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Abstract: This document compares two protocols, MHVB and NHDP. While both protocols are intended for wireless multi-hop ad hoc networks, they differ fundamentally, both in operation and in purpose: MHVB is a location-based, general-purpose transport protocol for network wide information dissemination, whereas NHDP is a protocol enabling a router to acquire information describing its local network topology up to two hops away. Different as they may seem, these two protocols can, in certain situations, serve the same purpose. For example, MHVB can be employed by an ad hoc routing protocol in place of NHDP, for dissemination of topological information when location information is available. Similarly, NHDP may be used to carry certain location-based information, in place of MHVB.

This document examines the viability of NHDP and MHVB for neighborhood discovery, and analyses their performance as such. Aside from the usual set of performance parameters, special interest is accorded to the "freshness" of neighborhood information, obtained through each of the protocols.

Key-words: VANET, MANET, topology, location, MHVB, NHDP, neighbor discovery

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Résumé : Ce document compare deux protocoles : MHVB et NHDP. Même si les deux protocoles ont le but d'établir la communication sans fil par multi sauts sur les réseaux ad hoc, ils se diffèrent fondamentalement par rapport au fonctionnement et à l'utilisation: MHVB est un protocole générique de la couche de transport basé sur l'information géographique des routeurs du réseau, qui aide à la diffusion de l'information à l'échelle du réseau. Cependant, NHDP est un protocole qui permet à un routeur d'acquérir de l'information décrivant la topologie de réseau local à deux sauts consécutifs maximum. Bien que ces deux protocoles paraissent différents, dans certaines situations, ils peuvent servir le même objectif. Par exemple, MHVB peut être utilisé par un protocole de routage ad hoc à la place de NHDP, pour la diffusion de l'information topologique lorsque de l'information géographique des routeurs est disponible. De même, NHDP peut être utilisé pour diffuser de l'information basée sur des positions géographiques, à la place de MHVB.

Ce document examine la viabilité de NHDP et MHVB pour la découverte des voisins d'un routeur et analyse leurs performances. En dehors de la considération des paramètres communs, nous portons un intérêt particulier sur la fraicheur de l'information de voisinage, obtenu par chacun des protocoles pour approfondir notre analyse de la performance.

Mots-clés : VANET, MANET, topologie, géographique, MHVB, NHDP, neighbor discovery

1 Introduction

A wireless multi-hop ad hoc network is composed from a set of devices, each of which is equipped with a wireless network interface. These devices are not all within direct radio range of each other, and so these devices rely on relaying of information by intermediaries – by routers – for attaining multi-hop connectivity across the network. The network is an ad hoc network, i.e. is operating without any assumptions of pre-planning, notably without any a priori designation of which devices are to be acting as routers in order for connectivity in the the network to be assured. Furthermore, as the network may change over time, both in terms of number of devices, their relative position, and the communications ability between pairs of devices (e.g. due to radio interference), any such pre-planning might soon become obsolete.

A slightly more abstract way of describing a wireless multi-hop ad hoc network is, that such a network does not lend itself to an a-priori graph abstraction such as is common in "classic" networks: identifiable links, identifiable leafs (hosts) and identifiable inner nodes (routers), and where network configuration (set of routers, links) changes are epochal.

1.1 Topology-based Protocols

A by now common way of "managing" a wireless multi-hop ad hoc network is to attempt to reflect it by a graph abstraction, which applies at a given instance in time, and use this for enabling operation of classic algorithms such as link state routing, construction of dominating sets, etc. The first challenge in this approach is to ensure that the graph abstraction is constructed and maintained such that its topology reflects the actual communications abilities of the wireless multi-hop ad hoc network. The second challenge in this approach is if the topology of the graph abstraction changes very frequently due to frequent changes in the underlying communications ability of the wireless multi-hop ad hoc network: convergence properties and necessary information exchange by classic algorithms and protocols may yield unsatisfactory performance, and require that the classic algorithms be adapted, still.

A large number of current protocols and algorithms are based on the approach of (i) having a mechanism whereby the communications ability of the wireless multi-hop network is reflected into a graph abstraction and (ii) employing adaptations of classic algorithms and protocols, in order to allow proper operation of these over a graph abstraction with a rapidly changing topology. Such protocols and algorithms are denoted *topology based*, and examples include OLSR [1], NHDP [2], and AODV [3].

1.2 Location-based Protocols

An alternative way of "managing" a wireless multi-hop ad hoc network is to assume that a graph abstraction is unattainable – at least, a graph abstraction whose topology remains valid for sufficiently long time to allow for an algorithm to converge – and in its place assume that each device is able to identify its own geographic location. Such geographic locations may be used for, *e.g.* selecting paths according to which router is closer (geographically) to the desired destination, and lend itself to a different class of algorithms for operating a wireless multi-hop ad hoc network. As an example, rather than having the source of a transmission explicitly designate a “next hop”, it might make encode the geographic location of itself and the destination in the transmission, and having recipients of that transmission decide to retransmit or not. These recipients determine if they are a suitable next hop on the path towards the destination, based on if their geographic location is “closer to” the destination. Such protocols and algorithms are denoted *location based*, and examples include GPSR [4], GRA [5] and MOPR [6].

