IPv6 over Wireless Sensor Networks

Tiny6 Project

Why IP?

- IP focuses on network platforms interconnection:
  - Metcalfe's law: Network value = $user^2$
  - 80's: IP became dominant in data networks
  - 90's: IP telephony
  - 2000's: Television
  - 2010's: Objects, Machine to Machine

Why IPv6?

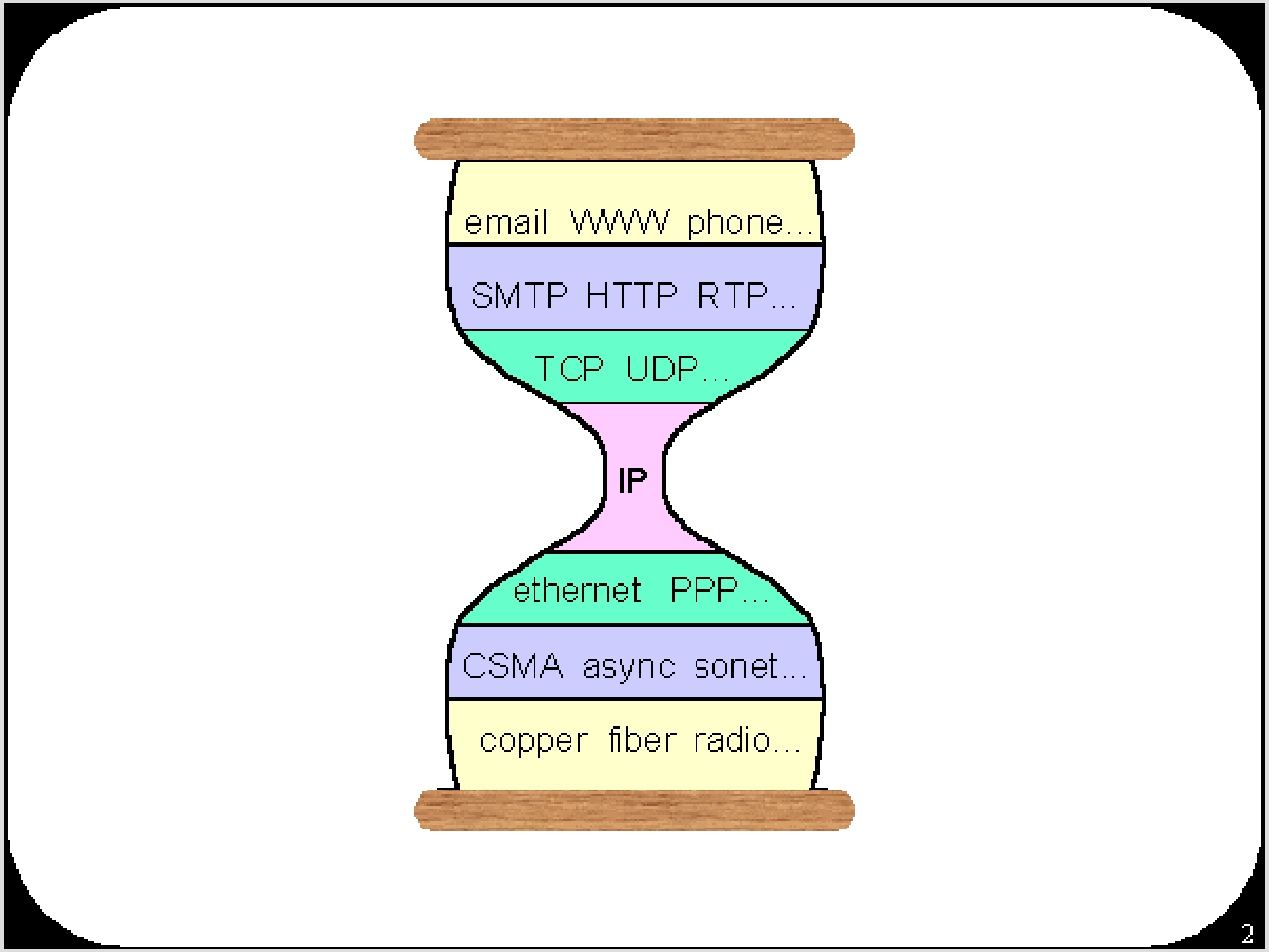
- IPv4 address is small (32 bits ~ 4 billion)
- IPv4 address space is saturated
- IPv6 development started in 1994
  - Specifications are standards
  - Networks are in function
  - Addresses are 4 times larger than IPv4
  - But Metcalfe's law is against IPv6 for traditional applications

Why IPv6?

- IPv6 addressing plan is almost illimited
- Interconnection can create more powerful application
  - Mobile phone may send message to an activator
  - Sensor may exchange information
  - ...

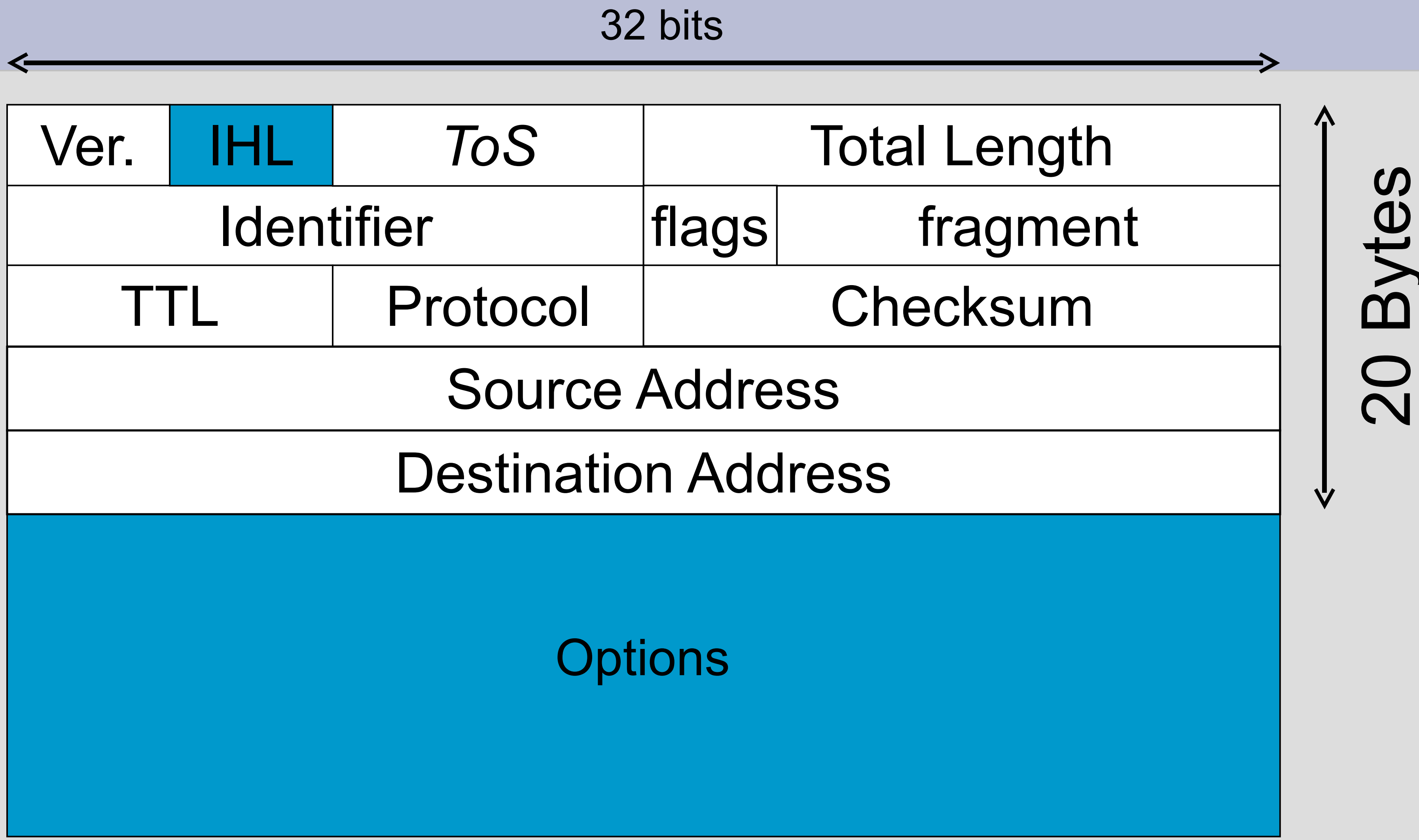
- IPv6 Addressing may also evolve
  - Sensor Network is the premise to embedded systems

