Ad Hoc Routing Protocol Performance in a Realistic Environment

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Abstract

Multiple wireless devices jointly create and maintain ad hoc networks; their employment is favored to happen in a variety of environments with distinct topological characteristics. Diversified environmental conditions are expected to vary network performance. In fact, obstacles, buildings and/or mountains may act as either barriers, or source of noise for the radio signals. Nevertheless, most of the previous performance evaluation studies based on simulation, neglected this consideration; they used simulation models that were too simplistic, and too narrow (i.e. idealistic) in their scopes. With this paper we propose a new, complete and realistic Urban Mobility Model (UMM). It realistically models users motion, and radio signals propagation in a city-like scenario. Our aim is to study the effects of realistic network simulation on routing performance. The results prove that a realistic scenario with roads and buildings has a significant impact on routing.

1. Introduction

Wireless ad hoc networks consist of a set of handset devices, such as notebooks, mobile phones, Personal Digital Assistants (PDAs) that exchange information between each other. They are self configuring, and capable of operating without any fixed infrastructure. Classrooms, battlefields, cities, and disaster areas are some examples of the context where they can be employed.

In these networks, topology has the tendency to change dynamically, rapidly and in an unpredictable way owing to members' mobility. Furthermore, the wireless medium experiences high variability in channel quality due to fading effect. Hence, routing performance globally vary because of link and node failures that may require redirection of traffic and/or updating of the forwarding databases maintained at the network nodes. We need to design routing and transport layer protocols to adapt to the changing topology, and possibly maintain the performance high.

The MANET research community acts to investigate the factors that may alter network performance. Simulation has become a valuable tool in performance evaluation of mobile systems; it allows to study large scale systems that cannot be built practically. By artificially controlling the movement of the Mobile Nodes (MN), and the wireless conditions between them, simulation provides excellent reproducibility across experimental trials. In a wireless context, simulation relies on some synthetic *Mobility Models* (MM) that describe nodes motion, and on *Radio Propagation Models* (RPM) that predict signal propagation under given channel conditions.

In order to conduct meaningful performance analysis of routing algorithms, it is essential that the underlying mobility model on which the simulation is based, reflects realistic mobility behavior. A number of performance evaluation studies have been previously carried by exploring a wide range of possible mobility fashions [6, 7, 22]; we felt that in most of these cases, the mobility model failed to represent real life situations. Thus, our research proposes a novel Mobility Model, that pinpoints to describe real world details of a city-like environment, such as the presence of streets and buildings. We aim to demonstrate the impacts of more realistic mobility patterns, and radio propagation models on the performance of MANET routing protocols. We will provide routing performance estimates that were gathered through simulation, by investigating a common reactive routing protocol DSR [15].

2. Network performance evaluation

The routing protocol is a system parameter that significantly contributes to change the network performance [5, 6]. Also, the mobility pattern may significantly contribute to vary network results. Different mobility patterns impact links, and routes stability, that obviously have an effect on the overall network performance [7, 22]. Additionally, we believe that the topological characteristics of the environment also affect the performance. Let us consider as an example an outdoor MANET application; typically network's members, are not directly capable of communicating with all their neighbors since they often lack Line of Sight (LOS) due to the presence of some physical restriction such as buildings, and/or mountains. Thus, RPMs that keep into account possible radio signals degradation, have to be designed as one building block of the network simulator.

2.1. Routing protocols classification

A number of routing protocols exists to allow networking under various conditions [16, 20]. Some maintain complete and regularly updated information, describing the network topology in every instant. Others, do not keep any complete information, but they analyze the network only whenever it is necessary; i.e. just upon a sending request. The former kind of protocol is referred to as *proactive* [19], while the latter one as *reactive* [8, 14].

While a reactive protocol needs some additional overhead to actually discover a path on demand, a proactive protocol is always able to fetch instantly the required route from the vast tables kept in memory. Of course, proactive protocols have undeniably better route creation time, but on the other hand they need plenty of storage, and communication resources. In a mobile network with presumably frequent topology changes, the necessary overhead to maintain the link tables, exceeds the advantage of quick route creation. In fact, mobile devices should exploit their limited resources efficiently, so that it is preferable to employ reactive protocols.

2.2. Mobility models

A mobile system is characterized by the movement of its constituents. In a wireless network, MNs' mobility can be alternatively reproduced through the observation of existing systems, or by synthetically generating nodes motion. While the empirical measurement of existing systems, namely *tracing*, provides accurate and precise information; it demands a long period or phase of measurements to survey the system in action. Additionally, privacy issues, often prohibit the data collection and their distribution. Thus, it is preferable to reproduce mobility with *synthetic* models.

