Line 2. While, on Line 4 and Line 5 we see that node 50 turns off at time *220.4 seconds* and node 61 turns *off* at time *374.8 seconds*. The only difference between the two nodes can be seen on Line 3 where node 61 is given a destination to move at, by use of the NS 2 $setdest$ command. The destination is located by (x, y) coordinates, $(117.6, 509.4)$, and also is assigned an average speed of *1.5 miles/second* to move toward the assigned destination. On the other hand, node 50 is not given any destination to move at. The difference we just described defines the type of the nodes, specifically node 50 is stationary, therefore it stays in the same place for the time it is active, while node 61 is mobile.

Hereby, we provide the explanation for the parser output. For example, in Fig. 9 we provide the snapshot of the parser output, which includes the node number (called *Node-ID*), the flavor of the node (called *Type*), the time the node turned on (called *Time-On*), and the time when the node turned off



```
Line 1: \$ ns_ at 26.6 "$node_ (50) on"
Line 2: \$ ns_ at 27.0 "$node_ (61) on"
Line 3: \$ ns_ at 27.0 "$node_ (61) setdest 117.6 509.4 1.5"
Line 4: \$ ns_ at 220.4 "$node_ (50) off"
Line 5: \$ ns_ at 374.8 "$node_ (61) off"
```

Fig. 8. Output generated from RealMobGen.



Node-ID	Type	Time-On	Time-Off
50	Stationary	26.6	220.4
61	Mobile	27.0	374.8

Fig. 9. Output generated from Interconnected Traffic Parser.

(called *Time-Off*). The parsed information is then fed to the traffic tool. The traffic tool is modified to be able to gain knowledge fed by the parser.

4.2. RealTrafficGen model

RealTrafficGen model, which stands for real traffic generator, integrates with RealMobGen not only by retrieving the dynamic membership of the wireless nodes, but also by adding three new features, which are based on the type of the node, as follows:

1. The generated traffic is dependent on the location, thus this model introduces distributions for each hotspot (based on real data).
2. Mobile nodes send more traffic then stationary wireless nodes, due to forwarded traffic from different hotspots, as well as their own traffic. This is the first model that differentiates the amount of traffic generated by the type of the node.
3. Traffic is likely to satisfy self-similarity property, rather then stationary distributions, due to diurnal circle; it is implemented as Weibull distribution.

The model creates `HotspotTrafficArray` (see an example below). The first row provides the number of hotspot, while the second row shows the traffic flow at that hotspot, which is a Weibull distribution with parameters the shape (β) and mean (μ). For example, the Weibull distributions for hotspot 1 and hotspot 8 are shown in Fig. 10.

$$\begin{array}{cccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ (0.013, 0.85) & (0.028, 0.98) & (0.019, 0.95) & (0.006, 1.31) & (0.005, 1.48) & (0.010, 0.74) & (0.011, 0.70) & (0.007, 0.18) \end{array}$$

5. Simulation results

For the simulation results, we designed two set of experiments. The first set evaluates through exploratory analysis the effect of transmission range on the connectivity graph of the RealMobGen. The second set evaluates the performance of ad hoc routing protocols.

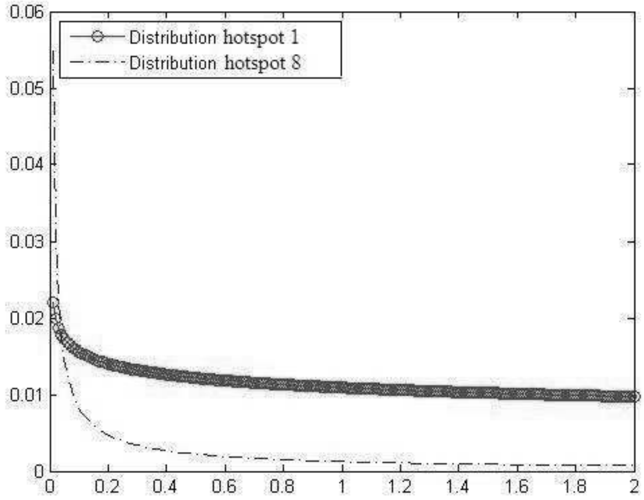


Fig. 10. Weibull probability distribution function for hotspot 1 and 8.

