The Internet of Things
"Dream or Reality ?"

Italy – July 2010

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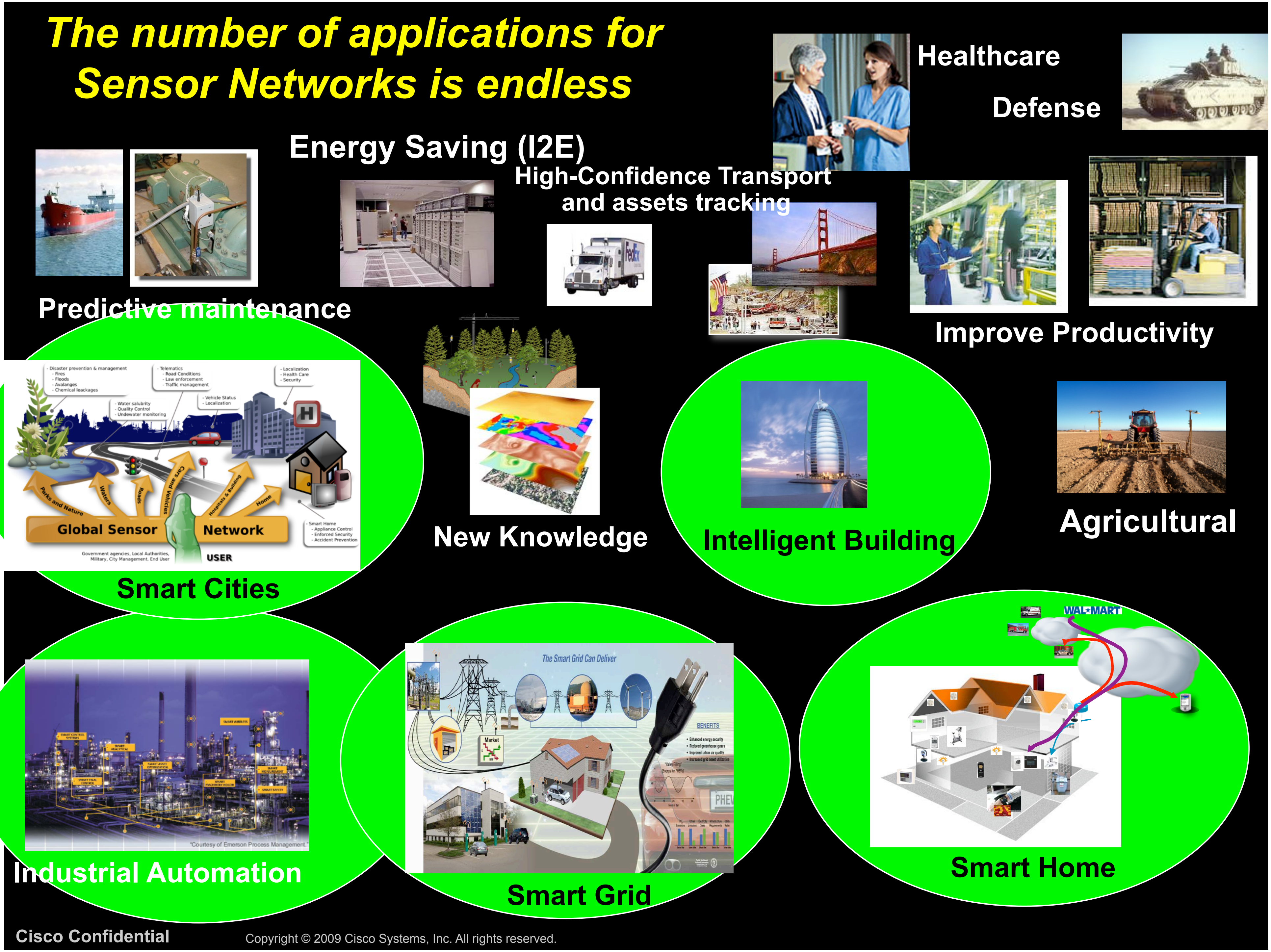
Chair: IETF ROLL and PCE Working group, IEEE P1901.2 IPPAL sub-group, Wavenis IP WG, IPSO Technology Advisory Board

Few words …

- Thanks to Sensorcomm
- First presentation on the subject matter in 2007 in Spain
- Due to lack of time, we could not run a demo … next year ?
- My only objective ?

Demonstrate with facts this the Internet of Things (IP Smart Objects networks) is a reality !


The number of applications for Sensor Networks is endless
Healthcare
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High-Confidence Transport and assets tracking
Predictive maintenance
Improve Productivity
Global Sensor
Network
USER
Smart Cities
New Knowledge
Intelligent Building
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The Smart Grid Can Deliver
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One of the major issues ~3 years ago …

- High number of ***proprietary or semi-closed*** solutions: Zigbee, Z-Wave, Xmesh, SmartMesh/TSMP, … at many layers (physical, MAC, L3) and most chip vendor claim to be compatible with their own ***standard***
- Many non-interoperable "solutions" addressing specific problems ("*My application is specific" syndrome*)
  - Different **Architectures**,
  - Different **Protocols**

… with … The usual "*My environment has specific requirements and requires a specific solution*" syndrome => Local versus global optimum !!

