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MACsec

Encryption for the wired LAN

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Netdev1.1, Seville, 2016

Outline

- Introduction to MACsec (architecture, protocol, related standards)
- Linux kernel implementation
- Future work

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1 Introduction

1 **Introduction**
- Overview
- Modes
- Protocol details

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What is MACsec

- IEEE standard (802.1AE-2006) for encryption over Ethernet
- Encrypt and authenticate all traffic in a LAN with GCM-AES-128

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Why MACsec

- Security within LANs (layer 2) is pretty bad
  - rogue DHCP/router advertisements
  - ARP/ndisc spoofing
- IPsec is L3, cannot protect ARP/ndisc on untrusted links
- Cloud environment: VXLAN
  - Encrypted VXLAN: encryption on the tunnel endpoints, not in the VM ⇒ Tenant has no control over the keys
  - MACsec over VXLAN: encryption in the VM, doesn't need to be aware of the underlay network

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MACsec concepts, architecture, and definitions

Secure channel (SC) unidirectional channel

- from one node to many
- sequence of successive, overlapping secure associations

Secure association (SA) within a SC

- every frame transmitted over MACsec belongs to one particular SA
- packet number and key are per-SA

Security Entity (SecY) instance of the MACsec implementation within a node

Uncontrolled port network interface providing insecure service

- MACsec is built on top of this

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Configuration and relation with IEEE 802.1X

- option 1: admin can configure SC/SA/keys manually
- option 2: use 802.1X with MACsec extensions
    - MKA (MACsec Key Agreement protocol)
    - discovery of other MACsec nodes
    - setup of SC/SA
    - key generation and distribution
    - synchronization of packet numbers

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Encryption and integrity

mandatory integrity+authenticity, optional encryption

- default crypto algorithm: GCM-AES
  - authenticated encryption with additional data
- the entire MACsec packet is always authenticated
- admin can choose whether to use encryption
  - no encryption, integrity/authenticity only: entire MACsec packet as additional data
  - encryption + integrity/authenticity: ethernet + MACsec header as additional data, original payload is encrypted and authenticated

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Strict validation

Three possible validation modes for incoming packets:

Strict Non-protected, invalid, or impossible to verify (no matching channel configured) frames are dropped

Check These frames are counted as “invalid” and accepted, if possible

Disabled Incoming frames are simply accepted, if possible

- Encrypted frames cannot be accepted without a matching channel and key

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Replay protection

- each frame has a 32-bit packet number
- on RX, the node may validate the PN against the lowest PN it expects to get
- configurable replay window
  - some amount of reordering is acceptable

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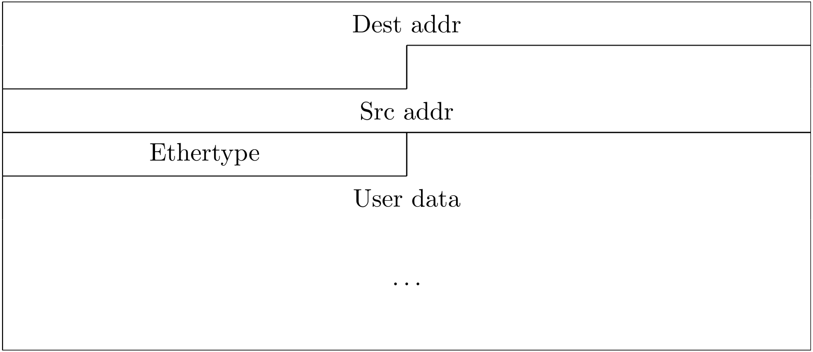
Packet format (unprotected frame)



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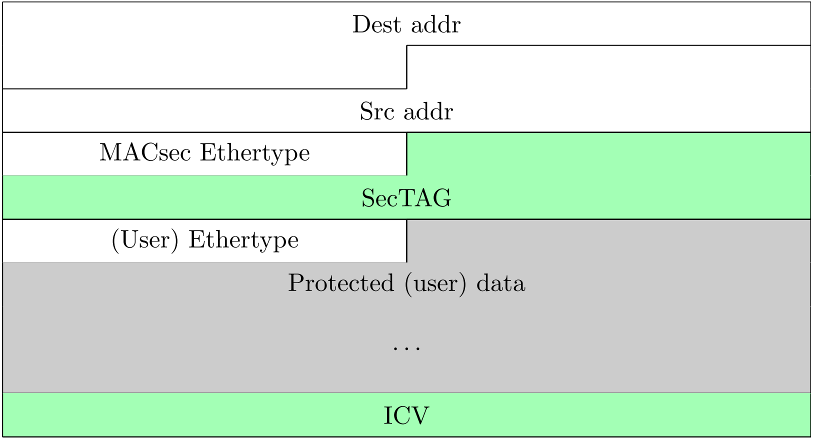
Packet format (protected frame)



