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Neighborhood discovery overhead in dual rate ad hoc networks

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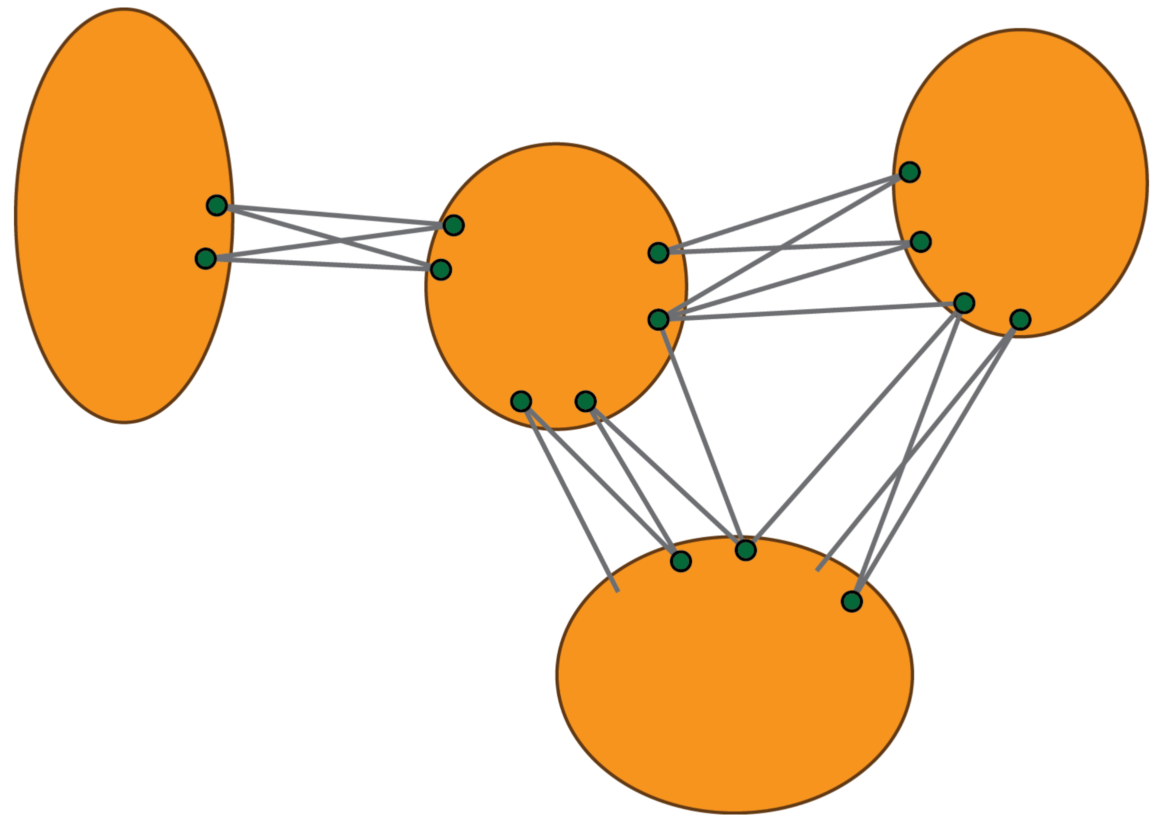

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Sammanfattning

När nätverkstopologin förändras på grund av nodernas mobilitet i ett ad hoc-nät måste protokollen uppdateras för att kunna hantera detta. En väsentlig del för att åstadkomma detta är att noderna håller koll på sin lokala omgivning. I denna rapport analyserar vi först overhead-kostnaderna för att hålla sådan information uppdaterad och studerar för vilka nätverksstorlekar och länkdatatakter denna overhead kan hållas på en rimlig nivå. Två olika representationer av nodernas grannskap undersöks för att skicka den nödvändiga topologi-informationen: det meddelandeformat ("Hello message") som används av OLSR och en minimal grannskapsrepresentation. Därefter beskrivs en vågform som hanterar två datataktsnivåer, en hög datataktsnivå och en låg datataktsnivå, med en betydande skillnad mellan de två nivåerna. Overheadkostnader för denna vågform analyseras och diskuteras. Syftet med den lägre datahastigheten är huvudsakligen att upprätthålla konnektivitet och för att sända viktig information mellan nätsegment som var och en är förbundna i högdatataktsläget. På detta sätt kan lågdatataktslänkar hanteras i betydligt större nät än vad som är möjligt i ett rent lågdatataktsnät. Dessutom visas att overhead-kostnaden för uppdatering av lokal grannskapsinformation även för stora nät är acceptabel med ett effektivt meddelandeformat.