Currently, there is a number of Mobility Models known in literature [7, 10, 22]. Movements are characterized by their direction, speed, and either a destination point to reach or a duration of travel. When a mobile node concludes its movement, the MM decides a new movement to perform for the next period of time. This iteratively continues from the beginning of the simulation until its end, and it is done for every Mobile Node.

Synthetic mobility patterns can be classified according to a very good distinction presented by *Q. Zheng et al.* in [22]. They have proposed to classify Synthetic patterns as either *Constrained Topology Based* [13], or *Statistical models*. According to the cited grouping, in the first category they include those MMs which simulate real world scenarios, but still have some randomness to provide for variability. For example patterns mimicking freeway scenarios [2, 11] belong to this category. Likewise, the mobility model proposed in this paper is evidently a Constrained Topology Based model. On the contrary, common MMs such as Random Waypoint (RWP) [7, 21], Random Direction (RD) [7], and Random Walk (RW) [7, 9], belong to the purely statistical models category. In fact, MNs can move to any destination, and their velocities and directions are randomly chosen. Evidently such models are sorely idealistic.

2.3. Modeling signals propagation

Wireless LAN communicate through the radio channel at an assigned frequency band. The radio channel has many various parameters that must be kept into account when signals propagation has to be emulated. Some are easy to determine within simulations, like distance between sender and receiver or the utilized frequency. But others must be represented as random functions or constant factors, like interferences or fading effects.

To allow reasonable simulations within an acceptable amount of time, propagation models must simplify the calculations, and reduce the required computations to a minimum. NS-2 [18], offers the implementation of three different Radio Propagation Models (RPMs), to predict the wireless signal strength. They all assume a flat surface, where the simulation environment contains no objects that could block the signal from the direct path S/R. In Section 3.3 we will introduce a more sophisticated RPM for simulation, where signals do not propagate similarly to all directions but are affected by the obstacles.

3. Theory

We aim to represent an urban environment where typically ad-hoc networks are expected to operate. With this purpose we proposed, and tested a new complete and realistic entity mobility model. In order to rely on some simulation tool for our experiments, we have enhanced the standard NS-2 simulator with three extensions:

- New mobility algorithm
- Torus shaped simulation map
- Radio propagation model with obstacles

Table 1. The map parameters.

Parameter	*Referred to as*
# Horz. streets	N_h
# Vert. streets	N_v
Width	w
Height	h
Buildings	$B = \{b_1, ..., b_m\}$

3.1. Urban mobility model

Urban Mobility Model (UMM), is based on geographical model of modern cities with a grid architecture, where mobile nodes are moving only along predefined streets. A flat grid is compound of horizontal and vertical lines that function as bidirectional lanes on streets. They are parallel, and equidistant from each other. The city section contains a set of buildings that negatively impact radio signals propagation. The map, and its grid are uniquely depending on the parameters reported in Table 1.

We define a set of Buildings B, to be a set of rectangles with their basis parallel to the X axis[1]. Formally, we define a building $b_{\overline{\nu}_1,\overline{\nu}_2}$ as the rectangle $R_{\overline{\nu}_1,\overline{\nu}_2}$ with its left bottom vertex $\overline{\nu}_1 = (x1, y1)$, and its right top vertex $\overline{\nu}_2 = (x2, y2)$.

At the beginning of the simulation, nodes start from a crossing point of streets. Their initial location is randomly chosen in $\{P_1, P_2, ..., P_m\}$; where P_i is a generic crossing point formed by the roads, and where the probability distribution is uniform. Their time of departure is established according to a uniform distribution between $[T_{min}, T_{max}]$, and it is expected to be different for each MN. Once that MNs are disposed in the area, an iterative process begins to determine separately the nodes motion. The algorithm firstly chooses a speed in a uniform distribution between $[Speed_{min}, Speed_{max}]$. Lastly, it decides either a point of interest[2] to travel toward, or a pause time. When the node reaches the destination, it repeats the process iteratively until the simulation time runs out.

Mobility state machine is illustrated in Figure 1. The state chart has five different states that respectively stand for: no movement (0), horizontal step backward (1), horizontal step forward (2), vertical step forward (3), and vertical step backward (4). Observe that the state (0) is also the initial state. The size of the horizontal and vertical steps $H_s = \frac{w}{N_v}, V_s = \frac{h}{N_h}$ are function of the map's parameters Because of our boundless assumptions reported in Section 3.2, the decrement/increment of the x and y coordinates, internally reported in the states, are obtained as an operation modulo $width$ for x and modulo $height$ for y. Every transition in the state chart occurs in the simulation with the probability specified on the arcs. In the figure, the ingoing transitions to (0) imply a pause time.

