Internet of Things

Lecture 4 - 6LoWPAN & RPL

Network Protocols

IPv4	IPv6	6LoWPAN
Exhausted in 2011 32-bit address	128-bit addresses	Limited processing capability Shows compression mechanism with IPv6 over 802.15.4

6LoWPAN

6LoWPAN Standard

- Internet Engineering Task Force (IETF)
  - TCP, UDP, HTTP, CoAP, etc.
- RFC 4944 - first 6LoWPAN standard
- RFC 6282 - header compression
- RFC 6775 - neighbor discovery
- Over IEEE 802.15.4
- Adapted to work with other low-power technologies
  - Bluetooth Smart
  - Wi-Fi low-power

Network Architecture

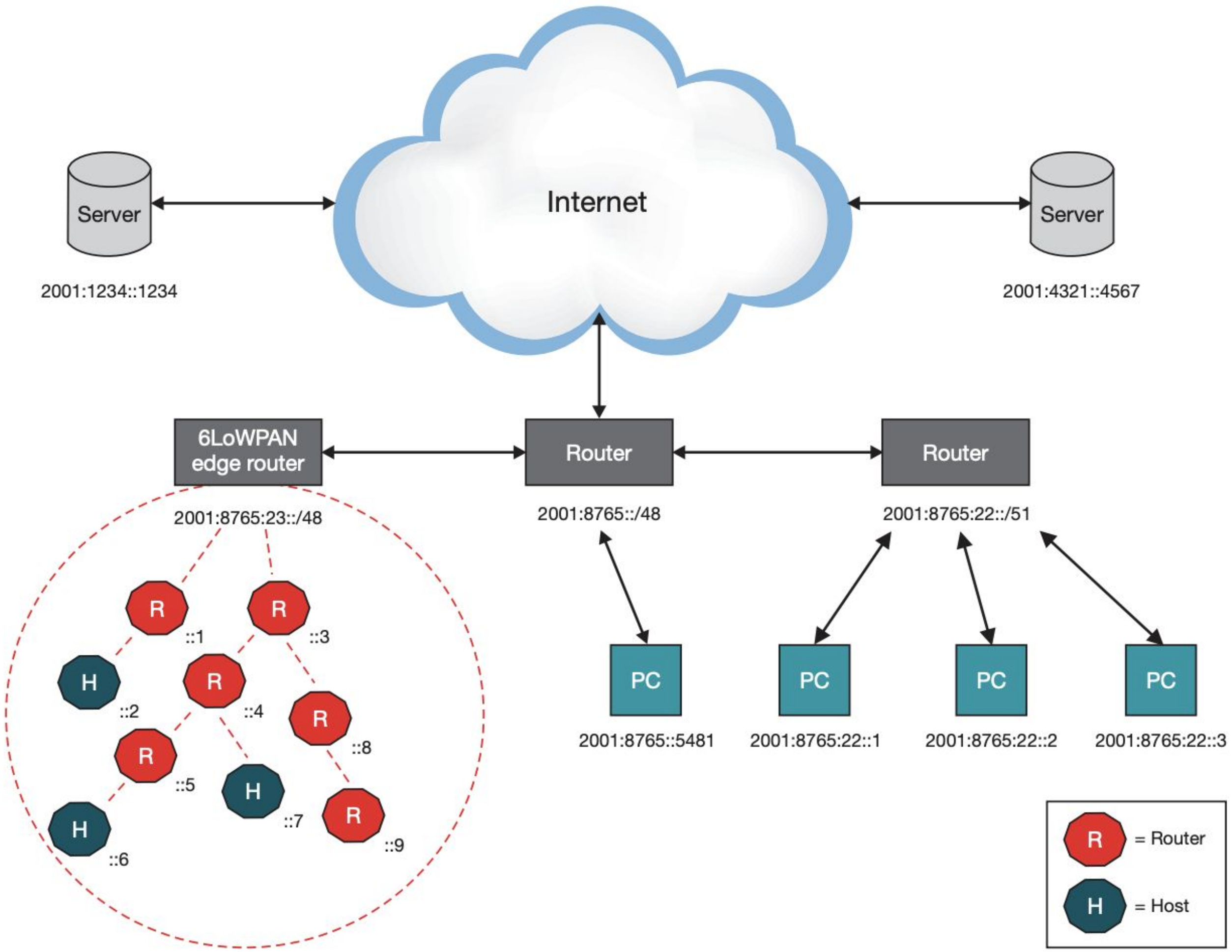


Figure 1. An example of an IPv6 network with a 6LoWPAN mesh network

- 6LoWPAN mesh network
- Edge router (6LBR)
- Routers (6LR)
- Hosts (6LN)

Image source: Olsson, Jonas. "6LoWPAN demystified." Texas Instruments 13 (2014).