Nyckelord: Ad hoc-nät, topologi-information, overhead, grannskapsinformation, hallå-meddelanden

Summary

In mobile ad hoc networks when nodes are moving, the network topology will change. Such dynamic topology changes must be handled by the ad hoc network radio protocols. In order to do this the network nodes need to keep track of their local neighbourhoods. In this report, we first analyse the overhead cost of keeping such information updated and study at which network sizes and link data rates the overhead can be kept at a reasonable level. In this analysis, two message representations to send the necessary topology information are included, the OLSR Hello message format and a “minimal neighbourhood representation”. Thereafter, a two mode waveform consisting of a high data rate mode and a significantly lower data rate mode is outlined and its overhead cost analysed. The aim is to use the lower data rate mode mainly to uphold connectivity and for sending essential information between network parts in a network that is fragmented at the high data rate mode. In this way low data rate links can be added to the network for network sizes far larger than a solely low rate network can handle. Also, the overhead needed for maintaining the necessary local neighbourhood topology information of the two mode waveform is shown to be acceptable if the minimal neighbourhood representation is used.

Keywords: Ad Hoc networks, topology information, overhead, local neighbourhood, Hello messages

Contents

1 Introduction

Mobile ad hoc networks are used to obtain radio communication where infrastructure is missing. An ad hoc network is a multi-hop network, which means that information is relayed between intermediate nodes in the network. When nodes are moving, the network topology will change. Such dynamic topology changes must be handled by the ad hoc network radio protocols. One of the more important things the network nodes need to keep track of is their local neighbourhood, commonly done through so called Hello messages. Such information can then be used for further control of the network routing and scheduling.

In this report, we first analyse the overhead cost of keeping the local neighbourhood information updated (the cost of Hello messages) and study at which network sizes and link data rates that this overhead can be kept at a reasonable level. This is done both when neighbourhood information is represented as efficiently as possible and when a more standardized approach is being used (Optimized Link State Routing Protocol ,OLSR [1]). We show that an efficient representation is needed for low link data rates but even then the possible network size will be limited.

There is a trade-off between the available data rate and the direct transmission range between two nodes in a radio system. We say that there is a link between two nodes if they can communicate directly on a certain data rate. Increasing the data rate in the network results in a shorter range and thereby the network will be less connected, since it contains fewer usable links. As long as the network remains connected, a higher data rate may be of advantage but if the network becomes fragmented it may significantly reduce the performance of the network.

Using more than a single data rate may both keep the network connected while achieving the advantage of the higher data rates whenever it can be used. A problem though, is that in order to get a significant range extension, the link data rate may need to be decreased a lot. Therefore, in order to keep a mobile network constantly connected, the added lower data rate may need to be much lower than the normally used data rate. This means that the low rate links connecting the network can’t be expected to handle much traffic.

In this report we therefore also suggest and analyse a method to update neighbourhood information in a network with two different data rate levels, where one of them is significantly lower than the other. We analyse this suggested method and show that as long as most nodes can use the high data rate mode, low rate links can be added to the network for network sizes far larger than a purely low rate network can handle.

2 The Hello message

In a mobile network, it is important to keep track of the network topology: which links and communication paths that presently can be used and what capacity the links have at the moment. As this information only has relevance when traffic is going to be sent through the network, there are two different philosophies about how to handle this problem: a reactive approach and a proactive approach. In the reactive approach, paths and resources are only reserved when needed. If no user traffic is to be sent, there will be no exchange of topology information between the nodes. This approach works best if there are only a few nodes that are transmitting or receiving traffic at a time. In the proactive approach, topology information about the network is constantly being updated. In this report, we consider the proactive approach to handle topology information in the network, since it fits military applications best such as broadcast of position information and voice.

The Hello message is used by proactive routing algorithms such as OLSR [1] to keep track of the local neighbourhood of a node. We say that the neighbours of a node are all other nodes that can communicate directly (within radio transmission range) to the node. A Hello message is transmitted to the neighbours of a node and includes a list of the node's neighbours and the status of the links to them. In this way, all nodes will be given information about the neighbours of its neighbours, that is, its two-hop neighbourhood. This information can be used to reduce the number of transmissions needed to reach all nodes in a network as compared to flooding where all nodes retransmit every message. In addition, it can be mentioned that similar information will be needed on the Medium Access Control (MAC) layer if a scheduled MAC approach is used.

In a network that use more than one data rate, the use of Hello messages need to be more complex since the local neighbourhood may not be the same for different data rates. It is only possible to estimate the quality of a link for higher data rates than the rate that was used to send the Hello message. This in short means that in order to detect a low rate link, the Hello messages must be sent on this rate or lower. However, a lower rate also means a longer range and therefore more neighbours, which requires a larger size of the Hello message.

