
Linux Optimized Link State Routing Protocol (OLSR) IPv6 HOWTO

Lars Strand <lars (at) unik no>

2004-04-23

Revision History

Revision 1.0	2004-04-23	EJH
Final review complete. Document published to the LDP collection.		
Revision 0.6	2004-04-19	LKS
Thanks to Thomas Zimmerman <thomas (at) zimres net> for a language review! Updated to latest version number and added a section on plugin-support in OLSRd. Changed lisenace back to GFDL [http://www.gnu.org/copyleft/fdl.html]		
Revision 0.5	2004-03-08	LKS
An almost complete rewrite. Adding OLSRd (old uOLSR), updated to RFC3626. Removed NROLSR and CRCOLSR. Converted to XML Docbook. Changed the license from GFDL [http://www.gnu.org/copyleft/fdl.html] to OPL [http://www.opencontent.org/openpub/] due to some GFDL problems. [http://people.debian.org/~srivasta/Position_Statement.xhtml]		
Revision 0.3	2003-08-05	LKS
Initial release.		

Abstract

This document describes the software and procedures to set up and use Optimized Link State Routing Protocol (OLSR) [<http://www.ietf.org/rfc/rfc3626>] with IPv6 for Linux. OLSR is used as a routing protocol for Mobile Ad-Hoc Networks (MANET [<http://www.ietf.org/rfc/rfc2501.txt>]) (also called “spontaneous network”).

Table of Contents

Introduction	2
Why Ad-Hoc network?	2
What is a MANET?	2
What is Optimized Link State Routing (OLSR)?	2
How does OLSR work?	2
What about IBSS (IEEE ad-hoc mode)?	3
IPv6	4
OLSR for Linux	4
Installing OLSRd	5
Using OLSRd	5
What about HNA messages?	9
Plugin support	10
Optional GUI	10
Other OLSR implementations	11
FAQ	11
Useful Resources	12
Copyright, acknowledgments and miscellaneous	12
Copyright and License	12
How this document was produced	13
Feedback	13
Acknowledgments	13

A. GNU Free Documentation License	13
PREAMBLE	13
APPLICABILITY AND DEFINITIONS	14
VERBATIM COPYING	15
COPYING IN QUANTITY	15
MODIFICATIONS	15
COMBINING DOCUMENTS	17
COLLECTIONS OF DOCUMENTS	17
AGGREGATION WITH INDEPENDENT WORKS	17
TRANSLATION	18
TERMINATION	18
FUTURE REVISIONS OF THIS LICENSE	18
ADDENDUM: How to use this License for your documents	18

Introduction

This document describes the software and procedures to set up and use Optimized Link State Routing Protocol (OLSR) with IPv6 for Linux.

Why Ad-Hoc network?

An English translation of *ad-hoc* is “For a particular purpose (improvised, made up in an instant)” (source: Wikipedia [http://en.wikipedia.org/wiki/List_of_Latin_phrases#A]). An Ad-hoc network, or “spontaneous network”, is especially useful when dealing with wireless devices in which some of the devices are part of the network only for the duration of a communications session and the need for a dynamic network topology is eminent. A “Mobile Ad hoc Network” is usually called a *MANET*.

What is a MANET?

“A MANET consists of mobile platforms (e.g., a router with multiple hosts and wireless communications devices)--herein simply referred to as ‘nodes’--which are free to move about arbitrarily. The nodes may be located in or on airplanes, ships, trucks, cars, perhaps even on people or very small devices, and there may be multiple hosts per router. A MANET is an autonomous system of mobile nodes. The system may operate in isolation, or may have gateways to and interface with a fixed network.” --- RFC2501: Mobile Ad hoc Networking (MANET), section 3 (page 3). [<http://www.ietf.org/rfc/rfc2501.txt>]

What is Optimized Link State Routing (OLSR)?

“OLSR is a proactive routing protocol for mobile ad hoc networks. The protocol inherits the stability of a link state algorithm and has the advantage of having routes immediately available when needed due to its proactive nature. OLSR is an optimization over the classical link state protocol, tailored for mobile ad hoc networks.”

“OLSR is designed to work in a completely distributed manner and does not depend on any central entity. The protocol does NOT REQUIRE reliable transmission of control messages: each node sends control messages periodically, and can therefore sustain a reasonable loss of some such messages. Such losses occur frequently in radio networks due to collisions or other transmission problems.” --- RFC3626: OLSR, section 1.3 (page 8) [<http://www.ietf.org/rfc/rfc3626.txt>]

How does OLSR work?

