# hange Log (Hidden Slide)

| ase | Date | Owner | Changes |
| --- | --- | --- | --- |
| 0 | 17-Oct-2011 | Jeff Apcar | Reformatted previous V1.9 into new Cisco style (greens/yellows) *Draft*<br>Added a new connected devices growth chart replacing IBSG one |
| 1 | 30-Nov-2011 | Jeff Apcar | Further updates to tables, SUN information, Updated RPL technical concepts, added Object Code Point Slide<br>Clarified constraints and metrics distribution<br>Released for review by BU team |

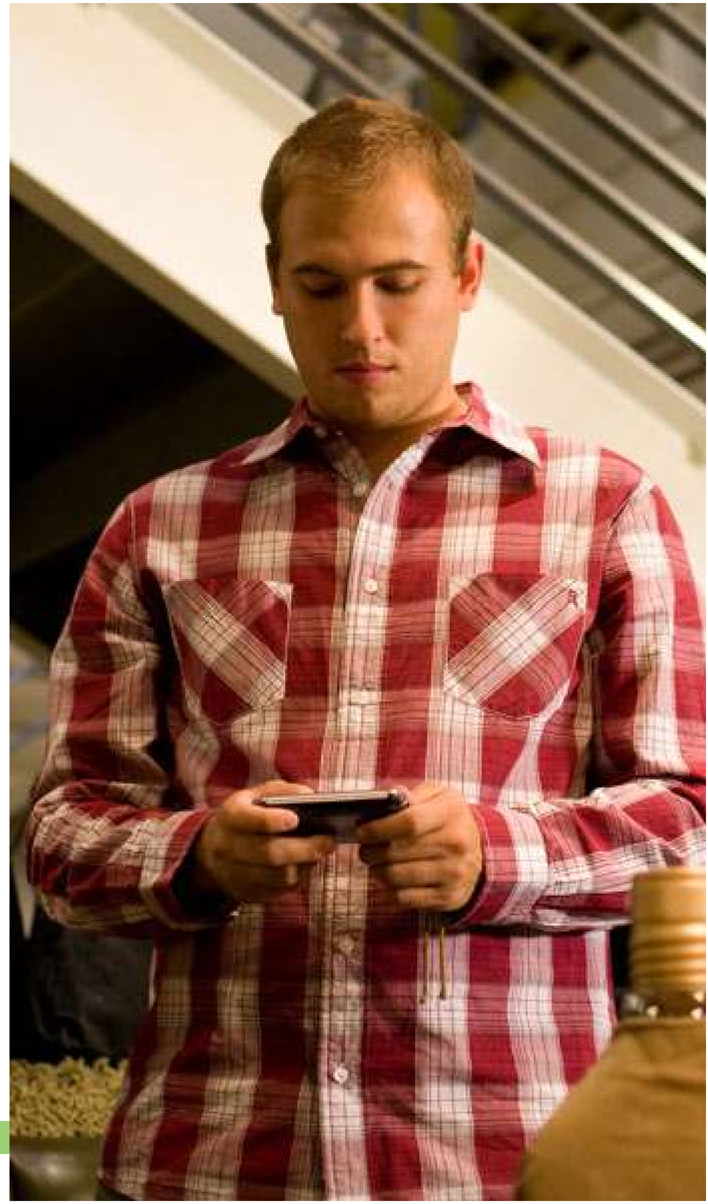
# P in Smart Object Networks

f Apcar
tinguished Services Engineer

acknowledgement to JP Vasseur
o Fellow, Co-Chair IETF Roll Working Group, TAB Chair IPSO Alliance

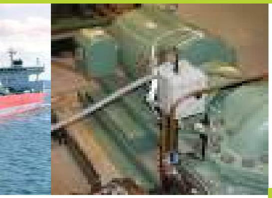
# genda

- world of sensors
- mart Objects
- ow Power Lossy Networks (LLN)
- 02.15.4 Low Power PAN
- Jsing IP for Smart Objects
- LoWPAN Working Group
- Roll Working Group
- Routing over Low Power Lossy Networks (RPL)
- Conclusion



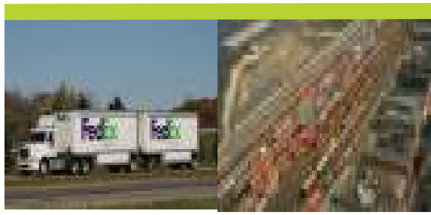
# World of Sensors

- Mostly RS485 wired actuators/sensors
- Generally proprietary architectures for specific applications



**Predictive Maintenance**

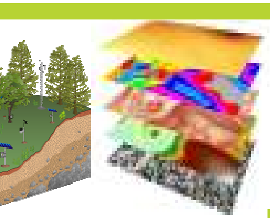
**Energy Saving Smart Grid**



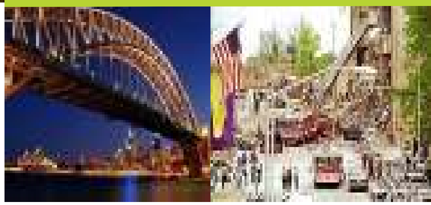
**High-Confidence Transport and Asset Tracking**

**Intelligent Buildings**

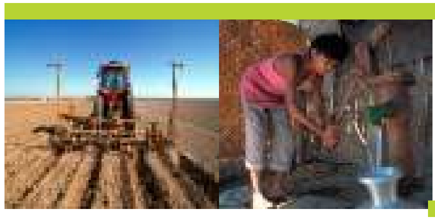
**Improve Productivit**



**Enable New Knowledge**



**Enhanced Safety & Security**



**Improve Food and $H^2O$**

**Healthcare**

**Smart Home S+CC**

# World of Proprietary Protocols

- Many legacy networks use closed and proprietary protocols
  - Each with different implementations at each layer (Physical, Link, Network)
  - Many non-interoperable “solutions” addressing specific problems
  - Resulting in different architectures and protocols
- Interoperability partially addressed (poorly) by protocol gateways
  - Inherently complex to design, deploy and manage
  - Results in inefficient and fragmented networks, QOS, convergence
- Similar situation to computer networks in the 1980s
  - Islands of systems communicating using SNA, IPX, Appletalk, DECnet, VINES
  - Interconnected using multiprotocol gateways

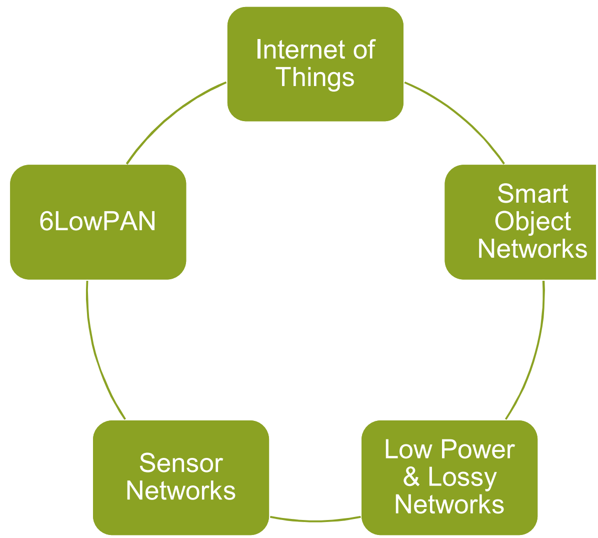
# he Internet of Things

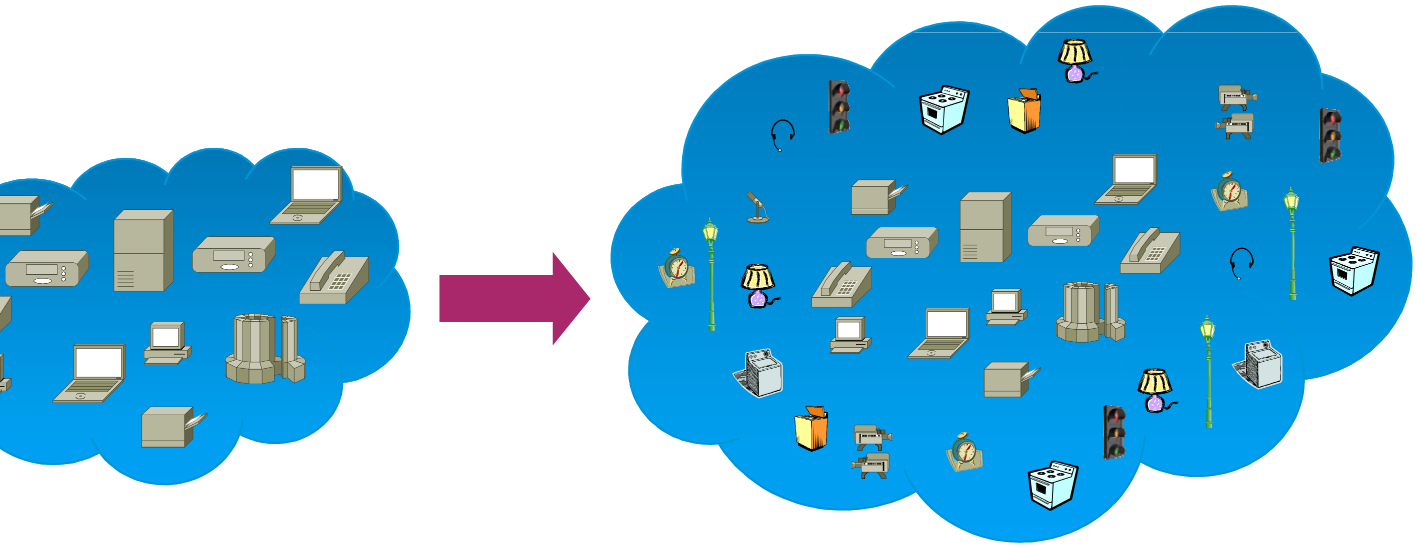
Standardise IP into sensors and other smart objects

Any object or environmental condition can be monitored

Expand the current Internet to virtually anything and everything

Form the Internet of Things

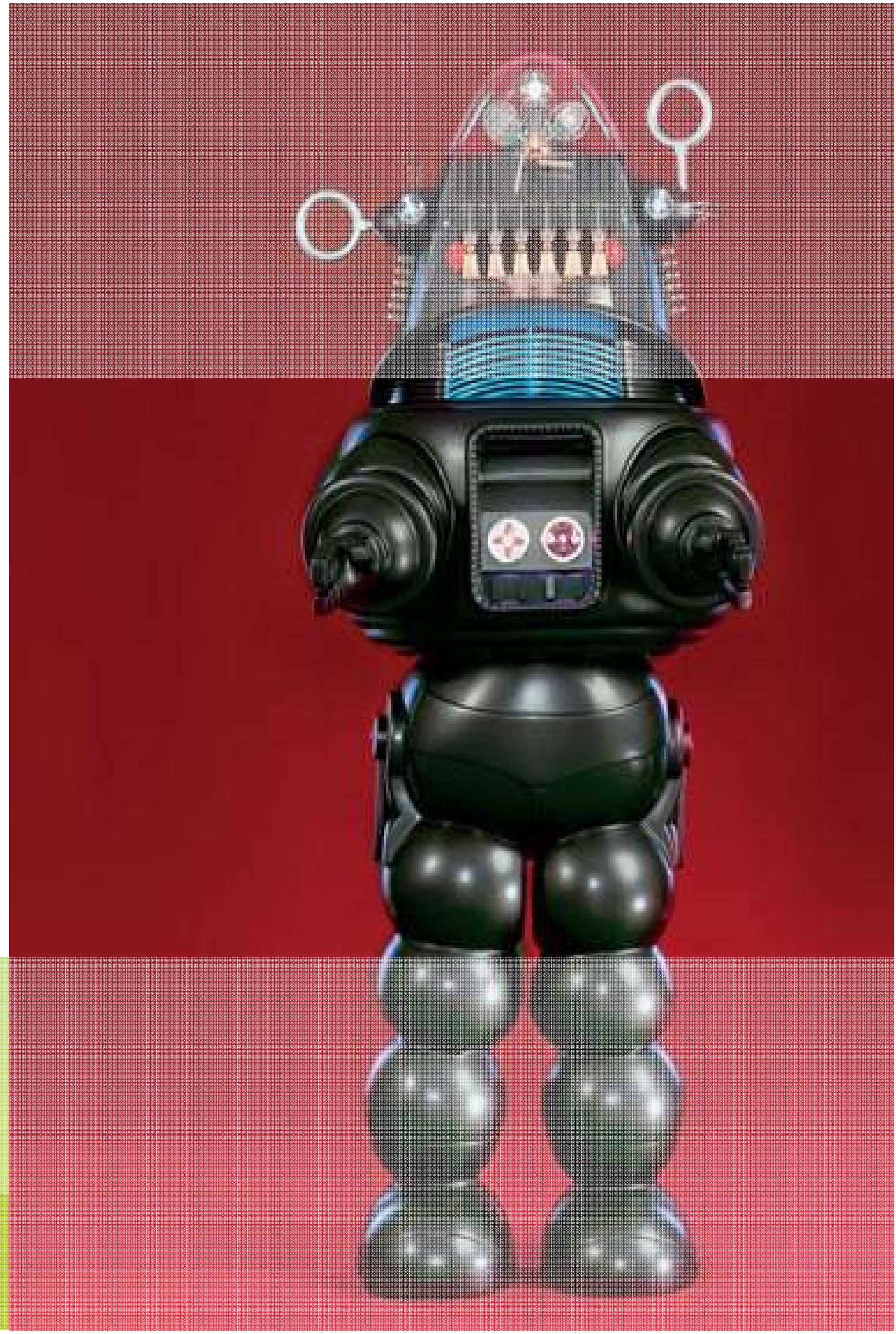


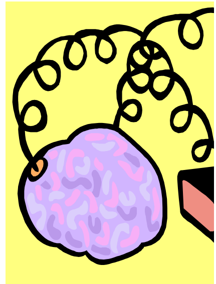
"A pervasive and ubiquitous net which enables monitoring and control of physical environmen collecting, processing, and analysing the data generated b Smart-Objects"

