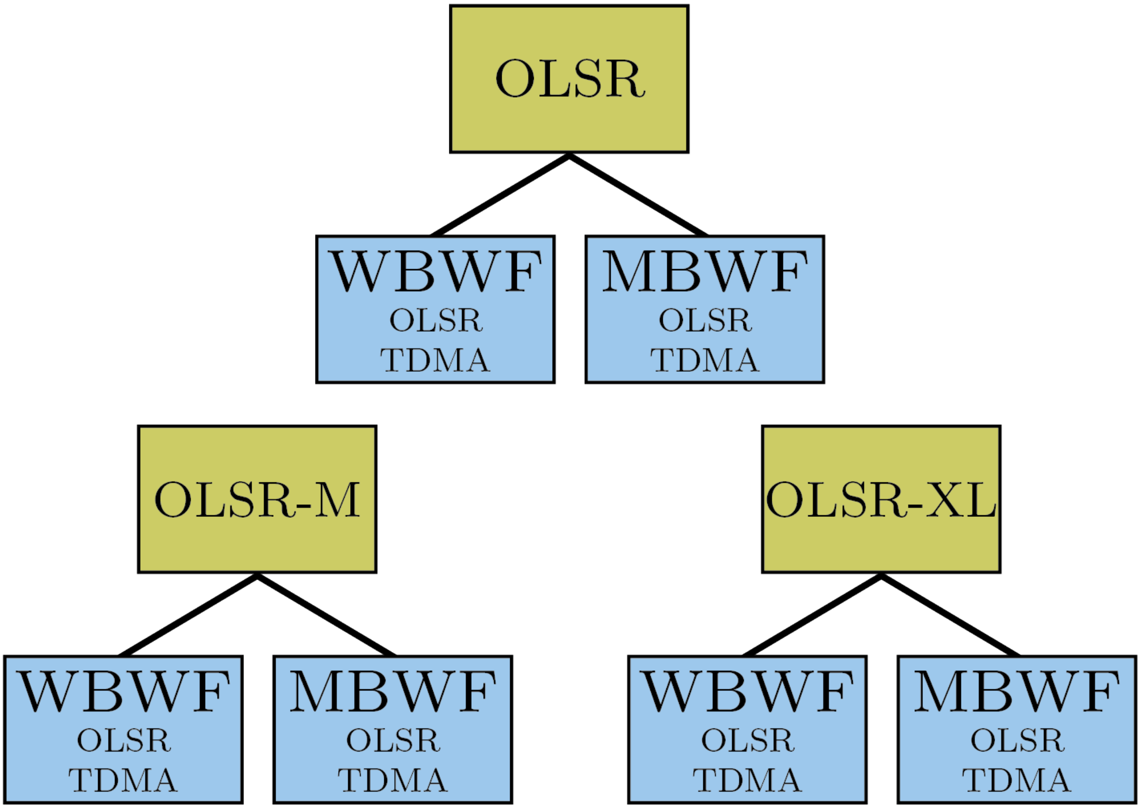
Evaluation of a Multi-Layer OLSR Design for Heterogeneous Networks

ANDERS HANSSON, JAN NILSSON, ULF STERNER



FOI-R--4879--SE
ISSN 1650-1942 November 2019

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Titel	Utvärdering av en OLSR-design över flera lager för heterogena nät
Title	Evaluation of a Multi-Layer OLSR Design for Heterogeneous Networks
Rapportnr / Report No.	FOI-R-4879--SE
Månad / Month	November / November
Utgivningsår / Year	2019
Antal sidor / Pages	35
ISSN	1650-1942
Kund / Customer	FM
Forskningsområde	4. Informationssäkerhet och kommunikation
FoT område	Ledning och MSI
Projektnr / Project No.	E72754
Godkänd av / Approved by	Christian Jönsson
Ansvarig avdelning	Ledningsteknologi

Abstract

In larger military units, military networks are heterogeneous in nature. This means that underlying flat sub-networks need to be interconnected. The heterogeneous network comprises a variety of networks with different bandwidths as one radio system (transmission technology) cannot support all requirements.

In this report, a layer 3 routing approach using OLSR to connect sub-networks is investigated. The aim of the study was to understand the design requirements for layer 3 routing with OLSR in more challenging scenarios, mainly in terms of scalability and mobility handling. To do so, basic OLSR and two different modifications of OLSR were tested. The overall design goal was to keep the overhead generated by the OLSR control traffic low while at the same time, maintaining a high packet delivery ratio. The results show that the overhead was reduced with the tested OLSR modifications, but also that the packet delivery ratio was notably reduced. Still, there is need for further work. Somewhat larger modifications and additions to OLSR seem to be necessary to make the OLSR to work satisfactorily in this type of scenarios.

Keywords: ad hoc networks, multiple interfaces, L3, L2, waveforms, OLSR

Sammanfattning

I större militära enheter är de militära nätverken heterogena. Det innebär att underliggande delnätverk behöver kopplas ihop. Det heterogena nätverket omfattar en mängd bredbands- och smalbandsnätverk. En anledning till att flera typer av nätverk krävs är att ett radiosystem (radioteknologi) inte kan uppfylla alla krav.

I rapporten undersöks en lager 3-routingmetod med OLSR för att koppla ihop delnätverk. Syftet med utredningen är att förstå designkraven för en lager 3-routingmetod med OLSR i mer utmanande scenarier, främst när det gäller skalbarhet och hantering av rörlighet. För att göra det testades en icke modifierad version av OLSR samt två olika modifieringar av OLSR. Det övergripande designmålet var att hålla den overhead som genereras av OLSR:s kontrolltrafik låg samtidigt som datapaketen fortsatt levererades med en hög sannolikhet.

Resultaten visar att overheaden reducerades med de testade modifieringarna av OLSR, men sannolikheten att paketeten levereras minskade märkbart. Det finns därför ett behov av ytterligare arbete. Något större modifieringar och tillägg till OLSR verkar vara nödvändigt för att få OLSR att fungera tillfredsställande i denna tillämpning.

Nyckelord: ad hoc-nätverk, multipla interface, L3, L2, vågformer, OLSR

Contents

1 Introduction

Large military networks are heterogeneous in nature and comprise a variety of wideband and narrowband networks. One reason is that one radio system (transmission technology) cannot support all requirements. Another reason is that the systems are in different phases of their lifecycles, leading to coexistence of the legacy system and new systems. Many different wireless transmission technologies will be utilized in the future, including various kinds of purpose-built tactical radios in the VHF and UHF bands with their respective waveforms and HF systems. However, satellite-based technologies, cellular systems such as LTE, 5G, and even Wi-Fi may also be part of the heterogeneous network. Finding a viable architecture that can incorporate many different types of networks of different sizes is essential.

The size of a single flat tactical radio network in terms of number of nodes can vary depending on the requirements for data rate, range, network topology and underlaying radio technology. However, at some point, when larger military units (e.g., brigades) are considered, several flat networks need to be interconnected. This can be implemented in many different ways.

In this report a solution to interconnect sub-networks based on OLSR routing at layer 3 (L3) is investigated. The design requirements for an L3 router daemon depends on the type of scenarios it should be able to handle. When two networks are connected through a single node, routing with preconfigured routes might be a working solution. However, more dynamic routing solutions are required when networks can be connected through different nodes and when mobility may cause the networks to merge or split.

The flat sub-networks can be of various types, but are built with layer 2 waveforms. This layer 2 waveform may, or may not, have an internal L2 router. Many tactical radios used today have waveforms with built-in L2 routing. There are also examples of waveforms without L2 routing, e.g., synchronized cooperative broadcast (SCB).