1.3 Terminology

This document is, consciously, not employing the term “MANET” for describing wireless multi-hop ad hoc networks. This is in no small part due to the strong association between that term and protocols developed by a specific working group in the IETF[1] – which are all *topology-based* protocols.

In order to avoid confusion, the term *“wireless multi-hop ad hoc network”* is employed for describing the underlying network communication characteristics, whereas the terms *“topology-based”* and *“location-based”* are employed for classifying the assumptions which the protocols and algorithms make for their operation.

1.4 Objective

This document examines an instance of a topology-based and an instance of a location-based protocol for neighborhood discovery in wireless multi-hop ad hoc networks, specifically NHDP [2] and MHVB [7, 8], and study the viability and performance of each for this task.

A part of this work will also investigate the performance of MHVB and NHDP especially in high-density scenarios. OLSRv2 [9] uses NHDP as the de facto neighbor discovery mechanism in order for each router to determine the presence of, and connectivity to, its 1-hop and symmetric 2-hop neighbors. When the network density increases and routers are mobile, there is an increased bandwidth consumption for control overhead due to redundant advertizements of neighbors when using topological neighbor discovery. As MHVB uses a backfire algorithm to prevent redundant relaying, this work will also serve as a starting step in investigating the use of MHVB in OLSRv2 for neighbor discovery.

1.5 Document Outline

The remainder of this document is organized as follows. Section 2 overviews the operation of MHVB and NHDP. Section 3 contrasts the two, and introduces the necessary adaptations to each to allow a reasonable comparison: in order that the comparison is reasonable, the two protocols must provide the same “abstract” functionality, specifically the same set of information, to protocols such as OLSRv2, and provides the comparison parameters that are important to evaluate neighborhood discovery protocols. The two protocols are compared in a network simulator using NS2, thus section 4 presents the simulator and the

[1] http://www.ietf.org/dyn/wg/charter/manet-charter.html

scenario parameters, and section 5 presents the protocol comparison results. Finally, section 6 concludes this document.

2 Overview of MHVB and NHDP

The two protocols under study are the location-based protocol MHVB (Multi Hop Vehicular Broadcast) and the topology-based protocol NHDP. The two following subsections provide an overview of each of these protocols, with sufficient detail to understand the adaptations in section 3 and the results in section 5.

2.1 MHVB

MHVB [8, 7] is fundamentally a location-based transport protocol for network-wide dissemination of data in a vehicular network. The protocol operates according to the general principle described in section 1.2, by having the originator of a message encode its geographic position in the header of each message generated.

When a message is transmitted over a wireless interface, all nodes within radio-range will receive the transmission. Each node will, then, set a waiting-time, inversely proportional to the geographic distance to the position of the originator of the message, after which it will retransmit the message. If before the expiration of that waiting-time the node overhears retransmission (by some other node) of that same message, retransmission by this node may not be necessary – the node is "backfired"[2]. Thus, far-away nodes have, by virtue of their distance to the source, priority for self-selecting as relays and their retransmissions "backfire" less-far away nodes thereby eliminate unnecessary retransmissions.

2.2 NHDP

The Neighborhood Discovery Protocol (NHDP) [2] is a topology-based neighbor discovery protocol, developed by the MANET working group within the IETF. NHDP is based on the neighbor discovery process of the Optimized Link State Routing protocol (OLSR) [1] and is used by the successor OLSRv2 [9].

In NHDP, topological information about direct neighbors as well as symmetric two-hop neighbors is exchanged by means of HELLO messages, using a message format defined by [10]. Every router periodically sends HELLO messages on each of its interfaces, therein advertizing addresses of all its neighbors. Hence, every router can acquire information of the routers up to two hops away.

Figure 1 depicts such a basic message exchange between three routers MR_1, MR_2 and MR_3, all equipped with a single network interface, assuming that MR_1 and MR_3 cannot communicate directly. MR_2 can communicate with both MR_1 and MR_3. In the example, MR_1 sends a HELLO not advertizing any neighbor at time t_0. In the HELLO message of MR_2, the address of the heard neighbor MR_1 will be advertized. When MR_3 hears the HELLO from MR_2 (i.e. at time t_1), it has the full topology up to two hops away.

