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MAC Protocols for sensing systems

Internet of Things a.a. 2018/2019

Un. of Rome "La Sapienza"

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6LowPAN

- See:
- http://www.ti.com/lit/wp/swry013/swry013.pdf
- 6LoWPAN: Incorporating IEEE 802.15.4 into the IP architecture. Internet Protocol for Smart Objects (IPSO) Alliance, White paper # 3. By Jonathan Hui, David Culler, Samita Chakrabarti.

Adaptation layer: 6LoWPAN

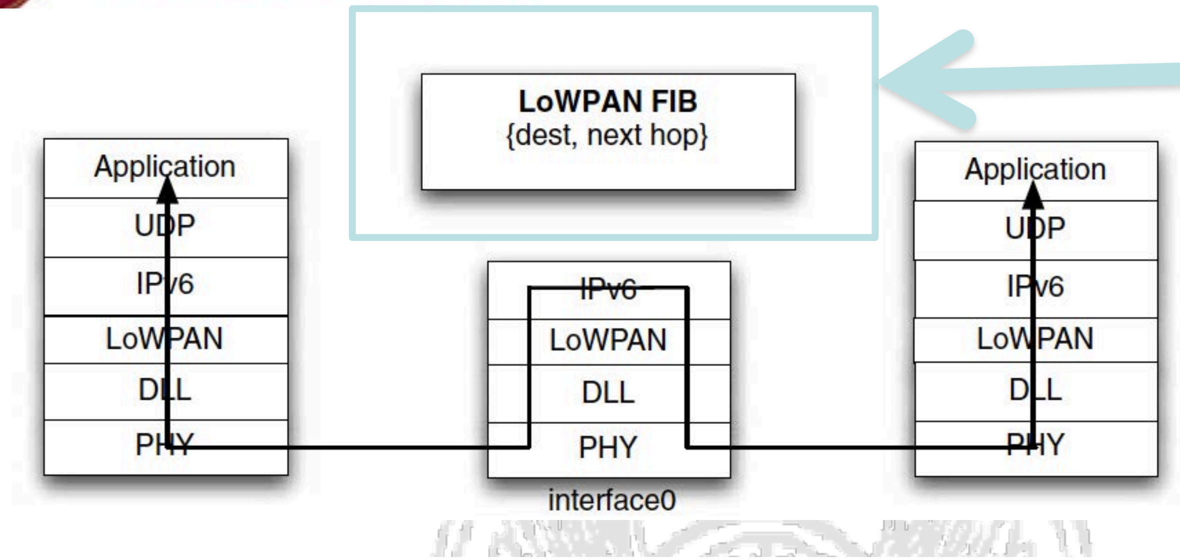
- Addressing: not routable local addresses. Smart objects are permanently identified by EUI-64 identifiers (8 bytes)
  - short 16 bit local address is assigned during network bootstrapping to reduce overhead

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     OUI     |L|M|           OUI (cont.)           |           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+               +
|                     extension identifier                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- IPv6 address can be (and must be in 6LoWPAN) obtained by concatenating a 64bit network address with the EUI-64

6LoWPAN Routing

Updated by the Selected routing protocol




```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1 0|V|F|HopsLft| originator address, final address ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1 0|V|F|1 1 1 1|   Hops Left   | originator address, final address...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch    /
```

Specifies type and subtype of the header (i.e., which is the meaning of the following information, how many bits Are allocated to each field)

The fragmentation header is elided for packets that fit into one single IEEE 802.15.4 frame. The mesh header is not used when sending data over one hop only.

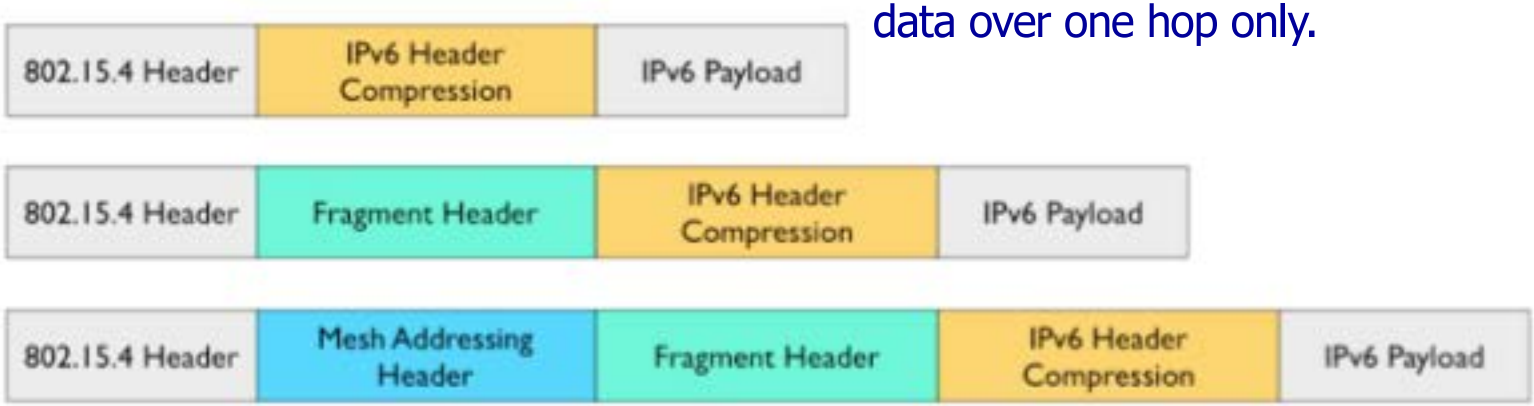


Figure 2. Typical 6LoWPAN Header Stacks.

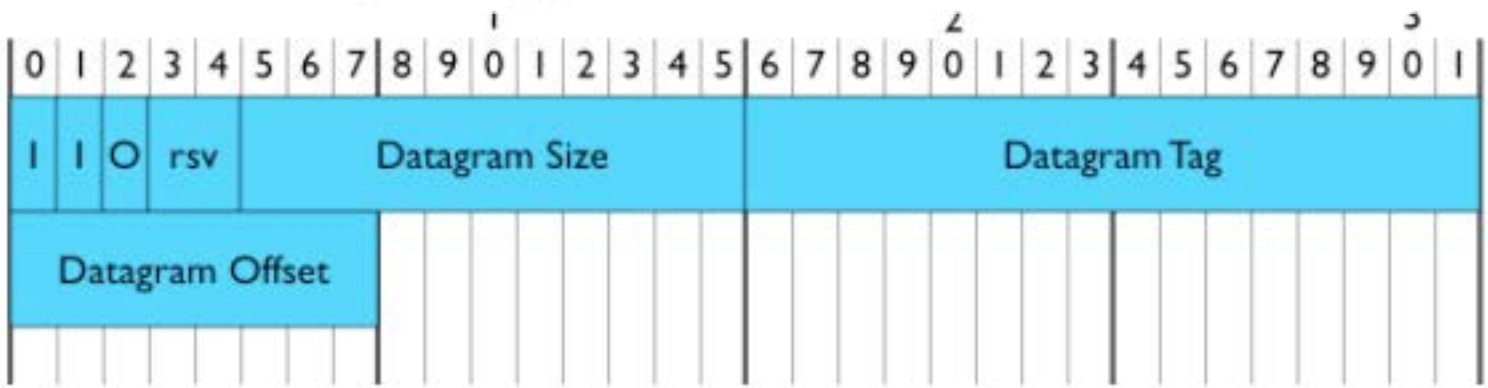


Figure 3. 6LoWPAN Fragment Header.

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Fragmentation

- Used when transmitting L2-L3 PDU larger than 128 bytes
- Fragmentation/reassembly performed at the link level.

Fragmentation header:

Together with source/destination used to Identify the original packet

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1 1 1 0 0|    datagram_size      |         datagram_tag          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|datagram_offset|
+-+-+-+-+-+-+-+-+
 \_ dispatch  _/
```

Identifies order of fragment within the sequence of fragments of the same packet

- Compression again as key apect for header design.

Fragmentation

- Used when transmitting L2-L3 PDU larger than 128 bytes
- Fragmentation/reassembly performed at the link level.

Fragmentation header:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1 1 1 0 0|    datagram_size        |         datagram_tag          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|datagram_offset|
+-+-+-+-+-+-+-+-+
 \_ dispatch  _/
```

Set to zero for the first fragment

- Datagram size describes the total (un-fragmented) payload.
- Datagram tag identifies the set of fragments and is used to match fragments of the same payload.
- Datagram offset identifies the fragment's offset within the un-fragmented payload.
- The fragment header length is 4 bytes for the first header and 5 bytes for all subsequent headers

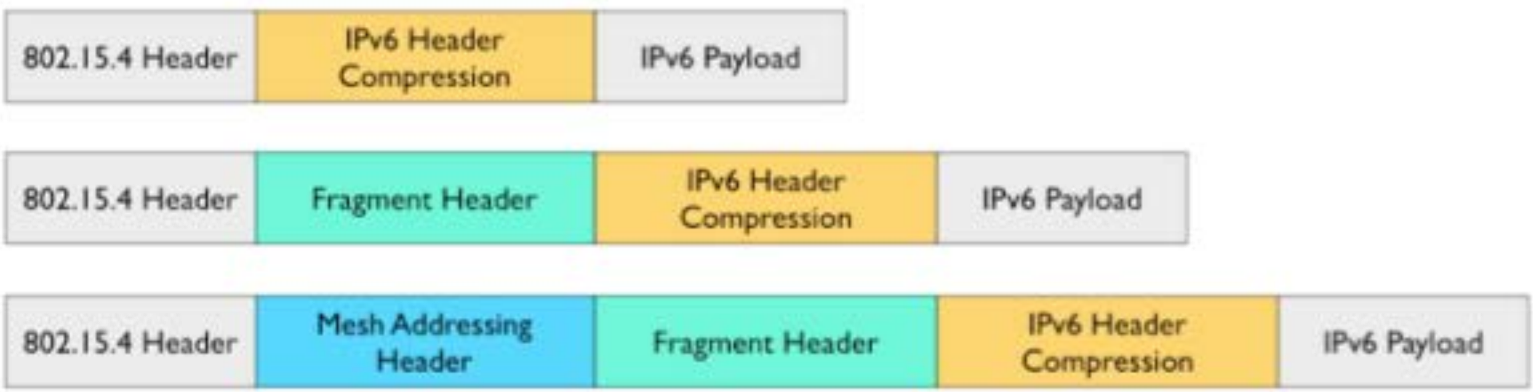


Figure 2. Typical 6LoWPAN Header Stacks.

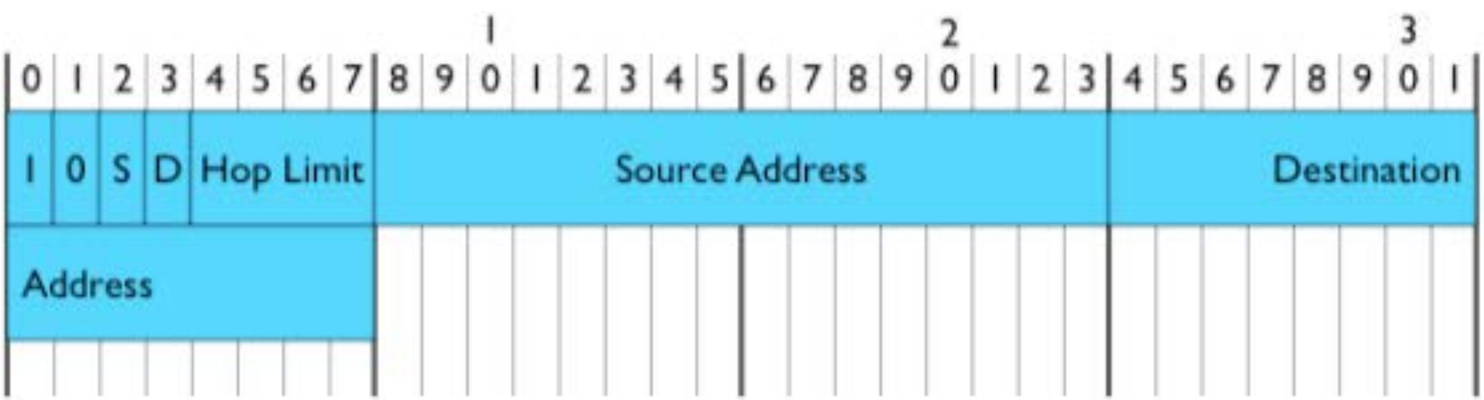
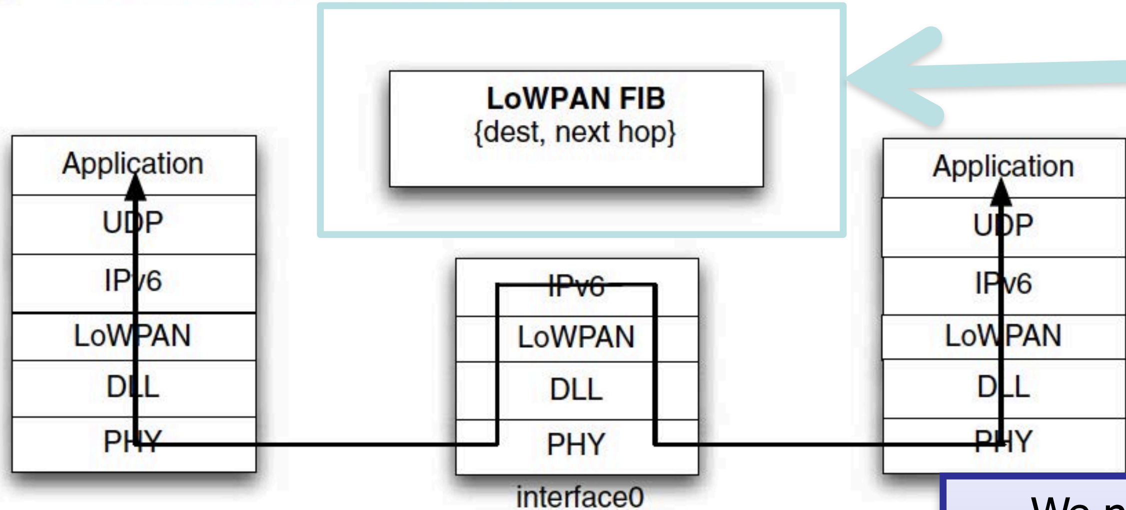


Figure 4. 6LoWPAN Mesh Addressing Header.