IP Model

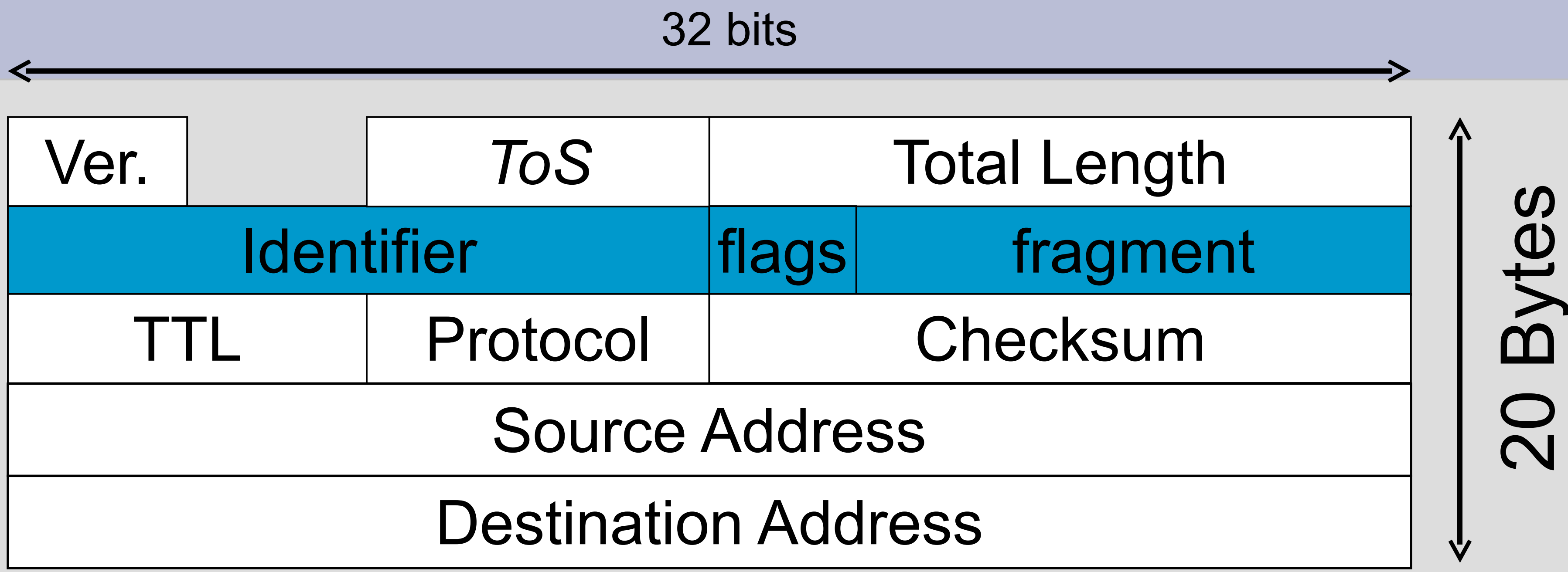


email WWW phone...
SMTP HTTP RTP...
TCP UDP...
IP
ethernet PPP...
CSMA async sonet...
copper fiber radio...
2

IPv4 Header


32 bits
Ver.
IHL
ToS
Total Length
Identifier
flags
fragment
TTL
Protocol
Checksum
Source Address
Destination Address
Options
20 Bytes

IPv4 Header


32 bits
Ver.
ToS
Total Length
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flags
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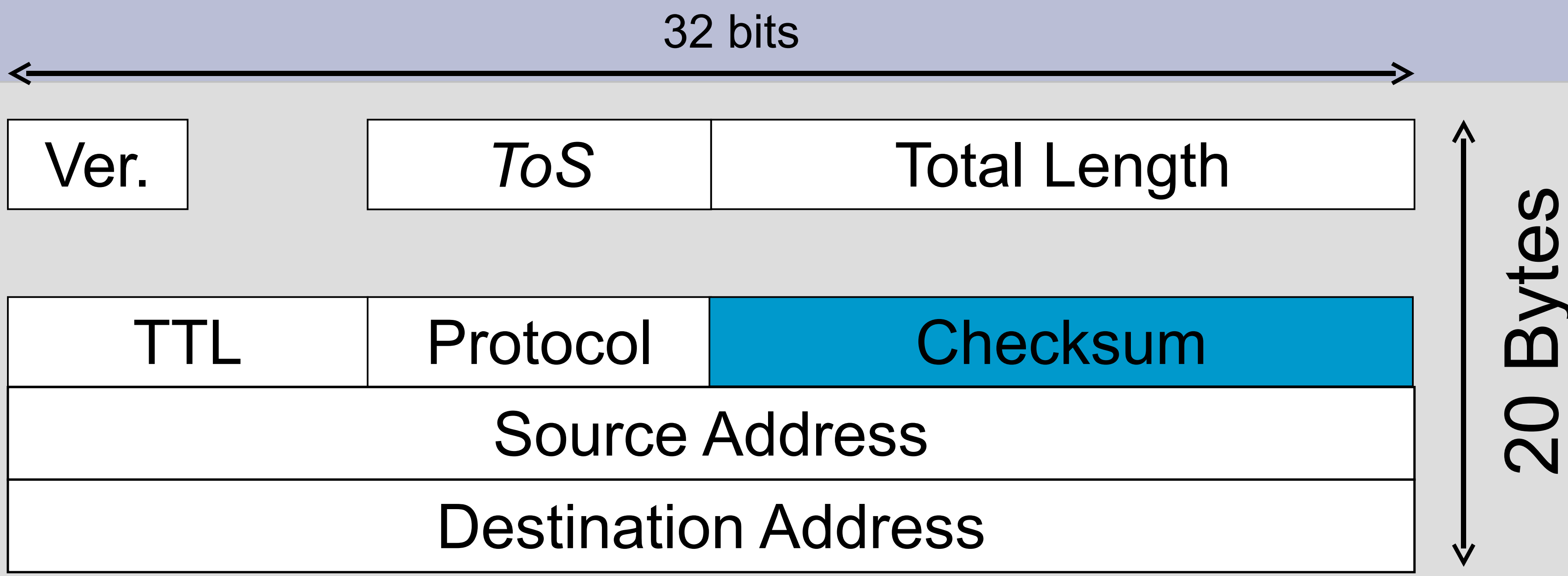
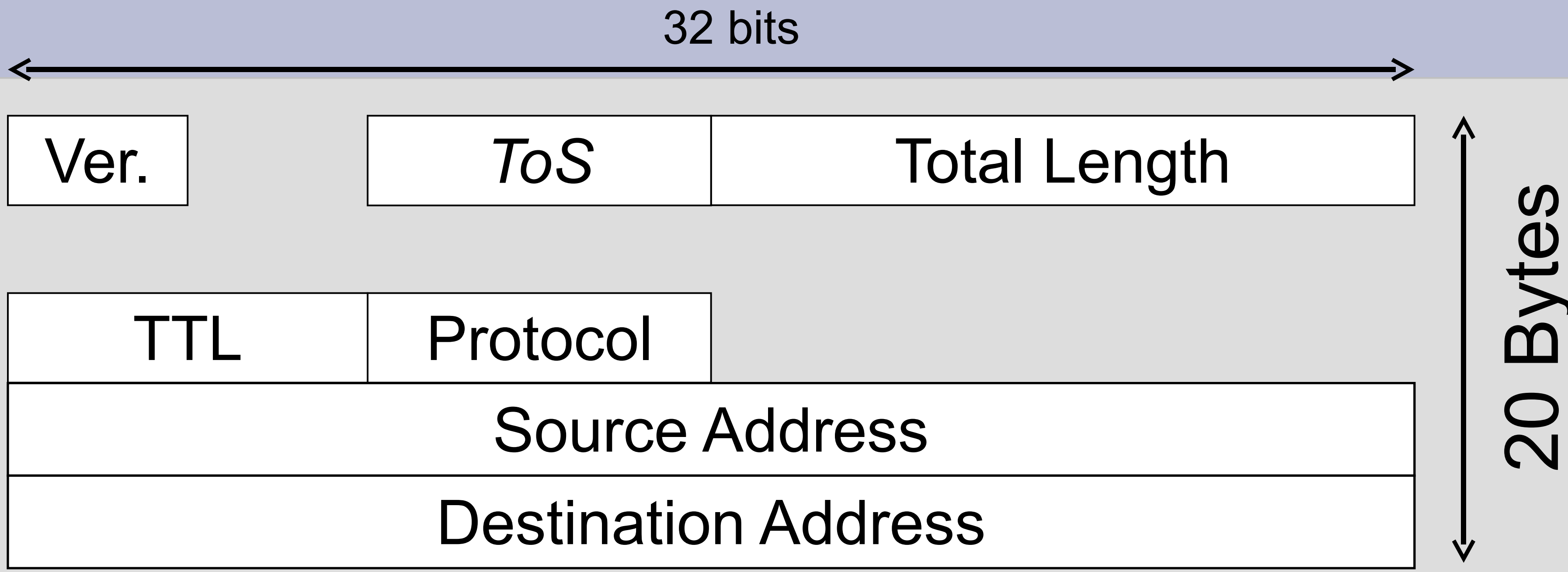
Protocol
Checksum
Source Address
Destination Address
20 Bytes