# Smart Objects



# What is a Smart Object?

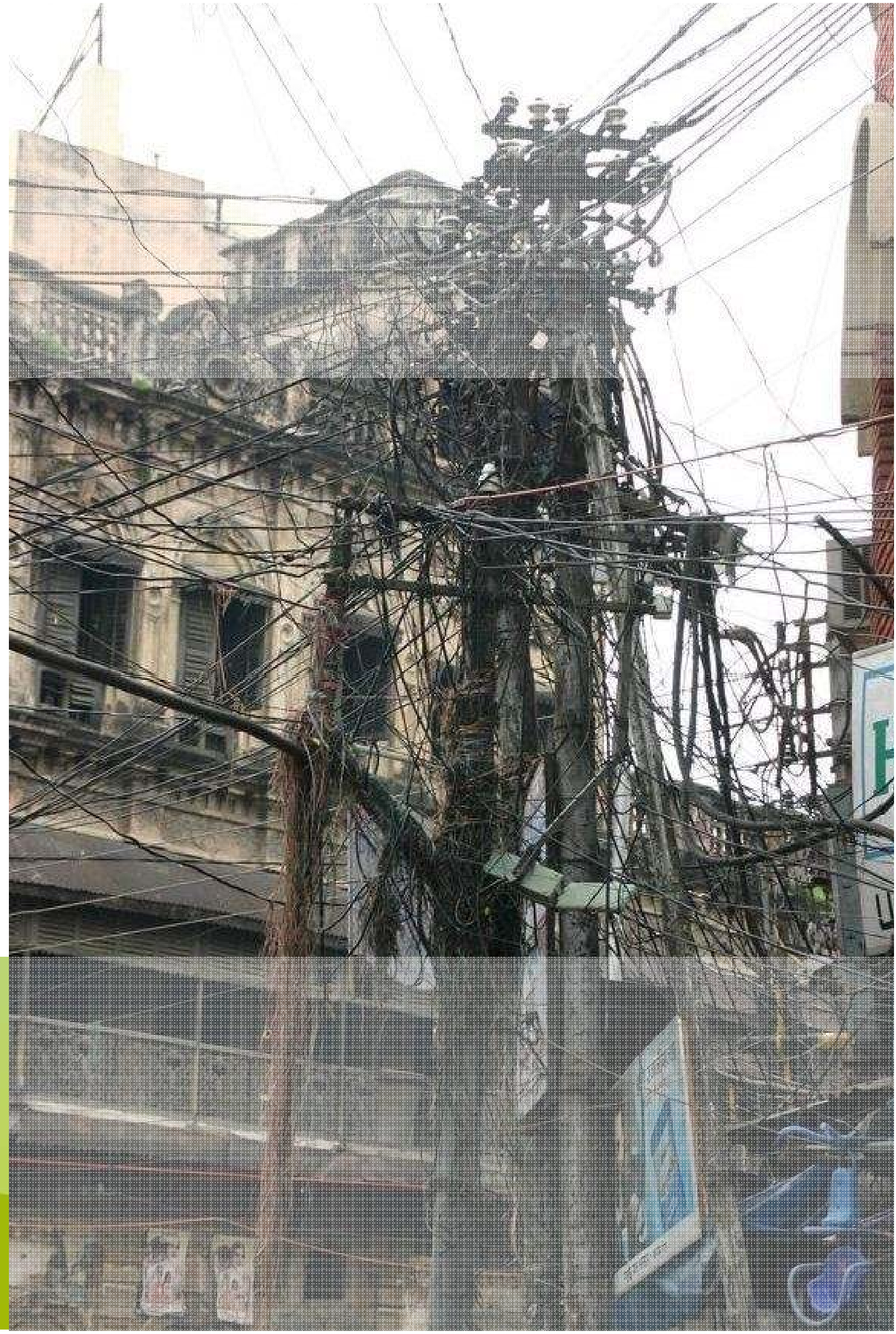


- A tiny and low cost computing device that may contain
  - A sensor that can measure physical data (e.g., temperature, vibration, pollution)
  - An actuator capable of performing a task (e.g., change traffic lights, rotate a mirror)
  - A communication device to receive instructions , send data or possibly route information
- This device can be 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

# haracteristics of Smart Objects

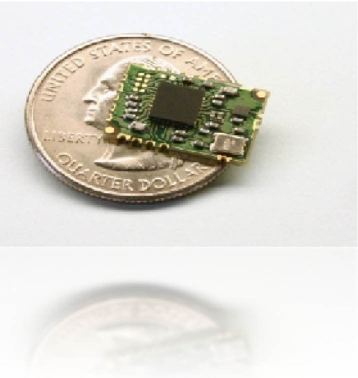
- hese devices are highly constrained in terms of
  - Physical size
  - CPU power
  - Memory (few tens of kilobytes)
  - Bandwidth (Maximum of 250 KB/s, lower rates the norm)
- ower consumption is critical
  - If it is battery powered then energy efficiency is paramount
  - Batteries might have to last for years
- lay operate in harsh environments
  - Challenging physical environment (heat, dust, moisture, interference)
- Vireless capabilities based on Low Power & Lossy Network (LLNs) technology
  - Predominantly IEEE 802.15.4 (2.4 GHz and 900 MHz)
  - Newer RF technologies IEEE 802.15.4g Smart Utility Network (SUN)

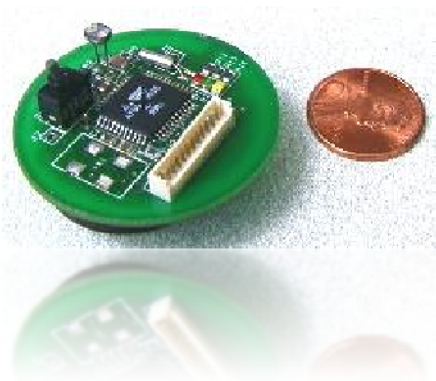
# ow Power
# ossy Networks (LLN)

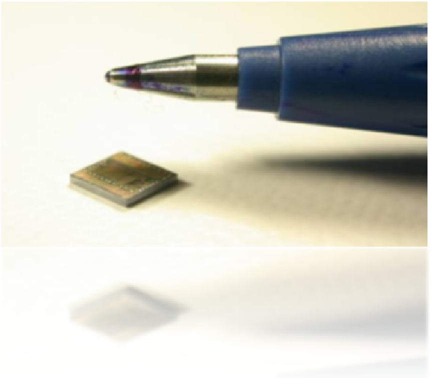


# /hat is a Low Power Lossy Network (LLN)?

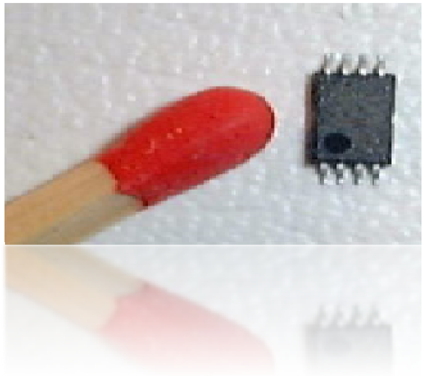
- LLNs comprise a large number of highly constrained devices (smart objects) interconnected by predominantly wireless links of unpredictable quality
- LLNs cover a wide scope of applications
  - Industrial Monitoring, Building Automation, Connected Home, Healthcare, Environmental Monitoring, Urba Sensor 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)







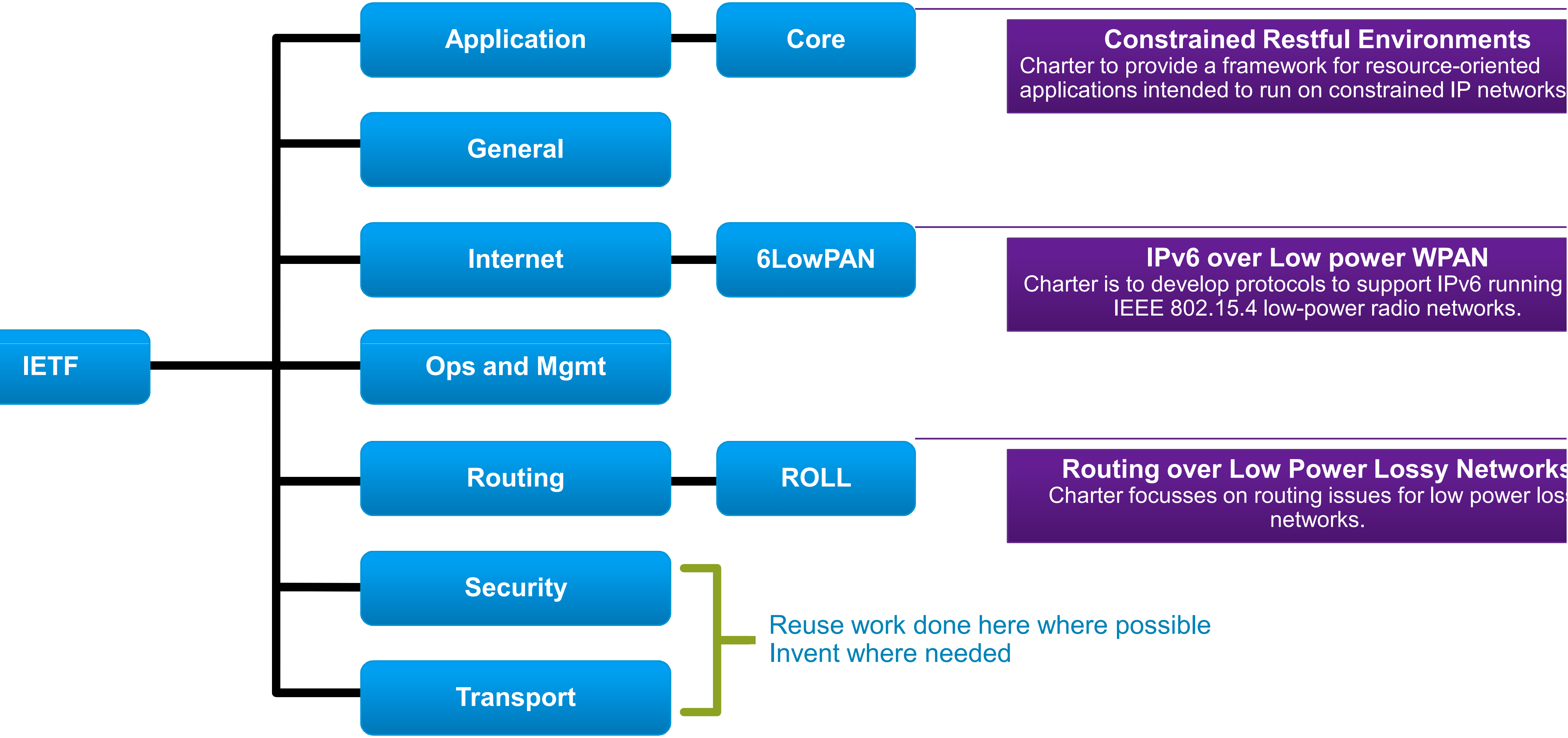
World's smallest web server



# haracteristics of LLNs

- LNs operate with a hard, very small bound on state
- LNs are optimised for saving energy in the majority of cases
- raffic patterns can be MP2P, P2P and P2MP flows
- ypically LLNs deployed over link layers with restricted frame-sizes
  - Minimise the time a packet is in the air hence the small frame size
  - The routing protocol for LLNs should be  adapted for such links
- LN routing protocols must consider efficiency versus generality
  - Many LLN nodes do not have resources to waste

# ETF LLN Related Workgroups



# for Smart Objects (IPSO) Alliance

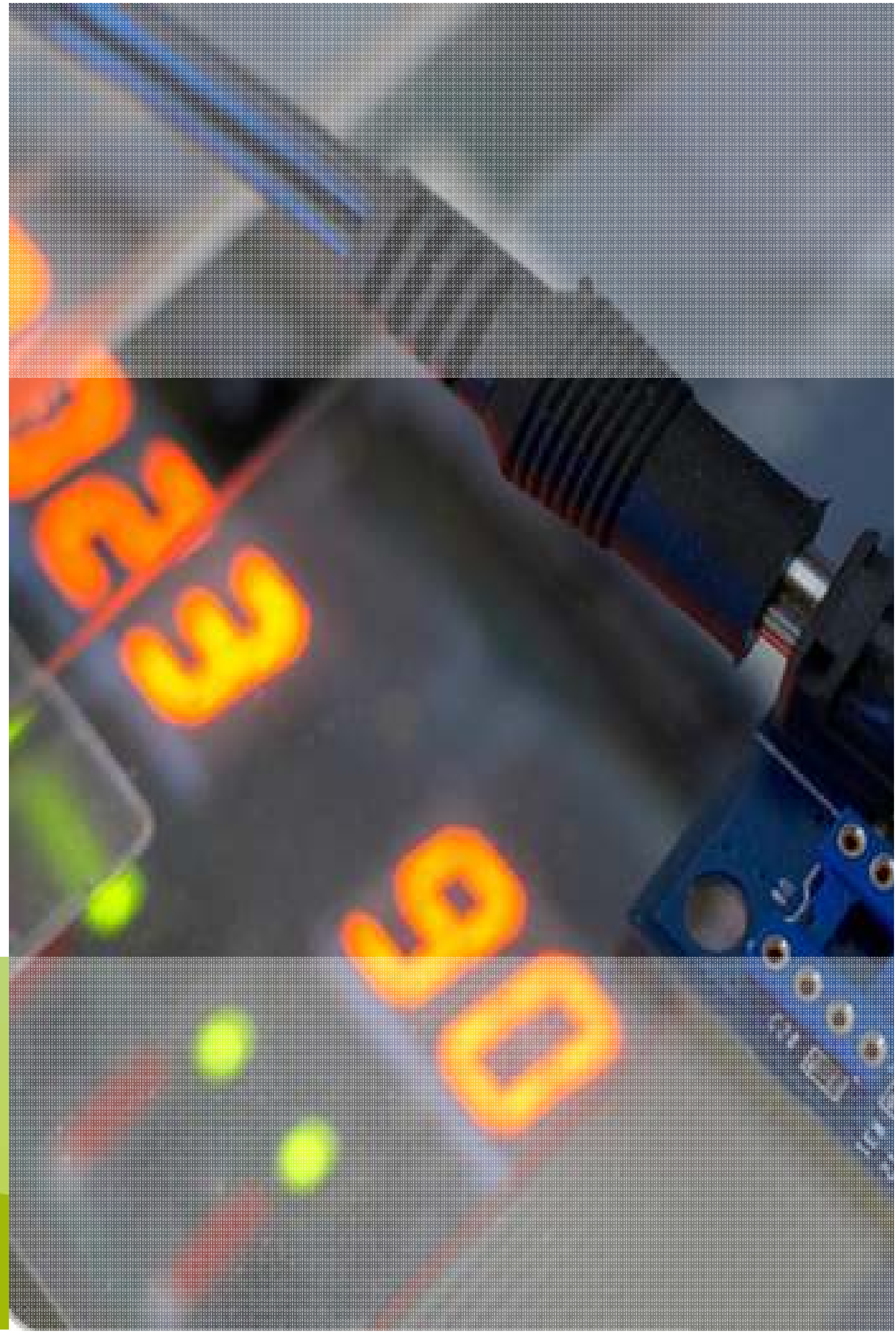
- PSO Alliance formed drive standardisation and inter-operability
  - Create awareness of available and developing technology
- s of 2011 More than 50 members in the alliance
- ocument use of new IP based smart object technologies
  - Generate tutorials, webinars, white papers and highlight use cases
  - Provide an information repository for interested parties
- oordinate and combine member marketing efforts
- upport and organise interoperability events
  - COMPLIANCE program (Based on IPv6 forum)

ttp://www.ipso-alliance.org

Promoters

Contributors

# EEE 802.15.4 PAN



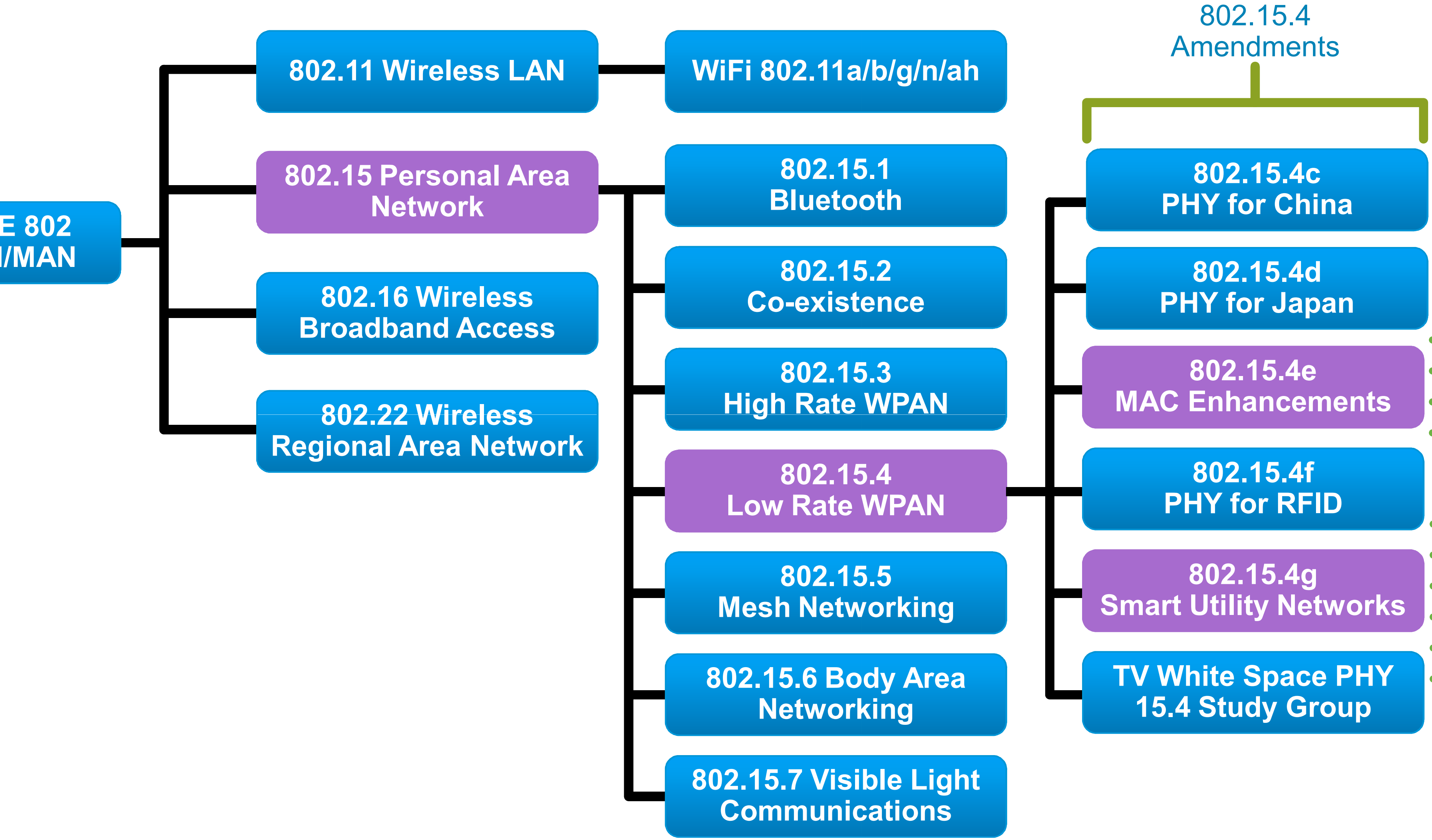
# 02.15.4 Scope

- nitial activities focused on wearable devices "Personal Area Networks"
- Activities have proven to be much more diverse and varied
  - Data rates from Kb/s to Gb/s
  - Ranges from tens of metres to Kilometres
  - Frequencies from MHz to THz
  - Various applications not necessarily IP based
- Focus is on "specialty", typically short range, communications
  - If it is wireless and not a LAN, MAN, RAN, or WAN, odds are its 802.15
- The only IEEE 802 Working Group with multiple MACs