6LoWPAN Routing



Updated by the Selected routing protocol

```
 0                   1                   2
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
|1 0|V|F|HopsLft| originator address, final ad

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
|1 0|V|F|1 1 1 1|   Hops Left   | originator a
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch   /
```

We need info on very first node (V—source node), e.g., for reassembly, and on final destination (F) for routing. Such information are always provided In the mesh header (which is the first Header in multi-hop networks)

Specifies type and subtype of the header (i.e., which is the meaning of the following information, how many bits Are allocated to each field)

6LoWPAN Routing

two categories of routing are defined: mesh-under or route-over. Mesh-under uses the layer-two (link layer) addresses (IEEE 802.15.4 MAC or short address) to forward data packets (the network is seen as a single IP SubNet); while route-over uses layer three (network layer) addresses (IP addresses). In the latter case the routing protocol is RPL.

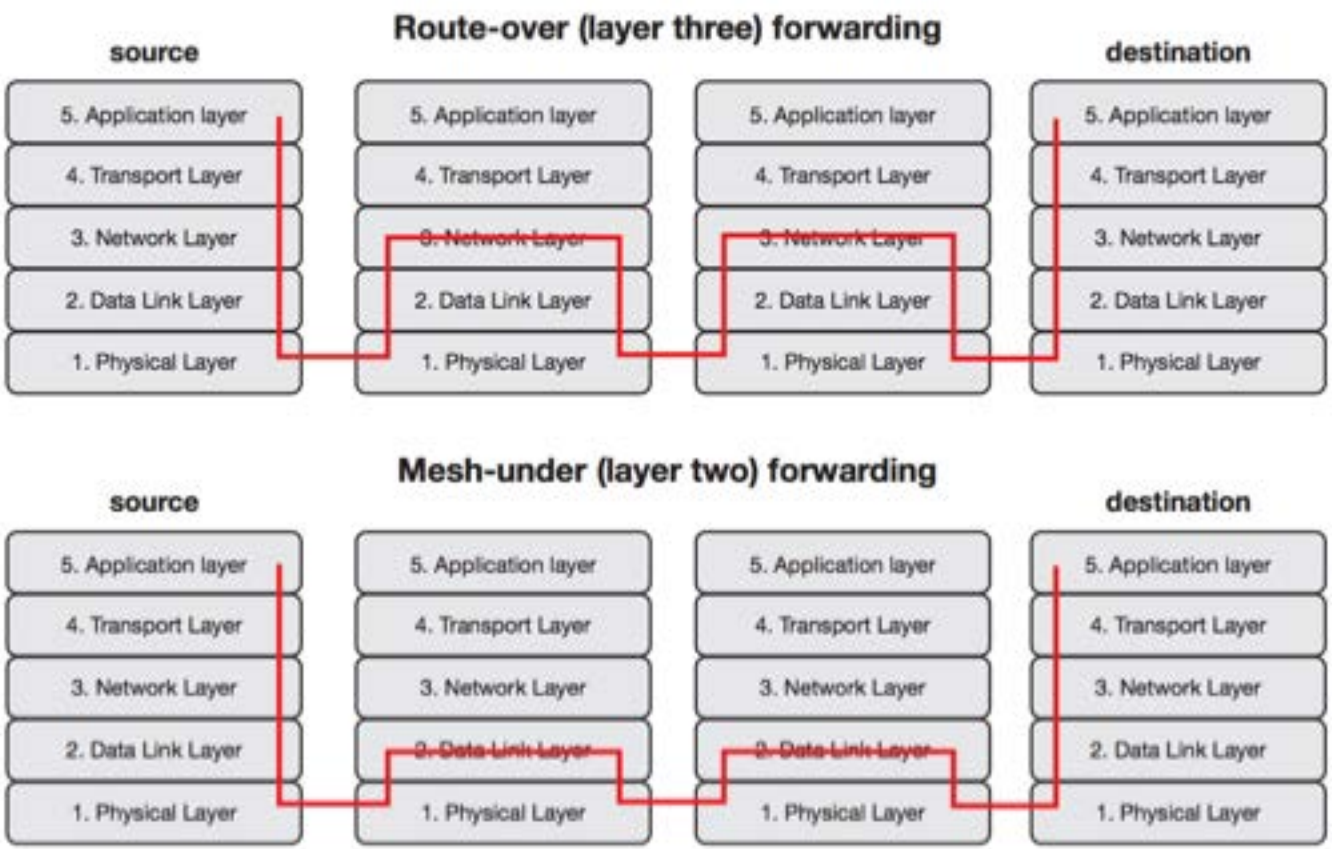


Figure 5. Mesh-under and route-over packet forwarding

6LowPAN

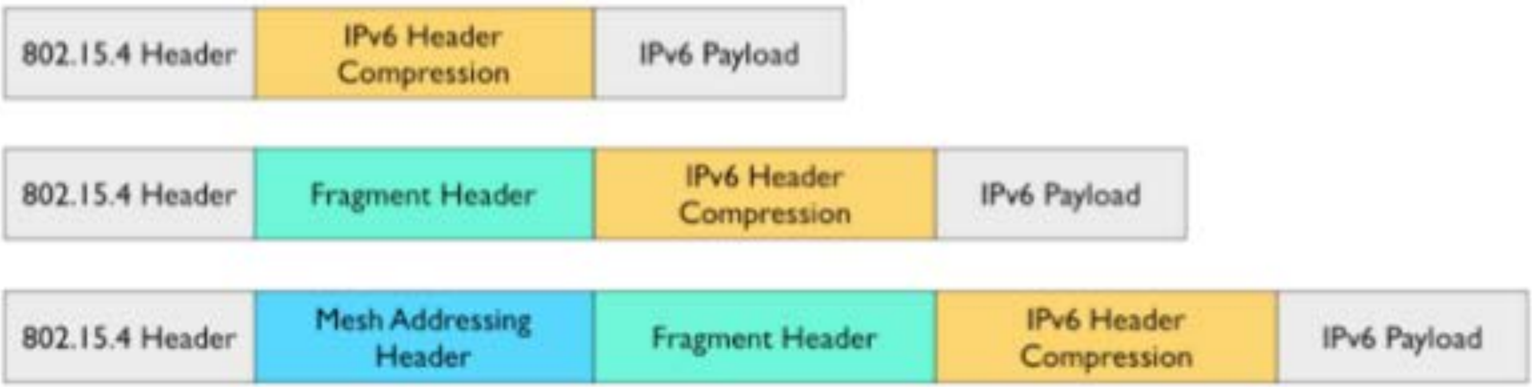
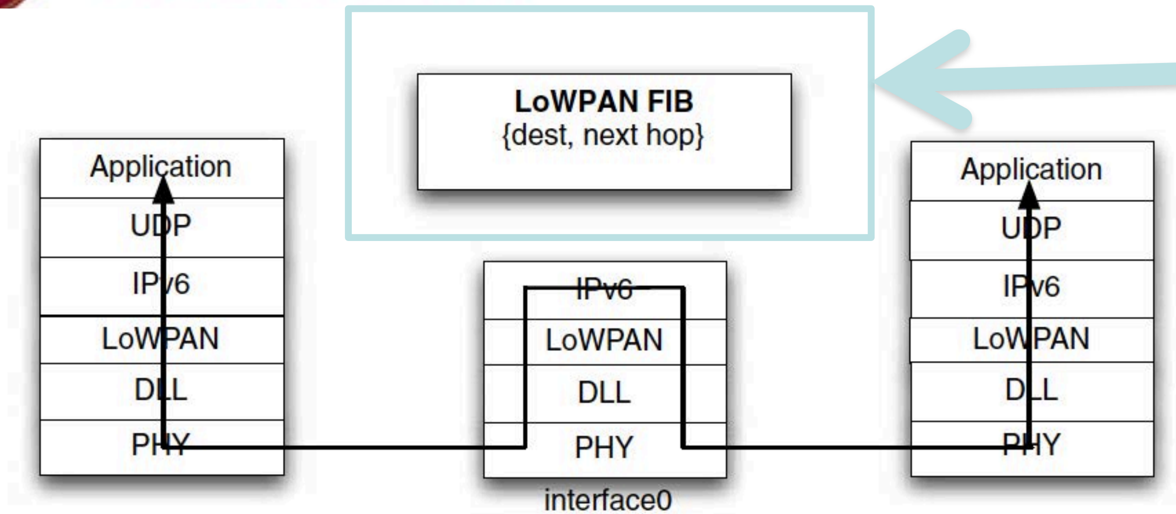


Figure 2. Typical 6LoWPAN Header Stacks.

Figure 5. 6LoWPAN RFC 4944 IPv6 Header Compression.

6LoWPAN Routing

Updated by the Selected routing protocol



V and F bits say whether a 64 or 16 bit Address will follow

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1 0|V|F|HopsLft| originator address, final address ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1 0|V|F|1 1 1 1|    Hops Left    | originator address, final address...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch    /
```

Specifies type and subtype of the header (i.e., which is the meaning of the following information, how many bits Are allocated to each field)

Header Compression

- Limited Packet size
- Transmitting 128bits addresses + information needed for security purposes can lead to very high overhead
- Solution: header compression
  - Stateless header compression
    - ✓ HC1: compresses IPv6 headers
    - ✓ HC2 compresses UDP headers

HC1 compression

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 1 0 0 0 0 1 0|SAE|DAE|C|NH |0|      Non-Compressed fields...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch   _/ \_ HC1 header_/
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 1 0 0 0 0 1 0|SAE|DAE|C|NH |1|S|D|L|_________| N.-C. fields...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch   _/ \_ HC1 header_/ \_ HC2 header_/
```

Identifies that an HC2 header follows

Header Compression

- Limited Packet size
- Transmitting 128bits addresses + information needed for security purposes can lead to very high overhead
- Solution: header compression
  - Stateless header compression

Some likely values (UDP,TCP,ICMP) expressed by The two bit NH. If NH !=0 can be skipped

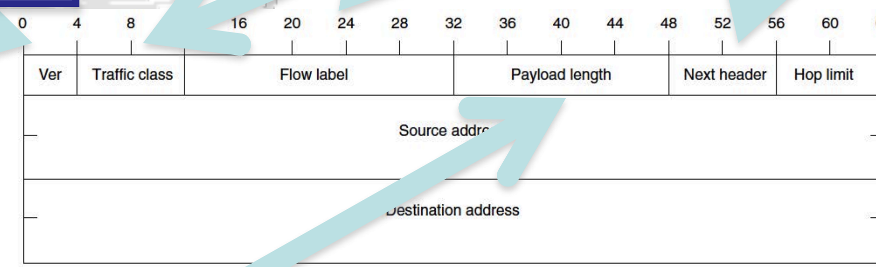
Often 0. C=1 means their values are zero

Used to avoid transmitting First 64 bits of the address

Always 6 not transmitted in HC1

```
 0                   1                   2                   3
 0 1 2 3 4 5                 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 1 0 0 0 0 1 0|SAE|DAE|C|NH |0|      Non-Compressed fields...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch   _/ \_ HC1 header_/

 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 1 0 0 0 0 1 0|SAE|DAE|C|NH |1|S|D|L|_________| N.-C. fields...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch   _/ \_ HC1 header_/ \_ HC2 header_/
```



IPv6 packet header

Can be inferred by other Headers--Not transmitted

Header Compression

- Limited Packet size
- Transmitting 128bits addresses + information needed for security purposes can lead to very high overhead
- Solution: header compression
  - Stateless header compression
    - ✓ HC1: compresses IPv6 headers
    - ✓ HC2 compresses UDP headers

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 1 0 0 0 0 1 0|SAE|DAE|C|NH |0|      Non-Compressed fields...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch   _/ \_ HC1 header_/

 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 1 0 0 0 0 1 0|SAE|DAE|C|NH |1|S|D|L|_______| N.-C. fields...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch   _/ \_ HC1 header_/ \_ HC2 header_/
```

Source/destination

port field compression

How? favoring port selection

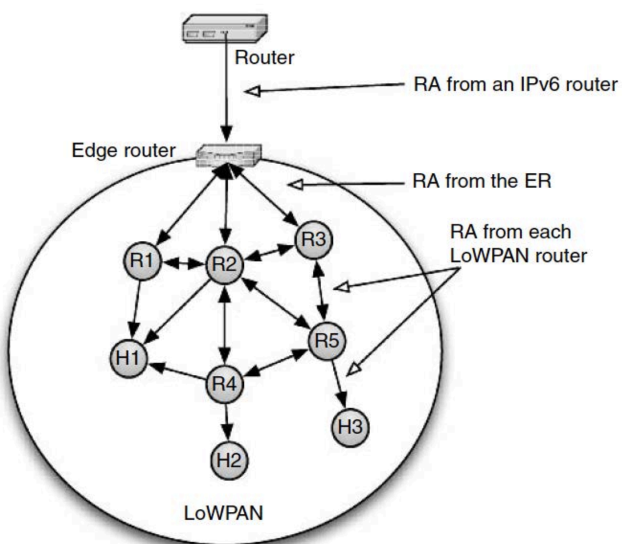
among a subset of possible

ports

Indicates length size can be inferred and is thus not included

Bootstrapping an IoT network

- Edge Router broadcasts general information
- Association procedure for new nodes (they select the router to affiliate to based on ER metric; Node registration/confirmation)
- Procedure to assign local addresses, identify and solve duplicate addresses.