For our further assessment, we now estimate the minimum required size of a Hello message. A Hello message needs to contain information about the neighbours to a node and some status information about the link. This means that the Hello message consists of a list of neighbour addresses and their associated link status. The size of an Internet network address for IPv4 is 32 bits and a layer 2 Ethernet address is 48 bits. The purpose of these addresses is to be globally unique though, which is not a necessary condition for a unique identification of the nodes in the local network. The locally used address only needs to be unique in the specific network. The required address size will therefore be dependent on network size; an appropriate size may be 8 bits, giving us a maximum network size of 255 nodes. Just including the network address in a message is not sufficient. More information about the link status is necessary, for example if the links are bidirectional or if the neighbour is selected as a Multi-Point Relay (MPR). Also, information about link quality may be needed and can include information about data rate and signal-to-noise ratio, to help the routing process to choose appropriate paths. For our estimation, we assume that four bits of status information is sufficient to describe the link status, which support 16 different levels of link status.

The neighbourhood information, including all neighbours' identity and link status, can be represented in several ways. In order to give an estimate of a representation that requires a minimum number of bits, we consider the following three different neighbourhood representations. We denote the minimum of these three representations by "*the minimal neighbourhood representation*" further on in this report.

1. One way to represent the neighbour information is to list the identity for each neighbour together with its link status. The size of a Hello message will then on average be $12Ne$ bits with this representation, where Ne is the average number of one-hop neighbours in the network.
2. With 254 possible neighbours and only 16 possible status levels, a number of links may have the same status. A second alternative for representing neighbour information is to list all neighbour identities with the same link status together. A header of each neighbour list contains the link status level and the list length (the number of neighbours with this link status). The list length is necessary in order to determine where in the message the next neighbour list begins. It is sufficient to use 8 bits for the neighbour list length, since we assume less than 255 neighbours in the network. Hence, each neighbour list header requires 4+8 bits. Since there are at most 16 neighbour list headers in the message, this result in a neighbourhood representation with at most $192 + 8Ne$ bits. If there are few status levels in the neighbourhood, this representation is efficient.
3. A third alternative is to use a vector representation of the neighbour identity and the link status, with four link status bits for each node in the network. The size of this neighbourhood representation is $4N$ bits, where N is the number of nodes in the network. If the network is dense, with many neighbours to each node, this representation will be more efficient than the first two representations. This representation is most efficient if the number of bits used for link status is small compared to the address size.

We define the size S of a Hello message using the minimal neighbourhood representation as the minimum size of these three representation alternatives. Each Hello message must also contain the identity (8 bits) of the node that sends the message, thus the Hello message size S can be calculated as:

$$S = 8 + \min\{12Ne, 192 + 8Ne, 4N\} \text{ bits}$$

See Figure 1 for an example of the size of the minimal neighbourhood representation for network size $N = 200$.

As a comparison of Hello message size, we now consider the routing protocol OLSR given in [1], where one or more OLSR messages can be sent in an OLSR packet, see Figure 2. Each OLSR packet is sent over IP and UDP. Assuming IPv4, the headers of IP and UDP sums up to 224 bits (the IP header size is 160 bits and the UDP header size is 64 bits). The OLSR packet header size is 32 bits and in the OLSR packet, there is an internal header of 96 bits before each OLSR message. As a worst case, we assume that only one OLSR message is sent in each OLSR packet, resulting in a total header size of 128 bits in the OLSR packet containing the Hello message. Including the UDP and IP header we get a total header size of 352 bits.

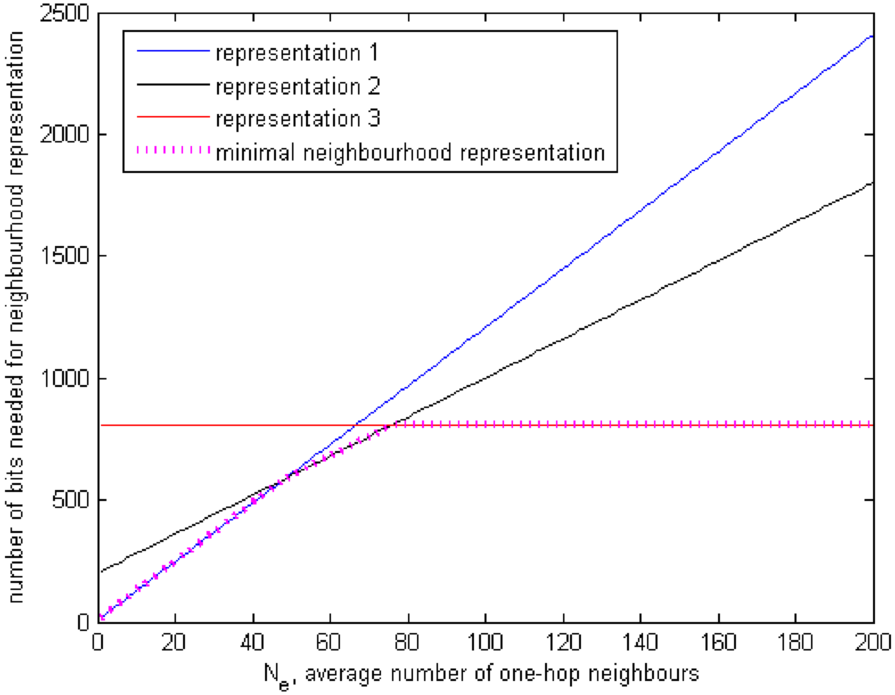

Figure 1 The size of the minimal neighborhood representation for network size $N = 200$.