NHDP is a protocol designed for the particular characteristics of wireless multi hop ad hoc networks, including as asymmetry of links and rapidly changing topologies. Providing two-hop neighborhood in addition to only the direct neighbors allows routing protocols to apply more efficient message dissemination such as MPR selection (e.g. as in [9]). NHDP uses a flexible message

[2] [8] details supplementary considerations for a node to be "backfired", *e.g.* to not backfire nodes necessary for network coverage.

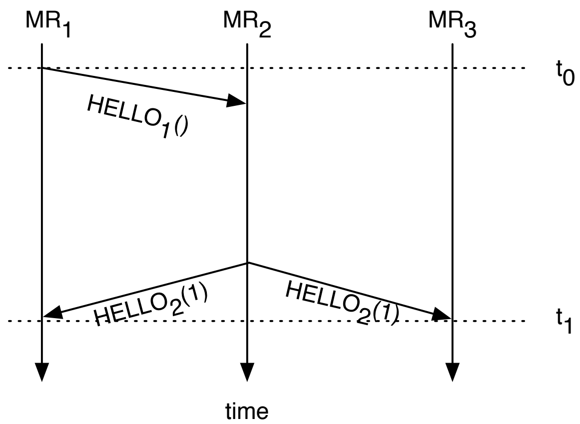

Figure 1: Basic message exchange in NHDP. $HELLO_R(1, 2, ...)$ means that router R sends a $HELLO$ and advertizes addresses $1, 2, ...$

format [10] which allows to encapsulate any additional information in TLVs (type-length-value structures), while keeping compatibility with protocols that do not recognize such TLVs. As such, it is suitable for protocol extensions such as security and geographic features.

2.3 Functional Differences between MHVB and NHDP

The main functional differences between MHVB and NHDP are summarized in table 1.

MHVB	NHDP
Location-based (i.e. messages include location and movement information)	Topology-based (i.e. messages include IP addresses and hop count values)
Transport layer protocol	Network layer protocol
Entire message is forwarded from the source through piggy-backing	A new HELLO message is created which advertizes IP addresses of all neighbors
Each node applies a waiting time to forward every received message from a node	The message advertizement does not have any explicit waiting time
Nodes farther away from source have higher priority to forward when compared to those near the source	No prioritization of the advertizement
Forwarding is restricted based on distance from the source	Neighbor advertizement restricted to two-hop region of the source

Table 1: Functional differences between MHVB and NHDP

In MHVB, when a router broadcasts a message to its neighbors, it "piggybacks" messages from its neighbor routers for forwarding them (refer to [8]). Before a message is forwarded by a router, the router waits for a certain time. This time is dependent on the distance from that router to the originator of the message. The higher the distance, the lower the waiting time. This is used for the backfire mechanism in order to avoid redundant message dissemination. Figure 2 depicts this behavior, using a similar example as before, with three routers MR_1, MR_2, and MR_3. MR_2 piggybacks Message_1 to its own Message_2, and waits a certain time, depending on the router's distance to the originator of Message_1.

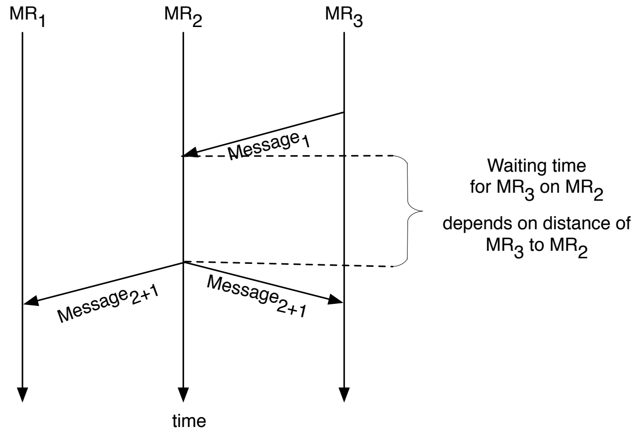

Figure 2: MHVB waiting time example

NHDP does not forward any HELLO messages. Instead, each router periodically advertizes its neighbors in HELLO messages. The time between receiving a HELLO message from a neighbor and advertizing this neighbor in the next HELLO is henceforth called "waiting time" for the sake of comparison. However, this time is independent of the distance from the source. The time is also independent from the time when the HELLO has been received (apart from triggered messages), because HELLOs are sent periodically, and the clocks of the routers are not synchronized. Refer to figure 3 for an example.

In MHVB, forwarding of messages is restricted by the distance to the source. That means that routers only forward messages if they are within a predefined distance to the source. In NHDP, no HELLO message is ever forwarded. But since every router advertizes the addresses of its neighbors, a router in a two-hop distance of another router acquires the information about that source.