5.1. *The effect of transmission range on RealMobGen*

We used exploratory analysis to study the effect of the transmission range (R) on the connectivity graph of RealMobGen. The visualization tool used is iNSpect [17]. We generated several mobility files using RealMobGen on 40 and 100 number of nodes. On each evaluations the transmission range was set as one of the values in the array 100 m, 150 m, 200 m, 250 m; on a simulation area of 900 m × 1200 m; 14 Hotspots; and 900 s simulation time.

For example, the connectivity graphs on 40 nodes with 100 m and 150 m transmission ranges are shown in Fig. 11. The graph demonstrates that there are 15 partitions or connected components when $R = 100$ and 8 partitions when $R = 150$ m, versus 2 connected components when the transmission range is set to 250 m, as shown in Fig. 12.

However, the snapshots were taken at the initial time of the simulation. Due to mobility of the nodes, the number of partitions decreases in RealMobGen. Specifically, at simulation time 619 s, the connectivity graph of RealMobGen on 40 nodes with $R = 150$ m becomes fully connected (see Fig. 13). The average time of different scenarios showed that the graph becomes and remains fully connected at 600 s simulation time, thus we should try to set a higher simulation time to rigourously test the protocols.

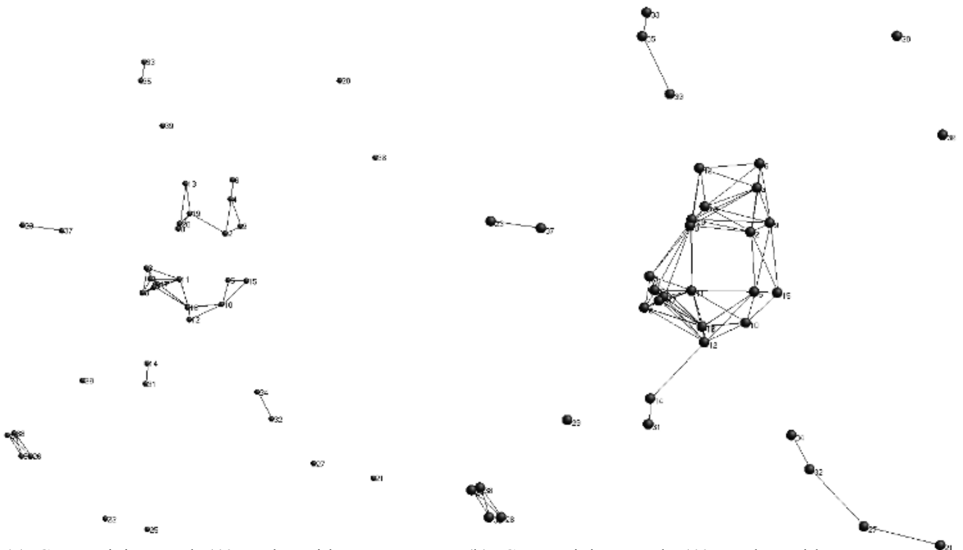
If R is set such that the connectivity graph has many partitions throughout the simulation, then we do expect the protocol performance to be low. Thus, we can use R to design better protocols/mechanisms that takes into account the transmission range and the partitioning on the network. Also, there is a need to define mobility metrics based on the connectivity graph to aid protocol designers to draft performance wireless benchmarking standards, i.e., design better protocols that take mobility into account.

5.2. *Performance evaluations*

The RWM and RealMobGen mobility tools were used to generate mobility. We used the CBR and Integrated CBR traffic tools to generate traffic for comparison reasons. In the routing layer AODV [21] and DSR [12] were selected, since they are the most used ones in the performance evaluations studies. In

Table 1
Simulation parameters

Parameter	Value (s)
Routing	AODV and DSR
MAC	802.11
Number of nodes	40
Simulation area	1200 m × 900 m
Simulation time	900 s
Propagation model	Two-ray-ground
Radio range	250 m
Traffic	CBR and integrated
Mobility	RWM and RealMobGen



(a) Connectivity graph (40 Nodes with $R = 100m$).