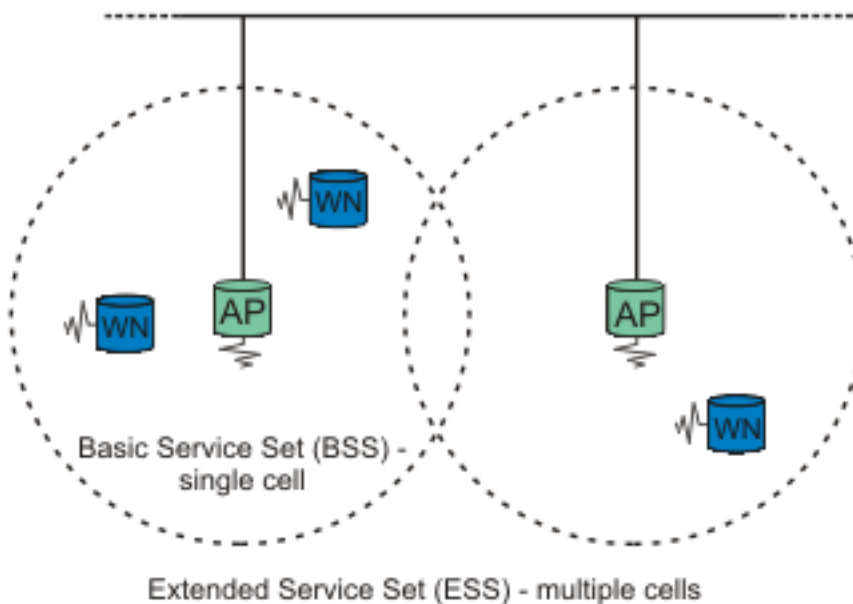
“The Optimized Link State Routing Protocol (OLSR) is developed for mobile ad hoc networks. It operates as a table driven, proactive protocol, i.e., exchanges topology information with other nodes of the network

regularly. Each node selects a set of its neighbor nodes as ‘multi-point relays’ (MPR). In OLSR, only nodes, selected as such MPRs, are responsible for forwarding control traffic, intended for diffusion into the entire network. MPRs provide an efficient mechanism for flooding control traffic by reducing the number of transmissions required.” --- RFC3626: OLSR, section 1 (page 4) [<http://www.ietf.org/rfc/rfc3626.txt>]

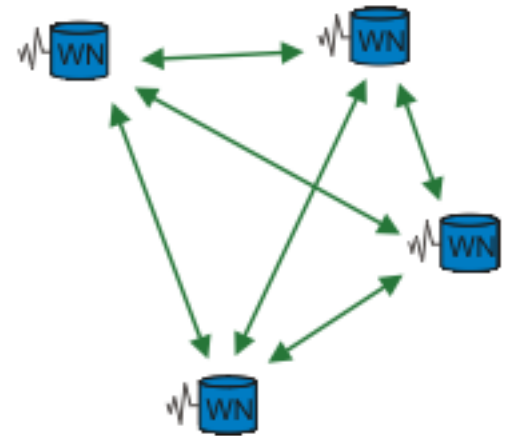
What about IBSS (IEEE ad-hoc mode)?

The IEEE 802.11 standard defines two modes:

Infrastructure Mode:



IEEE Ad-hoc Mode:

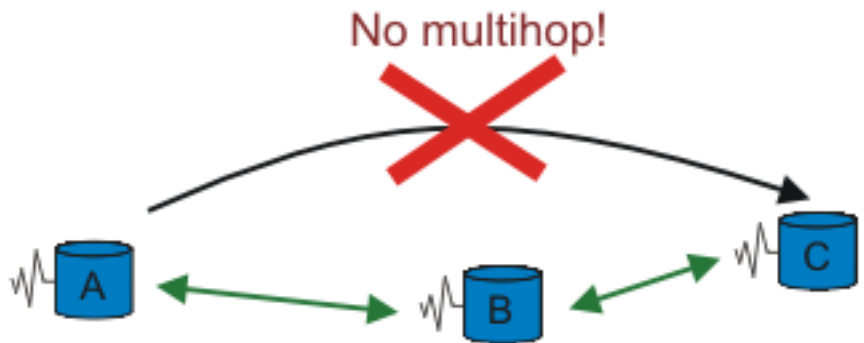


IEEE 802.11 standard

1. *Infrastructure mode*: The wireless network consist of at least one access point (AP) connected to the wired network and a set of wireless nodes (WN). This configuration is called a *Basic Service Set (BSS)*. Extended Service Set (ESS) is a set of two or more BSSs (multiple cells).
2. *Ad hoc mode*: Also called “IEEE ad-hoc mode” or “peer-to-peer mode”. This configuration is called *Independent Basic Service Set (IBSS)* and is useful for establishing a network where wireless infrastructure does not exist or where services are not required.