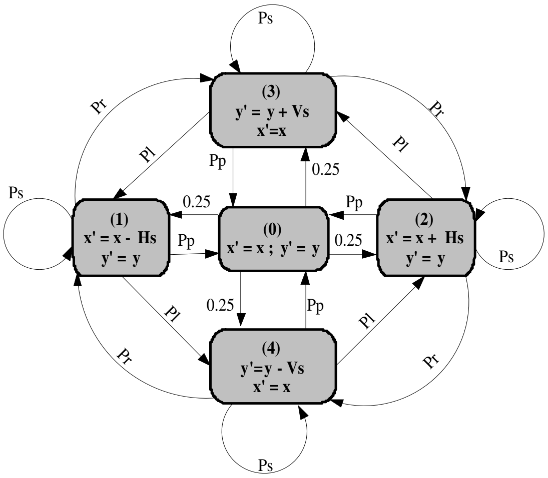

Figure 1. The state chart describing the motion of UMM.

With turning probabilities in the state diagram, it is possible to model various grid mobility patterns. The probabilities of not moving, going straight, turning left and turning right can be respectively set as $\{P_p, P_s, P_l, P_r\}$. Our motion model does not consider the case of making a step backward to the point where a node came from.

3.2. Boundless simulation world

Common MMs consider simulation areas which are bounded by their edges. The presence of such borders leads to a series of unpleasant side effects [3, 4]. In fact, nodes approaching the edges must force their route to be changed against the normal mobility rules, and redirect it toward the center. MNs tend to converge and disperse repetitively; this causes the nodes to be unevenly distributed within the area.

A *Boundless Simulation Area MM* was proposed in [7], that allows nodes to travel unobstructed in the simulation surface. In this new fashion, a moving mobile which ”crashes” against an edge, can continue proceeding in the same direction simply by entering the area from the opposite side (wrap-around border behavior). Moreover, radio signals propagate through the edges enabling communication as illustrated in Figure 2

Considering a boundless simulation surface (TORUS), increases the realism of the motion. In fact, in an urban framework it is undesirable to experience sharp changes from a direction to its opposite value. Additionally, a torus topology provides a uniform spatial distribution of the nodes within the simulation terrain [4]. A boundless en-

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[1] Buildings more complicated in shape can be modeled by locating rectangles close to each other.

[2] A *Point of interest* is always one of the adjacent crossing points.

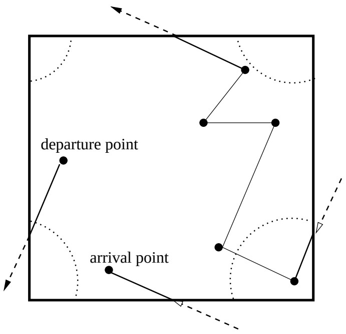

Figure 2. A random movement pattern for a MN internally moving into a torus.

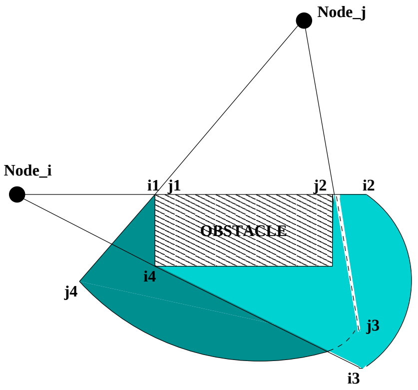

Figure 3. An example of two areas of dark.

vironment also permits to simulate maps arbitrarily big in size, by keeping the execution time under reasonable thresholds.

3.3. Radio propagation model with obstacles

The main idea with this radio propagation model is to introduce more realism on the simulation. *Radio Propagation Model with Obstacles* (RPMO), is an improvement of the Two Ray Ground (TRG) model defined in [1], and it resembles a propagation model introduced by *A. Jardosh et al.* in [12].

In our implementation, a simulation area can contain a set of obstacles $O = \{obs_1, ..., obs_m\}$ of whatever shape, that totally hinder signals propagation. This feature causes nodes to have a non-circular coverage range when they are close to a block. In such a case there exist a cone shaped part of the normal circular coverage range, that is an area of dark. Specifically, an *area of dark* is a surface where the radio signals cannot propagate due to the blocks obstruction.

The case is represented in Figure 3. There are two potential transmitters $Node\_i$, and $Node\_j$ nearby to a rectangular obstacle. The figure shows that the area behind the rectangle is an area of dark, where signals do not propagate at all. In particular, the dark areas for the two nodes are marked with different gray scales, and delimited by four vertexes for each node. Obviously, these areas vary while mobile entities move, and they can be multiple for each node, whenever a node is nearby to more than one block. Every potential receiving node r_i, located in any of the areas of darkness of another sending peer s, will not hear any radio signal sent from s.