```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|1|LOWPAN_BC0 |Sequence Number|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 \_ dispatch  _/
```

Broadcast packet

Standard-like routing Protocols for WSNs

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Collection Tree Protocol in Proceedings of ACM Sensys 2009
https://sing.stanford.edu/gnawali/ctp/sensys09-ctp.pdf ***http://www.vs.inf.ethz.ch/publ/papers/santinis11_ctp-castalia_new.pdf***

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Kyle Jamieson (University College London)

David Moss (People Power Company)

Philip Levis (Stanford University)

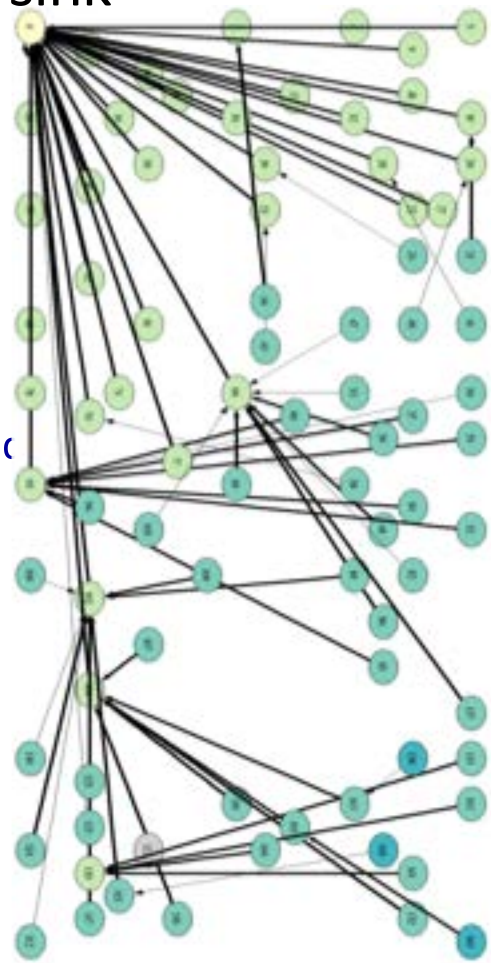
Slides partially taken from the presentation given by the authors at ACM SenSys

November 4, 2009

Collection

- Anycast route to the sink(s)
  - Used to collect data from the network to a small number of sinks (roots, base stations)
  - Each node selects one of its neighbors nodes as its parent
    - ✓ Parents handle packets received from the children and further forward them towards the sink
    - ✓ when there are multiple sinks, data re sent to the one with the minimum cost
- A distance vector protocol
  - Metric for selecting next hop:
    - ✓ Distance in hops from the sink
    - ✓ Quality of the local communication link

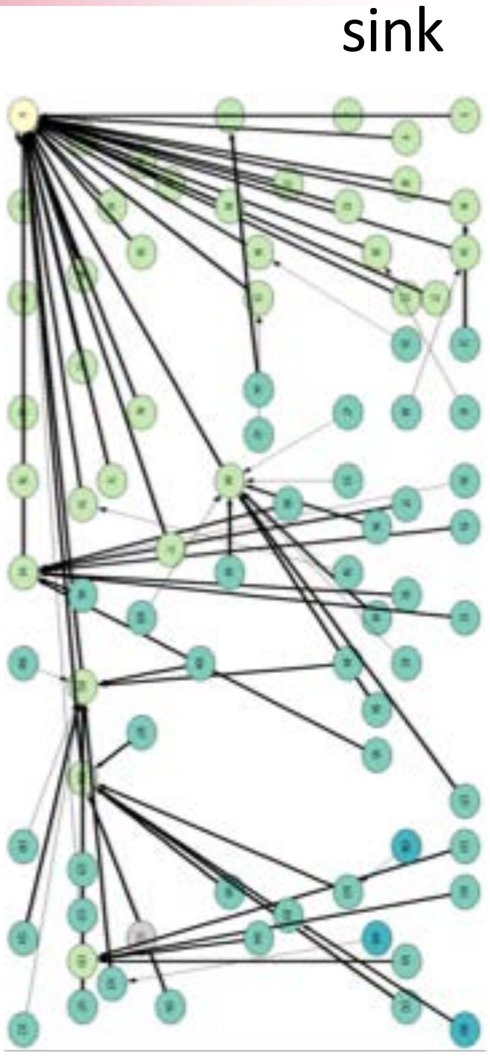
sink



Desirable properties for collection tree protocol

- Reliability: a protocol should deliver at least 90% of end-to-end packets when a route exists
- Robustness: it should be able to operate without tuning or configuration in a wide range of network conditions;
- Energy Efficiency
- Hardware Independence

Observation: link quality changes fast (even every 0,5s)



Common Architecture

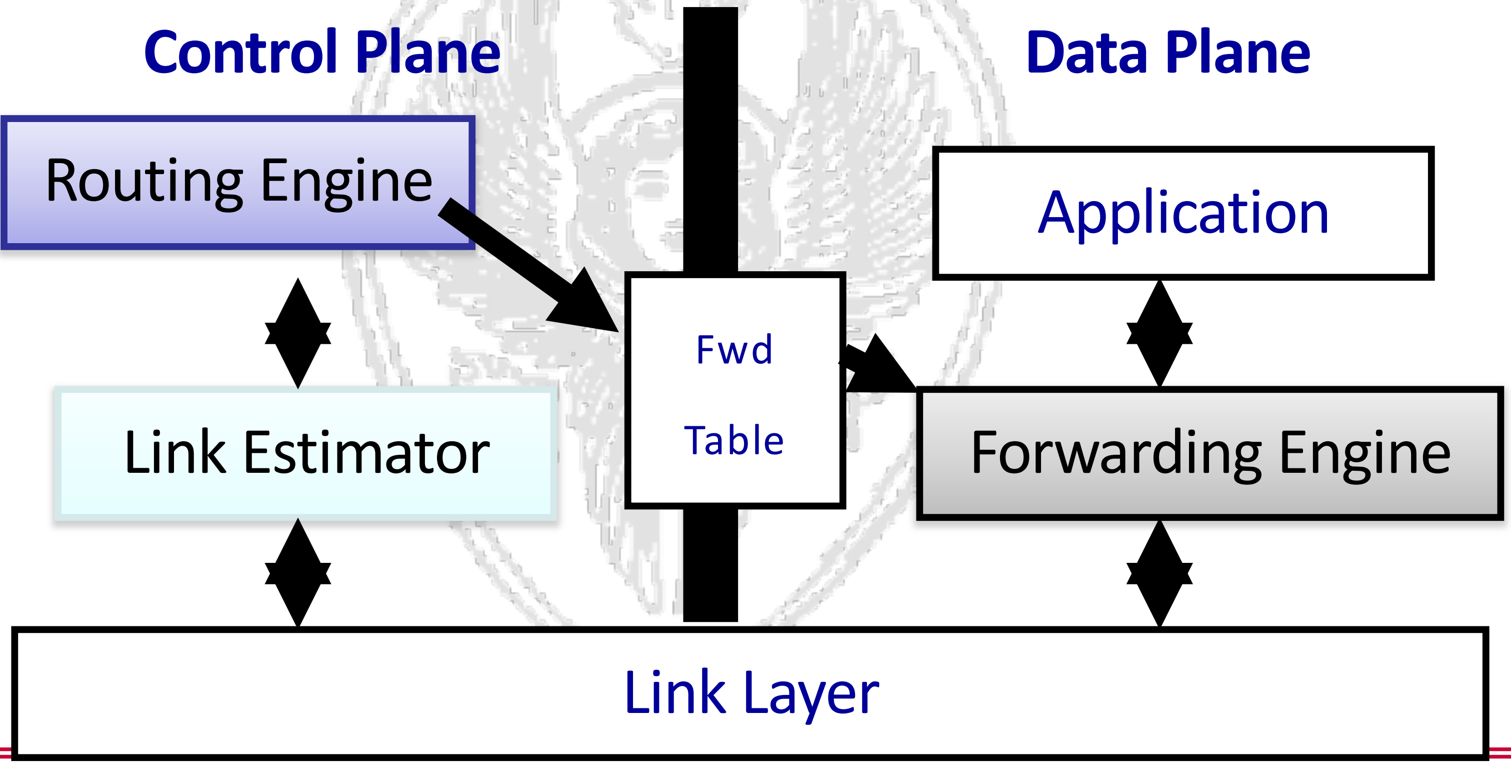
Sending and receiving beacons

for route construction and maintenance

Creating and updating the routing table

Perform forwarding

Detect and Repair Loops, filter duplicate packets



Parent selection metric

- ETX = Expected Number of Transmissions to reach the sink
- Computed based on performance experienced in the recent past by beacon and data packets for the local 1-hop ETX_{loc}

$$Q_u = \frac{n_u}{n_a}. \qquad Q_b[k] = \alpha_b \frac{n_b}{N_b} + (1-\alpha_b) Q_b[k-1].$$