So why use OLSR when we can use “IEEE ad-hoc mode”? *IEEE ad-hoc mode does NOT support multi-hop*. See figure below

IEEE Ad-hoc Mode:
A can NOT talk to
C through B!



**OLSR Ad-Hoc
("real ad-hoc"):**
A can talk to
C through B!



“IEEE 8102.11 Ad hoc” mode has *no* support for multihop, something OLSR does have.

IPv6

IP version 6 (IPv6) is a new version of the Internet Protocol, designed as the successor to IP version 4 (IPv4) [RFC-791] [<http://www.ietf.org/rfc/rfc791.txt>]. The changes from IPv4 to IPv6 fall primarily into the following categories:

- Expanded addressing capabilities
- Header format simplification
- Improved support for extensions and options
- Flow labeling capability
- Authentication and privacy capabilities

For more information on IPv6 in general, visit the IETF's IPv6 Working Group [<http://www.ietf.org/html.charters/ipv6-charter.html>].

OLSR for Linux

There are several OLSR implementation for Linux, but not all of them support IPv6. You should know how to enable and use IPv6 on Linux. Peter Bieringer has written an excellent Linux IPv6 HOWTO [<http://ldp.linux.no/HOWTO/Linux+IPv6-HOWTO/>].

There is one OLSR implementation that is becoming the “standard” and most widely used. It goes by the descriptive name “OLSRd” (old Unik-OLSR).

OLSRd is an implementation based on the INRA C code, but has been almost completely rewritten, so there is not much left of the original INRA code (that mean it almost GPL). OLSRd also is under very rapid development, and if you report in a bug, it is usually fixed in a matter of hours.

OLSRd fully comply [<http://www.olsr.org/index.cgi?action=comp>] to the OLSR RFC, support for plugins, and it has an optional GUI interface (to see what's going on). The implementation also has a informative “up-to-date” web-page [<http://www.olsr.org>] with links to mailing lists and papers.

Installing OLSRd

There are up-to multiple new releases of OLSRd each month, so check the OLSRd web-site [<http://www.olsr.org>] for the newest release.

1. The latest release as of this writing is 0.4.3, but by the time you read this there is almost certain a new release. Fetch the latest release from <http://www.olsr.org/index.cgi?action=download> [<http://www.olsr.org/index.cgi?action=download>].
2. Unpack, compile and install the source code:

```
# tar jxvf uolsrd-x.y.z
# cd unik-olsrd-x.y.z
# make
# make install
```

3. The **olsrd** gets installed to `/usr/bin/` and a default config file, `olsrd.conf` can be found under `/etc`

Check out the `/etc/olsrd.conf` config file, and change values to fit your system. All values in this file can be overridden with command line options to **olsrd**. The main options to change are:

```
# Debug level(0-9)
# If set to 0 the daemon runs in the background
DEBUG          1
# IP version to use (4 or 6)
IPVERSION      6
# A list of whitespace separated interface names
INTERFACES     eth1
```

Later on, when you know OLSRd is configured correctly, you may set “DEBUG” to **0** to make it run in the background. You may then also add it to your init scripts. But to test that everything first, set this to at least **1** (setting this higher will produce a lot more info messages on APM, forwarding, parsing of the config file etc.)

Using OLSRd

On one host

When OLSRd is installed and configured, it can be started as root with:

```
# olsrd
```

All the settings in `/etc/olsrd.conf` can be overridden by command line options:

```
# olsrd -i eth1 -ipv6 -d 1
```

Would start `olsrd` listening on interface `eth1` using IPv6 and with debug messages.

