Integration of Mobile Ad Hoc Networks into the Internet without Dedicated Gateways

A. Triviño-Cabrera *, S. Singh +, E. Casilari-Pérez *, F. J. González-Cañete*
* Dpto. Tecnologia Electrónica, University of Málaga, Spain
+ Communications Lab, Samsung Advanced Institute of Technology, South Korea
atc@uma.es

Abstract

Different mechanisms have been proposed to integrate MANETs into the Internet. Most of them assume the presence of a dedicated entity acting as the Internet Gateway. This characteristic prevents MANET from operating in scenarios prepared for one-hop Wireless LAN where a Gateway is not pre-existing or configured. One possible solution to suppress this restriction is described in the mobile multi-gateway support that transfers the gateway functionalities to a MANET component that is directly connected to the edge router. Due to this transfer, multi-hop ad hoc networks get the flexibility to be integrated into the Internet in scenarios prepared for one-hop WLAN. This paper describes this mechanism and shows its performance by means of simulations.

1. Introduction

Initial concept of mobile ad hoc networks (MANET) goes back to 1970s when DARPA's packet radio project was started with the aim of establishing communication among various wireless terminals in the battlefield. Ease of deployment, non reliance on existing infrastructure, faster to deploy are some of the features of this type of networks that make them appropriate for scenarios such as sensor networks, conference networks, etc. Most of the research in this area is related to routing protocols and performance of isolated ad hoc networks, i.e. where terminals only communicate with some other nodes that belong to the same network. However, the development of new services that require the connection to external networks such as the Internet has extended this idea. Thus, nowadays it is necessary to extend the existing mechanisms related to MANETs in order to incorporate new techniques that integrate multi-hop wireless networks into external networks and into the Internet.

An initial step for the integration is the inclusion of an Access Router that also acts as the interface between the wireless medium and the wired network. However, in the IPv6 context, the introduction of a router is not sufficient as connecting MANET terminals to the exterior requires taking into consideration several technologies. Firstly, the mobile nodes need a global IPv6 address in order to be reachable from external networks. To ensure the Internet hierarchical scheme, an entity must be responsible for providing the necessary information to allow mobile nodes to configure an IPv6 address appropriate to the network topology. This functionality could be associated to a dedicated entity, as in DHCP, which provides the IPv6 global address to all the terminals within a specific domain under its control [1]. Although this strategy has been proposed in several mechanisms, it possesses a principal drawback: its demand for additional equipment (a centralized entity) that restricts the scenarios where MANET could operate [2] [3] [4] [5].

An alternative to DHCP is stateless auto-configuration mechanism where the Access Router periodically notifies all the prefixes that it processes by means of the diffusion of Router Advertisements (RA messages) [6]. Those terminals that need a global IPv6 address concatenate a random value, for example the EUI-64 MAC identifier, to the prefix it is going to use [7]. As this operation does not ensure the uniqueness of the address as in the previous strategy, the mobile nodes should initiate a Duplicate Address Detection (DAD) to confirm that the selected address is unique [8] [9].

The reception of RA messages also allows mobile nodes to know the domain where they are placed. When a terminal detects changes in the RA messages it assumes to be moved to another domain. Consequently, it initiates the correspondent procedures to continue the on-going sessions. In the IPv6 context, the Mobile IPv6 technology specifies the procedures to communicate meanwhile changes in the point of attachment are present [10].

As previously exposed, RA messages are crucial to ensure the global connectivity of mobile nodes as their information is used in the address auto-configuration procedures of nodes as well as in the Mobile IP technology. However, the RA messages are defined in the Neighbor Discovery protocol (NDP) which restricts its messages to one hop [6]. In real multi-hop wireless LAN,

0-7695-2629-2/06/$20.00 (c) 2006 IEEE

the one-hop restriction is a clear disadvantage as those nodes that are several hops away from the Access Router are unable to receive RA messages and hence the prefix information. To solve this limitation, an extra element should be introduced in the MANET. This new device is responsible for propagating the information contained in the RA messages by means of the diffusion of Modified Router Advertisements (MRA messages) that are not one hop restricted [11]. This element also complements the Access Router capabilities as it includes the ad hoc routing functionalities that are not present in the Access Router. Due to this ability, this element is called the Internet Gateway. Most of the solutions proposed to integrate MANETs into the Internet are based on a Gateway that is considered as a dedicated entity that must be previously installed in those scenarios where ad hoc networks are going to be deployed [11] [12] [13]. This prevision does not follow the MANET essence, i.e. to operate anywhere and anytime. In order to overcome this restriction, mobile multi-gateway support could be applied [14]. In this solution, gateways functionalities are transferred to a MANET node that is one hop away from the Access Router. The transfer adds the flexibility to integrate multi-hop ad hoc networks into the Internet in scenarios prepared for one-hop Wireless LAN. In this paper, the authors analyse the performance of the mobile multi gateway support by means of simulations.

