Basic Architecture & Routing in the Internet of Things

Eric Sturzinger

Group Meeting

22 JULY 2016

UCDAVIS

Overview

- General theory and idea of IoT
- Current IETF (Internet Engineering Task Force) Standards
  - 802.15.4
  - 6LoWPAN/IPv6
- ZigBee Alliance – Topologies
- Routing Protocol - RPL
- Objective Functions
  - Metrics
  - Constraints
- Conclusion

General Theory and Idea of IoT

- The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.

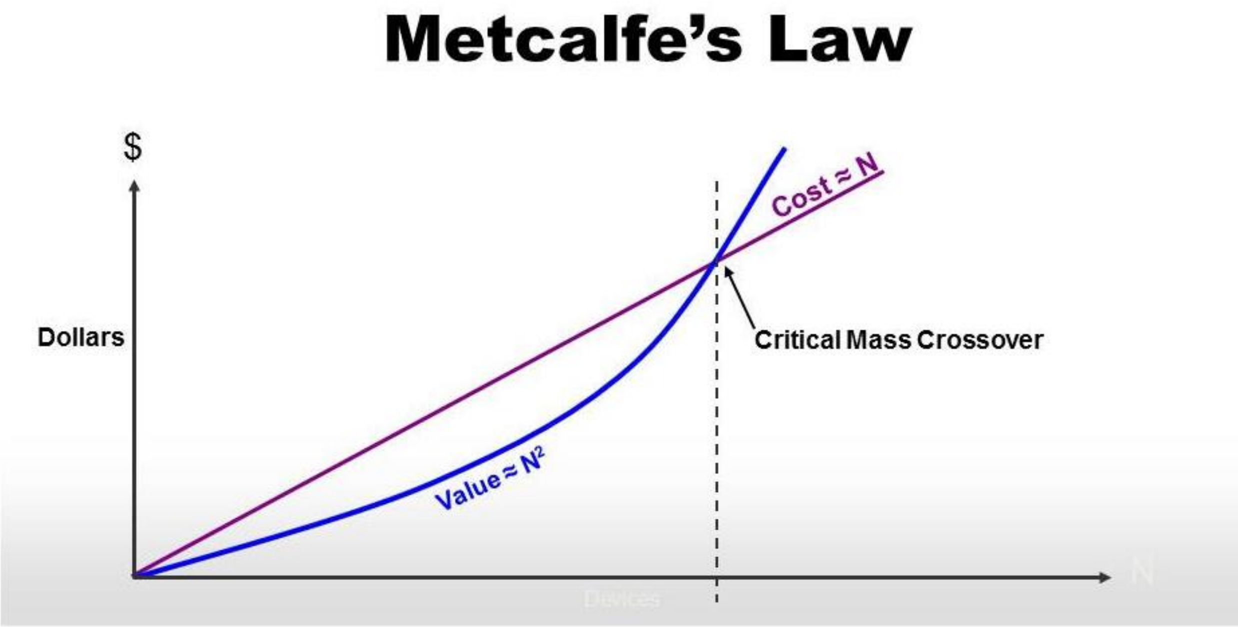
  http://www.gartner.com/it-glossary/internet-of-things/

- Although the core Internet architecture may not change much with the emergence of the IoT, the interaction between distant sensors (or between a sensor and a user) as well as IoT protocols themselves will greatly affect future traffic characteristics and network performance.

- The physical world will become even more integrated with the communications world through sensors/actuators.

- Sensor/device longevity is the single most critical capability enabling the efficient performance of the IoT.

General Theory and Idea of IoT (cont.)



"The Value of a Network is Equal to the Square of the Number of Devices Connected to It"

Estimated 50 Billion devices connected to the Internet by 2020, up from ~15 Billion today.

~$1.7 Trillion spending in 2020, compared to $656 Billion today.

Smart Home Industry alone - $79 Billion in 2014.

