# 6TiSCH

towards an IPv6-based Industrial Internet

**Technical Track**

# Why the IT/OT convergence?

**Operational technology (OT)** is hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise.

Next % point of optimization => 100s of billions savings / next 15 years.

Requires collecting and processing of **live "big data"**, huge amounts of missing measurements by **widely distributed sensing and analytics** capabilities.

Achievable by combination of the best of IT and OT technologies together, forming the IT/OT convergence, aka **Industrial Internet**.

Deterministic Wireless Industrial Networking technologies must be extended to reach **higher scales at lower costs** (with lower guarantees).

Architectural approach, standards, Industry adoption needed to embrace radical changes happening in IT networking technologies.

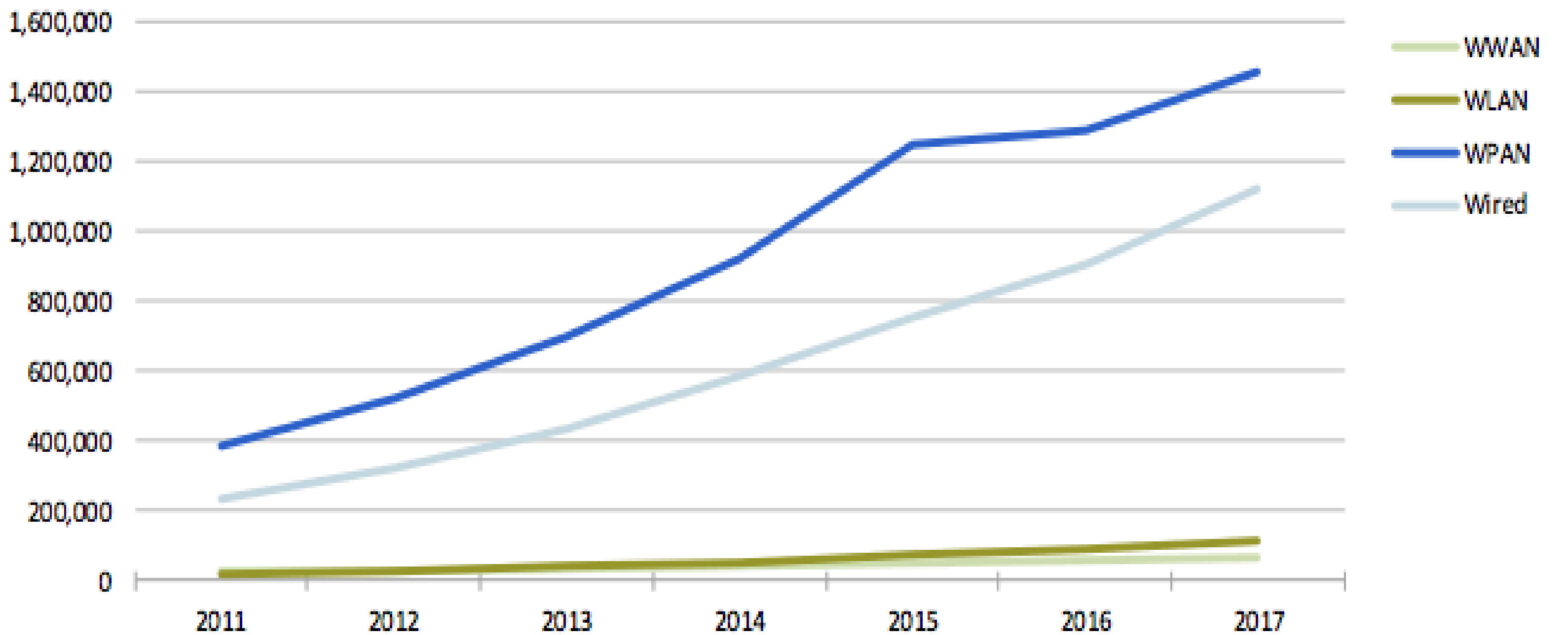
Secured-by-default model required throughout network lifecycle.

# Industrial connected device growth

Figure 8.8

**Industrial - Internet Connected Devices - New Shipments by Connectivity and Class**

000s of Connected Devices




**Source: IMS Research** **Aug-12**

WWAN: GSM – LTE WLAN: 802.11 WPAN: 802.15.4, ISA100.11a, WirelessHART

# WSN open standards

## IEEE

- Covers MAC and eventually LLC
- Also link security (CCM*, 802.1x)

## IETF

- Typically routing, end-to-end security and transport
- RPL, DTLS, CoAP
- Trouble: 7000+ RFCs
- Trouble: problem spanning layers and SDOs

## Industry alliances for test and certification

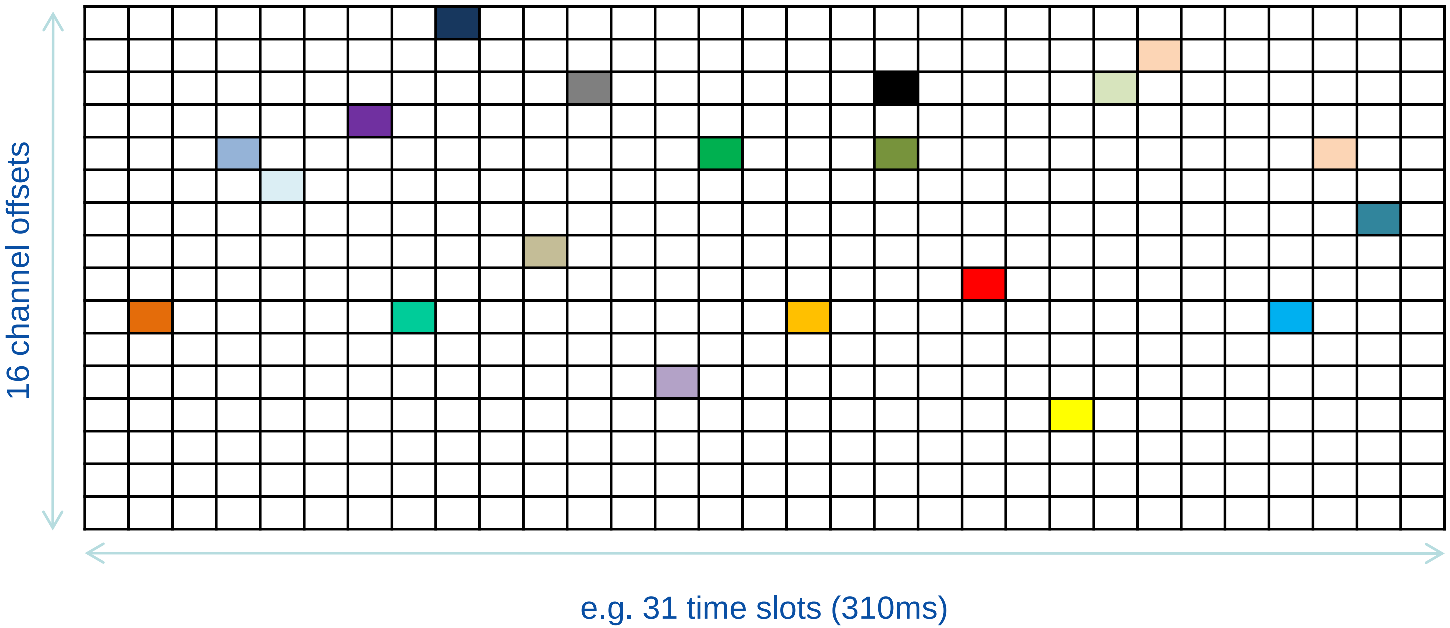
## 6TiSCH is an harmonized solution

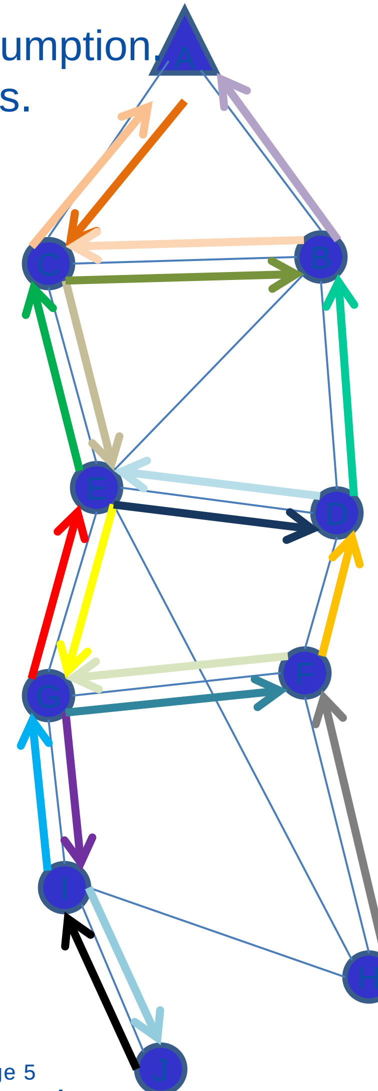
- IETF + IEEE extensions via IG

The 6TiSCH WG is chartered to provide a bundled architecture based on (mostly) existing RFCs.

# IEEE802.15.4e TimeSlotted Channel Hopping (TSCH)

Schedule => direct **trade-off** between throughput, latency and power consumption.
A **collision-free** communication schedule is typical in industrial applications.
IEEE802.15.4e **published** April 2012.



15.4e defines how to execute a schedule, but not how to build/maintain it.