Networking Stack

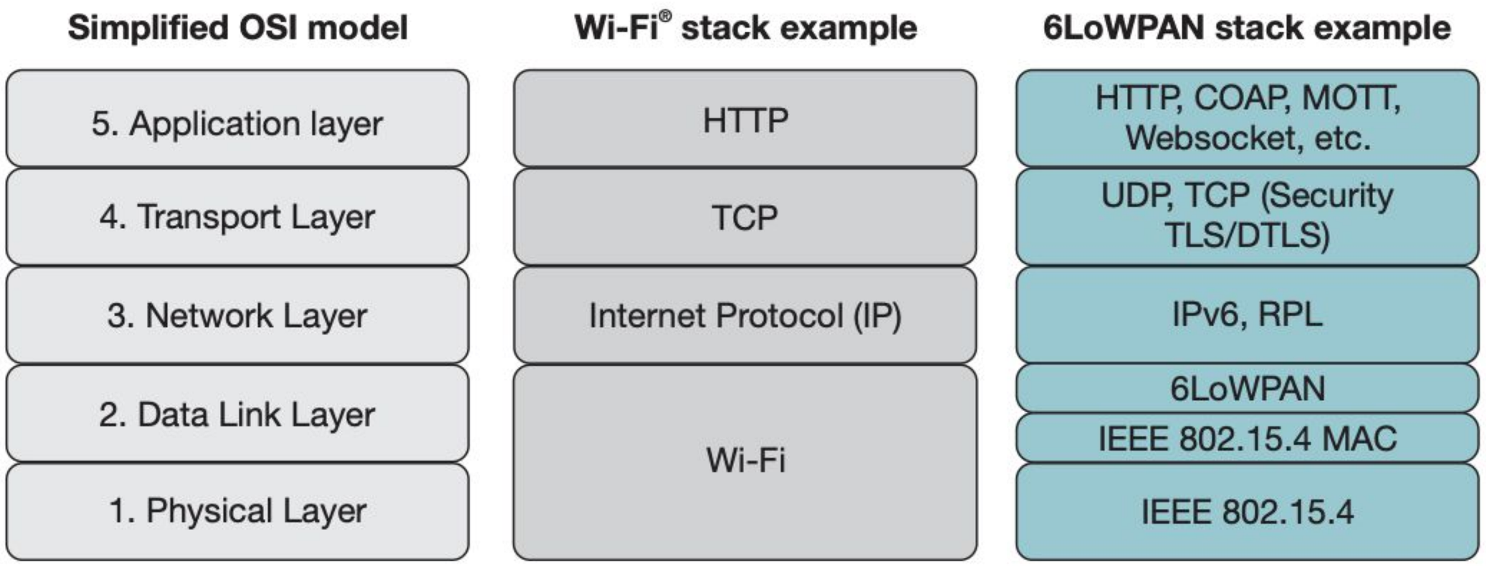


Figure 2. The OSI model, a Wi-Fi® stack example and the 6LoWPAN stack

Image source: Olsson, Jonas. "6LoWPAN demystified." Texas Instruments 13 (2014).

IPv6 over IEEE 802.15.4

- IPv6
  - minimum MTU is 1280 bytes
  - reflects technology advancement
- 802.15.4
  - maximum bandwidth 250 Kpbs
  - frame size is 127 bytes
  - MAC addresses on 64 bits or 16 bits
  - Minimize header overhead, minimize memory consumption

IPv6 over IEEE 802.15.4

- Main challenges for using IPv6 over 802.15.4
  - IPv6 has minimum MTU 10 times larger
  - IPv6 has 40 bytes headers
  - Low power and lossy networks
- Solutions:
  - Fragmentation & header compression
  - Adaptive and responsive network layer

IETF - RFC 6282

- 6LoWPAN Working Group from IETF => RFC 6282
  - Encapsulation of IPv6 packet into 802.15.4 frame
- Header compression
  - The elimination of header fields that can be derived from other headers
  - Stateless or context-based compression
  - Same network prefix
  - Determine IPv6 addresses and field sizes
- Fragmentation
- Stateless auto-configuration
  - DAD