"The IEEE 802.15 TG4 was chartered t investigate a low data rate solution wit multi-month to multi-year battery life a very low complexity. It is operating in a unlicensed, international frequency band. Potential applications are senso interactive toys, smart badges, remote controls, and home automation."

http://www.ieee802.org/15/pub/TG4.html
IEEE 802.15 WPAN™ Task Group 4 (TG4) Cha

# EEE Wireless Standards



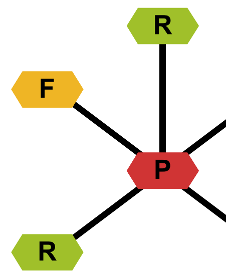

- Industrial strength
- Minimised listening c
- Improved security
- Improved link reliabili

- Support smart-grid ne
- Up to 1 Km transmiss
- >100Kbps
- Millions of fixed endp
- Outdoor use
- Larger frame size

# EEE 802.15.4 Features

- esigned 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
  - Transmission Range varies
- ully acknowledged protocol for transfer reliability
- ata rates of 851, 250, 100, 40 and 20 kbps (IEEE 802.15.4-2011 05-Sep-2011)
  - Frequency and coding dependent
- wo addressing modes; 16-bit short (local allocation) and 64-bit IEEE (unique global)
- possible unlicensed frequency bands
  - (Europe 868-868.8 MHz – 3 chans , USA 902-928 MHz – 30 chans, World 2400-2483.5 MHz – 16 chans)

# EEE 802.15.4 Node Types




## ull Function Device (FFD)

- Can operate as a PAN co-ordinator (allocates local addresses, gateway to other PANs)
- Can communicate with any other device (FFD or RFD)
- Ability to relay messages (PAN co-ordinator)

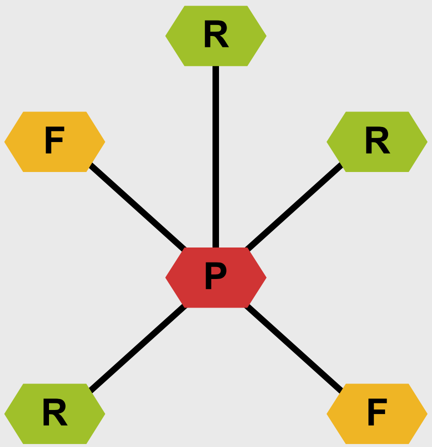
## educed Function Device (RFD)

- Very simple device, modest resource requirements
- Can only communicate with FFD
- Intended for extremely simple applications

# EEE 802.15.4 Topologies

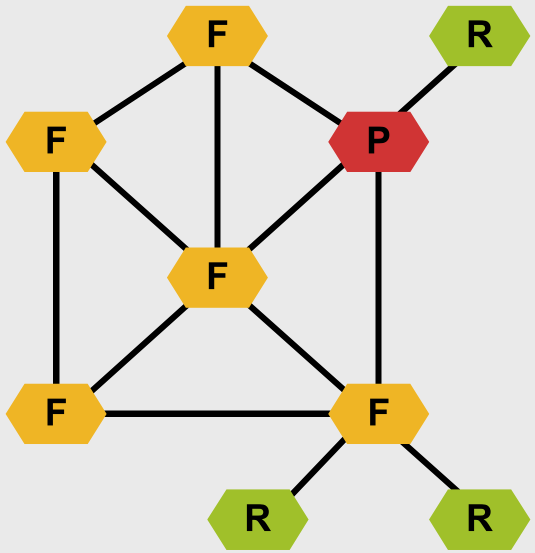
- Operates at Layer 2

- Star Topology



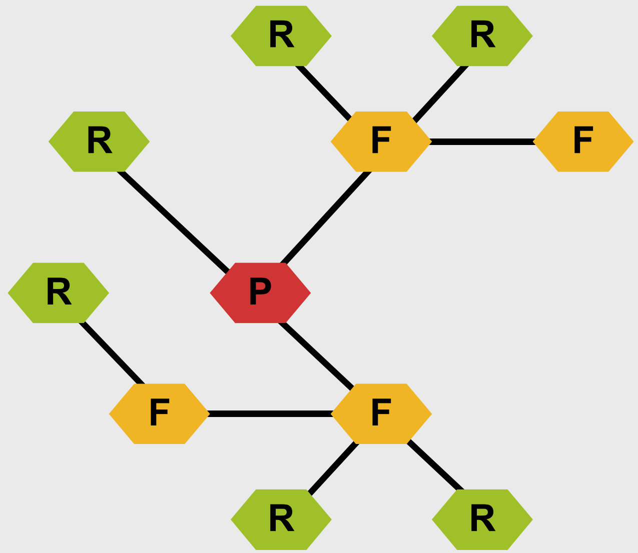

- All devices communicate to PAN co-ordinator which uses mains power
- Other devices can be battery/scavenger

- Mesh Topology




- Devices can communicate directly if within range

- Cluster Tree

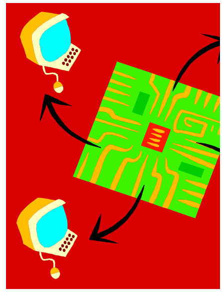



- Higher layer protocols like RPL may create their own topology that do not follow 802.15.4 topologies

- Single PAN co-ordinator exists for all topologies

# Jsing IP for Smart Objects

# ' in Smart Object Networks



- 'oday's computer networks are almost exclusively IP based
  - Provides end-to-end reliable connectivity
  - Brings scalability, flexibility and reliability
  - Supports wide a range of devices, transports and applications
    - Email, WWW, VOIP, Video, Collaboration
- 'mart Object Networks standardising on IP
  - General consensus is that IP based Smart Objects networks are the future
  - Move away from proprietary and closed protocols
  - Solid standardisation base allows future innovation
  - Allows quick adoption of emerging applications
  - Allows the creation of the "Internet of Things"

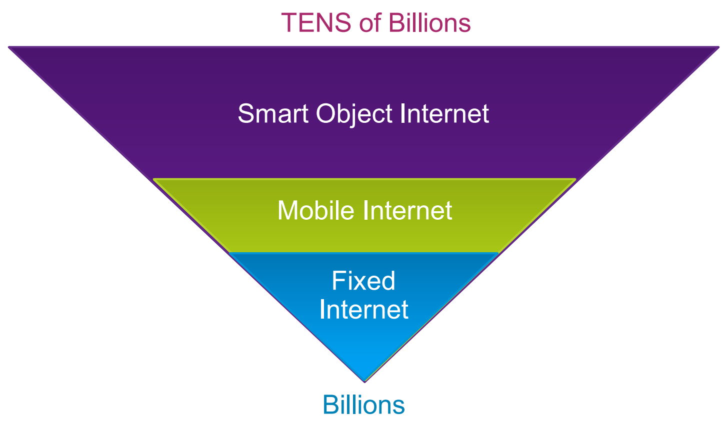
# ' is both an Architecture & Protocol

: can meet all the requirements to support a Smart Object Network

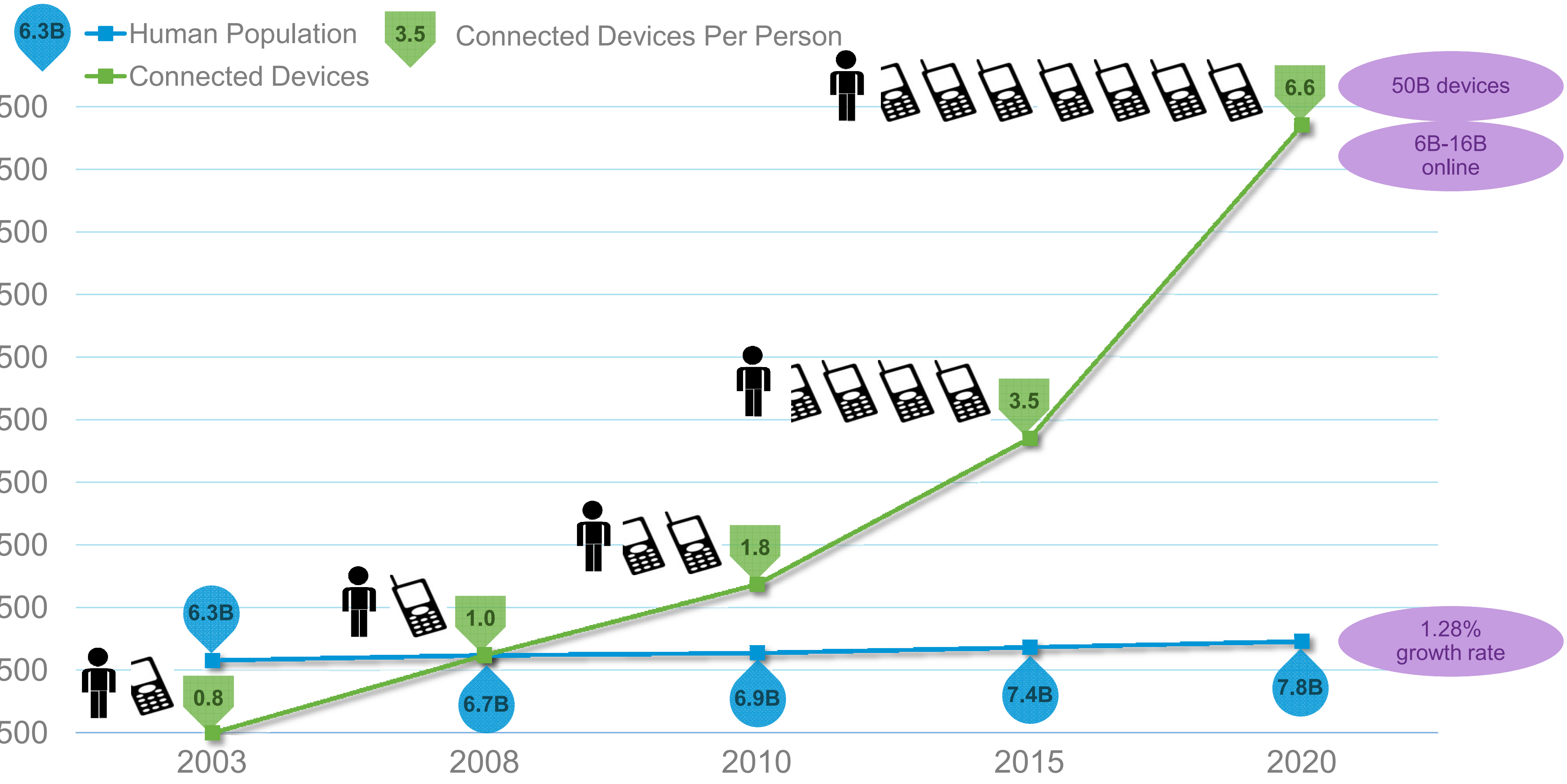
- 3ased on open standards
  - IETF RFCs
- 'lexibility in many dimensions
  - Support a wide range of media - Serial, SDH, Ethernet, DWDM, FR, ATM
  - Support a wide range of devices - From phones to routers
- \lways favor global than local optimum
  - IP is capable of supporting many different applications; voice, video, data, mobile
- 3ecure
- 'lug & Play
- 3calable
  - The Internet comprises billions of connected devices

# Pv4 or IPv6

- he current Internet comprises several billion devices
  - Add to this growing 3G, 4G mobile devices
  - There is no scope for IPv4 to support Smart Object Networks
- mart Objects will add tens of billions of additional devices
- Pv6 is the only viable way forward
  - Solution to address exhaustion
  - Stateless Auto-configuration thanks to Neighbour Discovery Protocol
- ome issues with IPv6 address size
  - Smart Object Networks use low power wireless with small frame size
  - Solution to use stateless and stateful header compression (6LoWPAN)