As we can see inFigure 3, the OLSR Hello message consists of a 32-bit header followed by a number of link messages. Each link message, in turn, starts with a 32-bit link message header specifying the link and neighbour type of the succeeding neighbour interface addresses. The possible link and neighbour types are specified in section 6.1.1 in [1]. To simplify the calculations, we assume that the average number of combinations of links type and node type is three in the transmitted OLSR Hello messages. In the next chapter, we compare the Hello overhead for minimal neighbourhood representation and OLSR, using the following estimate of the size of an OLSR Hello packet without IP and UDP headers, S_{OLSR} and with IP and UDP headers, $S_{\mathrm{OLSR,IP}}$:

$$S_{\mathrm{OLSR}} = 128 + 32(Ne + 3)$$

$$S_{\mathrm{OLSR,IP}} = 352 + 32(Ne + 3).$$

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Packet Length         |    Packet Sequence Number     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Message Type |     Vtime     |         Message Size          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Originator Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time To Live |   Hop Count   |    Message Sequence Number    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
:                            MESSAGE                            :
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Message Type |     Vtime     |         Message Size          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Originator Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time To Live |   Hop Count   |    Message Sequence Number    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
:                            MESSAGE                            :
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
```

Figure 2 The basic layout of an OLSR packet (omitting IP and UDP headers).

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Reserved             |     Htime     |  Willingness  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Link Code   |   Reserved    |       Link Message Size       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Neighbor Interface Address                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Neighbor Interface Address                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                             .  .  .                           :
:                                                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Link Code   |   Reserved    |       Link Message Size       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Neighbor Interface Address                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Neighbor Interface Address                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
```

Figure 3 The OLSR Hello message format.

3 Overhead estimation for Hello messages

All nodes in the network transmit Hello messages. We assume an equal Hello interval T for all nodes. Furthermore, we assume that spatial reuse (geographically separated nodes transmitting in the same time slot) is not used for Hello messages. If the messages are used to measure the channel, spatial reuse may not be possible since that would disturb the channel measurements. With N nodes in the network and an average size S of a Hello message, the amount of resources needed (in bit/s) for Hello traffic is:

$$N * \frac{S}{T}$$

In OLSR the default Hello interval is $T = 2$ seconds,We use this value for the resource estimation. See Table 1 for some examples of resource estimations for different network size and connectivity and for both minimum size Hello messages as well as the OLSR Hello messages. From the result in Table 1 we can see that the cost to keep track of neighbour information increases rapidly with size and connectivity. The OLSR protocol generates much more overhead than the minimal neighbourhood representation. Whether this cost is a problem, is mostly dependent on the available link data rates.

If all nodes can use a data rate of 1 Mbps, not even the dense 200-node network will be a problem for the minimum representation. With OLSR Hello packets on the other hand, more than 60% of the capacity will be needed for Hello messages. From the table it can be seen that in order to have a reasonable overhead using the OLSR Hello packets, the network should probably not be larger than around 100 nodes unless the network always is very sparse.

For a low rate network, with a link data rate of 25 kbps, the resource requirement for OLSR is a problem even for a small network with 15 nodes. The required resources are 15-20% of the data rate for OLSR Hello packets and 22-27% for OLSR Hello packets also including IPv4 and UDP headers.

Even using a minimal data representation in the hello packets requires a noticeable overhead for a low rate network with data rates of 25 kbps. For a dense network with 40 nodes, more than 10% of the capacity is used for Hello messages. For a dense network with 80 nodes, about 50% of the capacity is used.

Network size, N	Number of neighbours, Ne	Resource requirement Minimal Hello (kbps)	Resource requirement OLSR (kbps)	Resource requirement OLSR, UDP, IP (kbps)
15	9	0,5	4,1	5,8
15	14	0,5	5,3	7,0
40	9	2,3	10,9	15,4
40	19	3,4	17,3	21,8
40	39	3,4	30,1	34,6
80	9	4,6	21,8	30,7
80	19	9,4	34,6	43,5
80	79	13,1	111,4	120,3
120	9	7,0	32,6	46,1
120	19	14,2	51,8	65,3
120	30	22,1	73,0	86,4
120	119	29,3	243,8	257,3
160	9	9,3	43,5	61,4
160	19	18,9	69,1	87,0
160	30	29,4	97,3	115,2
160	159	51,8	427,5	445,4
200	9	11,6	54,4	76,8
200	19	23,6	86,4	108,8
200	30	36,8	121,6	144,0
200	199	80,8	662,4	684,8

Table 1 The cost of Hello messages for different network size and connectivity.