- ETX_{mhp} via a given neighbor computed as the sum of the ETX_{loc} and of the estimated ETX_{mhp} at that neighbor

Number of bits needed
To tx successfully Nb ones

Parent selected only among uncongested nodes

Paren

Pull bit

- ETX = Expected Number of Tra
- Comput Congested bit forma past by beacon and data packe

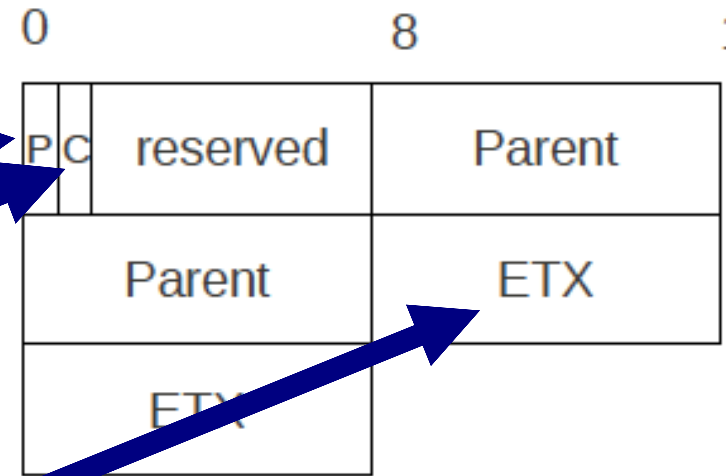
$$Q_u = \frac{n_u}{n_a}.$$

Routing cost

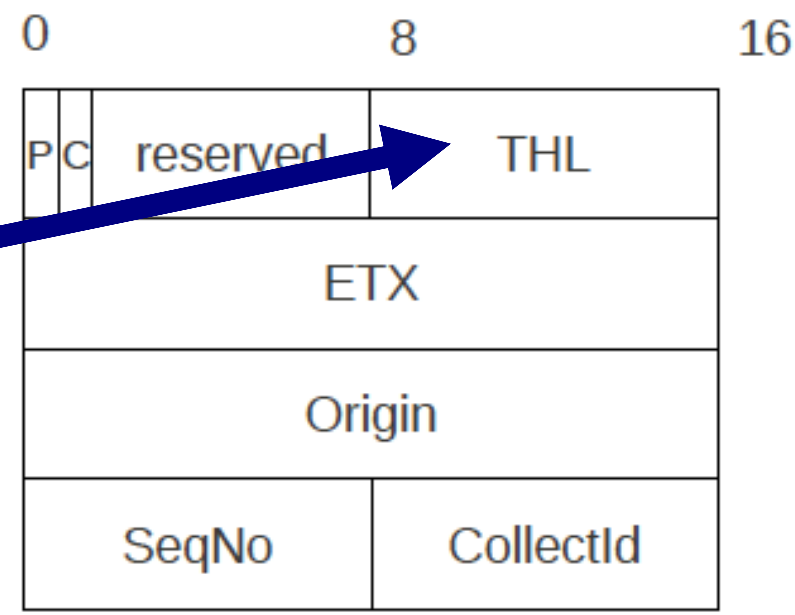
- ETX_{mhp} via a given neighbor co ETX_{loc} and of the estimated ETX at that neigh

Time has lived

Parent selected only amon



a. CTP Routing Frame

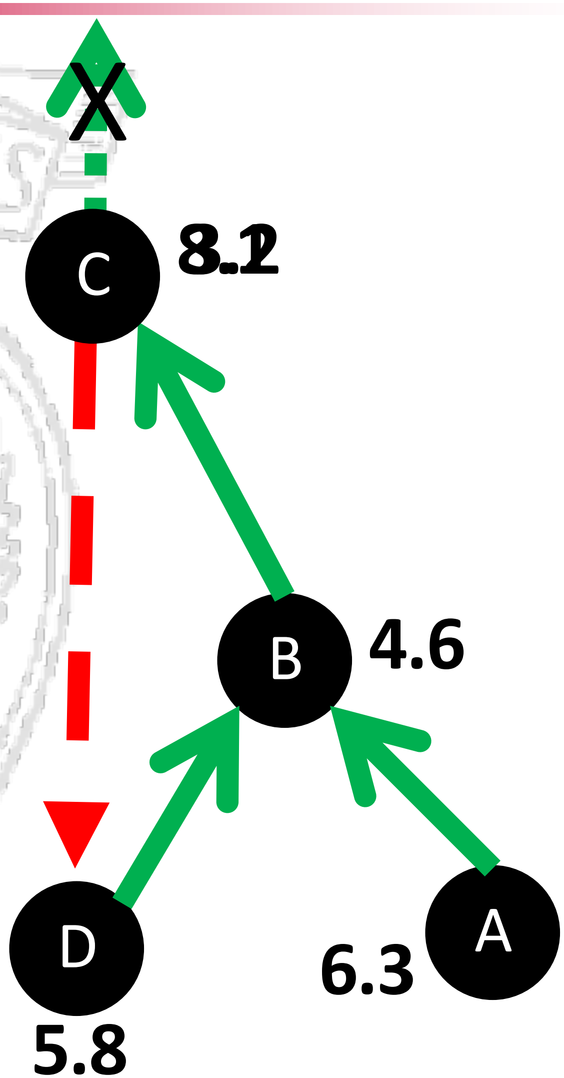


b. CTP Data Frame

Routing Loops

– Cost does not decrease

Parent selected as the neighbor with lowest cost

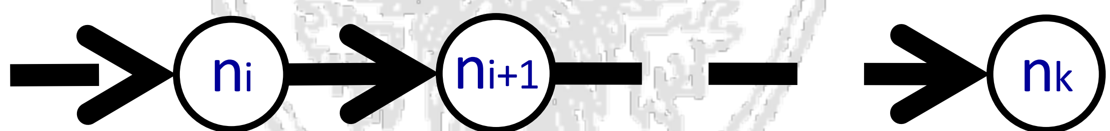


Routing Consistency

- *Next hop* should be closer to the destination
- Maintain this consistency criteria on a path

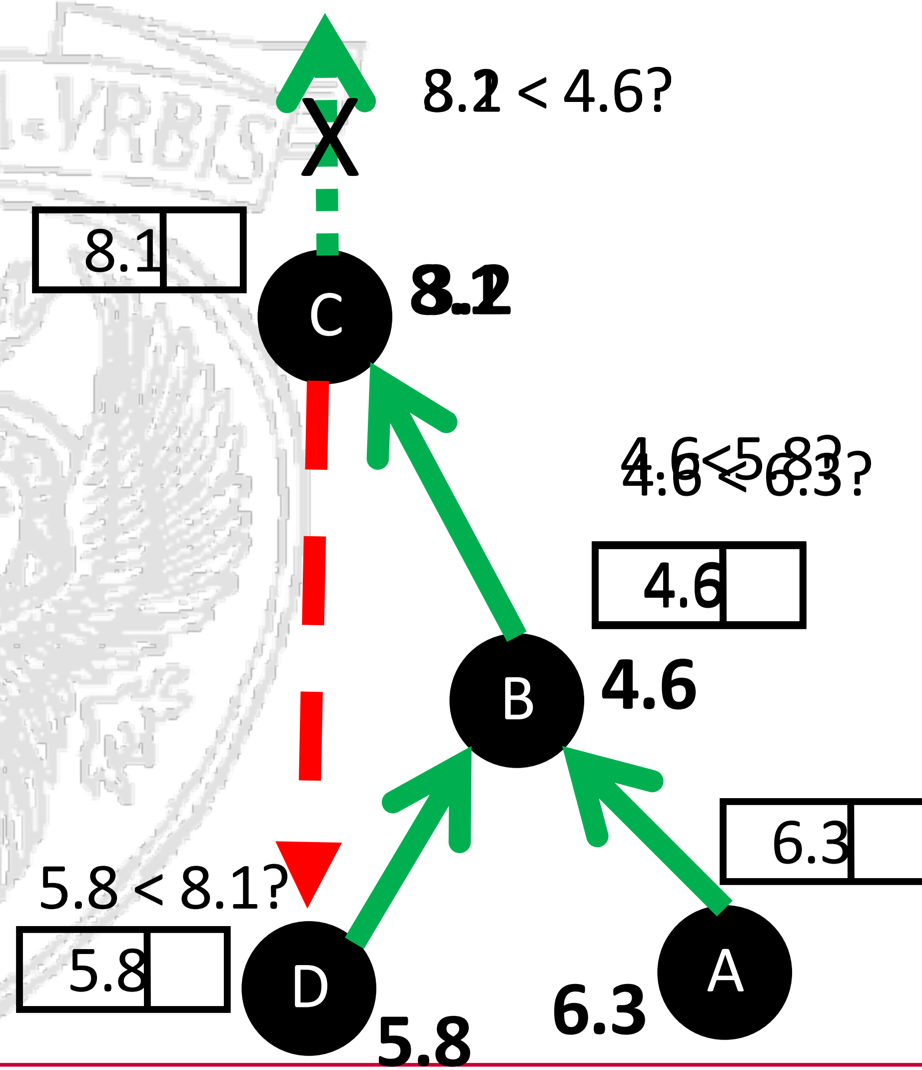
$$\forall i \in \{0, k-1\},\ ETX(n_i) > ETX(n_{i+1})$$

- Inconsistency due to stale state



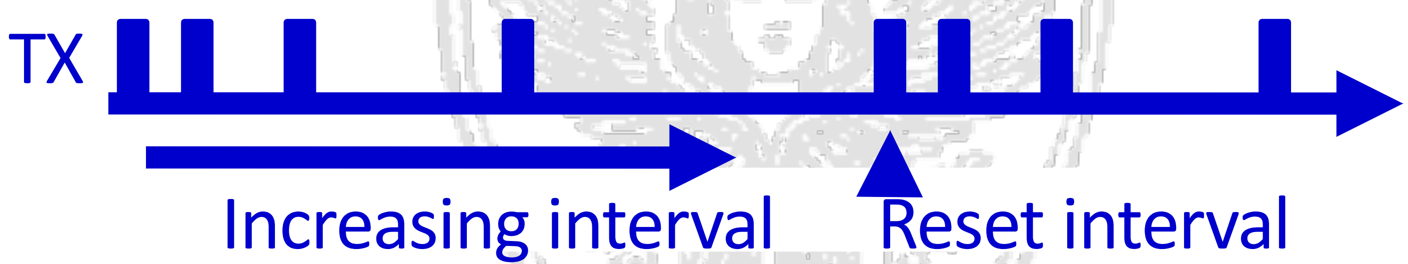
Detecting Routing Loops

- Datapath validation
  - Cost in the packet
  - Receiver checks
- Inconsistency
  - Larger cost than on the packet
- On Inconsistency
  - Don't drop the packets
  - Signal the control plane



Control Traffic Timing

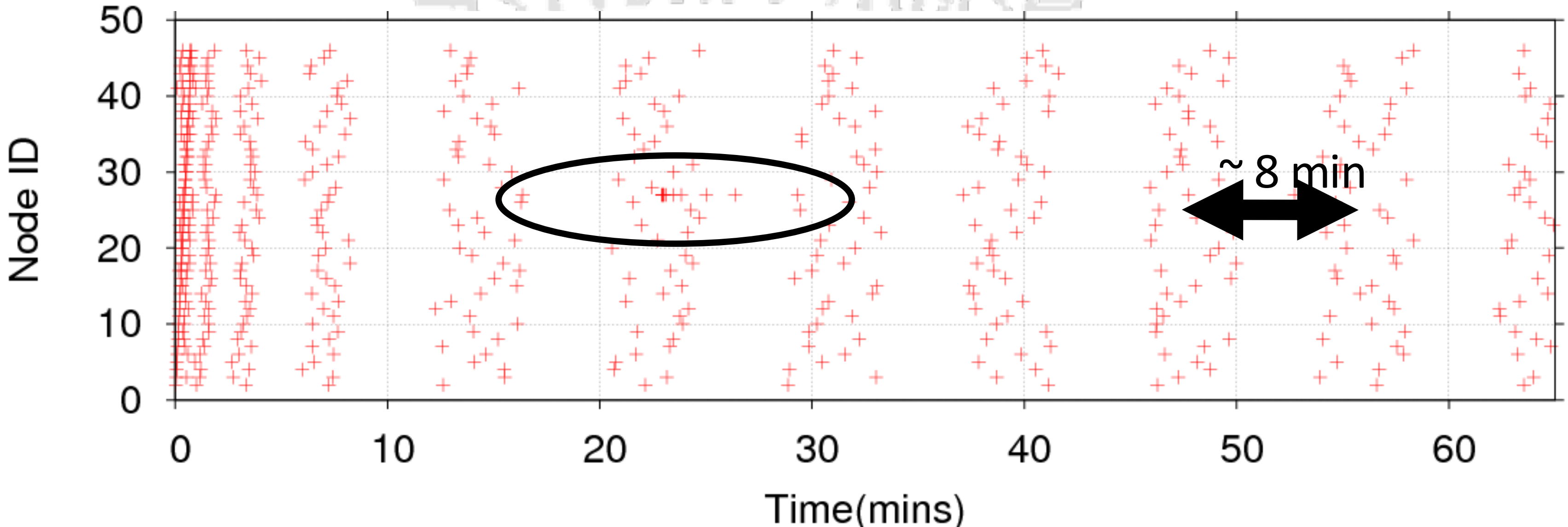
- Extend Trickle to time routing beacons
- Reset the interval
    - ✓ ETX(receiver) >= ETX(sender)
    - ✓ Significant decrease in gradient
    - ✓ “Pull” bit



Control propagation rate

- Start with a small interval
- Double the interval up to some max
- Reset to the small interval when inconsistency identified

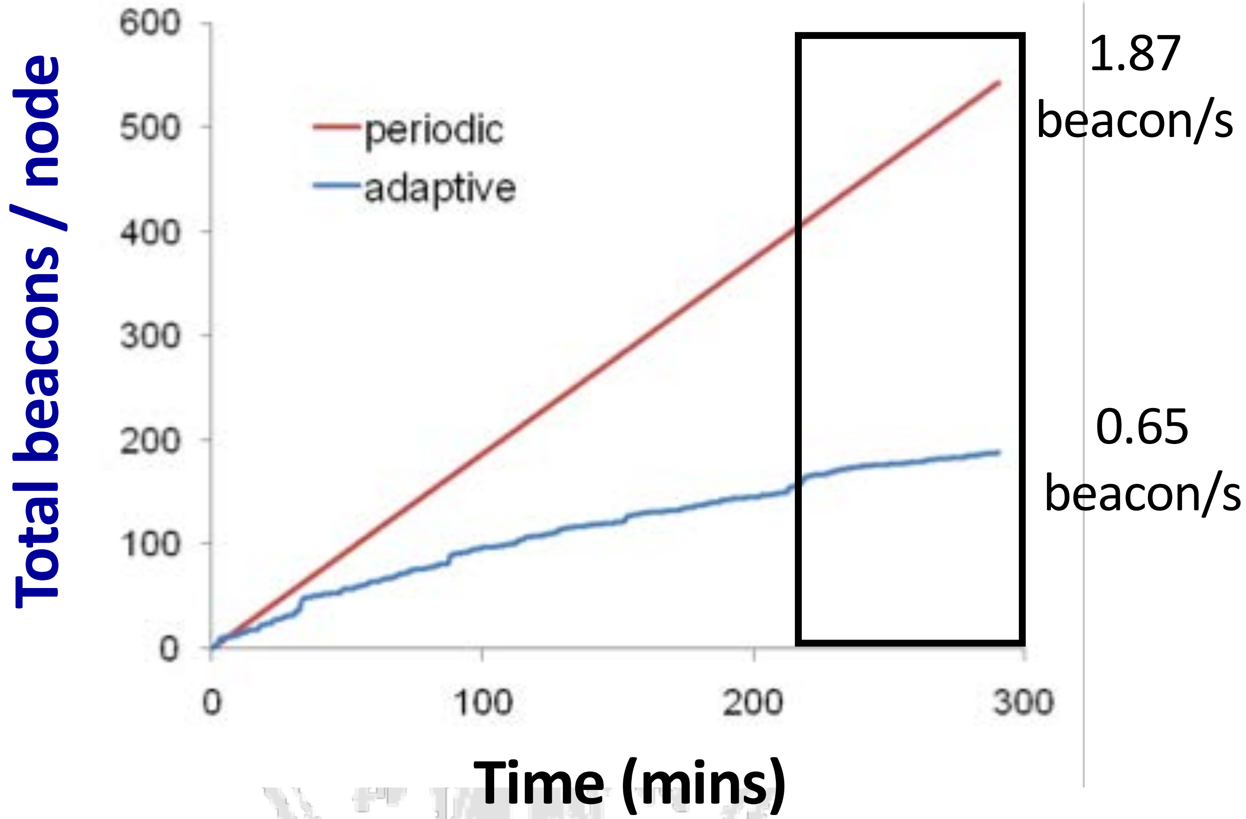
Adaptive Beacon Timing



Tutornet

Infrequent beacons in the long run

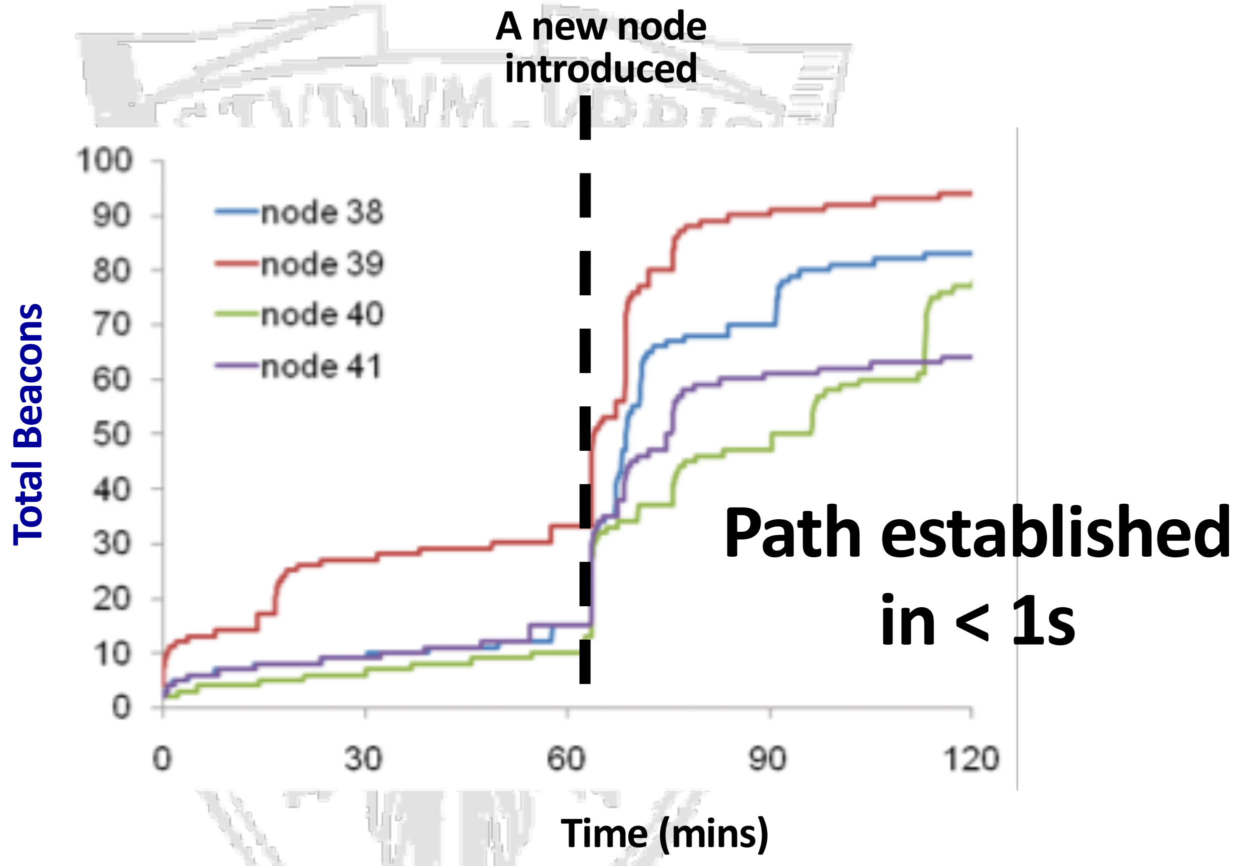
Adaptive vs Periodic Beacons



Tutornet

Less overhead compared to 30s-periodic

Node Discovery



Tutornet

Efficient and agile at the same time

Experiments

- 12 testbeds
- 20-310 nodes
- 7 hardware platforms
- 4 radio technologies
- 6 link layers

Testbed	Platform	Nodes	Physical size m^2 or m^3
Tutornet	Tmote	91	$50\times25\times10$
Wymanpark	Tmote	47	80×10
Motelab	Tmote	131	$40\times20\times15$
Kansei	TelosB	310	40×20
Mirage	Mica2dot	35	50×20