The rest of this paper is organized as follows. In section 2, we summarize the principal characteristics and drawbacks of some solutions that integrate MANET into the Internet. The mobile multi-gateway support is described in Section 3. The performance of the mechanism is shown by means of simulations that are explained in Section 4. Section 5 exposes the simulation results. Finally, in Section 6 the paper is concluded.

2. Related Work

In the IPv6 context, one of the earliest references for Internet connection was due to R. Wakikawa et al. [11]. This mechanism, often called global connectivity, is based on a fixed Gateway attached to each access router that provides globally routable addresses to the ad hoc nodes. Some other authors have provided interesting work based on this mechanism [15] [16].

On the other hand, C. Jelger et al. proposed a mechanism where gateways are responsible for the autoconfiguration of global addresses by sending periodical messages that inform about its existence as well as the prefix it processes [12]. As multiple gateways may coexist in the same ad hoc network, the nodes may receive multiple autoconfiguration messages originated at different gateways. In order to avoid an excessive load, a mobile node does not forward all of them, but, based on some criteria, it will choose one gateway and it will send its updated message. By this method, mobile nodes can have a continuous path to the Gateway where all of nodes that compose the path share the same prefix.

In the previous solutions Gateways are understood as fixed elements. One of the first mechanisms where mobility is attached to the Gateway was published by H. Ammari and H. El-Rewini [17]. They proposed a three layer implementation. The first layer corresponds to the wired backbone and fixed routers. The middle layer is composed of all the devices that are one hop away from the elements of the first layer and finally, in the third layer the rest of the nodes are included. In the middle layer Gateways may coexist. In this mechanism some of the MANET nodes can act as Gateways. They can move but they are restricted to not leave the coverage area of the access router. Through simulations they show the performance of this mechanism is related to the number of mobile gateways as well as their maximum speed.

The restriction imposed on the gateways by the former mechanism is avoided in the mobile multiple gateway support [14]. In this solution, mobile gateways can leave the coverage area of the access router and therefore, a distributed algorithm is required for dynamic gateway selection. As this paper presents and analyzes the mechanism and performance of the mobile multiple gateway, it will be explained in the following sections.

Finally, S. Ruffino and P. Stupar have proposed the use of multiple fixed gateways to provide access to the Internet [18]. These elements periodically announce their prefixes through special messages so that nodes receiving this information generate the corresponding IPv6 addresses even if they are not going to use them immediately. As nodes possess IPv6 addresses appropriate to all the gateways in the MANET, they can dynamically change the global address that they utilize for their external communications if, for example, one gateway is not operative any longer.

3. Mobile Multi-Gateway mechanism

The mobile multi-gateway support is intended to simplify the restrictions associated with the integration of MANET into external networks in heterogeneous scenarios. It is based on the transfer of Gateway functionalities to a MANET node, characteristic that avoids the pre-installation of a dedicated Gateway. Therefore, the scenarios where MANETs can operate increase. The mechanism is useful for coverage area extensions in cellular networks where mobile nodes belonging to the same ad hoc network communicate among them without the use of the deployed network. However, the communication with external host requires the use of a MANET node acting as the Gateway that is not controlled by the telecommunication operator. On the other hand this support is also appropriate for automotive scenarios where a vehicle temporally connects to a petrol station or to an UMTS access and it performs the Gateway functionalities for some other vehicles [19].

In both situations the gateway can freely move. The method of selecting the node to operate as Gateway as well as the treatment associated to its mobility are the main characteristics of this mechanism. In the following section these procedures will be described. It is worth noting that the implementation of the mechanism shows the lack of certain specifications in the IETF Draft. In order to overcome it, several changes are proposed along the following explanation.

3.1 Internet Gateways

Among all the devices that are in the coverage area of the Access Router, one of them is temporally selected to behave as the Internet Gateway. This node is called the Default Gateway (DG) meanwhile the rest of the terminals sited in the abovementioned area are referred as the Candidate Gateways (CG). Therefore, at a certain instant of time, one DG and none or multiple CG could coexist in each Access Router scenario.