IPv4 Header

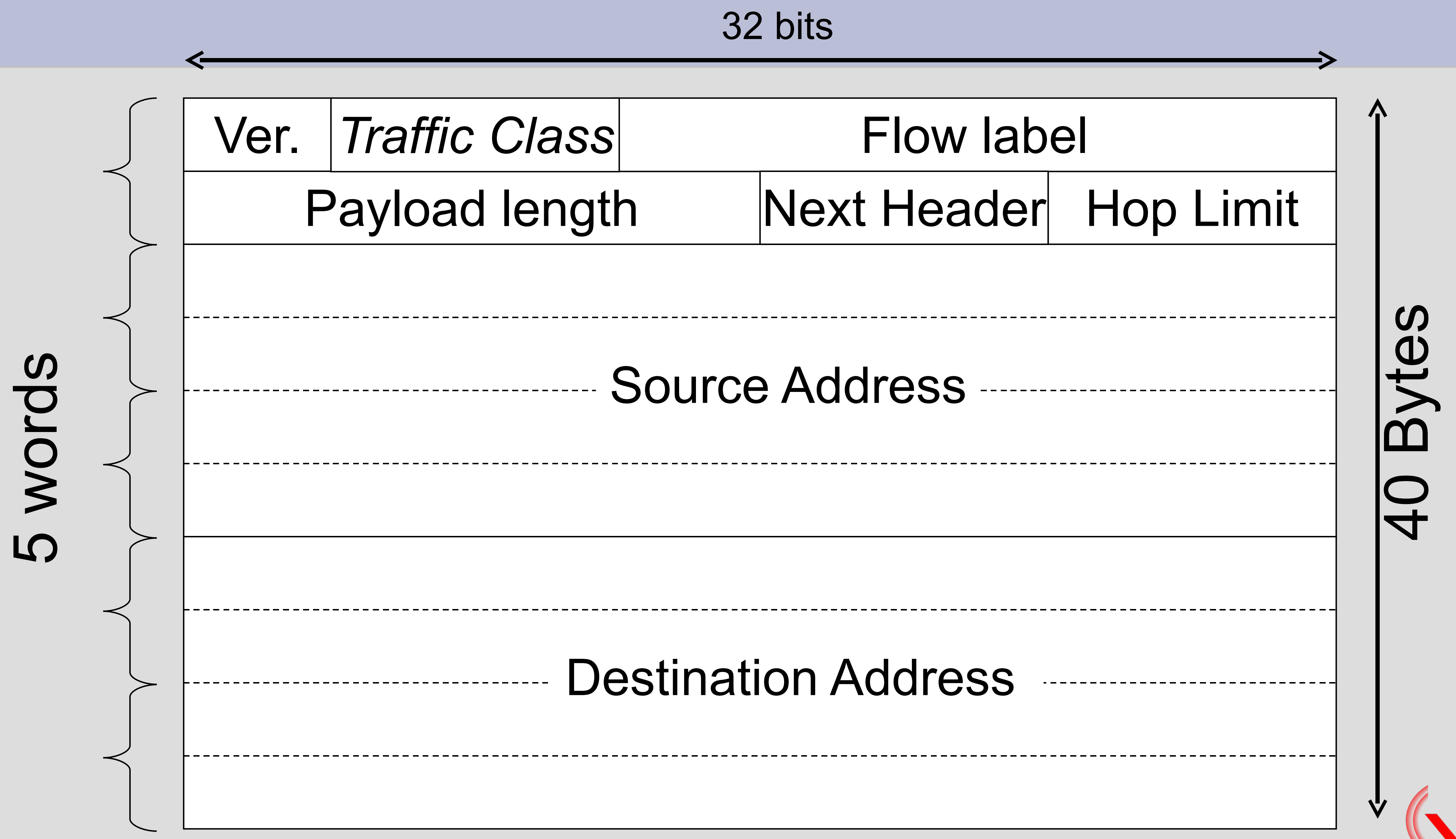

32 bits
Ver.
ToS
Total Length
TTL
Protocol
Checksum
Source Address
Destination Address
20 Bytes

IPv4 Header



32 bits
Ver.
ToS
Total Length
TTL
Protocol
Source Address
Destination Address
20 Bytes

IPv6: Header simplification



Is it enough for the future ?

- Address length
  - Between 1 564 and 3 911 873 538 269 506 102 addresses by m^2
  - 60,000 trillion trillion addresses per inhabitant of the earth
  - Addresses for every grain of sand in the world

- => Justification of a fix address length

- **An address for everything <u>on the network</u>**

  and not

  An address for everything

Textual Address Format

- Base format (a 16 byte **Global IPv6 Address):**
  - **2001:0660:3003:0001:0000:0000:6543:210F**
- Compact Format:

2001:660:3003:1::6543:210F

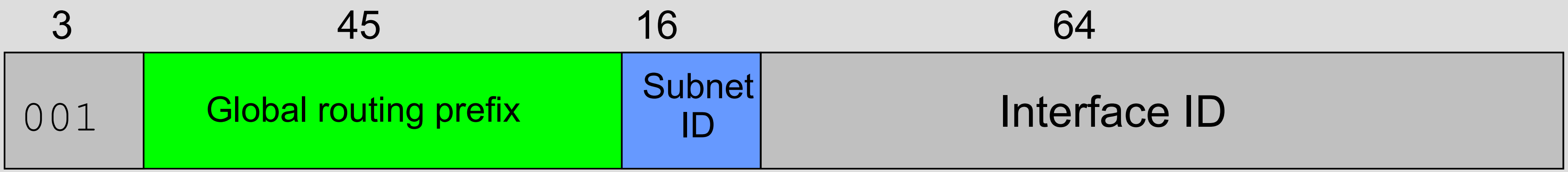
  - In order to avoid ambiguity, “::” can occur only once

Address Space

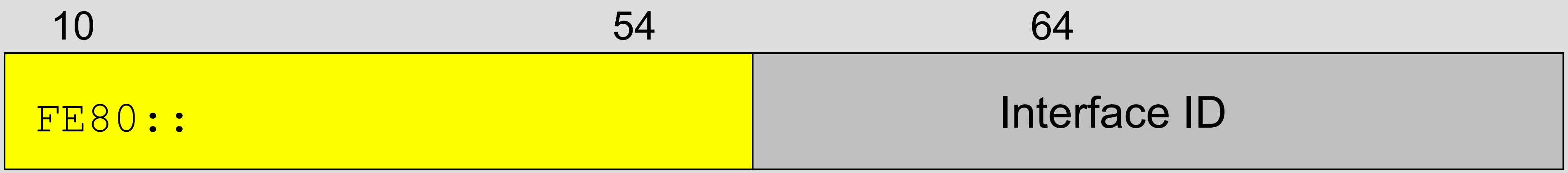
0000::/8	**Reserved by IETF**	**[RFC4291]**
0100::/8	Reserved by IETF	[RFC4291]
0200::/7	Reserved by IETF	[RFC4048]
0400::/6	Reserved by IETF	[RFC4291]
0800::/5	Reserved by IETF	[RFC4291]
1000::/4	Reserved by IETF	[RFC4291]
2000::/3	**Global Unicast**	**[RFC4291]**
4000::/3	Reserved by IETF	[RFC4291]
6000::/3	Reserved by IETF	[RFC4291]
8000::/3	Reserved by IETF	[RFC4291]
A000::/3	Reserved by IETF	[RFC4291]
C000::/3	Reserved by IETF	[RFC4291]
E000::/4	Reserved by IETF	[RFC4291]
F000::/5	Reserved by IETF	[RFC4291]
F800::/6	Reserved by IETF	[RFC4291]
FC00::/7	**Unique Local Unicast**	**[RFC4193]**
FE00::/9	Reserved by IETF	[RFC4291]
FE80::/10	**Link Local Unicast**	**[RFC4291]**
FEC0::/10	Reserved by IETF	[RFC3879]
FF00::/8	**Multicast**	**[RFC4291]**

IPv6 addresses

Global Prefixes:

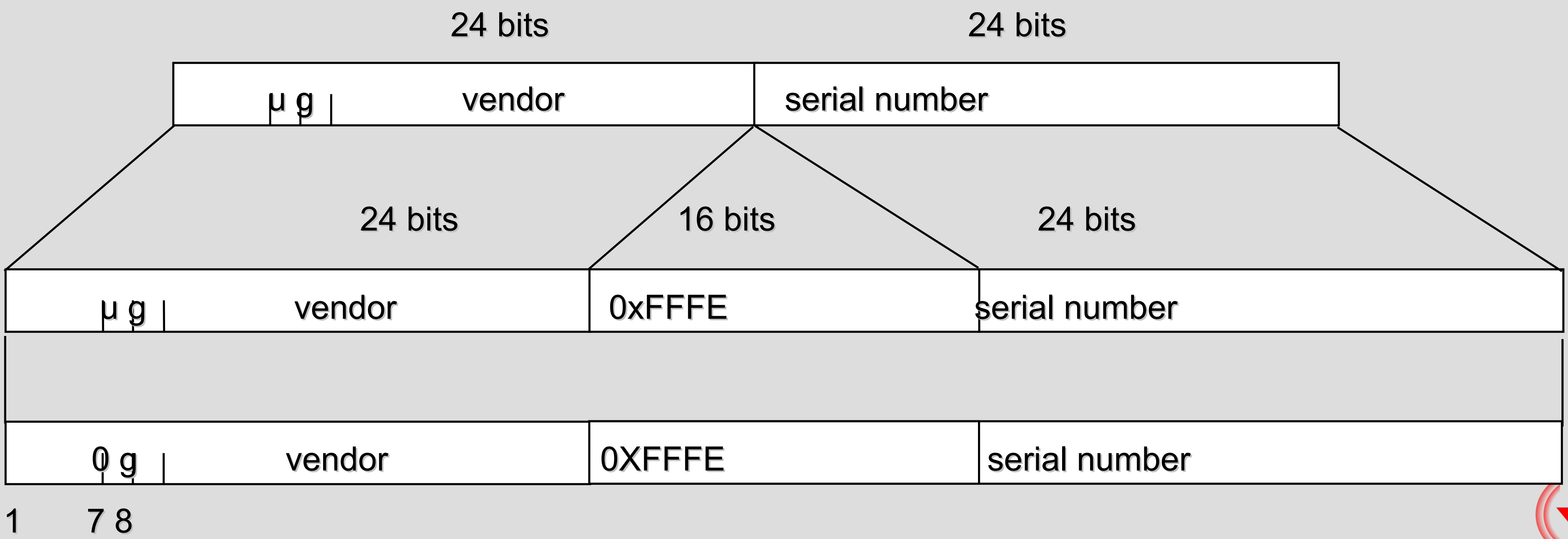


Link Local:



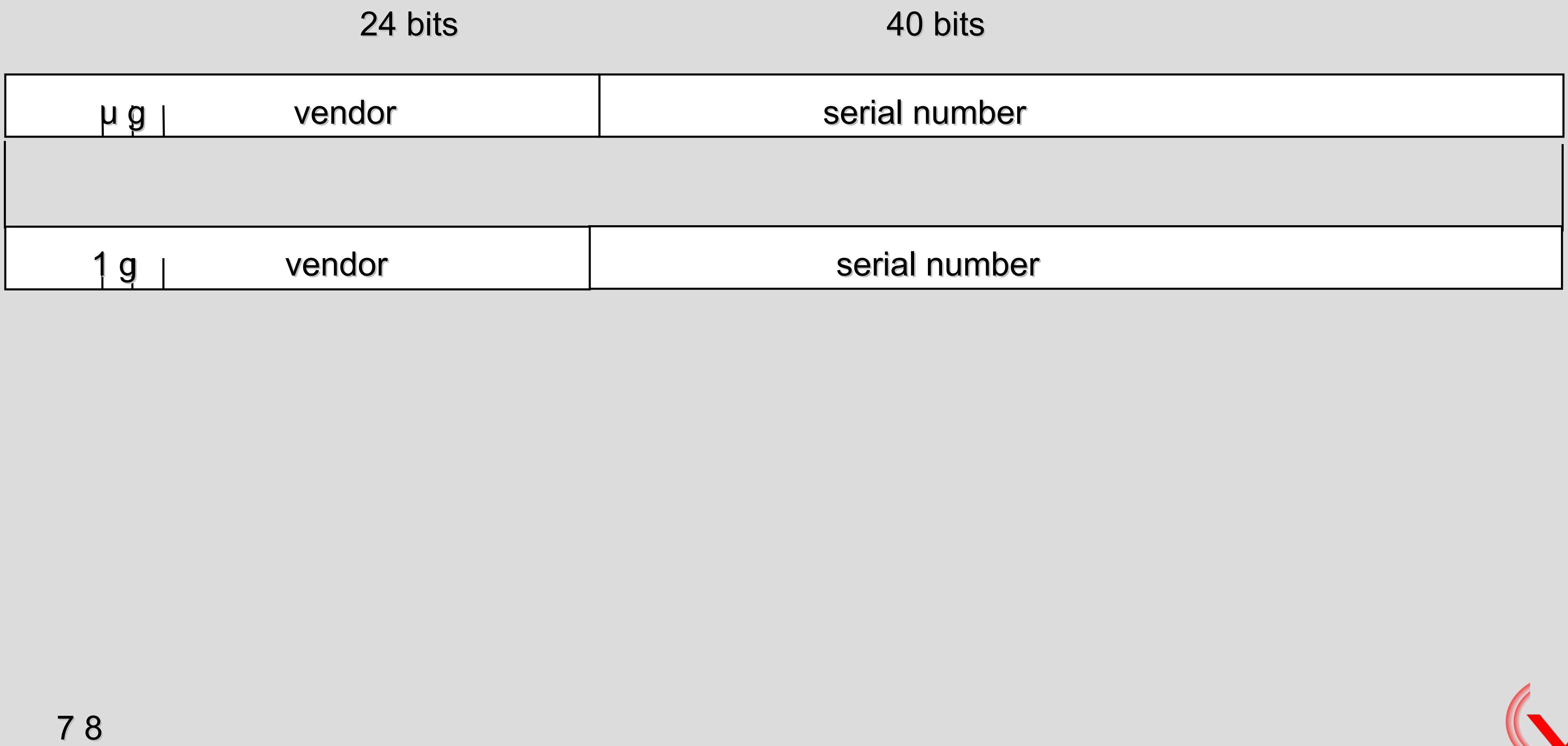
Interface Identifier

- Stateless Auto-configuration
- IEEE defines the mechanism to create an EUI-64 from IEEE 802 MAC addresses (Ethernet, FDDI)



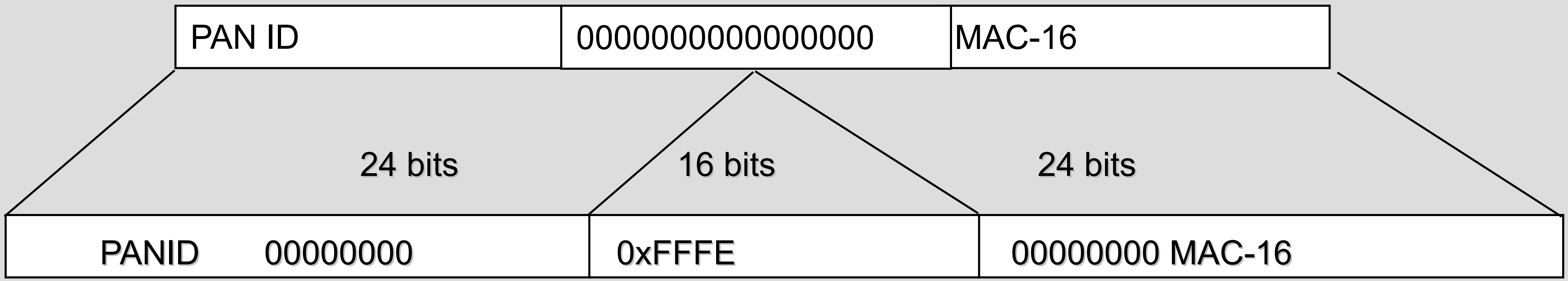
Interface Identifier for IEEE 802.15.4

- EUI-64



Interface Identifier for IEEE 802.15.4

- MAC-16



IID Value

- IID from MAC address is just a convenience:
  - Fixed IID may be better for servers
    - Especially DNS
  - Random value improves security
    - May cause DNS registration problem
  - Cryptographic value is under studies
    - Derived from a host's public key hash
    - Allow to authenticate the sender
    - Used in HIP (Host Identity Protocol), Shim6 and Secure Neighbor Discovery.

Anycast Addresses (RFC 2526)

– Anycast IDs are defined in RFC 2526
– Anycast addresses have been defined for routers only so far
  - Subnet prefix = unchanged
  - Anycast ID = highest 128 interface ID values

– 2 different scenarios:

```
|            64 bits              |      57 bits     |   7 bits   |
+---------------------------------+------------------+------------+
|         subnet prefix           | 1111110111...111 | anycast ID |
+---------------------------------+------------------+------------+
                                  | interface identifier field    |

|             n bits              |    121-n bits    |   7 bits   |
+---------------------------------+------------------+------------+
|         subnet prefix           | 1111111111...111 | anycast ID |
+---------------------------------+------------------+------------+
                                  | interface identifier field    |
```

– Anycast address of all home agent in 2001:660:3001:4002::/64
`2001:660:3001:4002:FDFF:FFFF:FFFF:FFFE -> home agents anycast ID`

Multicast Addresses

11111111	Flag	Scope	Group ID
8 bits	*4 bits*	*4 bits*	*112 bits*

Flag bits: 0 R P T

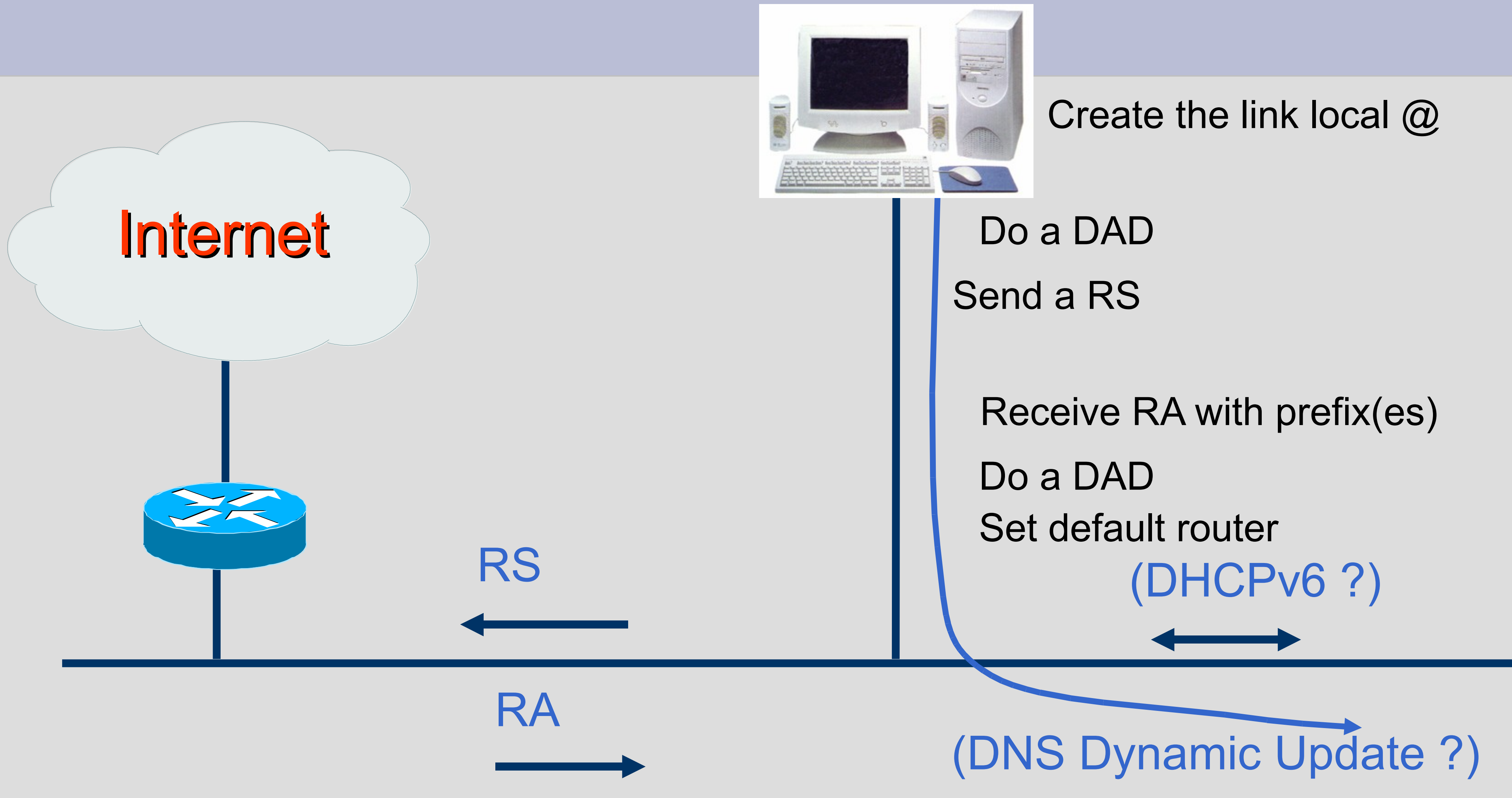
T = 0
permanent addresses (managed by IANA)
T = 1
transient multicast addresses
P = 1 > T = 1
derived from unicast prefix (RFC3306)
R = 1 > P = 1 > T = 1
embedded RP addresses (I-D)