From these figures it is easy to see that it is important to use an efficient representation of neighbourhood information for low rate networks, which due to range requirements and jamming resilience are rather common in military networks. Note that the figures only include administrative traffic for neighbour information. Routing information about paths further away, inside and outside the local network, may also be required. Also, administrative overhead for scheduling and other layer 2 processes may require as much additionally overhead as the Hello overhead.

4 Low rate links in an ad hoc network

A low data rate is a common feature of links with special properties such as long range, anti-jamming protection (AJ) and low probability of interception/detection (LPI/LPD).

Using dual rate links in a network won't change the results from previous chapter much as long as only links with higher rates are added. The primary problem in such cases is that the topology change rate may potentially increase, which may require us to send Hello messages more often.

Using lower rate links on the other hand will cause more problems. To detect low rate links, the Hello message needs to be sent on a low rate, which makes the transmission more expensive as the transmission will take longer time on a lower rate. This is the case even if the nodes send on higher rates the rest of the time. Additionally, the ranges will mostly be longer than normal links which results in more and more of the nodes being part of the neighbourhood of a node (not necessarily the case for the AJ and LPI/LPD types of links though) and therefore the Hello messages will be larger.

From the above discussion it is clear that if low data rate links needs to be added into a network of any reasonable size, only a subset of the links can be tracked at any given time. On the other hand it will be difficult (often even impossible) to beforehand know which nodes that will need to have access to low rate links. Some of them can be estimated in advance due to their operational roles, but which nodes they may reach in the main part of the network is more difficult to predict. (If sufficient number of nodes moves in close groups this may be less of a problem, but for networks of sizes approaching 200 nodes, these groups needs to be of at least 8-10 nodes in size in order to reduce the number sufficiently to add 25 kbps links without excessive overhead). Therefore, ideally all nodes need to be capable of handling low rate links whenever needed, but only a subset of these nodes should actively attempt to keep track of the network at any specific time.

In order to be able to detect nodes where low rate links are needed all nodes need to send Hello messages at low rates (slow Hello) regularly, but as been stated above most nodes cannot send these as often as would be needed to actually keep track of low rate links. Instead all nodes need to transmit slow-Hello messages seldom; the rate depends on the how quickly partitions need to be detected. These messages cannot be allowed to contain more than a few addresses to reduce the size of each message as well. For example, if each node in a 200 node network sends a 200 bit slow-Hello message every 10 seconds, it would require

4000 bits/s, or 16% of the capacity of the network if they are sent at 25 kbps. If messages are sent every 40 seconds, 4% of the capacity is required.

As long as high capacity routes exist, the low capacity links shouldn't be needed and only these rare slow-Hello messages will be sent at a limited capacity cost. If the network partitions though, low rate links are needed and therefore some nodes need to send slow-Hello messages more often, in addition these messages may need to contain more information than in the rare transmission case. Theoretically, it may be sufficient with one single link between two partitions, but considering the rate at which now links can be set up it is probably better to have a few parallel links to quicker cover link failures.

5 Managing low data rate links

To know if a link to a neighbouring node exists and which data rate R that can be used on the link a message (in this case a Hello message) needs to be sent over the link. If a Hello message is sent on a link L and received successfully at rate R, any data rate lower than R could be used at link L, but other links that cannot use as high data rate as R will not be detectable by this Hello message. Sending messages at a data rate higher than R over link L may also possible, but in that case we have to rely on estimations from the quality of the received Hello message to estimate what data rates that would work.

To use a low data rate for the Hello messages is desirable in order to obtain a good topology picture of the network, but this will be costly. Therefore, we propose a method using different Hello messages, one at a high data rate which is the normal data rate used and two types at a considerably lower data rate called passive slow-Hello message, and one called active slow-Hello message.

In [2], the communication distances where investigated for different terrain types and bandwidths at the 240-380 MHz and at the 30-88 MHz band. Roughly, reducing the data rate from 1 Mbps to 25 kbps (40 times) increase the communication distance 1.5-2 times at the 240-380 MHz band. When the lower data rate mode 25 kbps uses the 30-88 MHz band instead 2-4 times increased distance is possible to obtain.

As examples in the following investigation we will consider these two data rates; i.e., for the low data rate mode 25 kbps, and for the high data rate mode 1 Mbps.

Basic method:

Let us consider nodes having one transceiver and only two data rates: 1 Mbps and 25 kbps. First we consider how the payload is sent before we go into how the network control, which is the main topic, is managed. The low data rate links are used to keep the network connected. As long as the network is connected at the high data rate, low data rate links are not used. However, whenever the networks get fragmented into sub-networks a few nodes will be selected to bridge the network parts with low data rate links. We call them LDR nodes, even if they also use high data rates part of the time, and the other nodes simply HDR (High Data Rate) nodes. To choose the right LDR nodes is not an easy task even if the basic strategy for which nodes that could be suited as LDR nodes is rather straightforward. For example, it is desirable to have more than one single link (two LDR nodes) available to bridge a gap between sub-networks. Thus, a few LDR nodes need to be selected. An LDR node will manage a sub-network that consists of nodes that all can be reached by high data rates.