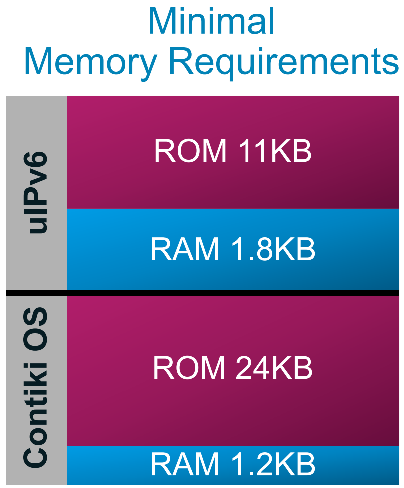
# onnected Devices Growth



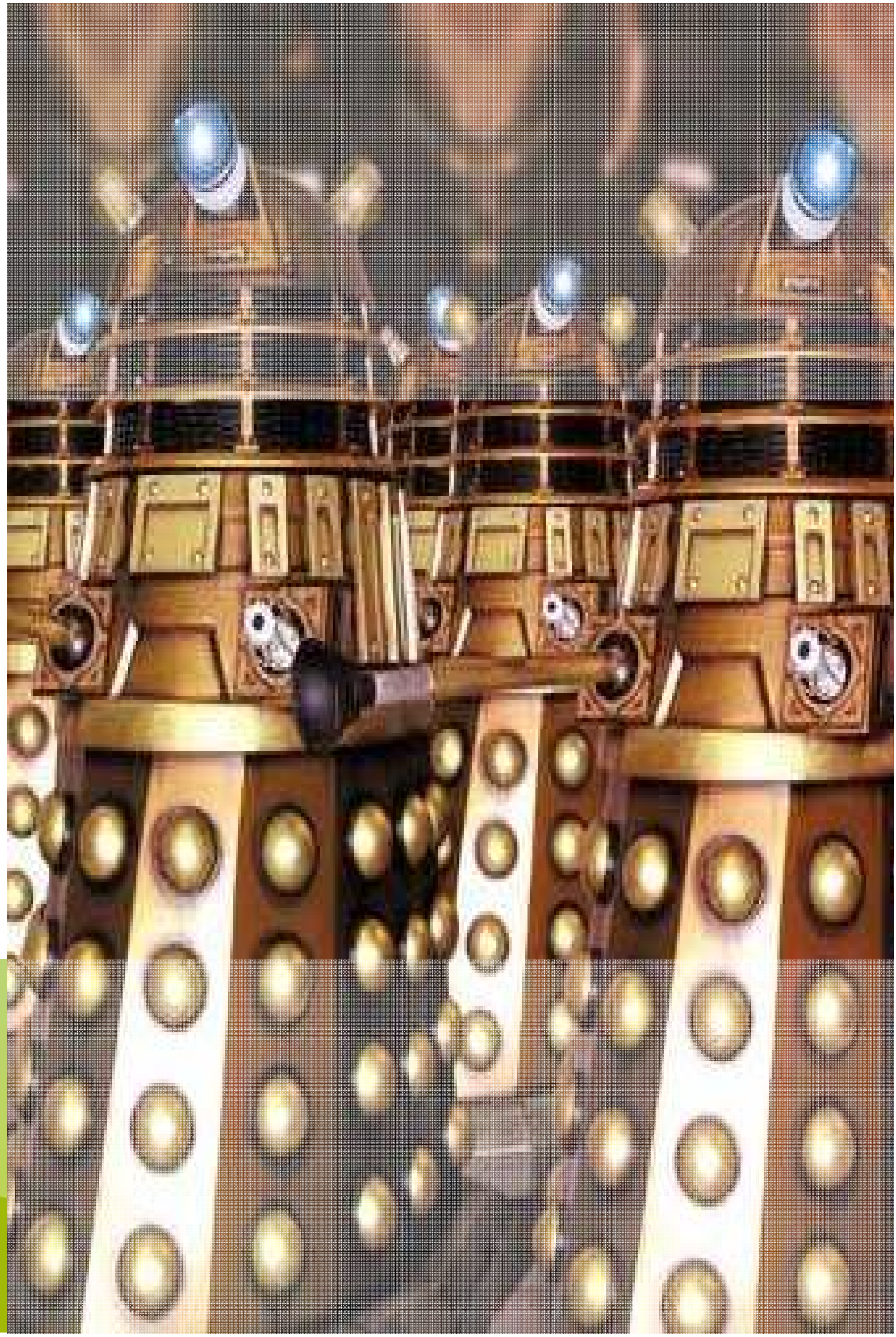

o IBSG projections, UN Economic & Social Affairs http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

# ontiki + uIPv6 Code for Smart Objects

- ontiki is a memory efficient O/S for smart objects
  - Open source  operating system for the Internet of Things
- IPv6 is world’s small certified stack for objects such as actuators and sensors
  - uIPv6 does not require an O/S (such as Contiki)
  - Able to run over any link layer (for example, 802.15.4)
- ll IPv6 features (except MLD) are implemented from RFC4294
- btained IPv6 ready phase 1 logo
- pen source release http://www.sics.se/contiki
- emory requirements for IPv6/6LoWPAN/802.15.4
  - 35K ROM 3K RAM (minimal O/S features)
  - 40KB ROM 10KB RAM (full O/S features)



# LoWPAN
# Working Group







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# /hat is 6LoWPAN ?

Pv6 over Low power Wireless Personal Area Networks

- An adaptation layer for IPv6 over IEEE 802.15.4 links

/Vhy 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

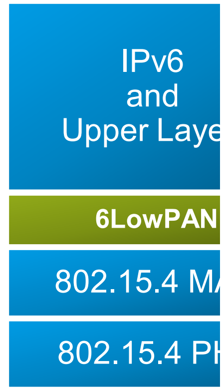
Performs 3 functions each with its own 6LoWPAN header

- IPv6 Header compression
- IPv6 packet fragmentation and re-assembly
- Layer 2 forwarding (also referred to as mesh under)

RFC4919 defines the Problem Statement

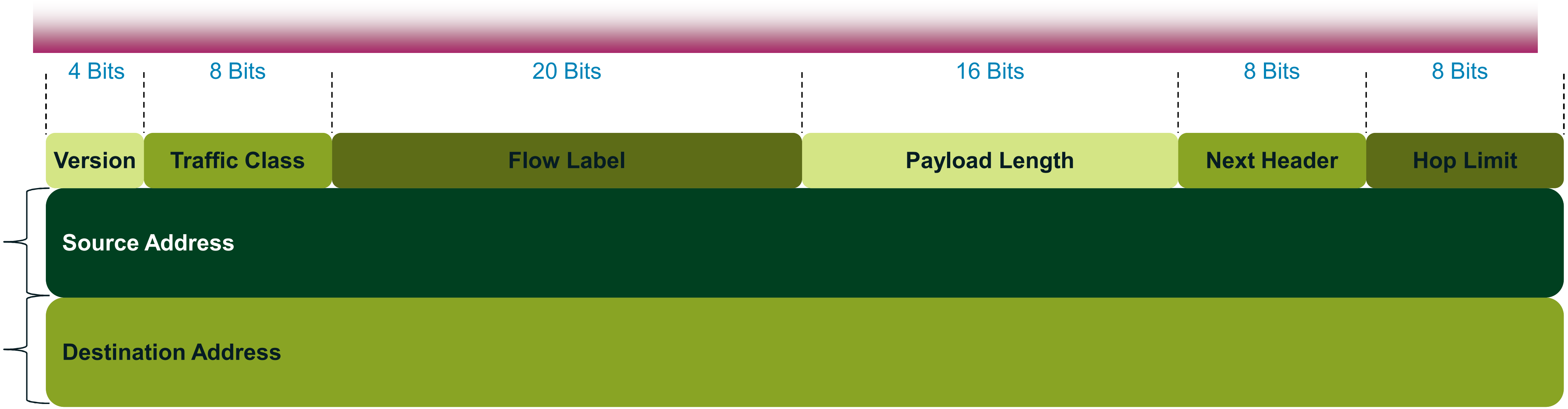
RFC4944 defines Transmission of IPv6 Packets over IEEE 802.15.4

- Improved header compression being worked on may deprecate RFC4944




**smart object networks go better with IPv6 & IEEE 802.15.4**

# asic IPv6 Header




/inimum headersize is 40 bytes (double that of IPv4)

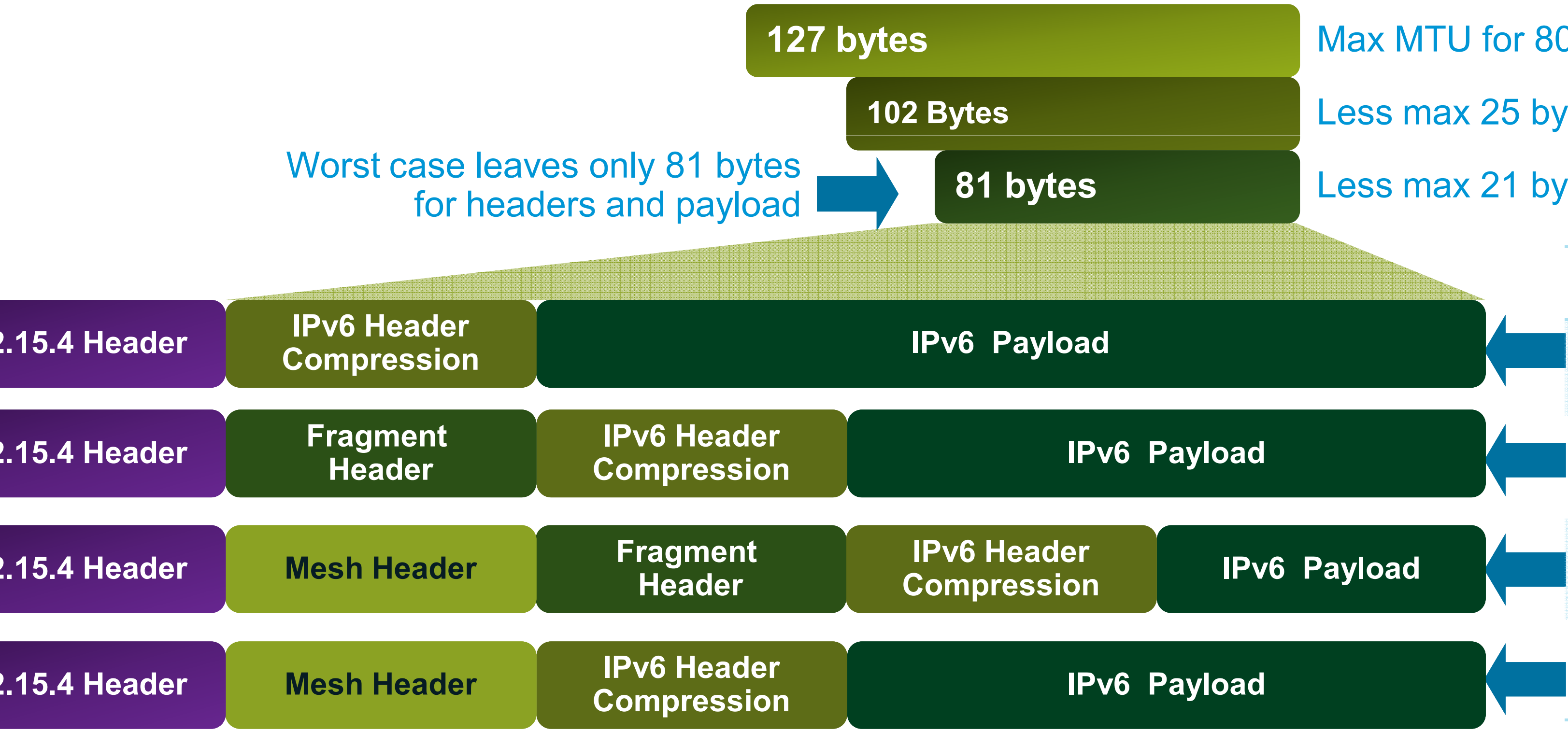
3asic header can be extended by additional headers

Fragmentation must be performed by end nodes

# LoWPAN Header Stacks

- Several 6LoWPAN headers are included when necessary
  - IPv6 compression header
  - Fragmentation header (eliminated if single datagram can fit entire IPv6 payload)
  - Mesh or Layer 2 forwarding header (currently not used/implemented)




| IPv6 Fragmentation | Multiple L |
|---|---|
| No | No |
| Yes | No |
| Yes | Yes (Fu |
| No | Yes (Fu |

# ROLL Working Group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# /hat is ROLL?

- ‹outing 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)
- ‹lission: To define routing solutions for LLNs
- ‹pplication specific LLN routing RFC have been developed

| FC | Application | Title |
|---|---|---|
| FC 5673 | Industrial | Industrial Routing Requirements in Low-Power and Lossy Networks |
| FC 5548 | Urban | Routing Requirements for Urban Low-Power and Lossy Networks |
| FC 5826 | Home | Home Automation Routing Requirements in Low-Power and Lossy Networks |
| FC 5867 | Building | Building Automation Routing Requirements in Low-Power and Lossy Networks |

- ;pecifying the routing protocol for smart object networks
  - Routing Protocol for LLNs (RPL) currently WG document

# /here Should Routing Take Place ?

- listorically, a number of interesting research initiatives on WSN
  - Work on Wireless Sensors Network focussed on algorithms … not architecture
- Лost work assumed the use of MAC addresses
  - Layer 2 "routing" (mesh-under)
- ;upport of multiple PHY/MAC is a MUST
  - IEEE 802.15.4, Low Power Wifi, Power Line Communications (PLC)
- Jse IP to route
  - Supports multiple PHY/MAC
  - Moves from mesh-under (L2) to router-over(L3)

# haracteristics of Internet vs SObject Networks

| Current Internet | Smart Object Networks |
|---|---|
| es are routers | Nodes are sensor/actuators and routers |
| with typically few hundreds of 100 nodes | An order of magnitude larger in nodes |
| s and Nodes are stable | Links are highly unstable Nodes fail more frequently |
| e and link bandwidth constraints are generally non-issues | Nodes & links are high constrained |
| ting is not application aware | Application-aware routing, in-Band processing is a MUST |

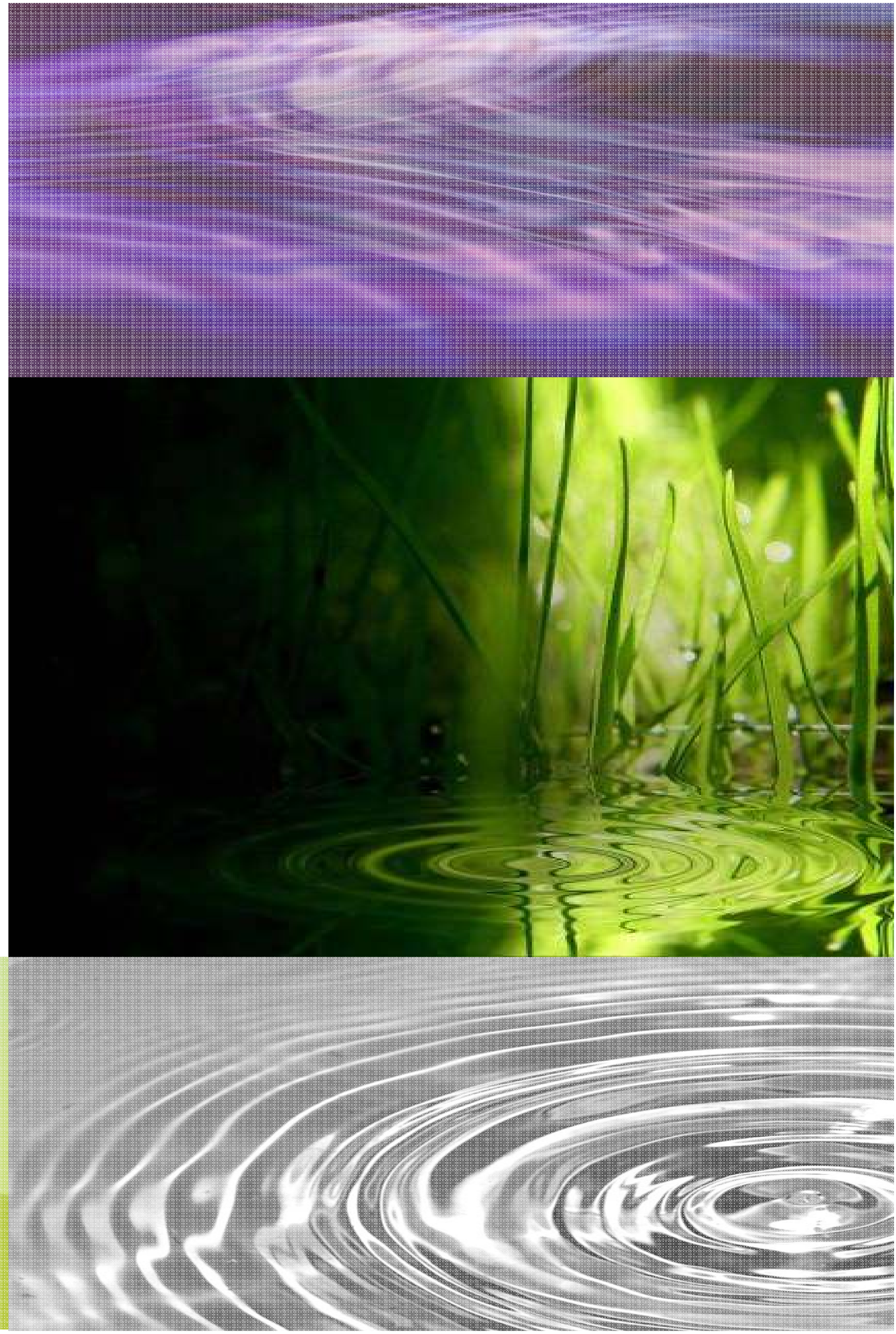
# echnical Challenges

- Energy consumption is a major issue (battery powered sensors/actuators)
- imited processing power
- /ery dynamic topologies
  - Link failure
  - Node failures (triggered or non triggered)
  - Node mobility (in some environments)
- Data processing usually required on the node itself
- Sometimes deployed in harsh environments (Industrial)
- otentially deployed at very large scale (millions of nodes)
- Must be self-managed (auto-discovery, self-organizing networks)