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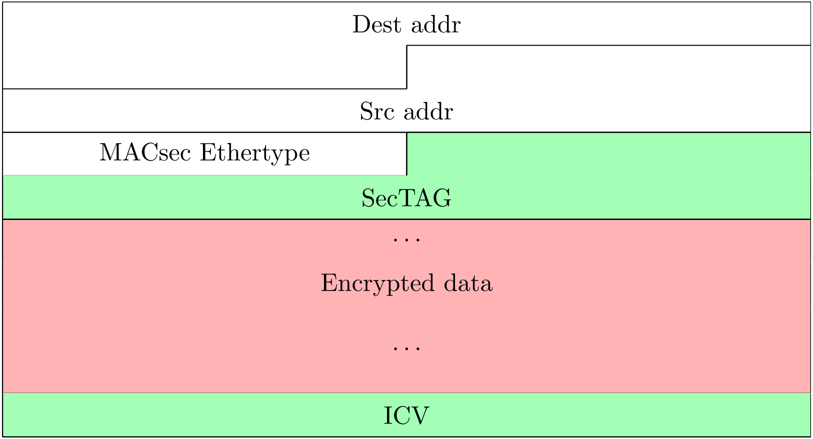
Packet format (encrypted frame)



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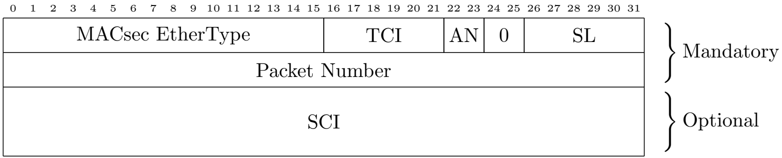
SecTAG format



TCI tag control information

AN association number (SA identifier, 2 bits)

SL short length, non-zero for frame lengths under 64B

SCI secure channel identifier, 64 bits

- 48 bits "system identifier" (MAC address)
- 16 bits "port number"

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SecTAG format: TCI field

0	1	2	3	4	5	6	7
V=0	ES	SC	SCB	E	C	AN	

SC SCI present

E Encrypted payload

C Changed text

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Interaction with other protocols and layers

Figure: unprotected VLAN frame

Figure: MACsec-protected VLAN frame

- VLAN tag is part of the encrypted payload

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Packet handling: Transmit

Figure: Packet coming from the stack

1. push SecTAG
2. compute and append ICV
3. pass down to the underlying device

Figure: Packet passed down to the network

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Packet handling: Receive

Figure: Packet coming from the network

1. verify packet/SecTAG format
2. check packet number (replay protection, optional)
   - just drop the packet, no feedback to a potential attacker
   - helps defend against DoS attacks: don't perform heavy computation on obviously wrong packets
3. decrypt/verify ICV
4. re-check packet number (replay protection after decryption)
5. remove ICV, pop SecTAG

Figure: Packet passed up the stack

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2 Implementation

2 Implementation

- First idea: Transparent mode
- Better idea: Full netdevice
- Implementation details

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Transparent mode: description

- configure MACsec directly on the (real) netdevice
- all packets that go through the device are transparently encrypted and decrypted

advantages

- no extra overhead of adding more netdevices
- seemed easier from a configuration point of view
- looked like it would “just work”
- qdisc layer sees the original packet (no SecTAG, not encrypted)

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Transparent mode: problems

- needs hooks in the normal packet processing path (`__netif_receive_skb_core`, `xmit_one`)
  - pretty much a non-starter
- makes it very hard to reject RX packets that were not encrypted (including DHCP)
  - possible with hacks in various places to check that the packet was actually decrypted (clearly unacceptable)
  - or let the user add filtering rules manually
    - not really “transparent”