NetEye	Tmote	125	6×4
Mirage	MicaZ	86	50×20
Quanto	Epic-Quanto	49	35×30
Twist	Tmote	100	$30\times13\times17$
Twist	eyesIFXv2	102	$30\times13\times17$
Vinelab	Tmote	48	60×30
Blaze	Blaze	20	30×30

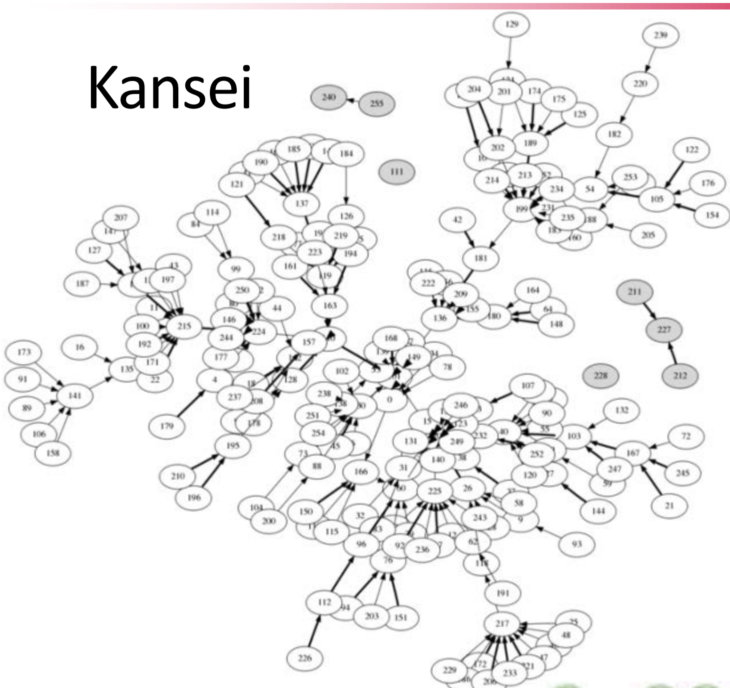
Variations in hardware, software, RF environment, and topology

Evaluation Goals

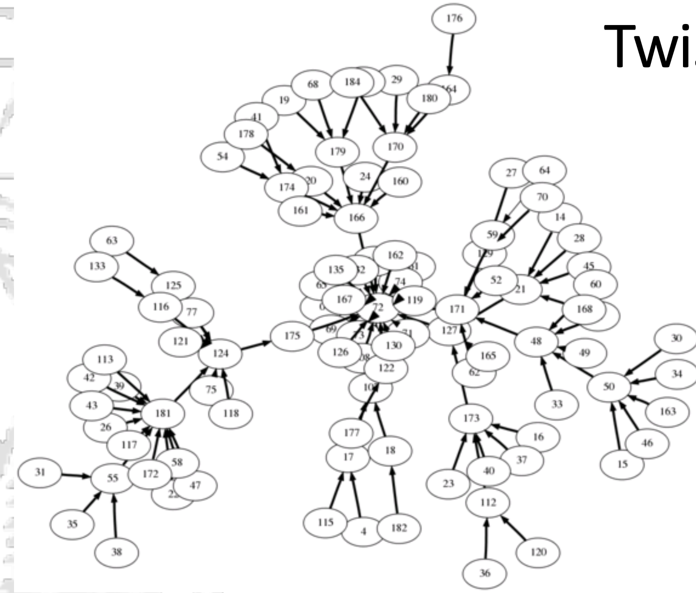
- Reliable?
  - Packets delivered to the sink
- Efficient?
  - TX required per packet delivery
- Robust?
  - Performance with disruption

CTP Noe Trees

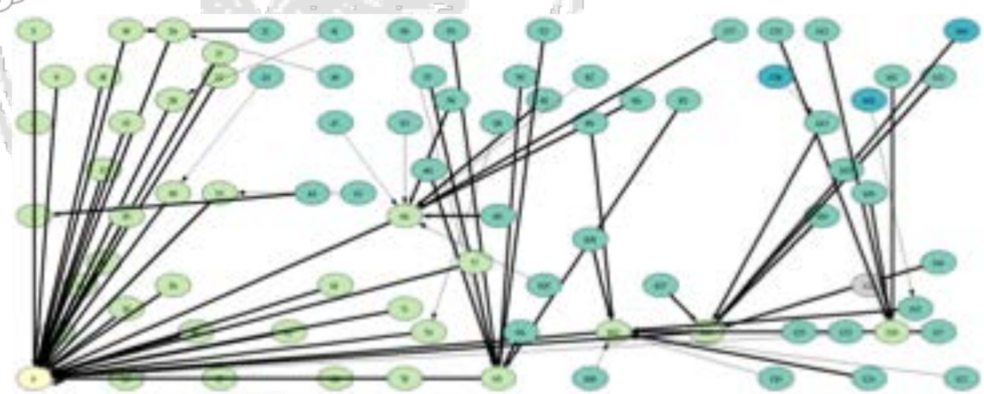
Kansei

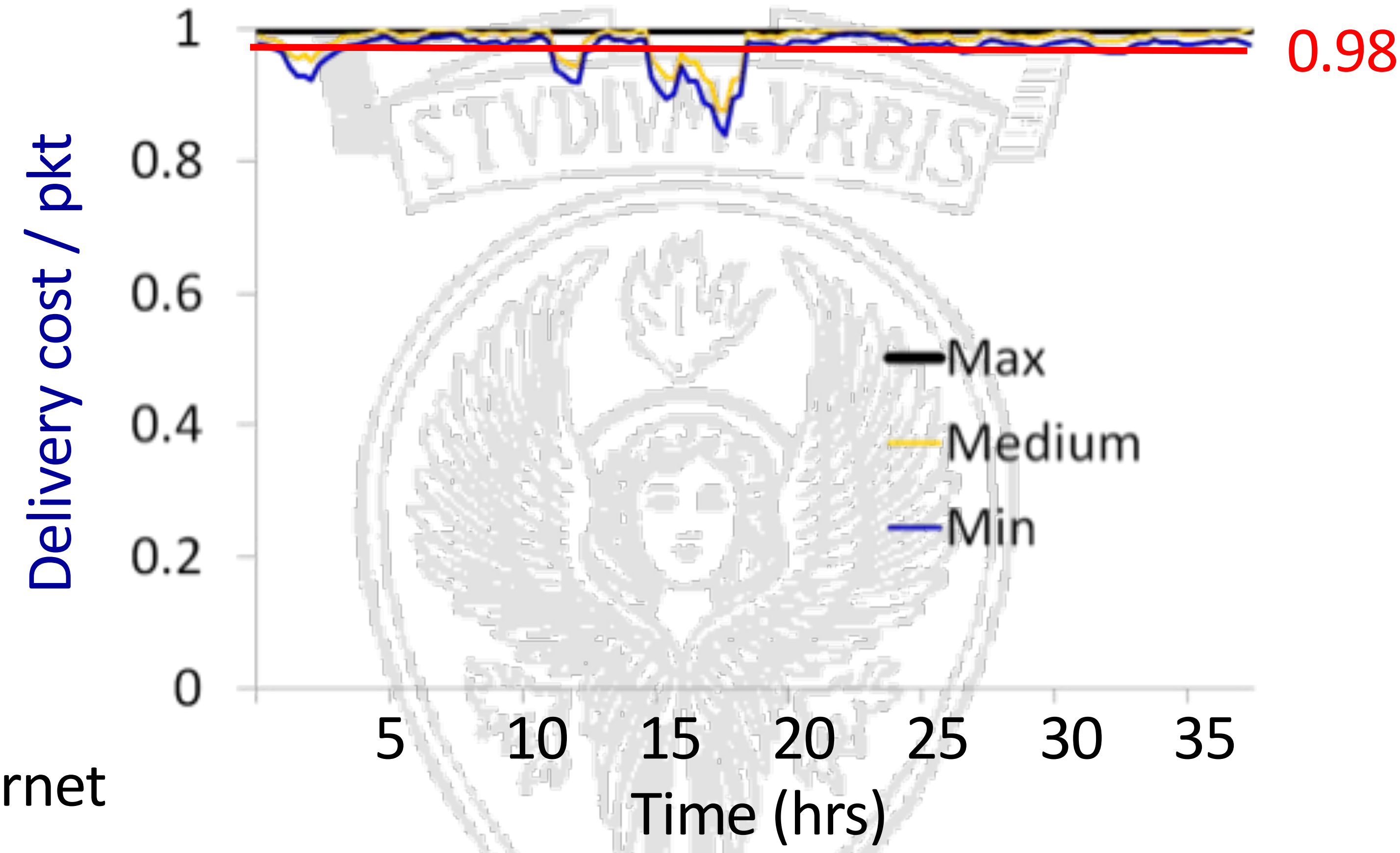


Twist



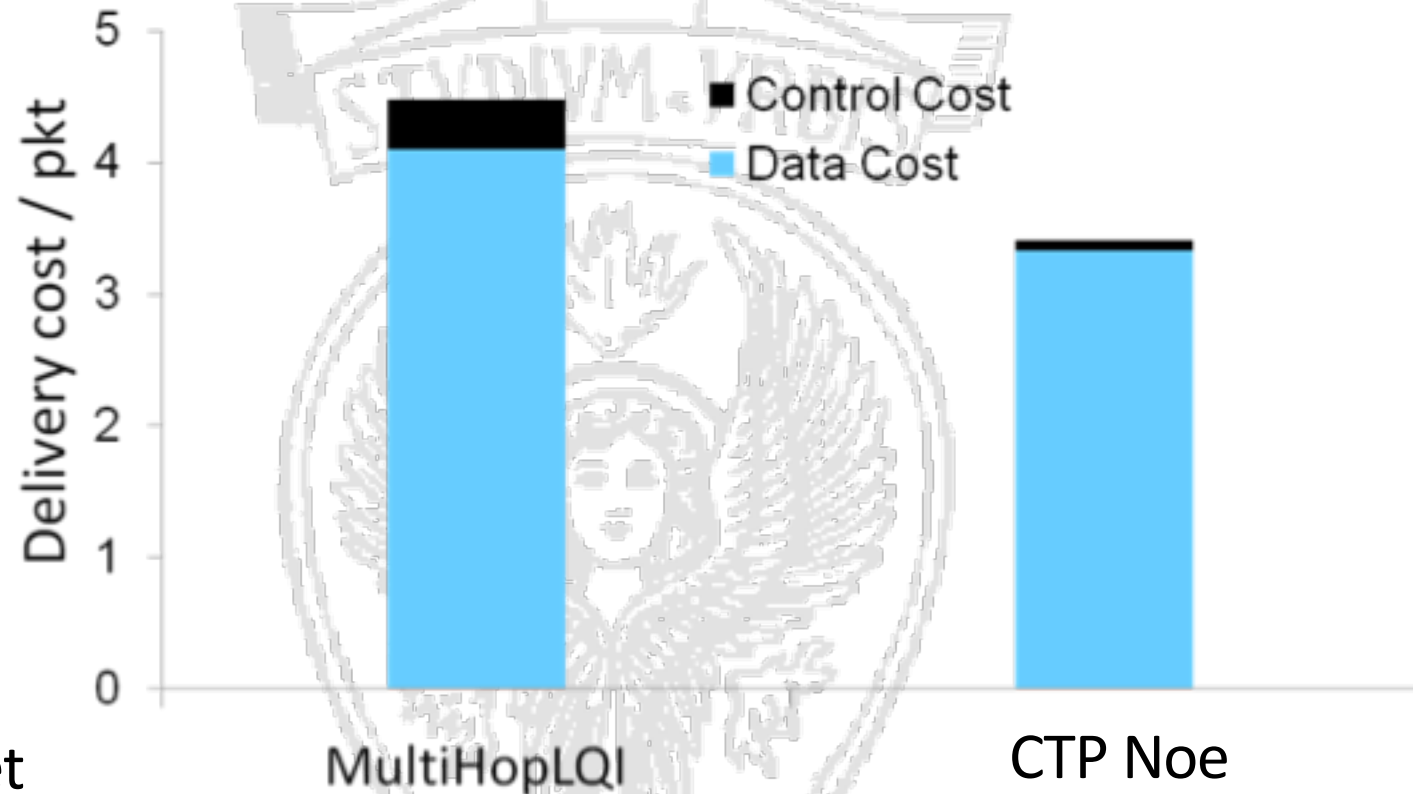
Mirage





Tutornet

High delivery ratio across time
(short experiments can be misleading!)



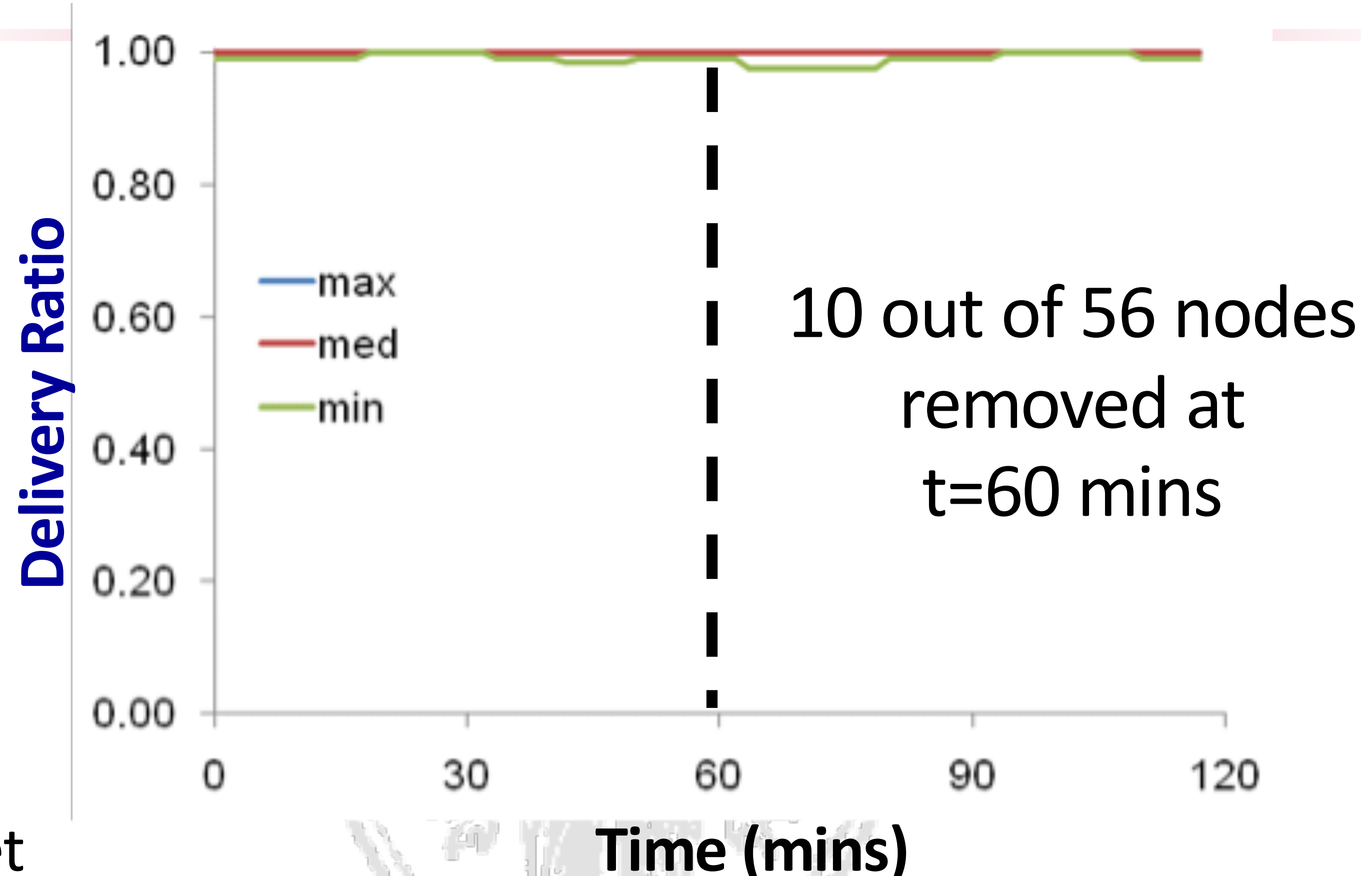
Tutornet

CTP Noe

Low data and control cost

Link Layer	Average Delivery	PL	Cost	Cost / PL	Duty Cycle Median	Duty Cycle Mean
CSMA	94.7%	3.05	5.53	1.81	100.0%	100%
BoX-50ms	94.4%	3.28	6.48	1.98	24.8%	24.9%
BoX-500ms	97.1%	3.38	6.61	1.96	4.0%	4.6%
BoX-1s	95.1%	5.40	8.34	1.54	2.8%	3.8%
LPP-500ms	90.5%	3.76	8.55	2.27	6.6%	6.6%

Low duty-cycle with low-power MACs

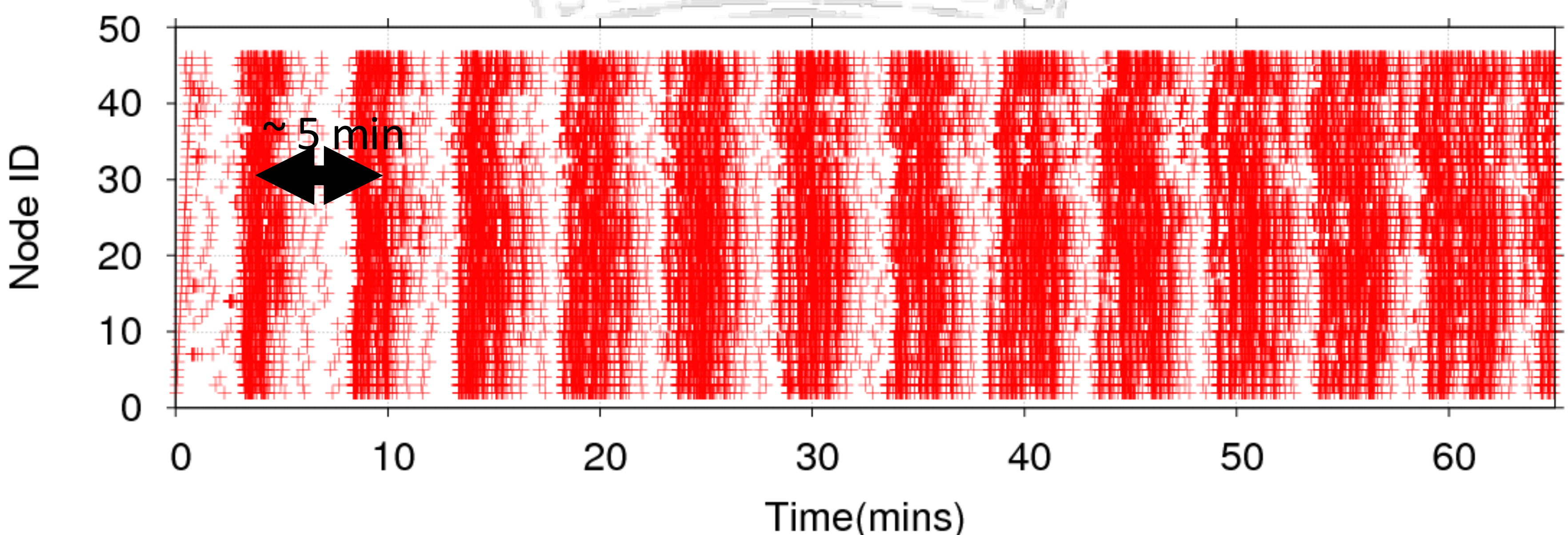


Tutornet

No disruption in packet delivery

Nodes reboot every 5 mins

Routing Beacons



Tutornet

Delivery Ratio > 0.99

High delivery ratio despite serious network-wide disruption (most loss due to reboot while buffering packet)

RPL, 2012

http://home.deib.polimi.it/cesana/teaching/IoT/2017/papers/6lowpan/RPL.pdf

Routing in IoT

- Desirable features
  - Energy aware, small factor, lightweight solutions, low overhead
  - Should scale to thousands of smart objects
  - Long lasting systems (years or decades)
  - Auto-configuration, self-managing
  - Robust even in presence of varying link quality and unreliable links

ROLL--Routing Over Low power and Lossy

- “Ripple” routing protocol RPL-- Proactive distance vector routing;
  - specifies how to build a destination oriented acyclic graph (DODAG)
- Multi-hop support
- Flexible metric
  - <Find paths with the best ETX and avoid non encrypted links> or <Find the best path in terms of latency while avoiding battery operated nodes>.
  - Administrator may decide to have multiple routing topologies active at the same time to carry traffic with different requirements