# urrent Routing Protocols

- he 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)
- ot 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
- GP needs the ability to consider different metric/constraint categories
  - Node vs Links
  - Qualitative vs Quantitative
  - Dynamic vs Static

# Routing over low Power Lossy etworks (RPL)

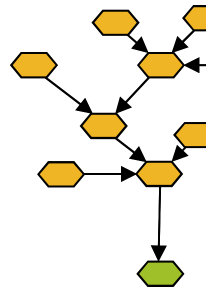


# PL - Routing Protocol for LLNs

RPL is pronounc
"Ripple"

- RPL is an extensible proactive IPv6 distance vector protocol
  - Builds a Destination Oriented Directed Acyclic Graph (DODAG) based on an objective
  - 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
  - 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)
- ttp://datatracker.ietf.org/doc/draft-ietf-roll-rpl/
  - Currently on last call implementation 19 (Feb 2011)

# Vhat is a DAG?



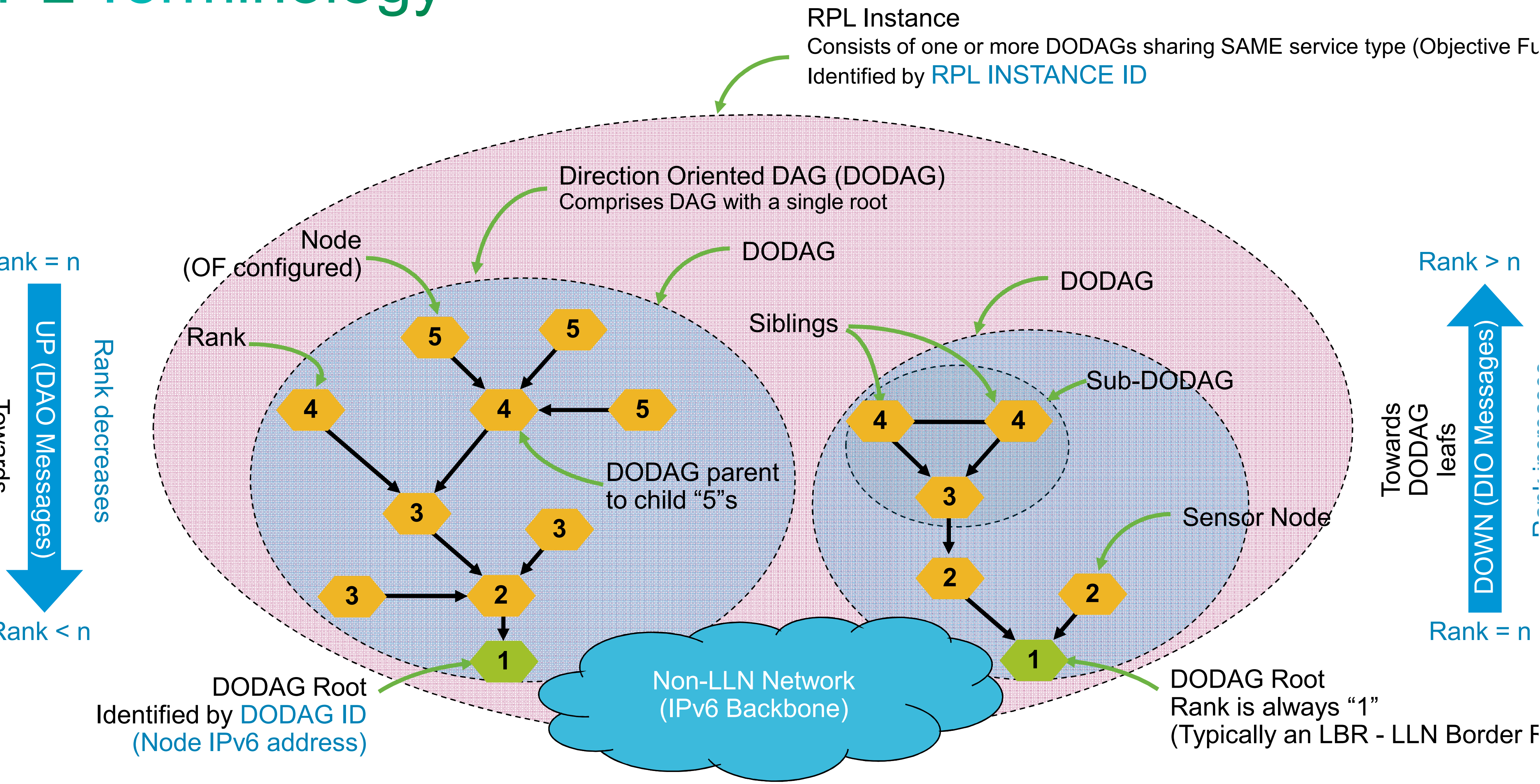
## Directed Acyclic Graph

In the context of routing, a DAG is formed b a collection of vertices (nodes) and edges (links).

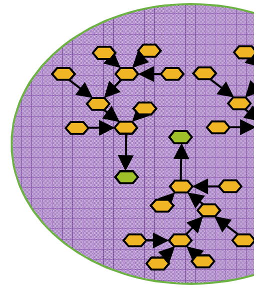
Each edge connecting one node to anothe (directed) in such a way that it is not possible to start at Node X and follow a directed path that cycles back to Node X (acyclic).

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

# PL Terminology

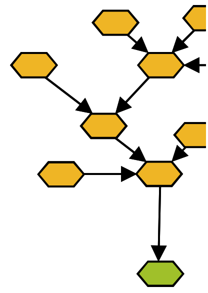


# PL Instances



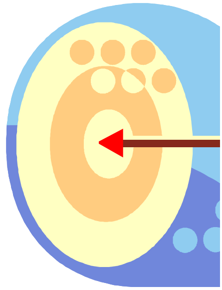
- RPL can form multiple instances
  - Each instance honours a particular routing objective/constraint
  - Instance consists one or more DODAGs derived from the same OBJECTIVE FUNCTION (OF)
  - Nodes select a parent (towards root) based on metric, OF and loop avoidance
- Allows upwards and downwards routing (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

# PL DODAGs



- RPL enables nodes to discover each other and form DODAGs
  - Uses ICMPv6 control messages with RPL message codes
- Each root uses a unique  DODAG ID (IPv6 address) to identify itself within an RPL Instance
- Routing is performed over the DODAG using distance vector techniques
- Every hop to the root MUST have an alternate path
  - (Quite possible and expected 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}

# bjective Function (OF)



- n OF defines how nodes select paths towards DODAG root
  - Dictates rules on how nodes satisfy a optimisation objective (e.g., minimise latency)
  - Based on routing metrics and constraints carried ICMPv6 control messages
- he OF computes a device rank relative to its distance from the DODAG root

Rank =

| Objective Function Example | |
|---|---|
| •Energy Minimisation<br>•Latency | •Link Metrics<br>•Node Metrics |

Rank is higher as distance increases from DODAG root

- erived rank is advertised to other nodes
- F decoupled from the routing protocol
- he RPL specification does not include OF definitions
  - OF related to specific applications defined in separate documents (RFCs)
- ne Objective Function = One RPL Instance {One or more DODAGS}

# bjective Code Points (OCP)

- he OCP indicates the method that must be used to construct the DODAG to meet an OF
  - It allows nodes to be consistent in their rank calculations (all follow the same rules)
  - Defines how node should combine a set of metrics and constraints  in a consistent manner
  - Allows nodes to select DODAG parents and derive a rank to advertise to neighboring nodes
- PL allows OCP to be very flexible in its methods and use of constraints

| xample | OCP Method | DODAG Root |
|---|---|---|
| ixed | Link Latency MUST be < 10 seconds | DODAG root  cannot override  latency constraint |
| lexible | Link Latency SHOULD be < 10 seconds | DODAG root can advertise new latency constraint |
| eneral | Use link with best latency | DODAG root does not advertise any constraint |
| efer | Link Latency should meet advertisedconstraint | DODAG root advertises actual constraint |

- ODAG root can advertise constraints in ICMPv6 messages
- bjective Code Points are 16 bit values assigned by IANA
  - OCP0 defined as the default objective function http://datatracker.ietf.org/doc/draft-ietf-roll-of0/

# outing Metrics and Constraints in LLNs

| | |
|---|---|
| onstraint | Provides a path filter for more suitable nodes and links |
| etric | A quantitative value used to evaluate a path cost |

oncept of routing objects that can be treated as a metric or a constraint

- Low pass thresholds used to avoid unnecessarily recomputing DAG
- Metrics and constraints are advertised in DIO messages

omputing dynamic metrics takes up power and can change rapidly

- Solved by abstracting number of discrete values to a metric

| Link Quality Metric Example | |
|---|---|
| 0 | Unknown |
| 1 | High |

Tradeoff

Reduced accuracy vs overhead and processing efficiency

ttp://datatracker.ietf.org/doc/draft-ietf-roll-routing-metrics/

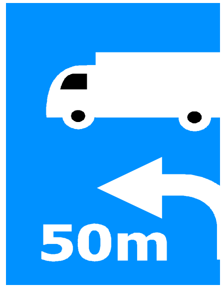
- Specifies the set of link and node LLN routing metrics and constraints

# urrent Routing Metric/Constraint Objects in LLNs

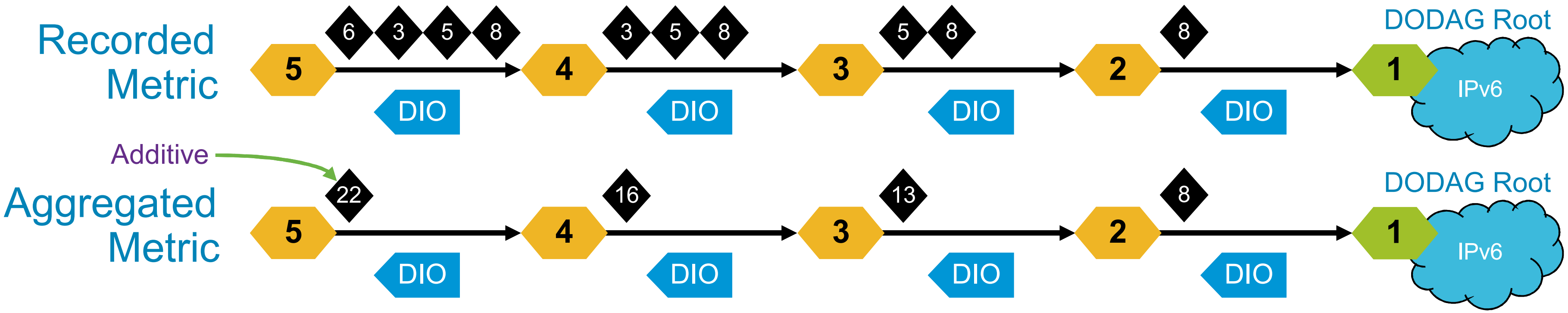
| Node Object | Link Object |
| --- | --- |
| e State and Attributes Object<br>Purpose is to reflects node workload (CPU, Memory…)<br>"O" flag signals overload of resource<br>"A" flag signal node can act as traffic aggregator | Throughput Object<br>Currently available throughput (Bytes per second)<br>Throughput range supported |
| e Energy Object<br>"T" flag: Node type: 0 = Mains, 1 = Battery, 2 = Scavenger<br>"I" bit: 0 = Exclude, 1 = Include (bits set in node type field)<br>"E" flag: Estimated energy remaining flag<br>"E-E" field contains estimated % energy remaining | Latency<br>Can be used as a metric or constraint<br>Constraint - max latency allowable on path<br>Metric - additive metric updated along path |
| Count Object<br>Can be used as a metric or constraint<br>Constraint - max number of hops that can be traversed<br>Metric - total number of hops traversed | Link Reliability<br>Link Quality Level Reliability (LQL)<br>0=Unknown, 1=Highest … …7=Lowest<br>Expected Transmission Count (ETX)<br>(Average number of TX to deliver a packet) |
| | Link Colour<br>Metric or constraint, arbitrary admin value |

k and Node metrics are usually (but not necessarily) additive along a path to the DODAG root

# dvertising Routing Metrics




- lode advertise node and link metrics in a DIO message metric container
- letrics can be recorded or aggregated along the path up to the DODAG root

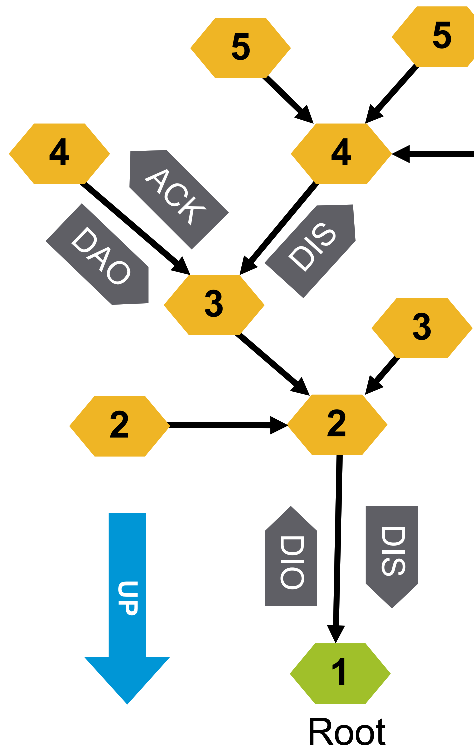



- n aggregated routing metric can be processed in several ways

| Agg Type | Processing | Metric at 5 |
|---|---|---|
| 0x00 | The routing metric is additive | 22 |
| 0x01 | The routing metric reports a maximum | 8 |
| 0x02 | The routing metric reports a minimum | 3 |
| 0x03 | The routing metric is multiplicative | 5760 |

# CMPv6 RPL Control Messages

| ssage | Meaning | Function |
|---|---|---|
| D | DODAG Information Object | DODAG discovery, formation, maintenance |
| S | DODAG Information Solicitation | Probe neigbourhood for nearby DODAGs (DIO messages) |
| O | Destination Advertisement Object | Propagates destination information up DODAG |
| O-ACK | DAO Acknowledgement | Unicast acknowledgement to a DAO message |
| | Consistency Check | Check secure message counters (for secure RPL) |



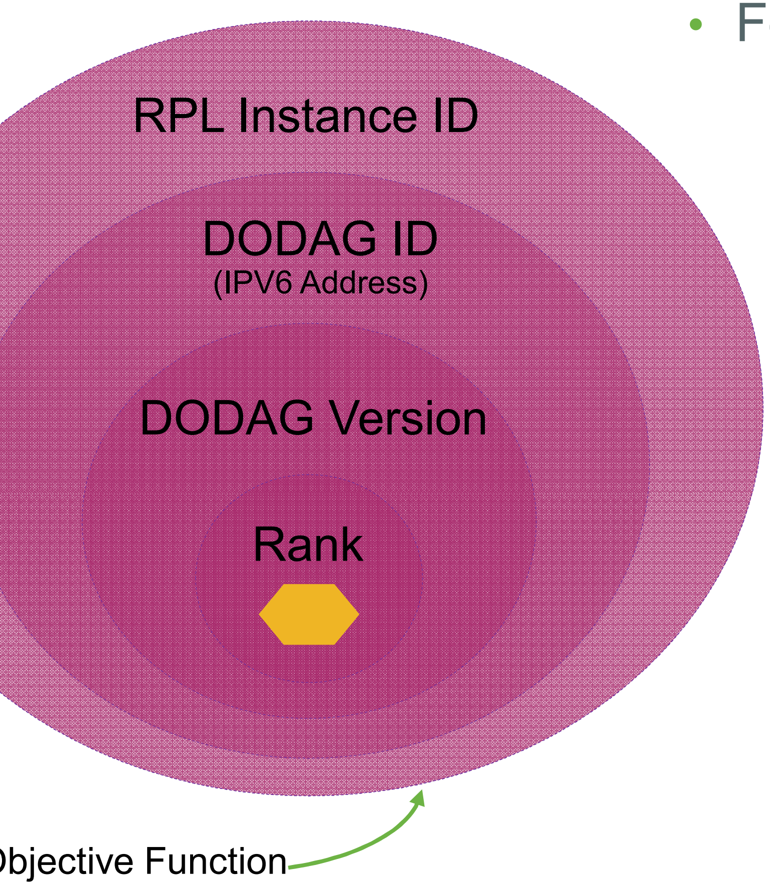

CMPv6 message type 155 - RPL Control message
- Each RPL control message has a secure variant (Refer Section 6.1 of RPL specification)