The formula to calculate the signal strength in reception is reported in Equation 1. In particular, the equation is exactly the same of Two Ray Ground when no obstacles prevent the signals propagation, and it is zero otherwise (we have not considered obstacles that partially pass radio signals).

$$P_{r-RPMO} = \begin{cases} Pw_{r-TRG} & No\ Obstruction \\ 0 & Else \end{cases} \tag{1}$$

4. Hypotheses

We have three hypotheses that we will prove with our simulations:

- Significant impact of obstacles
- Slight impact of UMM motion
- Small impact of the simulation area size on reachability of mobile nodes

As the obstacles cause sudden blockage of radio signal, the radio links are more prone to break; in addition there are fewer neighboring nodes. Thus lifetime of the links or paths should be shorter, that causes more frequent path breakage, and more signaling traffic needed for route rediscovery. Obviously, the larger block sizes should indicate higher impacts on the reachability.

The UMM motion should impact on the link lifetime in two ways when compared with RWP. First, it should introduce a significant amount of links to stay up for very short time due to orthogonal movement of the nodes. Second, the model should also favor MNs to move along common routes following each other. Thus, there should be a change on the link lifetime distribution having some additional longer living links. These circumstances will respectively decrease, and increase the performance of UMM in respect with those of RWP. Therefore our expectation is that the mobility impact will be globally slight.

Size of the simulation area should impact somewhat on the results. Within wider terrains, the mobile nodes that are

Table 2. Three scenarios under study.

Scenario referred to as:	*Mobility Model*	*Radio Prop. Model*
RWP	RWP	TRG
UMMoff	UMM	TRG
UMMon	UMM	RPMO

in communication with some counterpart are further away from each other, thus needing longer paths, than in the case where the area is smaller.

5. Simulation experiments

The presence of streets, and the existence of building blocks within the simulation area, are definitely two features that succeed to represent real life details. We aimed to gain valuable insights, that could aid to comprehend how each of these realistic assumptions may impact the performance of the routing protocol. With this purpose, each individual component of our novel Simulation Pattern was separately evaluated.

We have inferred the effects that each single component causes on the performance results, by isolating it. The simulation process surveyed distinct network configurations (scenarios), solely differing from each other in terms of Mobility algorithm (MM), and Radio Propagation Model (RPM). Hence, since now on we will refer to each specific simulation scenario, by simply specifying a pair Mobility Model, Radio Propagation Model; formally (MM,RPM).

Clearly, the herein notation omits significant simulation parameters such as the traffic pattern, and the transport layer protocol. In our experiments we randomly selected 20 pairs S/R that exchanged small packets of $8\ byte$, at a constant frequency of $1\ Hz$. We chose a minimal packets' size, in order to find out the theoretical maximum reachability between two arbitrary nodes in the network. In this way the impact of upper layer protocols, such as TCP/IP, is omitted.

Our simulation experiments, provide protocol performance estimates that were achieved by studying three different network scenarios reported in Table 2. Considering these scenarios in comparison with each other, permits to infer the implications coming from both the components of our interest.

The scenario named *RWP* joins the features of the Mobility Model RWP, along with those of the most commonly used RPM. It is undeniably, that this combination fails to capture the characteristics of the real-life situations. In fact, RWP reflects movement patterns that are idealistic to occur in an urban environment, and Two Ray Ground poorly models the signals propagation in the concerned framework. Nevertheless, we still studied the routing performance obtained with RWP, and TRG for comparison purpose with the other more realistic fashion UMM.

Any possible routing performance difference, observed in a comparison between the first two scenarios, will be certainly attributable to Mobility. Likewise, as the only differing parameter between the last two scenarios is the Propagation Model, any possible performance difference that could stand out in a comparison, will be attributable to the presence of buildings.

Each of the three general scenarios, was further split up in sub-scenarios by varying the speed of mobiles, and the size of the simulation area as specified in Section 5.2.

5.1. Simulation parameters

Initially, a first set of runs were performed with both RWP and UMM by varying the maximum speed in $Vel = \{5, 10, 15, 20\}\ [m/s]$. Subsequently, a second slightly different set of experiments have been ran with both RWP and UMM, by varying the size of the simulation area. The sizes under study were $\{800, 1000, 1200\}\ [m^2]$.

Before executing the real experiments, we ran a restricted set of consistency tests whose findings are found in [17]. The objective of such a pre study, was to select the proper value for some common input parameters that intuitively were deemed to be the most important that may have a significant impact on the final results.

In particular, the consistency experiments determined the length of the initial transient interval of time t_i [7], needed for the MNs to dispose themselves in a manner that is representative of the Mobility Pattern under study. Additionally, the consistency tests also guided us to establish an appropriate value for the *Concentration of nodes* per unit of area.