# Case for IPv6 addressability

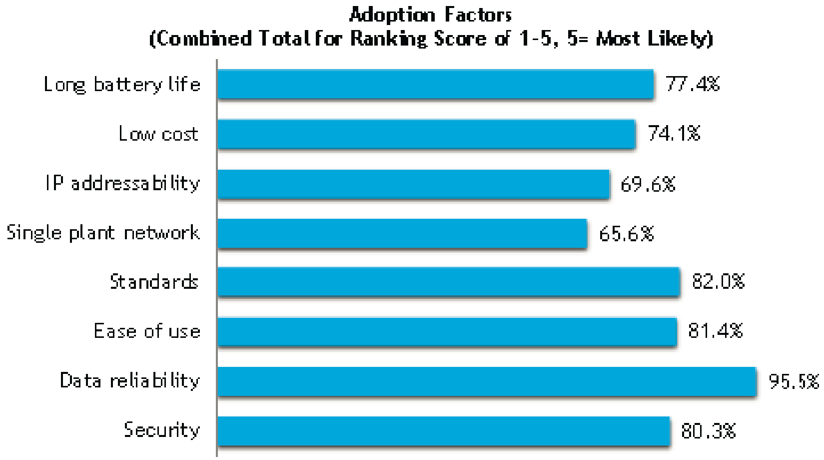
## Adoption of Wireless In Industrial Automation

OnWorld conducted polls and published results based on interviews with 105 plant managers, process integrators and system engineers

Results are clearly indicative of industrial end user's concerns

***IPv6 addressability*** is a major factor for adoption of wireless technologies employed in industrial automation

***IPv6 addressability*** is tightly coupled with future extensibility of industrial wireless standards based products



# 6TiSCH: IPv6 over TSCH

**Large scale IPv6 subnet with backbone (50K +)**

**Integrated autonomic bootstrap & security profiles**

**Designed for time-sensitive IEEE802.15.4e TSCH**

**Direct IPv6 access to device**

- e.g. for common network management

**Integrates RPL (RFC 6550)**

- Distributed Routing Protocol designed by IETF
- Coming with distributed scheduling
- Supports loopless time distribution

# Addressing Industrial applications and needs

## Control Loops

- require tight latency control
- Fully scheduled operations
- Centralized routing computation
- Short periods (order of a second)

## Large Scale Monitoring (10Ks and more)

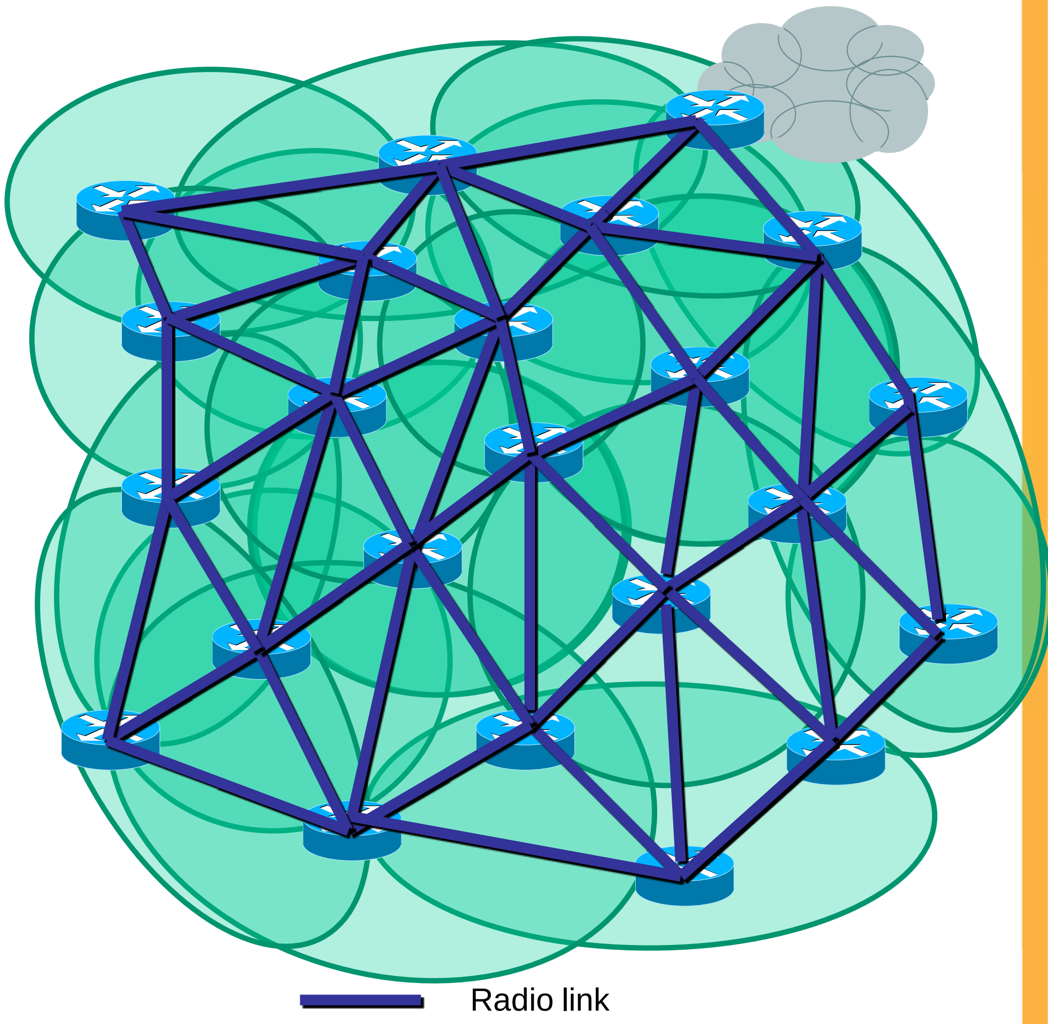
- e.g. Corrosion: Long lines along pipes, widespread over tanks
- Required distributed operations for scheduling and routing
- Live “Big Data” is an Emerging application, not fully covered by existing standards
- Longer periods (order of a day)
- Highly sensitive to power consumption

# Centralized vs. Distributed routing

| Centralized | Distributed |
| --- | --- |
| God's view optimization | Autonomic & Mobile |
| Multipath redundancy | Highly available (DARPA) |
| Deterministic (optimized) | Deterministic |
| Virtualization | Scalability |

# Example radio connecticity

**At a given point of time connectivity is (fuzzy)**



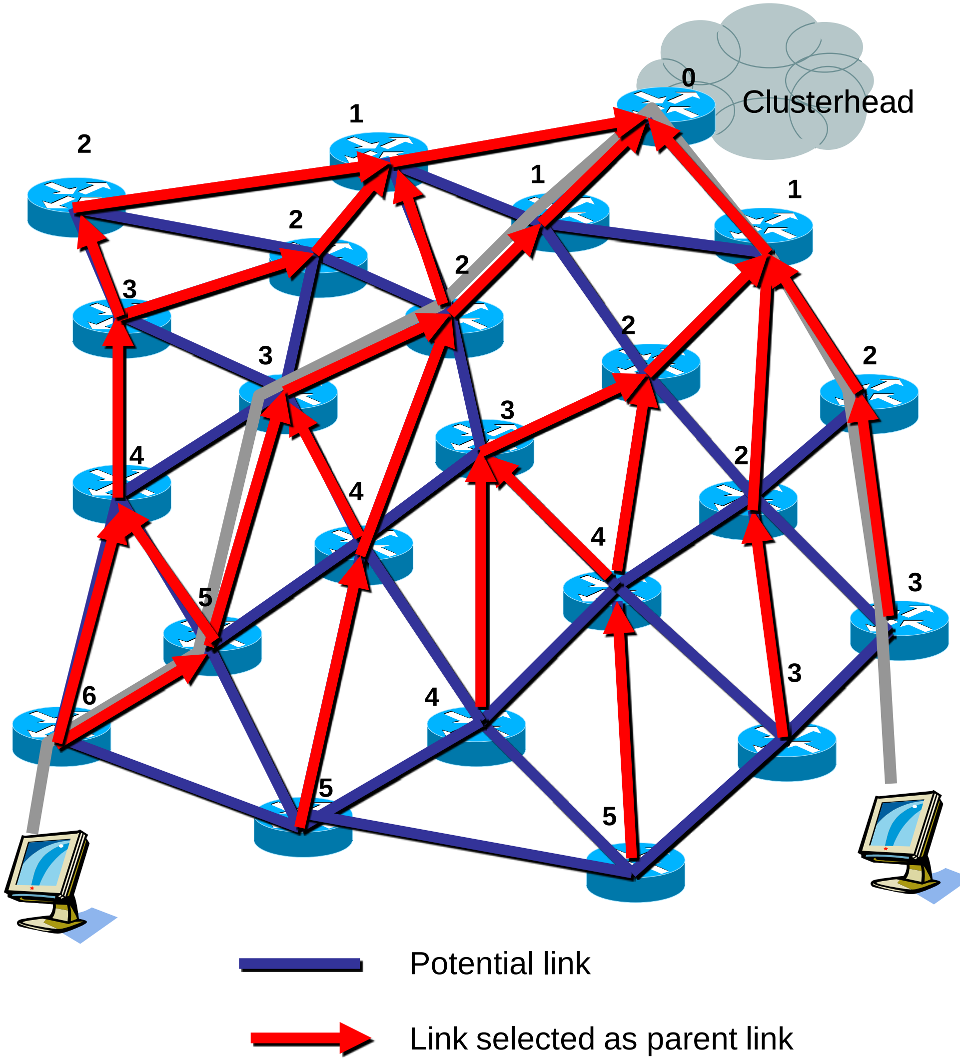
# Applying RPL

## 1st pass (DIO)

- Establishes a logical Directed Acyclic Graph (DAG) topology
- Trickle Subnet/config Info
- Sets default route
- Self forming / self healing