Scope
- 0: Reserved
- 1: Interface-local
- 2: Link-local
- 3: Subnet-local
- 4: Admin-local
- 5: Site-local
- 8: Organization-local
- E: Global
- F: Reserved

Neighbor Discovery

- Neighbor Solicitation (NS):
  - to determine the link-layer @ of a neighbor
  - or to check its impeachability
  - also used to detect duplicate addresses (DAD)
- Neighbor Advertisement (NA):
  - answer to a NS packet
  - advertise the change of physical address
- Redirect:
  - Used by a router to inform a host a better route to a given destination

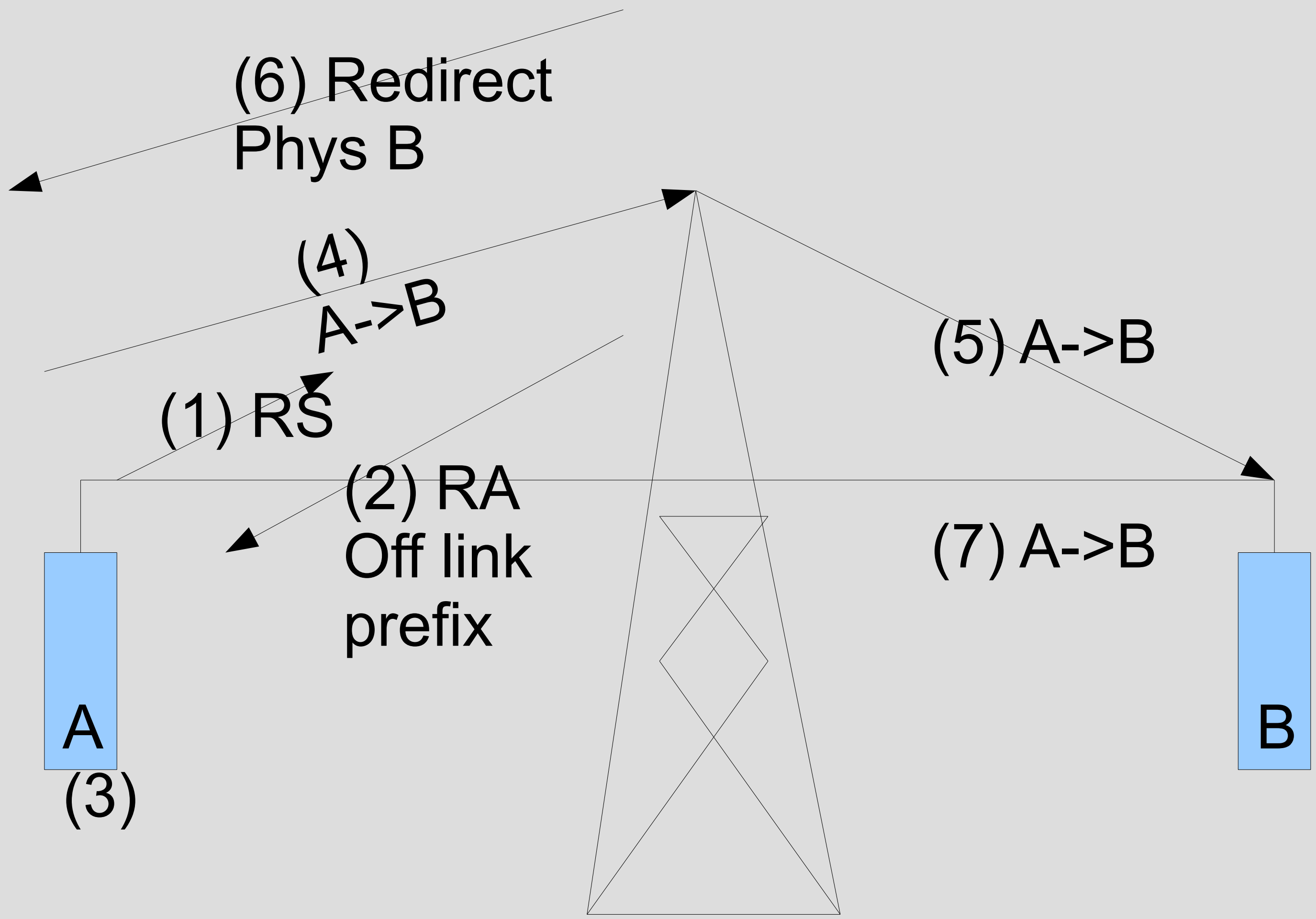
Auto-configuration: Summary



NBMA network

- Off-link model. Two kinds of NBMA:
  - Always a central point (such as 3G)
  - Possibility of direct communication between two hosts, but no broadcast (i.e. Frame Relay, ATM,...)
- RS: set a bit to indicate this state
- No Neighbor Sollicitation
  - All packets are sent to central router
  - Redirect can be used

NBMA Network



Optimistic DAD

- When an address is created, DAD is sent
  - Based on Timeout
  - Repeated several times (datagram)
  - About 3sec before using the address
- Risk of collision is quite low
  - Optimistic DAD: use the address immediatly,
  - Suppress it in case of failure of DAD

6LoWPAN

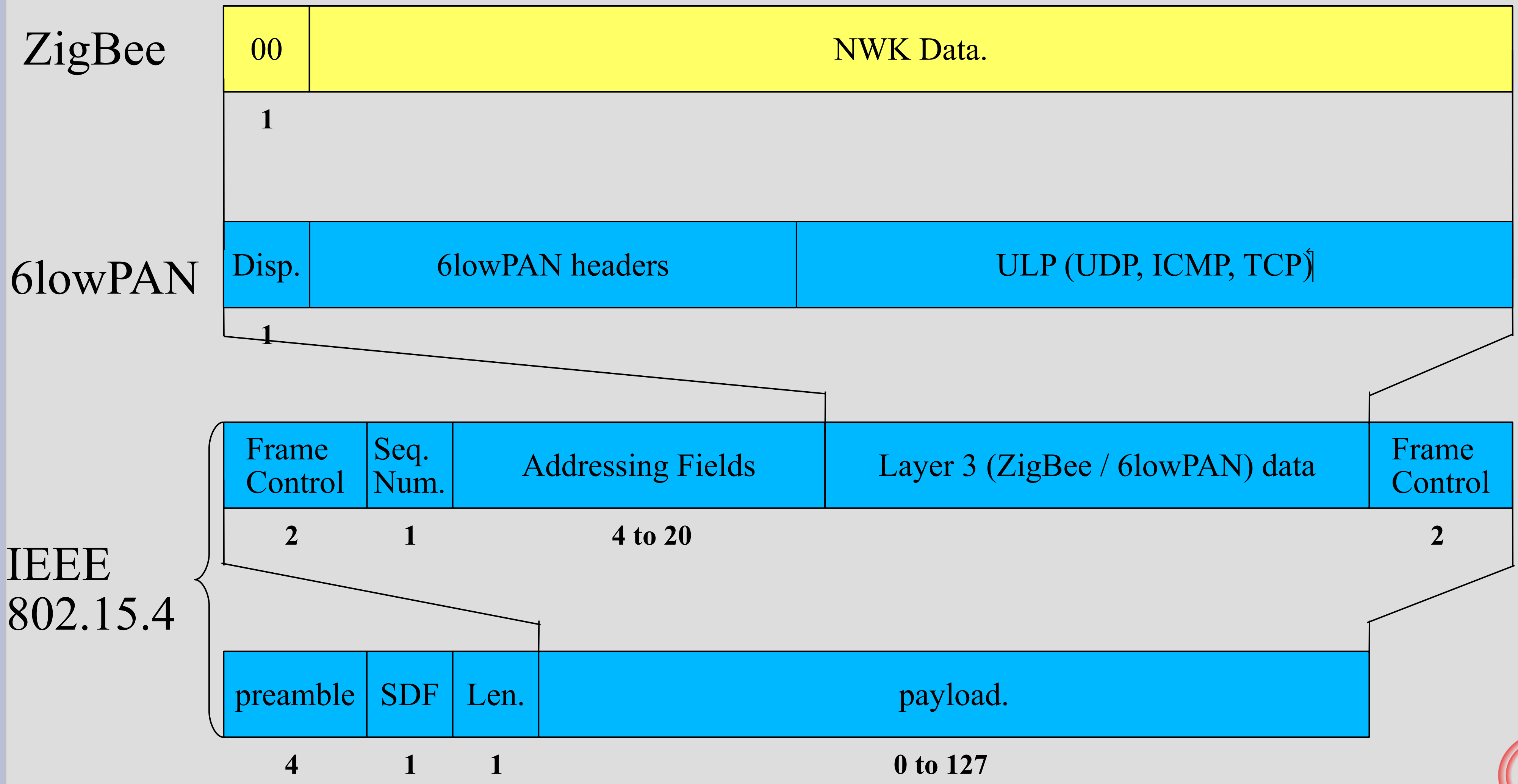
6LoWPAN

- IPv6 mandate that L2 supports at least a 1280 bytes frame
- IEEE 802.14.5 maximum frame size is 127 Bytes
  - Without headers
- 6lowPAN is an adaptation layer to carry large IPv6 packet