We start `olsrd`:

```
# olsrd -i eth1 -d 1 -ipv6

*** UniK olsrd-0.4.3 ***

hello interval = 2.00          hello int nonwireless: = 4.00
tc interval = 5.00            polling interval = 0.10
neighbor_hold_time = 6.00     neighbor_hold_time_nw = 12.00
topology_hold_time = 15.00    tos setting = 16
hna_interval = 15.00         mid_interval = 5.00
Willingness set to 3 - next update in 20.000000 secs
Using IP version 6
Using multicast address ff05::15

---- Interface configuration ----

eth1:
Address: fec0:106:2700::10
Multicast: ff05::15
Interface eth1 set up for use with index 0

Main address: fec0:106:2700::10

NEIGHBORS: l=linkstate, m=MPR, w=willingness

Thread created - polling every 0.10 seconds
neighbor list: 11:43:17.214807
neighbor list: 11:43:19.194967
neighbor list: 11:43:21.395046
neighbor list: 11:43:23.604800
neighbor list: 11:43:25.694875
```

This shows all the settings OLSRd is using. You may override these by either specifying it in the config file (`/etc/olsrd.conf`) or specify it at the command line. Read the OLSR RFC [<http://www.ietf.org/rfc/rfc3626.txt>] for a description on what all these settings means.

OLSRd found our interface. If you are using OLSRd with multiple interfaces, “Multiple Interface Declaration” (MID) messages will be generated.

If you are using OLSRd with multiple interfaces, it will pick the first interface specified as the “main” address.

Since no other hosts are running OLSRd, this list is empty.

Another thing worth noticing, is that an entry is added to our routing table:

```
# route -A inet6
Destination:   Next Hop   Flags   Metric   Ref   Use Iface
...
ff05::15/128  ff05::15   UAC     0         1    1   eth1
...
```

This is the IPv6 multicast address OLSR is using to talk to other nodes running OLSR.

Adding other hosts

There is no point in using OLSRd on only one node, so we add some nodes. You will then see the “neighbor list” gets updated:

```
neighbor list: 12:55:14.733586
neighbor list: 12:55:18.803585
Willingness for fec0:106:2700::11 changed from 0 to 3 - UPDATING
neighbor list: 12:55:22.763585
fec0:106:2700::11:l=0:m=0:w=3[2hlist:]
neighbor list: 12:55:26.833589
fec0:106:2700::11:l=1:m=0:w=3[2hlist:]
Willingness for fec0:106:2700::12 changed from 0 to 2 - UPDATING
neighbor list: 12:55:30.903585
fec0:106:2700::12:l=0:m=0:w=2[2hlist:]
fec0:106:2700::11:l=1:m=0:w=3[2hlist:]
neighbor list: 12:55:34.863585
fec0:106:2700::12:l=0:m=0:w=2[2hlist:]
fec0:106:2700::11:l=1:m=0:w=3[2hlist:]
neighbor list: 12:55:39.153586
fec0:106:2700::12:l=1:m=0:w=2[2hlist:fec0:106:2700::11:]
fec0:106:2700::11:l=1:m=0:w=3[2hlist:fec0:106:2700::12:]
neighbor list: 12:55:43.443605
fec0:106:2700::12:l=1:m=0:w=2[2hlist:fec0:106:2700::11:]
fec0:106:2700::11:l=1:m=0:w=3[2hlist:fec0:106:2700::12:]
```

Another node detected (node B). This specifies the willingness of a node to carry and forward traffic for other nodes. Here the new node **fec0:106:2700::11** is willing to forward traffic. A host with low battery may not be willing to forward large amount of traffic, - so it will proclaim a lower willingness value (routing based on powerstatus is available as a plugin).

The node has been added to our routing table. We can not (yet) reach any other node by way of this node, since the 2-hop neighbor list (**[2hlist:]**) is empty. A 2-hop neighbor is a node heard by a neighbor.

Here is a third node (node C) running OLSRd.

After a short time, when all nodes have been updated and routes calculated, we may also reach any of the other nodes via the other. The 2-hop neighbor list (**[2hlist:]**) is populated: We can reach node **B** via **C**.

Here we can reach node **C** via **B**.

You will also see the routing table is updated with the new hosts:

```
# route -A inet6
Destination:          Next Hop   Flags   Metric   Ref   Use  Iface
...
fec0:106:2700::11/128  ::        UH      1        0    0   eth1
fec0:106:2700::12/128  ::        UH      1        0    0   eth1
...
```

The real beauty of OLSR is when you add a bunch of nodes and move them around. You can still reach each one of them either directly (if they are close), or through other nodes.