Header Compression

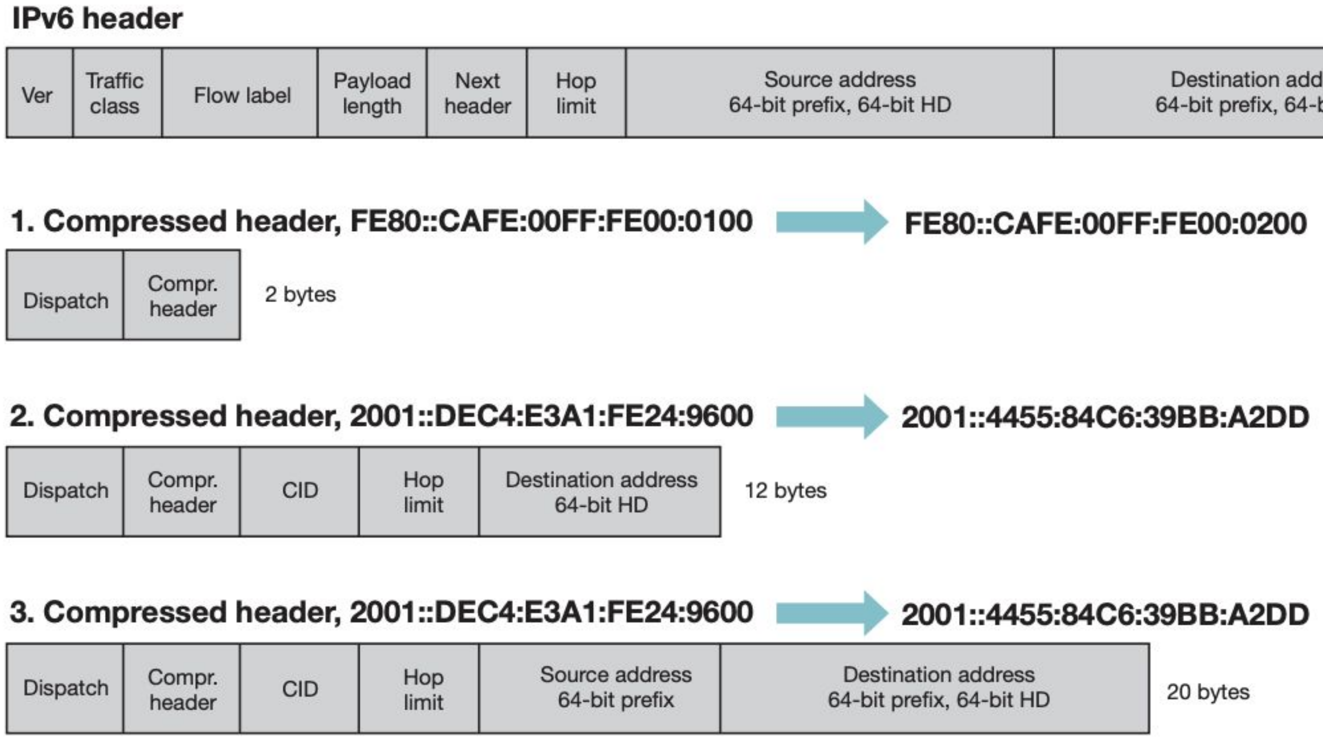


Figure 3. 6LoWPAN IPv6 header compression examples

Image source: Olsson, Jonas. "6LoWPAN demystified." Texas Instruments 13 (2014).

- Stateless & shared-context compression
- The routing protocol does not affect compression

1. between nodes from the local 6LoWPAN network (useful for routing protocols)
2. destination is external but prefix is known
3. destination is external and prefix is not known (50% compression)

- Interface ID - derived from MAC address

Fragmentation

- Packets are divided into smaller segments
- Additional information in the headers for the reassembly
- mesh-under routing:
  - packets are reassembled at the destination
  - quick routing of fragments
- route-over routing:
  - packet is reconstructed at each hop
  - hops are devices with more resources
- Avoid fragmentation - reduced payload + header compression

Stacked headers

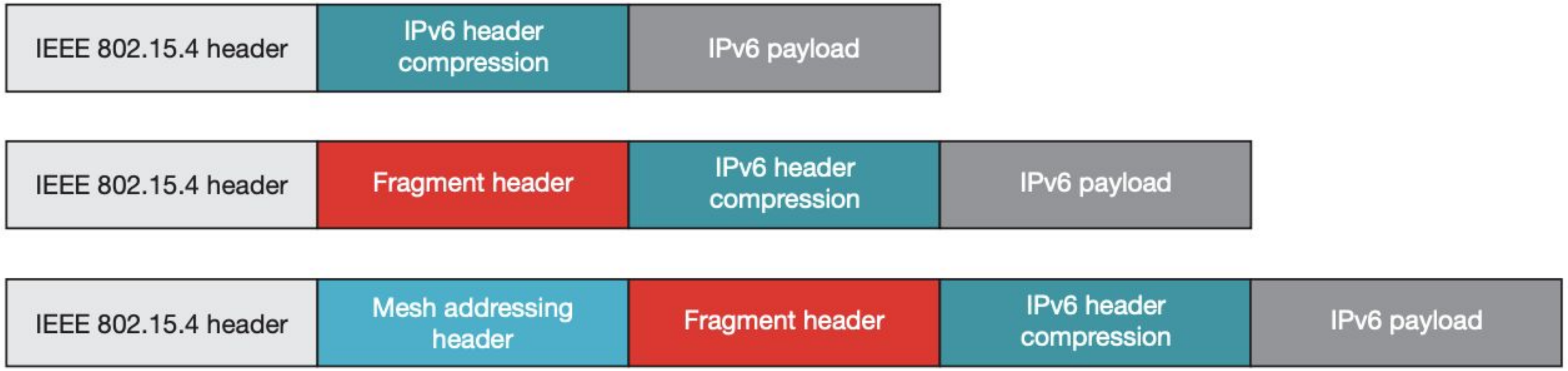


Figure 4. 6LoWPAN stacked headers

Image source: Olsson, Jonas. "6LoWPAN demystified." Texas Instruments 13 (2014).

