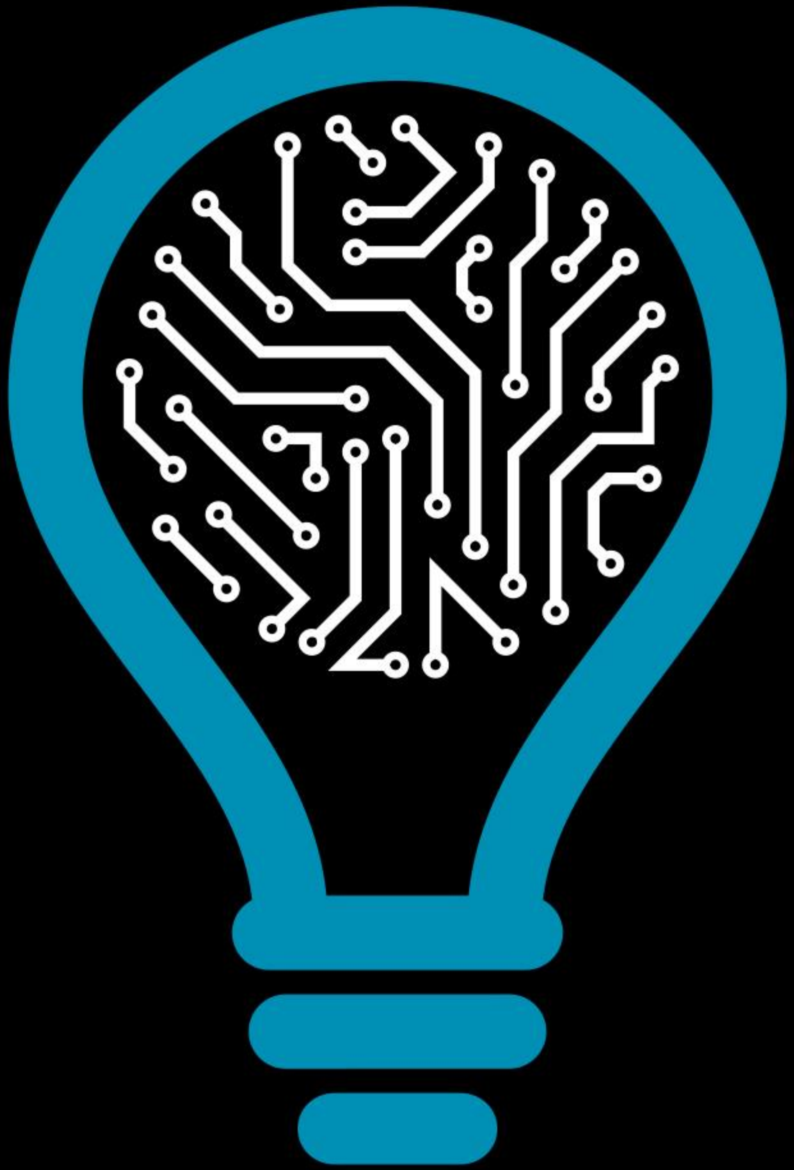
from knowledge
production to
science-based
innovation



INESCTEC

INSTITUTE FOR SYSTEMS
AND COMPUTER ENGINEERING,
TECHNOLOGY AND SCIENCE

INESC TEC

Centre for Telecomunications and Multimedia

21 March 2017

Manuel Ricardo
CTM Coordinator

CTM Scientific Areas

Information Processing and Pattern Recognition (IPPR)
- computer vision
- intelligent information processing

Multimedia Communications Technologies (MCT)
- context-aware content management and distribution
- sound, music and video computing

Wireless Networks (WIN)
- wireless networks
- network management, quality of service

Optical and Electronic Technologies (OET)
- microwave circuits, antennas, optical communications
- microelectronics, programmable logic