Movement

When every node can reach every other node, it's no fun. Let's start moving the nodes, so that node "A" and "B" are out of (radio) range of each other. So when we move node "A" far enough away so that it can't hear node "C", all traffic must go through node "B":



We move our three nodes so that node **A** and **C** must speak through node **B** to reach each other.

Tip: Instead of physically moving the nodes around, you can use `ip6tables`. You can drop all packet using the MAC-address. You just need to block on one node:

```
# ip6tables -A INPUT -m mac --mac-source XX:XX:XX:XX:XX:XX -j DROP
```

The output from OLSRd on host A is then:

```
neighbor list: 13:22:35.693587
fec0:106:2700::11:l=1:m=1:w=3[2hlist:fec0:106:2700::12:]
neighbor list: 13:22:40.093588
fec0:106:2700::11:l=1:m=1:w=3[2hlist:fec0:106:2700::12:]
neighbor list: 13:22:44.053594
fec0:106:2700::11:l=1:m=1:w=3[2hlist:fec0:106:2700::12:]
neighbor list: 13:22:48.233594
fec0:106:2700::11:l=1:m=1:w=3[2hlist:fec0:106:2700::12:]
neighbor list: 13:22:52.193605
fec0:106:2700::11:l=1:m=1:w=3[2hlist:fec0:106:2700::12:]
```

We can reach node **B** directly, and via node **B** we can reach node **C**.

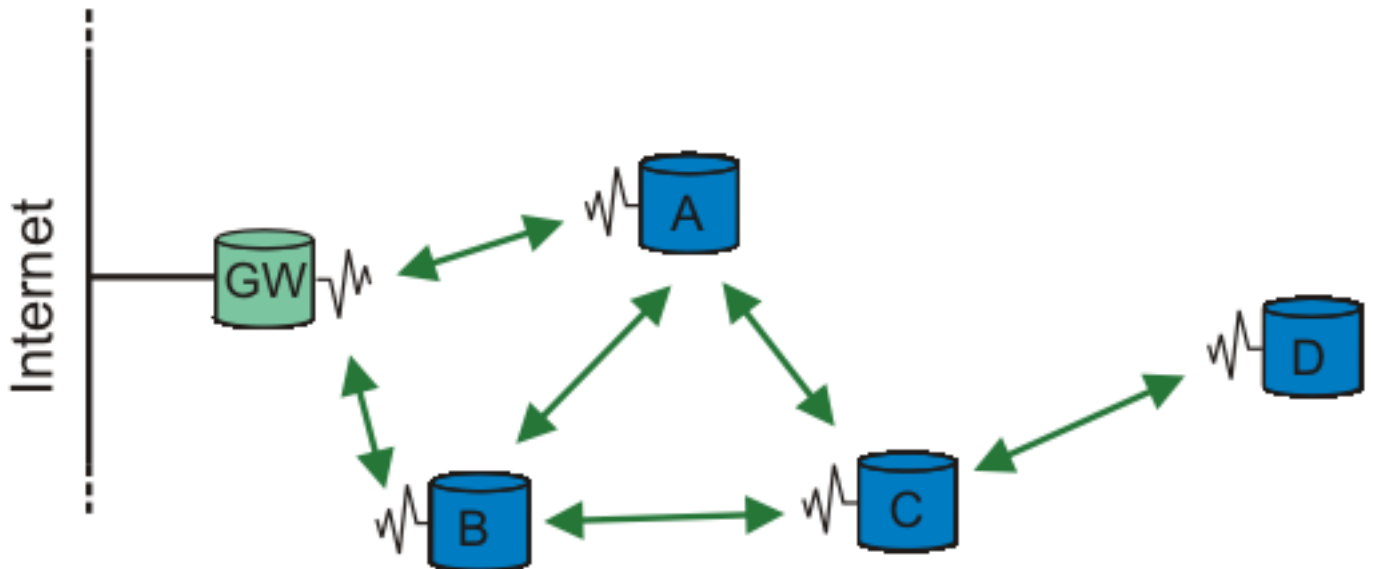
The routing table also gets updated. For node **A** to reach node **C** it must go through node **B**:


```
# route -A inet6
Destination:           Next Hop           Flags  Metric  Ref  Use  Iface
...
fec0:106:2700::11/128  ::                UH     1       1   0   eth1
fec0:106:2700::12/128  fec0:106:2700::11 UGH    2       0   0   eth1
...
```

What about HNA messages?