The aim of this study was to understand the design requirements for L3 routing in more challenging scenarios, mainly in terms of scalability and mobility handling. There is a tradeoff between packet delivery ratios and overhead generated by OLSR control traffic. A solution that can provide a sufficient delivery ratio without generating too much overhead is desired. To understand how such a solution should be designed, two modifications of OLSR were evaluated.

2 Background

The radio system considered in this report utilizes two waveforms on two different interfaces; one wideband waveform (WBWF), and one mediumband waveform (MBWF). The WBFW has 1 MHz and the MBWF 250 KHz bandwidth. These waveforms can be of different types and three different types of waveforms are discussed in this report. One type uses TDMA and performs the routing both at layer 2 and layer 3. The second type uses TDMA as MAC protocol at the link layer and OLSR routing at layer 3. The third type uses Synchronized Cooperative Broadcasting (SCB). Broadcast traffic refers to cases when packets are transmitted from a source node to all of the nodes in the heterogeneous network. The evaluations in the report were performed both for unicast and broadcast traffic.

2.1 The OSI model

TCP/IP consists of a number of protocols that together enable all communication between applications (computer programs) on the Internet [1]. The TCP/IP protocols are ordered into four layers that originate in the seven layers of the OSI model, see Figure 2.1. The OSI model *Open Systems Interconnection standard* [2] is a slightly more detailed breakdown of the protocols function, but since it is difficult to separate functionality at that high level of detail in practice, some of the layers of the OSI model are grouped together into one layer in the TCP/IP-model, see Figure 2.1. Layer numbers usually refer to the layer of the OSI model. This convention was followed in this report, where the seven layers in the OSI model are numbered from the bottom to the top as in the figure. Thus, layer two (L2) refer to the link layer and layer three (L3) to the network layer. Below, is a brief description of each layer in the TCP/IP-model along with examples of the protocols contained in the different layers.

Application layer (OSI layer 5-7): These layers contain programs or processes that utilize the communication in the network, such as HTTP and DNS. The applications in the application layer are closest to the user. Compared to the OSI model, the application layer of the TCP/IP-model also contains functionality from the session and presentation layer.

Transport layer (OSI layer 4): Contains protocols implemented in the transmitter and the receiver for identifying and linking applications with end-user systems (hosts), i.e., ensuring that user data that has reached its destination also reaches the correct application at the recipiend. The connection can also be made more reliable by detecting packet errors and retransmitting lost packets.

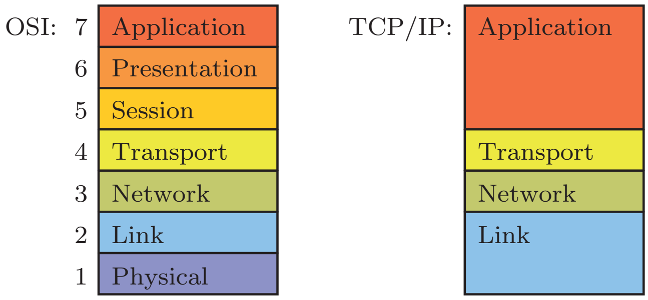

Figure 2.1: The OSI model to the left and the TCP/IP-model to the right.

Network layer (OSI layer 3): The network layer handles node addressing and methods for finding the nodes in the network. IP (Internet Protocol) is a required protocol to connect to the Internet. There are two versions, IPv4 and IPv6, where the latter version is newer and about to be introduced on a greater scale.

Link layer (OSI layer 1-2): Contains protocols required for the transmission over a single physical chanel, such as ethernet or Wi-Fi. This layer also contains features such as medium access control (MAC).

2.2 Synchronized Cooperative Broadcasting

In synchronized cooperative broadcasting (SCB), all nodes that receive a packet retransmit it simultaneously. Packets that are relayed simultaneously from nodes within range are always identical, and a receiving node handles the received signals as multipath propagation. The retransmissions continue until all nodes in the local network have received the packet. In order to synchronize the relay transmissions, time is divided into repeated TDMA frames consisting of time slots. Forwarding of packets are performed below the IP network layer (OSI layer3). Forwarding is repeated with a group of time slots that is used for transmission and relaying of packets from a single source.

2.3 Dynamic scheduling

The MAC protocol TDMA can be fixed or dynamic. A fixed protocol is preallocated, e.g., each node in the network gets one time slot each in a round robin fashion. In a dynamic protocol, the slots are allocated based on network topology and user traffic. A node that has much traffic to transmit is allocated additional slots. In dynamic SCB, the TDMA slots only have to be rescheduled due to changes in traffic and not because of changes in the network topology. In

Figure 2.2: Example of SCB with dynamic scheduling.

Figure 2.2, dynamic scheduling of SCB is illustrated. The control traffic needed for the scheduling (scheduling overhead) is sent in special administrative time slots. Of the three forward slots shown in Figure 2.2, one is used by the source node to send a user packet, and the other two are used to relay that packet. A dynamic protocol has the potential to be more efficient than a fixed one as long the necessary control traffic can be kept low.

2.4 OLSR

The Optimized Link State Routing Protocol (OLSR) is a proactive link-state routing protocol, optimized for mobile ad hoc networks. In the evaluation, an implementation was used in the simulator, which is from now referred to as *basic OLSR* or *unmodified OLSR*. The implementation follow RFC 3626 [3] that describes the protocol OLSR. For broadcast traffic, the *Multi-Point Relay* (MPR) flooding mechanism of OLSR that was of interest, originally designed for efficient flooding of OLSR control messages. MPRs relay messages between nodes and instead of all nodes, a subset of the nodes in a network is selected as MPRs. The basic idea is that each node selects a subset of its one-hop neighbours as multipoint relays (MPR). The MPRs are chosen so that all two-hop neighbours of a node will be reached if all its MPRs retransmit a message. To select the MPRs, a node requires updated information about its two-hop neighbourhood.

Control traffic in OLSR is mainly exchanged through two different types of messages: HELLO and TC (Topology Control) messages. HELLO messages are exchanged periodically among neighbor nodes, in order to detect links to neighbors, and detect the identity of neighbors and to signal MPR selection. On receiving a HELLO message, a node examines the lists of addresses of the transmitting nodes neighbors. If its own address is included, it receives confirmation that bidirectional communication is possible between the originator and the recipient of the HELLO message. When a link is confirmed as bidirectional, this is advertised periodically by a node with a corresponding link status of *symmetric*. In addition to giving information about neighbor nodes, periodic exchange of HELLO messages also allows each node to maintain information describing the links between neighbor nodes and nodes two hops away. This information is recorded in a node's 2-hop neighbor set and is explicitly utilized for the MPR optimization.

Topology Control messages are periodically flooded to the entire network in order to spread link state (topological) information to all nodes. A TC message contains a set of bi-directional links between a node and a subset of its neighbors. The topological information is used in the MPR optimization. Only nodes that have been selected as an MPR nodes generate (and relay) TC messages. The TC message contains a field with the Advertised Neighbor Sequence Number (ANSN). This number is associated with the node's advertised neighbor set and is incremented each time the node detects a change in this set.