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Transparent mode: problems

- tcpdump becomes messy (both encrypted and unencrypted packets are captured)
- harder to properly handle VLANs
- unsolved question: how to use multiple TX channels
  - setup rules that match the (unencrypted) TX packets
  - then configure the MACsec encryption process to use a specific TX channel for these matched packets

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Full netdevice: description

- create a new netdevice for each TX channel on a specific device
  - similar to VLANs or macvlans
  - "parent" device sees only the raw packets
    - ie, the encrypted/protected packets for all its children MACsec devices
    - and all the non-protected traffic (802.1X, maybe also some normal LAN traffic)
  - good match for the uncontrolled/controlled port model in the IEEE standards
- uses `rx_handler` and `ndo_start_xmit`

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Crypto

- uses the kernel's crypto API for Authenticated Encryption with Additional Data (AEAD)
- can use HW acceleration (`aesni`) if available

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Structures

`struct macsec_dev`

Private data for MACsec netdevice

`struct macsec_secy`

- SecY parameters (validation mode, SCI)
- list of RX channels

`struct macsec_tx_sc`

MACsec TX channel, container for the SAs

`struct macsec_rx_sc`

SCI, container for the SAs

`struct macsec_[tr]x_sa`

- MACsec SA representation
- key
- statistics
- packet number

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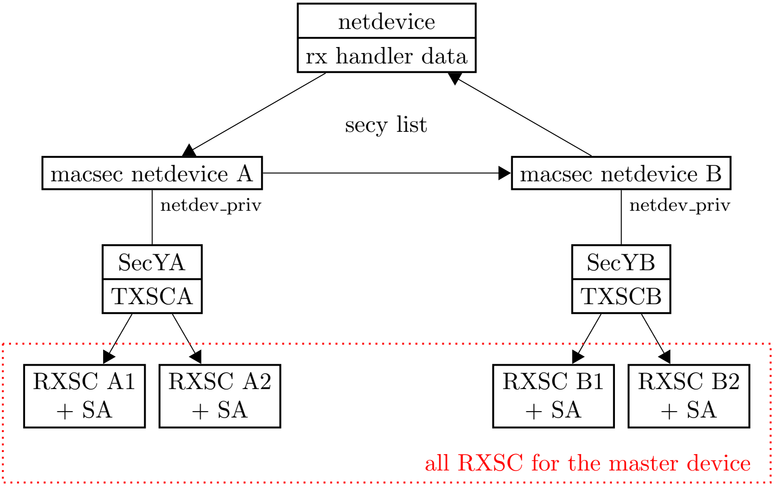
Structures



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RX and TX: `rx_handler`

- also used by bond, macvlan, bridge, etc
- if SCI not present in SecTAG: rebuild from MAC address + default port
- find the RX SC that matches the SCI for the received packet on the receiving `net_device`
    - `net_device` → SecY list → per-SecY RXSC list
    - the packet goes up the stack with `skb->dev` set to the `net_device` for the SecY associated with the matching RXSC

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RX and TX: Replay protection

- check the packet number against RX window before decrypting
- check again after decrypting
- then update RX window

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RX and TX: `ndo_start_xmit`

- 1-to-1 between the MACsec `net_device` and the TX secure channel
- encrypt/protect with the currently active SA (`encoding_sa`)

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Configuration

- API split between rtnetlink and genetlink
- rtnetlink with MACsec-specific options to create the `net_device` and configure SecY attributes
- genetlink to configure TXSA, RXSC, RXSA
  - provides demux between the commands for the 3 kinds of objects
  - cleaner API design than if we had to configure everything over rtnetlink

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3 Use cases

3 Use cases

- Normal use case: LAN
- Normal use case (2): LAN with multiple channels
- Extension: VLAN
- Link aggregation
- In the cloud: VXLAN

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MACsec LAN setup

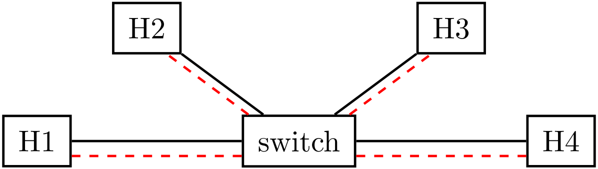

Figure: Example LAN setup

- configure MACsec on the hosts and on each switch port
  - need a switch with MACsec support
- configure MACsec only on the hosts
  - works with any switch
  - switch sees only MACsec-protected traffic