=> Deployments were limited in **scope** *and* **scale,**

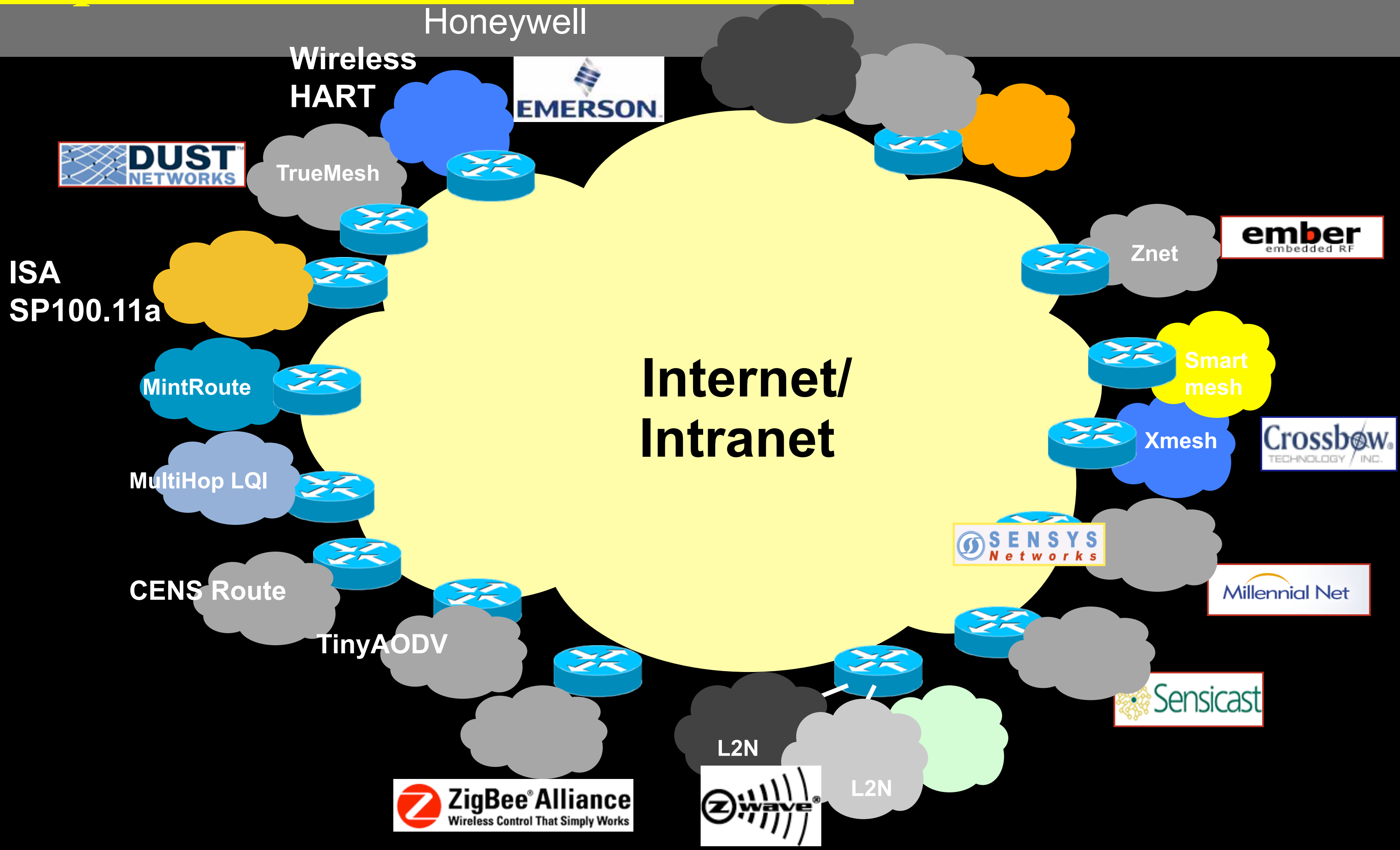
Why not IP ?

A Long list of myths and/or misunderstandings …

- **IP is way too greedy and heavyweight for constrained devices …**
- **IP is unsecure**
- **Proprietary means secure …**
- **IP not optimized for these constrained environments (several protocols not usable in LLNs)**
- **IP smart object networks are opened to anyone in the Internet**

Just wrong … see next slides

So far … WAS (Wait And See) - *The current Trend* *(Slide presented at the IETF – 2007)*



Most promoters of non-IP solutions have understood that IP was a MUST: they call this "IP convergence": A protocol translation gateway ! Or Tunneling …

IP end to end for "The Internet of Things" is a MUST …

Why not using protocol translation gateways ?

- Very different situation than 15 years ago with SNA, IPX, …
- Just fine as a *migration* strategy (to migrate "legacy" protocols)
- Protocol translation gateways is the wrong approach for the "Internet of Things":
  - Expensive and difficult to manage (CAPEX and OPEX)
  - Number of technical issues: end to end lack of QoS, routing and fast recovery consistency
  - Force down the path of the least common denominator
  - Clearly not an enabler for innovation
  - Different scale !
  - Security holes …

So … which protocol and architecture for sensor networks ?

- The architecture and protocol MUST have a specific properties:
- Based on **open standards**: for interoperability, cost reduction and innovation … almost all proprietary protocols died …
- **Flexibility** in many dimensions:
  - Support a wide range of media
  - Support a wide range of devices
- **Always favor global than local optimum**: all protocols solving very specific issues never survived ☹ - We live in a fast changing world
- Highly secure
- **Plug & Play**
- **Scalable**

A plethora of emerging new low power media for Smart Object

- Things are fast changing since the historical serial connection with RS485 …
- Then wide adoption of IEEE 802.15.4 as *the* low power RF technology (2.4 GHz *and* 900 MHz)
- As expected (and this is the good news) several other low power technologies have emerged:

  Power Line Communication (PLC): key for the home and the Smart Grid: see new ITU initiative (G.nem), IEE P1901.2 and HP Green PHY

  Low power Wifi

  New RF technologies: IEEE 802.15.4g, Wavenis, …

IP Smart obejcts networks are made of a variety of links !

Isn't IP too greedy for constrained devices ?

Open source lightweight stack delivered →uIPv6

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Cisco, Atmel and the Swedish Institute of Computer Science (SICS) Collaborate to Support a Future Where Any Device Can Be Connected to the Internet

One of the World's Smallest Open-Source, IPv6-Ready Protocol Stack Enables Cost-Effective Deployment of Sensor- Based 'Smart' Objects

SAN JOSE, Calif., and BANGALORE, India, October 14, 2008 - Cisco, Atmel and the Swedish Institute of Computer Science (SICS) today announced the availability of uIPv6, one of the world's smallest open-source, IPv6-ready protocol stack, which could enable every device, no matter how limited by power or memory to have an Internet Protocol address.