General Electric: The "Industrial Internet" market, which refers to connected industrial machinery, will add $10 to $15 trillion to the global GDP within the next 20 years.

https://www.silabs.com/.../bringing-the-**internet-of-things**-to-life.pdf

802.15.4 – 2003, 2006, 2011

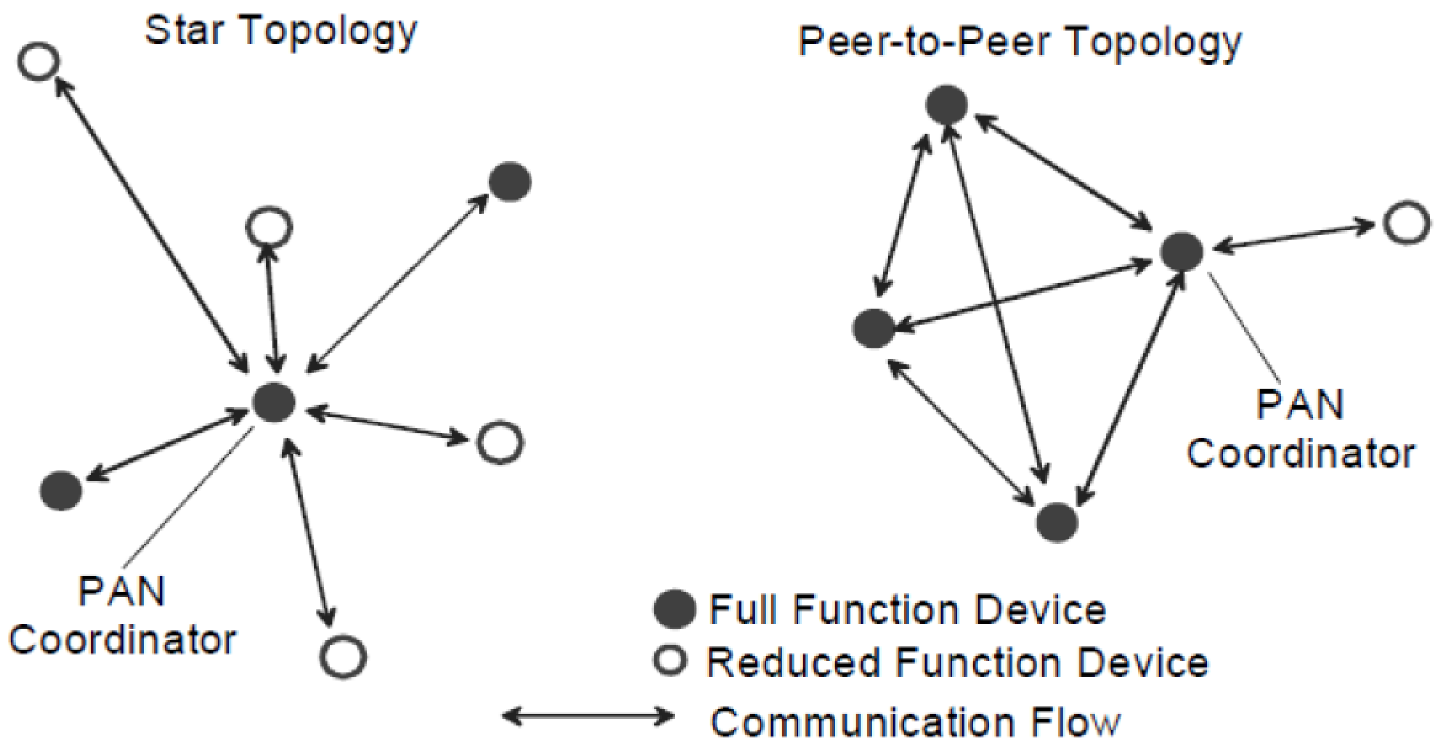
Defines the protocols and their operation at the Medium Access Control (MAC) layer and PHY layer of low-rate Wireless Personal Area Networks (LR-WPANs).