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MACsec LAN sample configuration

H1

```
ip link add link eth0 macsec0 type macsec
ip macsec add macsec0 tx sa 0 on pn 100 key 0 $KEY_0
ip macsec add macsec0 rx address $H2_ADDR port 1
ip macsec add macsec0 rx address $H2_ADDR port 1 \
    sa 0 pn 100 on key 1 $KEY_1
```

H2

```
ip link add link eth0 macsec0 type macsec
ip macsec add macsec0 tx sa 0 on pn 100 key 1 $KEY_1
ip macsec add macsec0 rx address $H1_ADDR port 1
ip macsec add macsec0 rx address $H1_ADDR port 1 \
    sa 0 pn 100 on key 0 $KEY_0
```

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Important configuration parameters

Changing the current active TXSA

```
ip link set macsec0 type macsec encoding 2
```

Enabling encryption (optional)

```
ip link add link eth0 macsec0 type macsec ...
# setup SA and RX ...

ip link set macsec0 type macsec encrypt on
```

Enabling replay protection (optional)

```
ip link add link eth0 macsec0 type macsec ...
# setup SA and RX ...

ip link set macsec0 type macsec replay on window 128
```

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MACsec LAN setup for multiple secure channels

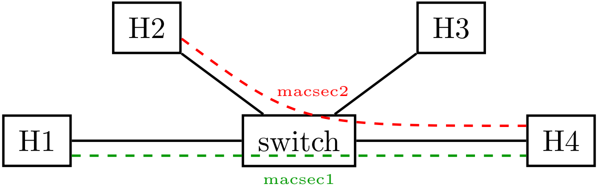

Figure: Example LAN setup with multiple channels

- Nodes H1 and H2 have only one secure channel
  - like in the previous example
- Node H4 has two secure channels
  - different crypto parameters and separate keys for each

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Multiple channels on an interface

H4

```
# channel to H1
ip link add link eth0 macsec0 type macsec
ip macsec add macsec0 tx sa 0 on pn 100 key 1 $KEY_1
ip macsec add macsec0 rx address $H1_ADDR port 1
ip macsec add macsec0 rx address $H1_ADDR port 1 \
    sa 0 pn 100 on key 0 $KEY_0

# channel to H2
ip link add link eth0 macsec1 type macsec port 2
ip macsec add macsec1 tx sa 0 on pn 400 key 2 $KEY_2
ip macsec add macsec1 rx address $H2_ADDR port 1
ip macsec add macsec1 rx address $H2_ADDR port 1 \
    sa 0 pn 100 on key 3 $KEY_3
```

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MACsec VLAN setup

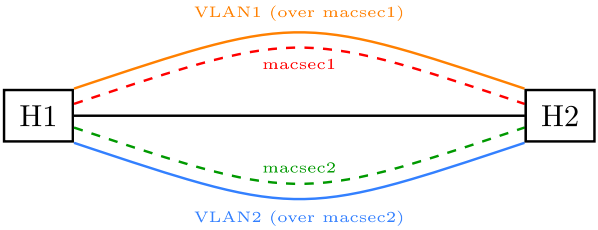

Figure: Example VLAN setup

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VLAN over MACsec configuration (VLAN1)

H1, VLAN1

```
ip link add link eth0 macsec0 type macsec
ip macsec add macsec0 tx sa 0 on pn 100 key 0 $KEY_0
ip macsec add macsec0 rx address $H2_ADDR port 1
ip macsec add macsec0 rx address $H2_ADDR port 1 \
    sa 0 pn 100 on key 1 $KEY_1

ip link add link macsec0 vlan0 type vlan id 42
```

H2, VLAN1

```
ip link add link eth0 macsec0 type macsec
ip macsec add macsec0 tx sa 0 on pn 100 key 1 $KEY_1
ip macsec add macsec0 rx address $H1_ADDR port 1
ip macsec add macsec0 rx address $H1_ADDR port 1 \
    sa 0 pn 100 on key 0 $KEY_0

ip link add link macsec0 vlan0 type vlan id 42
```

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VLAN over MACsec configuration (VLAN2)