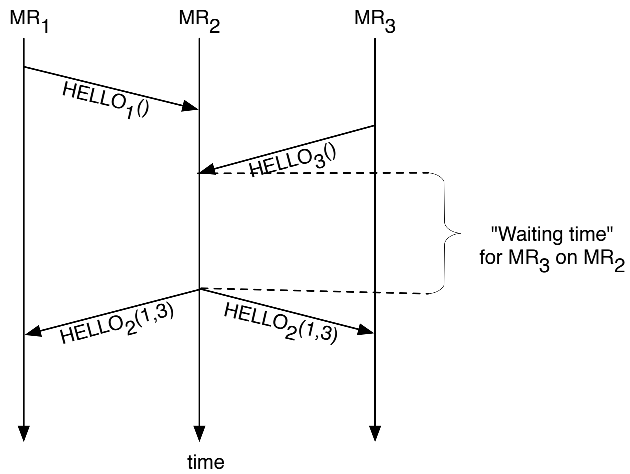

Figure 3: NHDP waiting time example

3 Comparison of MHVB and NHDP in a common Framework

This section presents the common framework that allows to compare MHVB and NHDP.

3.1 MHVB as a Neighbor Discovery Protocol

MHVB can be used for a topological neighbor discovery, if the maximum distance for forwarding messages is limited. For the comparisons in this document, it is assumed that the distance is limited to twice the radio range of the wireless interface. Thus, messages originating from a router effectively range up to routers two hops away. The previous example of figure 2 shows a case where MHVB can be used for neighbor discovery. When router MR_2 piggybacks Message$_1$ from MR_3, MR_1 can learn that MR_3 must be a two-hop neighbor.

3.2 NHDP including Location Information

NHDP can be used to include location information in addition to its original purpose as topology-based neighborhood discovery protocol. This can be accomplished by means of TLVs that include the information. Note that due to the flexibility of the message format [10], adding TLVs does not break compatibility with routers that use NHDP without additional TLVs. For the following simulations that compare NHDP and MHVB, a modified version of NHDP is included, that adds location information in HELLO messages.

In this modified NHDP version, a Message TLV is added to every HELLO, including a router's position, speed and timestamp when the message has been sent. In addition, a multi-value Address TLV is added that associates all advertized addresses of the HELLO message with position, speed and timestamps of the advertized neighbor interface addresses. Assuming that the geographic information uses 24 bytes for the value `position_x, position_y, position_z, speed,`
`timestamp` (as in table 2), the overhead for the geographic information for n advertized neighbor interface addresses in a single address block of a HELLO is $3 + 24n$. (3 bytes for the TLV header without index-start and index-stop fields, for $n > 0$).

Datum	Length	Data type
position (x, y, z)	3*4 bytes	float
speed	4 bytes	float
timestamp	8 bytes	double

Table 2: Location TLVs added to HELLOs in a modified version of NHDP suitable as location-based protocol

4 Simulation Settings

In section 3, a framework has been defined that allows to compare MHVB and NHDP in a common environment. For this comparison, a network simulation using the NS2 simulator has been performed. While network simulators have their limits, especially in terms of the fidelity of the lower layers and – for wireless network interfaces – in the fidelity of the propagation model used for representing the behavior of physical radio waves, their use is often allowing to understand high-level and algorithmic properties of given protocols. In particular in the area of multi-hop ad hoc networks, simulations are easier to perform than building a large test network of nodes, simulate mobility, and guarantee reproducibility of predefined scenarios.

This section therefore details the general settings of the simulation and the mobility models that are used in the simulation,

4.1 General Settings

Table 3 lists the general settings used for the simulation.

Parameter	Value
NS2 version	2.34
Mobility scenarios	Random way point and single lane model
Grid size	1000m by 1000m
Number of nodes	10 to 80
Communication range	250m
Pause time (for random waypoint model)	2s
Max. node velocity (for random waypoint model)	25 m/s
Radio propagation model	Two-ray ground
Simulation time	100 secs
Iterations	20 times
HELLO interval	2 secs
Expire interval	6 secs
Interface type	802.11b
Frequency	2.4 GHz

Table 3: NS2 parameters

4.2 Mobility Model

In the simulations, two different mobility models have been used: the single-lane model and the random waypoint model. Those two have been chosen to reflect a best-case and a worst-case scenario respectively.

In the random waypoint model, a number of nodes is uniformly distributed over a square area. Each node moves to a randomly chosen point in this area with a random speed uniformly chosen from within an interval. After having arrived at that destination, the node waits for a certain time, uniformly chosen from within an interval (called "pause time"). After having waited, the node selects a new destination. The random waypoint model can be considered as worst-case scenario for MHVB because due to the random movements, the sectoral backfire mechanism works less efficient for reducing redundant transmissions, while in the same time disseminating the packets to all routers.

The single-lane scenario is depicted in figure 4. Nodes are distributed on a line in equal distances, and do not move. For instance, a vehicular traffic jam on a single lane will resemble this kind of scenario. This mobility model allows for studying the behavior of the protocols in a simple scenario, and can be considered as best case for MHVB, because it allows to reduce redundant transmissions with the backfire algorithm.