Similar to 802.11x – 2.4GHz band, CSMA/CA, requires very low power, lower data rate ~ 250 kbps, nominal range 10-20 meters, ~ 1mW

Designed to be extremely low cost & interoperable in order to become the official MAC/PHY standard for all IoT "end" nodes within an LR-WPAN

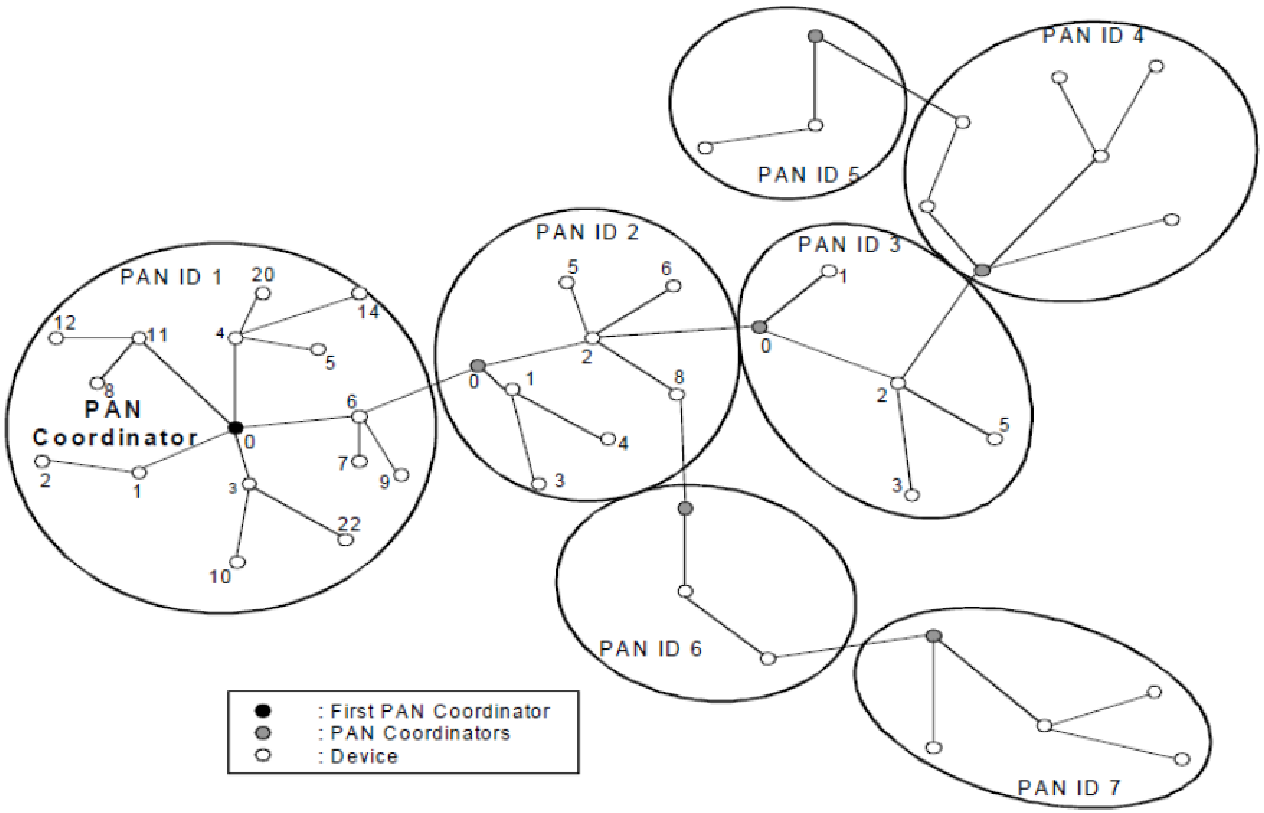
802.15.4 Topologies

MAC Address: 64 bits, manufacturer burned



IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), Sep 2013.