3 Problem description

A schematic image of a radio system with multiple interfaces is shown in Figure 3.1. It shows one networking layer 3 and multiple link/MAC layers (L2 in blue). Normally, the routing is done at layer 3. However, the radio systems may, or may not, have a built-in router also at L2. Advantages and disadvantages of having radio systems with built-in routers are described in [4]. A radio system with multiple interfaces can be set up in various ways. The different setups considered are further described in section 3.1. In order to enable efficient overall routing in the heterogeneous network, what information that can be delivered from L2 up to L3 is important. Furthermore, the routing overhead cost can be high in heterogeneous networks, with a large number of nodes and frequent topology information updates [5].

The information that can be delivered up to layer 3 varies depending on the radio waveform used. This section discusses what can be delivered in terms of multi-hop functionality and network topology.

A basic waveform without routing at layer 2 delivers single-hop functionality. In order to deliver multi-hop functionality, routing at layer 2 is required or, alternatively, that SCB is used. The information that can be delivered about the network topology on the interface up to layer 3 varies from nothing to a full picture of the network topology. The most common case is probably that nothing is delivered. For simplicity this is broken down in four levels of information delivery from L2 to L3:

- Nothing: A static TDMA protocol without physical layer information.
- Link quality on the links to neighboring nodes: A static TDMA protocol with access to physical layer information.
- Two-hop neighborhood topology information and the link qualities: A distributed TDMA protocol with physical layer information.

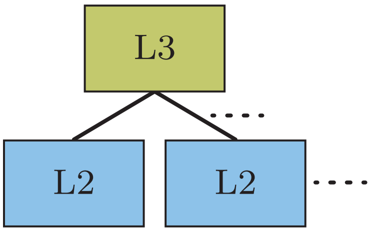

Figure 3.1: Multiple interfaces of a radio system.

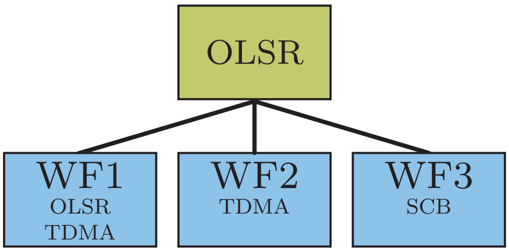

Figure 3.2: Three options of waveforms at layer 2.

- Full network topology (of the nodes that can be reached) with link qualities: A centralized dynamic TDMA protocol with physical layer information.

A fairly realistic delivery level is that the 2-hop link topology can be delivered, but only link metrics on the links to neighbouring nodes. In that case, cross-layer information is needed, but no link metrics need to be sent in the control messages. In addition, a dynamically distributed TDMA protocol normally needs, and therefore obtains, the 2-hop link topology. The last level is included as a reference of what could be obtained knowing the full network topology. However, a waveform supporting knowledge of full network topology is not likely. Even if the network link topology could be delivered, it is not likely that the link metrics on all links in the network are included in the control messages. These messages need to be broadcasted in the network, and such a solution would be very heavy in terms of control traffic. However, the link topology of the network being delivered is more feasible. Link topology information can be obtained in a centralized dynamic TDMA. Furthermore, a dynamic SCB is a more realistic case and can be set up so that the link topology of the network can be obtained.

3.1 Waveform options

At layer 3, only OLSR-based routing was considered in this report. Basic OLSR and two modified versions of OLSR were investigated. The aim was to understand the design requirements for L3 routing in more challenging scenarios, mainly in terms of scalability and mobility handling.

Different waveforms at layer 2 and below are possible, see the blue boxes in Figure 3.2. Note that the physical layer 1, which is below layer 2, is not shown in the figure. Routing may be performed at L2 above a MAC protocol as TDMA. The WF1 option in Figure 3.2. Options where all routing is performed at L3, i.e., no L2 routing, is also possible, as in the right WF2 and WF3 options in Figure 3.2. However, the latter two options were not investigated further. The report focuses on how the routing interactions between the routing at L3 and L2 performed.

Furthermore, waveforms with different bandwidths can be used. Two alternatives were considered; a WideBand WaveForm (WBWF) of 1 MHz, and a medium-band waveform (MBWF) of 250 KHz. The WBWF was used for intra-company communications, while the MBWF was used for inter-company communications. The WBWF was configured so that the nodes in each company formed an independent network. This was achieved by allocating different orthogonal frequency hopping patterns to the networks. To connect the wideband networks the MBWF was used.

3.2 MPR flooding overhead in OLSR

Figure 3.3 shows an example with MPR flooding (performed separatly at both L3 and L2) between four radio nodes over two companies, Company 1 and Company 2. It can be assumed that there are more nodes in the companies than the ones shown in the figure. A source node in Company 1 has selected two other nodes as MPRs, both in OLSR on L3 and in OLSR on L2/WBWF. Those nodes have in turn selected the node in Company 2 as their MPR, both in OLSR on L3 and in OLSR on L2/MBWF. In the example, the MPR nodes retransmit packets on all interfaces, also on the receiving interface. This is the default MPR flooding behaviour. As specified in OLSR, the MPR nodes retransmit packets on all interfaces, including the receiving interface.

First let us look at what happens at L3 in each node. The source sends the packet P1, which is flooded in the company WBWF network. All nodes in the company that receives the packet on WBWF identify the packet as P1 on L3 and retransmit it on all interfaces, both on WBWF and MBWF. The nodes in Company 2 that receives the packet on MBWF, identify the packet as P1 on L3 and rettransmit it on all interfaces. In every node, P1 is only retransmitted once on L3.

On L2, however, the L3 MPR flooding of P1 initiates several MPR floodings in both WBWF and MBWF. All of the packets P2 to P8 are sent in the networks by separate MPR floodings. Due to different headers in L2, it is not possible to directly detect that a retransmitted packet from L3 has already been flooded at L2. On L2, the following events will occur:

1. In the source node, the packet P1 from L3 gets additional headers on L2/WBWF. This new packet, P2, is sent as a source packet in MPR flooding in WBWF for Company 1.

2. The nodes that receive P2 and are selected as MPR in the WBWF network, retransmit P2 once. It is also passed up and identified as P1 in L3 in these nodes, and the L3 retransmission of P1 initiates a set of new separate MPR floodings on WBWF and MBWF with the packets P3, P4, P5 and P6.

3. The packet P4 is received on MBWF in Company 2 and is retransmitted on MBWF by the nodes that are selected as MPR on this waveform. It is also passed up and identified as P1 in L3, and the L3 retransmission of P1 initiates another set of new separate MPR floodings on WBWF and MBWF with the packets P7 and P8.

4. Furthermore, the packet P6 is received on MBWF in Company 2 and is retransmitted on MBWF by the nodes that are selected as MPR. This packet too is passed up and identified as P1 in L3. However, as specified in OLSR, P1 will not be retransmitted a second time.

It is obvious that the router at L3 should avoid retransmitting a packet on a receiving interface that is running MPR flooding. Examples of unnecessary floodings are the packets P3 and P5 (the packet P2 is already flooded), and the packets P6 and P7 (the packet P4 is already flooded).

3.3 Possible OLSR modifications

To reduce the MPR flooding overhead, two modified versions of OLSR at L3 were also defined, denoted: Muted OLSR (OLSR-M) and Cross-layer OLSR (OLSR-XL). The protocols OLSR-M and OLSR-XL are only used at L3.

