نزدهمین نشست تخصصی همگرایی اینترنت اشیاء ، داده ها حجیم و رایانش ابری

گروه آموزشی و پژوهشی سیب

Routing in Internet Of Things

M. Ali Azimi

     Cisco Systems EDCS-975929

Agenda

- Smart Objects

- Low Power Lossy Networks (LLN)

- 802.15.4 Low Power PAN

- Using IP for Smart Objects

- 6LoWPAN Working Group

- Roll Working Group

- Routing over Low Power Lossy Networks (RPL)

- Conclusion

Standardise to Build The Internet of Things

- Next iteration of the Internet

  Standardise IP into sensors and other smart objects

  Any object or environmental condition can be monitored

  Expand the current Internet to virtually anything and everything

- Internet of Things (IoT)

  Pervasive and ubiquitous network which enables monitoring and control of physical environment by collecting, processing, and analyzing the data generated by Smart-Objects

Smart Objects

What is a Smart Object?

- A tiny and low cost computer that may contain:

    A sensor that can measure physical data (e.g., temperature, vibration, pollution)

    An actuator capable of performing a task (e.g., change traffic lights, rotate a mirror)

    A communication device to receive instructions , send data or possibly route information

- This device is embedded into objects (to make them smart ☺)

    For example, thermometers, car engines, light switches, gas meters

- Smart Objects enable many sophisticated applications and solutions

    Smart+Connected Communities

    Smart Grid and Energy Management

    Home and Building Automation

    Connected Health

- Smart Objects can be organised into networks

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Characteristics of Smart Objects

- These devices are highly constrained in terms of
    - Physical size
    - CPU power
    - Memory (few tens of kilobytes)
    - Bandwidth (Maximum of 250 KB/s, lower rates the norm)

- Power consumption is critical
    - If battery powered then energy efficiency is paramount
    - Batteries might have to last for years

- May operate in harsh environments
    - Challenging physical environment (heat, dust, moisture, interference)

- Wireless capabilities based on Low Power & Lossy Network (LLNs) tech
    - Predominantly IEEE 802.15.4 (2.4 GHz *and* 900 MHz)
    - Newer RF technologies IEEE 802.15.4g (Smart Utility Network PHY)

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Power Lossy Networks
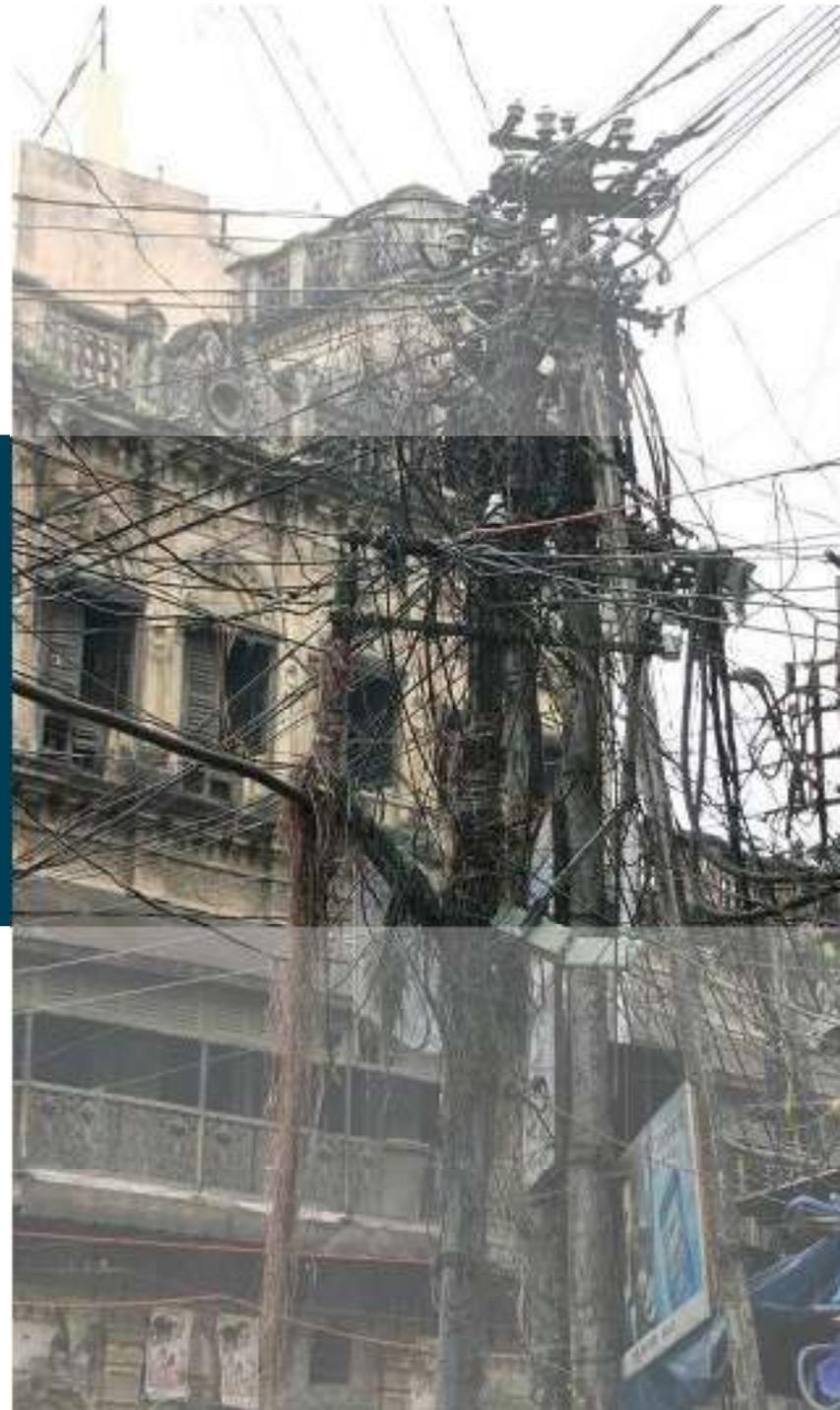
What is a Low Power Lossy Network (LLN)?

- LLNs comprise a large number of highly constrained devices (smart objects) interconnected by predominantly wireless links of unpredictable quality

- LLNs cover a wide scope of applications

  Industrial Monitoring, Building Automation, Connected Home, Healthcare, Environmental Monitoring, Urban Sensor Networks, Energy Management, Asset Tracking, Refrigeration

- Several IETF working groups and Industry Alliance addressing LLNs

  IETF - CoRE, 6Lowpan, ROLL

  Alliances - IP for Smart Objects Alliance (IPSO)