6lowPAN

- 6lowPAN offers a fragmentation mechanism
- 6lowPAN compresses IPv6 header
  - RFC 4944 compression method soon deprecated
- 6lowPAN offers support for Mesh Routing and Broadcast

IEEE 802.15.4 encapsulation



6LoWPAN Dispatch

- First byte of packet
  - Used to distinguish between 6lowPAN and ZigBee packet
  - First two bits 00 is used by Zigbee data packets
  - 6lowPAN avoid this value
  - But
    - Zigbee also uses other values
- Dispatch is not a SAP
- Other values 01, 10 and 11 are used by 6lowPAN to define header type

Dispatch Values

- 01 000001 Uncompressed IPv6
- 01 000010 ~~Compressed IPv6~~
- 01 010000 Broadcast
- 01 1xxxxx Alternative proposal
  - Used to suppress routing loops
- 10 xxxxxx MESH
  - Kind of tunnel to carry source and destination addresses
- 11 000xxx Fragmentation (first)
- 11 100xxx Fragmentation (subsequent)

Uncompressed IPv6 header

- Only between 77 and 101 Bytes left
  - RS: 72 Bytes
  - Works only if addresses are 2 byte-long with no PANid
  - Otherwise fragmentation should be used

Compressed IPv6 header

- IPv6 header is very stable
  - Major part are source and destination addresses
- 6lowPAN compression is stateless
  - No context for session, only done on packet bases
- Only HL cannot be compressed, since this field may vary during transmission

Compressed IPv6 header

- Addresses are composed of two parts
  - 64 bits for prefix
  - 64 bits for IID
- If prefix is FE80::/64 it can be avoided
- If IID is derived from MAC address, it can be avoided
- If not compressed, then sent after the compressed header

Interface ID construction

- If MAC address is 64 bit-long
  - Use the standard algorithm (inverse 2nd bit)
- If MAC address is 16 bit-long
  - 0xxx xxxx xxxx xxxx: unicast addresses
  - IID = PANid:00FFFE00:MAC
  - 2nd bit is set to 0
- IPv6 multicast
  - 100x xxxx xxxx xxxx: multicast addresses
  - Map the last 13 bits of the IPv6 muticast address

Fragmentation

- If IPv6 packet is too big, fragmentation must be used
- Two headers are used:

5	11	16
11000	Datagram size	Datagram Tag

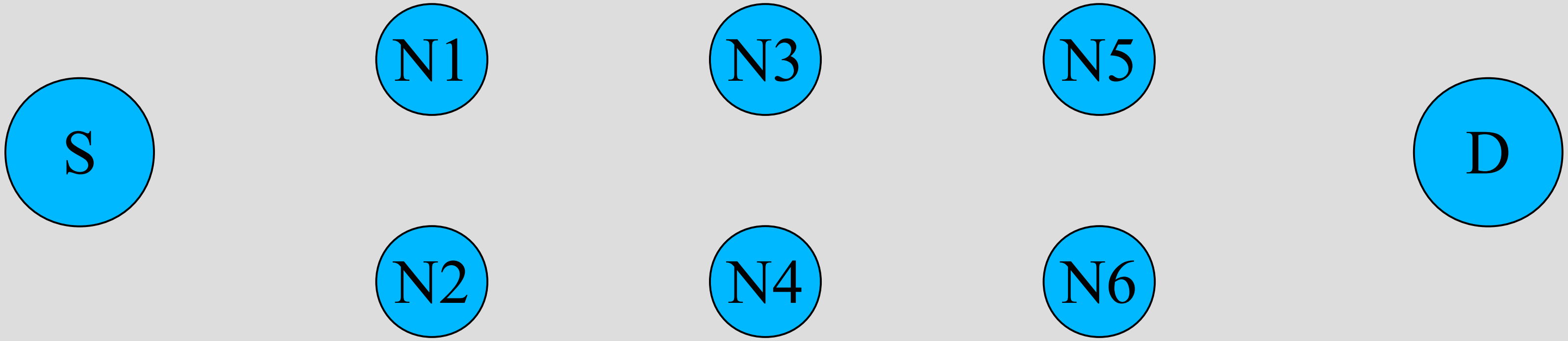
			8
11100	Datagram size	Datagram Tag	offset

6lowPAN in a meshed network

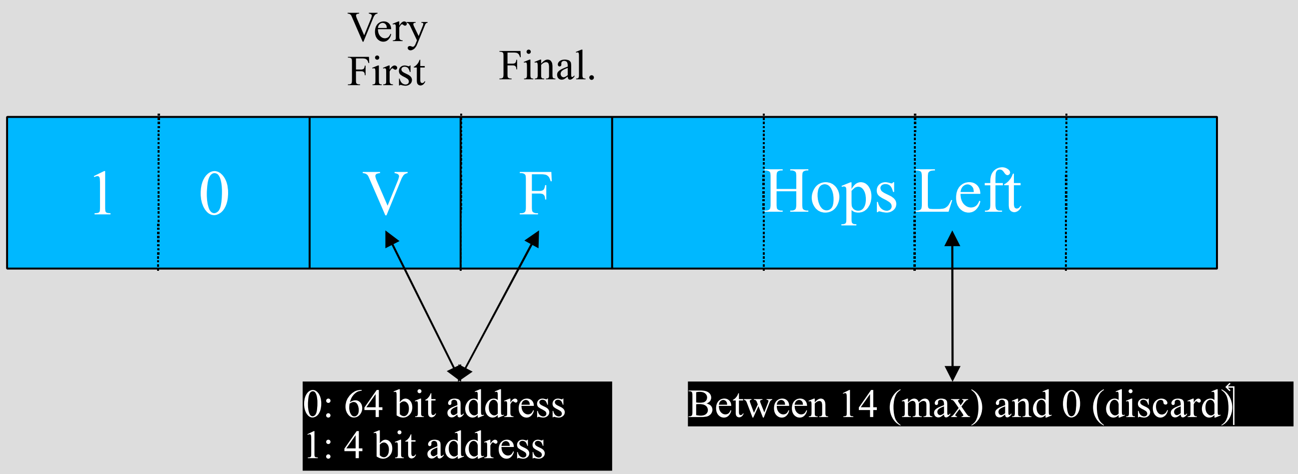
- Two appraoches:
  - Mesh-under
    - Mesh requires a routing protocol
    - 6lowPAN provide support for routing but does not define the routing protocol
    - From IP view the mesh is one prefix
  - Route-over
    - Forwarding is done at IP level
    - ROLL IETF Workin Group focuses on that topic
    - Several prefixes may be used
    - Closer to ad-hoc networks

Mesh header

- Radio is a broadcast medium
- The receiver must be explicitly specified
  - In wire technology bridging does not change source or destination addresses
- Mesh header allows to keep source and destination addresses
  - Kind of tunnel



Mesh header



Very
First
Final.
1
0
V
F
Hops Left
0: 64 bit address
1: 4 bit address
Between 14 (max) and 0 (discard)

Broadcast Header

- When broadcast is used destination address is FFFF
- All neighbors receives the frame
- Loops are created
- This field allow to distinguish copies of the same frame
- Node must remember sequence number and source address
  - If values are already in cache frame is discarded

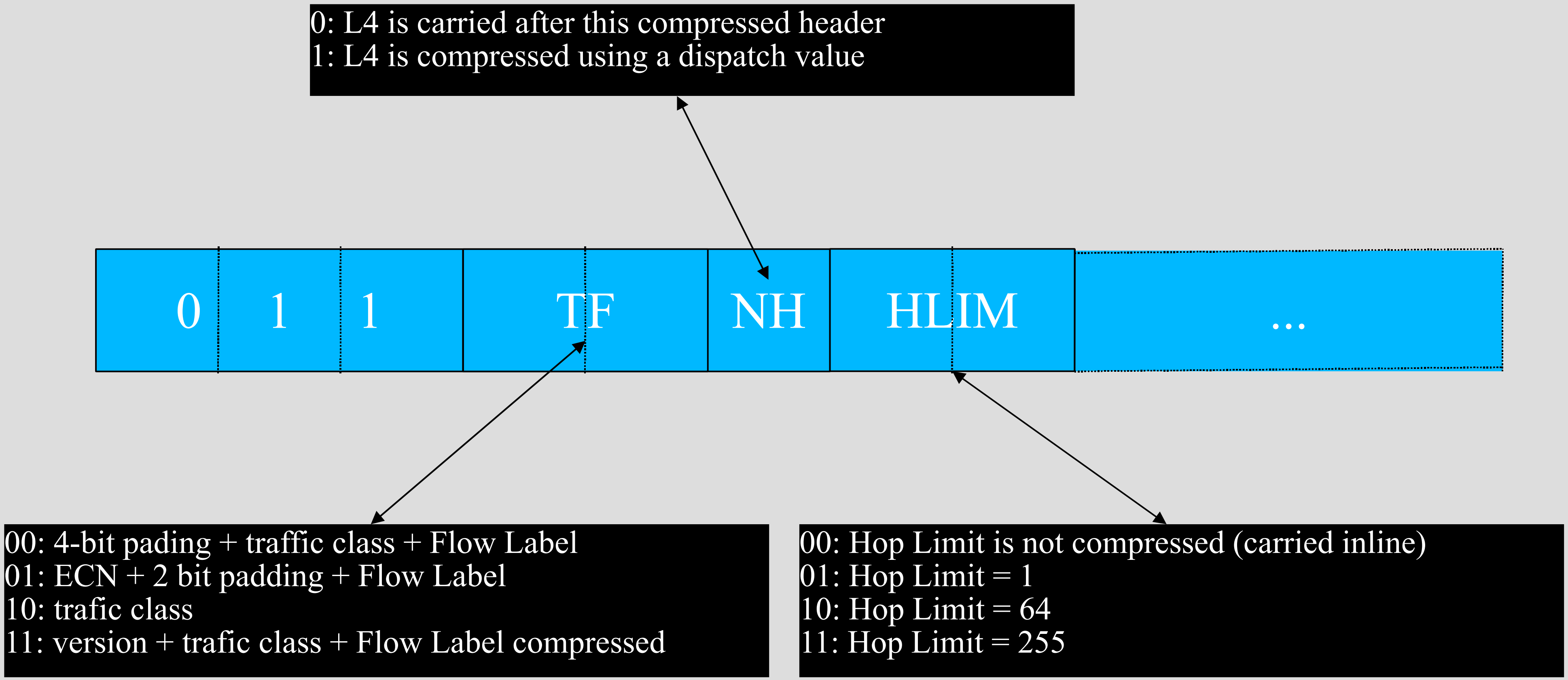
6LoWPAN alternative compression scheme

- RFC4944 is only efficient for packets with Link Local addresses
- Either:
  - Neighbor Discovery in one frame
  - Communication between Sensors
- Sensor will communicate with other equipements on the Internet
  - A draft specifies a more efficient compression scheme.

