Routing Protocol for LLNs (RPL)

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Agenda

- Introduction
- Network Stack
- Directory Structure
- Cooja Simulator
- Hands On Excersice

Introduction

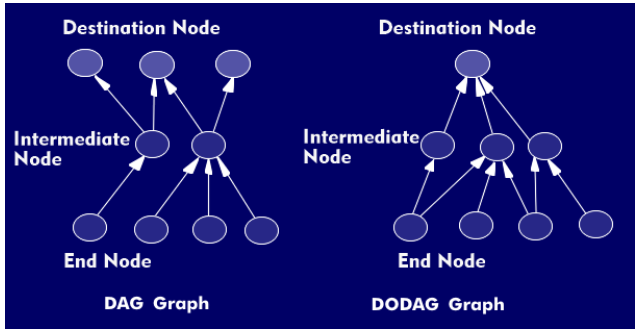
- Distance Vector IPv6 routing protocol for LLNs
- It constructs a Directed Acyclic Graph (DAG) to minimize path costs
- It defines a new IPv6 option to be added just after the main header called RPL Option
- RPL option adds routing information with each datagram that a router forwards

Features

- To bind the subnet together with a common prefix and to route within that subnet
- RPL uses IPv6 Neighbour Discovery (ND), Prefix Information Option and Route Information Option
- RPL node often combines Host and Router behaviors
  - As a host it will process Route information options
  - As a router, it may advertise the information in ND Router Advertisement (RA) message

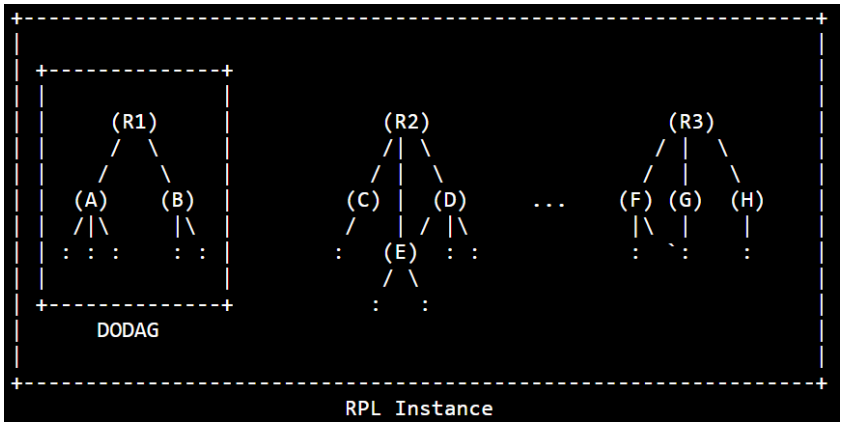
Terminology

- Directed Acyclic Graph – A path-oriented connection of edges/nodes in such a way that no cycles exists. Each node has a direction Forward or Backward
- DAG root – A DAG root is a node within DAG with not outgoing edge i.e. sink of DAG; at least one root must be there
- Destination Oriented DAG: single root DAGs
- DODAG root – root of DAG of DODAG



Terminology

- Rank – Position relative to other nodes with respect to DODAG root. Increases in Down direction and decreases in Up direction
- Objective Function (OF) – Compute the ranks in DODAG
- RPL Instance – It is a set of one or more DODAGs
- DODAGID- identifier of DODAG root. It is unique within RPL instance

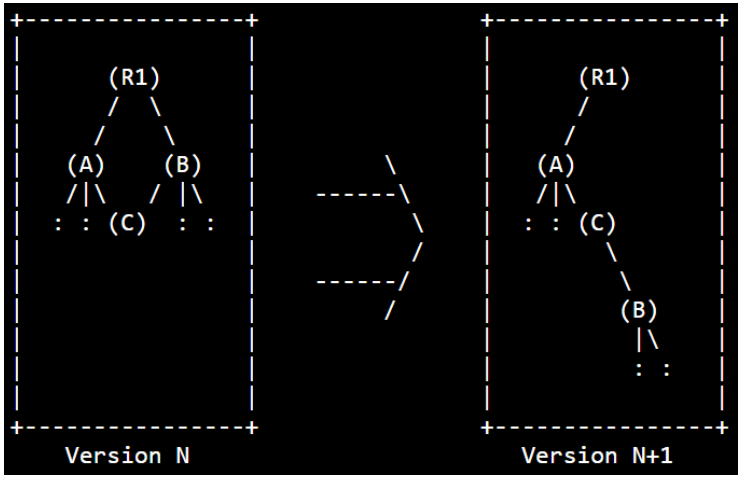


Terminology

- DODAG Information Object (DIO)
  - The DODAG Information Object carries information that allows a node to discover a RPL Instance, learn its configuration parameters, select a DODAG parent and maintain DODAG
- Destination Advertisement Object (DAO)
  - The Destination Advertisement Object (DAO) is used to propagate destination information Upward along the DODAG
- DODAG Information Solicitation (DIS)
  - The DODAG Information Solicitation (DIS) message may be used to solicit a DODAG Information Object from a RPL node
  - A node may use DIS to probe its neighborhood for nearby DODAGs