World's smallest web se

IETF LLN Related Workgroups

F
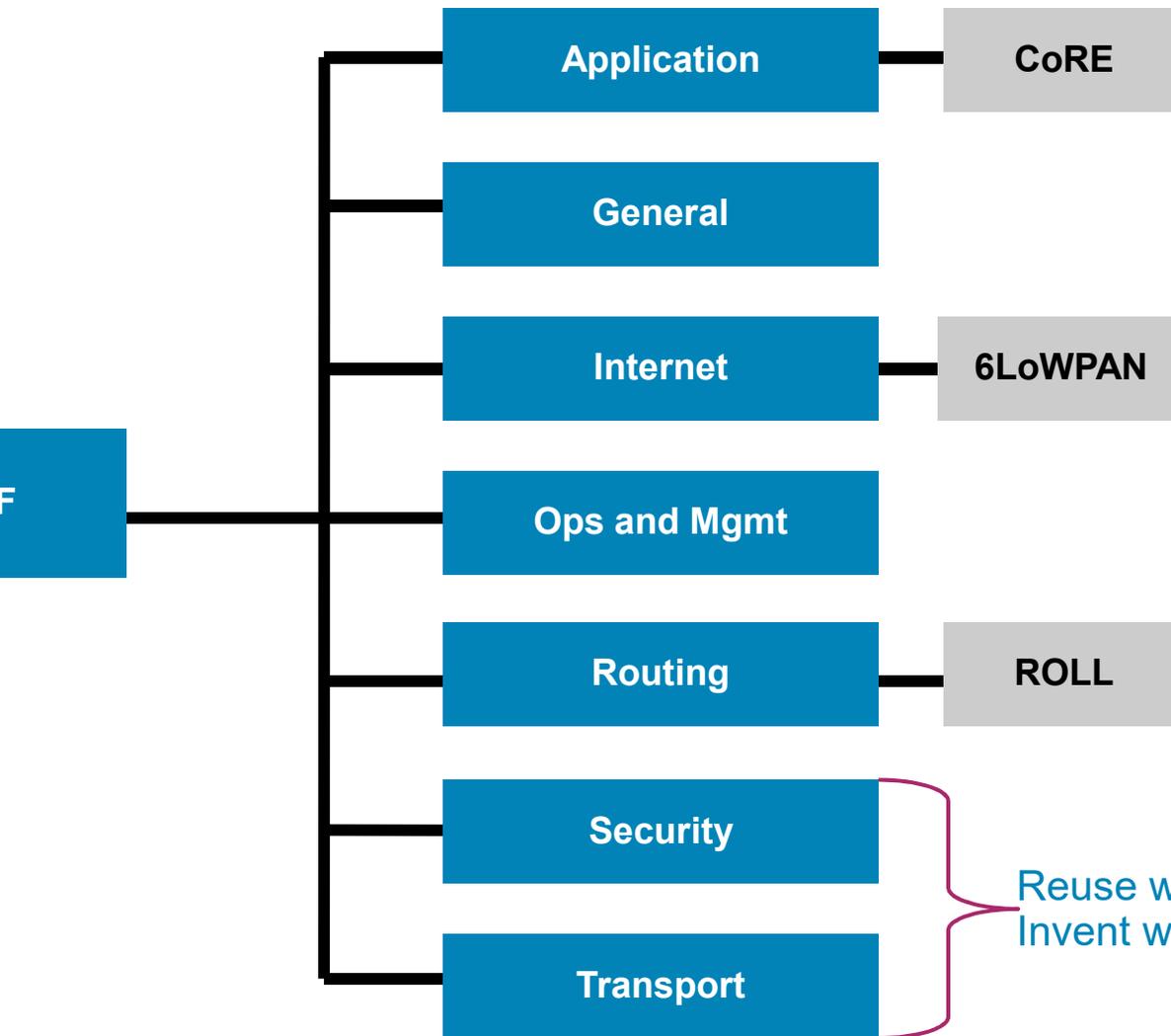
Application — **CoRE**

Constrained Restful Environments
Charter to provide a framework for resource-oriente
applications intended to run on constrained IP netw

General

Internet — **6LoWPAN**

IPv6 over Low power WPAN
Charter is to develop protocols to support IPv6 run
IEEE 802.15.4 low-power radio networks.

Ops and Mgmt

Routing — **ROLL**

Routing over Low Power Lossy Netw
Charter focusses on routing issues for low powe
networks.

Security

Transport

Reuse work done here where possible
Invent where needed

IEEE 802.15.4 PAN

IEEE Wireless Standards

802.11 – Wireless Local Area Networks (WiFi)

    802.11a, 802.11b, 80211g, 802.11n

802.15 – Wireless Personal Access Networks (WPAN)

Task Group 1	– Bluetooth (802.15.1)
Task Group 2	– Co-existence (802.15.2)
Task Group 3	– High Rate WPAN (802.15.3)
Task Group 4	– Low Rate WPAN (802.15.4 or 802.15 TG4)　— Used in LLNs
Task Group 5	– Mesh Networking (802.15.5)

802.16 – Wireless Metropolitan Area Networks (WiMax)

802.20 – Mobile Broadband Wireless Access (Mobile-Fi) - Defunct

802.22 – Wireless Regional Access Network (WRAN)

    Utilise free space in the allocated TV spectrum

IEEE 802.15.4 Features

Designed for low bandwidth, low transmit power, small frame size

- More limited than other WPAN technologies such as Bluetooth
- Low bit rate and packet size to ensure reasonably low packet error rates
- Packet size (127 bytes) reflects minimal buffering capabilities in Smart Objects
- Low power allows batteries to last for years

Data rates of 250 kbps, 40 kbps, and 20 kbps

Two addressing modes; 16-bit short (local allocation) and 64-bit IEEE (global allocation)

Communicates over multiple hops

- Range is in tens of metres, reduces transmission power

3 possible unlicensed frequency bands

- (Europe 868-868.8 MHz – 3 chans , USA 902-928 MHz – 30 chans, World 2400-2483.5 MHz – 16 chans)
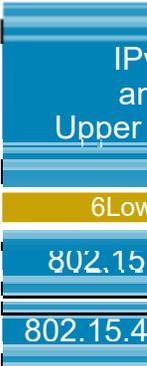
802.15.4 uses CSMA-CA

- Carrier Sense Multiple Access with Collision Avoidance

- Wireless networks cannot detect collisions

    Fundamental difference from wired networks

- Wired – CSMA/CD – Collision Detection

- Wireless – CSMA/CA – Collision Avoidance

    RX/TX antennas immediately next to each other

    Hence RX can only see its own TX when transmitting

6LoWPAN Working Group
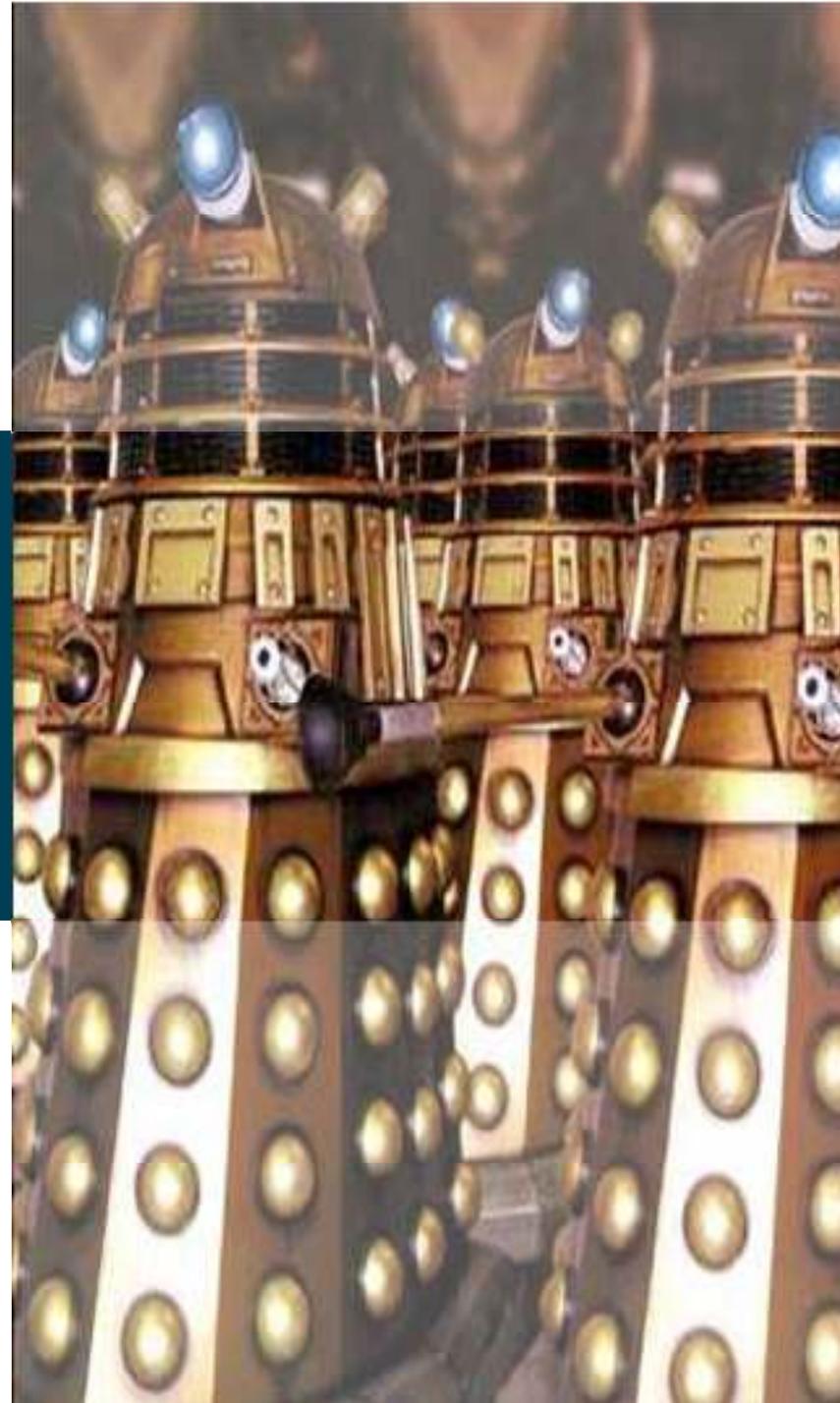
What is 6LoWPAN ?