(b) Connectivity graph (40 Nodes with $R = 150m$).

Fig. 11. Connectivity graph.

order to closely model the application under study (students walking on university campuses) we selected the propagation model that takes into account both ground reflection and the line-of-sight between two wireless nodes that want to communicate. The two-ray-ground [22] propagation model is implemented to take into account the properties of ground reflection and the line-of-sight. The parameters that were not varied in the simulations were the number of nodes set to 40, simulation area 900 m × 1200 m, simulation time set to 900 s, the IEEE 802.11 [1] as the protocol for the medium access control (MAC) layer model.

We summarize in Table 1 the parameters used in the simulation.

In addition, the derived parameters that are calculated from the number of nodes (40); the simulation area (900 m × 1200 m); and the transmission range ($R = 250$ m) are provided below (for further explanations on each of the derived parameters we refer the reader to [2].)

Node Density: Number of nodes divided by the simulation area. In our case it is $(900 \times 1200)/40$, thus 1 node for 27,000 m^2.

Coverage Area: Area with the transmission range as radius. In our case it is $\Pi * R^2 =$ 196,349 m^2.

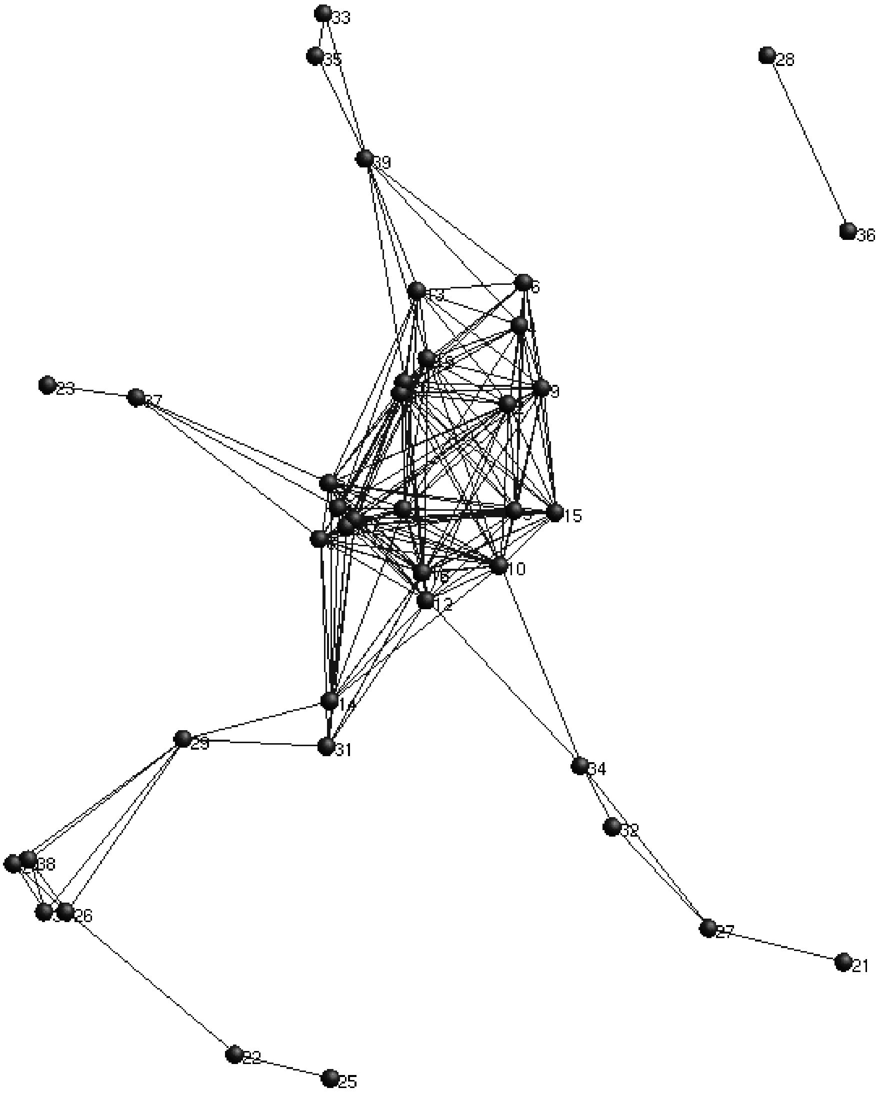


Fig. 12. Connectivity graph (40 Nodes with $R = 250$ m).