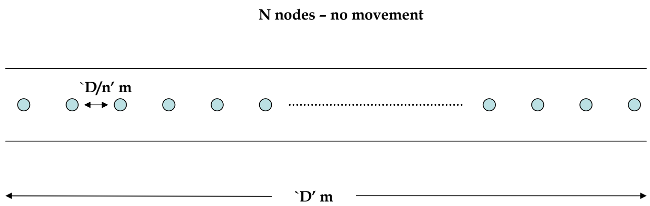

Figure 4: Single lane model

These two extreme cases are considered here to find the upper and the lower bounds of the analysis. Any other scenario falls within these bounds for that particular setup [11, 8].

4.3 Protocol Implementations

For the NHDP implementation, the Java based NHDP module from JOLSRv2 [12] has been used. This implementation adheres to the most recent version of the NHDP draft, and has been extensively tested for many simulations. MHVB has been implemented in Java as well. Both protocols use the AgentJ library [13], which allows to run Java protocols on NS2.

5 Simulation Results & Analysis

This section describes the results of the simulation.

5.1 Message Freshness

In [14], Hu et al. state that routing cache staleness presents a serious challenge to protocols which use route cache to choose routes. These routes change very often especially considering a multi-hop ad hoc network where topology changes are very frequent due to the mobility of the routers. So, for any routing protocol using a neighbor discovery mechanism, the freshness of the neighbor information becomes an important factor in order to have more accurate routes. For this purpose, we analyze the message freshness recorded during reception over a multi-hop network for low and high-density scenarios.

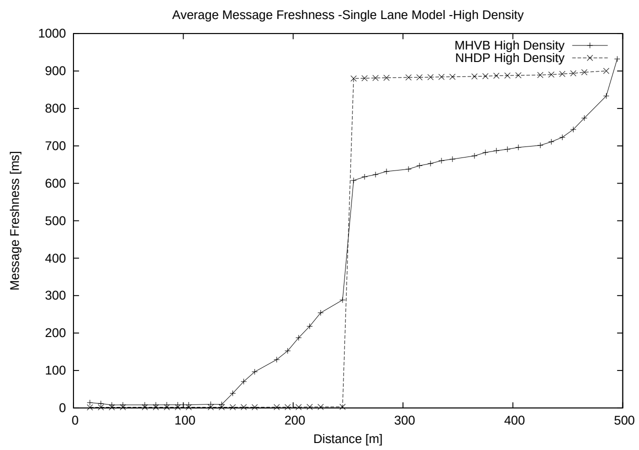

Figure 5: Message freshness: Non-mobile scenario over a single lane, high density

Considering the non-mobile scenario shown in figure 5, an observation that can be made is that for a low density scenario, the average message freshness of NHDP is comparatively better, whereas the average message freshness of MHVB is better for higher node densities. As MHVB gives a waiting time based on distance for each message to be transmitted, the curve grows gradually as a function of distance. Since there are no explicit waiting times involved in NHDP, the waiting time remains constant.

Considering the random way point scenario shown in figure 7, the freshness time increases with respect to distance on the whole. NHDP performs better than MHVB for positions closer towards the source in the second hop, and MHVB performs better for positions farther away from the source at the second hop. This impact is due to the property of the prioritization of messages in MHVB. High random mobility also causes the average value of freshness to increase from the figures 5 and 7.

5.2 Bandwidth Consumption

Bandwidth is an important criterium for evaluating the performance of a wireless communication protocol [15]. Bandwidth consumption is a measure of the