- IPv6 over Low power Wireless Personal Area Networks
  - An adaptation layer for IPv6 over IEEE 802.15.4 links

- Why do we need an adaption layer?
  - IEEE 802.15.4 MTU is only 127 bytes, IPv6 minimum MTU is 1280 bytes
  - IPv6 does not do fragmentation, left to end nodes or lower layers

- Performs 3 functions each with its own 6LoWPAN header
  - IPv6 Header compression
  - IPv6 packet fragmentation and re-assembly
  - Layer 2 forwarding (also referred to as mesh under)

- RFC4919 defines the Problem Statement

- RFC4944 defines Transmission of IPv6 Packets over IEEE 802.15.4
  - Improved header compression being worked on may deprecate RFC4944

smart object networks go
better
with
IPv6 & IEEE 802.

Basic IPv6 Header

1 Nibble	1 Byte	5 Bytes	4 Bytes	2 Bytes	2 Bytes
Version	Traffic Class	Flow Label	Payload Length	Next Header	Hop Limit

Source Address

Destination Address

Minimum size is 40 bytes (double that of IPv4)

Can be extended by additional headers

Fragmentation must be performed by end nodes

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Typical 6LoWPAN Header Stacks

6LoWPAN headers included only when needed

IPv6 compression header

Fragmentation header (eliminated if single datagram can fit entire IPv6 payload)

Mesh or Layer 2 forwarding header (currently not used/implemented)

127 bytes	Max MTU for 802.15.4
102 bytes	Less max 25 bytes for frame overhead
81 bytes	Less max 21 bytes link layer security

Worst case leaves only 81 bytes for headers and payload

				IPv6 Fragmentation	Multiple L2
4 Header	IPv6 Header Compression	IPv6 Payload		No	No
4 Header	Fragment Header	IPv6 Header Compression	IPv6 Payload	Yes	No
4 Header	Mesh Header	Fragment Header	IPv6 Header Compression / IPv6 Payload	Yes	Yes (Fu
4 Header	Mesh Header	IPv6 Header Compression	IPv6 Payload	No	Yes (Fu

ROLL Working Group

What is ROLL?

- Routing Over Low power and Lossy networks (2008)

  http://www.ietf.org/html.charters/roll-charter.html

  Co-chairs: JP Vasseur (Cisco), David Culler (Arch Rock)

- Mission: To define routing solutions for LLNs

- Application specific LLN routing requirements developed

  Industrial (RFC5673)

  Urban (RFC5548),

  Home Automation (RFC5826)

  Building Automation (RFC5867)

- Specifying the routing protocol for smart object networks

  Routing Protocol for LLNs (RPL) adopted as WG document

Where Should Routing Take Place ?

- Historically, a number of interesting research initiatives on WSN

  Work on Wireless Sensors Network focussed on algorithms … not architecture

- Most work assumed the use of MAC addresses

  Layer 2 "routing" (mesh-under)

- Support of multiple PHY/MAC is a MUST

  IEEE 802.15.4, Low Power Wifi, Power Line Communications (PLC)

- Use IP to route

  Supports multiple PHY/MAC

  Moves from mesh-under (L2) to router-over(L3)

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Characteristics for Smart Object Routing

Current Internet	Smart Object Networks
Nodes are routers	Nodes are sensor/actuators and routers
IGP with typically few hundreds of 100 nodes	An order of magnitude larger in nodes
Links and Nodes are stable	Links are highly unstable Nodes fail more frequently
Node and link bandwidth constraints are generally non-issues	Nodes & links are high constrained
Routing is not application aware	Application-aware routing

Technical Challenges

- Energy consumption is a major issue

(battery powered sensors/actuators)

- Limited processing power

- Very dynamic topologies

  Link failure (LP RF)

  Node failures (triggered or non triggered)

  Node mobility (in some environments),

- Data processing usually required on the node itself

- Sometimes deployed in harsh environments (e.g. Industrial)

- Potentially deployed at very large scale

- Must be self-managed (auto-discovery, self-organizing networks)
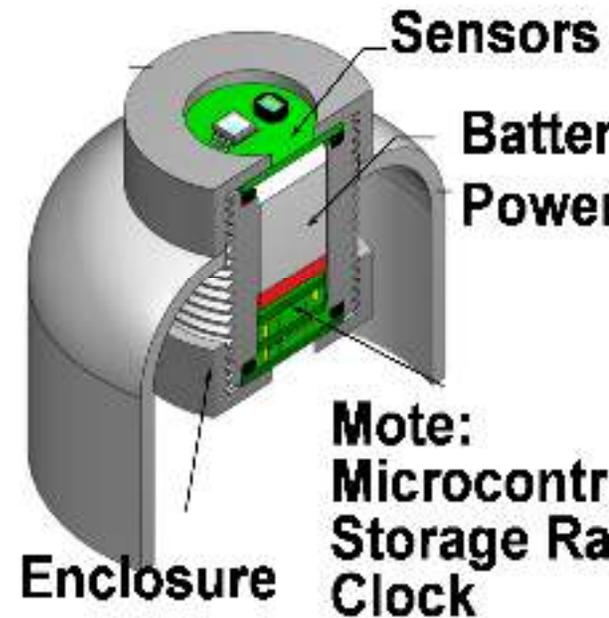
Current Routing Protocols

- The current IGPs (OSPF, ISIS) rely upon static link metrics
  - Used to create best/shortest path to destination
  - No account taken of node/router status (high CPU, hardware failures)

- Not suitable for the dynamic nature of an LLN with many variables
  - Wireless Signal Strength and Quality
  - Node resources such as residual energy
  - Link throughput and reliability

- IGP needs the ability to consider different metric/constraint categories
  - Node vs Links
  - Qualitative vs Quantitative
  - Dynamic vs Static

ing over low Power Lossy networks (RPL)
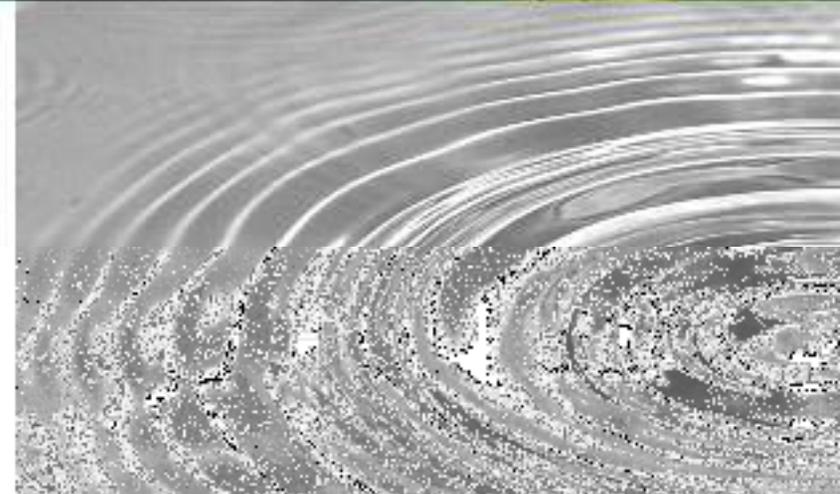
RPL - Routing Protocol for LLNs

- RPL is an extensible proactive IPv6 distance vector protocol

  Builds a Destination Oriented Directed Acyclic Graph (DODAG)

  RPL supports shortest-path constraint based routing applied to both links and nodes

  Supports MP2P, P2MP and P2P between devices (leaves) and a root (border router

- RPL specifically designed for "Lossy" networks

  Should not be categorised as a WSN routing protocol

  Agnostic to underlying link layer technologies (802.15.4, PLC, Low Power Wireless)

- RPL supports different LLN application requirements

  RFC 5548 (Urban) RFC 5673 (Industrial) RFC 5826 (Home) RFC 5867 (Building)

- http://datatracker.ietf.org/doc/draft-ietf-roll-rpl/

  Currently on last call implementation 18 (Feb 2011)

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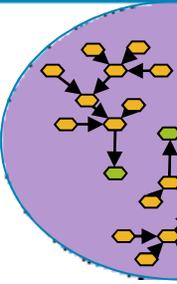# What is a Directed Acyclic Graph?