WIRELESS NETWORKS

Research Team

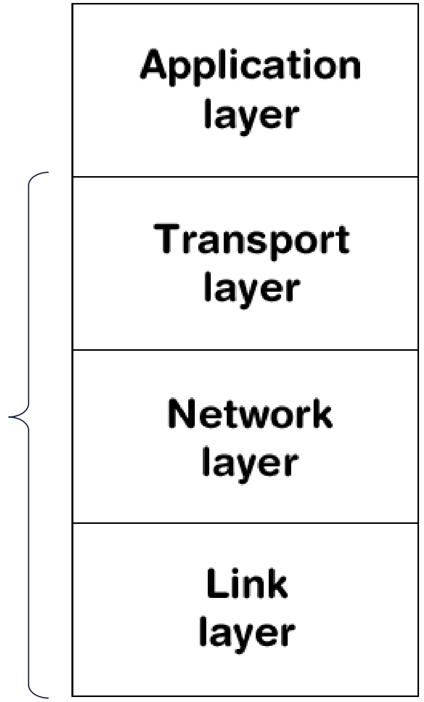
- 9 PhDs
- 5 MSc researchers
- 7 PhD students
- 4 MSc students

25 researchers

Research Topics

Wireless (Mesh) Networks

- static and mobile
- homogeneous and heterogeneous



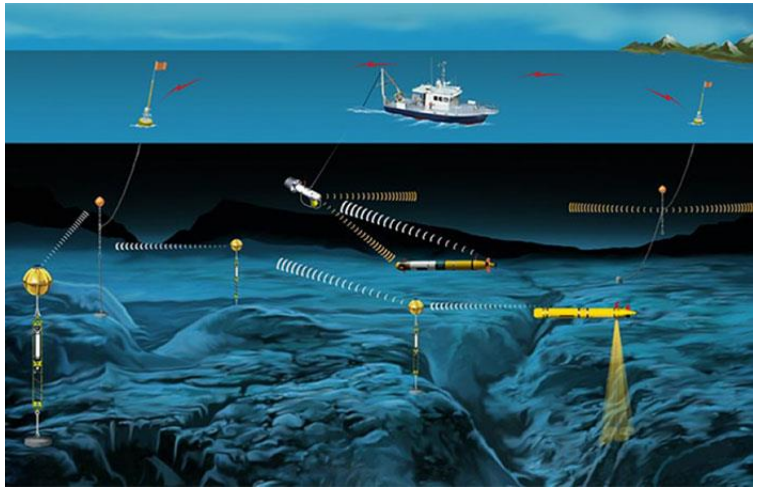
self-configuration
cross-layer optimization
congestion control
medium access control
mobility
QoS