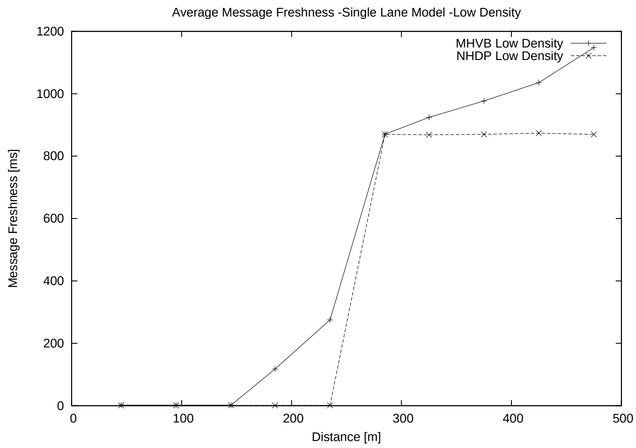

Figure 6: Message freshness: Non-mobile scenario over a single lane, low density

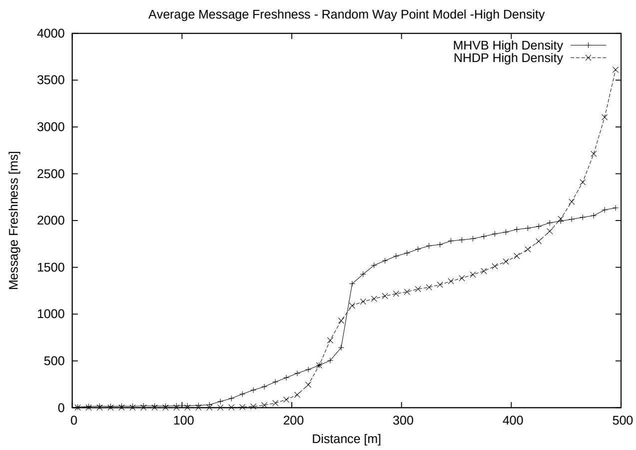

Figure 7: Message freshness: Random way point model, high density

amount of control traffic in bytes per second. If the bandwidth consumption of a protocol is high, less bandwidth is available for data traffic. In particular, for multi-hop ad hoc networks using wireless radio transmissions, bandwidth is usually limited [16]. A high bandwidth will also lead to more packet collisions if the medium access control at layer 2 does not provide a mechanism to avoid collisions. It is thus generally preferable if a protocol consumes less bandwidth for control traffic.

In this sub-section, we present the traffic control overhead due to the exchange of HELLO messages on the network, both for MHVB and NHDP (depicted in figure 7 and 9). Note that in these figures, the bandwidth consumption does not include lower layer headers, but only the control traffic payload. For NHDP, high mobility leads to frequent topology changes and thus triggers more HELLO messages causing an increased control overhead. For MHVB, high mobility does not affect the number of messages.

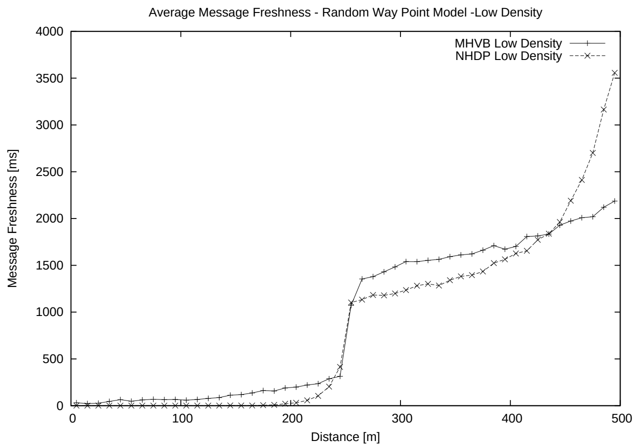

Figure 8: Message freshness: Random way point model, low density

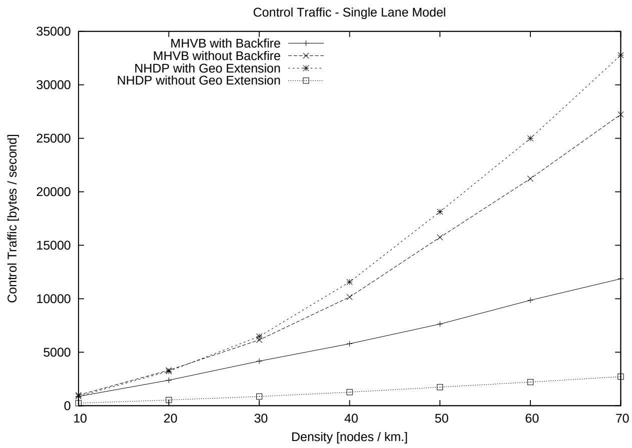

Figure 9: Bandwidth consumption: Non-mobile scenario over a single lane

As the node density increases on the networks, the control traffic of MHVB increases more than in NHDP because the piggy backing of the entire message leads to comparatively increased message size in MHVB, whereas in NHDP only the advertizement of the neighbor interface IP addresses causes a limited increase. Moreover, the message format of NHDP [10] uses an address compression algorithm which efficiently reduces the size of a message. Note that if geographic information is included into NHDP HELLO messages, the size of the message grows substantially. In that case, MHVB has a much lower bandwidth than NHDP with the extension, due to some less overhead, but also due to the backfire mechanism that avoids the transmission of many redundant messages.