## 2nd pass (DAO)

- paints with addresses and prefixes
- Any to any reachability
- But forwarding over DAG only
- saturates upper links of the DAG
- And does not use the full mesh properly



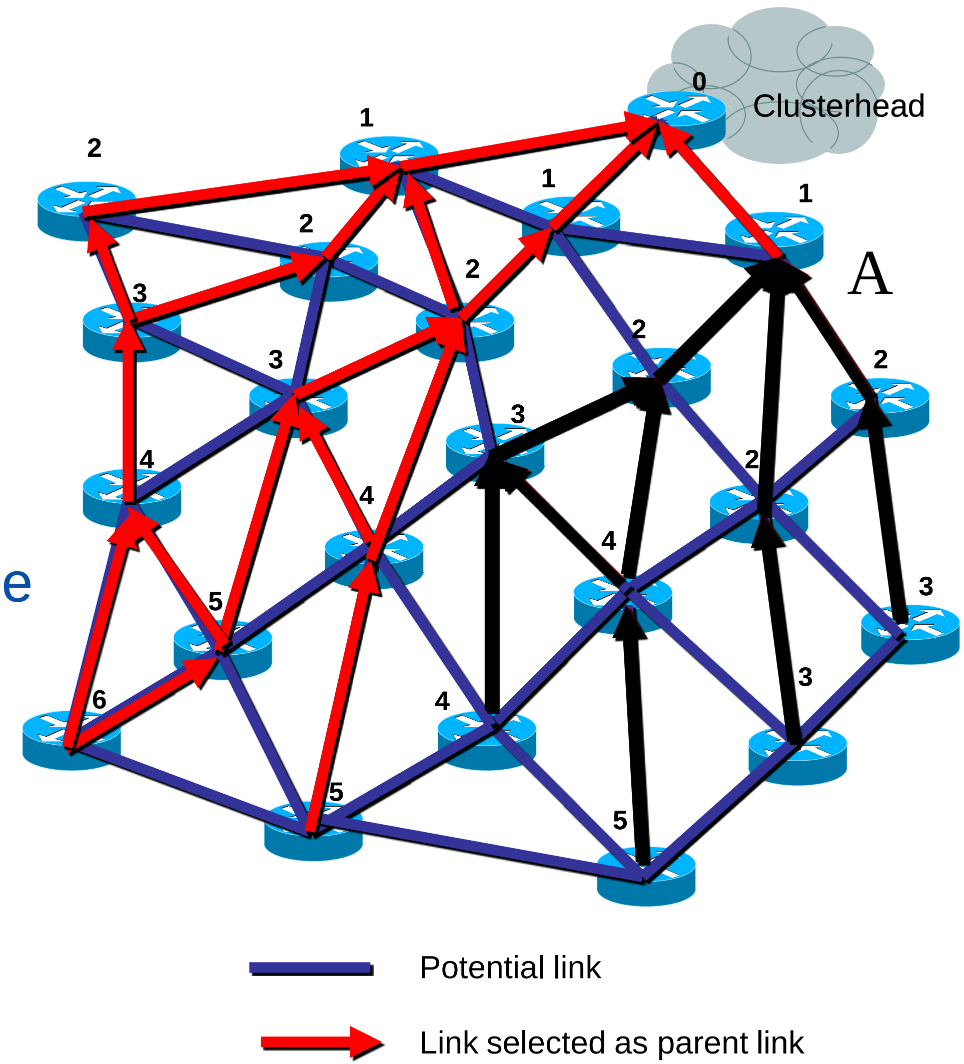
# Local recovery (step 1)

## A's link to root fails

- A loses connectivity
- Either poisons or detaches a subdag

## In black:

- the potentially impacted zone
- That is A's subDAG



# Local recovery (step 2)

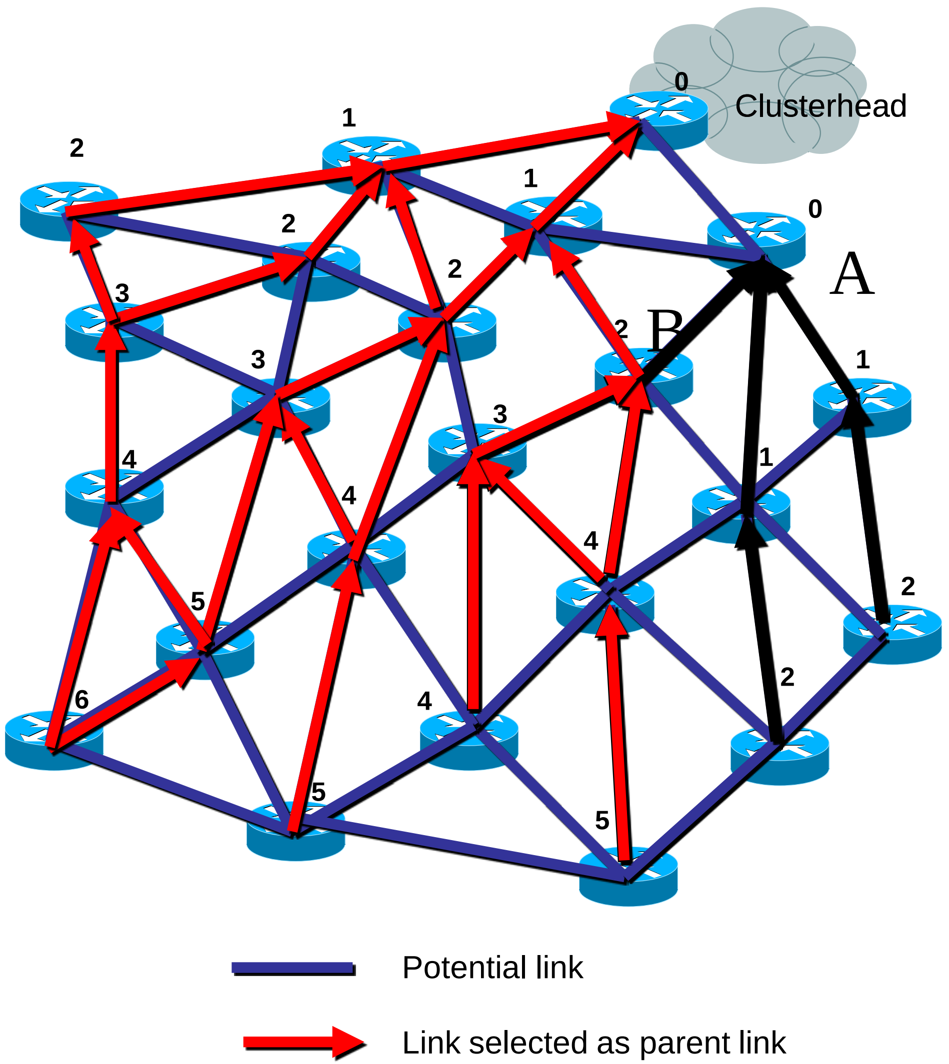
**B can reparent a same Rank so B's subDAG is safe**