The modification in OLSR-M entails that an MPR node never retransmits a packet on the receiving interface (if that interface is connected to an L2 router). For OLSR-XL, based on OLSR-M, more modifications were included. Note that a link at L3 may be a route of links in reality (which is visible at L2 but not

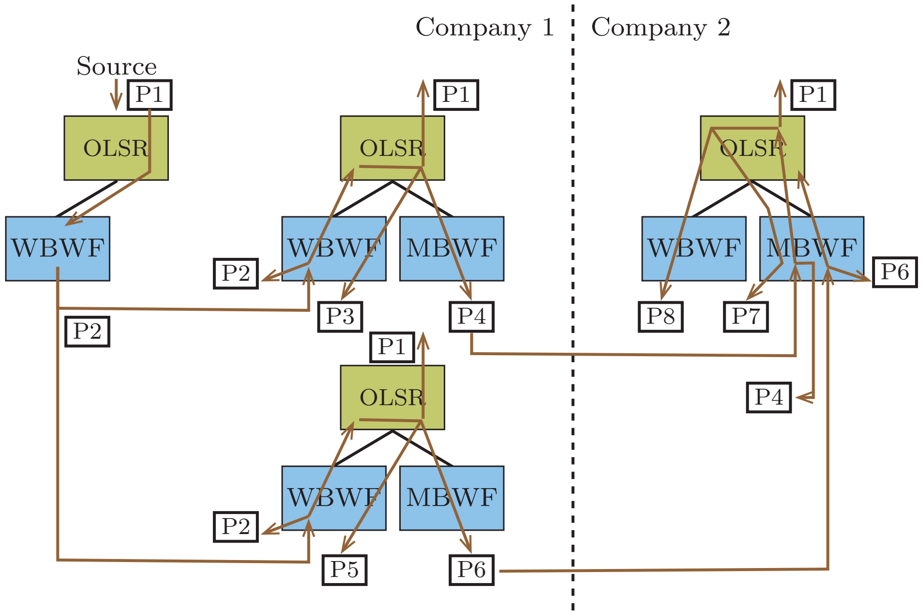

Figure 3.3: Example of OLSR broadcast traffic.

at L3). The following modifications were made, compared to the specification in RFC 3626 [3].

1. The detection of links at L3 is only based on information from L2
   (a) When links and associated neighbors are inserted in the OLSR database, the expire time parameter is set to infinity.
   (b) Links and associated neighbors at L3 are removed immediately when the corresponding route at L2 is detected as broken.
2. A node only sends a HELLO message when L3 detects a link change or when the MPR selection changes.
3. The minimum time between two HELLO messages is never less than the parameter min hello interval, which is set to two seconds in the present setup.
4. When a HELLO message is received, only MPR selectors and two-hop neighbors are updated according to the information in the message. In both cases, the expire time parameter is set to infinity. Two-hop neighbors and MPR selectors are removed from the database if they are missing in the HELLO message or if the associated neighbor is removed.

5. If the MPR set is changed, additional TC messages will be sent. The minimum time between two TC messages is never less than the parameter min TC interval, which is set to two seconds in the present setup.

4 Simulation Model and Setup

For this study, simulations were performed using Aquarius, an in-house radio network simulator. The simulator is written in C++ and models the system at packet level. Three different L3 solutions based on optimized link state routing (OLSR) were evaluated by simulations for a subset of the troop deployment vignette in the Anglova scenario. In the evaluation, all nodes used a company WBWF, and six nodes in each company were equipped with an MBWF interface: the company commander, the deputy company commander, and the platoon leaders of the other four platoons. Both waveforms ran OLSR on L2 and a TDMA protocol on the MAC layer. An L3 layer with OLSR connected the two waveforms. The scenario, simulation model, and performance metrics are described further below.

4.1 Scenario description

The scenario consisted of a part of the troop deployment vignette in the Anglova scenario [6], where a mechanized battalion consisting of 157 vehicles stage an attack against a hostile force. The area where the scenario takes place is made up of forest-covered hilly terrain. A subset of the battalion was used, consisting of the nodes forming two mechanized infantry companies and two tank companies. Furthermore, focus was on the phase in the scenario where the nodes had left the roads and started to move further south in the terrain, before the attack from scenario time 5,500 seconds to 6,501 seconds (Figure 4.1). Furthermore, the Figure 4.1 also shows the positions of each platoon at 6,501 seconds. On average, the nodes moved with a velocity of 15 km/h. In the evaluation, networks consisting of one, two, three, or all four companies were considered, i.e., the different network sizes were 24, 48, 72 and 96 nodes. The four different network setups were: (1) Company 1, (2) Company 1 and 3, (3) Company 1, 3 and 4, and (4) Company 1, 2, 3 and 4 (Figure 4.1).

It is essential to capture the channel effects of a highly dynamic mobile scenario. To model the large-scale behavior of the radio channel in the scenario, a UTD-model [7] in the propagation library was used DetVag-90® [8]. A digital terrain database was used to model the terrain. The 300 MHz and the 50 MHz frequency bands were considered. The MBWF used the 50 MHz band and the WBWF used the 300 MHz band. The antenna heights were set to 3 m in all simulations.

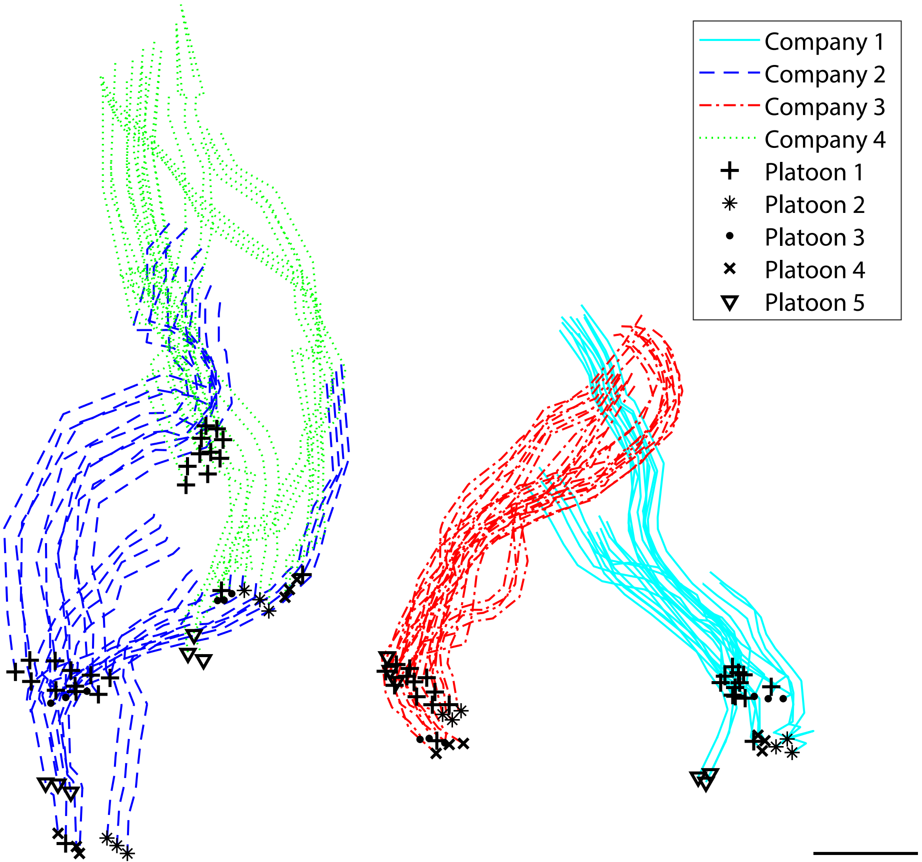

Figure 4.1: The trajectories for the vehicles from Anglova Vignette 2 that were used in the simulations.