Main focus areas

FLYING NETWORKS

MARITIME NETWORKS

SMART GRID COMMUNICATIONS



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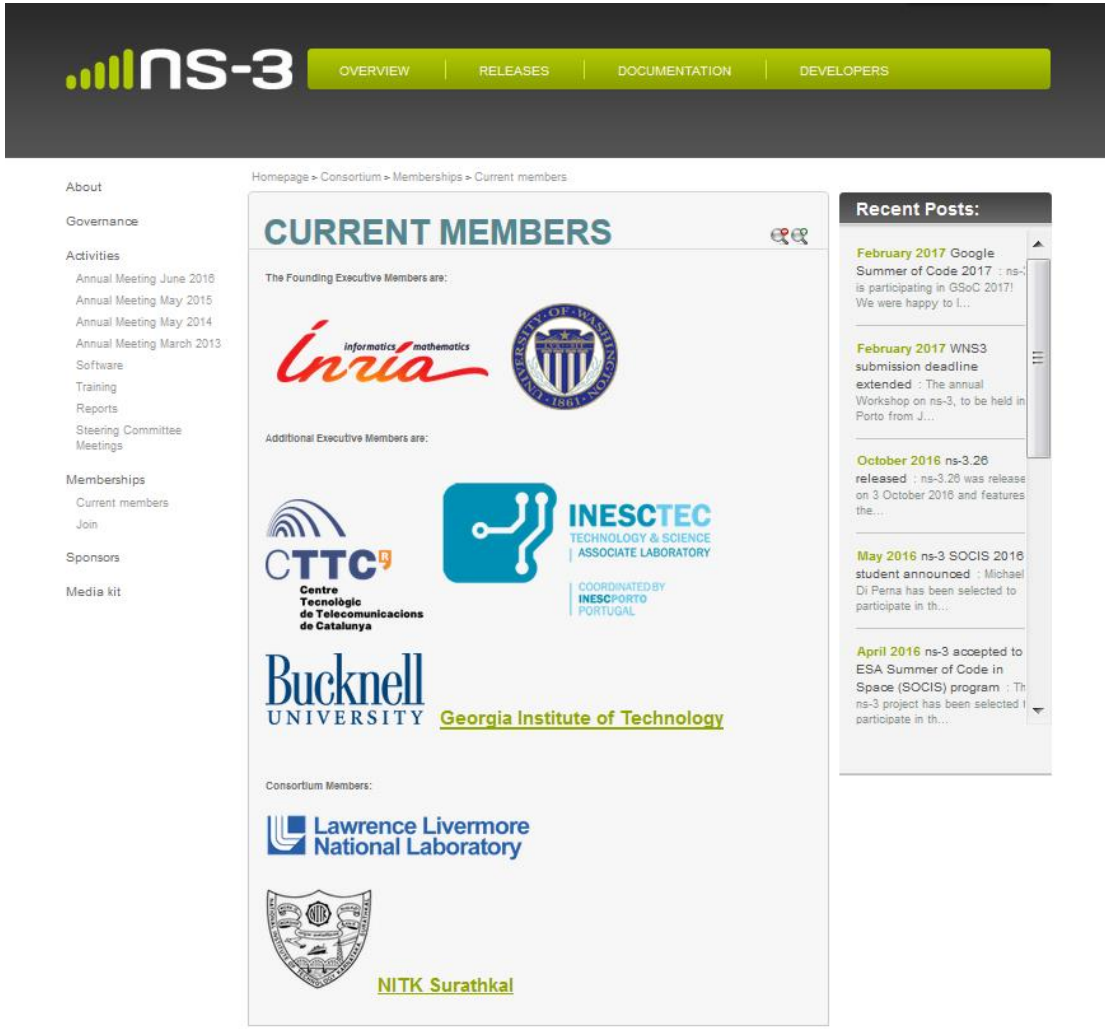
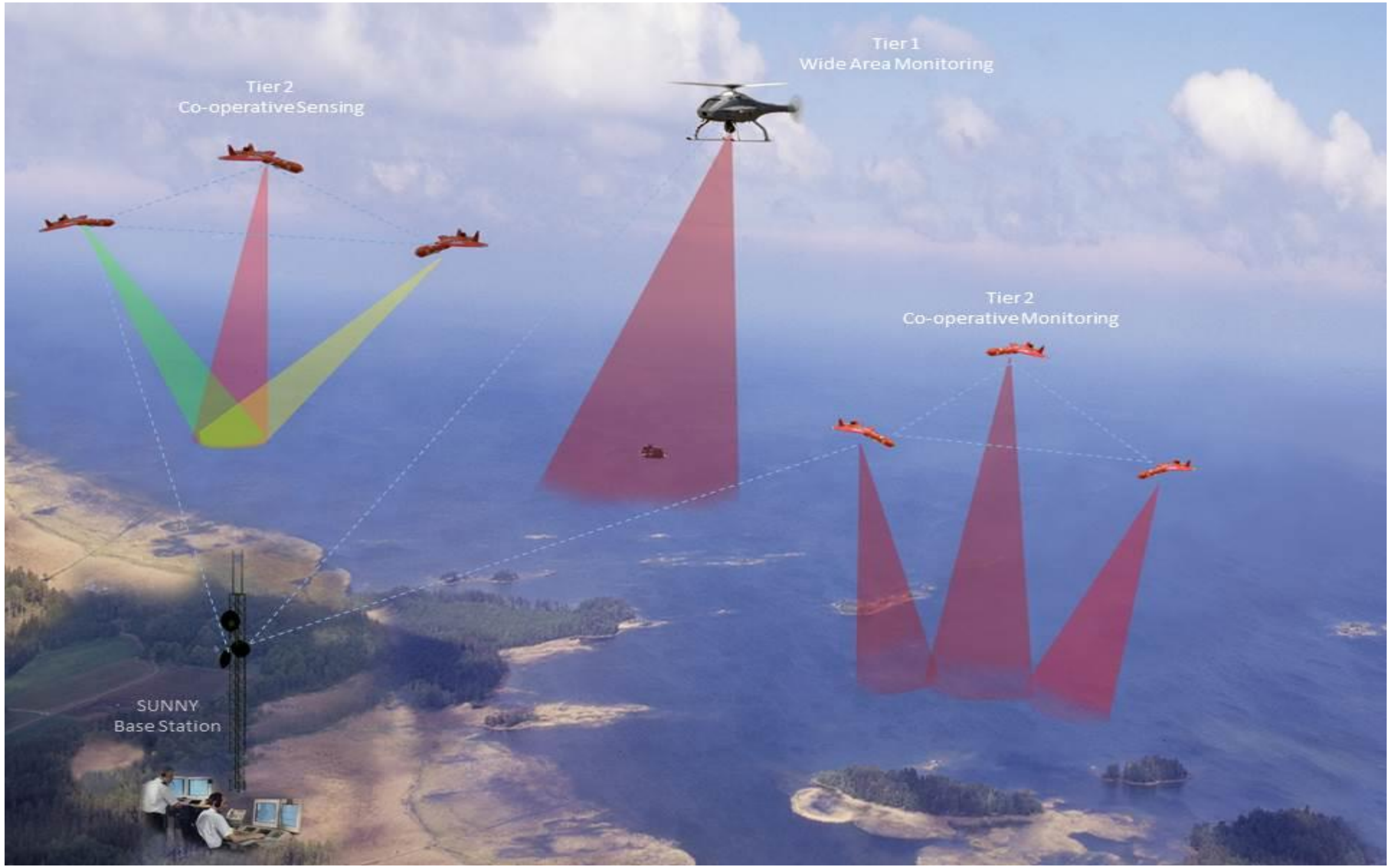
Research methodology