“In order to provide this capability of injecting external routing information into an OLSR MANET, a node with such non-MANET interfaces periodically issues a Host and Network Association (HNA) message, containing sufficient information for the recipients to construct an appropriate routing table.”

“An example of such a situation could be where a node is equipped with a fixed network (e.g., an Ethernet) connecting to a larger network as well as a wireless network interface running OLSR.” --- RFC3626: OLSR, section 12 (page 51). [<http://www.ietf.org/rfc/rfc2501.txt>]



OLSR with a gateway (GW), that sends out HNA messages. All the other nodes may then be accessing the “Internet”

To have one node, act as a gateway and send out HNA messages, you must change the **HNA6** in `/etc/olsrd.conf`:

```
# HNA IPv6 routes
# syntax: netaddr prefix
# Example Internet gateway
```

```
HNA6 :: 0
```

When you start **OLSRd**, you will see the node is sending out HNA messages periodically:

```
...
Sending HNA (48 bytes)...
...
```

When the other nodes receives a HNA message, they update their routing table:

```
# route -A inet6
Destination:           Next Hop           Flags  Metric  Ref  Use  Iface
...
::/0                   fec0:106:2700::1  UG     1       0    0   eth1
...
```

You may also have multiple nodes in a MANET to act as gateways (sending out HNA messages). Each mobile node then use the nearest gateway.

Plugin support

As of version 0.4.3 OLSRd also support plugins. Plugins may be used to add extended functionality in a MANET. If only a subset of the nodes knows how to interpret the messagetype, it will be forwarded by all the nodes by the “default forwarding algorithm” (see section 3.4.1 in the OLSR RFC [<http://ietf.org/rfc/rfc3626.txt>]). This way certain nodes may add special functionlity into OLSR.

As of this writing, two example plugins is included in the OLSRd release. One of these plugins add routing based on powerstatus. If one node has low battery, it can set its willingness lower and traffic may be routed through other nodes.

Optional GUI

OLSRd also has an optional GUI, which can show a list of available nodes and grab packets. To compile the GUI front end, you must have GTK2. In `unik-olsrd-x.y.z` directory do:

```
# cd front-end
# make
# make install
```

Note

Remember to start OLSRd with the `-ipc` switch or set `IPC-CONNECT yes` in `/etc/olsrd.conf` to enable the GUI to chat with OLSRd.

To see some examples of the use of GUI, check out <http://www.olsr.org/index.cgi?action=gui> [<http://www.olsr.org/index.cgi?action=gui>]

Other OLSR implementations

There is also other OLSR implementations, none have gained as much popularity as OLSRd, and none of them (except QOLSR [<http://qolsr.lri.fr/>]) are fully RFC compliant.

INRIA

INRIA was one of the first(?) implementation of OLSR <http://hipercom.inria.fr/olsr/#code>. Their web-site has not been updated for quite a while, and the OLSR code you can download only complies to draft-ietf-manet-olsr-03.txt (it's now an RFC). There is suppose to be another more up-to-date version of INRIA olsr, but I have not found it. INRIA OLSR does not support IPv6.

NROLSR

The “US Naval Research Laboratory” (NRL) also has an OLSR implementation. It is written in C++, and has IPv6 support. <http://pf.itd.nrl.navy.mil/projects/olsr/> [<http://pf.itd.nrl.navy.mil/projects/olsr/>]

CRCOLSR

CRCOLSR is a implementation based on the French INRIA code. It is supposed to be maintained by “Communication Research Center” (CRC) in Canada. But as of this writing, there have been no new releases since April 3, 2003. <http://pf.itd.nrl.navy.mil/projects/olsr/> [<http://pf.itd.nrl.navy.mil/projects/olsr/>]

QOLSR

QOLSR is aiming to provide “Quality of Service” routing in wireless mobile ad hoc networks. There is no QoS support at the time of this writing, and support for ipv4/ipv6 is triggered at compile time. Written in C++.

FAQ

Some of these question/answers are from the OLSRd [<http://www.olsr.org>] site.

1. If OLSRd fully RFC3626 compliant?

Yes. It even has implemented some of the extra functionality mentioned in the RFC. See the RFC Compliance [<http://www.olsr.org/index.cgi?action=comp>] section for complete list.

2. Can I mix site-local and global IPv6 addresses?

Yes. But keep in mind that they intentionally were not designed to be used at the same time. The network topology can be quite “messy” if you start using these two.