  - dynamic metrics (link quality, CPU overload, battery levels, all fast change over time…)
- Focus on energy constrained, secure solutions
- Routing supported across multiple types of link layers

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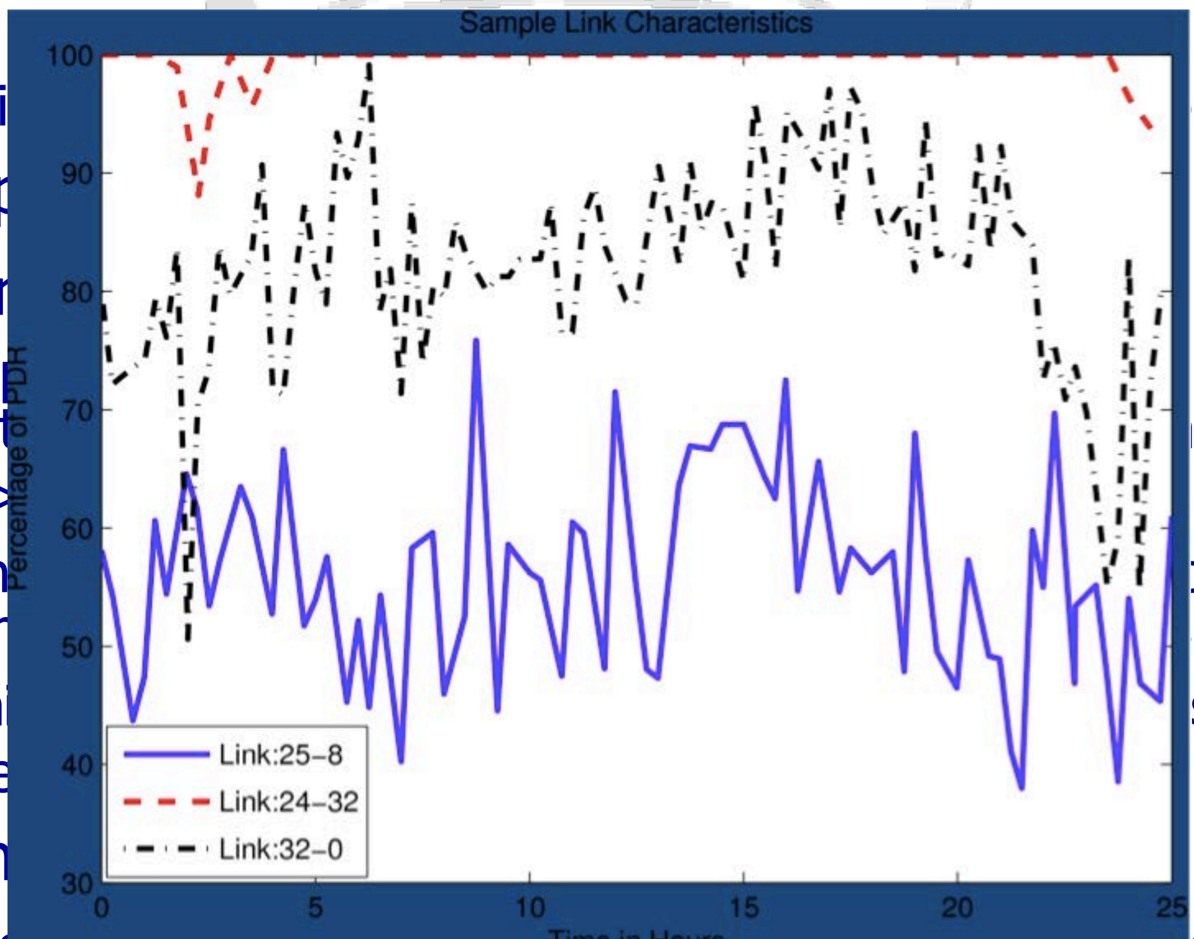
ROLL--Routing Over Low power and Lossy

- “Ripple” routing protocol RPL-- Proactive distance vector routing;
  - specifi h (DODAG)
- Multi-hop
- Flexible r
  - <Find links> or <Find t ttery operated nodes>
  - Admin ogies active at the sar
  - dynami s, all fast change
- Focus on
- Routing supported across multiple types of link layers



ROLL--Routing Over Low power and Lossy

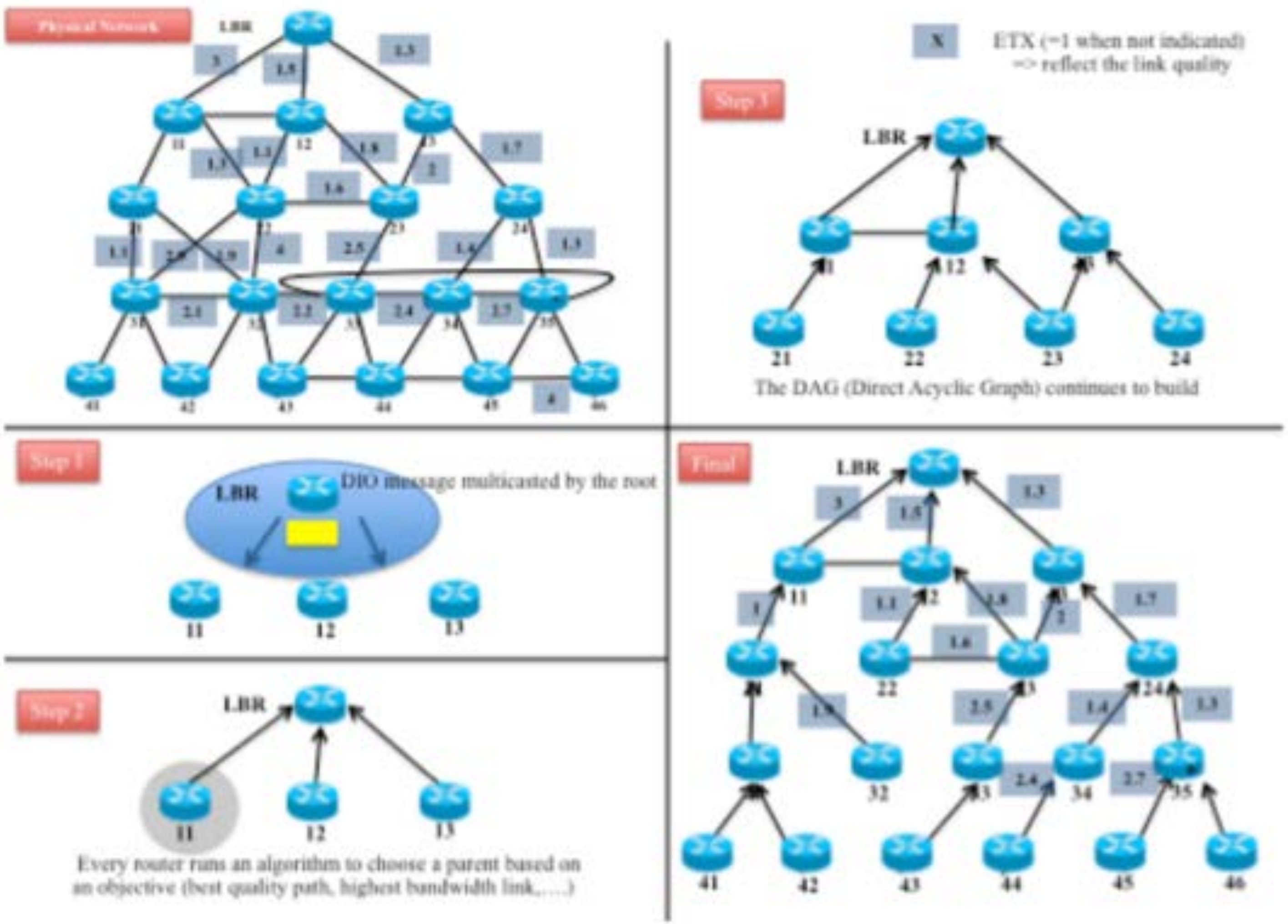
- “Ripple” routing protocol RPL-- Proactive distance vector routing;
  - specifies how to build a destination oriented acyclic graph (DODAG)
- Multi-hop support
- Flexible metric
- Focus on energy constrained, secure solutions → 32-bit and 64-bit MAC and ENC-MAC modes are supported as well as AES-128
- Routing supported across multiple types of link layers

RPL– DODAG formation

- RPL specifies how to build a destination oriented acyclic graph (DODAG)
- Root (ER-LowPAN Border Router) sends a DIO (DODAG Information Object) message
- Neighbors of the root will listen to the DIO and decide whether to join DODAG
  - Each of their neighbors, upon receiving the DIO, selects its parent (according to a suitable metric) and –if it is configured as a router- reforwards the DIO.
  - Leaf nodes do not reforward the DIO

This rippling effect builds the graph edges out from the root to the leaf nodes where the process terminates.

RPL– DODAG formation



RPL -- How to multicast messages

- Destination Advertisement Object (DAO)
- As a node joins the graph it sends a DAO to its parent (can also be solicited via a DODAG Information Solicitation message- This DIS message is used by the nodes to proactively solicit graph information)
- DAO messages are forwarded till the root
- Prefix reachability info exchange also enables peer to peer communication
  - up along the tree till the common ancestor, then down till the intended destination

DIS, DIO and DAO are new ICMPv6 control messages to exchange graph related information.