5.3 Average Message Size

While in subsection 5.2, the bandwidth consumption was measured in bytes per second, figures 11 and 12 show the average size per message. Due to the same reasons as mentioned in section 5.2, notably the address compression of NHDP,

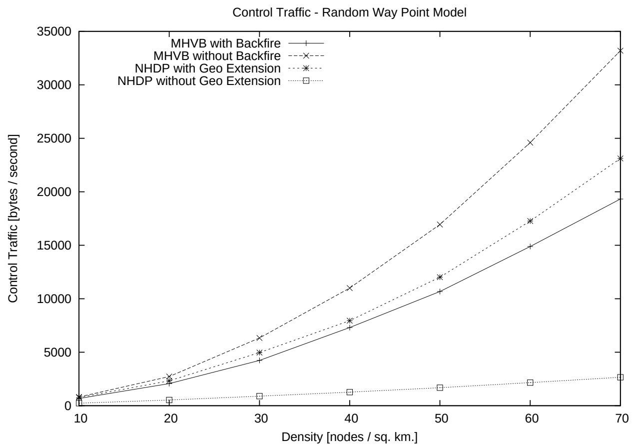

Figure 10: Bandwidth consumption: Random way point Model

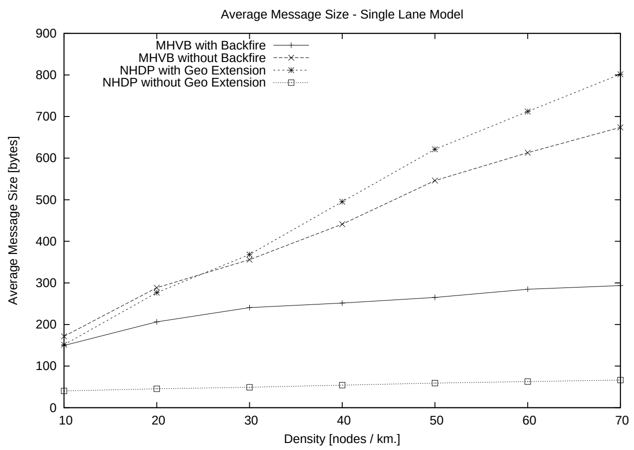

Figure 11: Average message size: Non-mobile scenario over a single lane

the message size of NHDP without the location extension is much lower than that of MHVB. Due to the additional overhead of the TLVs and the location information, the modified NHDP version has a higher average message size as NHDP.

5.4 Collision Ratio

In our simulations, no data traffic was used, and all simulation parameters apart from the used protocol were the same. Thus, the collision rate only depends on the number of control messages and the size of the messages. As expected, NHDP has a lower collision rate due to the reduced message size (refer to figure 13 and 14). The modified NHDP version including location information has a higher collision rate due to the higher message size.

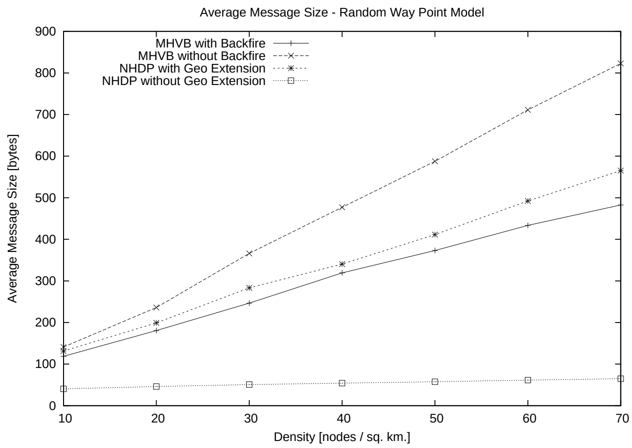

Figure 12: Average message size: Random way point model

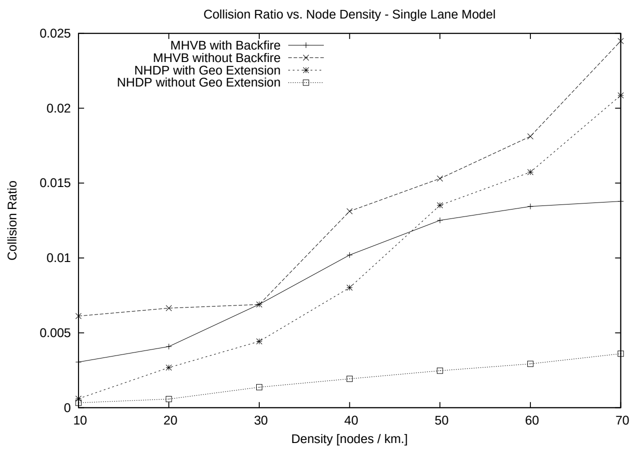

Figure 13: Collision ratio: Non-mobile scenario over a single lane

5.5 Number of Transmissions

This section shows the total number of transmissions over the whole simulation time.

For the single-lane mobility model (depicted in figure 15), the number of transmission for MHVB and NHDP are almost equal. As the same message intervals have been used for the simulation, this is expected. As NHDP uses triggered messages, the number of HELLO transmissions is higher as for MHVB in the random way point model (refer to figure 16). This is due to the constantly changing neighborhood of routers resulting from the mobility of the routers.