In Table 3, we specify a list of simulation parameters, along with their respective values. They were held constant in each of the experiments. Some further experimental choices, that include the mobile devices features, as well as the traffic pattern characteristics can be be consulted in [17].

Table 3. Simulation's common parameters.

Input Param.	*Value*
Initial transient t_i	$900sec$
Concentration of nodes	$40/km^2$
Communication range	$250m$

Notice that the nodes' radio communication range so as listed above, ensures a non complete coverage of the simulation area for each of the three terrain's size that were studied. This property guarantees that, even under our boundless assumptions, a MN leaving another node's radio domain, does not right away enter it from the opposite side.

5.2. Building blocks definition

When using the Urban Mobility Model (UMM) with the radio constraints activated *UMMon*, a set of shadowing buildings B, had to be provided as an input parameter. In our model, the buildings in the city had square shape, equal size, and neighboring buildings had the same distance from each other.

As intuitively comprehensible, buildings that almost totally obstruct the LoS between peers, could lead to observe unacceptable values for the network delivery fraction. For this reason we firstly measured this metric depending upon the size of the buildings, and subsequently we reasonably selected the buildings' side to be $100m$. This choice ensures that the routing protocol still successfully operates achieving an acceptable throughput value as shown in Table 4. With larger buildings, the possibility for successful communication falls quickly giving meaningless simulation results.

Table 4. Packet delivery ratio.

Buildings' side [mt]	*Netw. Throughput Rec/Sent*
—	0.9935
40	0.9845
100	0.9612
160	0.8629
199	0.0800

5.3. Metrics

We have adopted the following metrics in analyzing the routing performance. We calculated these metrics by averaging their value over the entire simulation time. Results obtained during the initial transient of time were discarded.

- *Packet Delivery Ratio*: The fraction between the number of data packets correctly received by all the receivers at their application layer, and the number of data packets originated by all the transmitters.

- *End to End Delay*: The time that the routing protocol takes to deliver a data packet from the transmitter's application layer, to the corresponding receiving one. This delay also includes possible time needed for either discovering an unknown route, or fetching it from the cache memory of the sending entity.

- *Path Length*: It measures how many hops a packet needs to traverse before it actually reaches the desired opposite end point. Similarly like with the end to end delay, the path length was computed out of all the correctly received data packets.

- *Routing Overhead*: It is the total number of protocol signaling packets transmitted during the simulation relative to the number of successfully delivered data packets. For signaling packets sent over multiple hops, the packets count as one transmission per every hop traversed. This allows to keep in consideration the overall amount of control traffic generated by the protocol [3].

6. Simulation results

The results portrayed in Figures 4-7, and 8-11 respectively show the overall protocol performance depending on: the speed of movement, and the size of the simulation area. These performance estimates resulted by joining multiple experiments; i.e. each of the points drawn is the average of thirty different experimentations. The data variability within the different runs is reported as upper and lower estimates, that represent 95% confidence interval. Each diagram includes three lines that individually match one scenario.

6.1. Speed of movement

In Figures 4,5,6, and 7 we include the protocol performance that were measured during our first set of simulation runs. From an analysis to the protocol behavior, depending on the speed of movement, we could not notice any relevant difference in any of the routing metrics that were evaluated. In fact, except for the routing overhead, we obtained a practically horizontal line in each diagram.

This surprisingly high stability, enables us to claim that within our model, as well as within RWP, performance results are reasonably insensible to speed variation. This observation was also previously pointed out for the RWP pattern by *T. Camp et al.* in [7]. We took a step further and proved that this yields even in our model UMM, regardless the presence of obstacles.

As an exception, we observe from Figure 7, that speed affects the amount of control traffic to be introduced into the network. DSR requires a major signaling effort as the nodes become faster. This fact is fully attributable to the nature of the reactive protocols. In fact, as we increase the speed at which the entities roam in the terrain, a reactive routing protocol has to cope with a higher network dynamism. Thus DSR needs to keep the routing tables consistent by broadcasting an increasing amount of control messages.

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[3] In the count of the routing packets are not inclusive neither the IEEE 802.11 MAC packets, nor the ARP packets. This is a rather natural choice due to the fact that a routing protocol could be run over a variety of possible medium access, or address resolution protocols.

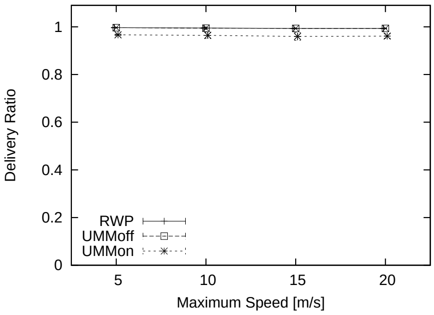

Figure 4. Average delivery ratio.