802.15.4 Topologies (cont.) – Cluster of Mesh/Stars



IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), Sep 2013.

UCDAVIS
UNIVERSITY OF CALIFORNIA

6LoWPAN

Ipv6 over Low Power Wireless Personal Area Networks – RFC 3944 – SEP 2007; updated multiple times

Used as an adaptation layer between IP and 802.15.4 in order to apply IP to low power, lossy networks.

Maximum Transmission Unit of IPv6 is min 1280 bytes; 6LoWPAN fragments in order to comply with 802.15.4's MTU of 127 bytes.

Other Features include: Ipv6 header compression: compress standard IPv6 header of 40 bytes down to 3 bytes by eliminating all information obtained from the 802.15.4 MAC header

Ultimately allows IP reachability to any sensor node to/from other location in Internet.

UCDAVIS
UNIVERSITY OF CALIFORNIA

ZigBee Alliance

- Group of specifications built upon 802.15.4 that provides a common application framework for various IoT related applications. First standardized in 2004.

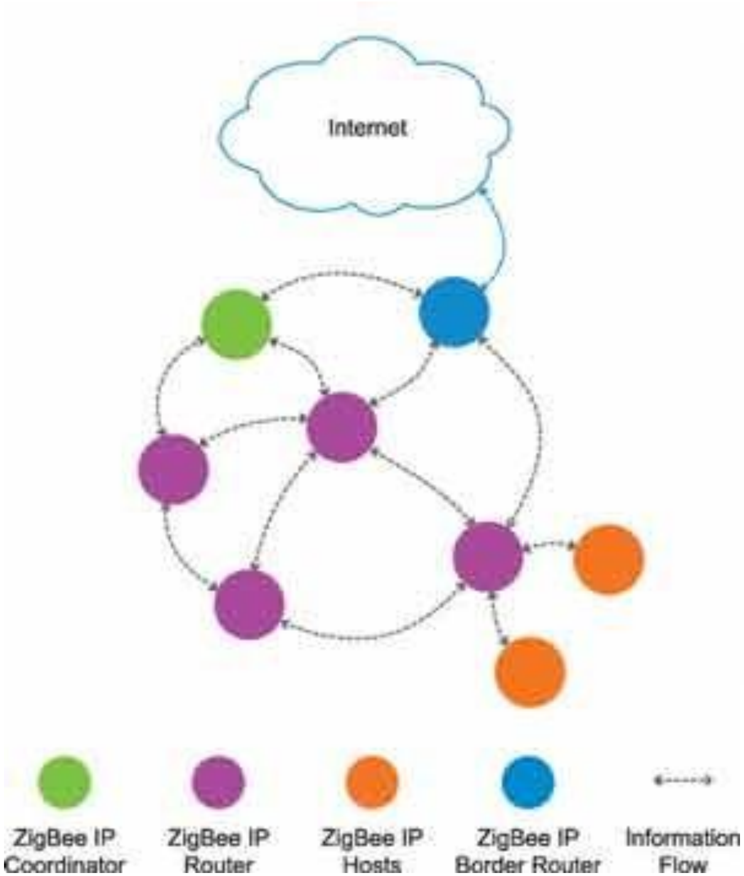
- Employs multiple types of network topologies