3 types of sub-headers:

- mesh addressing
- fragmentation
- header compression

Stacked headers

- Fragment header
  - when fragmentation is needed
  - 3 fields:
    - datagram size
    - datagram tag
    - datagram offset
- Mesh addressing header
  - used in multi-hop topologies
  - 3 fields:
    - hop limit
    - source address
    - destination address

Routing

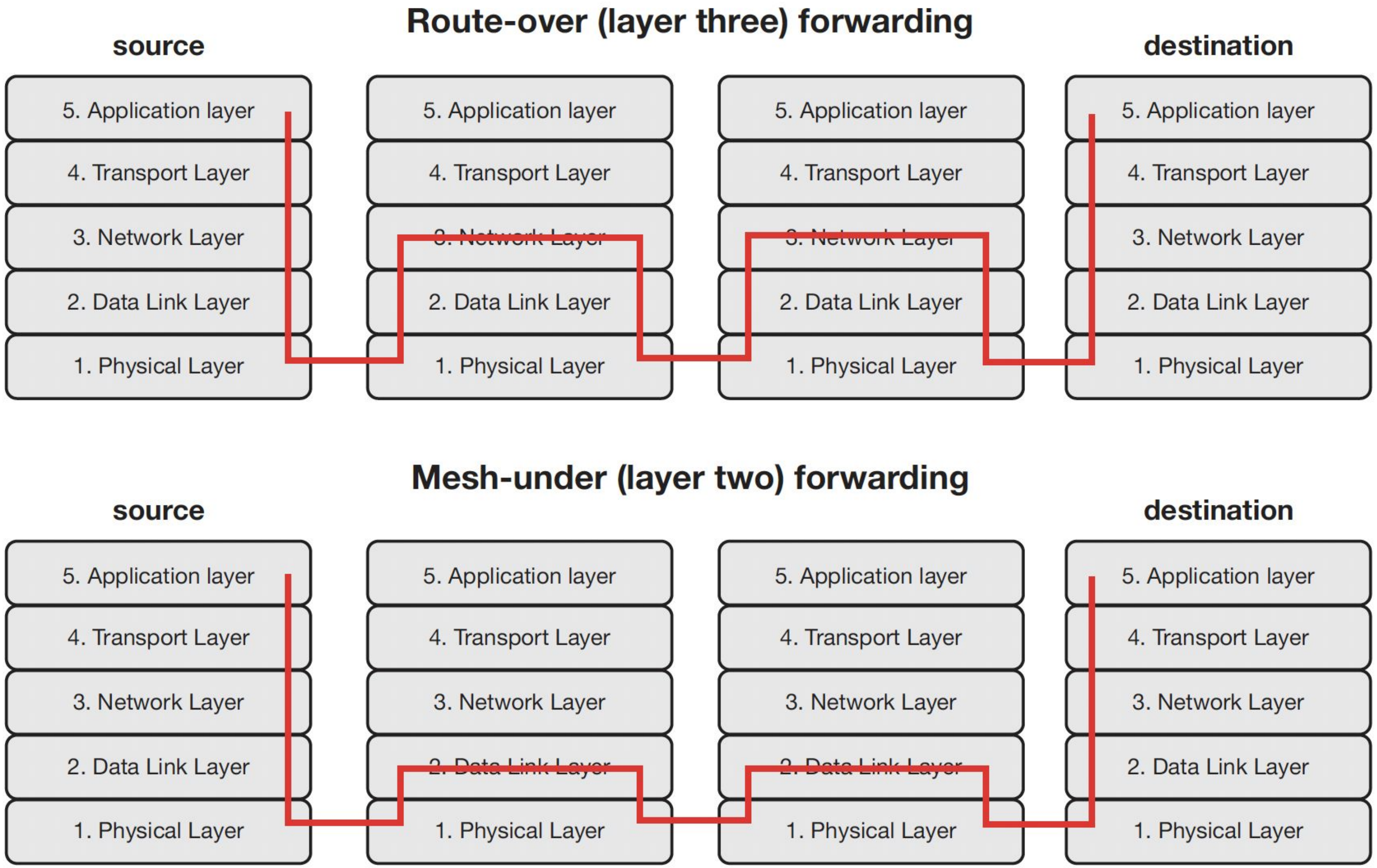


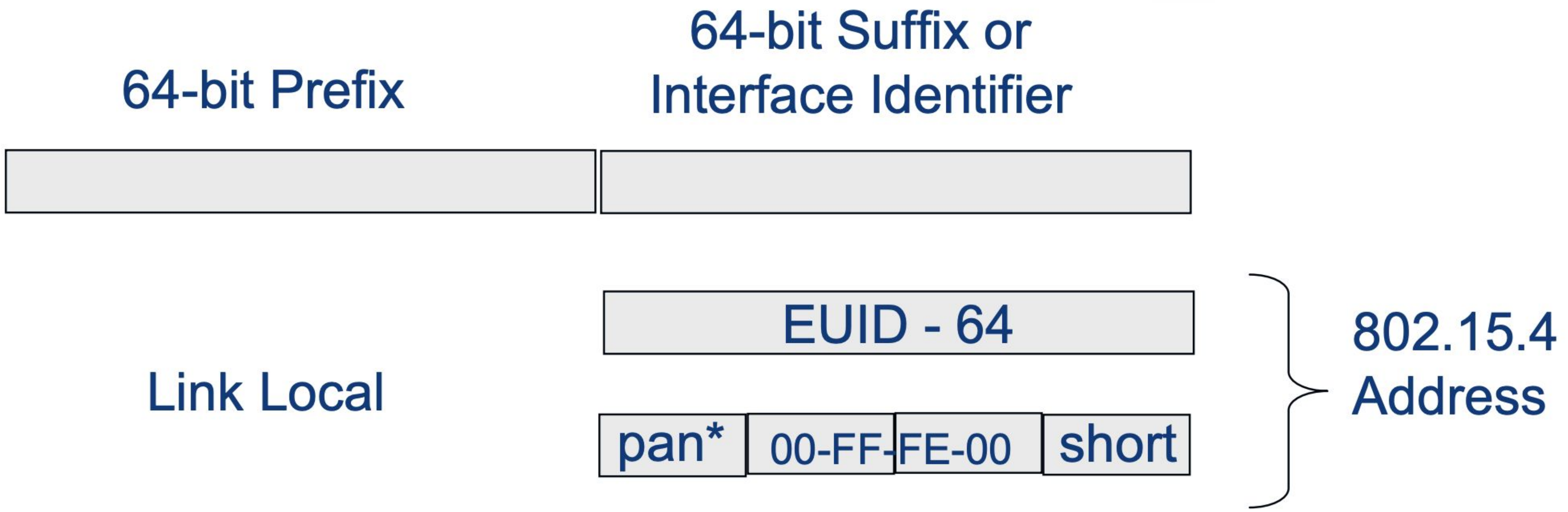
Figure 5. Mesh-under and route-over packet forwarding

Neighbor Discovery

- Neighbor Discovery Protocol (NDP)
  - Used for discovering neighbor devices, available devices, default routes, configuration parameters
- 4 types of messages:
  - Router solicitation (RS)
  - Router advertisement (RA)
  - Neighbor solicitation (NS)
  - Neighbor advertisement (NA)
- RS/RA - find prefix
- NS/NA - find duplicate addresses

Link-local address

- Link-local address derived from 802.15.4 address (64 or 16 bits)
- Link-local prefix is FE80::/64



Advantages of auto-configuration

- Mesh-under routing
  - local-link address is sufficient to communicate within the local 6LoWPAN network
- Router-over routing
  - local-link address for communicating with direct neighbors
  - for multi-hop communication it needs routable address
- Advantage => eliminate some fields to compress headers
- Same prefix in the network => also good for header compression

Security

- Attacks against IoT can impact users
- 802.15.4 link layer
  - AES-128 encryption
  - link authentication and encryption
- TLS
  - Works over TCP
  - not used in low-power networks
- DTLS
  - Works over UDP
  - more appropriate for constrained devices
- Hardware encryption engine is necessary

RPL

RPL

- Routing Protocol for Low power and lossy networks
- defined by IETF in RFC 6550
- IETF ROLL working group
- IP smart object networks / Low-power and lossy networks
- Distance-vector & source routing protocol
- “route-over” protocol
- Communication:
    - multipoint-to-point
    - point-to-multipoint
    - point-to-point

Topology

- Directed Acyclic Graph (DAG)
- Destination-Oriented DAGs (DODAGs),
  - Sink nodes/gateways - root of the DAG
- RPL instance = one or more DODAGs, with RPLInstanceID
  - A network may have multiple instances
  - A node may belong to several instances, but only to one DODAG in each instance
- Combines both hierarchical and mesh topologies
  - sending to parent
  - routing through siblings or children