In the context of routing, a DAG is formed by a collection of vertices (nodes) and edges (links), each edge connecting one node to another (directed) in such a way that it is not possible to start at *Node X* and follow a directed path that cycles back to *Node X (acyclic)*.

A Destination Oriented DAG is a DAG that comprises a single root node.

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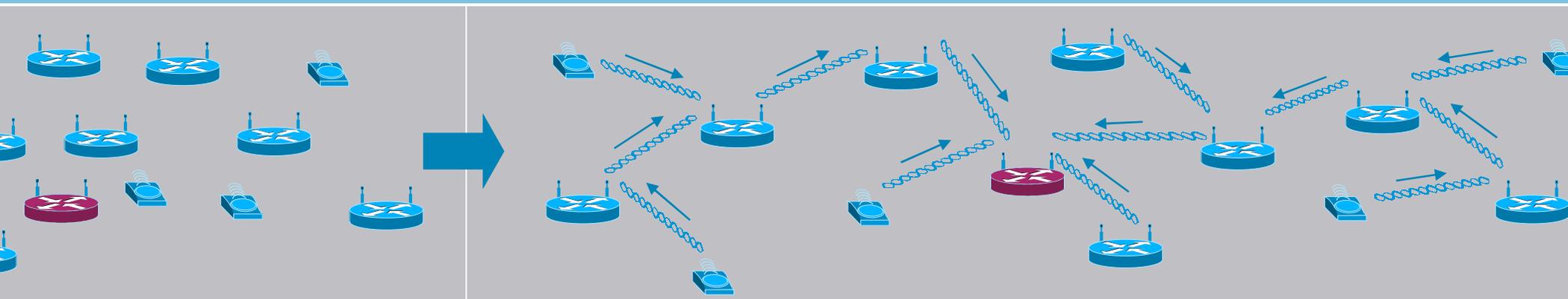
RPL Terminology

RPL Instance
Consists of one or more DODAGs sharing SAME service type (Objectiv...
Identified by RPL INSTANCE ID

Direction Oriented DAG (DODAG)
Comprises DAG with a single root

DODAG

Node
(OF configured)

DODAG

Siblings

Rank

Sub-DODAG

= n

Rank >

Rank decreases

UP (DAO Messages)

3

4

4

3

4

3

3

DODAG parent
to adjacent "4"s

Towards DODAG leafs

DOWN (DIO Messages)

2

2

2

1

1

1

1

< n

DODAG Root
Identified by DODAG ID

0

0

Rank

DODAG Root
(Typically an LBR - LLN Bord...

Non-LLN Network

(IPv6 Backbone)

RPL Instances

- RPL can form multiple instances

  Each instance honours a particular routing objective/constraint

  Instance consists one or more DODAGs derived from the *same* objective function

  Nodes select a parent (towards root) based on metric, OF and loop avoidance

- Allows upwards and downwards routing (from DODAG root)

- Trickle timers used to suppress redundant messages

  Saves on energy and bandwidth (Like OSPF exponential backoff)

- Under-react is the rule

  Local repair preferred versus global repair to cope with transient failures
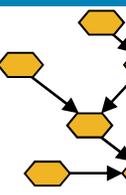
RPL DODAGs

- RPL enables nodes to discover each other and form DODAGs

  Uses special ICMPv6 control messages

- Each root uses a unique {DODAG ID} to identify itself within an RPL Instance

- Routing performed over the DODAG using distance vector techniques

- Every hop to the root MUST have an alternate path

  (Quite possible with Wireless/Radio Networks)

- A DODAG will ensure nodes always have a path up towards the root

- A DODAG is identified by {RPL Instance ID, DODAG ID}

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Objective Function (OF)

- An OF defines how nodes select paths towards DODAG root

    Dictates rules on how nodes satisfy a optimisation objective (e.g., minimise latency)

    Actual routing metrics and constraints carried ICMPv6 control messages

- A rank in the DODAG reflects its distance from the root

Rank =

Objective Function

Optimization Objective	Routing Metrics
•Energy Minimisation	•Link Metrics
•Latency	•Node Metrics
•Other Constraints	

Rank is higher as distance increases from DODAG root

- There is a single Objective Function per RPL Instance

    An instance can comprise one or more DODAGs (share same OF)

- http://datatracker.ietf.org/doc/draft-ietf-roll-of0/ (Basic OF specification)

ICMPv6 RPL Control Messages

- **DIO** - DODAG Information Object

  Used for DODAG discovery, formation and maintenance

- **DIS** - DODAG Information Solicitation Message

  Used to probe for DIO messages from RPL nodes

- **DAO** - DODAG Destination Advertisement Object

  Propagates prefix availability from leaves up the DODAG

  Supports P2MP and P2P traffic

- **DAO-ACK** - DODAG Destination Advertisement Object
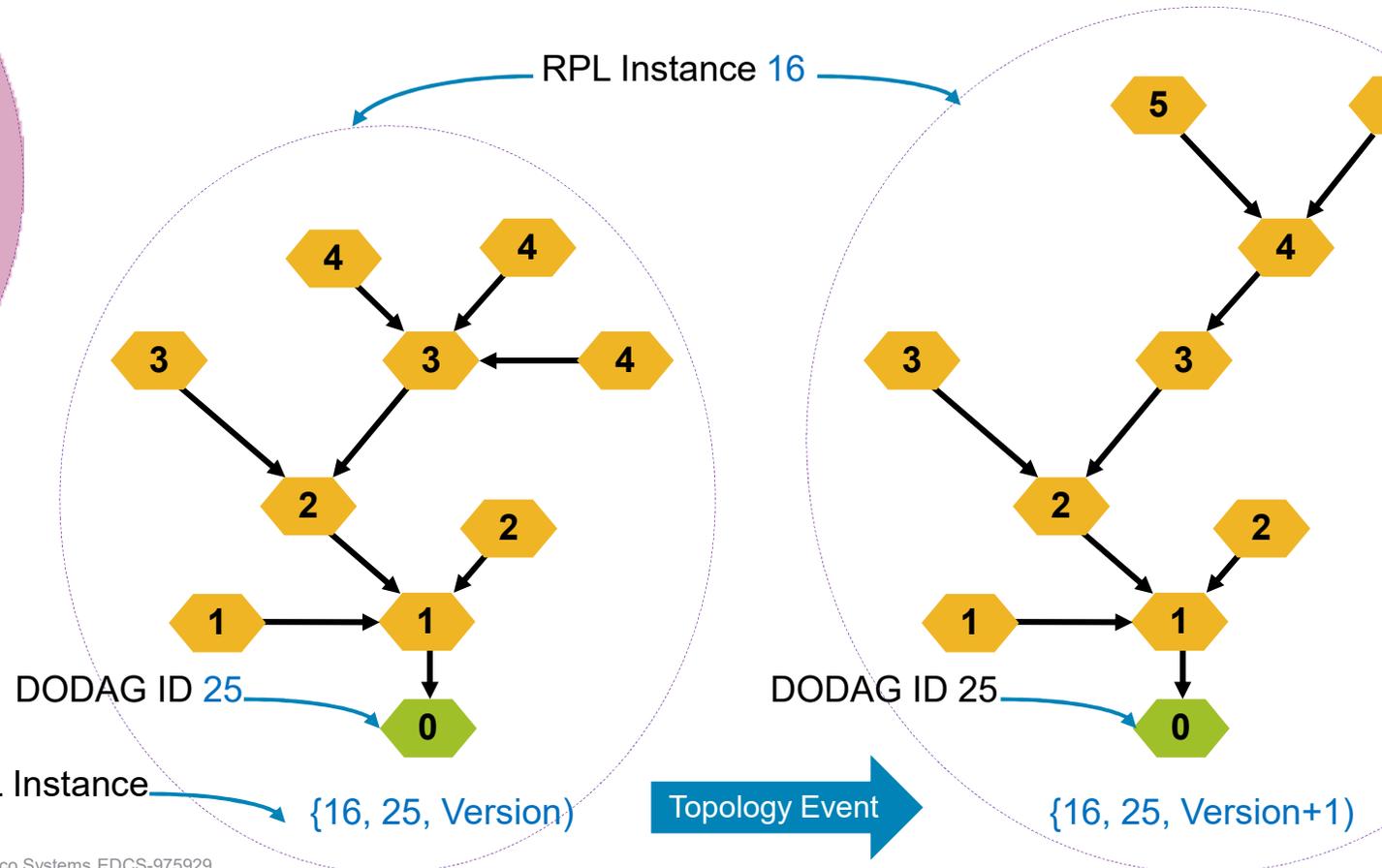
  Unicasted by a DAO recipient in response to a unicast DAO message
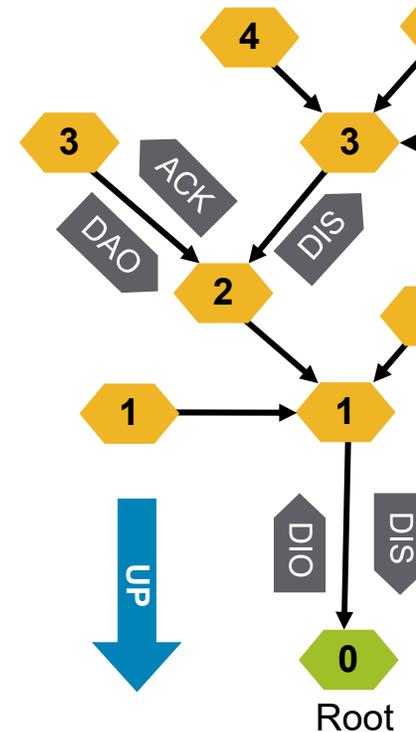
Link-local Destination	Link-local Source	RPL Control Payload
All-RPL-Nodes FF02::1A	Link-local Source	RPL Control Payload