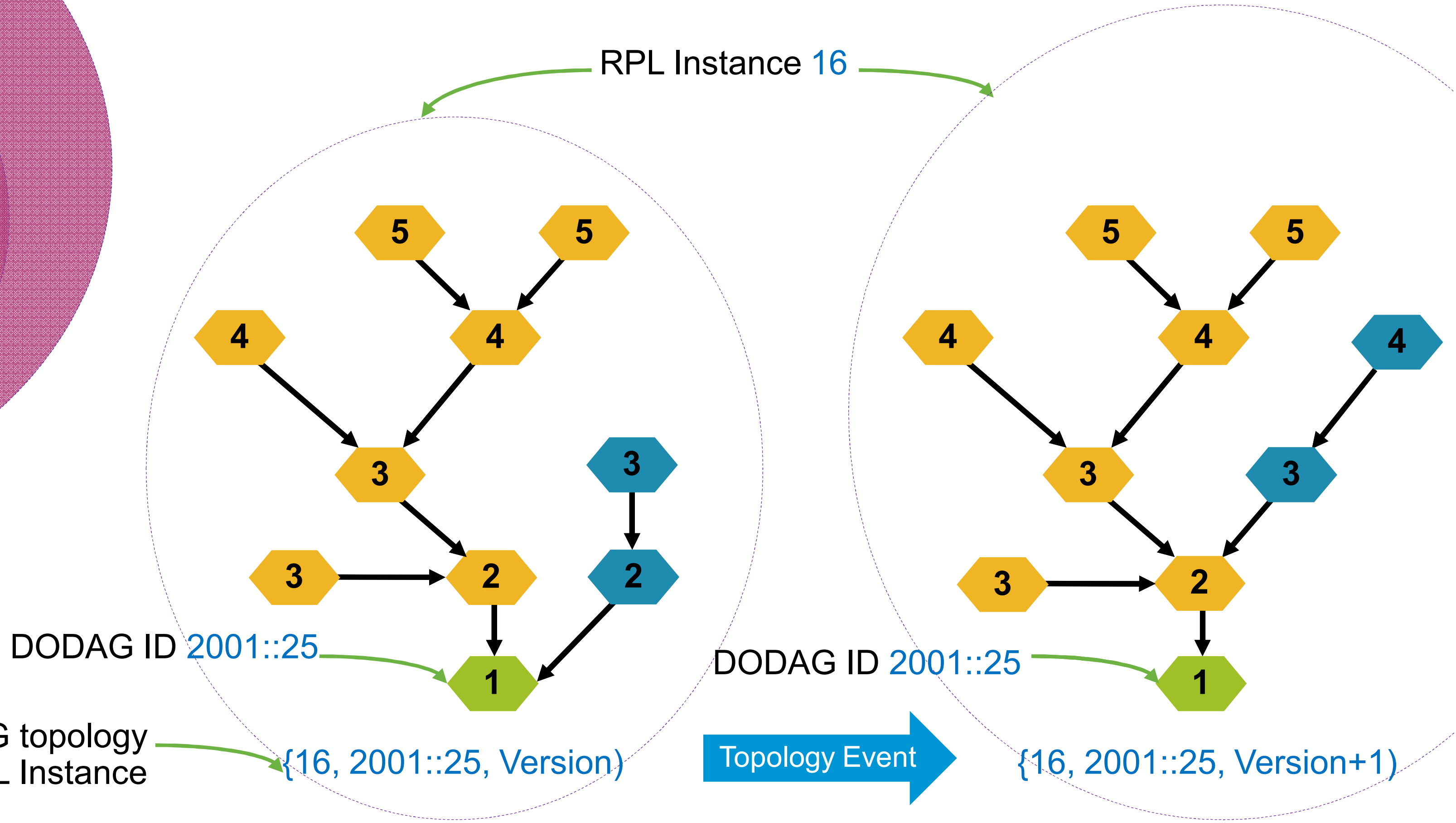
lost RPL control messages have scope of a link
- Exception is DAO/DAO-ACK in non-storing mode passes over multiple hops

| Destination | Source | |
|---|---|---|
| Link Local FE80::/64 | Link Local FE80::/64 | RPL Control Payload |
| All RPL Nodes FF02::1A | Link Local FE80::/64 | RPL Control Payload |
| Global/Unique Local 2000::/3 or FC00::/7 | Global/Unique Local 2000::/3 or FC00::/7 | DAO/DAO-ACK Payload (non-storing) |

# PL 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

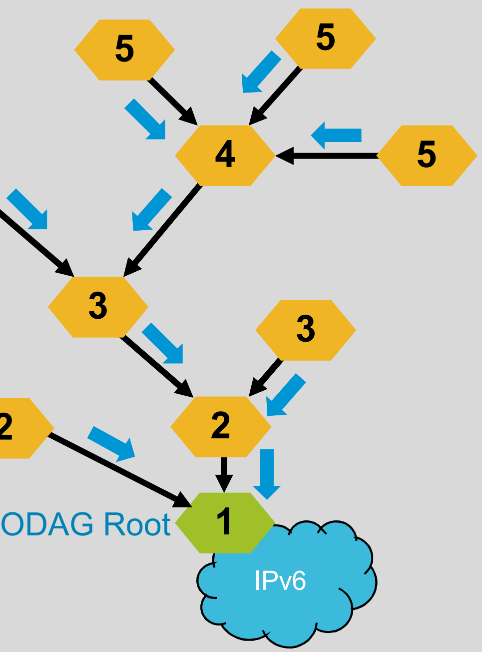


# PL Supported Traffic Flows

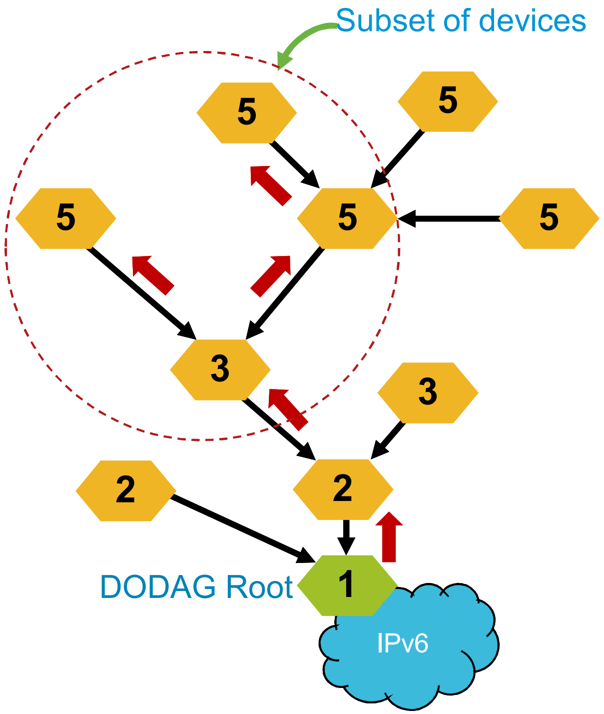
- ultipoint to Point

  DIO messages




- Point to Multipoint

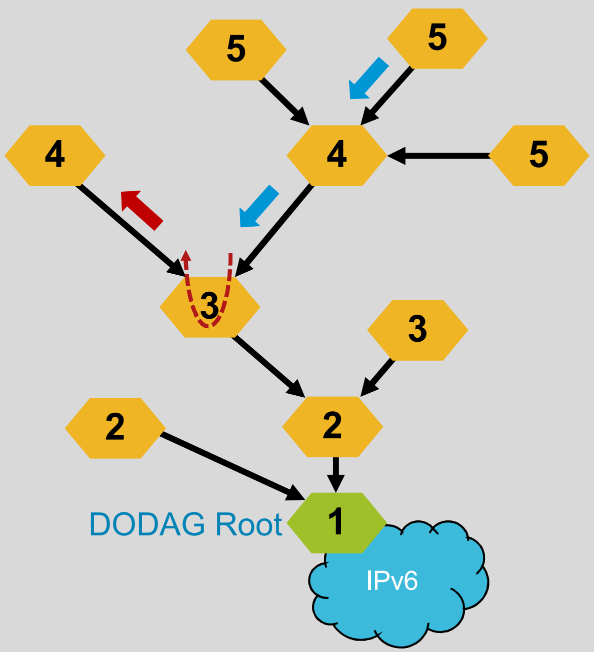
  DAO messages




- Point to Point

  Storing Mode, DAO

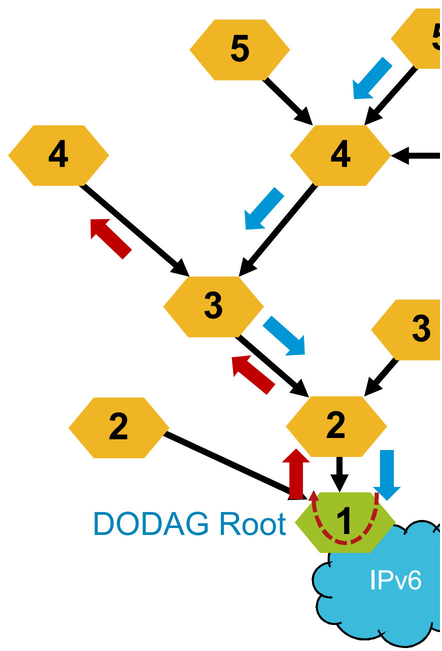
  Fully Stateful




- Point to Point

  Non-Storing Mode

  Source routed to r



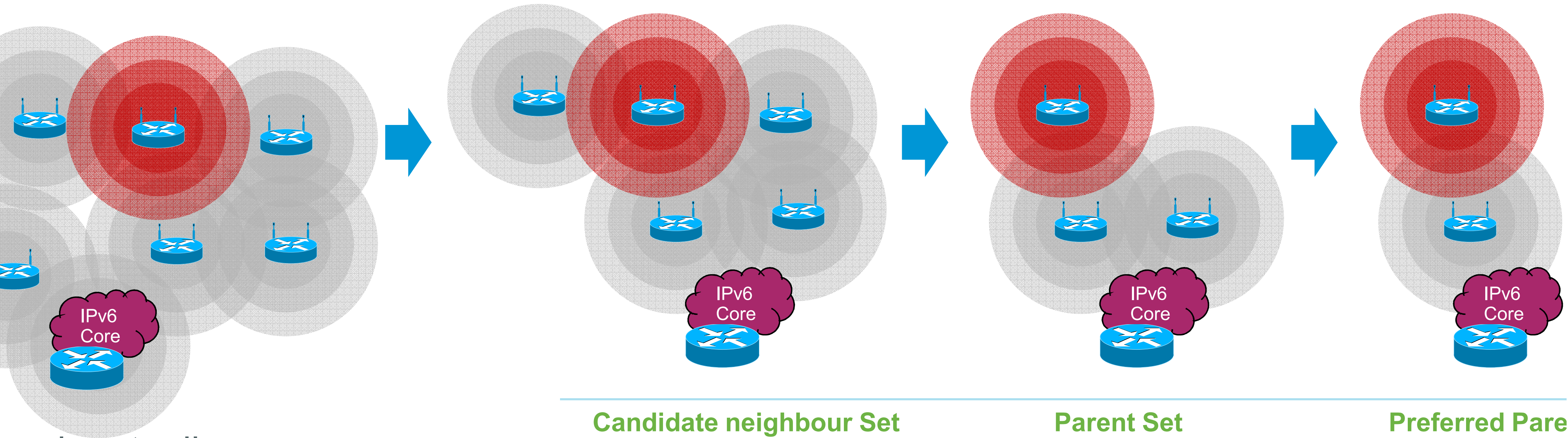
# ODAG Neighbours and Parent Selection

Geographic Layout

Set of Candidate Neighbours

Set of Parents

Preferred Par

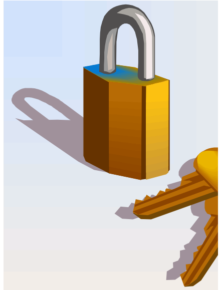



## ward route discovery

- omprises three logical sets of link-local des
- eighbours are learnt from DIO vertisements

| Candidate neighbour Set | Parent Set | Preferred Pare |
|---|---|---|
| Subset of nodes reachable via link-local multicast | Consists of nodes with a higher rank (lower #) | Preferred next-hop to DODAG Root |
| Elements in the set MAY belong to different DODAG versions | Elements in the set MUST belong to SAME DODAG version | Multiple preferred par possible if ranks are e |

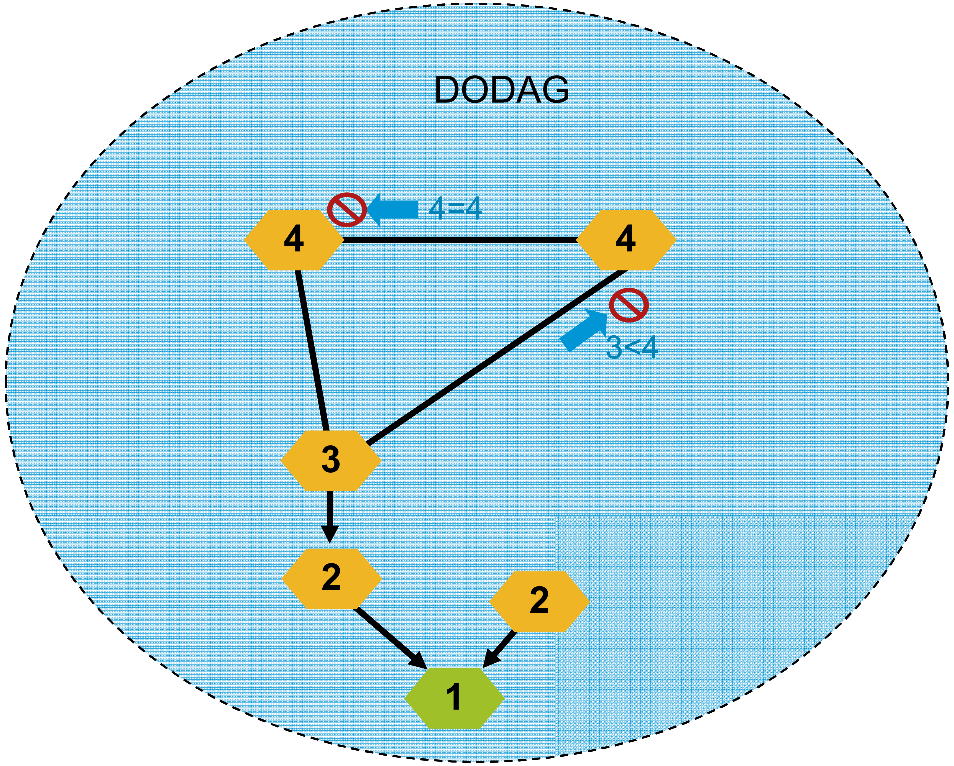
# PL Security



- RPL supports optional message confidentiality and integrity
  - Link-layer mechanisms can be used instead when available
  - RPL security mechanisms can be used in the absence of link-layer
  - Refer to Section 10 of RPL standard
- RPL supports three security modes

| curity Mode | Description |
|---|---|
| **nsecured** | RPL message sent unsecured - may underlying security mechanisms |
| **e-installed** | RPL nodes use same pre-shared/installed key to generate secure RPL messages |
| **uthenicated** | Uses pre-installed key to allow RPL node to join as a leaf only<br>To function as a router requires obtaining a key from authentication authority |