3. The GUI front-end failed to compile...why?

You probably don't have the GTK2.0 development libraries installed.

4. If there is multiply gateways present, how does the mobile node conclude to use the nearest one?

When a new gateway is detected, the Mobile Node checks the distance (number of hops) to this newly discovered gateway compared to the current gateway. If there is a shorter distance, this new gateway becomes the current (default) gateway. See section 12.6.2 in the OLSR RFC (RFC3626 [<http://www.ietf.org/rfc/rfc3626.txt>])

5. I get OLSRd up and running - but the nodes don't seem to “hear” each other!

Most of the time this is a configuration error: Check the following:

- If using WLAN interfaces make sure the ESSID/key match.
- Make sure the cards are set in “ad-hoc” mode and not “managed”.
- Make sure you are not blocking UDP/698. If using netfilter run `ip6tables -L` as root to see what rules are set. `ip6tables -F` flushes all rules.

Useful Resources

1. OLSRd (old uOLSR) <http://www.olsr.org> [<http://www.olsr.org>]
2. Optimized Link State Routing Protocol (OLSR) RFC3626 <http://www.ietf.org/rfc/rfc3626.txt> [<http://www.ietf.org/rfc/rfc3626.txt>]
3. Mobile Ad hoc Networking (MANET) RFC2501 <http://www.ietf.org/rfc/rfc3626.txt> [<http://www.ietf.org/rfc/rfc2501.txt>]
4. Mobile Ad-hoc Networks (manet) Working Group (IETF) <http://www.ietf.org/html.charters/manet-charter.html> [<http://www.ietf.org/html.charters/manet-charter.html>]
5. Open Shortest Path First IGP (ospf) <http://www.ietf.org/html.charters/ospf-charter.html> [<http://www.ietf.org/html.charters/ospf-charter.html>]
6. Protean Forge - OLSR software (CRC and NRL) <http://pf.itd.nrl.navy.mil/projects/olsr/> [<http://pf.itd.nrl.navy.mil/projects/olsr/>]
7. INRIA OLSR <http://hipercom.inria.fr/olsr/> [<http://hipercom.inria.fr/olsr/>]
8. QOLSR <http://qolsr.lri.fr/> [<http://qolsr.lri.fr/>]
9. IPv6 Working Group (IETF) <http://www.ietf.org/html.charters/ipv6-charter.html> [<http://www.ietf.org/html.charters/ipv6-charter.html>]
10. RFC2460 Internet Protocol, Version 6 (IPv6) Specification <http://www.ietf.org/rfc/rfc2460.txt> [<http://www.ietf.org/rfc/rfc2460.txt>]
11. Peter Bieringer's Linux IPv6 HOWTO (en) <http://ldp.linux.no/HOWTO/Linux+IPv6-HOWTO/> [<http://ldp.linux.no/HOWTO/Linux+IPv6-HOWTO/>]
12. Current Status of IPv6 Support for Networking Applications http://www.deepspace6.net/docs/ipv6_status_page_apps.html [http://www.deepspace6.net/docs/ipv6_status_page_apps.html]

Copyright, acknowledgments and miscellaneous

Copyright and License

Copyright (c) 2003, 2004 Lars Strand.

Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License [<http://www.gnu.org/licenses/fdl.html>], Version 1.2 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the license is included in the section entitled "GNU Free Documentation License".

How this document was produced

This document was originally written in LaTeX using Emacs. HTML version created with latex2html. Later it was converted to DocBook XML.

An up-to-date version of this document can be found at:

HTML: <http://www.tldp.org/HOWTO/OLSR-IPv6-HOWTO/index.html> [<http://www.tldp.org/HOWTO/OLSR-IPv6-HOWTO/index.html>]

Feedback

Suggestions, corrections, additions wanted. Contributors wanted and acknowledged. Flames not wanted.

I can always be reached at <lars at unik no>

Homepage: <http://www.gnist.org/~lars/> [<http://www.gnist.org/~lars/>]

Acknowledgments

This document was produced as a part of Interoperable Networks for Secure Communications (INSC task 6) [<http://insc.nodeca.mil.no/>]

Thanks to Andreas Hafslund (andreha [at] unik no) for initial support. Also thanks to UniK (University Graduate Center) <http://www.unik.no> and FFI (Norwegian Defence Research Establishment) <http://www.ffi.mil.no> for hardware support.