RPL identifiers

- Its uses four values to identify and maintain a topology
  - RPLInstanceId
  - DODAGID
  - DODAGVersionNumber
  - Rank



Ranks

- A parent of a node within a DODAG is one of the immediate successors of the node on a path towards the DODAG root
- A DODAG parent's Rank is lower than the node's

Rank Comparison

- It is thought of fixed point number
- MinHopRankIncrease is the minimum increase in Rank between a node and any of its DODAG parents
- It creates a trade-off between hop cost precision and maximum number of hops a network can support
- A large value allows precise characterization of a given hop’s effect on Rank but not many supported
- Uses function like – DAGRank(rank) = floor(rank/MinHopRankIncrease)

Rank Relationships

- DAGRank(M) is less than DAGRank(N)
- DAGRank(M) is equal to DAGRank(N)
- DAGRank(M) is greater than DAGRank(N)

RPL Security

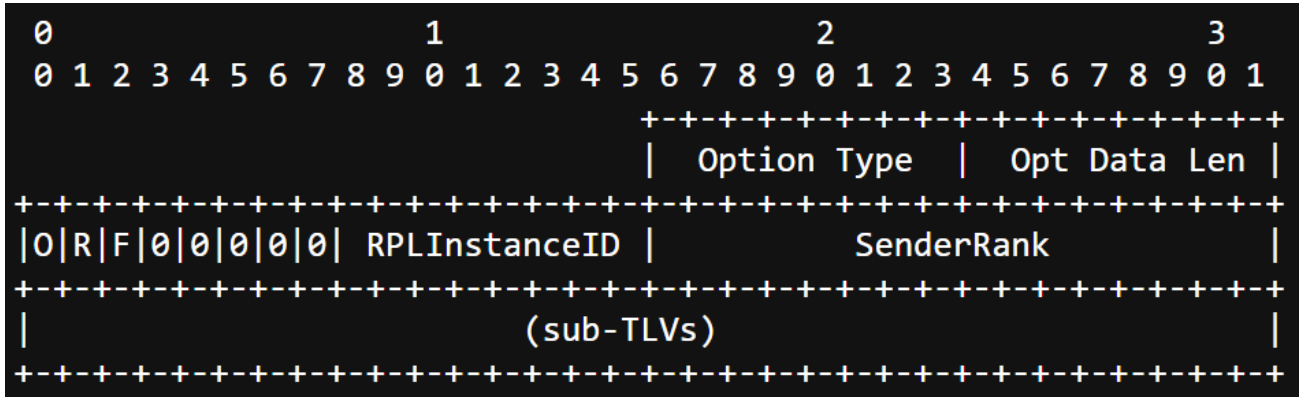
- Unsecure Mode
  - Messages sent without additional mechanism but Link Layer has option to use security
- Preinstalled Mode
  - Nodes joining RPL instance has preinstalled keys to generate secure messages
- Authenticated Mode
  - An authenticated RPL instance allows other nodes to join using preinstalled keys as leaf node

Trickle Timers

- RPL uses a slow process to construct and maintain a routing topology
- If routing inconsistencies detected, then RPL temporarily increases beacon rate to quickly resolve that
- This dynamic rate control operation is governed by the use of dynamic timers called as “Trickle” (RFC 6206)

Format of RPL Option

- IPv6 Hop-By-Hop Options header immediately follows RPL Option



RPL Option

- Option Type
  - Define by IANA as 0x63
- Opt Data Len
  - The length of option header
- Down
  - 1-bit flag indicating whether the packet is expected to progress Up or Down. A router sets the 'O' flag when the packet is expected to progress Down (using DAO routes), and clears it when forwarding toward the DODAG root
- Rank Error
  - A Rank error is detected when there is a mismatch in the relative Ranks and the direction as indicated in the 'O' bit.