4.2 Application layer

Both user and overhead traffic was sent in the networks. The user traffic was modeled as unicast and broadcast transmissions of packets. The unicast traffic was sent between randomly selected nodes pairs, and the broadcast traffic was sent from randomly selected nodes to all the nodes in the network. All packets were of equal size and arrived at the network according to a Poisson process with a mean arrival rate of 1 packet per node per second. The traffic load in the network was sufficiently low to prevent packet queues from building up in the nodes. However, a sent packet may not reach an intended receiving node, if the link to that node disappeared, resulting in reduced packet delivery ratio.

4.3 Network layer

In the used router setup, L2 appears as a network interface at L3. From the L2 perspective, L3 appears as an extra network protocol. When a packet is passed from L3 to L2, the next hop address set by L3 is used as the destination address in L2. Furthermore, if the destination address is a broadcast address, the destination address is remapped to *All Hosts multicast group* (the IP adress for all hosts on the same network segment). Hence, from the L3 perspective, L2 will appear as a one-hop network.

In the simulations, both L2 and L3 utilized OLSR [3]. The L3 daemons ran on the designated UDP port while the L2 daemons ran as a network protocol. To reduce the OLSR control traffic, the interface information spread by the MID messages was assumed to be preconfigured in the nodes. Thus, the MID messages were turned off. A MID message contains a list of addresses used by the interfaces on which a node runs OLSR (RFC 3626 [3]). To increase the robustness of the links used for L2 routing, signal-to-noise ratio (SNR) estimates from the physical layer were utilized to obtain a more accurate and, above all, faster estimate of the link quality [9]. The used metric was based on all packets that were detected on a link, including both user data packets and OLSR control packets. A link at L2 is considered reliable if SNR is greater than γ, where γ is the SNR threshold for the receiver. At L3, the link hysteresis framework, according to RFC 3626 as described in [9], was used to increase the robustness of the links. Conversely to the metric used at L2, this metric at L3 estimates the reliability of a link based solely on OLSR HELLO packets. Note that link symmetry is required, meaning that only OLSR HELLO packets from a neighbor that includes the node as a neighbor are counted. In the simulations, the default values for the hysteresis model were used [9].

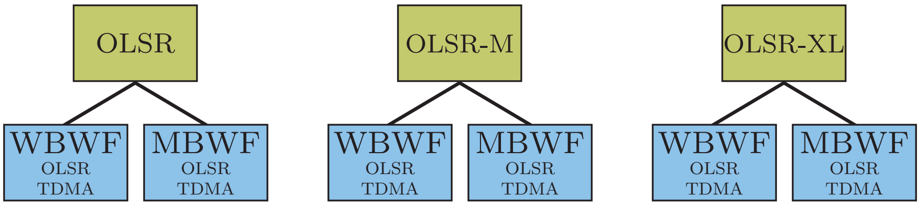

Figure 4.2: Three different routing setups on L3.

Three different routing setups on L3 were evaluated: OLSR, OLSR-M and OLSR-XL, as described in section 3.3, see Figure 4.2.

4.4 Data link layer

Many military networks use TDMA-based MAC protocols. In the simulations in this report, a static TDMA MAC protocol was used. The TDMA protocol divides the time into time slots, which are grouped into repeating frames. Each node in the network has a time slot in each frame. The traffic in the network is kept sufficiently low to avoid congestion in the network. The parameters describing the timeslot structure for the two waveforms are presented in Table 4.1.

Table 4.1: MAC layer parameters.

Description	Value		Unit
	WBWF	MBWF	
Time slot length	2.7	18.8	ms
Frequency hops per timeslot	3	10	-
Frequency hopping tuning time	100	100	μs
Time slot guard time	100	100	μs
User data rate	745	151	kbit/s

4.5 Physical layer

The physical layer was modelled at packet level in the simulator. To increase the robustness, the system used frequency hopping. Thus, each packet was divided into h packet segment that was transmitted on consecutive frequency hops. Slow frequency hopping was used, so several symbols were transmitted on each hop. All packets were coded over all h hops. Furthermore, it was assumed that the diversity obtained by frequency selective fading and frequency hopping was sufficient to ignore the effects of small-scale fading [9].

A packet was successfully received if the total channel capacity average over the entire packet length, T_p , exceeded the threshold C_γ, as described in

$$\frac{1}{T_\mathrm{p}}\sum_{i=1}^{M} C_i \Delta t_i > C_\gamma \tag{4.1}$$

where Δt_i is the time duration over which the channel capacity C_i is constant and M is the number of these time intervals. The channel capacity C_i was calculated as

$$C_i = \min\left(C_\mathrm{max}, \log_2\left(1 + \frac{S_i/L_\mathrm{imp}}{W_\mathrm{c}N + I_i}\right)\right) \tag{4.2}$$

where S_i is the aggregated received signal power on the intended communication channel, L_imp is the implementation loss, W_c is the bandwidth of the communication channel, N is the noise spectral density and I_i is the interference on the intended communication channel. There is also a limitation on the channel capacity, C_max , to prevent the capacity from exceeding the maximum possible capacity of the specified modulation and coding scheme.

The parameter settings for the physical layer of the two waveforms are presented in Table 4.2.

Table 4.2: Physical layer parameters.

Parameter	Description	Value		Unit
		WBWF	MBWF	
P	Output power	47	47	dBm
L_imp	Implementation loss	10	10	dB
W_c	Channel bandwidth	1000	250	kHz
f_c	Center frequency	300	50	MHz
F	Noise figure	10	16	dB
R	Link data rate	1000	250	kbit/s
C_γ	Channel capacity threshold	1	1	bit/s/Hz
C_max	Max channel capacity	1.55	1.55	bit/s/Hz
-	Preamble length	128	640	μs
-	SNR threshold preamble synchronization	0	0	dB

4.6 Performance metrics

Performance was measured in terms of network packet delivery ratio (PDR), average number of transmissions for a data packet, and overhead traffic sent by OLSR. The focus of this study was to analyze design requirements for an L3 routing solution. However, if OLSRs control traffic overloaded the network the value of the simulation would be limited. Hence, we chose to set the size of the OLSR packets, seen by the lower layers of the MBWF and WBWF, to zero so that they would never cause overload. Note that this did not affect the measured overhead traffic sent by OLSR, which was based on the real packet sizes. The overhead created by headers on layers below OLSR, primarily IP and UDP, is not negligible, but can be hard to estimate as they can be reduced by the radios. Therefore, estimated overhead numbers, in terms of bits/s, included OLSR headers and payload, but no additional headers added on transport layer or below.

In the case of WBWF, the traffic estimate was the overall WBWF traffic per that waveform and not per network. It was assumed that the available spectrum could support one WBWF per company. Then, it would be possible to divide the results by the number of companies in the network to obtain an estimate of what each individual WBWF network needed to handle. However, if the spectrum availability was limited, the scaling would be less straightforward.

5 Results

This chapter presents the results from simulations with the scenario and system setup described in Chapter 4. First, the packet delivery ratio (PDR) is presented, followed by overhead results.

The scenario was connected for all networks. Hence, a packet delivery ratio (PDR) below 1 indicates that the topological change rate was challenging. Figure 5.1 and 5.2 show the PDR for unicast and broadcast traffic, respectively, over the full scenario for the network consisting of 48 nodes for the three different L3 routing schemes. As can be seen, PDR varies over time. This is particularly true for unicast traffic, after around 900 seconds the PDR drops due to high mobility and possibly also due to longer routes. Due to the mobility, the OLSR solutions had difficulties updating routing information in a timely manner. The overall higher PDR values for broadcast traffic was most likely an effect of the generally higher robustness of MPR-flooding, compared to unicast routing [9, 10, 11].