All the Gateways (Default or Candidate) receive RA messages generated by the Access Router. However, only the DG is responsible for propagating the information it receives from the Access Router. With this purpose, the DG periodically sends MRA (Modified Router Advertisement) messages that can be forwarded through multiple hops. Using the information contained in the MRA message, the mobile device can auto-configure its global IPv6 address and update its correspondent route to de DG. When the terminal generates traffic for external hosts, it will forward the packets to the DG using this route.

On the other hand, when the Access Router receives packets whose destination is a MANET terminal, it will forward the packets to the DG which will initiate the ad hoc routing to the destination ad hoc node.

The information contained in the MRA messages can be used during a period of time associated to the lifetime field. Before this expiration time, the mobile nodes expect to receive a new MRA message. While the DG stays in the coverage area of the Access Router, the nodes in the MANET periodically receive the MRA message. However, as no mobility restriction is imposed on the DG, it could escape from the coverage area and immediately it would stop its gateway functionalities. The rest of the mobile nodes will assume there is no DG configured as they have not received an expected MRA message. At that moment, the CGs should initiate the default gateway selection procedure. This procedure is a distributed algorithm that respects the MANET nature as it does not need any centralised entity to select the future DG. This mechanism consists of starting a random internal timer. When this random time is over, the CG checks if it has received one MRA message since the timer was started. The reception of this message would imply the presence of a new DG, and consequently, the CG will not configure itself as the DG. However, if the CG verifies it has not received any MRA message it will automatically configure itself as the new DG. To inform the MANET about its new role, it will send a MRA message immediately.

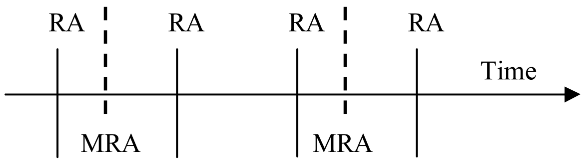
Although it is not specified in the IETF Draft, this technique may result in more than one DGs at the same time if the values of their random timers are very close or the loss of MRA occurs. As, only one DG may operate in a MANET, there should be a new procedure to ensure the uniqueness of this role. The authors of this paper propose the use of a simple algorithm based on the IPv6 address as a priority parameter for remaining as the DG: when a DG receives a MRA message generated at a node with smaller value of the lower 62 bits of the IPv6 address, it will stop its gateways functionalities.

In order to reduce the load in the network, the mobile devices in the MANET also apply this priority algorithm when they receive multiple MRA messages. Although the reception is used for route updates, they would only forward the message associated to the DG with a lower IPv6 address.

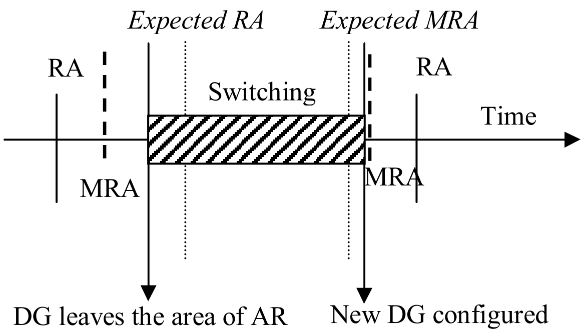
3.2 Gateway Switching

Gateways must check that they periodically receive RA messages in order to know if they continue in the coverage area of the Access Router. When the DG detects it has not received an expected RA message, it immediately stops its gateways related functionalities that includes the emission of MRA messages. The rest of the components of the MANET also expect the reception of MRA messages but as no default gateway exits, the expected reception will not occur. At that instant, one of Candidate Gateways is configured as the new Default Gateway following the procedure explained in the previous section.

As illustrated in figure 1, there is a period of time where no DG is configured. The length of the interval (the switching time) is quite significant in the behaviour of the mechanism as during that period the MANET behaves like an isolated entity.



a. Normal Procedure without Gateway Switching



b. Gateway Switching

Figure 1. Gateway Switching in the mobile multi-gateway support

4. Simulation Environment

The main parameter of mobile multi-gateway support is the MRA interval (TMRA). This interval affects the gateway switching and therefore, it is assumed it will also have consequences on the performance of the network. In order to evaluate the effects of TMRA a software module to include mobile multi-gateway support was developed and integrated with the Network Simulator, ns-2.1.9b on Linux machine [20].