Most RPL control messages have scope of a link

Global or Unique-Local	Global or Unique-Local	RPL Control Payload

DAO/DAO-ACK in non-storing mode passes over multiple hops
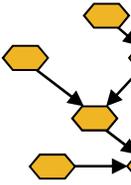
RPL Identifiers
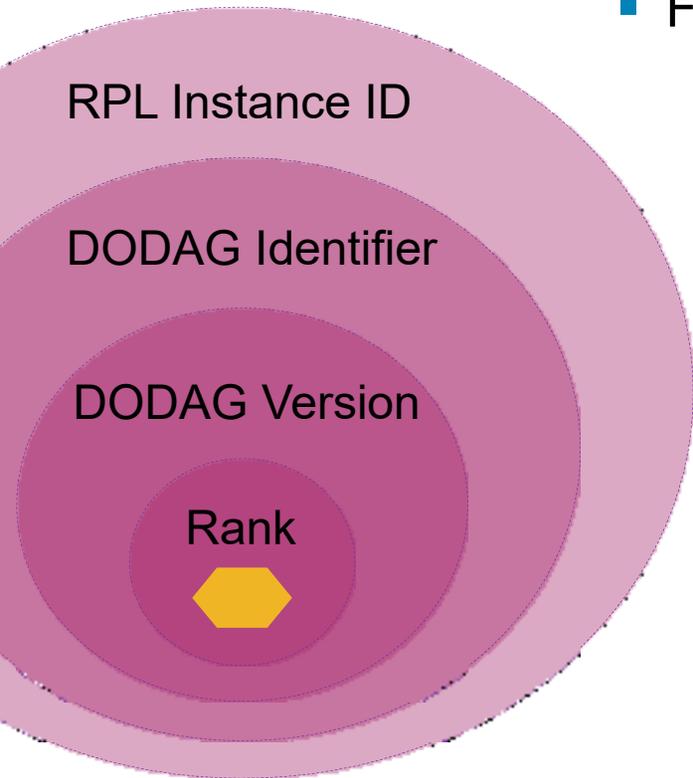
- Four values used to identify and maintain DODAG topology

  Nodes in a particular topology will belong to the same DODAG version

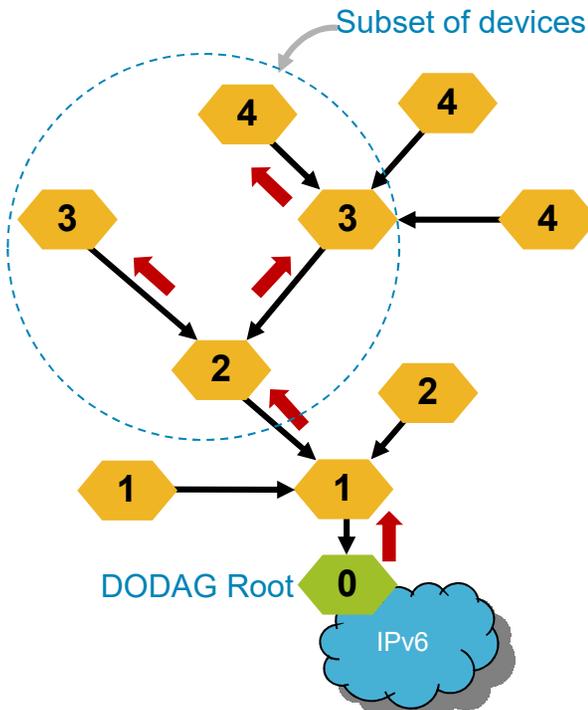 Rank within {RPL Instance ID, DODAG ID, DODAG Version} scope

RPL Instance ID

DODAG Identifier

DODAG Version

Rank

RPL Instance 16

DODAG ID 25

{16, 25, Version)

Topology Event

DODAG ID 25

{16, 25, Version+1}

...ifies unique DODAG topology within RPL Instance

RPL Supported Traffic Flows

point to Point
O messages
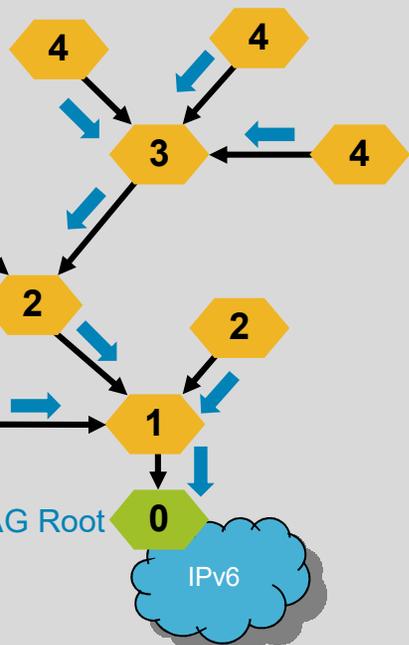
- **Point to Multipoint**
  DAO messages

  Subset of devices

- **Point to Point**
  Storing Mode, DAO
  Fully Stateful
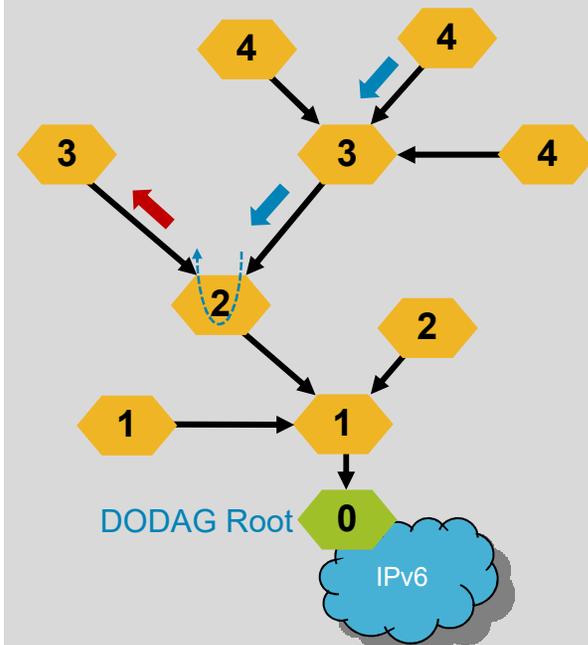
- **Point to Point**
  Non-Storing M
  Source routed