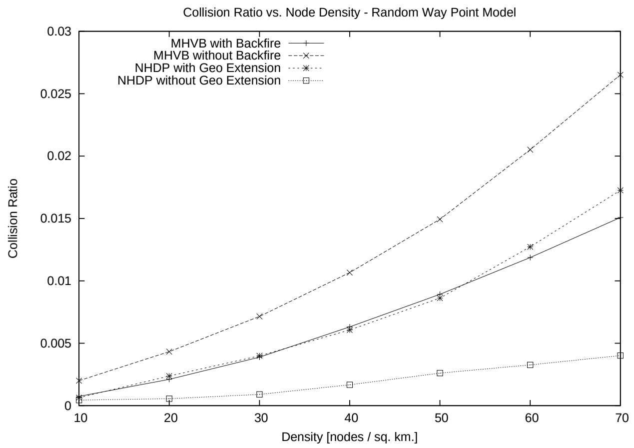

Figure 14: Collision ratio: Random way point model

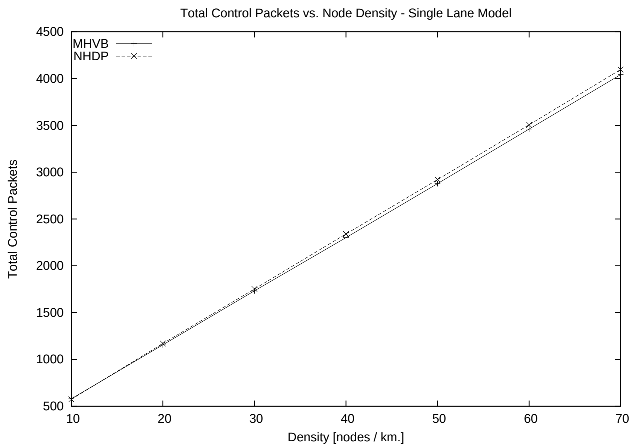

Figure 15: Total control packets: Non-mobile scenario over single lane

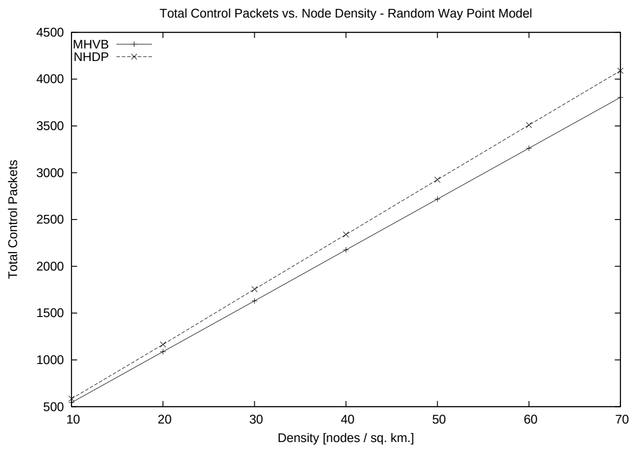

Figure 16: Total control packets: Random way point model

6 Conclusion

We have presented a comparative analysis of two protocols used in multi-hop ad hoc networks, namely NHDP and MHVB. Both protocols are representatives of different classes of protocols: MHVB is a location-based, general-purpose transport protocol for network wide information dissemination, whereas NHDP is a protocol enabling a router to acquire information describing its local network topology up to two hops away.

Different as these two protocols are, they can be used for the same purpose of neighbor discovery, when used with certain assumptions and extensions, as presented in this document.

For MHVB the maximum distance for forwarding messages is limited to twice the radio range of the wireless radio interface in order to collect neighbor information up to two hops. This assumption allows to create a similar topology for neighbors up to two hops away, such as in NHDP.

NHDP, due to its flexible message format, allows to introduce TLVs containing position information, speed and timestamp. This effectively facilitates to include location information in NHDP, and thus to compare it to the location-based protocol MHVB.

The comparison of the two protocols with the network simulator NS2 has shown that MHVB reduces overhead over NHDP with a geographic extension due to the backfire mechanism which reduces redundant transmissions in dense networks. The lower bandwidth consumption leads to a lower collision rate and to a lower utilization of the channel for control overhead.

Aside from the usual set of performance parameters such as control traffic overhead and collisions, special interest is accorded to the "freshness" of neighborhood information, obtained through each of the protocols. It was observed that for low density networks, the average message freshness of NHDP is comparatively better for lower node density, whereas the average message freshness of MHVB is better for higher node densities. This is because MHVB applies the so-called "backfire" algorithm which reduces redundant transmissions

This comparison of MHVB and NHDP in a common framework allows to understand properties of both MHVB and NHDP, and how they can be used for neighbor discovery with location information. As a future work, it is planned to study the behavior of OLSRv2 with NHDP being replaced by MHVB for neighborhood discovery.

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