**The rest of A's subDAG is isolated**

**Either poison ar build a floating DAG as illustrated**

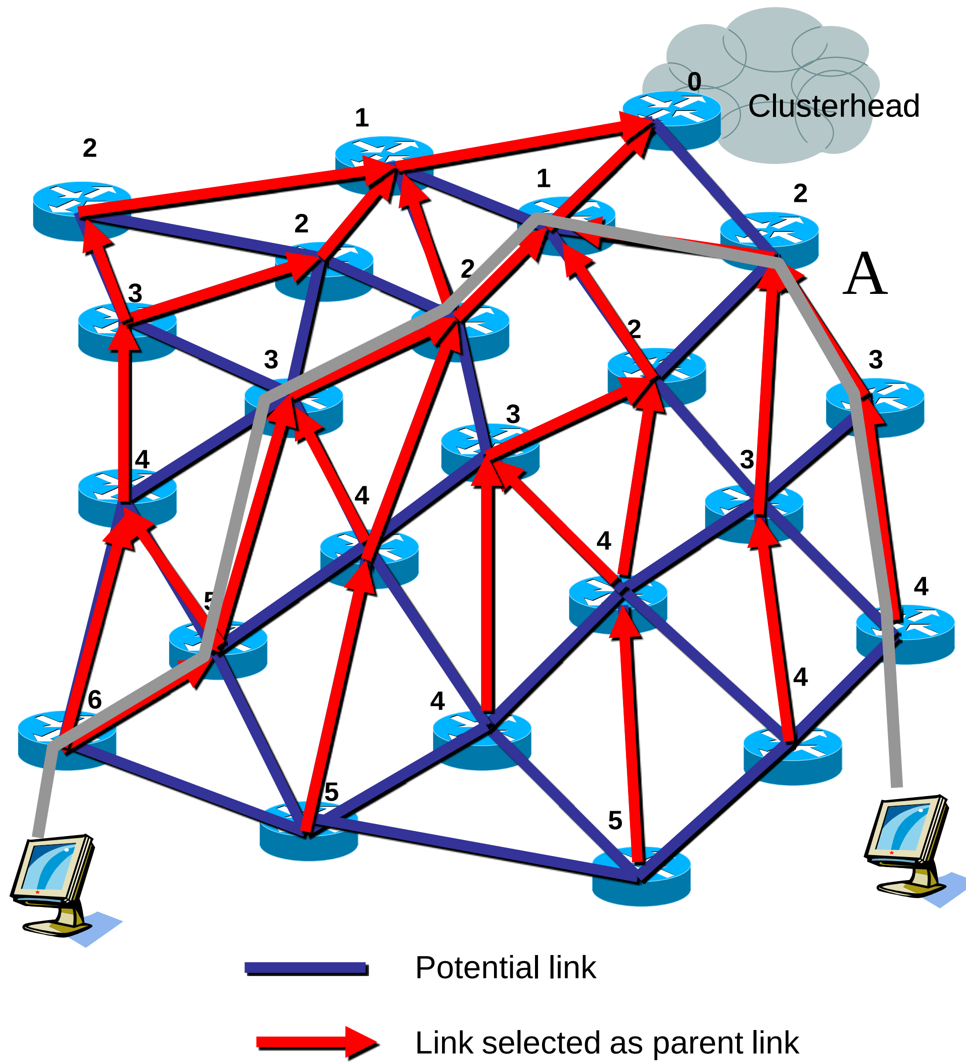
**In the floating DAG A is root**

**The structure is preserved**



# Local recovery (step 3)

- Once poisined nodes are identified
- It is possible for A to reparent safely
- A's descendants inherit from Rank shift
- Note: a depth dependent timer can help order things



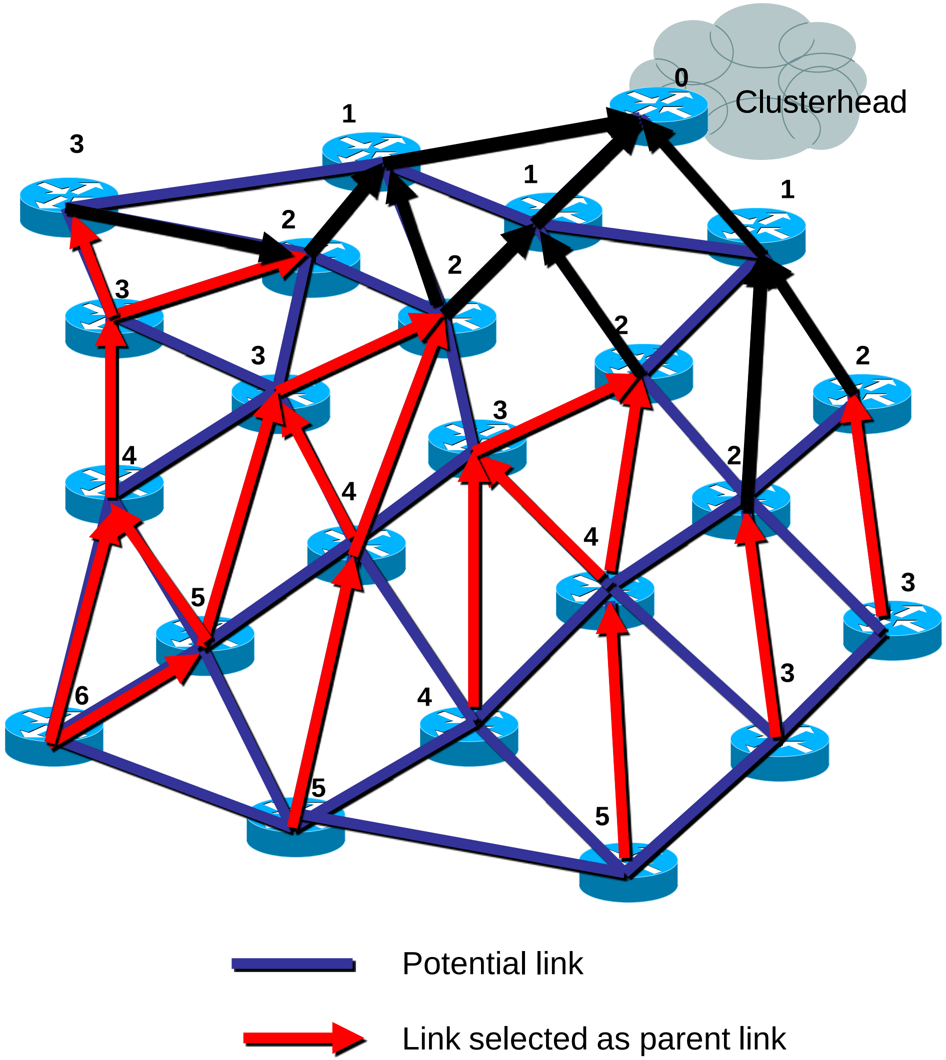
# Global recovery

## A new DAG iteration

- In black, the new DAG progressing

## Metrics have changed, the DAG may be different

## Forwarding upwards traffic from old to new iteration is allowed but not the other way around



# Multiple DODAGs within Instance

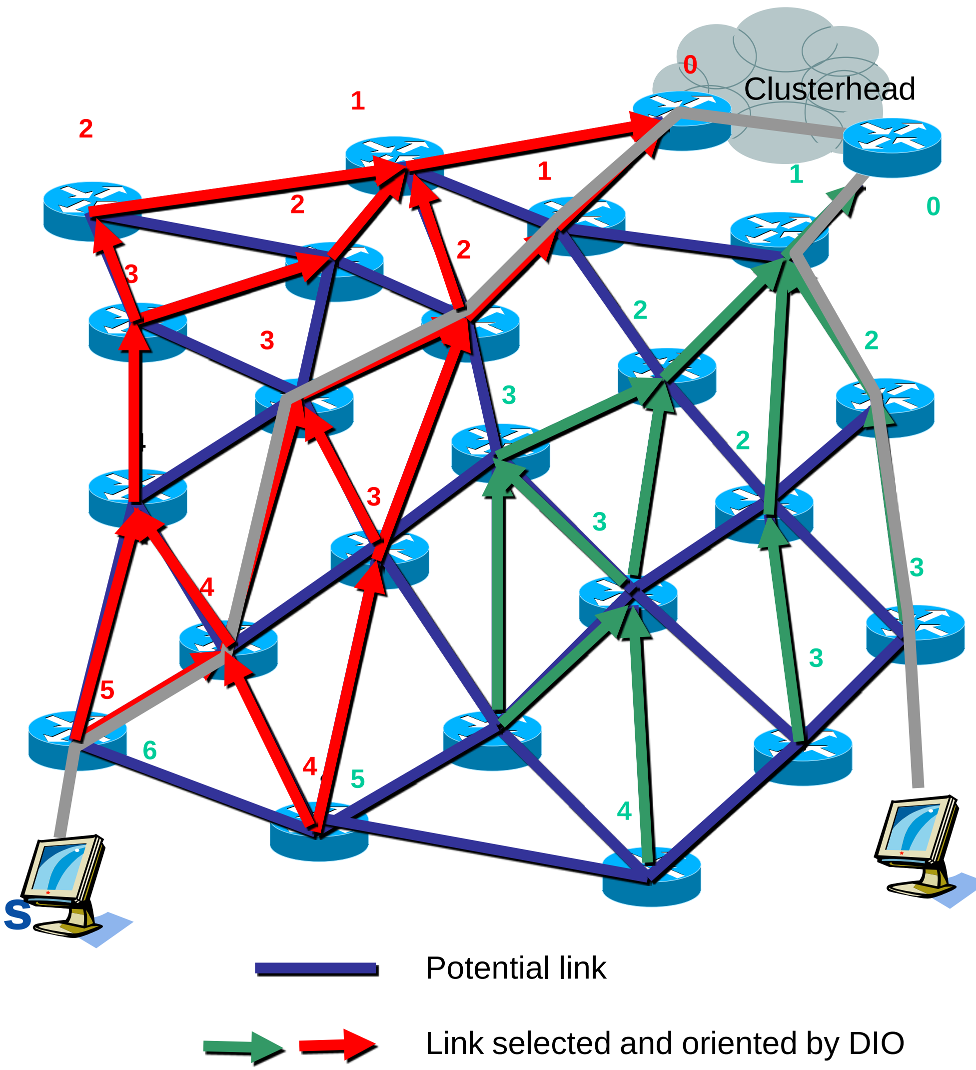
**A second root is available**
(within the same instance)