New header compression scheme

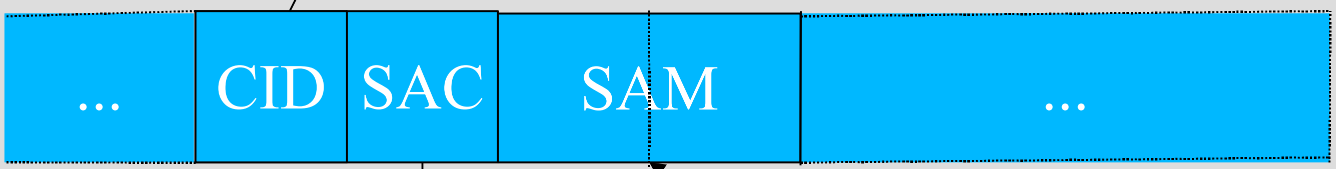
- draft-ietf-6lowpan-hc-05.txt
- New and more efficient coding for all king of frames
  - RFC 4944 works well only for NDP
- Global addresses can use a context to avoid to send full prefix
- Upper Layer are compressed independantly:
  - Dispatch value for each layer

compression scheme



Source address compression

0: Only default context (if used)
1: 8 bit context identifier just after DAM

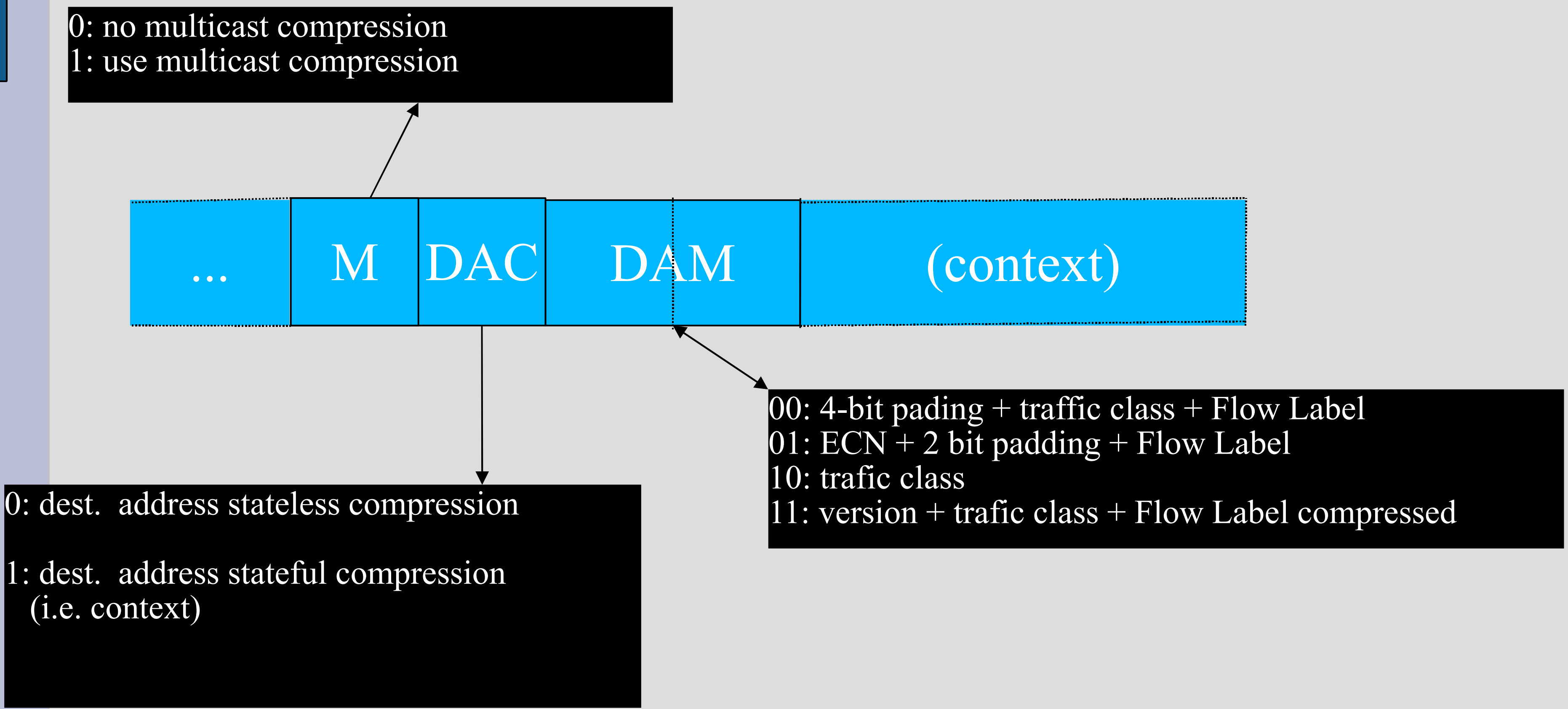


0: source address stateless compression
(generally Link Local address)
1: source address stateful compression
(i.e. context)

SAC = 0
00: not specified
01: first 64 bits are elided (rest online)
10: first 112 bits are elided (rest online)
11: as RFC 4944 compression (based on MAC)

SAC=1
00: address is not compressed (carried online)
01: last 64 bits specified online (first in context)
10: last 16 bits specified online (first in context)
11: first in context, last from MAC

Source address compression



Source address compression

0:
1:

	M=0 DAC=0	M=0 DAC=1	M=1 DAC=0	M=1 DAC=1
00	Full address on line	reserved	48 bits online FFXX::00XX:XXXX:XXXX	Dest. online
01	Link Local 64 first bits elided 64 last bits online	Context + 64 online	32 bits online FFXX::00XX:XXXX	48 bits online FFXX::XX[plen]:[prefix]:XXXX:XXXX
10	Link Local 112 first bit elided 16 last bits online	Context + 16 online	16 bits online FF0X:::0XXX	reserved
	Link Local Elided Used L2 addr	Context + L2 addr	8 bit online FF02::00XX	reserved

0: dest.

1: dest.
(i.e. c

Examples (Router Sollicitation)

- IPv6
  - TC + FL = 0
  - IPv6 source address: L-L
  - IPv6 destination address: FF02::2
  - ICMPv6

```
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
| 0 | 1 | 1 |   TF   |NH | HLIM  |CID|SAC|  SAM  | M |DAC|  DAM  |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
```

- HC1 = 011 11 0 11 + 0 0 11 1 0 11 + 02
  - 3 Bytes

L4 compression

- Only defined for UDP
  - A well knonw fixed port number and delta online
  - Checksum can be elided for some specific traffic
- Nothing for other L4
  - TCP
  - ICMP
  - ROLL ?