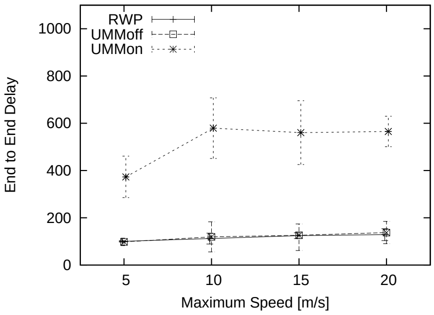

Figure 5. Average end to end delay.

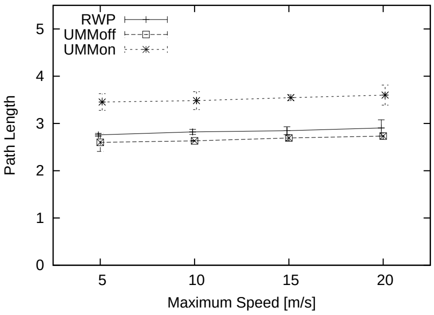

Figure 6. Average path length.

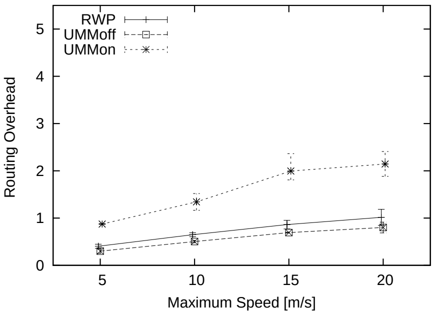

Figure 7. Average routing overhead.

6.2. Size of the simulation area

Contrarily to what we pointed out for the speed variation, we see from Figures 8,9,10, and 11, that a diverse configuration of the simulation area has an impact on the routing performance. We believe that this impact was somehow to be expected. In fact, when the radio communication range and the amount of nodes per unit of area remain constant, and when the simulation area grows in size, the average distance that separates two end points increases. Thus, even under our assumptions that the entities move within a torus surface, larger simulation area requires the usage of more relays to cover the distance between a communicating pair S/R, Figure 10.

Figure 9 displays how a wider simulation surface introduces additional delays. They are originated by the need to follow routes that become longer proportionally with the size of the area. Longer routes to be followed cause a packet to queue multiple times; once into each of the forwarding nodes. Hence, the more are the MNs to be traversed, the higher the end to end delay will be.

The usage of more relays, explains also the additional routing effort shown in Figure 11. As we have more intermediate, forwarding nodes we will also experience a more massive broadcasting of the control traffic.

6.3. Obstacles' size

As first outstanding simulation result, we show in Table 5 DSR's performance estimates obtained with our mobility model, depending on the size of the obstructing buildings.

The results point out that routing performance degrades when the obstacles size increases. The reason that clarifies this claim, is that the network graph experiences more link breakages. In fact, the areas of darkness of a node are subject to cover a portion of the simulation field that becomes larger with the blocks size. Consequently, the probability in order for a MN to be hidden from another counterpart, grows as well. This finding is also supported by Table 4, as fewer packets will go through when buildings enlarge.

7. Analysis

In Figures 4, and 8 it is reported the network throughput for each of the studied scenarios. A quasi-optimal delivery fraction was obtained for both the *UMMoff* and *RWP* conditions. Contrarily, when it comes to regard obstacle constraints in the city framework *UMMon*, the packet loss increases drastically to make the data delivery ratio going down of roughly five percent. Locating obstacles into the simulation terrain, causes existing links in *UMMon* to remain stable for a relatively short time. This leads more

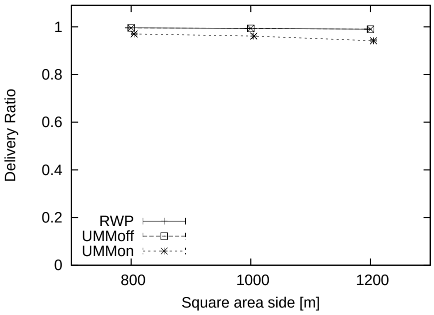

Figure 8. Average delivery ratio.

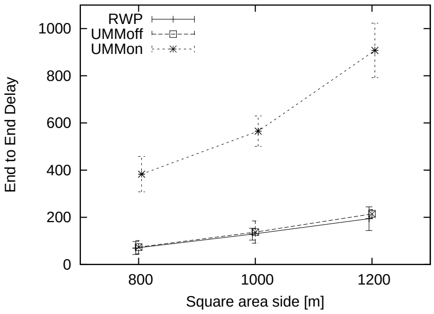

Figure 9. Average end to end delay.