H1, VLAN2

```
ip link add link eth0 macsec1 type macsec port 2
ip macsec add macsec1 tx sa 0 on pn 100 key 2 $KEY_2
ip macsec add macsec1 rx address $H2_ADDR port 2
ip macsec add macsec1 rx address $H2_ADDR port 2 \
    sa 0 pn 100 on key 3 $KEY_3

ip link add link macsec1 vlan0 type vlan id 10
```

H2, VLAN2

```
ip link add link eth0 macsec1 type macsec port 2
ip macsec add macsec1 tx sa 0 on pn 100 key 3 $KEY_3
ip macsec add macsec1 rx address $H1_ADDR port 2
ip macsec add macsec1 rx address $H1_ADDR port 2 \
    sa 0 pn 100 on key 2 $KEY_2

ip link add link macsec1 vlan0 type vlan id 10
```

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MACsec Bonding setup

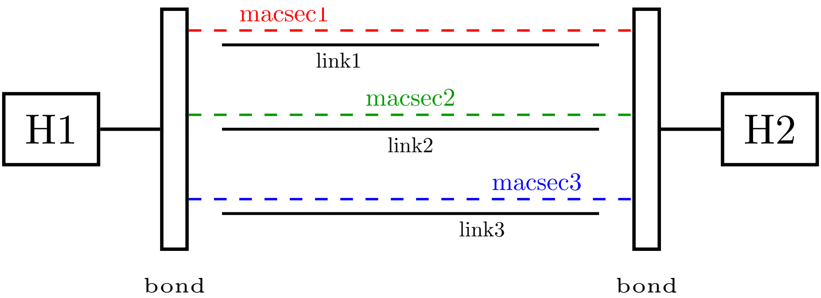

Figure: Example Bonding setup

- MACsec is configured separately on each underlying link
- MACsec netdevices are enslaved instead of the real links
- LACP/etc traffic is protected by MACsec

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MACsec bond configuration

Create bond

```
# modprobe bonding max_bonds=0
ip link add bond0 type bond [...]
ip link set bond0 up
```

Set up MACsec on each bonded link

```
ip link add link eth0 macsec0 type macsec ...
# setup SA and RX on macsec0 like before
ip link add link eth1 macsec1 type macsec ...
# setup SA and RX on macsec1 like before
```

Add the MACsec devices to the bond

```
ip link set macsec0 master bond0
ip link set macsec1 master bond0
```

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MACsec VXLAN setup

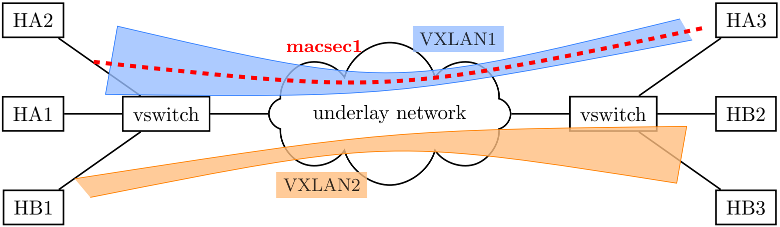

Figure: Example VXLAN setup

ETH	IP	UDP	VXLAN	ETH	SecTAG	Payload ...	ICV

Figure: Encapsulation for a MACsec over VXLAN packet

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MACsec VXLAN configuration

VXLAN

```
ip link add link vxlan0 type vxlan \
     id 10 group 239.0.0.10 ttl 5 dev eth0

ip link add link vxlan0 macsec0 type macsec ...
# setup SA and RX on macsec0 like before
```

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4 Conclusion

4 Conclusion

- Future work
- End

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In the kernel

- optional features
  - **confidentiality offset** the first 30 bytes of the packet are only integrity protected
  - **additional ciphersuite** GCM-AES-256
- hardware offload (at least for some Intel ixgbe NICs)
- performance improvements

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In userspace

- NetworkManager support
- `wpa_supplicant` already has MKA support, need to hook up the netlink API
  - MKA support: commits `7baec808efb5`, `887d9d01abc7`, `dd10abccc86d`

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More information

- IEEE 802.1AE-2006
  http://standards.ieee.org/getieee802/download/802.1AE-2006.pdf
- IEEE 802.1X-2010
  http://standards.ieee.org/getieee802/download/802.1X-2010.pdf
- Kernel submission (RFCv2 on netdev)
  http://www.spinics.net/lists/netdev/msg362389.html