RPL Option

- Forwarding Error
  - indicating that this node cannot forward the packet further towards the destination.
- RPL Instance ID
  - 8-bit field indicating the DODAG instance along which the packet is sent
- Sender Rank
  - 16-bit field set to zero by the source and to DAGRank(rank) by a router that forwards inside the RPL network

Router Behaviour

- Router must use IPv6-in-IPv6 tunneling to send data frames
- Tunneling ensures delivered datagram remains unchanged and errors are sent back to the source
- Tunnel Exit points is the RPL router for which the original packet is destined to
- Single Tunnels
- Multiple Tunnels

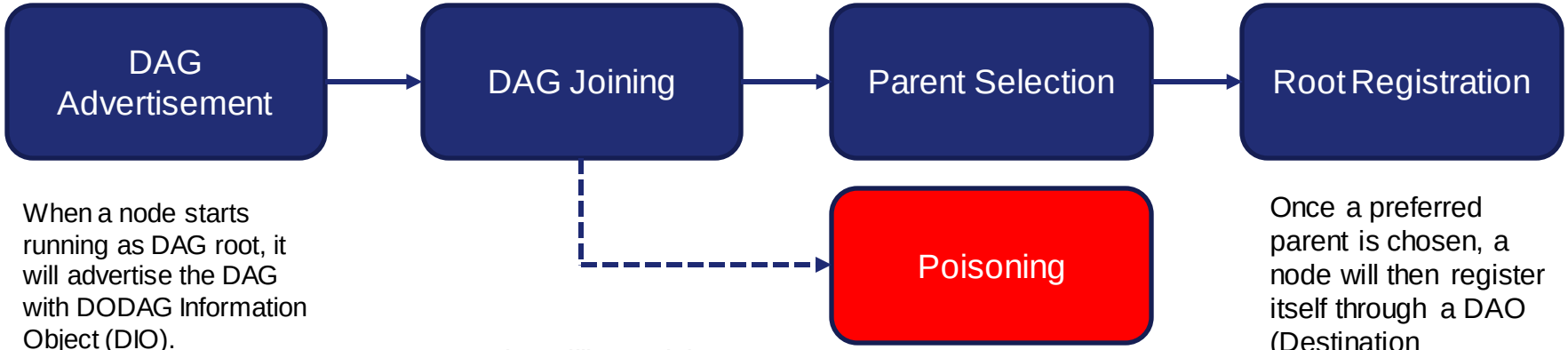
Security Aspects

- DAG Inconsistency Attacks
  - Using Down and SenderRank field, an attacker can trick routers to start Trickle timer more often
- Destination Advertisement Object (DAO) Inconsistency Attacks
  - In Storing mode, RPL routers maintain Downward routing state, which is cleaned by Forwarding-Error flag
  - To avoid use MAX_RPL_OPTION_FORWARD_ERRORS to discard state per hour. Recommended value 20
  - In Non-storing mode, only LBR maintains Downward routing state, so no Option-involved

Modes of Operation (MOP)

- The different modes of operation refer to the different ways downward routing is done
- Storing Mode
  - For storing mode, routing tables are stored on each node, which can impose a significant memory footprint in large networks and be hard to maintain consistently
- Non-Storing Mode
  - For non-storing mode, IPv6 source routing is employed, which means that nodes do not have to store routing tables for nodes below them in the DODAG

Topology Formation



When a node starts running as DAG root, it will advertise the DAG with DODAG Information Object (DIO).

DIO transmissions follow a Trickle timer

Nodes willing to join a network will transmit periodic DIS (DODAG Information Solicitation) to trigger Trickle reset at neighboring nodes, and increase their chances to hear a DIO

After enough probing, the node will select a neighbor as preferred parent. This is according to the selected Objective Function and metric.

When a node finds no more suitable preferred parent, it will start poisoning, i.e., advertise an infinite rank to let its sub-DAG know it no longer is a valid parent.

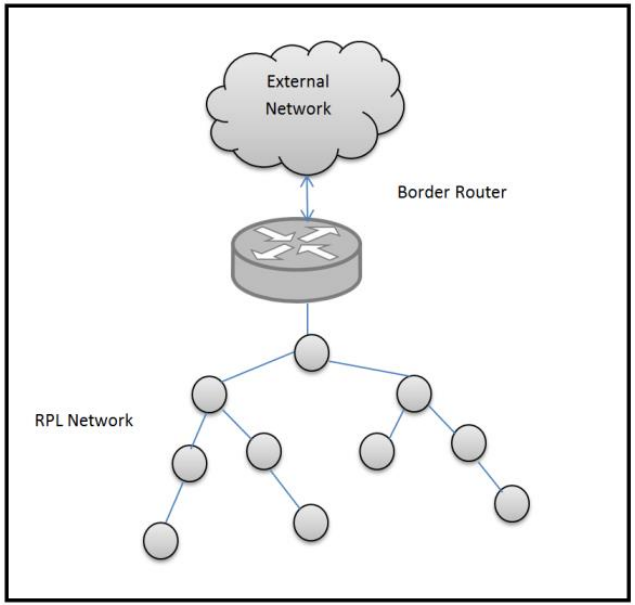
It will then leave the network after a delay

Once a preferred parent is chosen, a node will then register itself through a DAO (Destination Advertisement Object)

DAO-ACK confirms

RPL Border Router

- Border routers are routers that can be found at the edge of a network. Their function is to connect one network to another



Thank You