This collaborative project builds on Cisco's expertise in IP networking, Atmel's innovative low-power wireless hardware and SICS' knowledge in embedded operating systems design. "uIPv6 has the potential to impact a wide range of market verticals where automation is key, just as voice over IP did in enterprise telephony," said Rob Adams, senior director of Cisco's Corporate Development technology group.

"Smart" objects powered by a wide range of sensors and actuators are poised to enable a wide range of next-generation applications in building automation, industrial monitoring, smart cities and energy management, among many other areas. These applications help transmit information in the physical world about conditions or the environment (for example, temperature, light, motion, health status) to locations where the information can be analyzed, correlated with other data and acted upon.

The proliferation of such applications has however been held back by the large number of proprietary or semi-closed systems, and the cost associated with translating information before it can be effectively shared with other devices and systems. The use of IP as networking technology has long been recognized as the solution to this interoperability issue. Now, thanks to unique lower-layer energy management mechanisms and limited memory capacity, uIPv6 is highly power-efficient and ideal for most constrained devices.

Open-source uIPv6 includes standard IP applications and can be easily customized for specific requirements. It is integrated in the Contiki operating system developed by SICS, which provides all the necessary functionalities for networked smart objects. In addition, uIPv6's small footprint and memory usage allows it to run on the most constrained platforms. In particular, it was tested on Atmel's Raven wireless platform, chosen for its outstanding low-power performance.

"Efficient, low-power wireless systems require ultra-low-power embedded microcontrollers paired with excellent radio performance," said Magnus Pedersen, Atmel's director of product marketing, MCU Wireless Solutions. "The fact that Cisco and SICS chose the Atmel AVR Raven picoPower wireless platform as the basis for their uIPv6 and 6LoWPAN implementation confirms Atmel's leading edge in low-power embedded wireless technology."

uIPv6 is released under a permissive open-source license, and as a result can be used for both commercial and noncommercial applications.

"An open-source, standard-compliant, small-footprint IPv6 implementation is essential to enable the next generation of sensor network applications," said Adam Dunkels, senior scientist at SICS and Contiki project leader. Patrick Wetterwald, president of the IP for Smart Objects Alliance (IPSO) said, "By running an IPv6 stack, operating a network of sensors thus becomes as easy as operating a network of PCs, IP phones, or any other IP devices."

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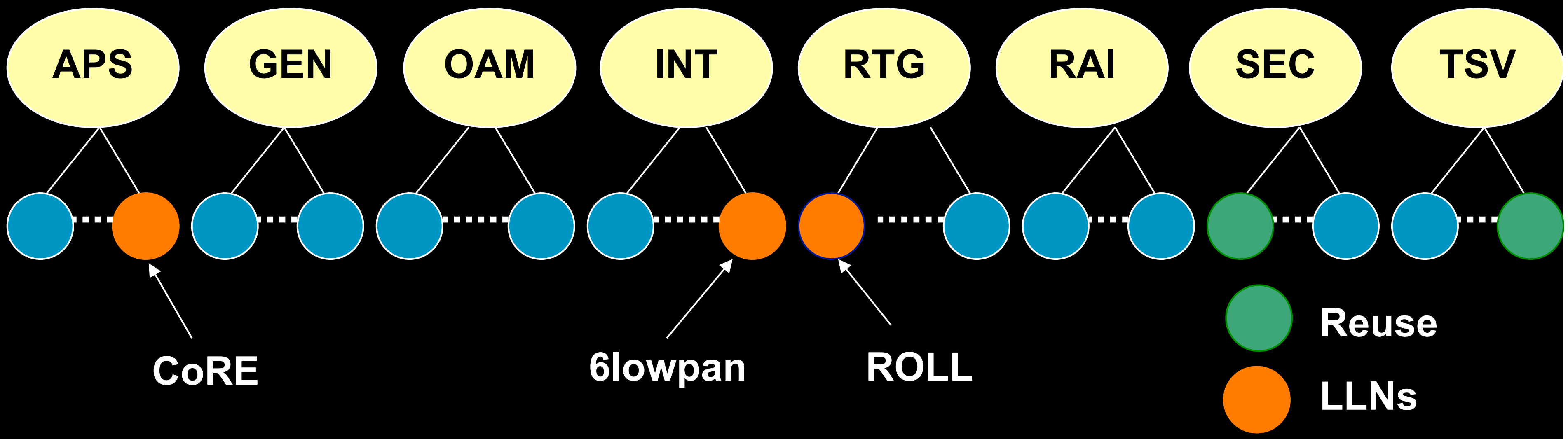
- ☑ Code base: Contiki OS/UIP stack + KAME stack
- ☑ All IPv6 features (except MLD) are implemented
  - Code size ≈ 11.5 KByte
  - RAM usage ≈ 0.2+**1.6** =1.8KByte
- ☑ Obtained IPv6 ready phase 1 logo
- ☑ Open source release October 14th, 2008
  - http://www.sics.se/contiki
- Other implementations: Archrock, Sensinode, PicosNet, Dust Networks, Gainspan, ZeroG, etc…
- To come: RPL, Security, …

Standardization

IETF Update

- IETF formed in 1986,
- Not considered as important for some time :-)
- Not government approved :-)
- Involving people not companies
- Motto: "*We reject kings, presidents and voting. We believe in rough consensus and running code*" Dave Clark (1992)
- Organized in areas made of WGs,



Reuse whenever possible, Invent where needed
In addition, Smart Grid directorate + numerous liaisons

6LoWPAN

What is 6lowpan ?