1. Design
2. ns-3 simulation
3. Lab experiments
4. Real-world experiments

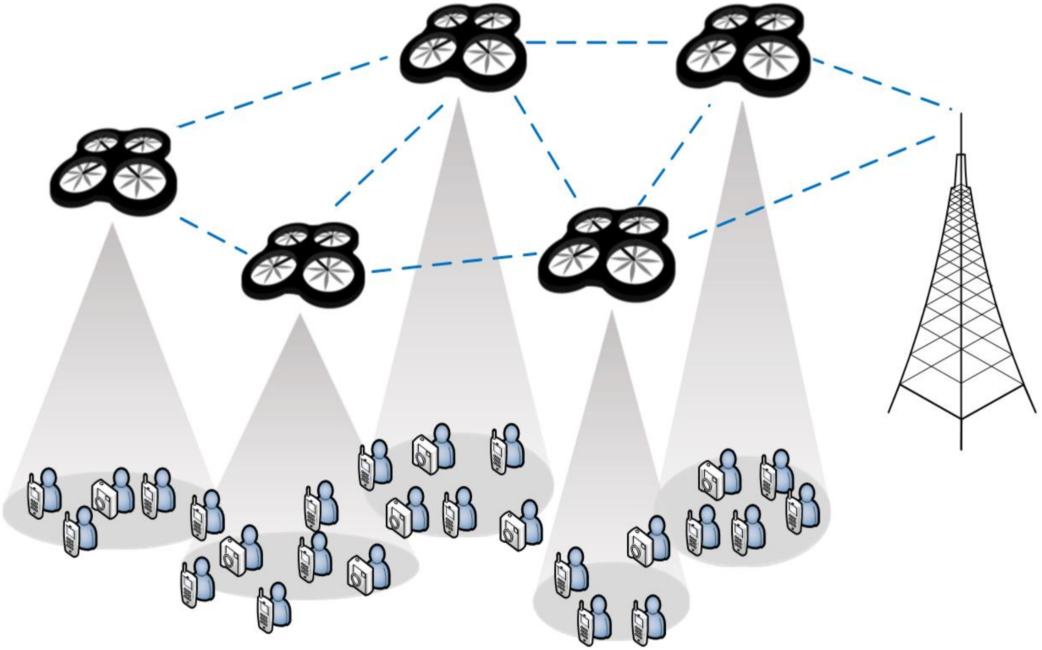
SUNNY

Smart UNattended airborne sensor Network for detection of vessels used for cross border crime and irregular entrY