**The DAG is partitioned**
**1 root = 1 DODAG**
**1 Node belongs to 1 DODAG**
(at most, per instance)

**Nodes may JUMP**
from one DODAG to the next

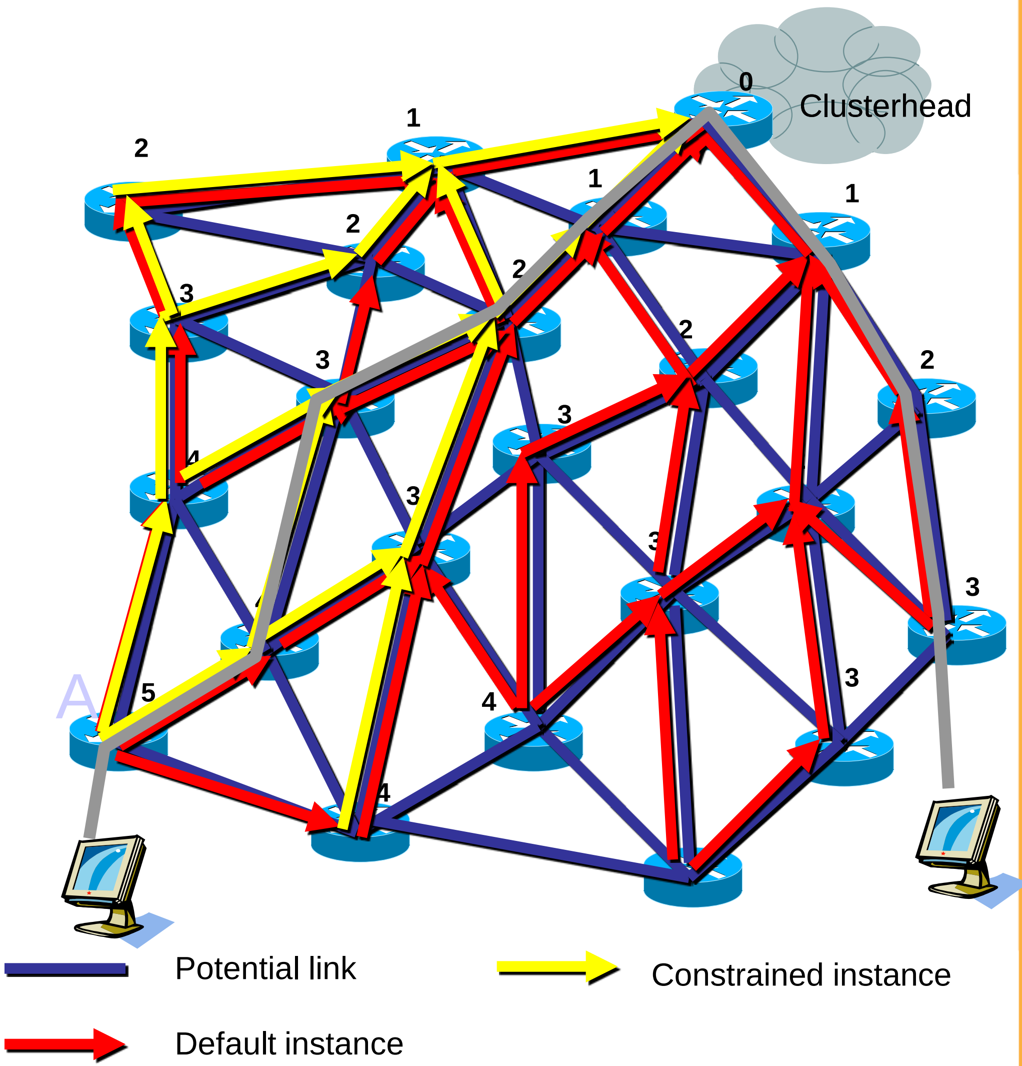
**Nodes may MOVE**
up the DODAG

**Going Down MAY cause loops**
May be done under CTI control

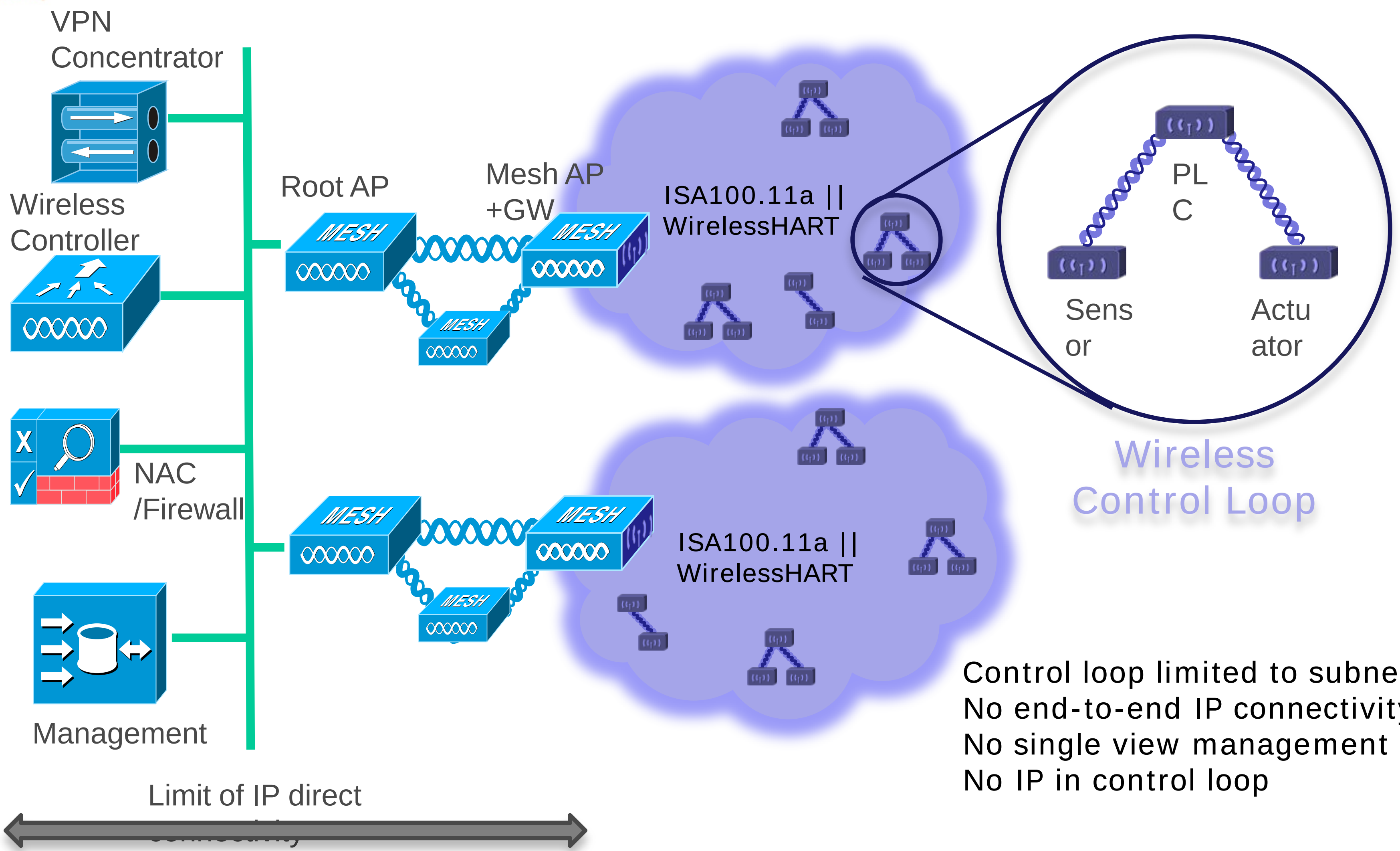


# Multiple Instances

- Running as Ships-in-the-night
- 1 instance = 1 DAG
- A DAG implements constraints
- Serving different Objective Functions
- For different optimizations
- Forwarding along a DODAG (like a vlan)