- 6LoWPAN is an adaption layer for IPv6 over IEEE 802.15.4 links, not a protocol stack, full solution for smart objects networks!
- Why do we need an adaptation layer ?
- IEEE 802.15.4 MTU is 127 bytes
- Performs 3 functions:
  - Packet fragmentation and re-assembly
  - Header compression
  - Mesh layer … (not a so good idea)

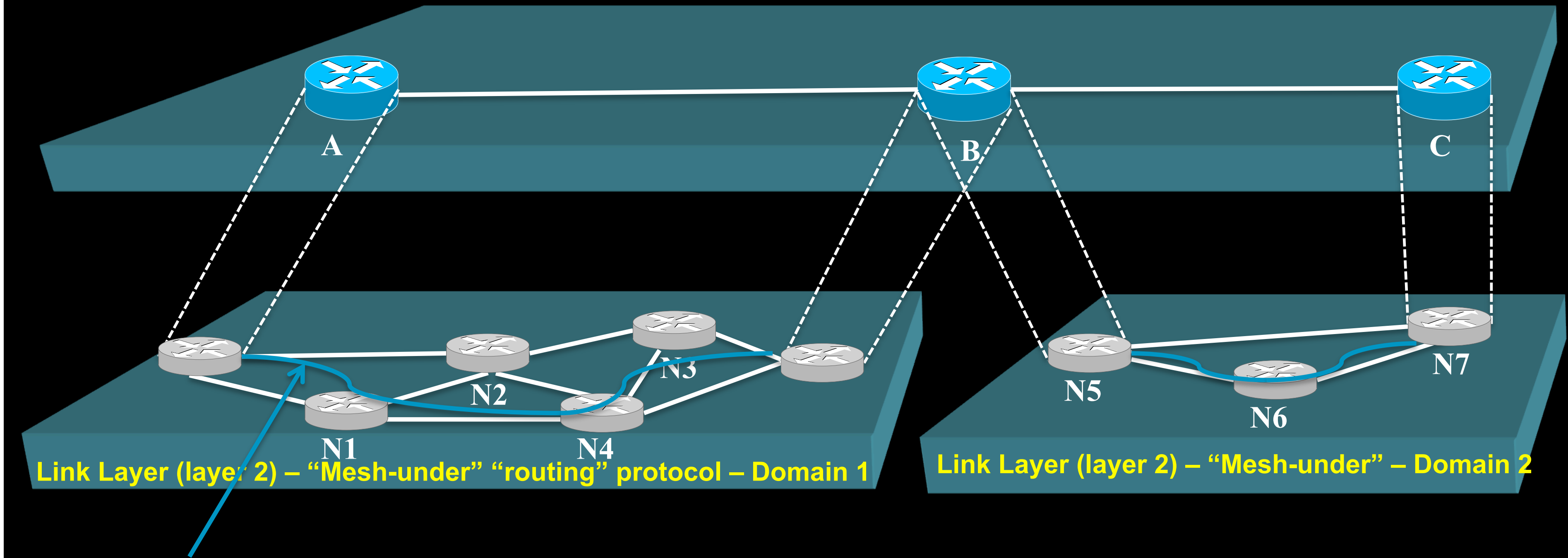
Routing in Smart Object Networks

The “Mesh Under” and Route Over” debate

IP Routing over 802.11s, 802.16J, 802.15.4

- *Haven’t we learned from the past ? Remember IP over ATM ?*
- IP layer with no visibility on the layer 2 path characteristic
- Makes “optimal” or “efficient” routing very difficult
- Layer 2 path (IP links) change because of layer 2 rerouting (failure or reoptimization) lead to IP kink metric changes. *How is this updated ?*
- There is still a need for an abstraction layer model but for Point to Point layer 2 links => Routing Metrics

Lack of L2 path visibility …



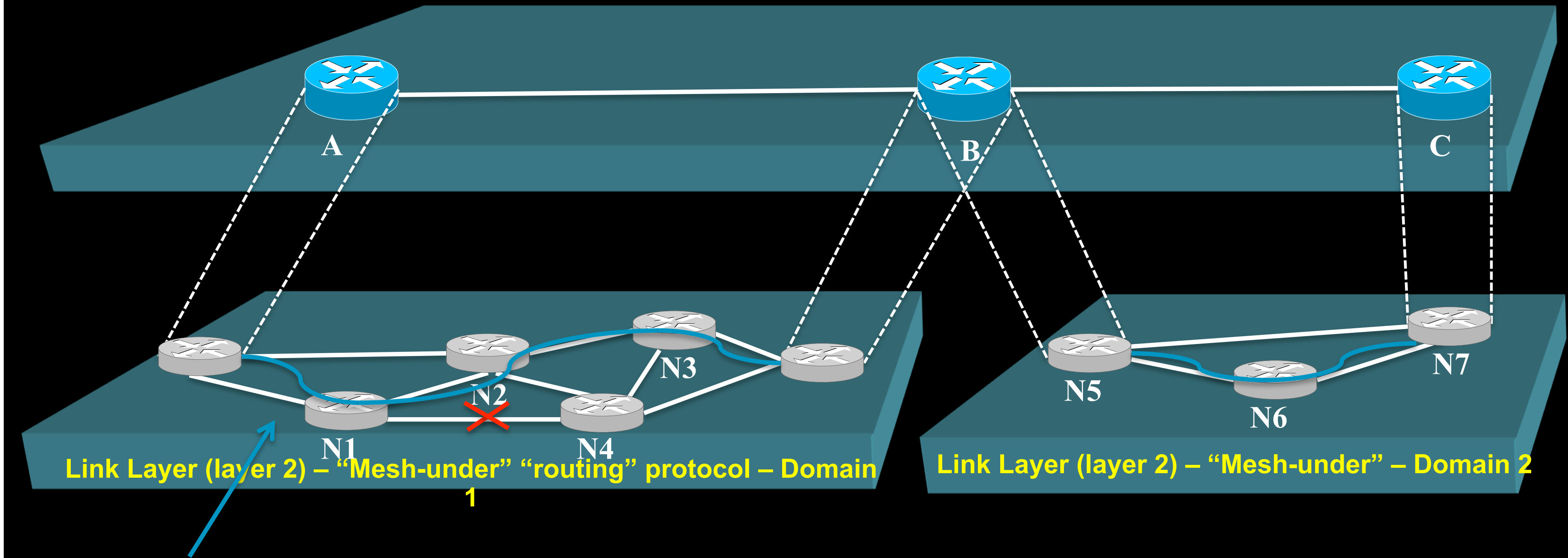
A-N1-N4-N3-B is the link layer path computed by the "mesh-under" "routing" protocol operating at the link layer in domain 1

Issue of Multi-layer recovery

Just Another major challenge: multi-layer recovery

- Require a multi-layer recovery approach
- Current models are timer-based:
  - Needs to be conservative and most of the time bottom-up
  - Increased recovery time for failures non recoverable at layer 2
- Inter-layer collaborative approaches have been studied (e.g. IP over Optical) => definitively too complex for current Sensor Hardware

Multi-layer Recovery Issue



A-N1-N2-N3-B is the new path computed by the "mesh-under" "routing" after the failure of the N1-N4 link

Where should Routing Take Place ?