DODAG Root — 0 — IPv6
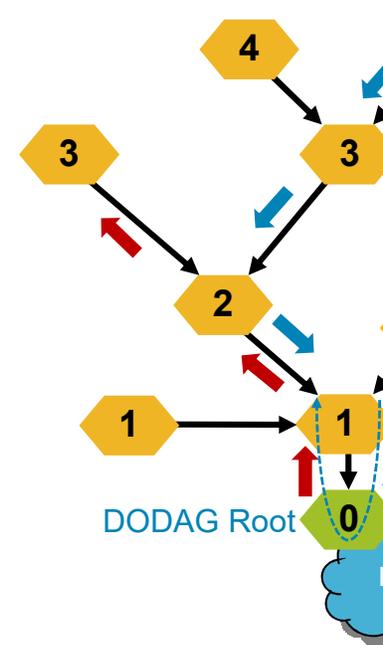
DODAG Neighbours and Parent Selection (Upward Routes)

Geographic Layout

Set of Candidate Neighbours

Set of Parents

Preferred P...

Logical sets of link-local nodes
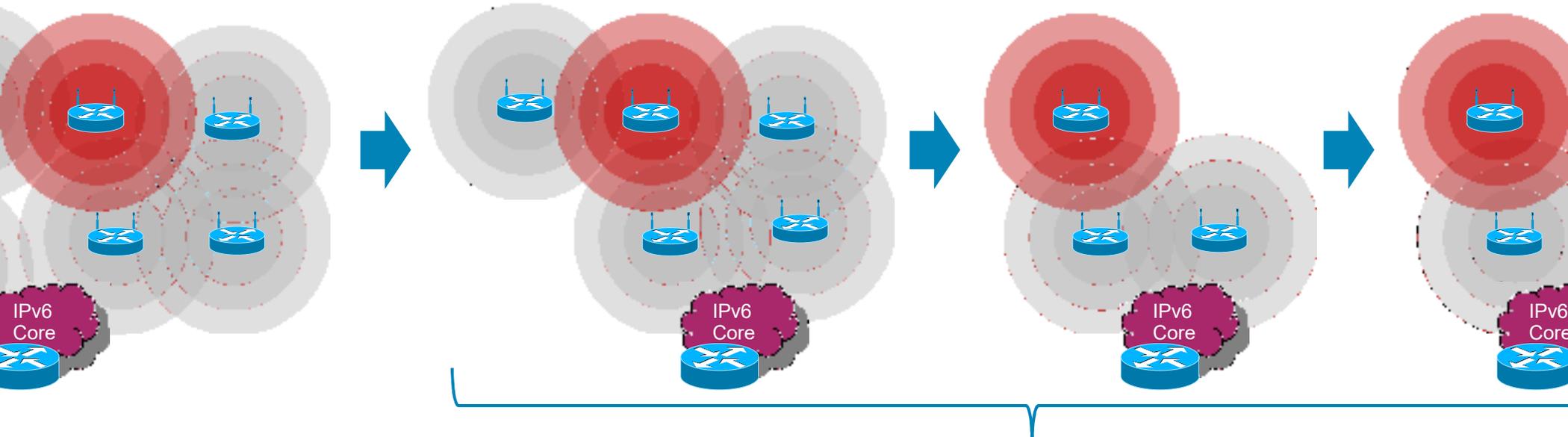
- **...rd route discovery**

  ...prises three logical sets ...k-local nodes

  ...hbours are learnt from ...advertisements

- **Candidate Neighbour Set**

  Subset of nodes reachable via link-local multicast

  Elements in the set may belong to different DODAG versions

- **Parent Set**

  Consists of nodes with a higher rank (lower #)

  Elements in the set must belong to SAME DODAG version

- **Preferred ...**

  Preferred ... the DODAG...

  Multiple pr... parents po... ranks are e...

Routing Metrics and Constraints in LLNs

- http://datatracker.ietf.org/doc/draft-ietf-roll-routing-metrics/
  - Specifies a set of link and node LLN routing metrics and constraints
- Constraints provide a path "filter" for more suitable nodes and links
- Metrics are the quantitative value used to evaluate the path cost
- Concept of routing objects that can be treated as a metric or a constraint
  - Low pass thresholds used to avoid unnecessarily recomputing DAG
- Computing dynamic metrics takes up power and can change rapidly
  - Solved by abstracting number of discrete values to a metric

| Link Quality Metric	
Value	Meaning
0	Unknown
1	High
2	Medium
3	Low

Tradeoff

Reduced accuracy vs overhead
and processing efficiency

Routing Metrics in LLNs

| Node Metrics	Link Metrics
tate and Attributes Object rpose is to reflects node workload (CPU, Memory…) flag signals overload of resource flag signal node can act as traffic aggregator	**Throughput Object** Currently available throughput (Bytes per second Throughput range supported
nergy Object flag: Node type: 0 = Mains, 1 = Battery, 2 = Scavenger bit: Use node type as a constraint (include/exclude) flag: Estimated energy remaining	**Latency** Can be used as a metric or constraint Constraint - max latency allowable on path Metric - additive metric updated along path
unt Object n be used as a metric or constraint nstraint - max number of hops that can be traversed tric - total number of hops traversed	**Link Reliability** Link Quality Level Reliability (LQL) 0=Unknown, 1=High, 2=Medium, 3=Low Expected Transmission Count (ETX) (Average number of TX to deliver a packet)
	Link Colour Metric or constraint, arbitrary admin value

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DODAG Example

Geographic Layout

DODAG Topology

LQL=3 (Poor)