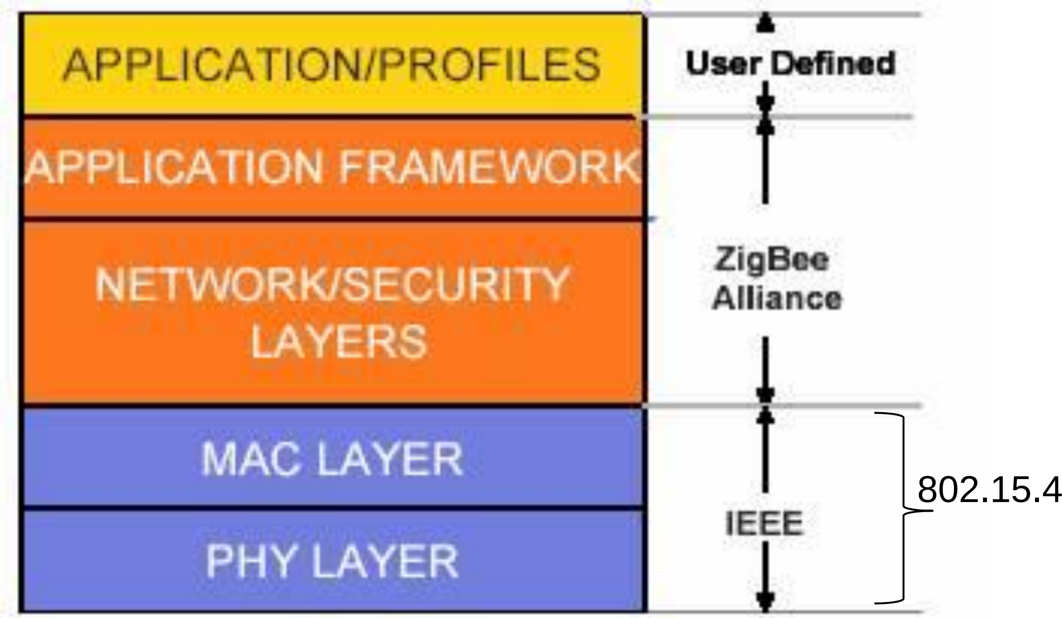
- Products standardized as Zigbee compliant: popular in Smart Home, Wireless Sensor Networks (WSNs), Smart Industrial, Medical, Building Automation, etc.

- Original standard not IP compatible, ZigBee IP released 2013: integrated IPv6 as network layer protocol to enable reachability across Internet by other ZigBee compliant devices.

www.zigbee.org

ZigBee Topologies



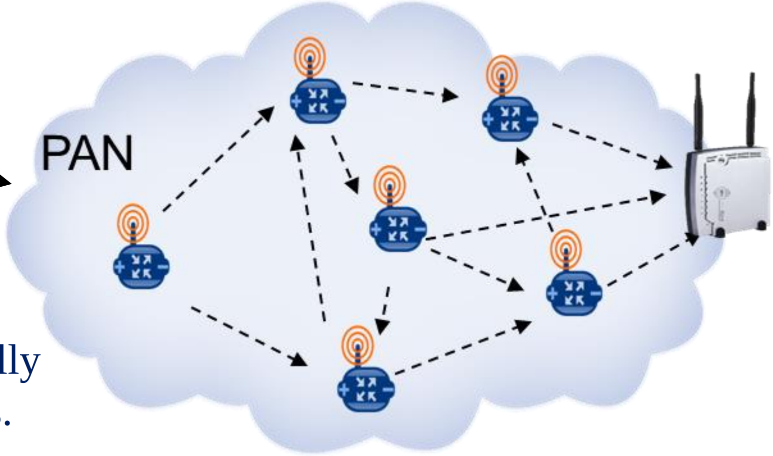


http://www.zigbee.org/zigbee-for-developers/network-specifications/zigbeeip/

Routing Approaches – Mesh Under

- Initial approach with 6LoWPAN: “Mesh-Under” refers to routing of packets below the IP layer.
  - Benefits: Backward compatibility with many non-IP sensor networks already deployed, c. 2011 and prior, transparent to IP layer

Mesh network treated as 1 IP subnet (broadcast domain).