# PL Loop Detection



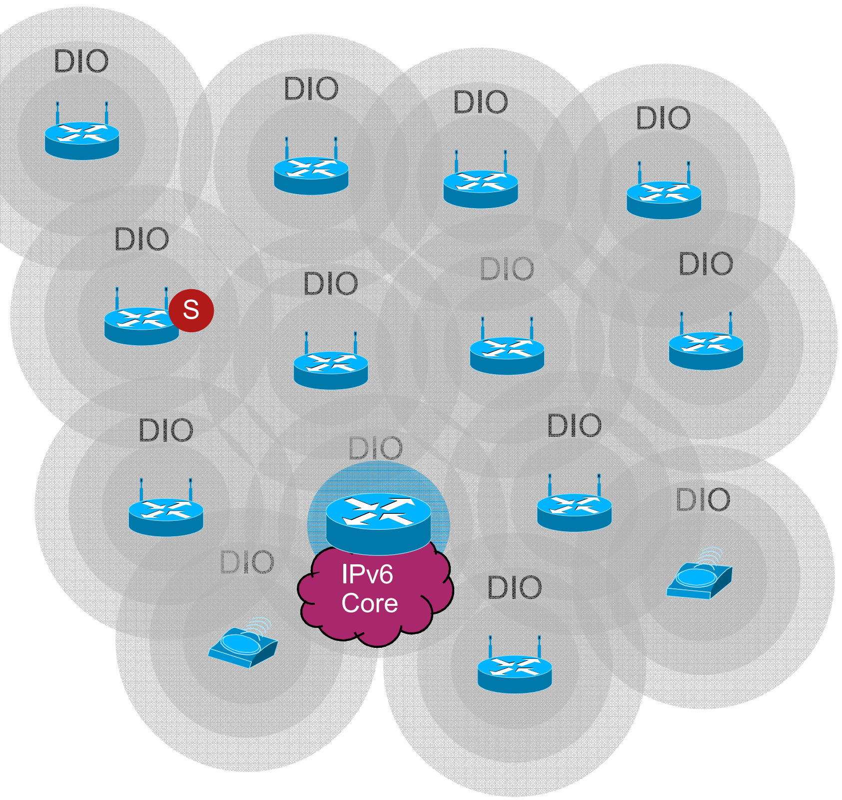

- ata path validation used to check for loops (Simple mechanism)
  - IPv6 options header carries rank of transmitter
- node receives packet with rank <= to its own, drop packet
  - Detection happens when link is actually used.

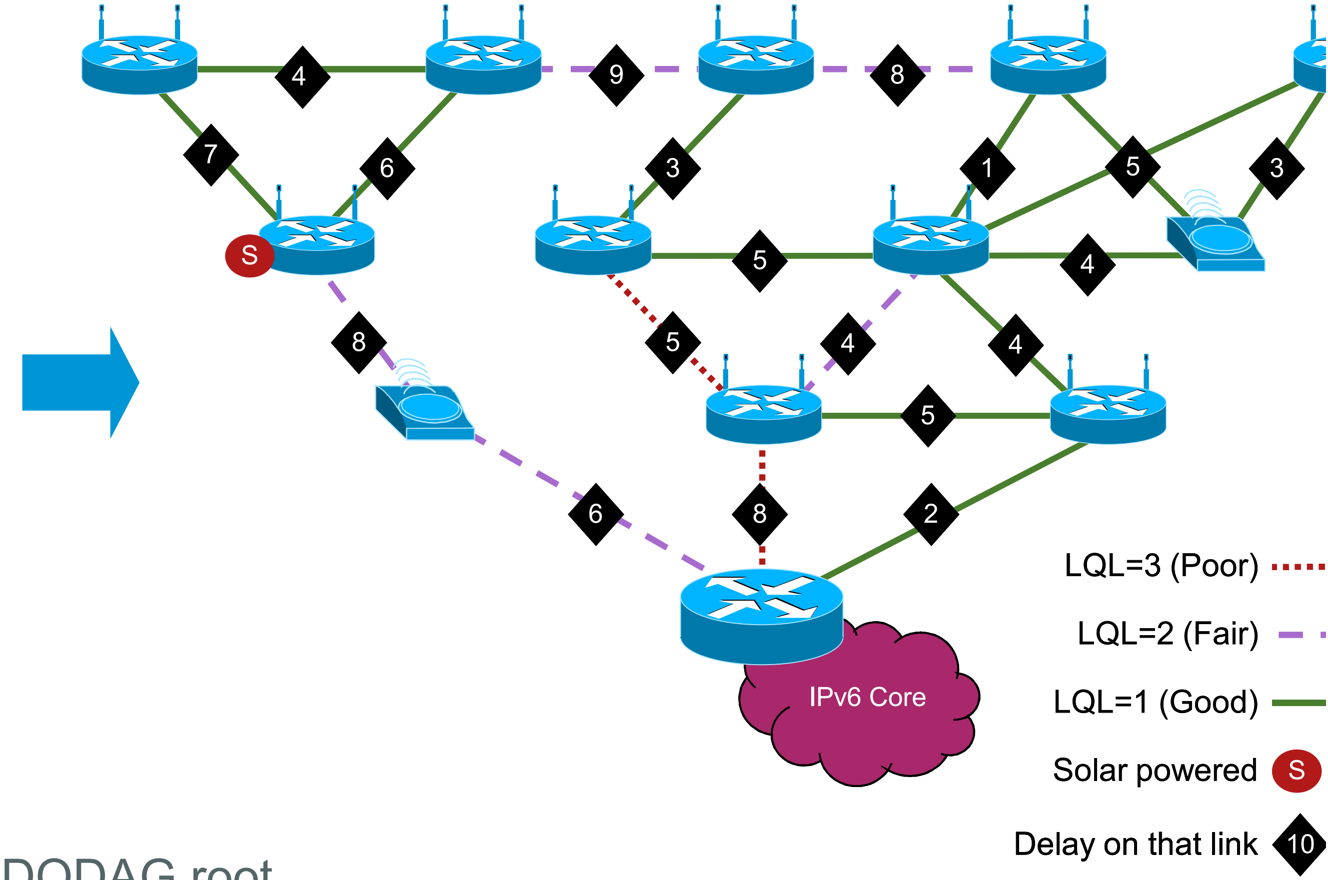
# ODAG Examples

# ODAG Examples

## Geographic Layout




## DODAG Topology

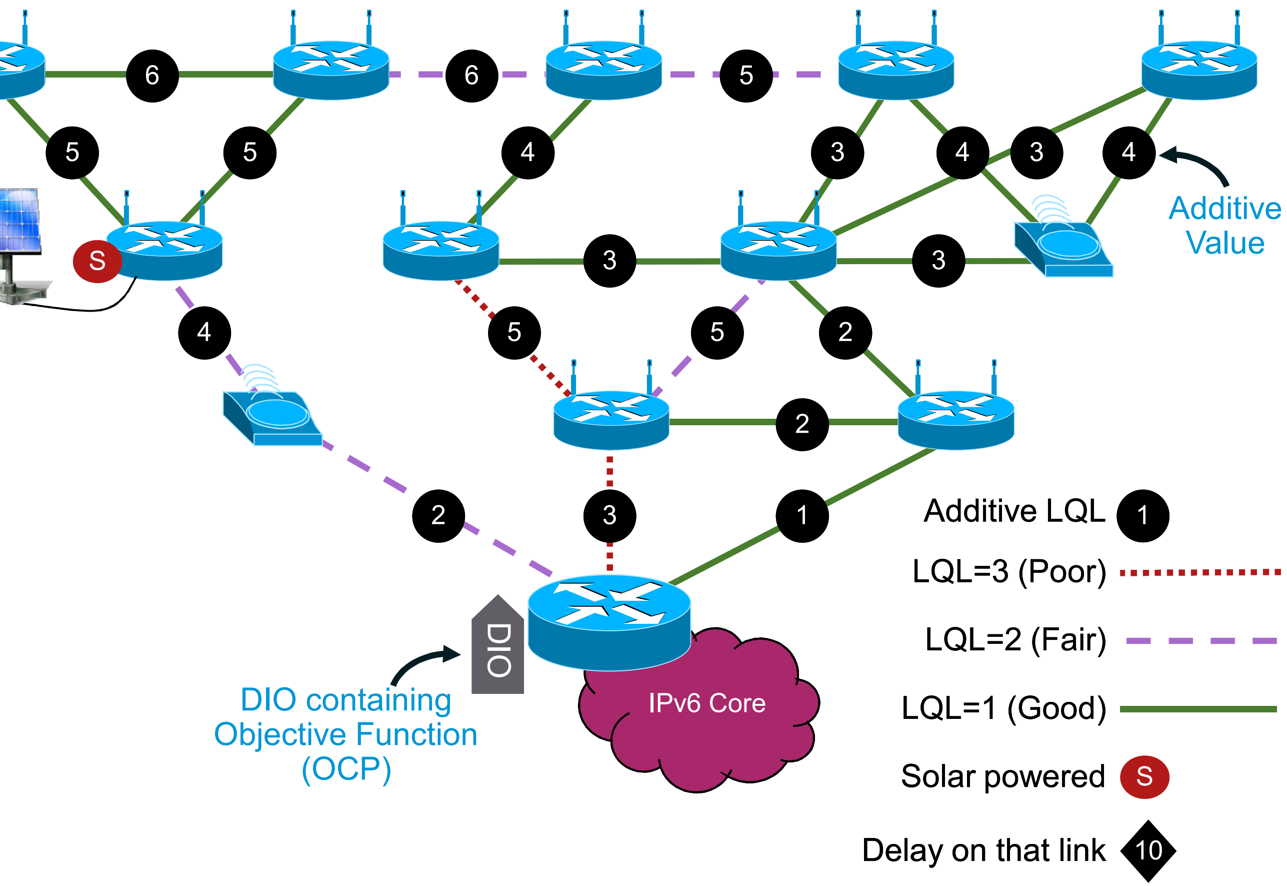



- DIO messages are propagated from the DODAG root
- Can carry OCP, metrics (recorded or aggregated), constraints

# bjective Function Example #1 - Candidate Neighbours

oid solar powered nodes and use the best available links (additive) to get to the DODAG root

## DODAG Topology




## Objective Function

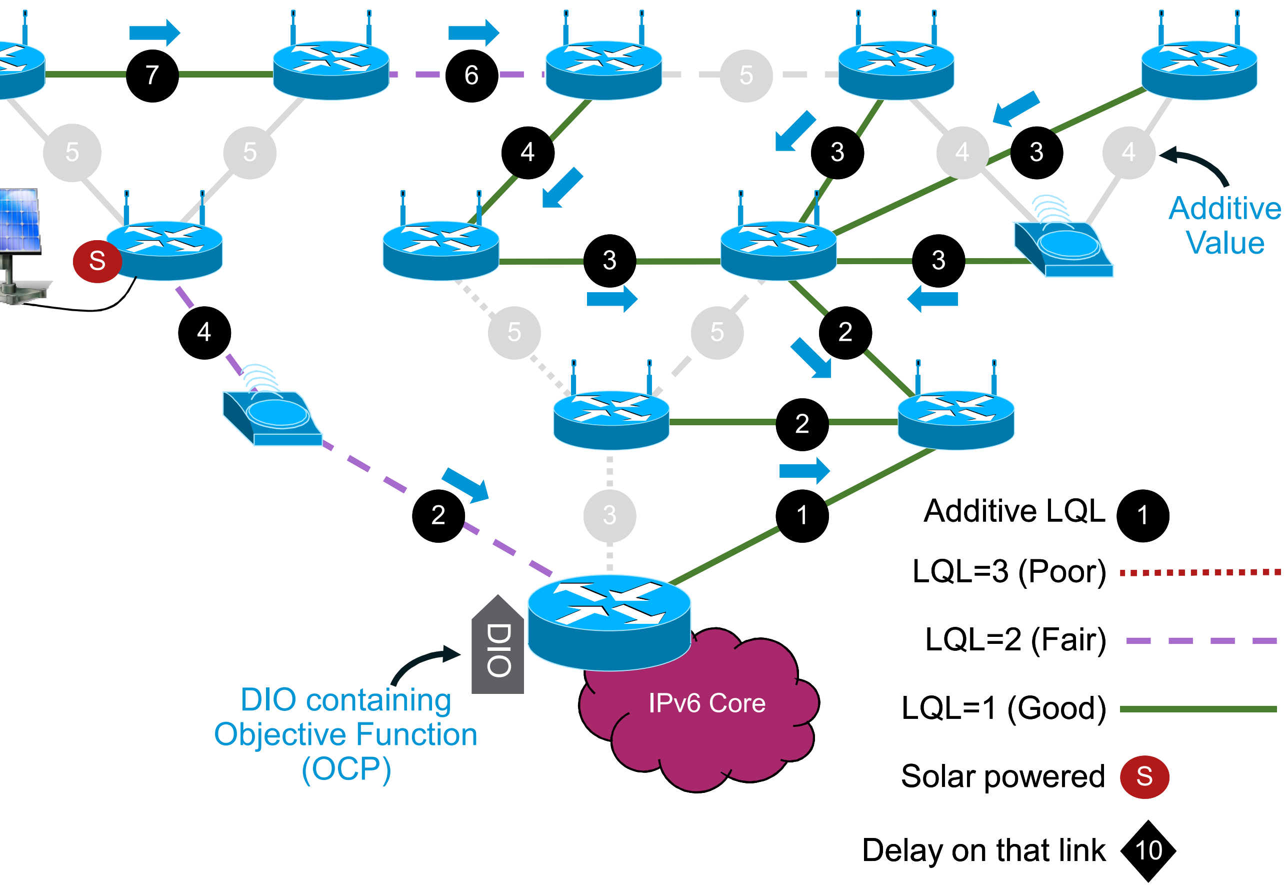
| Object | Constraint | Advertise |
|---|---|---|
| Node Energy | Exclude Scavenger | As per OC |
| Link Quality | Best Available (additive) | As per OC |
| Hop Count | Maximum 20 | Explicitly configure DODAG r |

- LQL metric advertised as additive
- Nodes choose links with lower LQL tota

# bjective Function Example #1 - Preferred Parents

oid solar powered nodes and use the best available links (additive) to get to the DODAG root

## DODAG Topology




## Objective Function

| Object | Constraint | Advertise |
|---|---|---|
| Node Energy | Exclude Scavenger | As per OC |
| Link Quality | Best Available (additive) | As per OC |
| Hop Count | Maximum 20 | Explicitly configured DODAG r |