RPL Topology Example

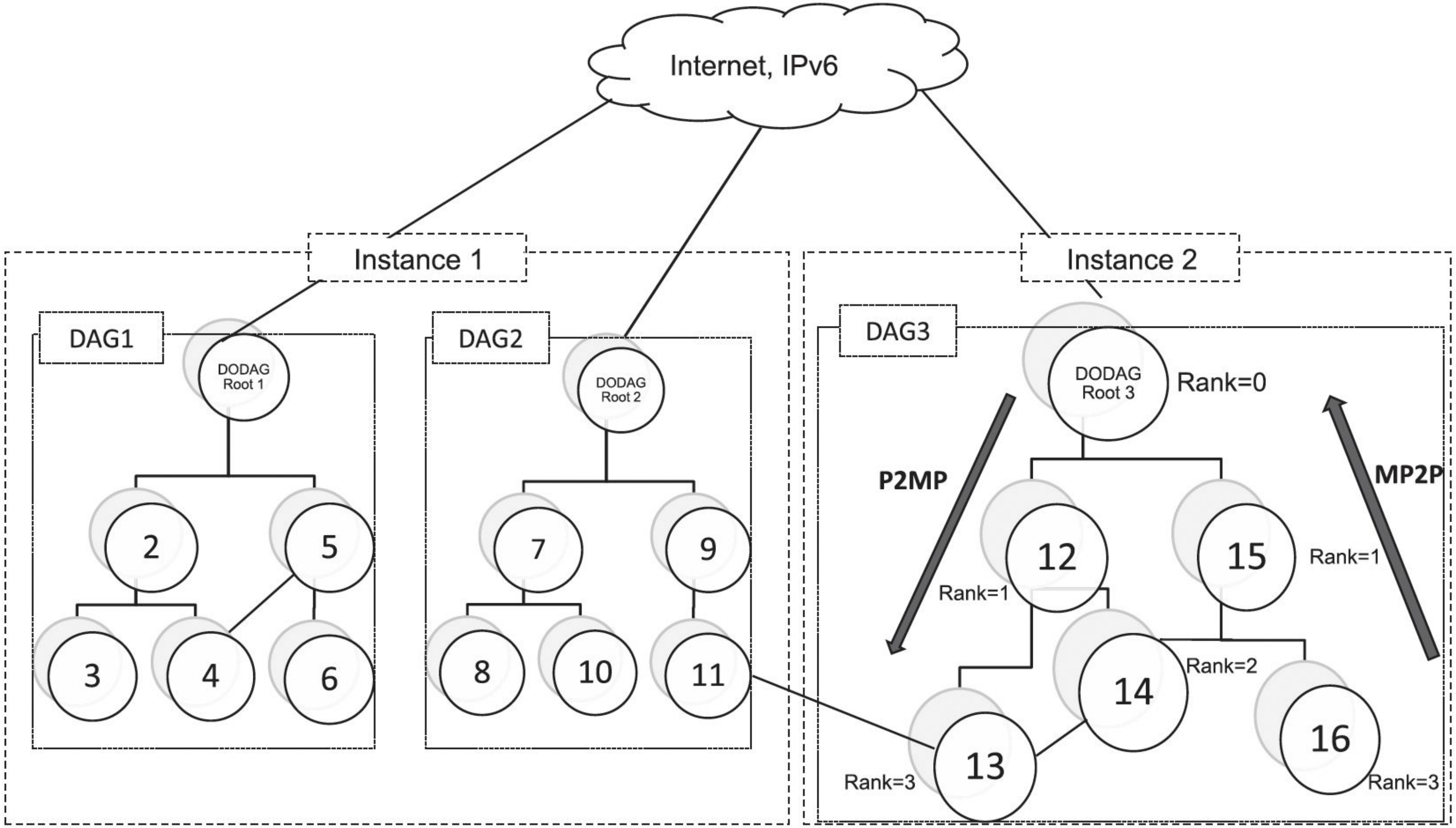


Fig. 1. A RPL network with three DODAGs in two instances.

Image source: Gaddour, Olfa, and Anis Koubâa. "RPL in a nutshell: A survey." Computer Networks 56.14 (2012): 3163-3178.

Features

- Auto-configuration
    - Neighbor Discovery
- Self-healing
    - Choose more than one parent
- Loop avoidance & detection
- Independence from link layer protocols
- Multiple edge routers
    - Each DAG root is an edge router

Network Model

- 3 types of nodes:
  - LBR
    - create DAG
    - gateway / edge router
  - Router
    - route packets
    - generate data packets
    - attach to DAG
  - Host
    - generate data packets

Network Model

- DODAG root
  - LBR, sink, gateway, final destination in DODAG
  - ability to create a DODAG
- Rank
  - integer value
  - position relative to other nodes
  - increases in downstream direction
  - used to detect and avoid loops
- Node can be associated with parent or sibling
  - List of potential parents and siblings in case the current parent fails

DODAG Construction

- Creating a DODAG is based on 2 operations:
  - broadcast DIO control messages
    - sent initially by the root
    - build routes in downward direction
  - unicast DAO control messages
    - generated by nodes
    - build routes in upward direction