The LDR node will need to switch between high data rate when communicating with the HDR nodes in its sub-network and the low data rate when communicating with other LDR nodes in other parts of the network. When it communicates with another sub-network it is blocked for communication with its on sub-network. Nevertheless, the other nodes in its sub-network that are HDR nodes can still communicate between each other. This requires that the LDR node switches between frequency bands (or hop patterns in case of Frequency Hopping).

The difficulty now will be to manage this setup, the topology information is conveyed through Hello messages (and possibly Topology Control (TC) messages as used in OLSR [1], but these will be ignored here). Besides, sending Hello messages at high data rate, the nodes also need to send Hello messages at low data rate but less frequent, we call them slow-Hello messages. For example; if network resources is allocated each 500 ms to these slow-Hello messages, each node in a 60 node network can send a slow-Hello message each 30 s. However, sending slow-Hello messages more frequently is required if we want to use the LDR links to communicate payload. Therefore, we define two different slow-Hello messages, a passive and an active which is send more often. The passive slow-Hello messages are sent by all nodes, and the active slow-Hello messages are only sent by those nodes selected as LDR nodes. Next we will discuss this basic method more in detail and also a strategy for selecting the LDR nodes. To summarize, we have introduced the following definitions

1) A sub-network is a network that is connected at the high data rate.
2) HDR node sends payload data at the HDR mode and sends
    a. Normal Hello messages at HDR mode
    b. Passive slow Hello messages at LDR mode
3) LDR node sends payload data both at HDR and LDR mode and sends
    a. Normal Hello messages at HDR mode
    b. Passive slow Hello messages at LDR mode
    c. Active slow Hello messages at LDR mode

6 Selecting LDR nodes

A HDR node does normally send slow Hello messages very seldom, and normally these contain only the address to the node itself and information that the node is a HDR node. Every time a node receives one of these messages, it checks whether the source is reachable through normal HDR links (information through normal Hello and TC messages) in which case the messages is ignored. If the source node cannot be reached in that way, however, it will be added to the destination nodes slow-Hello message set. In order to actually later use the link though this is not sufficient. Both nodes need to start transmitting slow Hello messages more often, which means that both nodes become LDR nodes and send active slow Hello so sufficient link information is obtained.

A problem here is the case with two sub-networks and when a lot of nodes detect each other without the normal HDR route options, methods for limiting the number of LDR links between these sub-networks are needed. In the multi-channel case we may want several independent links active at the same time, but in such case both sender and receiver(s) should be different. A solution could be to check the number of HDR or LDR nodes detected by the passive slow-Hello messages and see whether these nodes are reached by other nodes in the present sub-network. This means that a LDR node should add all HDR nodes it can hear into an active slow-Hello message though. Also, a HDR node should add all, or at least all LDR nodes into their passive slow-Hello. However, active slow-Hello messages are sent often. Therefore, since a LDR node only has to announce the HDR nodes it has in its sub-network with a much lower interval it is not efficient to add this information in the active slow-Hello messages. Instead, a separate message with this information can be sent sporadically.

In order to respond to links that goes up and down between sub-networks it is important to have multiple active links between sub-networks. Such links can have separate sender and receiver pairs or can try to use several links from a single node. The first case can be of advantage in multi-channel cases since it would allow better simultaneous resource utilizations. On the other hand it will require a larger number of nodes to be LDR nodes in order to get the same number of active links between two sub-networks. Two nodes on each side can result in four possible links for example, which otherwise would require four nodes on each side. Each node controlling more than one link also allows for easier MPR selections. Since the proposed method mainly focuses on minimizing overhead, a solution with not to many LDR nodes is preferred. On the other hand, to have more than a single LDR node in each sub-network is also preferred.

The basic strategy, for which nodes to select as LDR nodes, is rather straightforward. However, the development of an efficient protocol, including the messages that have to be sent for the selection and upholding process of LDR nodes, is far from straightforward. The development of such a protocol is left for further work. The basic strategy for selecting LDR nodes are:

- For each sub-network consisting of two or more nodes select at least two LDR nodes. The aim is to be able to avoid having a single link of failures between sub-networks. For large sub-networks consisting of 10 or more nodes more than two LDR nodes may be selected.
- Select LDR nodes that have favourable locations within the sub-network, that is, nodes having good connections to adjacent sub-networks but also with all other nodes with HDR links within the sub-network (not too many hops if possible).

We assume the following structure of the active and passive slow Hello messages. First define the identity of a sub-network to be the lowest identity of the nodes in the sub-networks. The slow Hello message contains a header with the identity of the sending node and its subnet identity (altogether 16 bits). This header is followed by a triple of identities for each sub-network that the sending node can reach directly with low data rate connections. Each triple of identities represent the node with the best connection, the second best connection and the identity of the sub-network that contain these two nodes (altogether 24 bits).