- Historically, a number of interesting research initiatives on routing in WSN,
- Main focus on algorithms … a bit less on architecture
- Most work assuming the use of MAC addresses – L2 “routing” (mesh-under)
- Support of multiple PHY/MAC is a MUST: IEEE 802.15.4, LP Wifi, PLC (number of flavors), …
- Now … if what you want is a layered architecture supporting multiple PHY/MAC, there aren’t that many options …

IP !

Routing Over Low power and Lossy Link (ROLL) WG

- Working Group Formed in Jan 2008 and already re-chartered

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

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

- Mission: define Routing Solutions for LLN (Low power and Lossy Networks)
- Very active work with a good variety of participants with at first little IETF background
- Rechartered to specify the routing protocol for smart objects networks (after protocol survey)
- DT formed (and now dissolved)
- Several proposals: one of then adopted as WG document, RPL (currently in LC)

IETF – Routing Protocols

- Long history in developing routing protocols at the IETF:
  - RIP,
  - OSPF,
  - IS-IS,
  - BGP
  - But also MANET: AODV, OLSR, NEMO, ..
- And non standardized IP routing protocol also exist: EIGRP

Approach

- Examine current ROLL application requirement drafts
  - Distill a set of common requirements across application domains
  - Establish a minimalist set of criteria
- Examine current IETF routing protocols
  - In RFCs or I-Ds that are on a working group's agenda
  - Evaluate these protocols in terms of ROLL criteria

Slide from IETF-72

Five Criteria

- Table scalability: how does the routing table size scale?
- Loss response: how expensive is it when links come and go?
- Control cost: how does the control overhead scale?
- Link cost: can the protocol consider link properties?
- Node cost: can the protocol consider node properties?

Slide from IETF-72

Summary

Name	Table Size	Loss Response	Control Cost	Link Cost	Node Cost
OSPF	fail	fail	fail	pass	fail
OLSRv2	fail	fail	fail	pass	pass
TBRPF	fail	pass	fail	pass	?
RIP	fail	fail	fail	?	fail
AODV	pass	?	pass	fail	fail
DSDV	fail	fail	fail	?	fail
DYMO[-low]	pass	fail	pass	fail	fail
DSR	fail	?	pass	fail	?

Slide from IETF-72

Specific Routing Requirements

- Deliberate choice of 4 main application areas
- Long series of MUST, SHOULD and MAY
- The MUST in RFC2119 language
- Support of unicast/anycast/multicast
- Adaptive routing with support of different metrics (latency, reliability, …)
- Support of constrained-based routing (energy, CPU, memory)
- Support of P2MP, MP2P and P2P with asymmetrical ECMP
- Scalability
- Discovery of nodes attributes (aggregator)

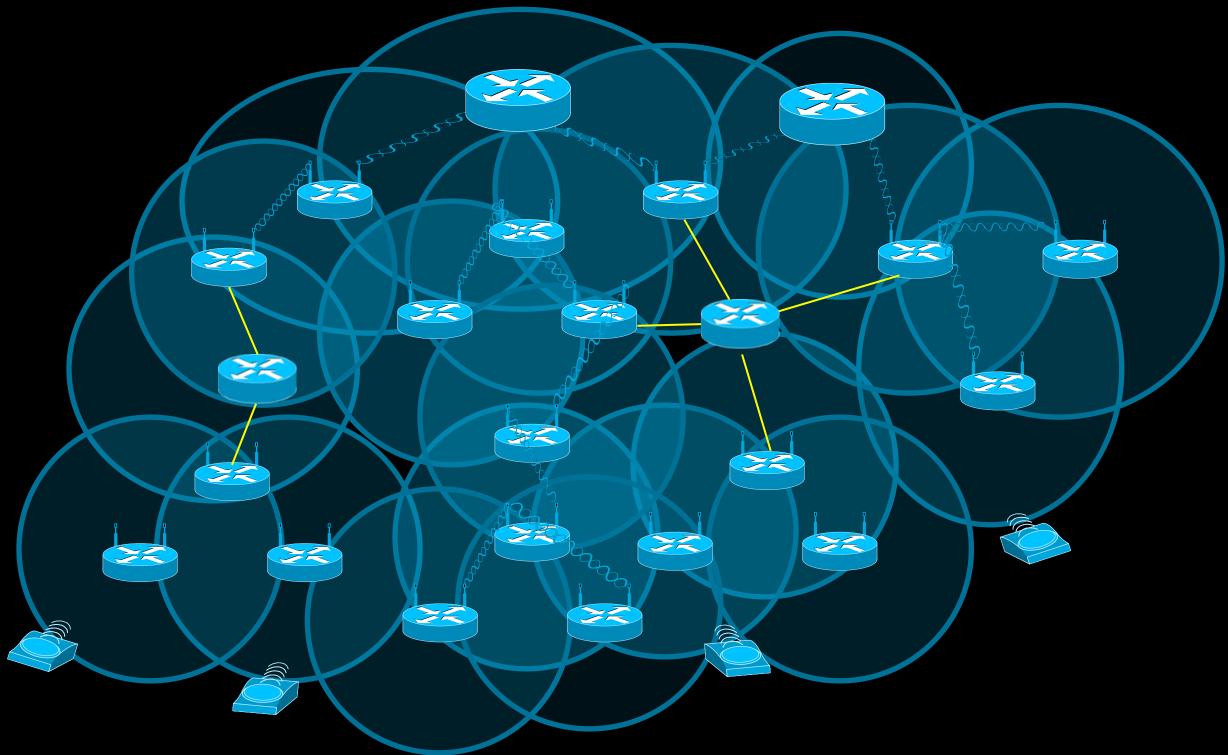
Specific Routing Requirements

- 0-config

  Warning not to add too many options !