LQL=2 (Fair)
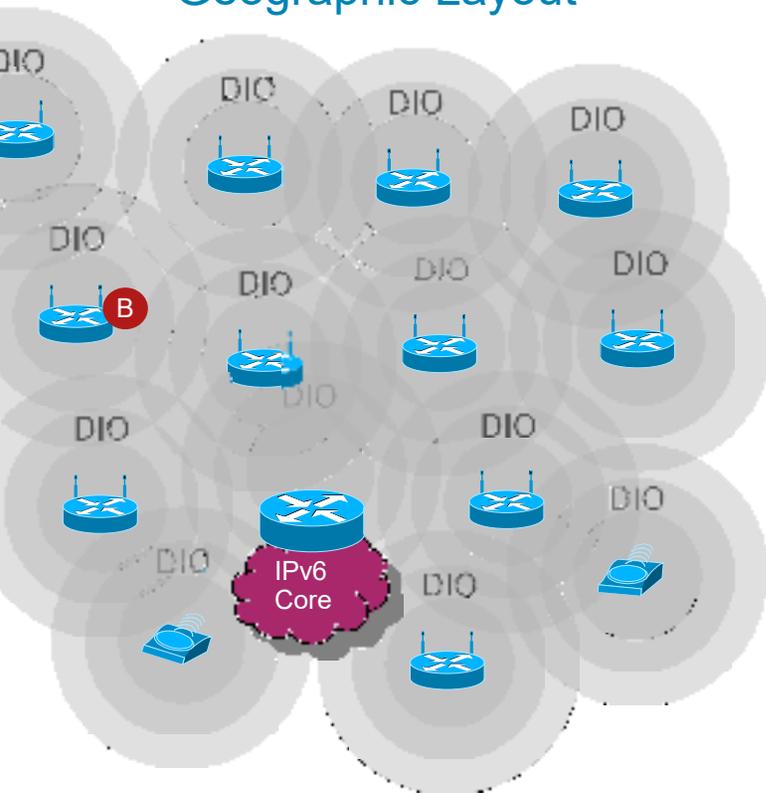
LQL=1 (Good)
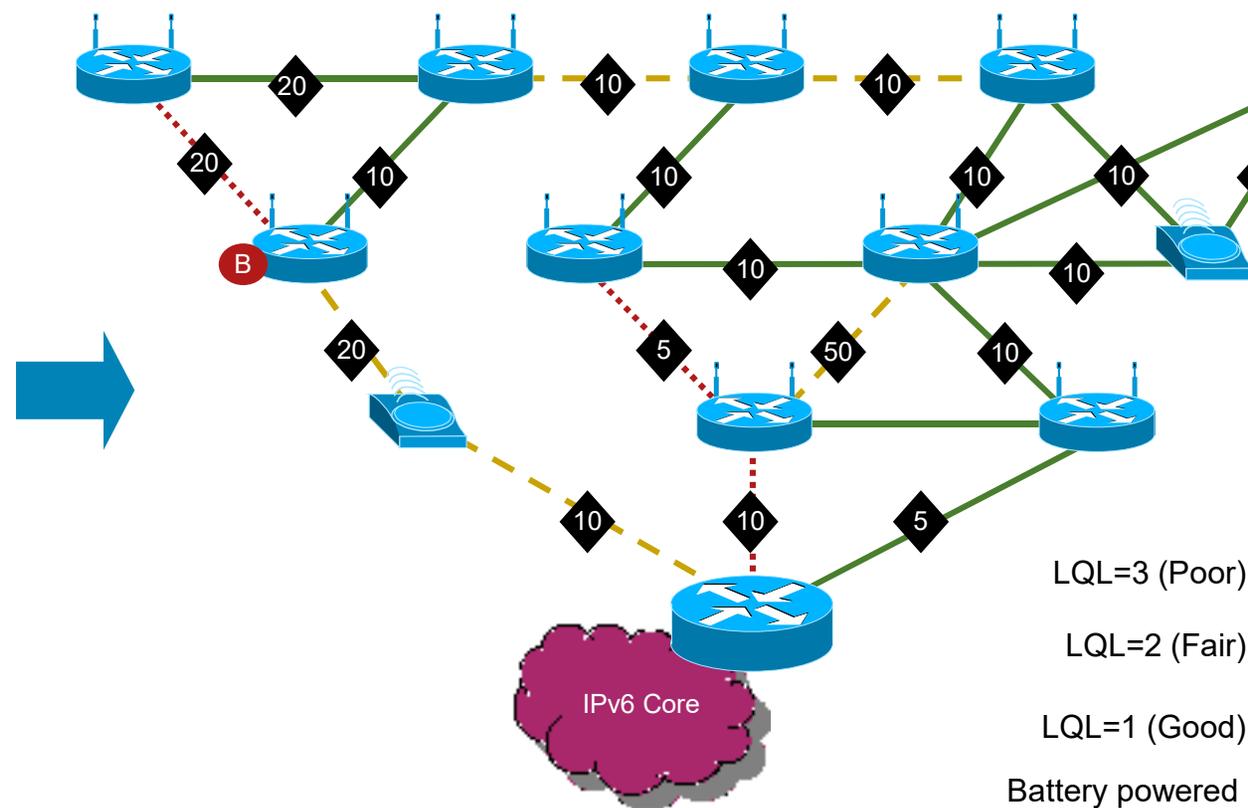
Battery powered

- DIO messages are propagated from the DODAG root

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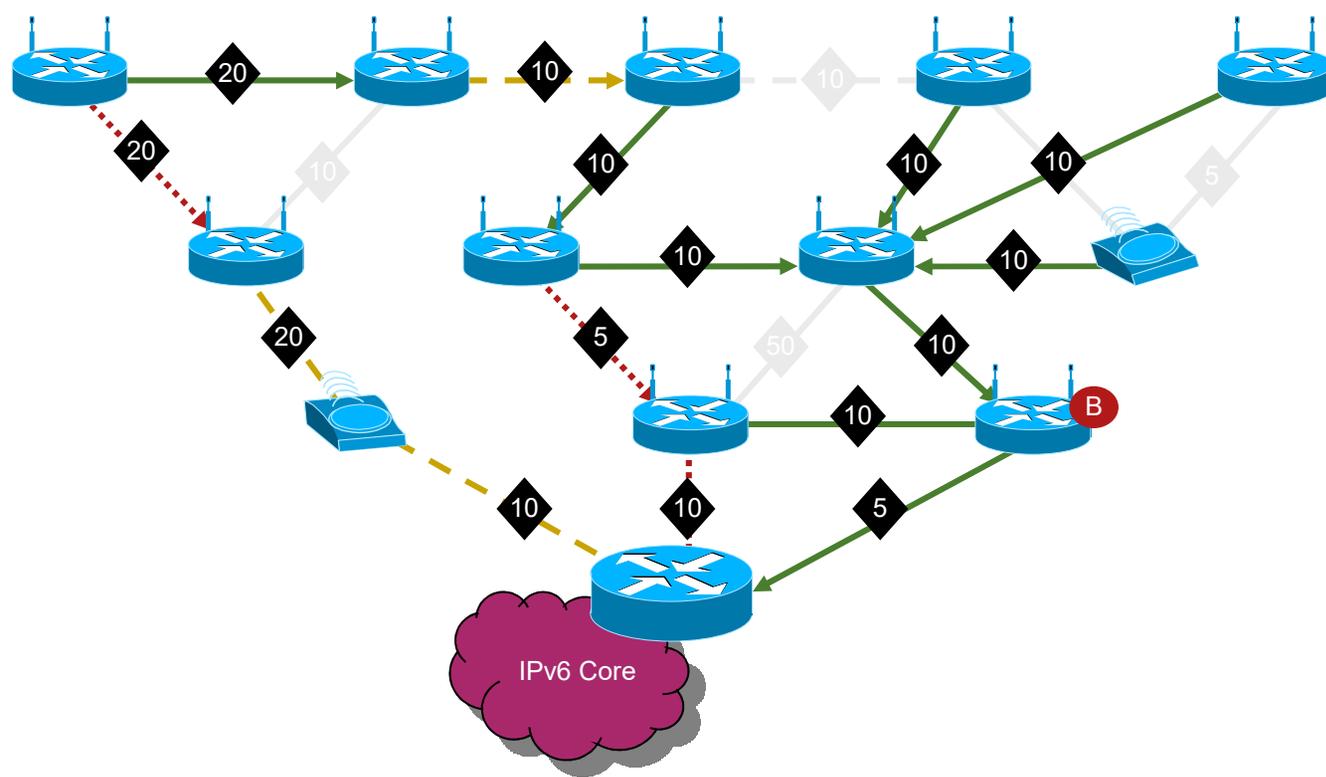# OF: Use High Quality Links, Avoid battery powered nodes

DODAG Topology
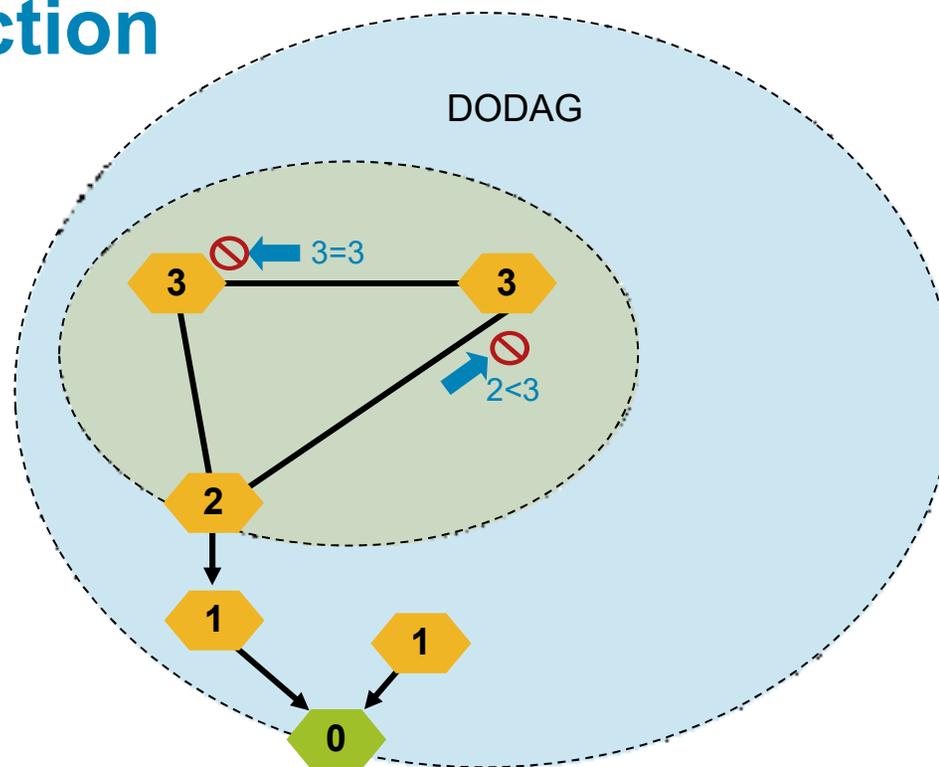
LQL=3 (Poor)
LQL=2 (Fair)
LQL=1 (Good)
Battery Powered