DODAG Construction

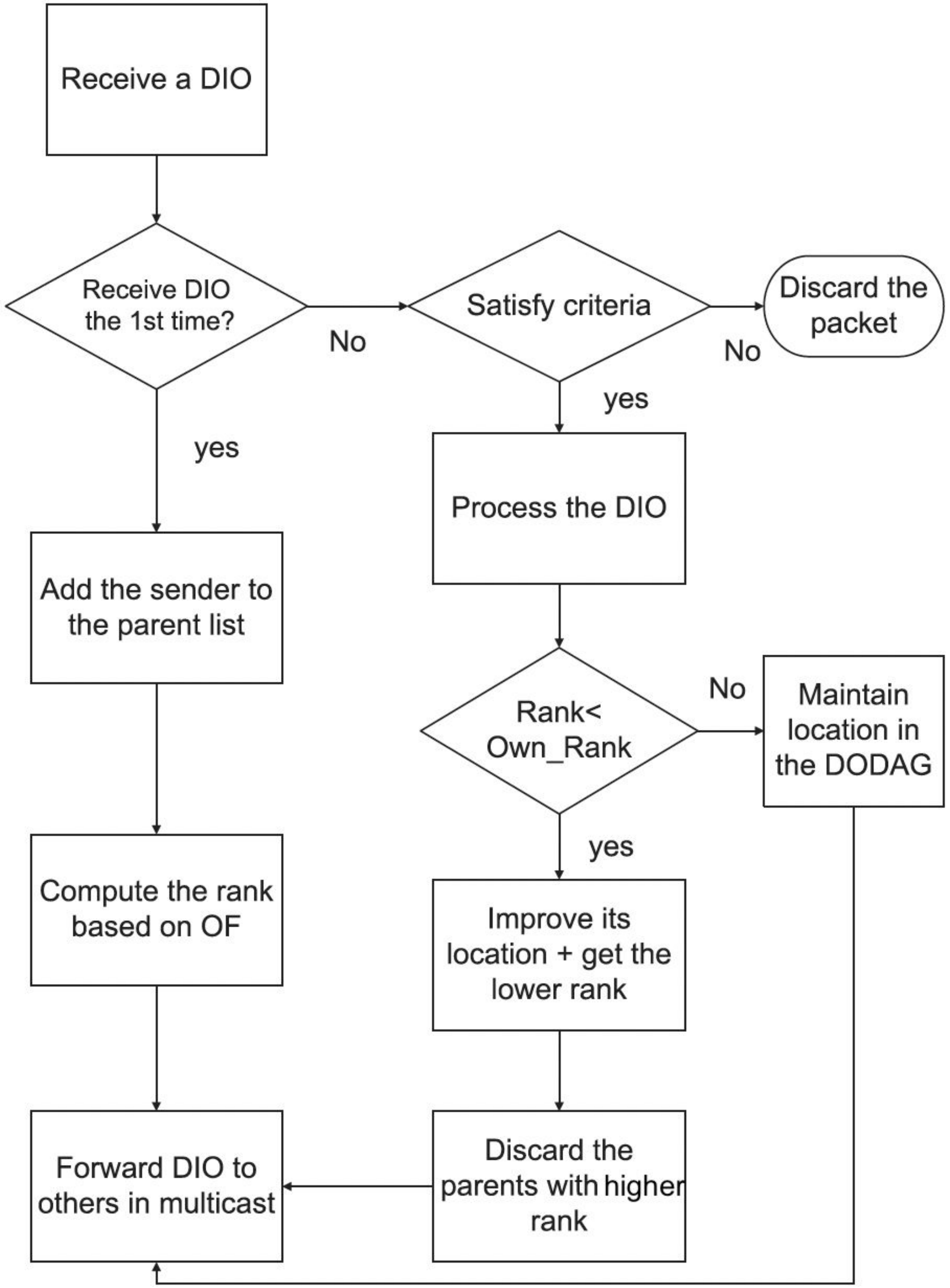
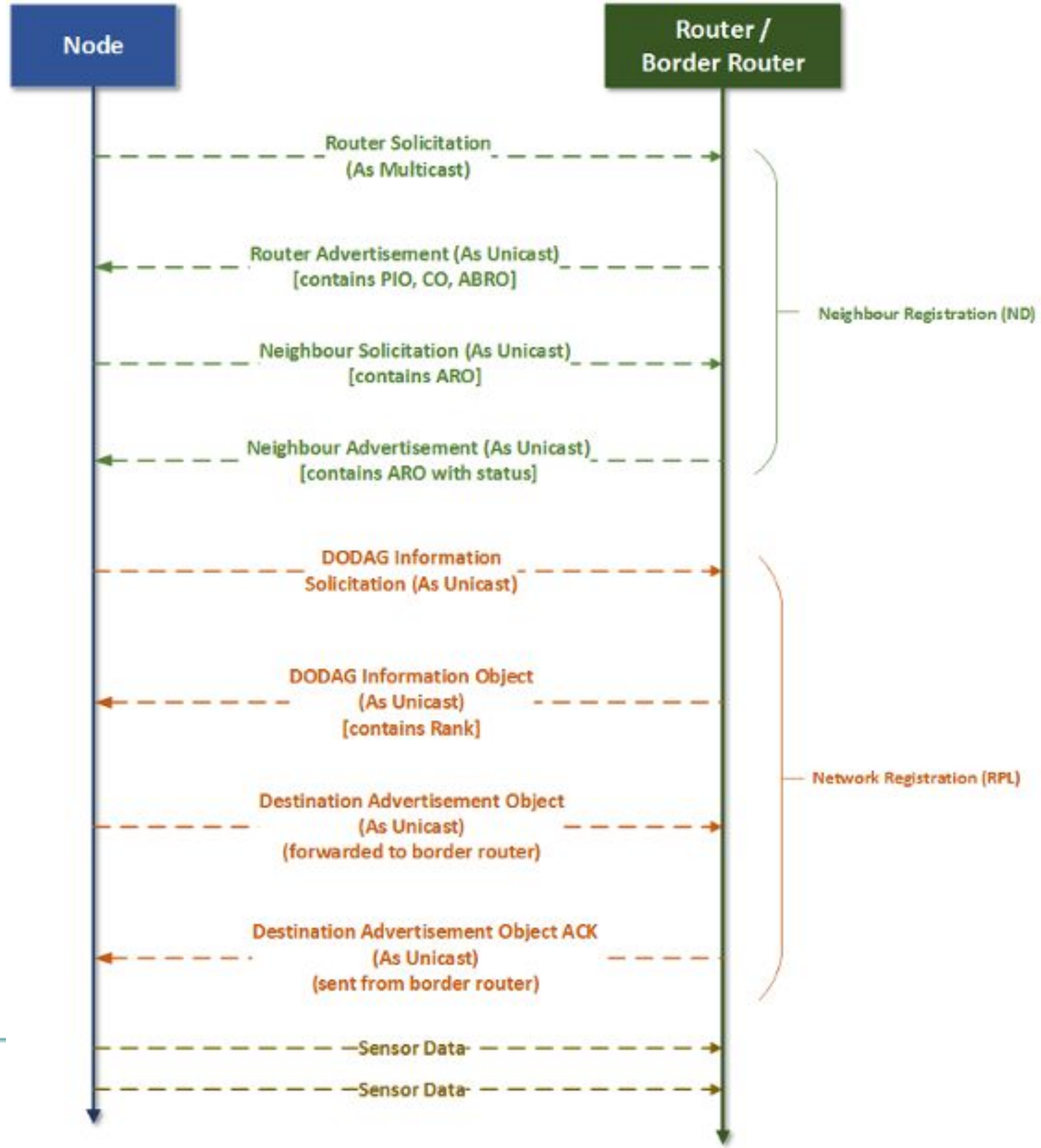