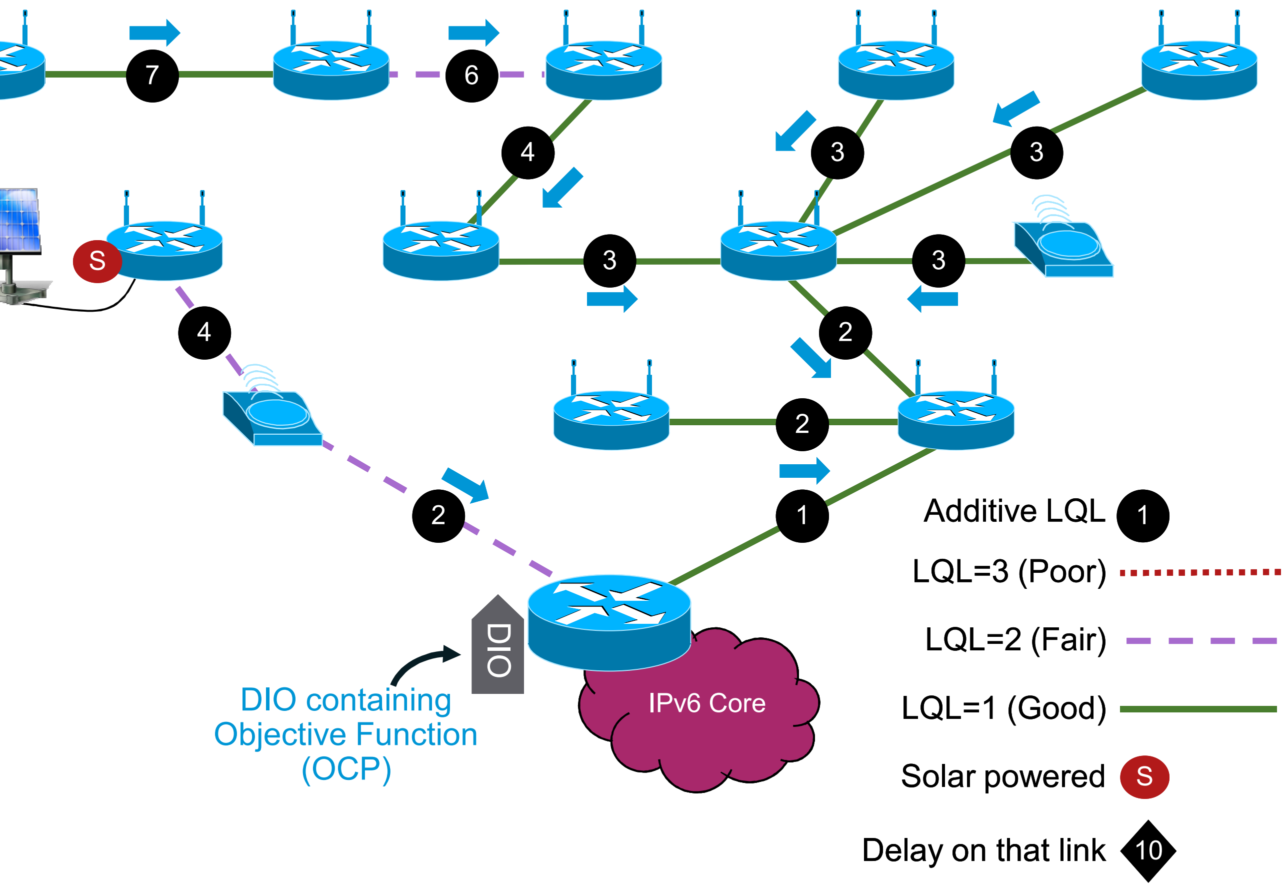
- LQL metric advertised as additive
- Nodes choose links with lower LQL tota

# bjective Function Example #1 - Resulting DODAG

oid battery powered nodes and use the best available links (additive) to get to the DODAG root

## DODAG Topology




## Objective Function

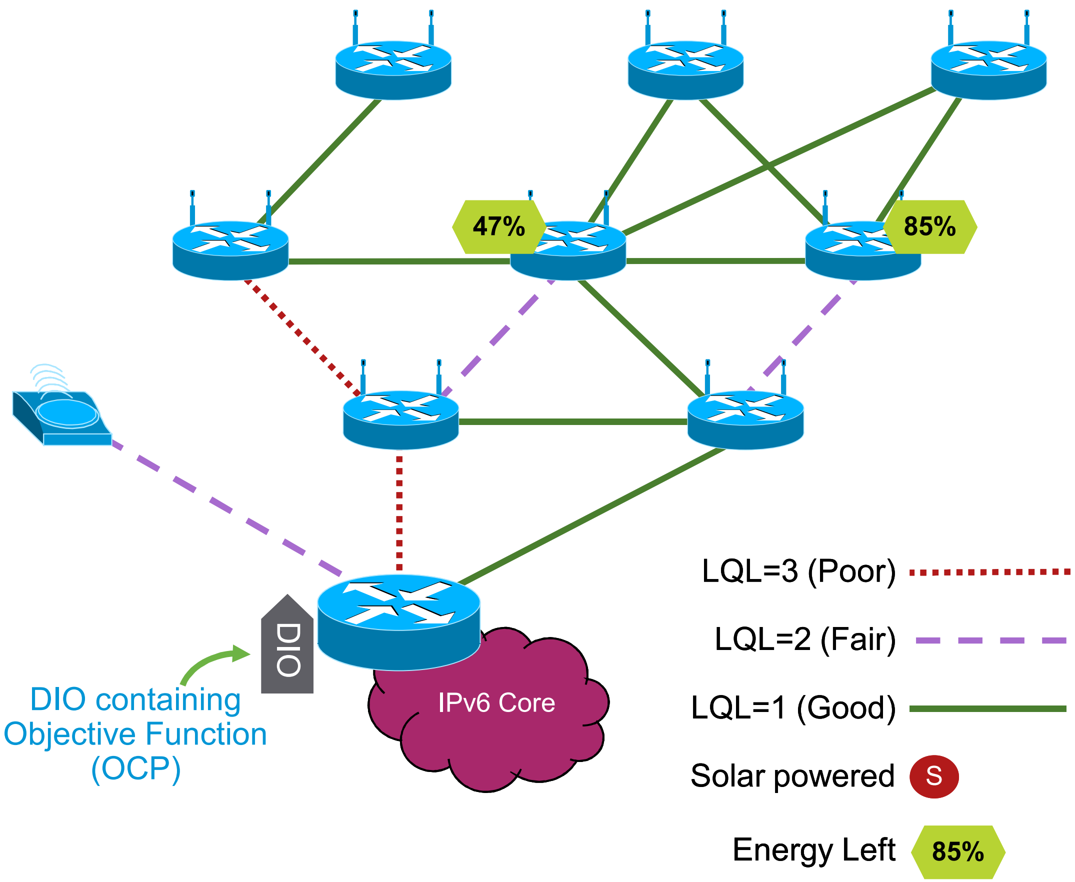
| Object | Constraint | Advertise |
|---|---|---|
| Node Energy | Exclude Scavenger | As per OC |
| Link Quality | Best Available (additive) | As per OC |
| Hop Count | Maximum 20 | Explicitly configured DODAG r |

- LQL metric advertised as additive
- Nodes choose links with lower LQL tota

# bjective Function Example #2 - Candidate Neighbours

e shortest number of hops and avoid low energy nodes

## DODAG Topology



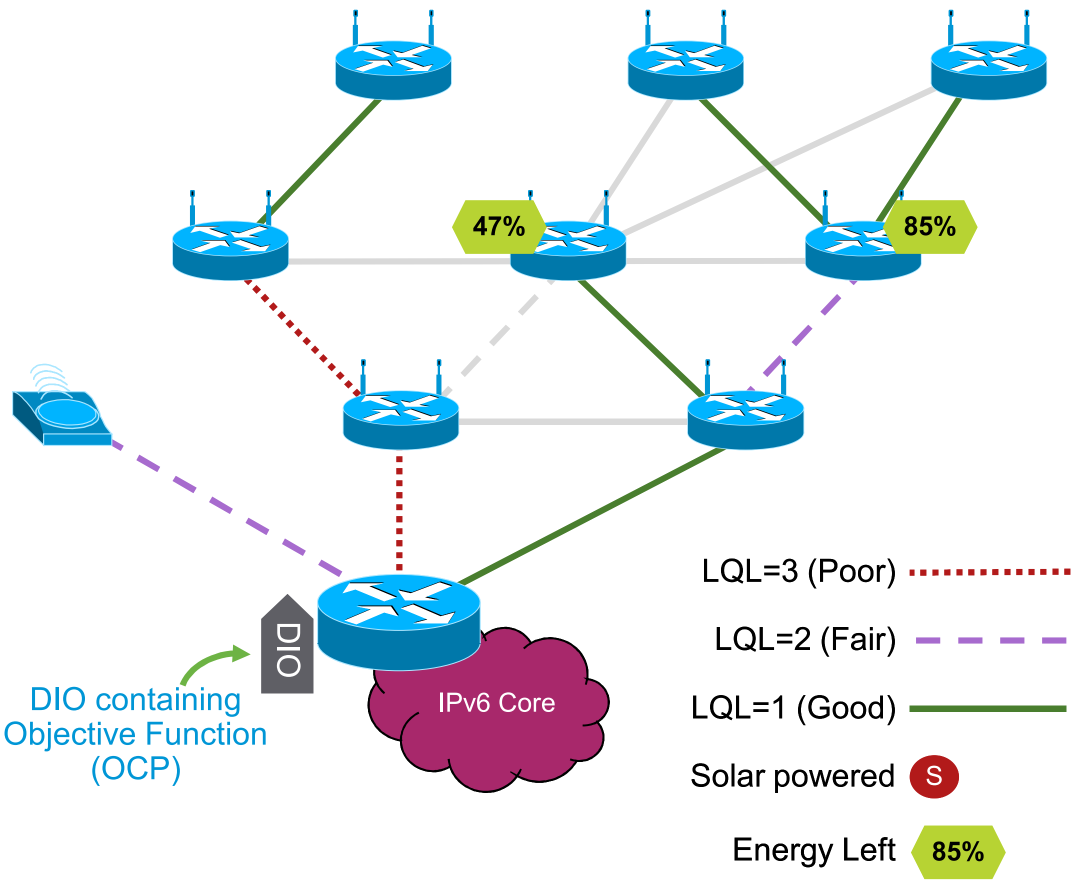

## Objective Function

| Object | Constraint | Advertised |
|---|---|---|
| Hops | Minimum Hops | As per OCP |
| Energy | Avoids nodes in path with < 50% energy | As configured DODAG root |

# bjective Function Example #2 - Preferred Parents

e shortest number of hops and avoid low energy nodes

## DODAG Topology



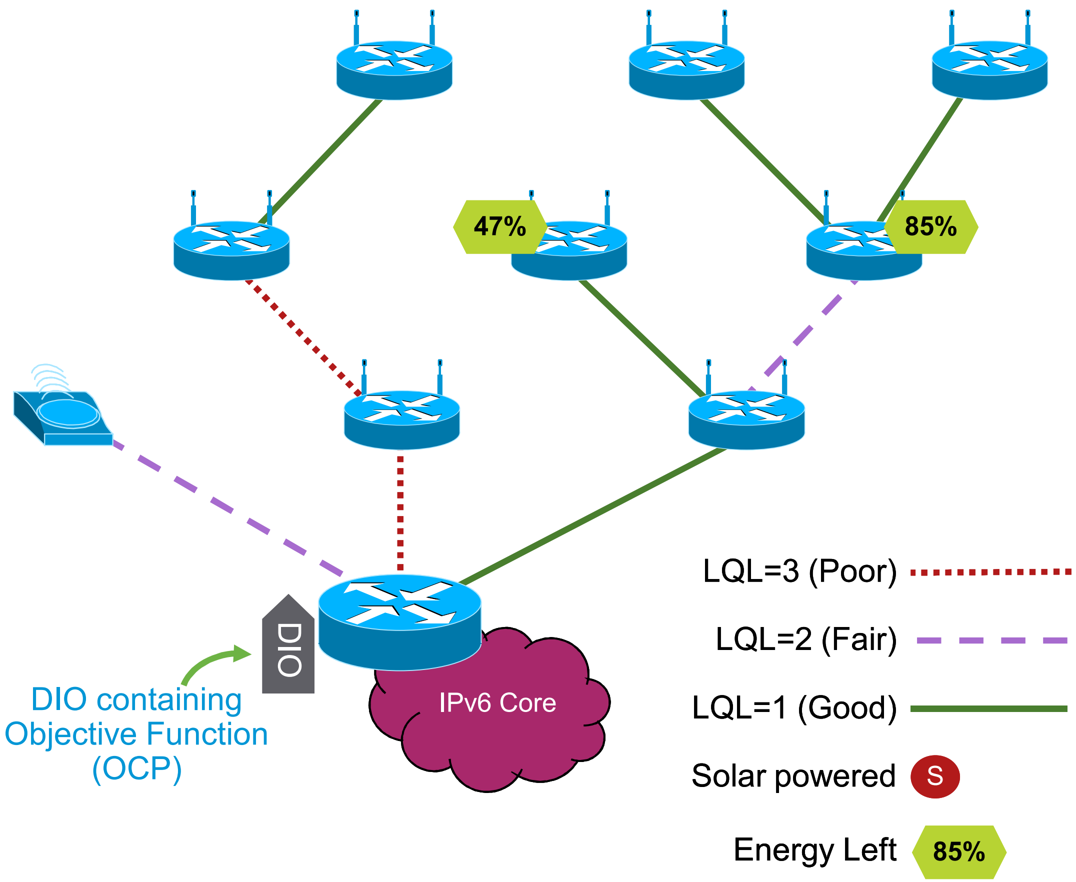

## Objective Function

| Object | Constraint | Advertised |
|---|---|---|
| Hops | Minimum Hops | As per OCP |
| Energy | Avoids nodes in path with < 50% energy | As configure DODAG root |

# bjective Function Example #2 - Resulting DODAG

e shortest number of hops and avoid low energy nodes

## DODAG Topology




## Objective Function

| Object | Constraint | Advertised |
|---|---|---|
| Hops | Minimum Hops | As per OCP |
| Energy | Avoids nodes in path with < 50% energy | As configured DODAG root |

# PL 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 comms)

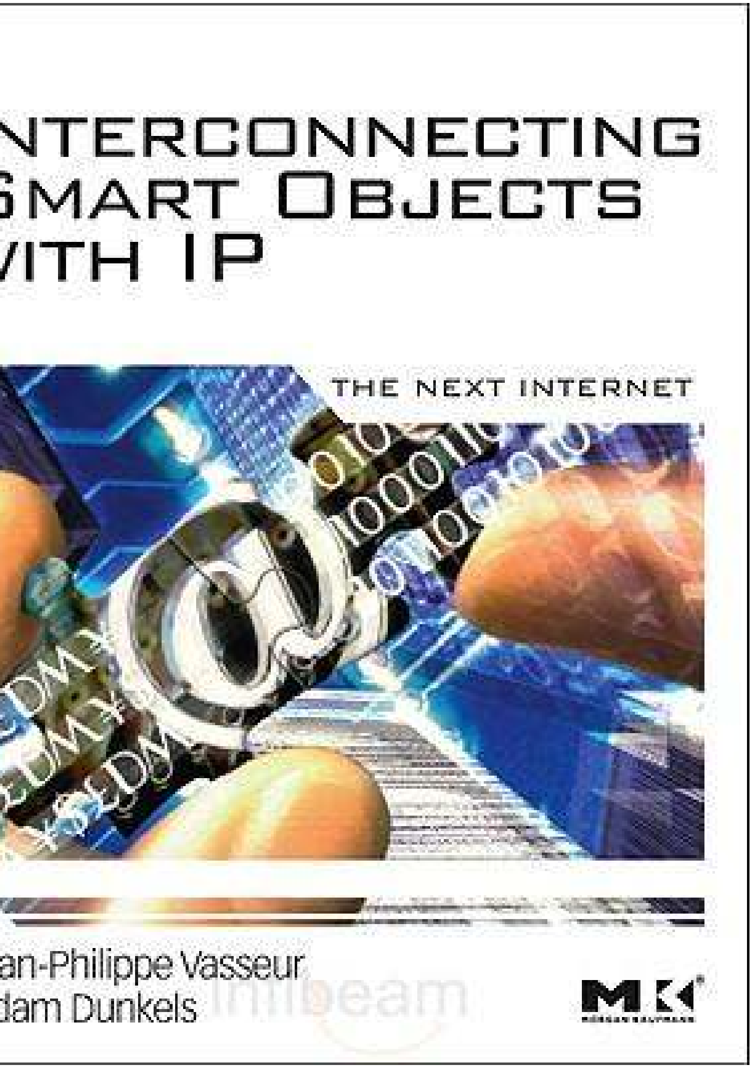
 

# Conclusion

# onclusion

- mart Objects have several major applications
  - Smart Grid, Green, Industrial, Connected building/homes, Smart Cities
  - There is a lot of momentum around using IP
- ajor progress in several key areas
  - IP-based technologies: 6Lowpan, RPL and now CoRE
  - IPSO alliance
  - Adoption of IP by several other SDOs/alliance: Zigbee/IP for SE2.0, Bacnet, ….
- nternet of Things is coming
  - Current Internet = Some things (computers and hosts)
  - Next Internet = Everything!

# ecommended reading




- 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)


cisco