B

IPv6 Core
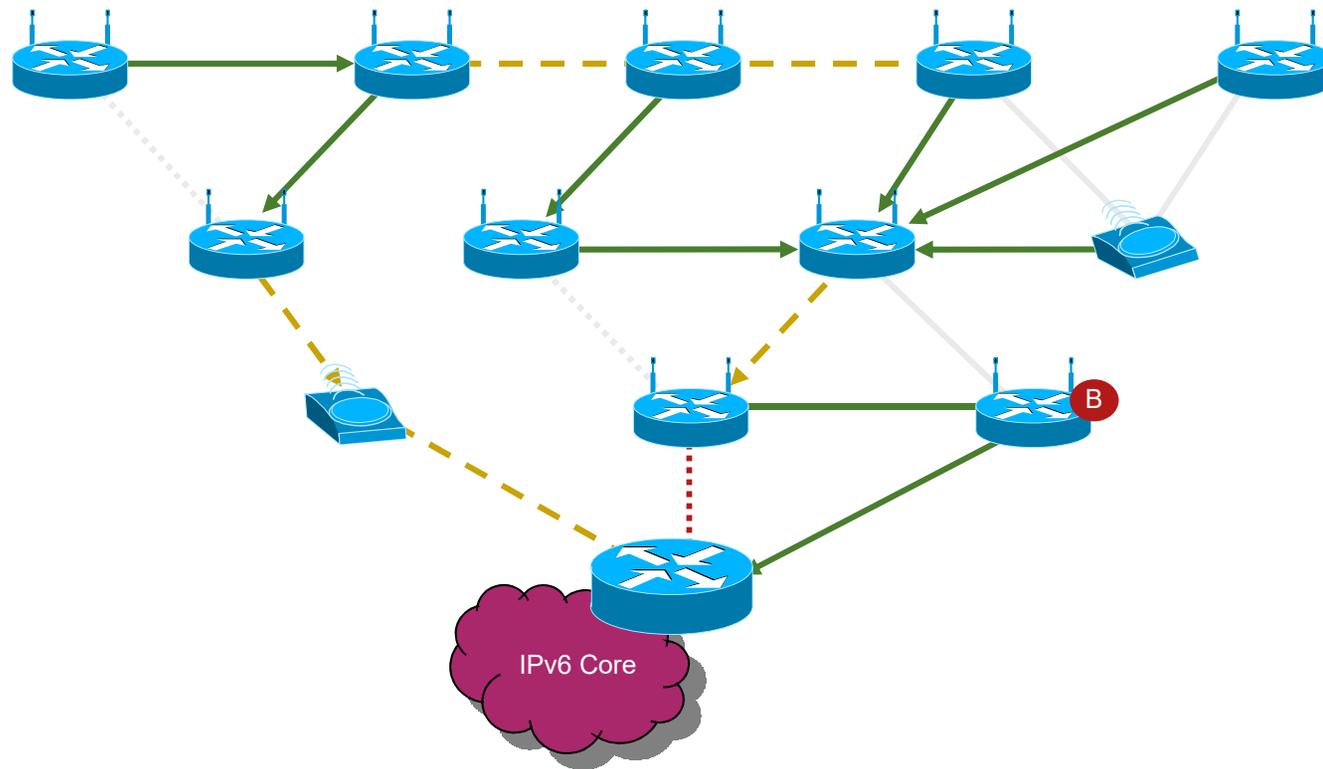
OF: Low Latency Paths only

DODAG Topology

LQL=3 (Poor)
LQL=2 (Fair)
LQL=1 (Good)
Battery Powered

IPv6 Core

# RPL Loop Detection

DODAG

3=3

2<3

3   3

2

1   1

0

- Data path validation used to check for loops (Simple mechanism)

    IPv6 options header carries rank of transmitter

- If node receives packet with rank <= to its own, drop packet

    Detection happens when link is actually used.

RPL Summary

- RPL is a foundation of the Internet of Things

  Open standard to meeting challenging requirements

- Promising technology to enable IP on many billions of smart objects

- Very compact code

  Supports wide range of media and devices

- Cisco Implementation

  Passed execute commit, planned for IOS 15.2PI16

  In roadmap for SGBU nextgen routers

- Standardisation Status (Dec 2010)

  Passed WG and IETF last call

  Adopted by several alliances: Zigbee/IP, Wavenis, IEEE P1901.2 (Power line comm

Recommended reading

INTERCONNECTING SMART OBJECTS WITH IP

THE NEXT INTERNET

Jean-Philippe Vasseur
Adam Dunkels

MK
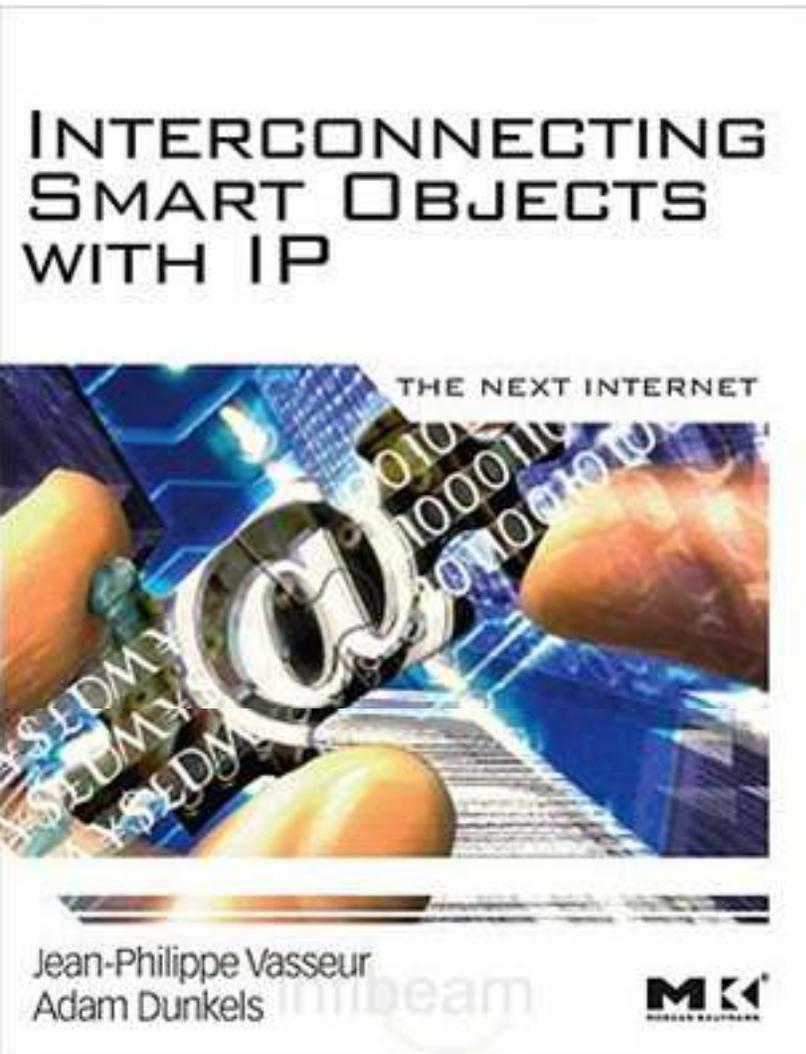
- Covers the trends in Smart Objects

- RPL protocol

- Detailed application scenarios

- Written by

  JP Vasseur (Cisco DE)

  Adam Dunkels (Inventor of Contiki O/S, uIPv6)