- Performance: indicative, not a good idea ! A lesson learned from the Internet
- Security

RPL: a DV routing protocol building a colored DAG



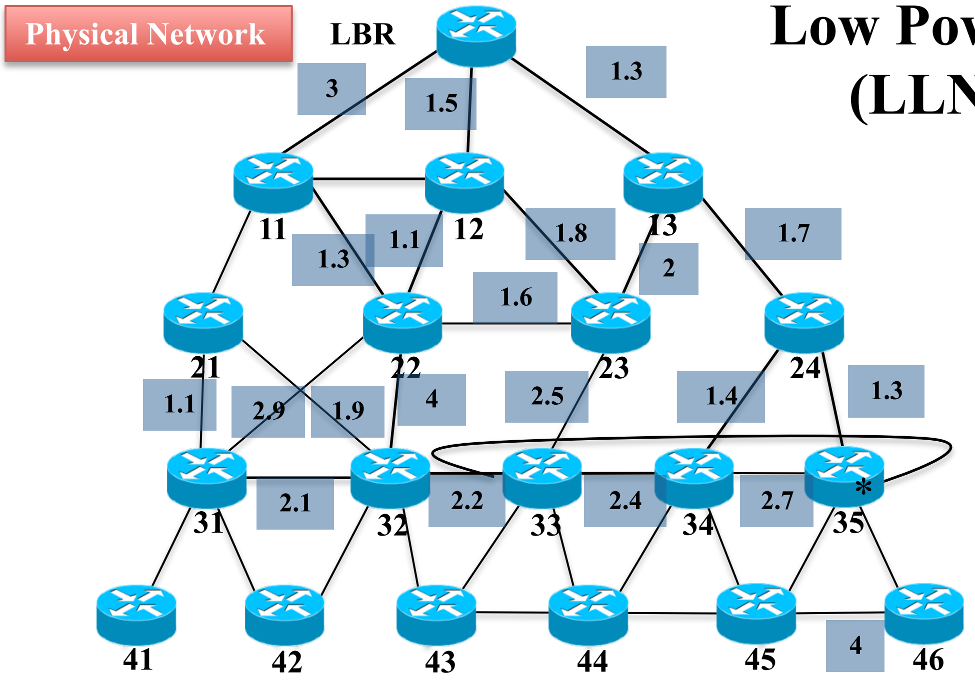
RPL is specified in draft-ietf-roll-rpl

- RPL: DV Based Routing Protocol – DAG Formation
- The DAG is colored (Constrained Based Routing)
- Rules for parent selection based on metric, OF and loop avoidance
- Under-react is the rule !! (local versus global reroutes) to cope with transient failures
- Governed by Trickle Timers

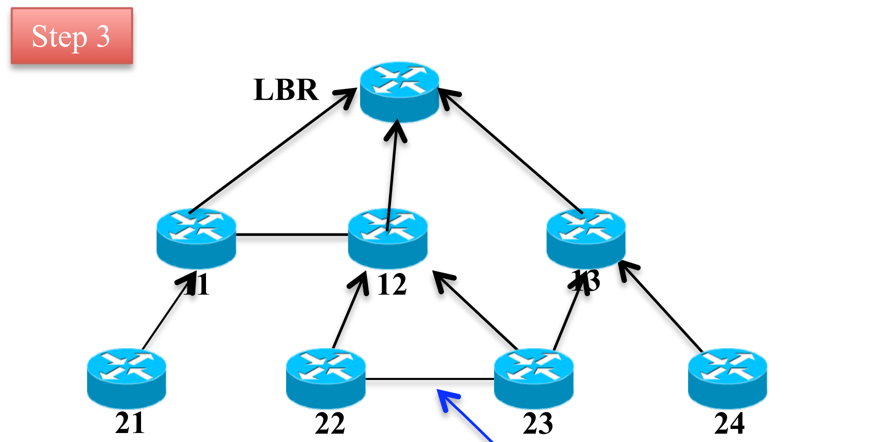
RPL builds Directed Acyclic Graphs

- Tree would have been simpler but need for redundancy
- RPL supports the concept of DAG instances (a colored DAG), concept similar to MTR
- Allows a node to join multiple colored DAG with different Objective Functions
- And within an instance, there might be multiple DODAG (Destination Oriented DAG)
- A node may belong to more than one DAG instance
- Packets are tagged to follow a specific instance (defined at the application layer): no loops between instances

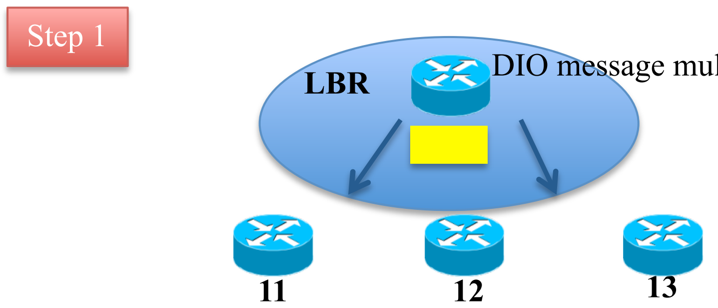
Low Power and Lossy (LLN) Network



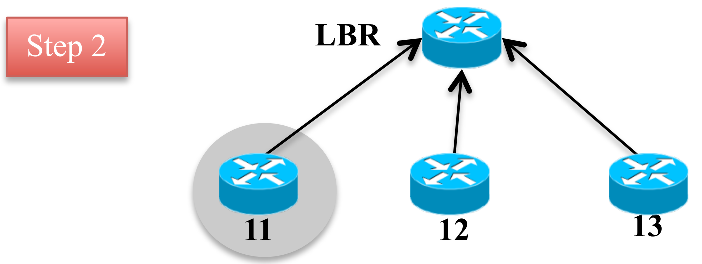
X ETX (=1 when not indicated)
=> reflect the link quality