Maximum Path Length: The diameter of the rectangle 900 m × 1200 m equals to 1500.

The network Diameter: The maximum path length divided by the transmission range, which in our case turns out to be 6 Hops.

Network connectivity no edge effect: The coverage area by the node density, which turns out to be 7.27 Hops.

The performance metrics used in the simulation are defined hereby. The first one is used to evaluate the protocols under the RWM synthetic mobility model. Unfortunately, none of the current mobility metrics can be used with RealMobGen, due to the feature of the dynamic membership. Therefore, there is a need to define new performance metrics, thus we propose *Availability* as a new performance metric to take into account the dynamic membership.

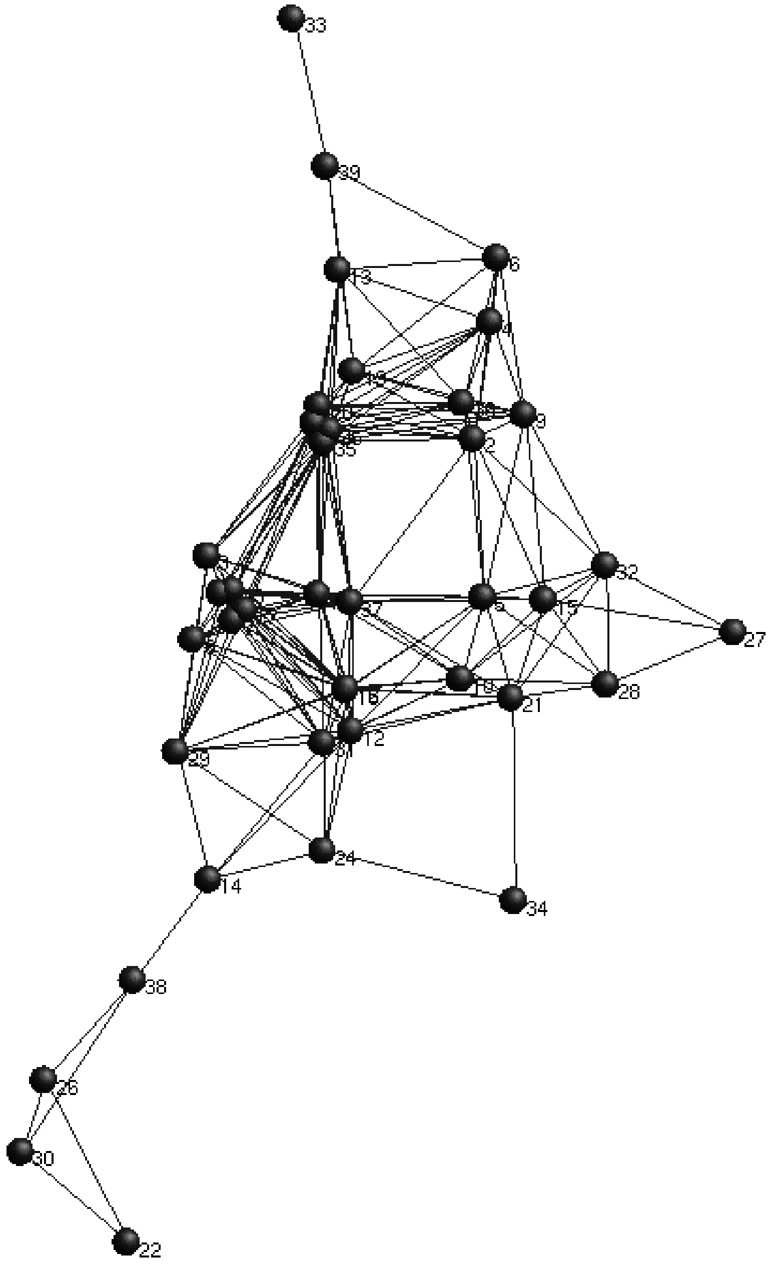


Fig. 13. Connectivity graph (40 Nodes with $R = 150$ m) at SimulationTime = 619 s).