The LDR nodes will seldom be connected to more than three other sub-networks. Therefore, the passive slow Hello message would require approximately 90 bits. However, it has to be sent as a separate packet at the low data rate. Due to additionally packet overhead and guard times, we therefore assume that the passive slow Hello message size corresponds to 200 bits.

7 Overhead estimation for a dual rate waveform

Next we consider for which cases the necessary overhead, caused by the two data rate mode waveform, is acceptable. That is, the control/overhead traffic should not occupy more than a certain fraction of the bandwidths, say 20 % for LDR nodes and say 10 % for HDR nodes. It is the overhead for the LDR nodes that is most important to consider. The LDR nodes will be blocked for sending and receiving payload during the fraction of time needed for overhead even if the HDR nodes can send data to other HDR nodes part of that time. By necessary overhead we mean the messages needed (the different Hello messages) to uphold the topology information at the two modes. Note, however, other control messages may be needed for the LDR selection protocol but those are not included in the overhead calculations and are estimated to have a negligible contribution to the overhead compared to the Hello messages.

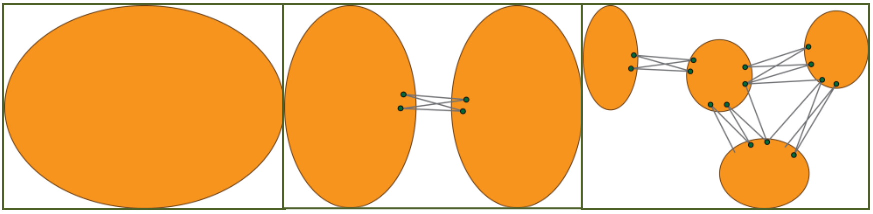

Figure 4 Case A (left), case B (middle) case C (right).

We evaluate three topology cases, see Figure 4. Case A is a connected network with no nodes in LDR mode. Case B consists of two equally large connected sub-networks, each with two LDR nodes. Case C consists of four equally large sub-networks, with two, six, three and four LDR nodes as indicated in the figure. In the following we will calculate the Hello overhead for the different topology cases. The lines represent links announced by the LDR nodes.

HDR nodes:

1. Each node sends normal Hello messages every T_H second in HDR mode
2. Each node sends passive slow Hello messages every T_p second in LDR mode

LDR nodes:

1. Each node sends normal Hello messages every T_H seconds in HDR mode

2. Each node sends passive slow Hello messages every T_p second in LDR mode
3. Additionally, each LDR node sends active slow Hello messages every T_a second in LDR mode.

In the evaluation, we set these parameters to: $T_H = 2$ seconds, $T_p = 30$ seconds and $T_a = 2$ seconds. Furthermore, let R_H be the HDR data rate, R_L be the LDR data rate. We use the data rates $R_H = 1$ Mbps and $R_L = 25$ kbps in the evaluation. As defined in chapter 2, N is the number of nodes in the network and Ne is the average number of one-hop neighbours in HDR mode.

Now, denote S_H as the average normal Hello message size. These messages contain the minimal neighbourhood representation and are calculated as described in Chapter 2:

$$S_H = 8 + \min\{12Ne, 192 + 8Ne, 4N\} \text{ bits},$$

The structure of the slow Hello messages are described in the previous chapter. We define S_p as the average passive slow Hello message size, assumed to be 200 bits and $S_a(n)$ as the active slow Hello message size for an LDR node n. So for an active node n in a sub-network with low-rate connections to l LDR nodes in other sub-networks we have:

$$S_a(n) = 16 + 24l.$$

In the different topology cases in Figure 4, we calculate the total sum $\sum_n S_a(n)$, of all active slow Hello messages repeatedly transmitted in the network. In case A, there are no LDR nodes, so we have

$$\sum_n S_a(n) = 0.$$

In case B we have four LDR nodes connected to one other sub-network:

$$\sum_n S_a(n) = 4 \cdot (16 + 24 \cdot 1).$$

In case C there are thirteen LDR nodes connected to one other sub-network and two LDR nodes connected to two other sub-networks:

$$\sum_n S_a(n) = 13 \cdot (16 + 24 \cdot 1) + 2 \cdot (16 + 24 \cdot 2).$$

With these parameters set, we obtain the overhead, expressed as the ratio of available bandwidth as:

- Overhead due to normal Hello messages:

$$O_H = \frac{N * \frac{S_H}{T_H}}{R_H}$$

- Overhead due to passive slow Hello messages:

$$O_p = \frac{N * \frac{S_p}{T_p}}{R_L}$$

- Overhead due to active slow Hello messages:

$$O_a = \frac{\frac{\sum_n S_a(n)}{T_a}}{R_L}$$

- Total Hello overhead:

$$O = O_H + O_p + O_a$$

The overhead figures for the different network sizes and average number of neighbours are displayed in Table 2 for topology case A, in Table 3 for topology case B and in Table 4 for topology case C.