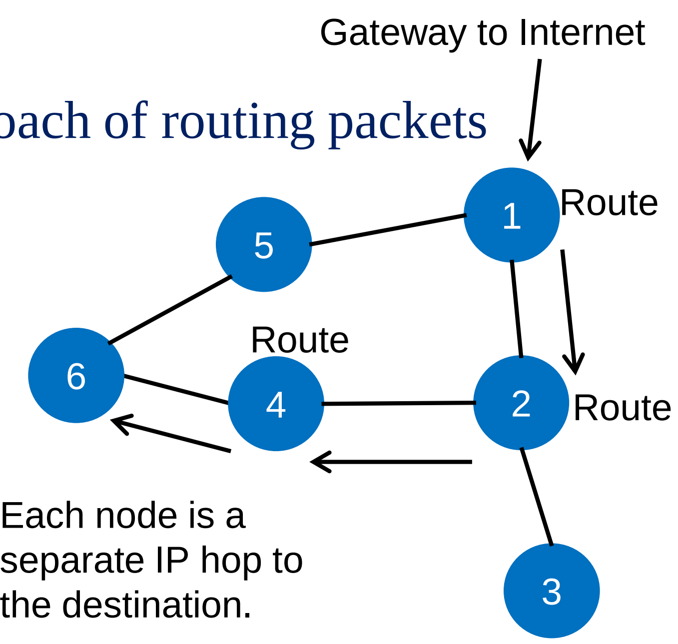
  - Drawbacks: End to end route metrics difficult to quantify accurately as some end points may be much further (logically & physically) from gateway than others.

“L6-6LoWPAN”, Culler, David, E., University of California, Berkeley, 2008.

UCDAVIS
UNIVERSITY OF CALIFORNIA

Routing Approaches – Route Over

- Route Over refers to the more traditional approach of routing packets at the IP layer, similar to traditional IP routing
- Benefits: End to end path metrics easier to compute, more reliable in larger, more complex LLNs
- Drawbacks: Older standards had to be updated to support IP (most new standards (ZigBee IP) employ Route-Over method)



“L6-6LoWPAN”, Culler, David, E., University of California, Berkeley, 2008.

RPL

- IETF RoLL WG: IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL), Approved 2012

- Distance Vector Protocol – specifies how to build the Destination Oriented Directed Acyclic Graph (DODAG)

- An Objective Function is used, with input metrics and constraints, to build the DODAG, computing the best path between nodes (or to the root).

- Traffic types to consider: Point-to-Point, Point-to-Multipoint (multicast), and Multipoint-to-Point: functions of applications

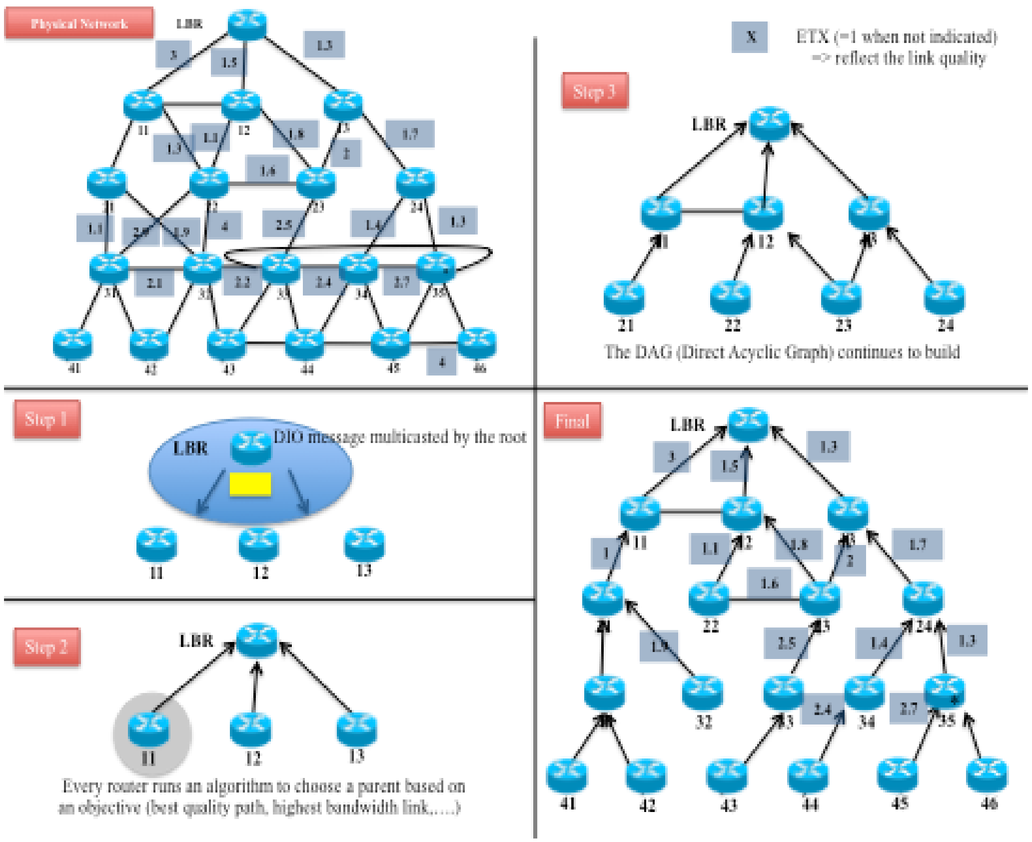
RPL (cont.)