Packet Delivery Ratio (PDR): The ratio between the number of packets sent by the source and the number of packets received by the destination.

Availability: We define Availability as the ratio between the number of packets sent by the source and the number of packets received by the destination, while the node is active.

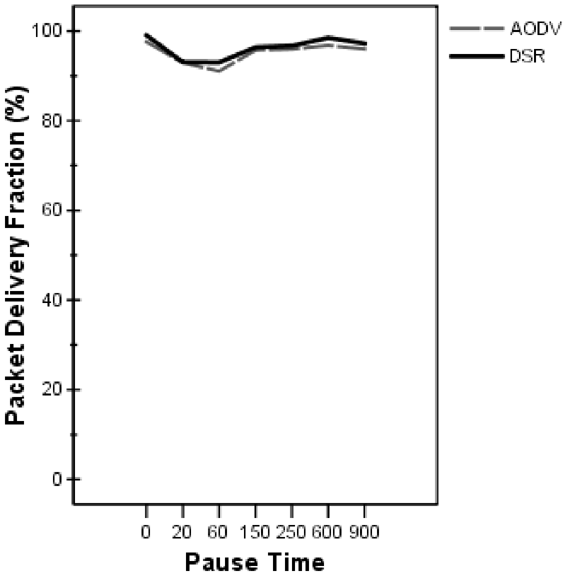


Fig. 14. Ad hoc protocol performance under RWM (*low speed*).

5.2.1. *Performance evaluations with RWM*

In order to measure protocol performance one needs to generate both mobility and traffic patterns and feed them to the simulator. First, the mobility patterns were generated using RWM model and CBR traffic with the following characteristics:

- *Maximum speed*: 4 m/s (in order to reflect closer the pedestrians maximum speed that is used in the real mobility model that is described in the next section).
- *Pause time*: Set to each of the values in (0, 20, 60, 150, 250, 600, 900).
- *Number of sources*: Set to each of the values in (10, 20, 30).
- *Rate of generating packets for CBR and integrated CBR*: 4.

We summarize the findings of the experiments (see Fig. 14), where each data point in the graph represents an average of five runs with identical traffic, but different randomly generated mobility scenarios. In order to determine the appropriate number of runs we used Cochran's sample size formula [6].

1. Performance drops for all protocols due to congestions in the network, as the number of sources increases.
2. Delivery ratio is very similar for both AODV and DSR for all pause times, thus could not clearly indicate the relative performance of the networks.

5.2.2. *Performance evaluations with RealMobGen and WIT*

The mobility file is generated under RealMobGen, while the traffic file is generated under interconnected traffic model with three different sources ((10, 20, 30) sources, resp.), 40 nodes, and the rate of generating packets was set to 4 packets. Each data point represents an average of *fifty* runs with different traffic and different randomly generated mobility scenarios. Both traffic and mobility patterns are re generated, since as we mentioned above, when using real mobility model the traffic has to be triggered

Table 2
Performance evaluation under RealMobGen and mobile nodes

Number of sources	Availability: AODV	95% CI: AODV	Availability: DSR	95% CI: DSR
30	67.85%	67.85 ± 5.35	68.33%	68.33 ± 5.38
20	67.74%	67.74 ± 6.02	68.48%	68.48 ± 6.01
10	72.69%	72.69 ± 5.14	73.92%	73.92 ± 5.00