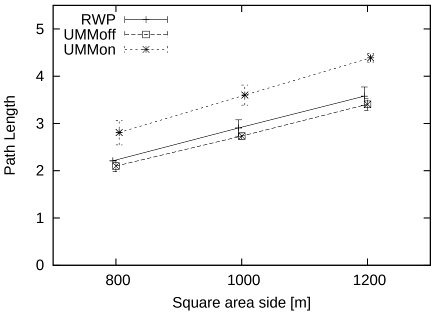

Figure 10. Average path length.

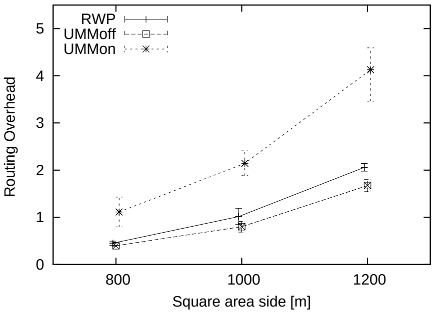

Figure 11. Average routing overhead.

packets to be dropped due to link breakages, resulting in a lower overall delivery fraction. With larger simulation terrain the impact is somewhat higher as the routes are longer, and therefore more prone to a link breakage.

In Figures 5, and 9 it is depicted the average end to end delay observed during the two simulation sets. In both the figures, RWP and UMM without obstacles, have both roughly the same results. Unlike, looking at the *UMMon* curve, it results evident the immense additional delay introduced by the presence of buildings. This additional delay comes from three factors: longer routes, longer route discovering time, and larger amount of Route Requests (RRs) to be performed.

The authors believe the first further contributes in a very small amount. In fact, from Figures 6, and 10 we noticed that the average routes length difference between *UMMon*, and *UMMoff* is roughly one hop that might cost up to only 40-50 msec. From a further analysis to the experiments, it has been noticed that a more significant delay is caused by the time required to find the route for an outgoing packet that yet does not have one. In fact, the analysis revealed the time needed to be about six times bigger in *UMMon* in comparison with *UMMoff*. Furthermore, it has been observed that in the *UMMon* case, the route discoveries that are needed, outnumber those of *UMMoff*.

Since in both cases the amount of data flows, and the sending rate were common, we can infer that the routes are subject to last for a shorter period of time. Therefore, more RRs are needed to be sent out by the transmitters. To strengthen our justifications, we enclose in Table 6 a detailed analysis of the signaling overhead. The table includes the average queuing time for those outgoing data packets that need to have a route discovery before proceeding, and the average amount of Route Requests needed throughout the whole simulation. The data are presented depending on the velocity of the MNs when the simulation terrain was a square of side $1000m$. The table reports percentages for each model in comparison with the *UMMon* case that has shown the worst performance.

Hence, the overall effect that introduces the immense delay in case of *UMMon* is originated by routes that are found at high cost, and that need to be set up again after being utilized for only few deliveries. In contrast, in both *RWP* and *UMMoff*, not only the routes are discovered at low cost, but also they last longer which is a double advantage.

A very interesting finding comes out from the diagrams that portray the average route length (Figures 6, and 10). When nodes move along the city's streets *UMMoff*, the data packets are delivered through shorter paths compared with both *UMMon*, and even *RWP* pattern.

It is easy and intuitive to explain why the presence of buildings in *UMMon*, lengthens the routes compared with

Table 5. DSR's performance within a simulation terrain of 1 km^2, MNs' max speed 20m/s.

Buildings' side [mt]	*e2e delay [ms]*	*path length*	*signaling load*
0	137	2.73	0.80
40	214	2.94	1.12
100	565	3.60	2.15
160	2469	4.09	3.81

the same scenario without them *UMMoff*. In fact, when a node wants to communicate with a peer which is hidden behind a block, it needs to utilize one or more relays.

It is more tricky to explain why *UMMoff* showed shorter routes in comparison with *RWP*. Even though, in either of the cases there is a 360 degrees omni-directional transmission antenna, *UMMoff* has constantly a higher density of neighbors over time. The situation is depicted in Figure 12. Having a higher density of neighbors increases the probability, in order for a sender, to have its receiver closer in terms of number of hops.

The reason, why on average the neighbors in *UMMoff* outnumber those of *RWP*, follows from the fact that the roads prevent MNs from being located somewhere else than on the streets themselves. Since the nodes can only traverse the predefined pathways, the area of the simulation terrain that can be occupied by a mobile is reduced. Thus, a higher clustering is implied, and a bigger amount of neighbors is constantly observed. This is also related to the simulation parameters, where the radio communication range is longer than the distance between streets.

In Figures 7, and 11 it is reported the protocol overhead for each of the studied scenarios. The city environment without shadowing blocks, *UMMoff*, is the easier scenario to be handled by the routing protocol. In contrast, the city framework with buildings, *UMMon*, requires a significant, additional effort in terms of control traffic to be put into the network.