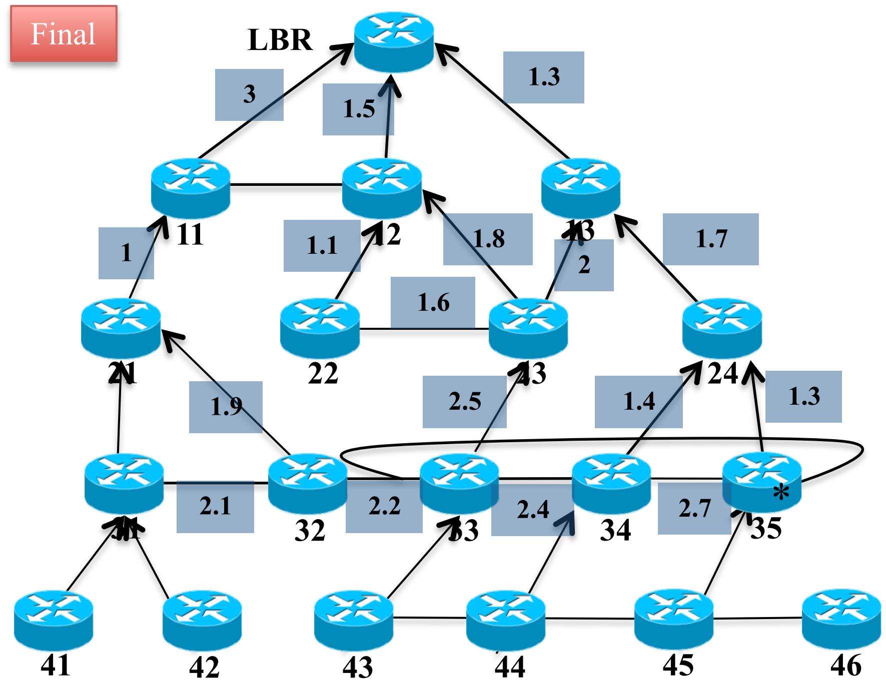
The DAG (Direct Acyclic Graph) continues to build … with siblings also



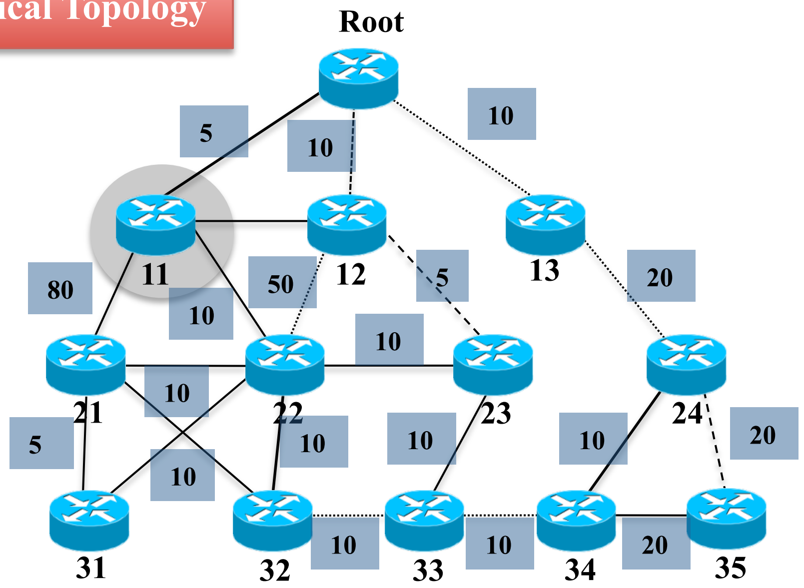
DIO message multicasted by the root



Every router runs an algorithm to choose a parent based on an objective (best quality path, highest bandwidth link,….)



Physical Topology



Support of QoS Aware Routing:

A multi-servive IP core

Battery Operated Node

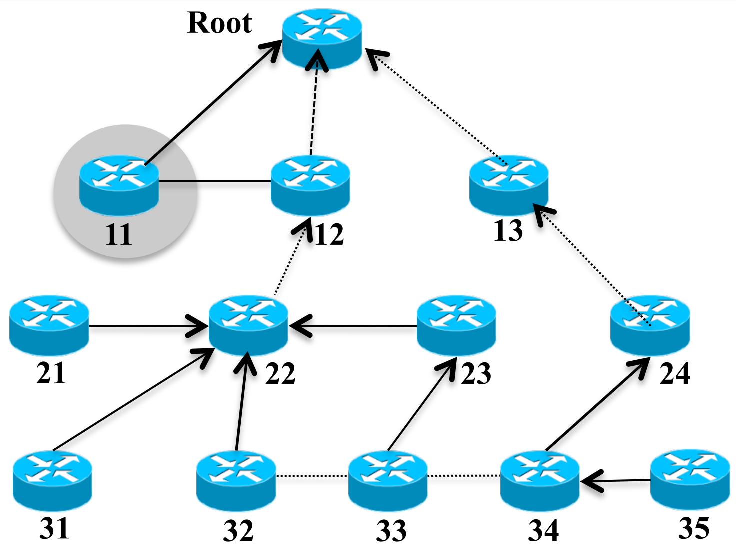
Poor Quality (LQL=3)

Fair Quality (LQL=2)

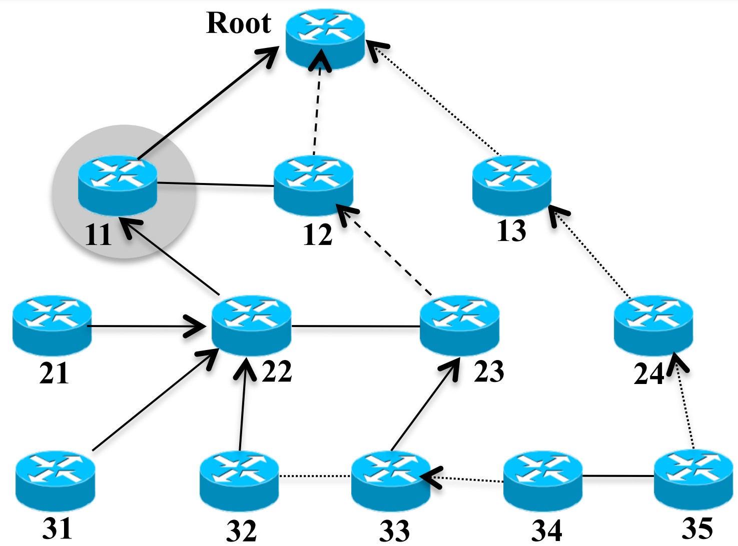
Good Quality (LQL=1)