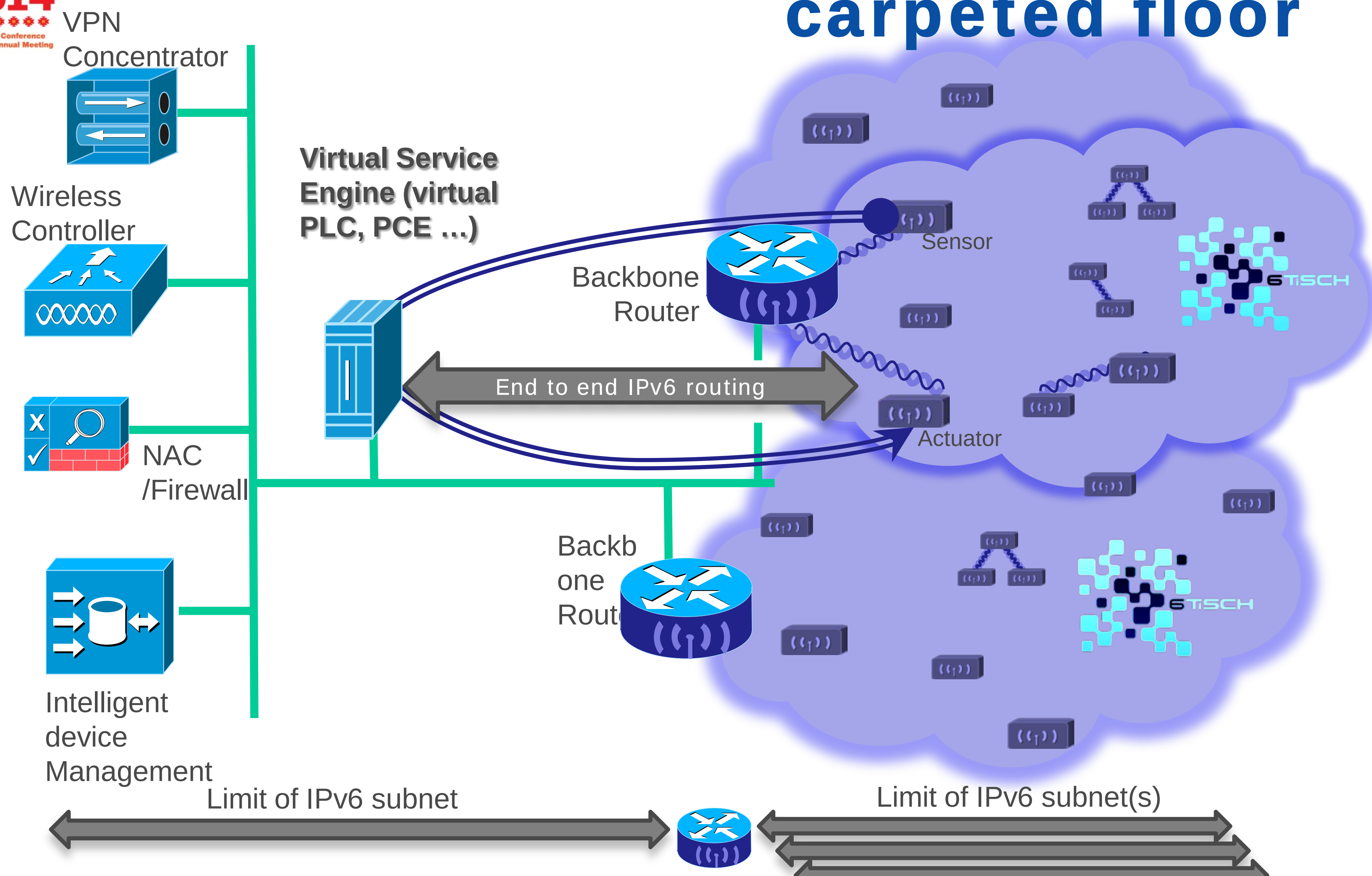


# Current architecture: isolated networks

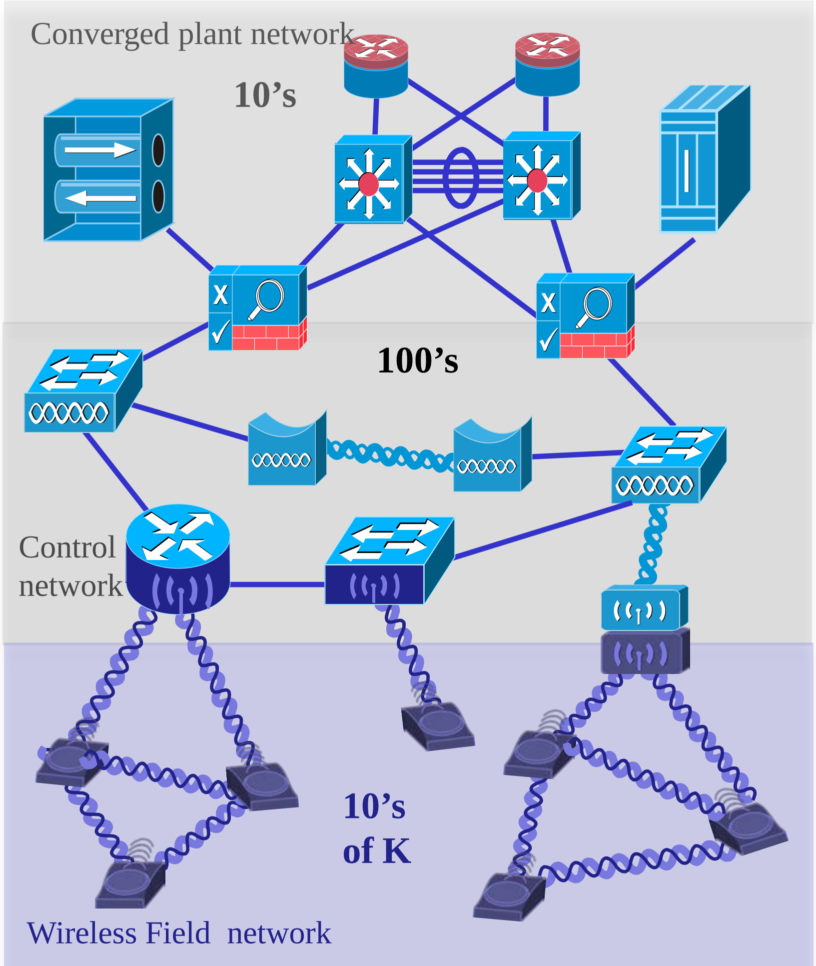



Control loop limited to subnet
No end-to-end IP connectivity
No single view management
No IP in control loop

# 6TiSCH subnets connected to carpeted floor



# IT/OT Network Convergence




## Converged Plant Network

- High availability
- Flow Isolation
- Guaranteed Bandwidth

## IP based Control Network

- Autonomic, zero touch commissioning
- Time Sensitive Networking for critical apps
- Packet Reliability

## IPv6-based Wireless Field Network

- Deterministic, Autonomic, Secure
- Large Scale for Monitoring (RPL)
- Backward Equivalence (TSCH)

# Thank You

# The Case for Industrial Wireless

## Cables can be inappropriate

- for rotating devices, moving cranes, robots arms or mobile handheld devices

## Cables are expensive

- Wire buried in conduit has high installation and maintenance cost, long lead time and extreme difficulties to repair

## GE's 1% lead to $15M/year in just 1 refinery

- Better process optimization and more accurate predictive maintenance increase profit
- Thus more and different sensors can be justified economically, if they can be connected

# Random Access vs. scheduled MAC operations

## Classical Random Access IEEE 802.15.4 (Zigbee IP, Zigbee)

- Long preamble; medium sampling
- 16 channels in the 2.4GHz ISM band,
- Similar to WiFi but simpler and less aggressive
- Simple / Ideal for stochastic traffic

## Wi-SUN

- Adds Frequency Agility to defeat interferences and multipath

## Scheduled IEEE 802.15.4e TimeSlotted Channel Hopping (TSCH)

- On of multiple modes in the new open standard
- Optimal battery consumption for deterministic sources (traffic known a priori)
- Enables Time Sensitive applications (ISA100.11a, WirelessHART)
- New IEEE Interest Group to support IETF work over this MAC (6TiSCH)

# Wireless Sensors Networks in Industrial Applications

WSNs can be used advantageously for rare event detection or periodic data collection for industrial applications. In rare event detection, sensors are used to detect and classify rare, random, and ephemeral events, such as alarm and fault detection notifications due to important changes in machine, process, plant security, operator actions, or instruments that are used intermittently.

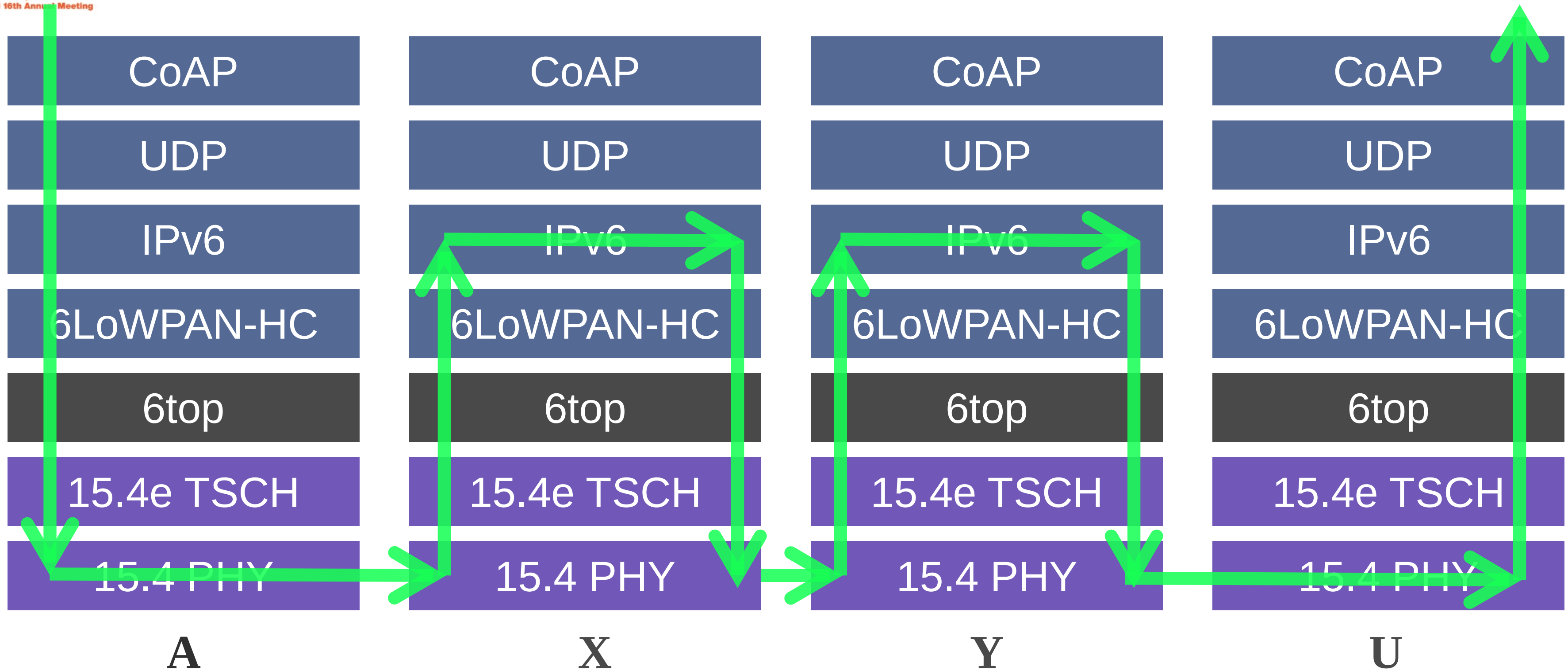
On the other hand, periodic data collection is required for operations such as tracking of the material flows, health monitoring of equipment/process. Such monitoring and control applications reduce the labour cost, human errors and prevent costly manufacturing downtime.