Simulations were run in a 1500x300 m^2 area with the AR located near the center of the network. MANET was formed among 50 nodes whose movements were based on the Random WayPoint model. In order to evaluate different mobility scenarios, maximum speed was varied as shown in table 2. Following the recommendations proposed in [21], minimum speed was fixed at 1 m/s. Additionally, the initial spatial distribution of the mobile nodes is equal to the stationary spatial distribution for the Random WayPoint in order to analyze stable results [22]. Traffic was associated to 10 CBR sources with data rate of 4 packets/seconds. Ad hoc nodes were used as the source node while the destination was Internet node that must be accessed through the access router.

Table 2 lists the parameters used in the simulations.

Table 1. Simulation parameters

Simulation Area	1500 m x 300 m
Mobile nodes	50
Mobility pattern	Max. speed: [1.1, 5,10,15] m/s. Minimum speed = 1 m/s Pause Time : [0%, 50%]
Traffic pattern	10 CBR sources Rate = 4 packets/s Packet size= 512 B
Simulation Time	5000 s
Transmission Range	250 m
Number of runs	3
Ad hoc protocol	AODV
Link Level Layer	802.11
Internal Queue	64 packets
RA interval	2 s
MRA interval	[2,4,6] s

As recommended in [23], below metrics were used for the performance analysis of the proposed mechanism:

- Percentage of Lost Packets: It is defined as the ratio between the lost data packets and the packets generated by the sources in the MANET. It was assumed that the number of packets that reach to the Correspondent Node (CN) is equivalent to the number of data packets received at the Access Router as no losses are assumed in the external Internet route. This measure corresponds to the opposite of the widely used PDR (Packet Delivery Ratio).
- End-To-End Delay: It represents the average value of the time the received packets take to reach the destination, i.e. the node in the exterior network, from their origin. This parameter includes the time the nodes stay in the internal queues, retransmissions at the MAC level, and the forwarding through multiple intermediate nodes.
- Normalized Overhead: It is equivalent to the total number of hops the routing packets takes during the simulation time divided by the sum of the data packets originated at the sources.

5. Simulation Results and Analysis

The obtained data are represented in Figures 2, 3 and 4. To facilitate the understanding and to show the general tendencies of the influence of the MRA interval, the results of the different simulations have been also interpolated through a linear regression, resulting in the straight lines of the figures.

Figure 2 shows the graph of the percentage of lost packets vs. the maximum speed of the mobile nodes. For all the analyzed values of the MRA interval, an augmentation of the percentage of lost packet occurs when the maximum speed increases. This fact is explained by two circumstances that are present in the mobile multi-gateway support. Firstly, higher node mobility results in frequent changes in the network topology and therefore, more control packets must be introduced in the network in order to update the routes the nodes employ. The overhead added in the network provokes packet collision.

On the other hand, more gateway switchings take place when the node mobility increases as the Default Gateway is expected to stay less time in the coverage area of the access router. During the switching time, the MANET is an isolated entity as no Default Gateway is configured. Mobile nodes pretending to communicate with exterior hosts keep their packets in an internal finite queue. If the space of this buffering is not enough or the delay associated to the packets is considered extremely high, packets will be dropped. As a consequence of these losses during the gateway switching, the percentage of lost packets value increases.

Additionally, MRA interval is directly related with the gateway switching interval i.e. the higher the MRA advertisement interval, the higher should be the switching interval. This is due to the fact that candidate gateway takes over the role of default gateway once it realizes that the default gateway is no more available. However, the candidate gateway learns about the presence or absence of default gateway depending on whether it receives MRA packet at the periodic time interval or not. Hence, a higher MRA advertisement interval means candidate gateway should wait longer before configuring itself as default gateway. In this proactive mechanism, the MRA interval also plays an important role in the update of routes. The higher the MRA interval, the sooner the routes become invalid and therefore, nodes wishing to communicate to exterior hosts must initiate the route discovery process. As commented earlier, the overhead in the network may provoke packet collisions.

In the graph, as expected, the percentage of lost packets for MRA equal to 2 seconds is lower than that of MRA equal to 4 seconds which again is lower than MRA interval equal to 6 seconds.