In Figure 5.3 and 5.4 the PDR is shown as an average over time for the four different network sizes (one to four companies as described in Section 4.1), and for the three OLSR routing setups, for both unicast and broadcast traffic. For both traffic types, the PDR decreased with increasing network size, an effect of longer routes and an increasing number of MPR nodes necessary to reach the destinations as the network size increased. The overall lower PDR values for the unicast traffic relative to the broadcast traffic was most likely an effect of the generally higher robustness of MPR-flooding compared to unicast routing. There was also a significant drop in PDR for OLSR-M and OLSR-XL, compared to OLSR, for unicast traffic in the larger networks. This drop may be due to the flooding reduction of the TC messages, which in turn can result in a lower quality of the topology information in the nodes. Furthermore, for broadcast traffic OLSR-XL had a higher PDR than OLSR-M, which may also be an effect of the flooding reduction of the TC messages.

The overhead reduction for the OLSR modifications was also evaluated. Only the overhead generated by L3 routing was included, whereas the L2 routing overhead was discarded. The reason for this was that it was the effects of the modifications on L3 that were of interest for the investigation. In Figure 5.5 and 5.6, the average number of transmissions per data packet is shown for unicast and broadcast traffic. Note the difference in scale on the y axis. The average was calculated over time and is shown for different network sizes. The smallest network did not need MBWF for connectivity, since it only involved one company and was connnected on WBWF. Figure 5.5, representing the unicast traffic, indicates that the networks formed by both the WBWF and the MBWF

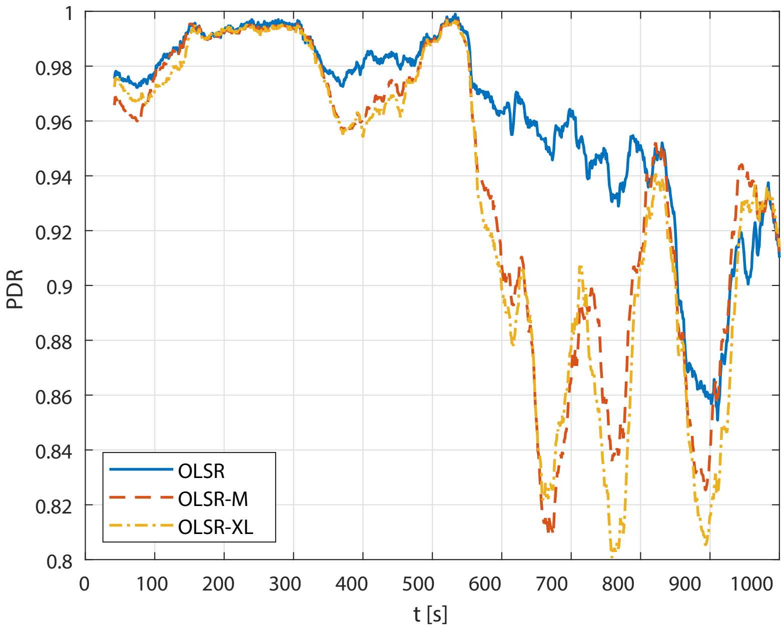

Figure 5.1: Unicast PDR over time.

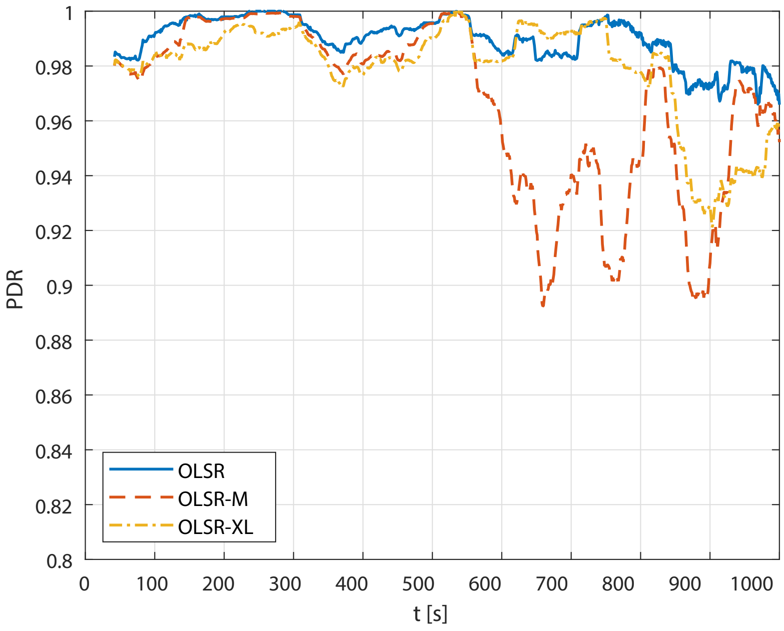

Figure 5.2: Broadcast traffic PDR over time.

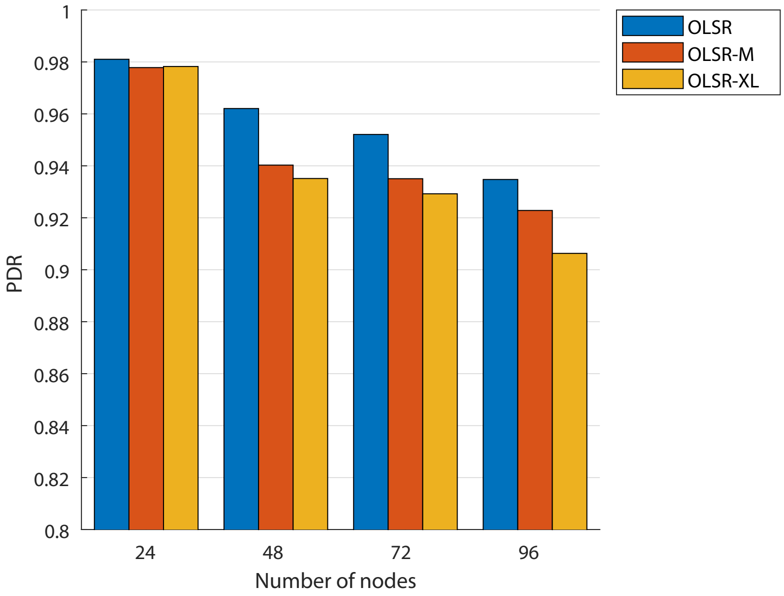

Figure 5.3: Unicast PDR versus network size.