1) To initiate graph construction, root sends messages to adjacent nodes. Nodes decide (via objective function) whether to join the DODAG, which node(s) will be its parent(s), etc. Node determines its rank from root (distance).

2) If configured as a router, node passes this information to its physical neighbors, etc., process repeats.

3) When all nodes have path(s) to root, process stops.

4) Upon joining the graph, a node also sends Destination Advertisement Object (DAO) messages to its parent to advertise the prefixes of downstream devices. (source routing for downstream traffic)

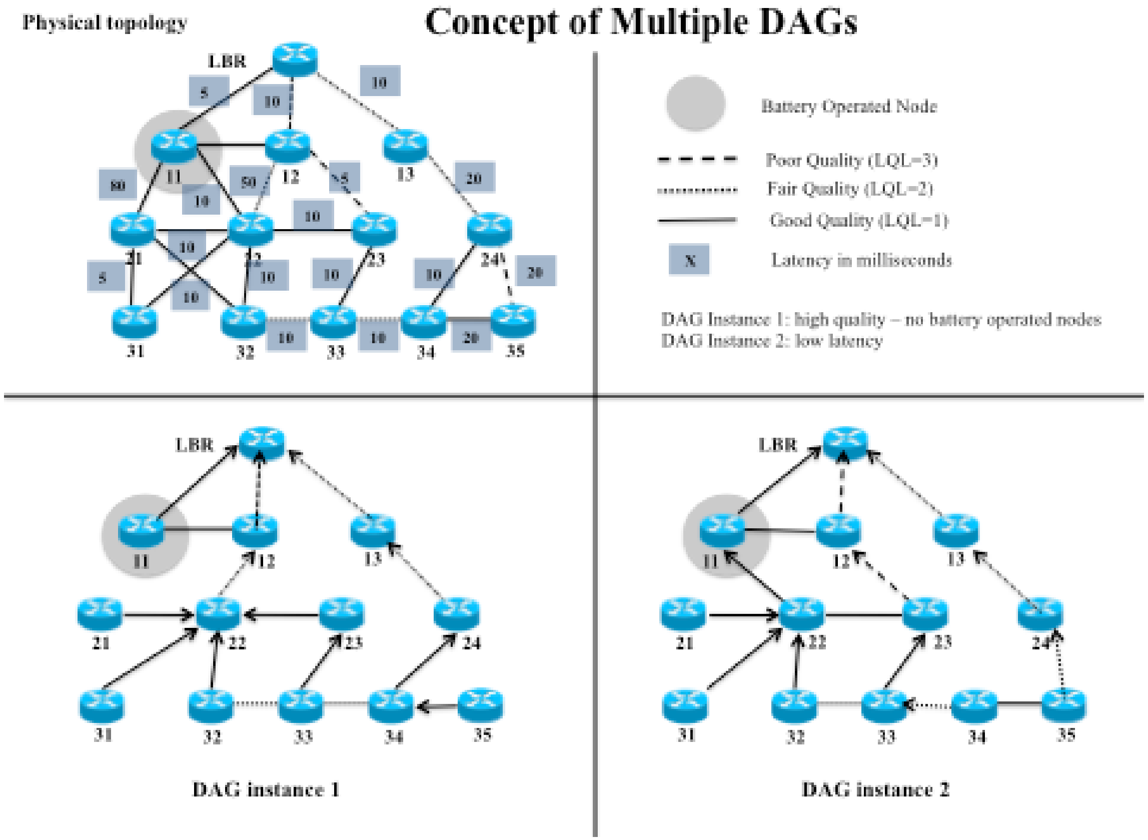


http://www.ipso-alliance.org/wp-content/media/rpl

UC DAVIS
UNIVERSITY OF CALIFORNIA

RPL (cont.)

Nodes can belong to different DODAG instances, allowing different types of traffic to be routed according to multiple sets of optimization objectives



Critical traffic carried over battery powered Node for low latency; remaining traffic over high quality path

Multi-topology-routing ideal for networks Supporting sets of diverse applications and Traffic patterns

UCDAVIS UNIVERSITY OF CALIFORNIA

http://www.ipso-alliance.org/wp-content/media/rpl

Metrics/Constraints

- Same concepts as with traditional routing parameters

- Node metrics: energy state (remaining lifetime), antenna sensitivity, ability to encrypt packets, CPU workload, available memory, type of power (battery, industrial, scavenger – solar, wind)

- Link metrics: actual throughput, actual path or link latency, reliability – packet/bit error rate, MTBF, Expected Number of Transmissions (ETX)

- Constraints: must use shortest path (hop count), processing power is maximum, link encryption support,
- Metrics and constraints used as inputs to Objective Functions

Objective Functions

- An Objective Function defines how one or more node and link metrics and constraints are used to compute the node rank and how the node's set of parents and preferred parent are chosen.