In Table 2 the overhead results for the HDR connected network (topology case A) is shown, in this case there are no practical benefit of adding the low rate links since they are not needed. As can be seen there are no active slow Hello messages generated. The cost of adding passive slow Hello messages are noticeable but can probably be handled even for the dense 200-node network.

In Table 3 and Table 4 the result for the fragmented networks, topology B and C, is shown. In this case the low rate links is needed to keep the network connected. Also in this case it can be seen that the total overhead can be handled even for the 200 node networks.

N	Ne	O_H(%)	O_p(%)	O_a(%)	O (%)
40	9	0,23	1,07	0	1,30
40	19	0,34	1,07	0	1,40
40	39	0,34	1,07	0	1,40
80	9	0,46	2,13	0	2,60
80	19	0,94	2,13	0	3,08
80	79	1,31	2,13	0	3,45
120	9	0,70	3,20	0	3,90
120	19	1,42	3,20	0	4,62
120	30	2,21	3,20	0	5,41
120	119	2,93	3,20	0	6,13
160	9	0,93	4,27	0	5,19
160	19	1,89	4,27	0	6,15
160	30	2,94	4,27	0	7,21
160	159	5,18	4,27	0	9,45
200	9	1,16	5,33	0	6,49
200	19	2,36	5,33	0	7,69
200	30	3,68	5,33	0	9,01
200	199	8,08	5,33	0	13,41

Table 2 Hello Overhead for topology case A.

N	Ne	O_H(%)	O_p(%)	O_a(%)	O (%)
40	9	0,23	1,07	0,32	1,62
40	19	0,34	1,07	0,32	1,72
80	9	0,46	2,13	0,32	2,92
80	19	0,94	2,13	0,32	3,40
120	9	0,70	3,20	0,32	4,22
120	19	1,42	3,20	0,32	4,94
120	30	2,21	3,20	0,32	5,73
160	9	0,93	4,27	0,32	5,51
160	19	1,89	4,27	0,32	6,47
160	30	2,94	4,27	0,32	7,53
200	9	1,16	5,33	0,32	6,81
200	19	2,36	5,33	0,32	8,01
200	30	3,68	5,33	0,32	9,33

Table 3 Hello Overhead for topology case B.

N	Ne	O_H(%)	O_p(%)	O_a(%)	O (%)
40	9	0,23	1,07	1,30	2,59
80	9	0,46	2,13	1,30	3,89
80	19	0,94	2,13	1,30	4,37
120	9	0,70	3,20	1,30	5,19
120	19	1,42	3,20	1,30	5,91
160	9	0,93	4,27	1,30	6,49
160	19	1,89	4,27	1,30	7,45
160	30	2,94	4,27	1,30	8,51
200	9	1,16	5,33	1,30	7,79
200	19	2,36	5,33	1,30	8,99
200	30	3,68	5,33	1,30	10,31

Table 4 Hello Overhead for topology case C.

From these results it can be seen that adding low rate links to uphold connectivity is possible in ad hoc networks. In addition, this can be done for much larger networks than a purely low rate network can achieve as long as only a few nodes is needed to bridge different parts of the network.

Notice, however, this conclusion requires that the minimal neighbourhood representation is used. With OLSR Hello messages the overhead will be considerable larger and a dual data rate mode waveform is unfeasible to realize.

Also, let us emphasize that using two data rate modes in the same waveform will inevitably reduce the capacity in the network considerably as soon as the LDR mode is used for larger payloads.

8 Conclusions

How to manage both a high data rate (HDR) mode and a significantly lower data rate (LDR) mode in the same waveform has been investigated. The assessment has shown that it is feasible with respect to the overhead needed for maintaining the necessary 2-hop neighbourhood topology information if a minimal Neighbourhood representation is used.

An OLSR Hello message generates a lot more overhead than the minimal Neighbourhood representation. Whether the overhead is a problem though, is mostly dependent on the available link data rates.

For high data rate networks with link data rates over 1 Mbits/s the OLSR Hello message can be afforded for networks up to around 100 nodes. On the other hand, with the minimal neighbourhood representation even dense 200 node networks can be handled.

For low data rate networks and using link data rates of around 25 kbps the problem of using the OLSR Hello message format becomes apparent. It can be difficult to handle even 15 nodes. Even by using the minimal neighbourhood representation, the overhead will cause a noticeable problem. For a dense network with 40 nodes, more than 10% of the capacity will be needed to transmit the Hello minimal messages.

As a consequence of these results; in the two mode waveform firstly an efficient neighbourhood representation is needed and secondly not too many nodes can be in the LDR mode. The outlined two mode waveform is supposed to use the LDR mode mainly to uphold connectivity. Then, as long the connectivity can be maintained with the HDR mode the additional overhead of the two mode waveform is low. This is because of the relative low overhead for sending the passive slow-Hello messages which facilitates the possibilities to establish the LDR mode.

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