Figure 3 shows the graph of the End-to-End Delay vs. the maximum speed. The delay is due to the storage of the data packets in internal queues meanwhile the integration into the Internet is re-established. This event could happen due to the absence of the Default Gateway in a gateway switching interval or because of the break of the route to the Default Gateway in the MANET. The higher the node mobility, the more packets will be affected by the gateway switching. In addition, the higher the value of the MRA interval, the higher the probability of maintaining an invalid route to the DG.

Figure 4 shows the graph of overhead vs. the maximum speed. Overhead in the considered network is introduced by MRA, RA, RREQ, RREP and RERR messages [24]. An increment in the number of these messages should result in the increased overhead. As the Gateway broadcasts MRA messages more frequently, the overhead increases. However, the contribution due to the RREQ is reduced as mobile nodes update their routes in the reception of MRA messages. For the characteristics of the analyzed network, the first factor is more significant than the second one. However, for high node mobility, the overhead in the network for a value of MRA interval equal to 6 seconds becomes similar to the values obtained when a value of 4 seconds is employed. It is possible to assume that the nodes require more frequent route updates.

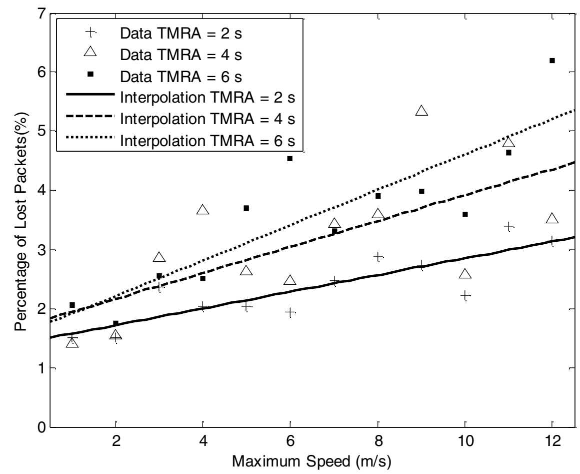


Figure 2. Percentage of Lost Packets versus maximum speed.

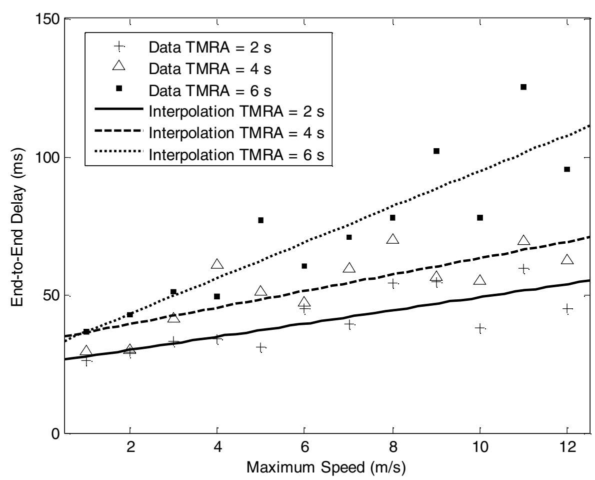


Figure 3. Overhead versus maximum speed.

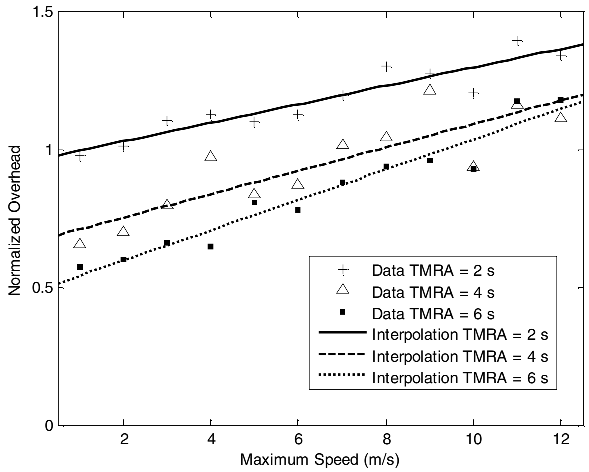


Figure 4. Delay versus maximum speed.

5. Conclusion

This paper proposes a novel mechanism for ad hoc networks, deployed at the edge of the Internet, to get connectivity with the IPv6 hosts located on the Internet The mechanism proposes the use of mobile multiple gateways for this purpose.

The proposed mechanism allows any ad hoc node, either directly connected to the Internet or via one or more intermediate nodes, to configure its interfaces with globally routable unique IPv6 addresses and exchange packets with host on the Internet. This is achieved by configuring and properly managing, which indeed is an important issue for such networks, one or more ad hoc nodes as mobile Internet gateways.