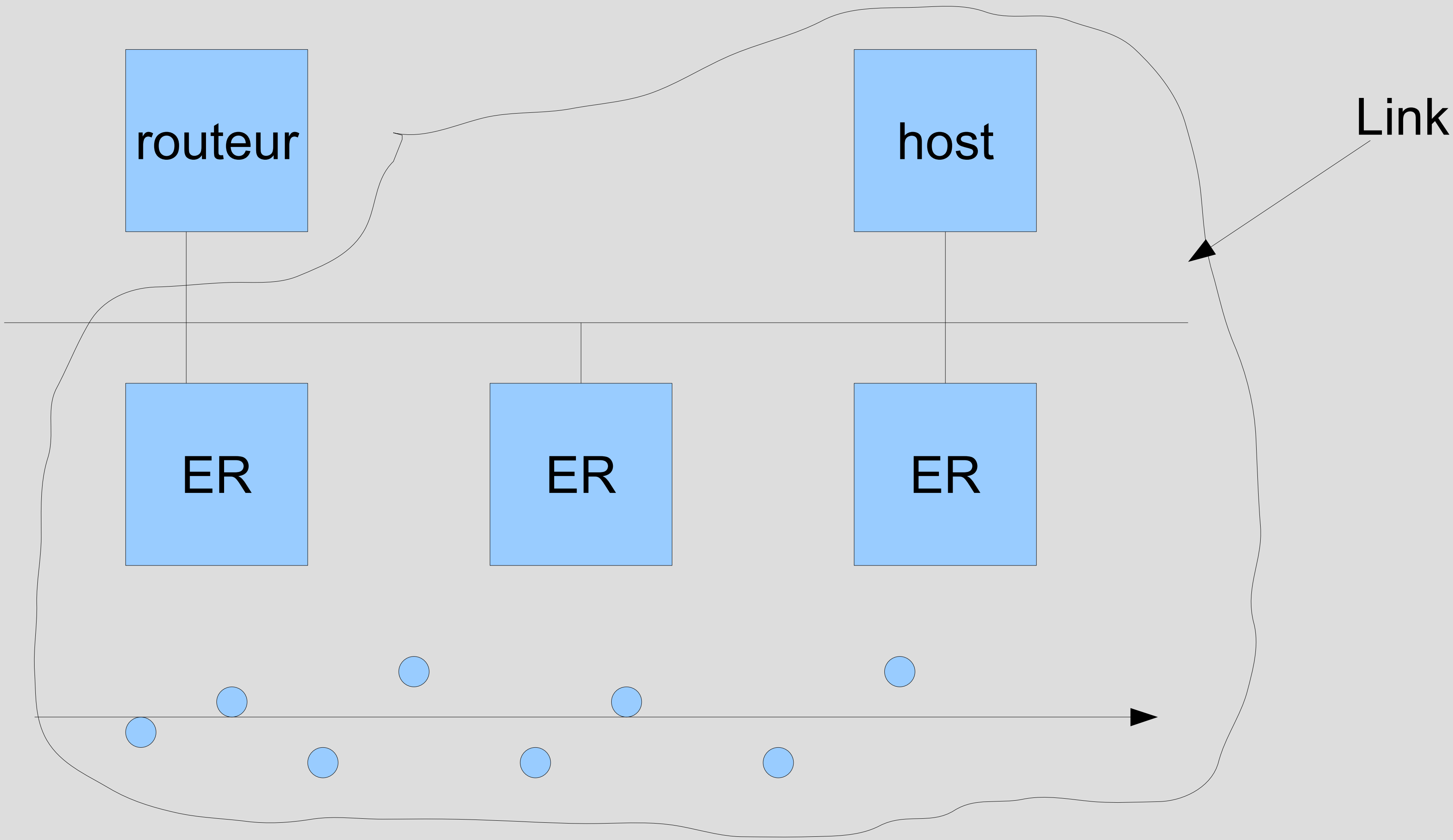
Revisiting Neighbor Discovery

ND optimization

- What is a link ? Not clear for WSN
- What is a site ? Administratively defined

- Radio range may vary:
  - DAD may not work efficiently
- No Multicast, so NS does not used sollicited address but broadcast.
- New NDP for LowPAN ?
  - draft-ietf-6lowpan-nd-00

Generic model



Whiteboard

- Whiteboards keep address registration:
  - Distributed among all edge routers
  - Ethernet link between ER is used to synchronise address registrations
  - Allows mobility inside the link.
  - In route-over mode, nodes with router functionnalities relay the information.
- New ICMP messages
- Registration is soft state (periodically renewed)

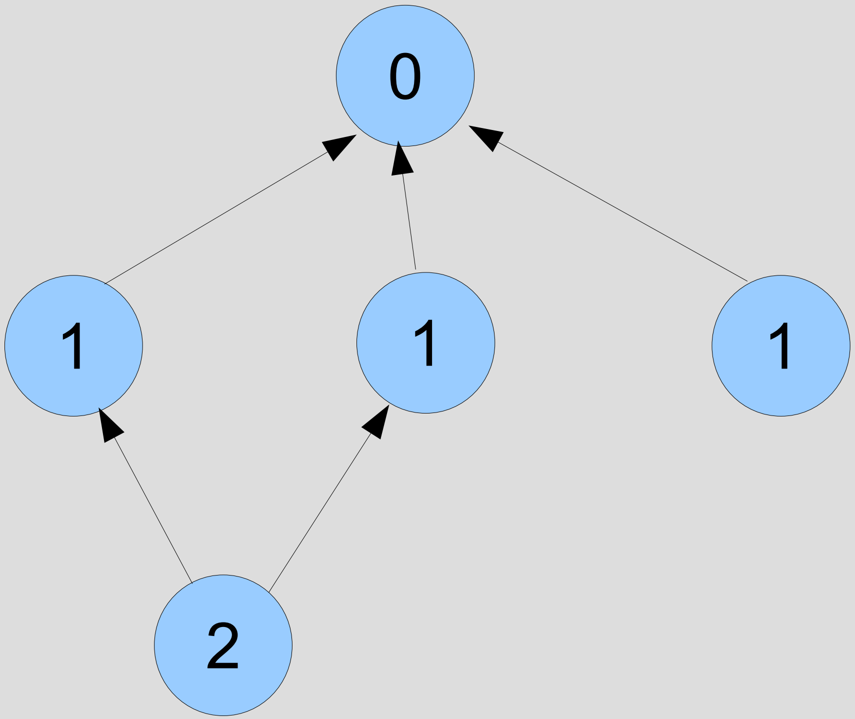
Routing: ROLL

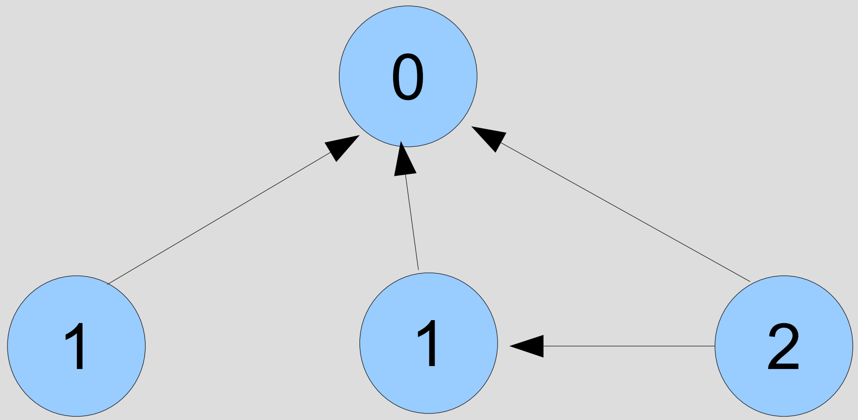
RPL

- Based on Distant Vector
- Different of RIP
  - Several parents (DAG)
  - Several DAG
  - Loop Avoidance (Try not to increase metric)
- Use Router Advertisement (RA)
  - With DAG Information Option (DIO)
  - To create default route
- Une Neighbor Advertisement (NA)
  - With Destination Advertisement Option
  - Route inside the WSN

RPL

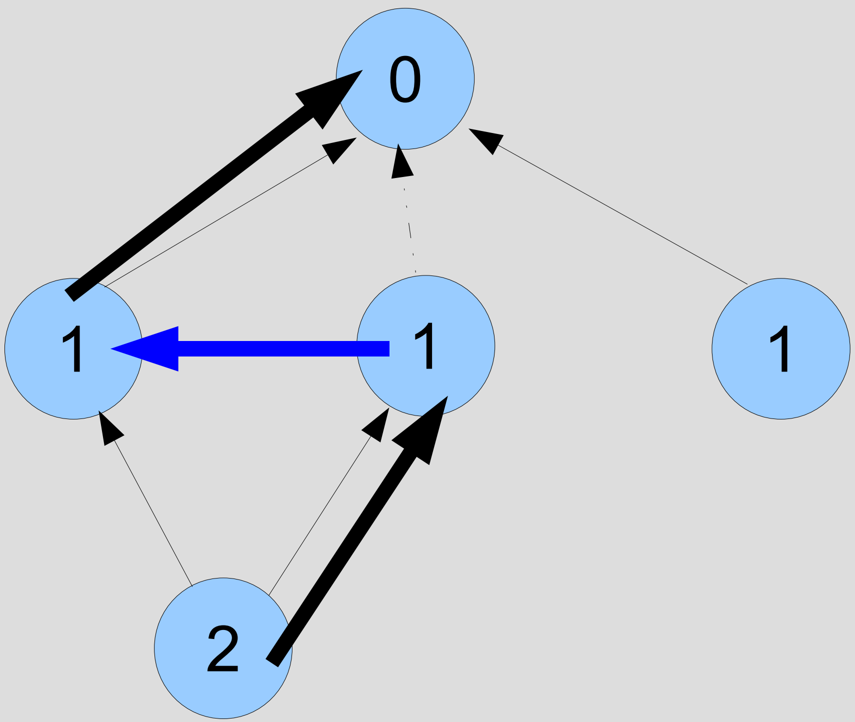
- Rank = max (Parent's Rank) +1
- Goal minimize Rank

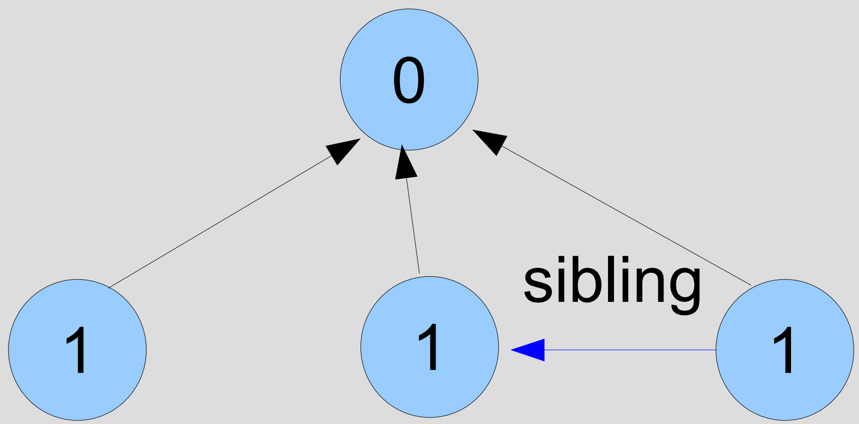




RPL sibling

- Used a same rang router to forward information
- Avoid to increase rank





Conclusion

Conclusion

- IPv6 is the common language between all sensors and applications
- This lead to a strong evolution of Internet paradigm:
  - From Interconnection model (same format) ...
  - … to interface model:
    - IPv6 header format is changed (+/-)
    - AC/border routers speak IPv6
- Work in progress, but:
  - Implementation of 6LoWPAN in WSN OS
  - RPL just started, some modification will happen