Also thanks to Andreas Tønnesen (andreto [at] unik no) for technical help updating this howto

Thanks also to the other HOWTO authors whose works I have referenced:

Linux IPv6 HOWTO (en) by Peter Bieringer

A. GNU Free Documentation License

Copyright (C) 2000,2001,2002 Free Software Foundation, Inc. 59 Temple Place, Suite 330, Boston, MA 02111-1307 USA Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

PREAMBLE

The purpose of this License is to make a manual, textbook, or other functional and useful document "free" in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or noncommercially. Secondly, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others.

This License is a kind of "copyleft", which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software.

We have designed this License in order to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that

the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference.

APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work, in any medium, that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. Such a notice grants a world-wide, royalty-free license, unlimited in duration, to use that work under the conditions stated herein. The "Document", below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as "you". You accept the license if you copy, modify or distribute the work in a way requiring permission under copyright law.

A "Modified Version" of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A "Secondary Section" is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document's overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (Thus, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The "Invariant Sections" are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The "Cover Texts" are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A "Transparent" copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not "Transparent" is called "Opaque".

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The "Title Page" means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, "Title Page" means the text near the most prominent appearance of the work's title, preceding the beginning of the body of the text.

A section "Entitled XYZ" means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as "Acknowledgements", "Dedications", "Endorsements", or "History".) To "Preserve the Title" of such a section when you modify the Document means that it remains a section "Entitled XYZ" according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties: any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License.

VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified

Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

- A. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.
- B. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement.
- C. State on the Title page the name of the publisher of the Modified Version, as the publisher.
- D. Preserve all the copyright notices of the Document.
- E. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.
- F. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.
- G. Preserve in that license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice.
- H. Include an unaltered copy of this License.
- I. Preserve the section Entitled "History", Preserve its Title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section Entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous sentence.
- J. Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the "History" section. You may omit a network location for a work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission.
- K. For any section Entitled "Acknowledgements" or "Dedications", Preserve the Title of the section, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein.
- L. Preserve all the Invariant Sections of the Document, unaltered in their text and in their titles. Section numbers or the equivalent are not considered part of the section titles.
- M. Delete any section Entitled "Endorsements". Such a section may not be included in the Modified Version.
- N. Do not retitle any existing section to be Entitled "Endorsements" or to conflict in title with any Invariant Section.
- O. Preserve any Warranty Disclaimers.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Sections and contain no material copied from the Document, you may at your option designate some or all

of these sections as invariant. To do this, add their titles to the list of Invariant Sections in the Modified Version's license notice. These titles must be distinct from any other section titles.

You may add a section Entitled "Endorsements", provided it contains nothing but endorsements of your Modified Version by various parties--for example, statements of peer review or that the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added by (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version.

COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice, and that you preserve all their Warranty Disclaimers.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled "History" in the various original documents, forming one section Entitled "History"; likewise combine any sections Entitled "Acknowledgements", and any sections Entitled "Dedications". You must delete all sections Entitled "Endorsements".

COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an "aggregate" if the copyright resulting from the compilation is not used to limit the legal rights of the compilation's users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document's Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate.

TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled "Acknowledgements", "Dedications", or "History", the requirement (section 4) to Preserve its Title (section 1) will typically require changing the actual title.

TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided for under this License. Any other attempt to copy, modify, sublicense or distribute the Document is void, and will automatically terminate your rights under this License. However, parties who have received copies, or rights, from you under this License will not have their licenses terminated so long as such parties remain in full compliance.

FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See <http://www.gnu.org/copyleft/>.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License "or any later version" applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation.

ADDENDUM: How to use this License for your documents

To use this License in a document you have written, include a copy of the License in the document and put the following copyright and license notices just after the title page:

Copyright (c) YEAR YOUR NAME. Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.2 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the license is included in the section entitled "GNU Free Documentation License".

If you have Invariant Sections, Front-Cover Texts and Back-Cover Texts, replace the "with...Texts." line with this:

with the Invariant Sections being LIST THEIR TITLES, with the Front-Cover Texts being LIST, and with the Back-Cover Texts being LIST.

If you have Invariant Sections without Cover Texts, or some other combination of the three, merge those two alternatives to suit the situation.

If your document contains nontrivial examples of program code, we recommend releasing these examples in parallel under your choice of free software license, such as the GNU General Public License, to permit their use in free software.