RPL -- How to multicast messages

- DAO messages are forwarded till the root
- Prefix reachability info exchange also enables peer to peer communication
  - up along the tree till the common ancestor, then down till the intended destination
  - **In case we operate in non-storing mode the message goes till the rot that adds a source route and send it down to the final destination**

RPL –trickle timers & other features

- How often are DIO messages sent?
  - Dynamically selected (trickle timer) based on how stable the system is
  - If the system stabilizes it is seldom sent
  - Whenever an inconsistency is detected (such as loop or changes in the DODAG) then the timer is reset to small values

- In case of anomalies (mechanism to detect them similar to CT) reaction does not necessary require to recompute the parents (e.g., there maybe multiple ones and a local repair maybe possible)
- Multiple DODAG can be configured →Different information flow based routing policies

Building the IoT

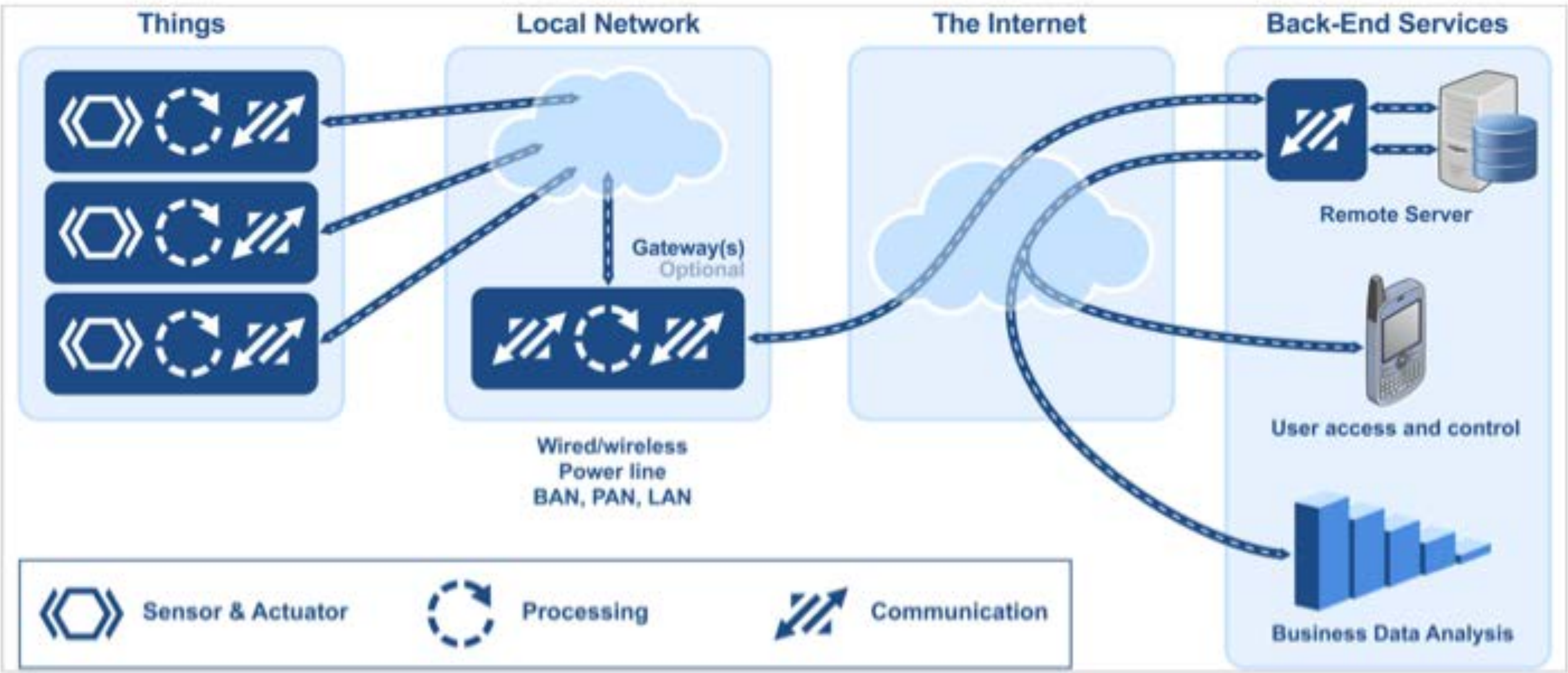
Internet of Things a.a. 2018/2019

Un. of Rome "La Sapienza"

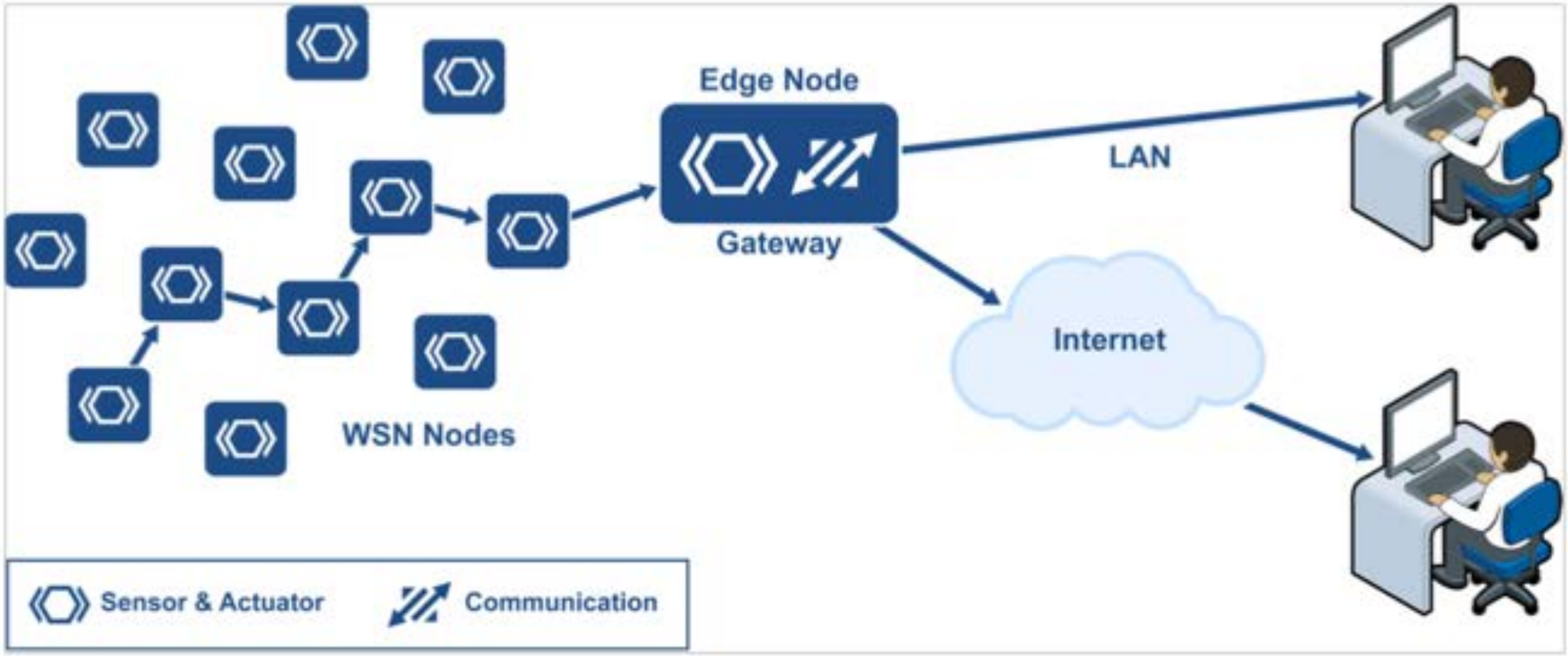
Chiara Petrioli[†]

[†] *Department of Computer Science – University of Rome "Sapienza" – Italy*

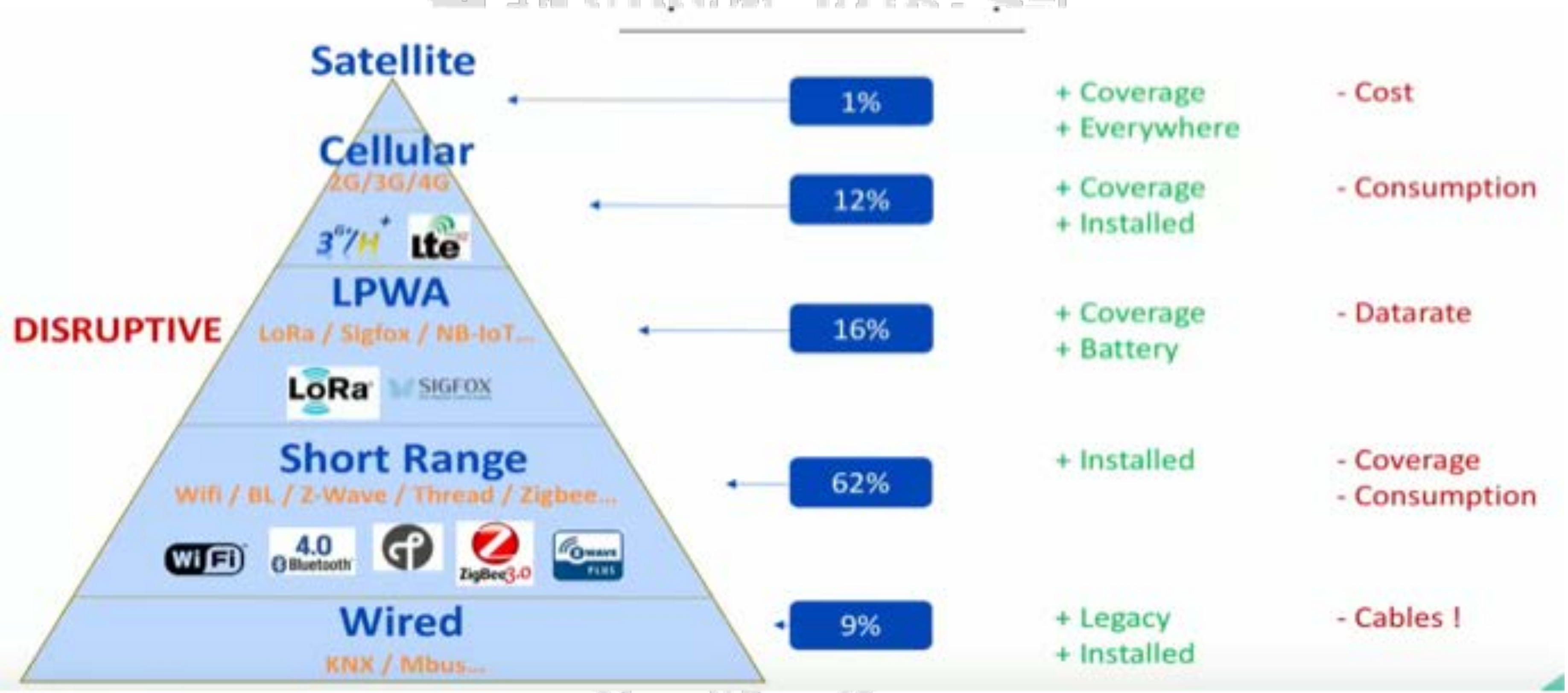
Current Scenario



Current Scenario



Current Scenario



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Current Scenario

Requirements

Low power,

Miniaturization,

Indoor/outdoor

What to sense,

Data Analysis capability,

Data rate, range,
security support, …

→

Embedded platform selection or design

Requirements

Area to cover, operational conditions, possible topologies of deployment

Operational states

State x: What to sense, where to sense, alarm thresholds, frequency of reporting,…

Required system management capabilities

Required data analysis capability, data access control, security requirements

…..

→

System architecture design

-Types of Nodes to develop (each with different capabilities)
→system components

-Network Topology

--Comm. among system components: protocols, APIs

-Gateway elements

-Software Architecture Backend/Frontend

Useful methodologies

Idea → [Proof/analysis]→Solution Simulation→Field Test

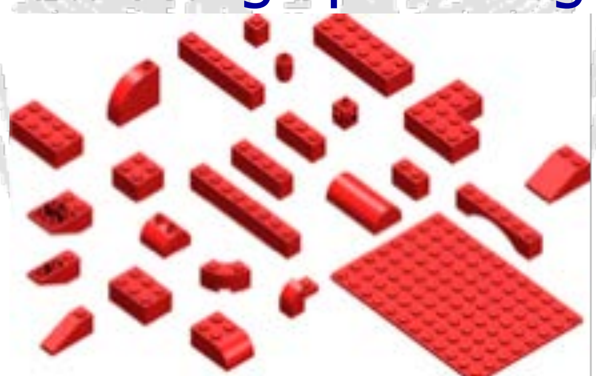