Table 3
Performance evaluation under RealMobGen and stationary nodes

Number of sources	Availability: AODV	95% CI: AODV	Availability: DSR	95% CI: DSR
30	74.93%	74.93 ± 4.92	75.44%	75.44 ± 4.92
20	87.93%	87.93 ± 4.68	87.90%	87.90 ± 4.69
10	98.41%	98.40 ± 2.03	98.41%	98.41 ± 2.04

Table 4
Performance evaluation under RealMobGen and hybrid nodes

Number of sources	Availability: AODV	95% CI: AODV	Availability: DSR	95% CI: DSR
30	79.95%	79.95 ± 7.82	84.17%	84.17 ± 6.53
20	87.13%	87.13 ± 2.89	87.88%	87.88 ± 2.92
10	98.00%	89.71 ± 3.09	89.31%	89.31 ± 3.01

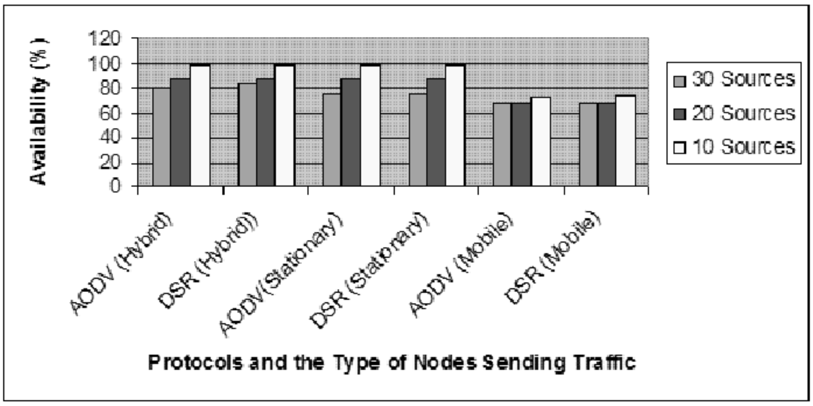


Fig. 15. Ad hoc protocol performance under RealMobGen.

and integrated with the state of the network, therefore changes in mobility file require changes in traffic file.

We run three set of experiments, where each set represents the nodes as stationary, mobile, or hybrid (mobile and stationary). For each set the performance metric of Availability was collected and the results are summarized in Fig. 15. The figure shows that the performance drops by approximately 30% when the nodes are mobile only. The reason for the drop mainly is due to the link breakages that mobility causes, which in turn requires that both AODV and DSR to discover new paths from (*source, destination*). In addition, the computational results are summarized in Tables 2, 3 and 4 (one table for each set of experiments). The results, also, include the 95% confidence intervals (CI) for validation of the experiments.

6. Conclusions

In this work we showed that in ad hoc wireless networks mobility and traffic tools are interconnected with each other. In addition, the performance metrics under real mobility models need to be re-evaluated. Thus, we proposed a new performance metric for real mobility models, namely Availability, which is the counterpart of the Packet Delivery Ratio metric for the synthetic mobility models. Furthermore, we showed that protocol performance depends on the type of the nodes that send traffic. Our results are also useful for the design of highly partitioned networks as well as for the definition of mobility metrics for performance benchmarking in ad hoc wireless networks.

Further work is needed to re-evaluate the other performance metrics for real mobility models, as well re-define the mobility metrics of link and path durations. Also, we are working on proposing a new cross layer protocol based on the integrated real traffic and real mobility, which proposes fairness on the MAC layer. The protocols schedules mobile nodes to send traffic first, due to higher traffic amount that they sent.

References

[1] Wireless lan medium access control (mac) and physical layer (phy)specifications. Technical report, IEEE Computer Society LAN MAN Standards Committee, 1997.

[2] J. Boleng, W. Navidi and T. Camp, Metrics to enable adaptive protocols for mobile ad hoc networks. In *International Conference onWireless Networks*, 2002, 293–298.

[3] L. Breslau, D. Estrin, K. Fall, S. Floyd, J. Heidemann, A. Helmy, P. Huang, S. McCanne, K. Varadhan, Y. Xu and H. Yu, Advances in network simulation, *Computer* **33**(5) (2000), 59–67.