Fig. 5. The operation of a router in a DODAG.

Image source: Gaddour, Olfa, and Anis Koubâa. "RPL in a nutshell: A survey." Computer Networks 56.14 (2012): 3163-3178.

Modes of Operation

- DIO messages contain a mode of operation flag
- different than zero
  - each node sends a DAO to parent
  - each parent adds its address and forwards DAO to its parent
  - until it reaches the root => full route between the root and each node
- Storing mode:
  - Parents aggregate DAO messages from all children then forwards to parent
  - Maintains a routing table
- Non-storing mode:
  - Parents add their addresses and forward DAO without storing the message
  - Only the root maintains a routing table
  - Source routing



Complete Flow

Source: https://ez.analog.com/wireless-sensor-networks-reference-library/ad6lowpan/w/documents/15030/how-does-a-6lowpan-device-register-to-network

Bibliography

- RFC 4944: https://datatracker.ietf.org/doc/html/rfc4944
- RFC 6282: https://datatracker.ietf.org/doc/html/rfc6282
- RFC 6775: https://datatracker.ietf.org/doc/html/rfc6775
- Olsson, Jonas. "6LoWPAN demystified." Texas Instruments 13 (2014).
- RFC 6550: https://datatracker.ietf.org/doc/html/rfc6550
- Gaddour, Olfa, and Anis Koubâa. "RPL in a nutshell: A survey." Computer Networks 56.14 (2012): 3163-3178.
- https://ez.analog.com/wireless-sensor-networks-reference-library/ad6lowpan/w/documents/15030/how-does-a-6lowpan-device-register-to-network

Keywords

- IPv6
- 6LoWPAN
- Header compression
- Fragmentation
- Routing
- RPL
- Neighbor discovery
- Auto-configuration
- Security