- The ETX Objective Function (ETXOF) is designed to select parent that provides delivery with the least number of transmissions.
- Computed using the ETS metric for a path to the root through a candidate neighbor n:

$$ETX = \frac{1}{D_f * D_r}$$

  - ETX(n) + MinPathETX(n), where ETX(n) is the ETX metric for the link to neighbor and MinPathETX(n) is the ETX metric advertised by that neighbor

Df = measured probability that a packet is received by the neighbor,
Dr = measured probability that the ack packet is successfully received

Gnawali, O., Levis, P.: The ETX Objective Function for RPL. draft-gnawali-rolletxof-01.txt (2010)

Objective Functions (cont.)

- Objective Function Zero – the default basic OF, calculates a node rank by adding a scalar to the rank of the candidate neighbor.
- The rank is increased by a weighted value (determined by the common link)
- Ideal to use this OF based on the ETX metric of the link toward the root
- LQL – Link Quality Level – used to quantify the link reliability using a discrete value: 0-7, 1 being the best value & 0 unknown.
- based on the link reliability metric: BER, packet error rate, etc

Df = measured probability that a packet is received by the neighbor,
Dr = measured probability that the ack packet is successfully received

UCDAVIS UNIVERSITY OF CALIFORNIA

Brachman, Agnieszka. "RPL objective function impact on LLNs topology and performance." *Internet of Things, Smart Spaces, and Next Generation Networking*. Springer Berlin Heidelberg, 2013. 340-351.

Further Analysis

- Application Profiles as a function of P2MP, P2P, MP2P traffic
  - Mixtures, not mutually exclusive
  - Profile per individual application?

- Effects of RPL and objective function design on network performance

- **Logical topology optimization as a result of a new objective function – tailored for specific application profiles**

- Correlate logical topology with desired performance metrics, by profile