X Latency in milliseconds

DAG Instance 1: high quality – no battery operated nodes
DAG Instance 2: low latency



DAG 1 is is optimized for Smart Metering readouts: not time sensitive, avoid battery operated node



DAG 2 is optimized for real-time delay sensitive traffic (alarms, distribution automation, …)

The dream of using adaptive metrics …

- Today's IGP use ***static link*** metrics
  - Administrative cost or polynomial cost
- Using dynamic metric is not a new idea (experimented in ARPANET-II based on average queue lenght)
  - Hard to control … routing oscillations
  - Issue with too frequent control traffic in LLN

New set of metrics

- Requirement for both link and node metrics and constraints in LLNs
- Routing objects can be used as a metric or as constraint
- Constraints used for constrained-based routing
- Some metrics are dynamic => use of low pass filters and multi thresholds to avoid oscillations
- Support of local and global metrics (path cost)
- Min, max and cumulative metrics
- Reliability metrics: ETX (mono-dimensional but Link layer independent) + Link Quality Level
- Use of Objective functions in RPL: defines the DAG Color (set of metrics and constraints to use)

Routing Metrics in LLNs

- Defined in draft-ietf-roll-routing-metrics
- Node metrics/constraints
  - Node state and Attribute: aggregator, overload bit (collapsing various resources states) in the presence of sustained overload
  - Node Energy: power mode, estimated lifetime
  - Node Fan out ratio (to equalize energy consumption, traffic load balancing)
- Link metrics/constraints
  - Hopcount
  - Throughput
  - Latency
  - Link Reliability: ETX (link layer agnostic) and LQL (from 0 to 3)
  - Link Colors (administrative): can be used as a constraint or a metric

Global versus Local Repair

- Global repair: rebuilt the DAG … requires a new DAG Sequence number generated by the root
  - Triggered by the root
  - Potentially signaled to the root (under investigation)
- Local Repair: find a "quick" local repair path
  - Only requiring local changes !
  - May not be optimal according to the Objective Function and overall DAG shape, which is fine
- Complementary approaches

Promoting the use of IP in networks of Smart Objects

http://www.ipso-alliance.org/

Objectives of IPSO

- Create awareness of available and developing technology with IP for Smart Objects
- Generate tutorials, white papers and highlight use cases
  - http://www.ipso-alliance.org/Pages/DocumentsAndWhitePapers.aspx
- Complement the IETF which defines standards, but does no marketing
- Link companies that support IP based sensing and control systems
- Coordinate and combine member marketing efforts
- Support and organize interoperability events

COMPLIANCE program (Based on IPv6 forum)

Members as of today

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Augusta systems
Bosch
CEA
Centria
Cisco
Convergence Wireless
Duke Energy
Dust Networks
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UC Berkeley

Conclusion

- The Internet Of things used to be seen as a promising “concept”, mostly a “research topic”
- Few limited trials due to a *highly fragmented market*, with a plethora a proprietary protocols and architecture
- The situation has dramatically changed:
  - Emergence a several key applications (Smart Grid, Smart Cities, …)
  - Momentum for the use of IPv6, the Internet Protocol
  - Standardization is very active (IETF, IEEE, ITU, …)
  - New alliances have been formed (NIST, Wavenis, …)
- We continue to work on many others features: discovery, CoAP, … and continue to be recognized for our technology leadership
- Need to work on many more research topics: architecture, aggregation, auto-conf, troubleshooting, management, …

Thank you for your attention

Questions?

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Publishing June 2010

Interconnecting Smart Objects with IP

The Next Internet

By Jean-Philippe Vasseur & Adam Dunkels

Features

- Shows in detail how connecting smart objects impacts our lives with practical implementation examples and case studies
- Provides an in depth understanding of the technological and architectural aspects underlying smart objects technology
- Offers an in-depth examination of relevant IP protocols to build large scale smart object networks in support of a myriad of new services

Smart object technology, sometimes called the Internet of Things, is having a profound impact on our day-to-day lives. *Interconnecting Smart Objects with IP* is the first book that takes a holistic approach to the revolutionary area of IP-based smart objects. Smart objects are the intersection of networked embedded systems, wireless sensor networks, ubiquitous and pervasive computing, mobile telephony and telemetry, and mobile computer networking.

This book consists of three parts, Part I focuses on the architecture of smart objects networking, Part II covers the hardware, software, and protocols for smart objects, and Part III provides case studies on how and where smart objects are being used today and in the future. The book covers the fundamentals of IP communication for smart objects, IPv6, and web services, as well as several newly specified low-power IP standards such as the IETF 6LoWPAN adaptation layer and the RPL routing protocol.

This book contains essential information not only for the technical reader but also for policy makers and decision makers in the area of smart objects both for private IP networks *and* the Internet.

The authors are among the primary architects in the field of IP-based smart objects:

- Jean-Philippe Vasseur is a Distinguished Engineer at Cisco Systems. He is the co-chair of the ROLL working group in the IETF and the chair of technology advisory board in the IP for Smart Objects (IPSO) Alliance.
- Adam Dunkels, PhD, is a senior researcher at the Swedish Institute of Computer Science. He is the well-known author of the Contiki operating system, and the uIP and lwIP embedded IP stacks. In 2009, MIT Technology Review named him a Top 35 Innovator under 35, for his work on IP for smart objects.

Both authors are founders of the IPSO Alliance, which TIME Magazine named as the top 30 innovation of 2008.

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