[4] J. Broch, D.A. Maltz, D.B. Johnson, Y.-C. Hu and J. Jetcheva, A performance comparison of multi-hop wireless ad hoc network routing protocols. In *MobiCom'98: Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking*, ACM Press, 1998, 85–97.

[5] T. Camp, J. Boleng and V. Davies, A survey of mobility models for ad hoc network research, *Wireless Communications and Mobile Computing* **2**(5) (2002), 483–502.

[6] G. Cochran, *Sampling Techniques*, Wiley & Sons, New York, USA, 1977.

[7] S.R. Das, C.E. Perkins,and E.E. Royer, Performance comparison of two on-demand routing protocols for ad hoc networks. In *INFOCOM* (*1*), 2000, 3–12.

[8] R. Draves, J. Padhye and B. Zill, Comparison of routing metrics for static multi-hop wireless networks. In *SIGCOMM'04: Proceedings of the 2004 conference on Applications, technologies, architectures, and protocols for computer communications*, 2004, 133–144.

[9] M. Gerla, From battlefields to urban grids: new research challenges in ad hoc wireless networks, *Pervasive Mob Comput* **1**(1) (2005), 77–93.

[10] T.V. Group, The network simulator – ns-2. URL: http://www.isi. edu/nsnam/ns/. Page accessed as of May 30th, 2006.

[11] W.J. Hsu, K. Merchant, H.W. Shu, C.H. Hsu and A. Helmy, Weighted waypoint mobility model and its impact on ad hoc networks, *SIGMOBILE Mobile Computer Communications Review* **9**(1) (2005), 59–63.

[12] D. Johnson and D.A. Maltz, Dynamic source routing in ad hoc wireless networks. In *Mobile Computing*, vol. 353, Kluwer Academic Publishers, 1996.

[13] T. Karagiannis, M. Molle, M. Faloutsos and A. Broido, A nonstationary poisson view of internet traffic. In *INFOCOM 2004: Proceedings of twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies*, vol. 3, 2004, 1558–1569.

[14] M. Kim, D. Kotz and S. Kim, Extracting a mobility model from real user traces. In *INFORCOM: Proceedings of the 25th Annual Joint Conference of the IEEE Computer and Communications Societies*, 2006, 1–13.

[15] L. Kleinrock, *Queueing Systems, Vol. II Computer Applications*, Wiley, New York, USA, 1976.

[16] T. Kunz, Implementation vs. simulation: Evaluating a manet multicast protocol. In *Proceedings of the Global Mobile Congress 2004*, 2004, 129–134.

[17] S. Kurkowski, T. Camp, M. Mushell and M. Colagrosso.

[18] A.M. Law, How to build valid and credible simulation models. In *WSC'06: Proceedings of the 38th conference on Winter simulation*, pages 58–66. Winter Simulation Conference, 2006.

[19] X.G. Meng, S.H.Y. Wong, Y. Yuan and S. Lu, Characterizing flows in large wireless data networks. In *MobiCom'04: Proceedings of the 10th annual international conference on Mobile computing and networking*, New York, NY, USA, ACM, 2004, 174–186.

[20] E. Nordström, P. Gunningberg, C. Rohner and O. Wibling, Evaluating wireless multi-hop networks using a combination of simulation, emulation, and real world experiments. In *MobiEval'07: Proceedings of the 1st International Workshop on System Evaluation for Mobile Platforms*, 2007, 29–34.

[21] C. Perkins and E. Royer, Ad-hoc on-demand distance vector routing. In *Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications*, 1999, 90–100.

[22] T. Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall PTR, Upper Saddle River, NJ, USA, 2001.

[23] C. Walsh, A. Doci and T. Camp, A call to arms: It's time for real mobility models, *ACM's Mobile Computing and Communications Review* **12**(1) (2008), 34–36.

Arta Doci is a PhD Candidate in Mathematical and Computer Science at Colorado School of Mines. Her research interest is the impact of mobility in wireless network architecture and design. Specifically, she has been looking into realistic mobility models, the impact of mobility into traffic, connectivity, and wireless protocols.