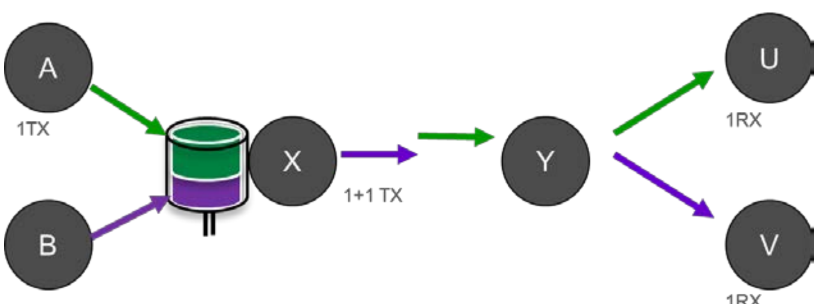
**What people usually miss is the order of magnitude. For each 'critical' wired measurement (e.g. control loops) there are hundreds missing ones that could (only) be addressed through wireless. Aiming at a scale a thousand times larger than early WSN deployments.**

**Missing measurements are the key to GE's 1% that justifies the Industrial Internet.**

http://community.emerson.com/process/emerson-exchange/b/weblog/archive/2013/10/03/why-are-there-missing-measurements.aspx

# Best effort routing



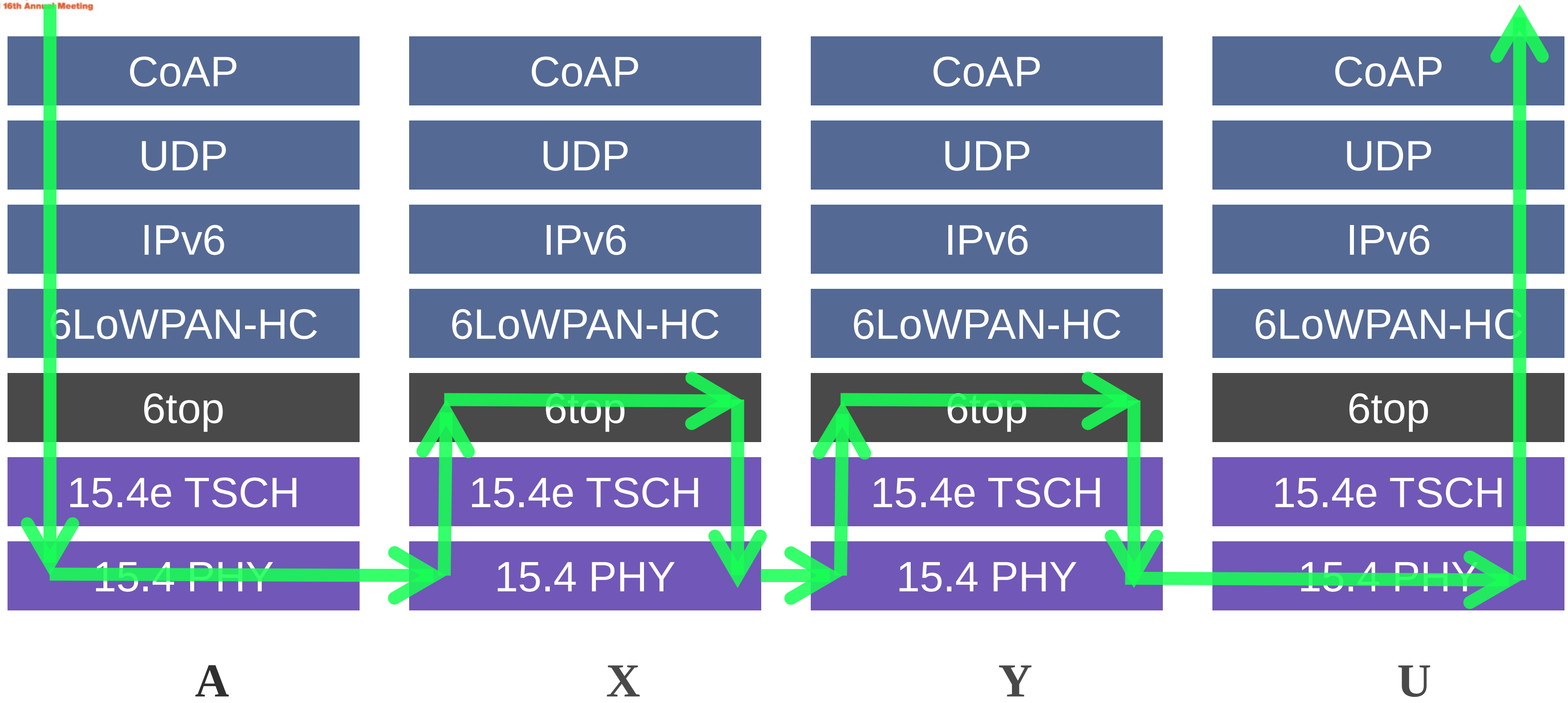

Bundle

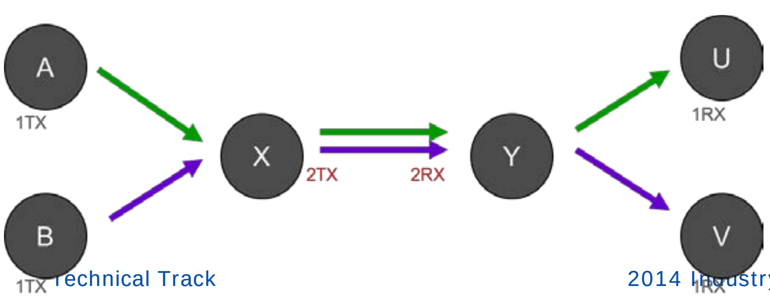
channelOffset

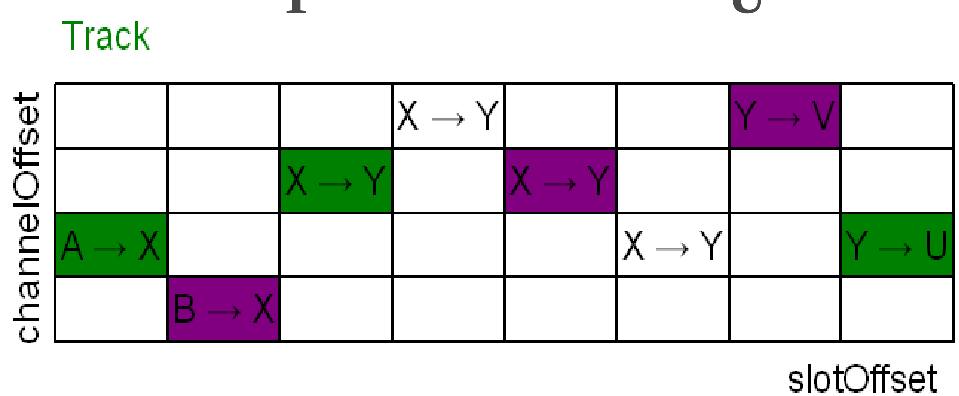
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | X → Y | | | Y → V | |
| | | | | | | | |
| A → X | | | | | X→ Y | | Y → U |
| | B → X | | | | | | |