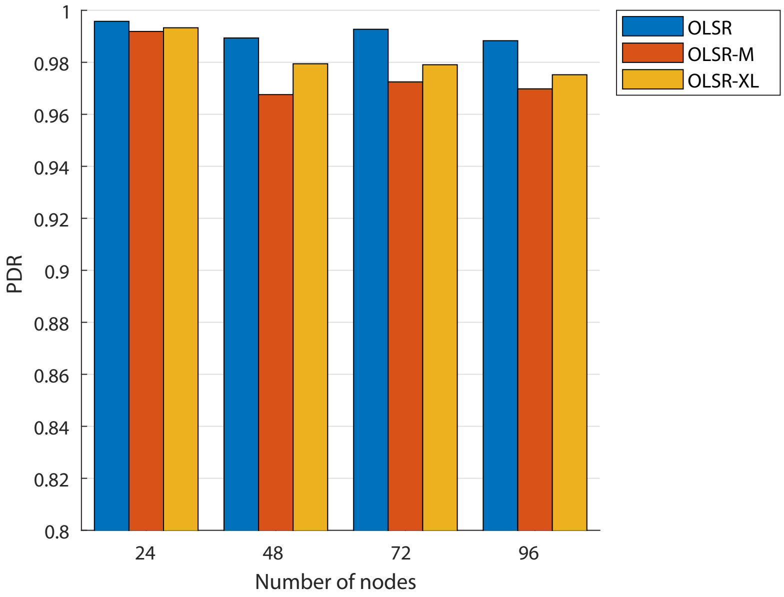

Figure 5.4: Broadcast traffic PDR versus network size.

network were mainly single hop networks. For example, in the network with 48 nodes, assuming that the two companies really were one-hop WBWF networks, nodes could reach their 23 company neighbours in one WBWF hop and the 24 nodes in the other company in two WBWF hops. Then, the resulting average number of WBWF hops would be $23/47 \cdot 1 + 24/47 \cdot 2 \approx 1.5$. The corresponding value from the simulation was actually somewhat lower, because the sources that had both MBWF and WBWF reached the other company directly on MBWF. The different OSLR variants had almost identical performance, because no MPR flooding was involved in the unicast transmissions. The fact that they did not perform identically was probably the result of different views of the topology, caused by the differences in the TC message distribution.

The cost of transmitting broadcast traffic packets, shown in Figure 5.6, was significantly higher than the cost for unicast packets, especially when the network size increased. For broadcast traffic there was a significant reduction in overhead for the modified OLSR versions. A contributing factor was that, in the unmodified version of OLSR, relaying MPR nodes at L3 retransmitted the packet on all interfaces, i.e., even on the interface that it was received on. In OLSR-M and OLSR-XL, MPR flooding did not involve retransmitting on the receiving interface. The number of transmissions was larger for OLSR-XL than for OLSR-M, as the total number of MPRs was larger in OLSR-SL.

Figure 5.7 to 5.9 show the average signalling overhead of the HELLO and TC messages passed from L3 down to L2 for the three OLSR systems. The overhead was calculated as an average over time, both for WBWF and MBWF. As expected, the TC message overhead was reduced in OLSR-M and OLSR-XL due to the muted interface MPR-flooding reduction. In Figure 5.9, a further overhead reduction occurred due to the introduced reactive mechanism for topology changes.

Figure 5.10 shows the average total network load caused by OLSR routing overhead generated at L3 for the three OLSR systems. In addition to the signalling overhead shown in Figure 5.7 to 5.9, it also includes the retransmissions of the HELLO and TC messages generated by L3. Note that the TC messages were affected by the broadcast traffic overhead reductions seen in Figure 5.6, since they were sent with MPR flooding. This was not the case for the HELLO messages, since they were not delivered by MPR flooding.

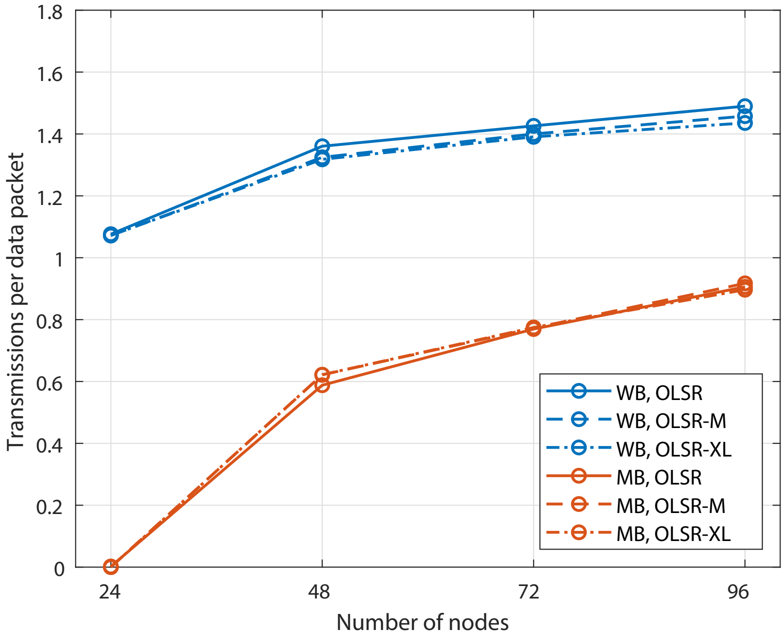

Figure 5.5: The number of unicast transmissions per data packet versus network size.

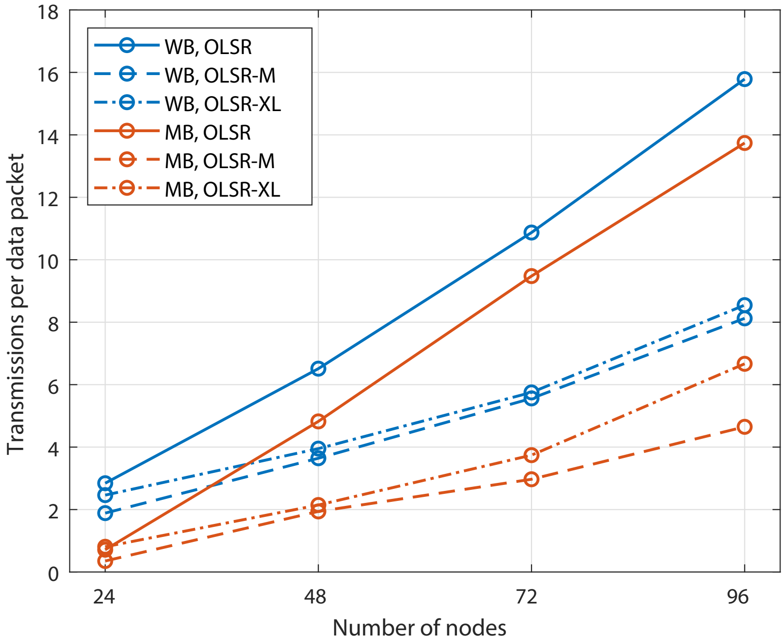

Figure 5.6: The number of broadcast traffic transmissions per data packet versus network size.

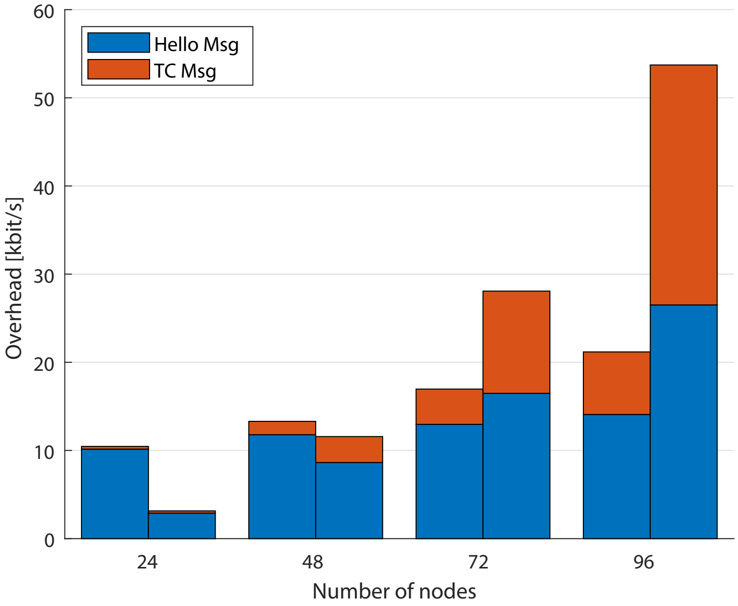

Figure 5.7: The unmodified OLSR signalling overhead that was passed from L3 down to L2, with WBWF to the left and MBWF to the right for each network size.