System Optimization

Useful methodologies

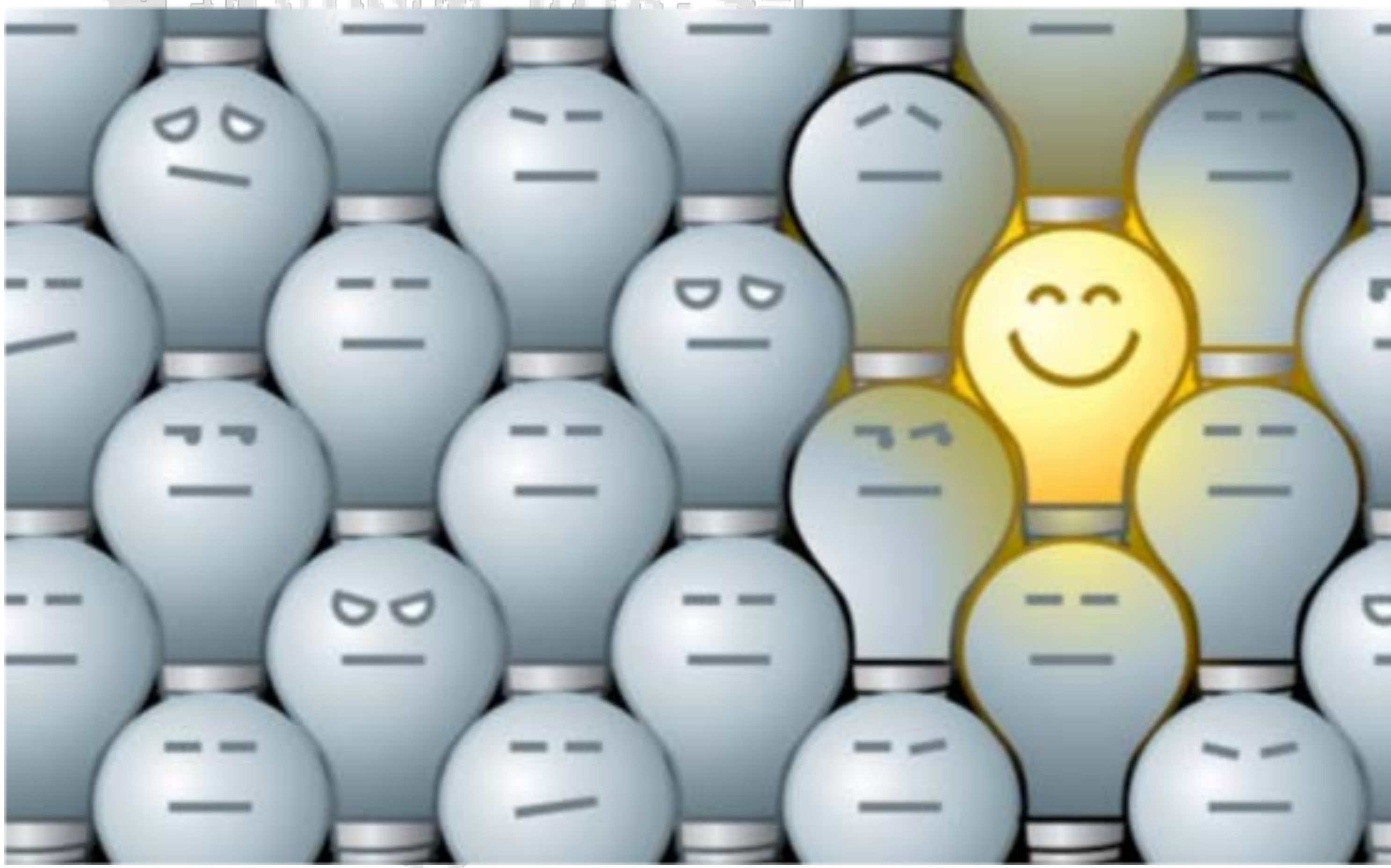
Idea → [Proof/analysis]→Solution Simulation→Field Test

System Optimization

What we are doing…providing you with the



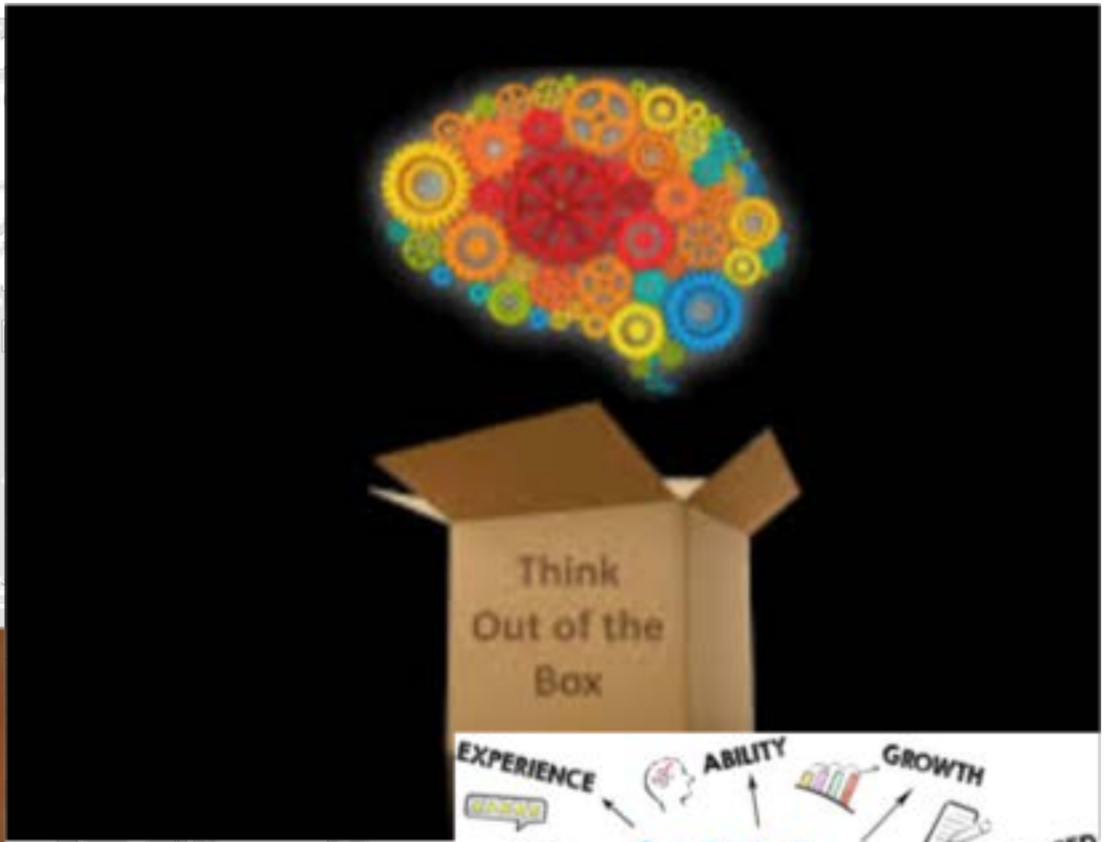
to combine, extend, in order to come up with innovative solutions



IoT Innovation

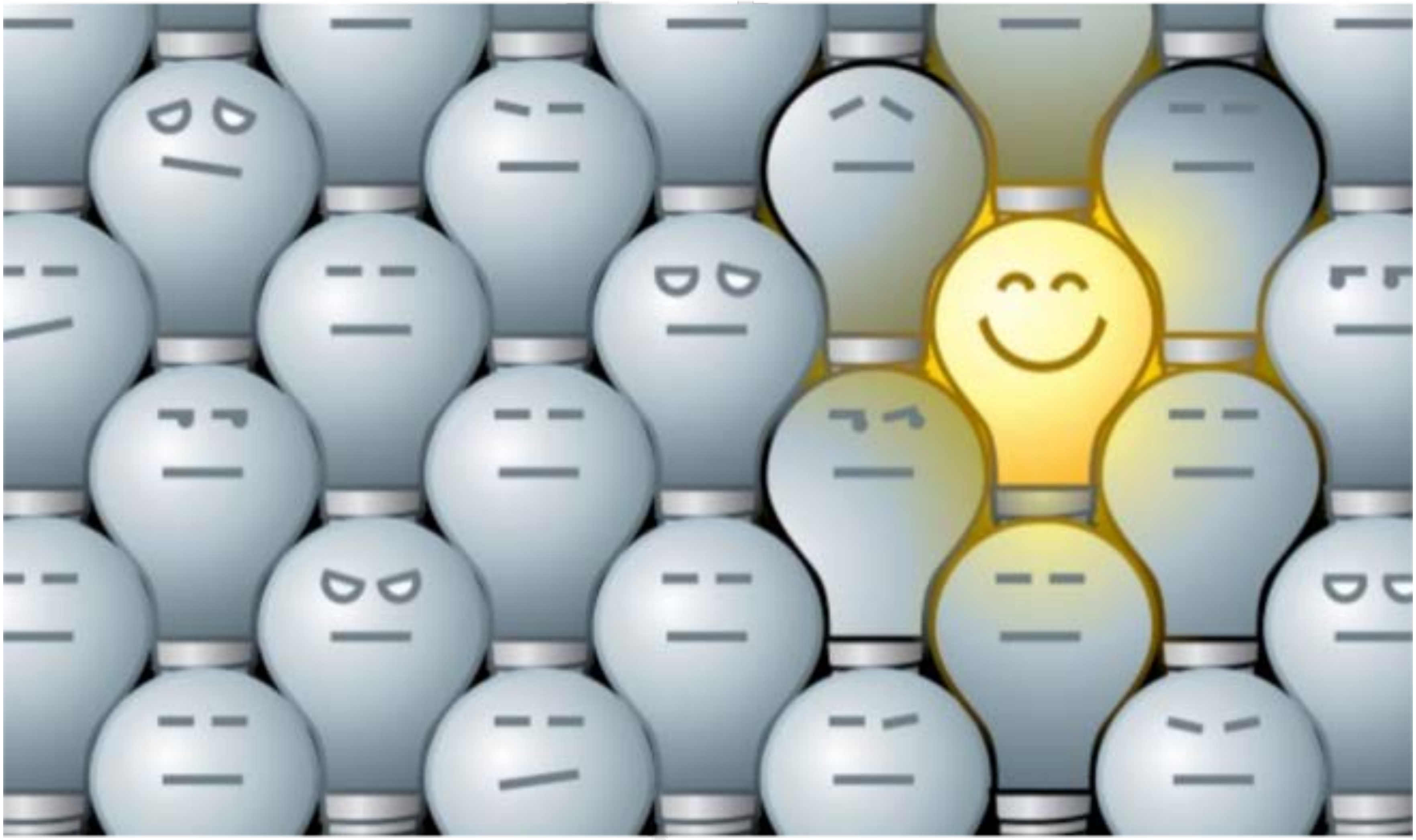
IoT Innovation


OPEN
KNOWLEDGE
POOL

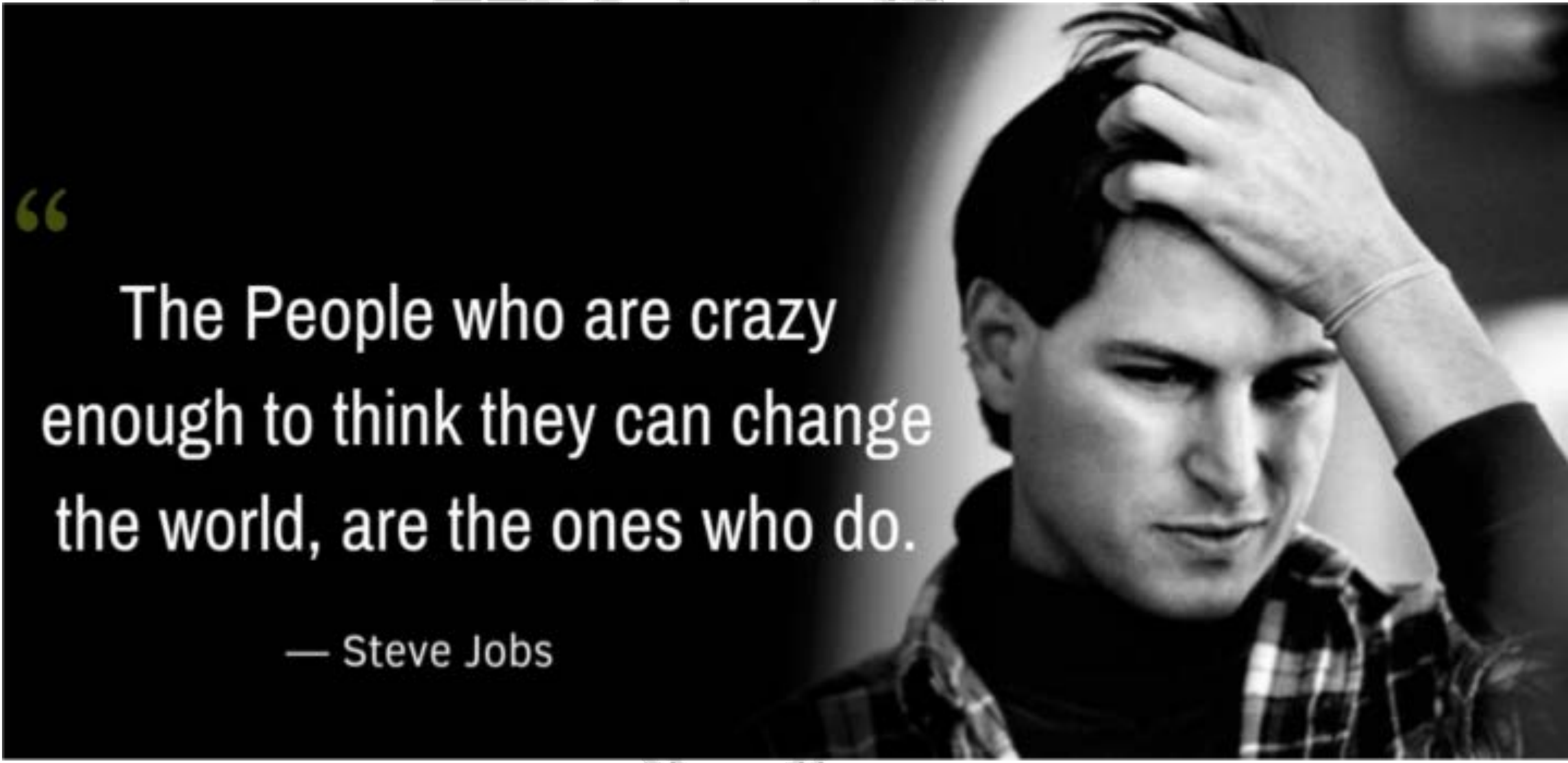

Think
Out of the
Box


I can't

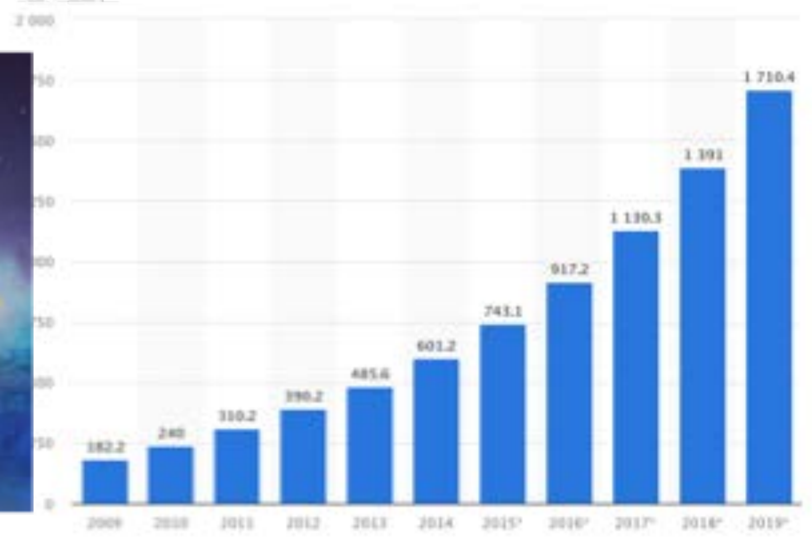

EXPERIENCE
ABILITY
GROWTH
TRAINING
SKILL
ADVANCED TRAINING
COMPETENCE
LEARNING
KNOWLEDGE




INNOVATION IS A STATE OF MIND


"
The People who are crazy
enough to think they can change
the world, are the ones who do.
— Steve Jobs

Why on IoT ?


2 000
182.2
240
310.2
390.2
485.6
601.2
743.1
917.2
1 130.3
1 391
1 710.4
0
2009
2010
2011
2012
2013
2014
2015*
2016*
2017*
2018*
2019*

Market Sizes

- IoT - **The global IoT market is expected to have a compound annual growth rate (CAGR) of nearly 27 percent from 2018 to 2024.** Overall, the market is expected to grow to **$6.5 trillion** in 2024

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- Today 500Bln

Market Sizes

- IoT - **The global IoT market is expected to have a compound annual growth rate (CAGR) of nearly 27 percent from 2018 to 2024.** Overall, the market is expected to grow to **$6.5 trillion** in 2024
- Today 500Bln
- What about other CS sectors?

- CS has many interesting fields and many are growing but the typical global market size also for hot fields is in the 20Bln-100Bln range.
- There is a reason why IoT is called the next industrial revolution!

Innovation Training

- For those of you who prove to have reached the needed level of knowledge (27-28/30) first half of the course an alternative type of exam will be offered to start being trained for innovation in this field (going deeper into some topics, send an email to me);
- Additional opportunity for the best students (based on what you are interested in):
  - Attività formativa complementare (extra 6 credits activity can be taken following up on a project under my supervision);
  - Borse di studio per attività di ricerca;
  - Possibility to attend a conf in the field;
  - Thesis.