slotOffset

# Track Switching in Transport Mode

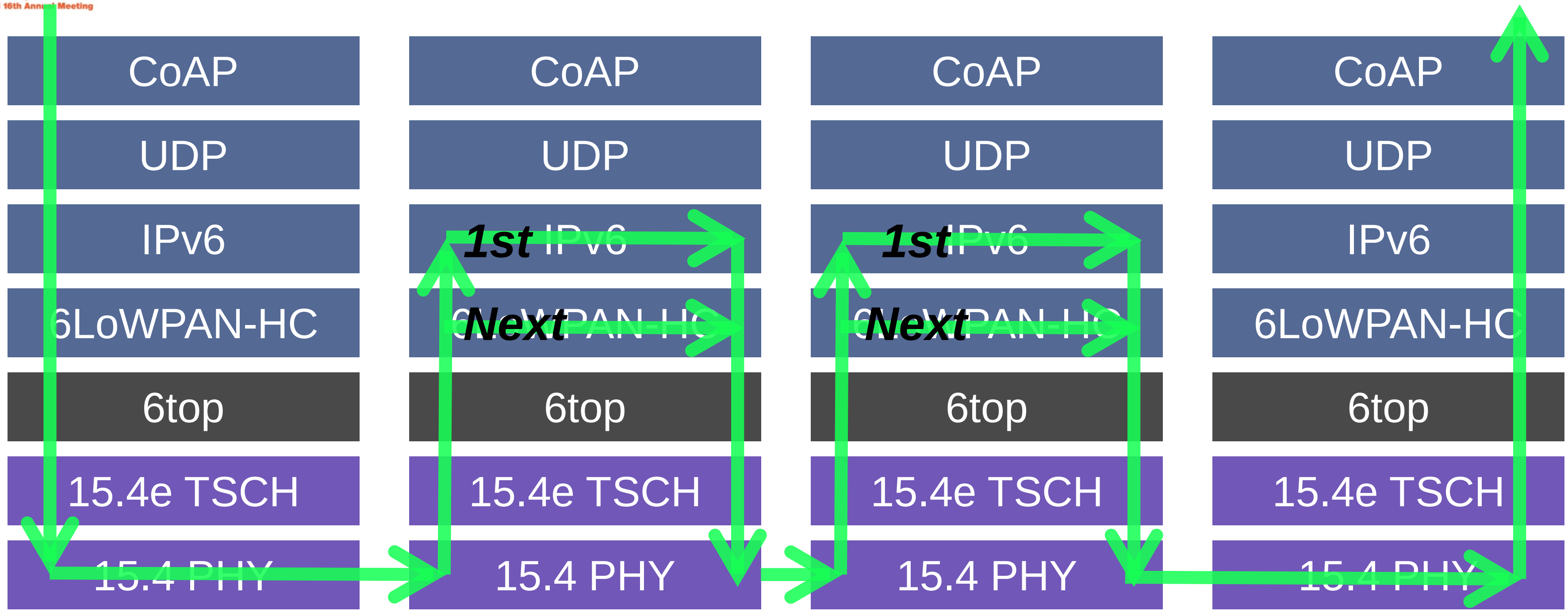


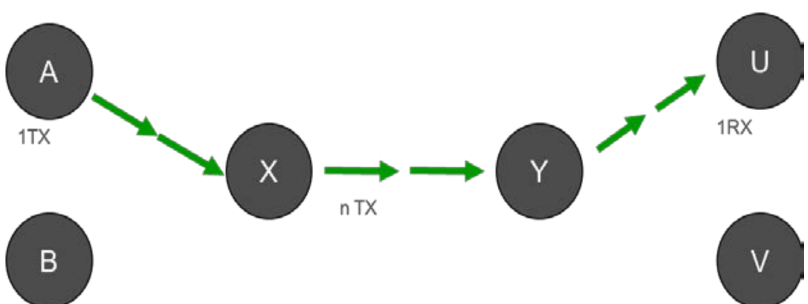



# Track Switching in Tunnel Mode

# 6LoWPAN Fragment forwarding




Bundle

channelOffset

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | X → Y | | | Y → V | |
| | | | | | | | |
| A → X | | | | | X→ Y | | Y → U |
| | B → X | | | | | | |

slotOffset

# Benefits


## For Users

- A step toward Harmonization (Hour Glass model)
- COTS price, Standard experience (e.g. crypto),
- IPv6 end to end, enabling virtualization, thus easier install and management
- Deterministic to the carpeted floor, enabling control loops with virtual PLC

## For Vendors

- Extends value proposition, less dedicated hardware, more software
- Extends the reach of IP technology, save on generic soft and hard components
- Reusable Improvements on generic capabilities (e.g. deterministic switching)
- App Servers in the control loop, added value in fog/cloud analytics

# Scalability requirements

**10s of Ks devices with multihop LLN access**

- No broadcast in the LLNs
- No renumbering (quasi permanent IPv6 address)

**Continuous reachability as a LLN device moves in Subnet**

- Radio conditions change cause network reorganisation
- Already use cases such as handheld, cranes, small vehicles

**Backward Compatibility with classical IPv4 and v6 devices**

**Support of discovery protocols throughout the subnet**

# Routing requirements

## Cost Optimized in the backbone

» Any to any traffic

» Multipath and load balancing a bonus

## Power Optimized in the LLNs

– Most traffic flows to or from the LLN Backbone Router

– Control traffic must be limited vs. Data traffic

## Broadcast or scalable multicast in the backbone

## Multicast or Controlled dissemination in the LLN

# Time-Sensitive requirements

**LLNs Time synchronization via the backbone**

to keep all LLNs in sync and

allow movement from one LLN to the next

**Slow deterministic LLNs (proces control)**

No need for Deterministic backbone

Until scale and congestion loss becomes an issue

**Upcoming faster deterministic wireless (factory automation)**

deterministic loops across networks and server OS

# Compatibility requirements

## End-to-End time-synchronization

- Synchronization via the backbone a plus
- Standard time exchange, adapted precision.
- Sync and schedule with the Deterministic backbone

## MTU size a complex issue across networks

- Ideally harmonize MTUs across multilink subnet or
- at least detect discrepancies

## Link Local lookups should be emulated

- Proxy operation (per protocol)
- Genralized hash based multicast

## IEC 62591

WirelessHART

- IEC based on HART 7.1.
- TDMA
- fixed time slots (10ms)
- Mesh only
- Shipped YE-2008.
- Vendor driven
- Emerson, E&H, ABB, Siemens

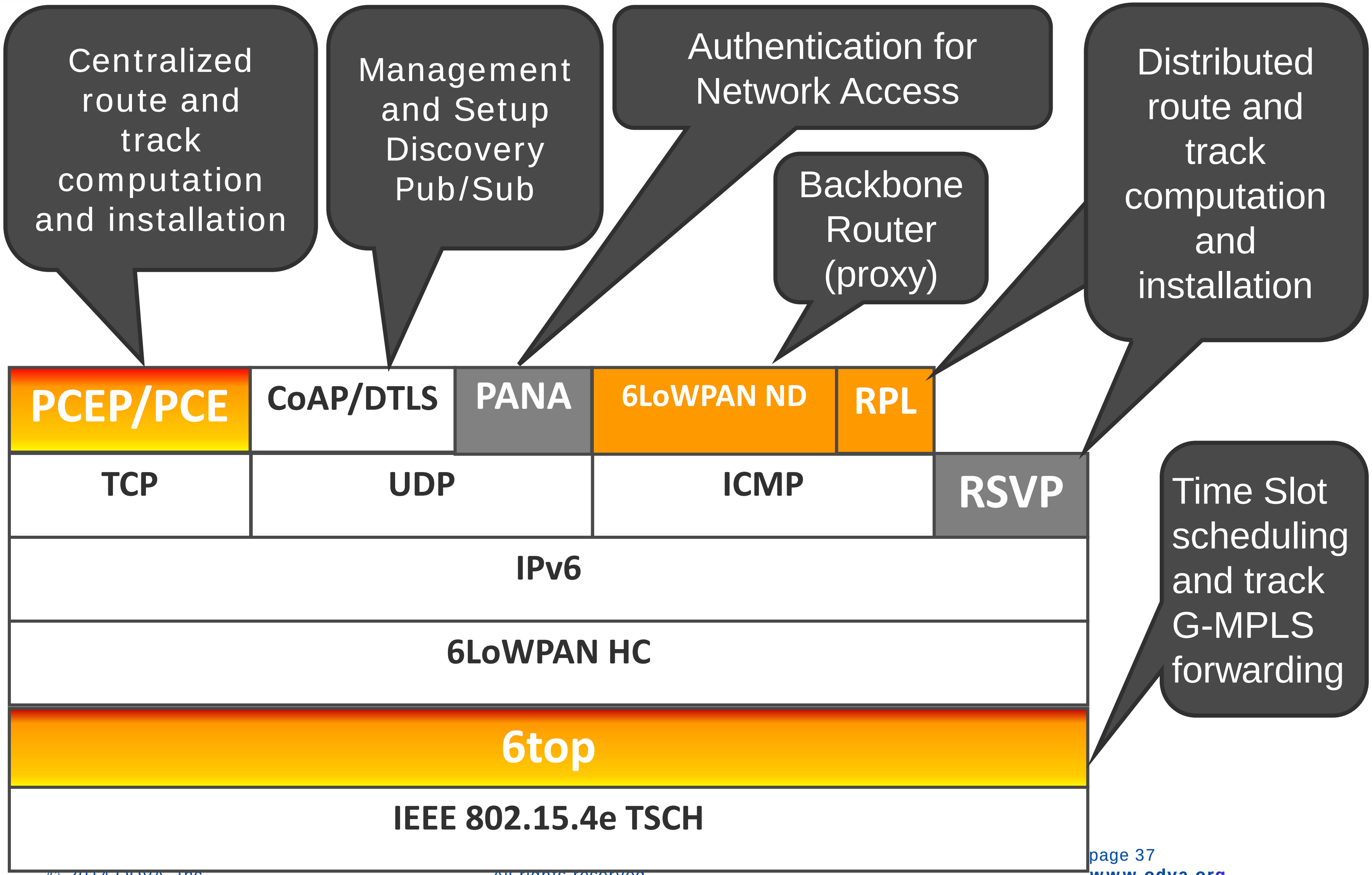
## IEC PAS 62734
## ISA100.11a

- IEC based on 2011 revision
- TDMA+CSMA
- Var. time slots
- Star, mesh and hybrid topology
- IPv6, 6LoWPAN, TCP-friendly
- Shipped mid-2010
- Mostly user driven
- Honeywell, Yokogawa, Invensys

## IEC 62601
## WIA-PA

- Alternate from China
- Star, mesh and hybrid topology
- Standardization work started in 2006.

# 6TSCH: Architecture



# Routing With RPL

| Low Power Lossy Nets | Addressed in RPL ? |
|---|---|
| Dynamic Topologies | ✓ |
| Peer selection | ✓ |
| Constrained Objects | ✓ |
| Fuzzy Links | ✓ |
| Routing, local Mobility | ✓ |
| Global Mobility | ✗ |