Validation and performance analysis of the proposed mechanism was done using the ns-2 simulation tool. Simulation results show that the gateway switching time is important for the overall network performance and the MRA advertisement interval should be properly chosen e.g. based on the node mobility, network size, node density and other network characteristics.

5. References

[1] Alexander, S., Droms, M. : DHCP Options and BOOTP Vendor Extensions, IETF RFC 2132 (March 1997)

[2] McAuley, A. ,K. Manousakis: Self-Configuring Networks, 21st Century Military Communications Conference Proceedings (2000)

[3] Mohsin, M. ,R. Prakash: IP Address Assignment in a Mobile Ad Hoc Network, MILCOM 2002 (2002)

[4] Tayal, A. and L. Patnaik,: An address assignment for the automatic configuration of mobile ad hoc networks, Personal Ubiquitous Computing (2004)

[5] Clausen, T. and E. Baccelli: Simple MANET Address Autoconfiguration, IETF InternetDraft,work in progress (February 2005)

[6] Narten, T., Nordmark, E., Simpson, W. : Neighbor Discovery for IP version 6, IETF RFC 2461 (December 1998)

[7] Huitema, C.: IPv6: the new Internet Protocol, Prentice-Hall, ISBN:0-13-850505-5 (1998)

[8] Perkins, C., Wakikawa, R., Malinen, J., Belding-Royer, E., Y. Suan: IP Address Autoconfiguration for Ad Hoc Networks", IETF Draft, work in progress, (November 2001)

[9] Vaidya, N. : Weak Duplicate Address Detection in Mobile Ad Hoc Networks, MOBIHOC'02 (2002)

[10] Johnson, D., Perkins, C., Arkko, J.: Mobility Support in IPv6, IETF RFC 3775 (June 2004)

[11] Wakikawa, R., Marinen, J., Perkins, C., Nilsson, A., Tuominen, A.J.: Global Connectivity for IPv6 Mobile Ad hoc Networks IETF Internet Draft, work in progress (January 2005)

[12] Jelger, C., Noel, T., Frey, A. : Gateway and address autoconfiguration for IPv6 adhoc networks, IETF Internet Draft, work in progress (October 2003)

[13] Cha, H.W., Park, J.S, Kim, H.J.: Extended Support for Global Connectivity for IPv6 Mobile Ad Hoc Networks, IETF Internet Draft, work in progress (October 2003)

[14] Singh, S., Kim J.H., Choi,Y.G., Kang, K.L., Roh, Y.S.: Mobile multi-gateway support for IPv6 mobile ad hoc networks, IETF Internet Draft, work in progress, (June 2004)

[15] Hamidian, A.: A study of Internet Connectivity for Mobile Ad Hoc Networks in NS 2, Master´s thesis, Lund Institute of Technology (January 2003)

[16] Ghassemian, M., Hofmann, P., Aghvami, H., Prehofer, C.: Analyses of Addressing and QoS Approaches for Ad Hoc Connectivity with the Internet, IEEE PIMRC 2003, Beijing, China (September 2003)

[17] Ammari,H., El-Rewini, H.: Integration of Mobile Ad Hoc Networks and the Internet Using Mobile Gateways, 18th International Parallel and Distributed Processing Symposium (IPDPS'04)

[18] Ruffino, S., Stupar, P.: Automatic configuration of IPv6 addresses for nodes in a MANET with multiple gateways, IETF Internet Draft, work in progress (February 2006)

[19] Ruffino, S., Stupar, P., Clausen, T., Singh, S.: Connectivity Scenarios for MANET, IETF Internet Draft, work in progress (July 2005)

[20] Fall,K., Varadhan, K. : Ns Notes and Documentation, The VINT Project. UCBerkey, LBN (2005)

[21] Yoon, J., Liu, M., Noble, B.: Random waypoint considered harmful, Proceedings of Infocom’03, pp. 1312-1321. San Francisco (April 2003)

[22] Hyytia E, Lassila P. Nieminen L. and Virtamo J.: Spatial Node Distribution in the Random WayPoint Mobility Model, IEEE Transactions on Mobile Computing (2005).

[23] Corson, S., Macker, J. : Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations, IETF RFC 2501 (January 1999)

[24] Perkins, C., Belding-Royer, E., Das, S.: Ad hoc On-Demand Distance Vector (AODV) Routing, IETF RFC 3561 (July 2003)