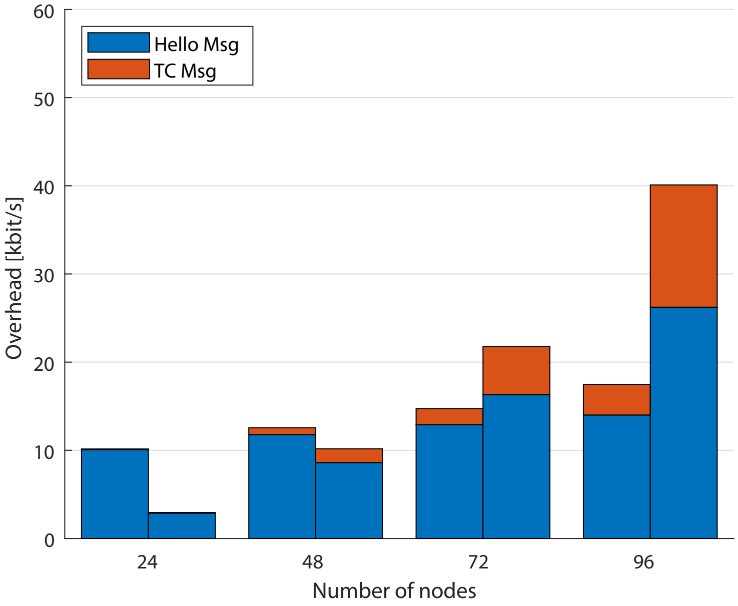

Figure 5.8: The OLSR-M amount of signalling overhead that was passed from L3 down to L2, with WBWF to the left and MBWF to the right for each network size.

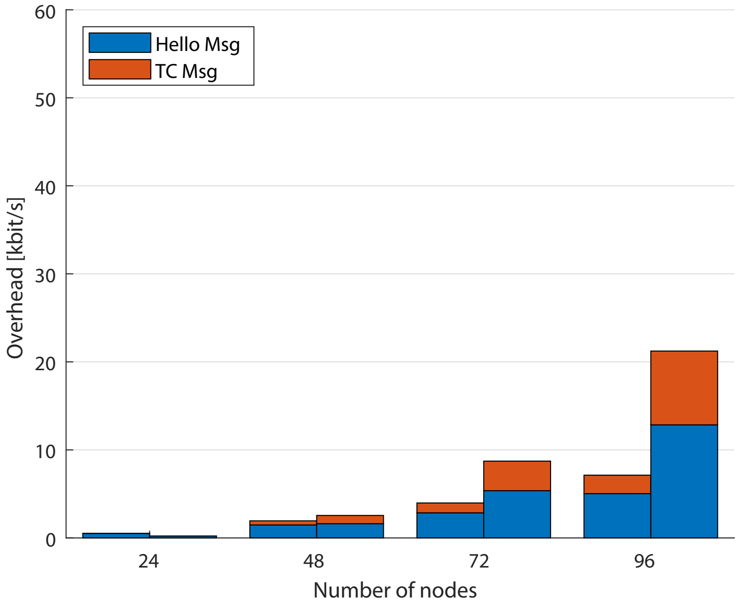

Figure 5.9: The OLSR-XL amount of signalling overhead that was passed from L3 down to L2, with WBWF to the left and MBWF to the right for each network size.

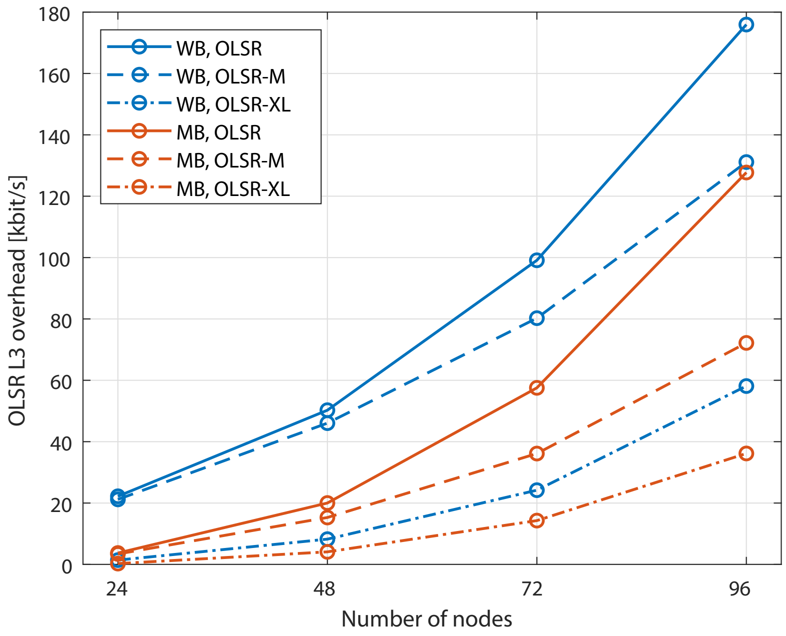

Figure 5.10: The total OLSR overhead that was generated by L3 versus network size.

As illustrated, the overhead reduction of the modified OSLR versions was significant, both for WBWF and MBWF. However, the MBWF overhead should probably not exceed around 10% of the user data rate to be manageable. With a user data rate of 151 kbit/s, that demand was satisfied for OLSR and OLSR-M up to a network size 24 nodes, and for OLSR-XL almost up to 72 nodes. For WBWF, the overhead was divided over the included companies. For the largest 96-node network, the overhead was about 180 kbit/s. This meant 45 kbit/s overhead in each 24-node company network, which was well below 10% of the user data rate of 745 kbit/s.

6 Conclusions

In this report, a routing approach using OLSR to connect sub-networks was studied. OLSR and two different modifications of OLSR were tested. For this purpose, a tactical scenario was used, with a MBWF connecting several companies using a WBWF.

The evaluations showed that the overhead was reduced with the tested OLSR modifications. Unfortunately, so was also the PDR. The loss in PDR was clearly notable in situations with high mobility. The overhead traffic was reduced with the modifications; for the largest 96-node network, the overhead was reduced about three times with OLSR-XL compared to unmodified OLSR. However, the results show a significant drop in PDR for OLSR-M and OLSR-XL compared to unmodified OLSR, especially for unicast traffic. For unicast traffic, the drop in PDR was higher for OLSR-XL than for OLSR-M. However, for broadcast traffic the drop was lower for OLSR-XL than for OLSR-M.

A contributing factor for the unmodified version of OLSR having a large overhead and high PDR, was that relaying MPR nodes at L3 retransmitted the packet on all interfaces, i.e., also on the interface that it was received on. A larger network diversity was therefore obtained with unmodified OLSR than OLSR-M and OLSR-XL. In OLSR-M and OLSR-XL, MPR flooding did not involve retransmitting on the receiving interface and, as expected, there was a significant reduction in overhead.

The modifications investigated were rather straightforward. On the other hand, these modifications did not seem to be sufficient due to problems with maintaining the same high PDR as unmodified OLSR. Furthermore, the MBWF OLSR overhead was probably still too high in the two larger networks (with 72 and 96 nodes). A general conclusion is that further work is required. Somewhat larger modifications and additions to OLSR seem to be necessary to make the OLSR work satisfactorily as an interconnecting routing protocol at layer 3 for tactical scenarios.

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