The increase in number of control packets, that we see in the case of *UMMon*, is certainly due to a shorter links life time. Therefore, the routing protocol is forced to originate a Route Discovery more frequently, compared with the fashions where buildings are not a component of the model.

8. Conclusions

The most of the existing mobility models previously taken into account by the MANET community, were an enhancement to the trivial RWP. With this paper, we argued that such artificial scenarios are too simplistic, and too narrow in their scopes. Thus, we proposed a new pattern compound of more sophisticated mechanisms to model mobility, and radio signals propagation, that contribute to make the simulation realistic.

Table 6. Average queuing time, and amount of RRs in different MMs relative to UMMon.

Max Velocity	**Queuing time**		
[m/s]	*UMMon*	*RWP*	*UMMoff*
5	100%	26%	14%
10	100%	26%	20%
15	100%	26%	16%
20	100%	23%	16%

Max Velocity	**Amount of RRs**		
[m/s]	*UMMon*	*RWP*	*UMMoff*
5	100%	35%	24%
10	100%	39%	29%
15	100%	39%	31%
20	100%	43%	33%

We introduced UMM, a novel model to set up an artificial, urban environment to be simulated with NS-2. The strength of our pattern is that an experimenter can select a few input parameters, to obtain the realistic city-like framework that better suits her needs. In fact, variants of UMM are easily obtainable, that represent the desired topological features in terms of roads and buildings.

During our research, we modeled a simple urban terrain and tested wireless performance, through the usage of DSR protocol. We found the following, main results that yield regardless mobility details such as speed, and size of the area, when the concentration of nodes $\frac{N}{Area}$ remains constant.

When comparing *UMMoff* with *UMMon*, it is proven effectively that the radio propagation constraints, i.e. obstacles, drastically influence the performance of the routing protocol. This can be seen as higher number of link breakages that generate additional signaling load in the network. As our network was moderately loaded due to short data packets, the delivery radio degraded only slightly i.e. an acceptable loss ratio was observed. As the total load in the network increases with longer data packets, the *UMMon* model will suffer worse performance degradation.

In a mobility model where the nodes are forced to move along predefined pathways *UMMoff*, DSR was observed to generate less control traffic in comparison with the RWP mobility pattern. Nevertheless, the throughput achieved by the two mobility patterns was observed to be equally optimal and indistinguishable.

Shortly, in accordance with our initial hypotheses, we can claim that the *presence of streets* slightly affects the DSR performance. Contrarily, a more realistic Radio Prop-

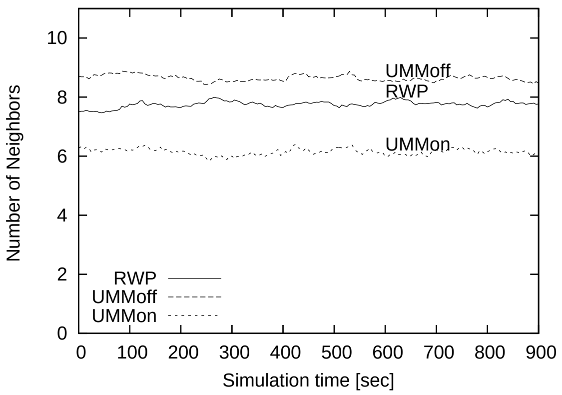

Figure 12. The average number of neighbors over time when the speed was 20 m/s.

agation Model influences, in a drastic and negative way, the performance of the routing protocol. Therefore, simulation based research should not make any gross simplification when defining a simulation topology. Otherwise, we will be taking the risk to get performance estimates, that too optimistically predict the protocol behavior.

With this paper we remarked the current distance from the existent simulation models and the real world situations. Our contribution is a first step to sensitize the research in the area to face with more realistic simulation models. They certainly help to draw more useful conclusions, but on the other hand they require a further computational effort to evaluate protocol performance. We believe that the benefit is worth the trouble.

There are several possible ways to integrate this initial work. In order to retrieve more general results depending on the particular configuration of roads and buildings, a wider set of realistic environments should be investigated. In fact, cities are only one of the many possible places of action of the ad hoc networks.

Furthermore, a study which compares a number of distinct routing protocols would draw conclusions regarding the choice of the best suited protocol to be employed in a precisely predefined realistic terrain.

Yet another extension, UMM could also be strengthened in terms of degree of realism, by enabling the mobiles to enter the buildings, and by introducing a restricted set of diverse mobile entities. Typically, in a city several classes of users have diverse mobility peculiarities. Think of pedestrians, and different types of vehicles such as cars, trucks, trains that move with different speeds, and along distinct paths to obey the traffic rules.

Finally, one could also assume that building's walls may not totally block the radio signal, but rather degrade it of few dBs.

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