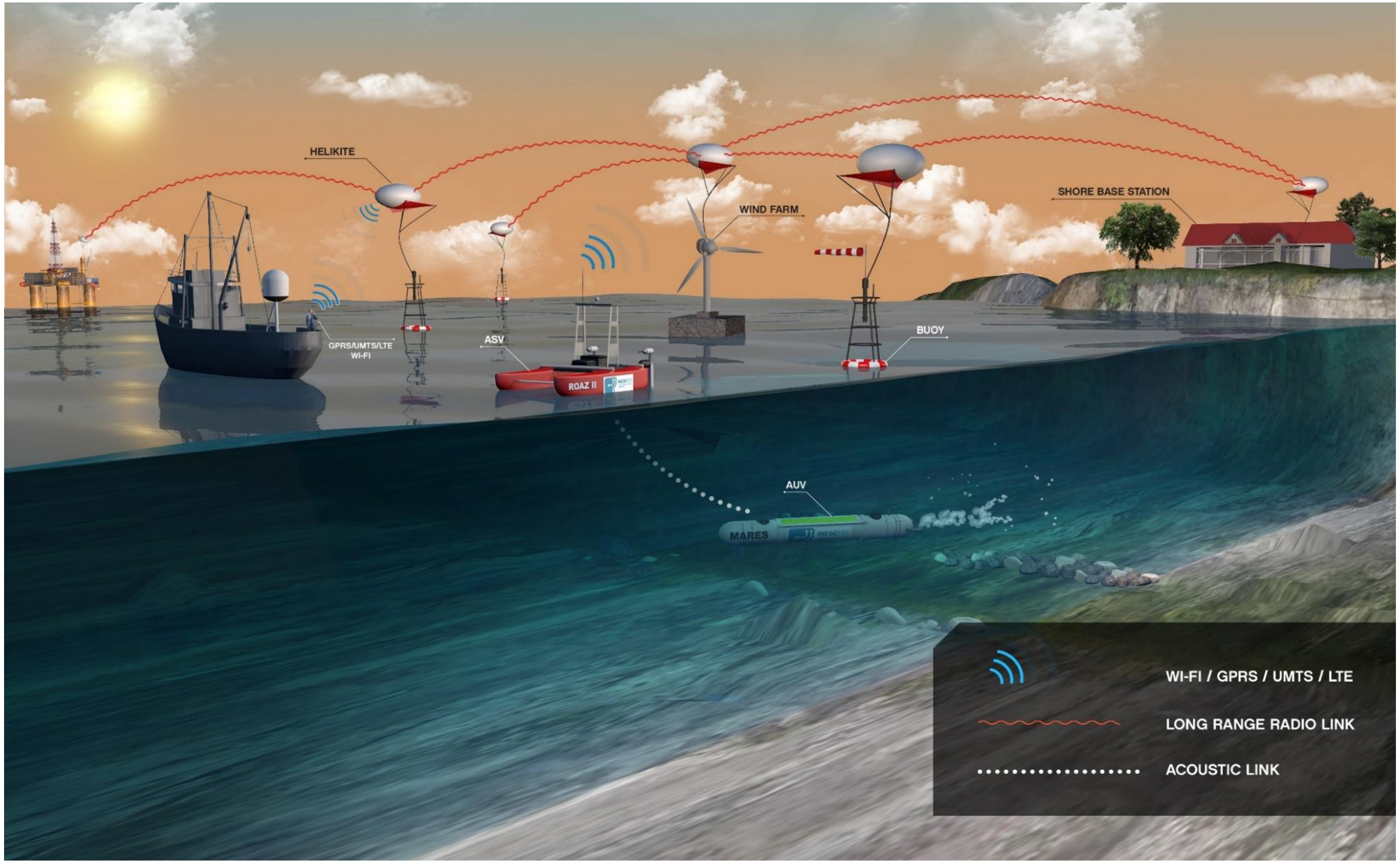
WISE

Traffic-aware Flying Backhaul Mesh Networks



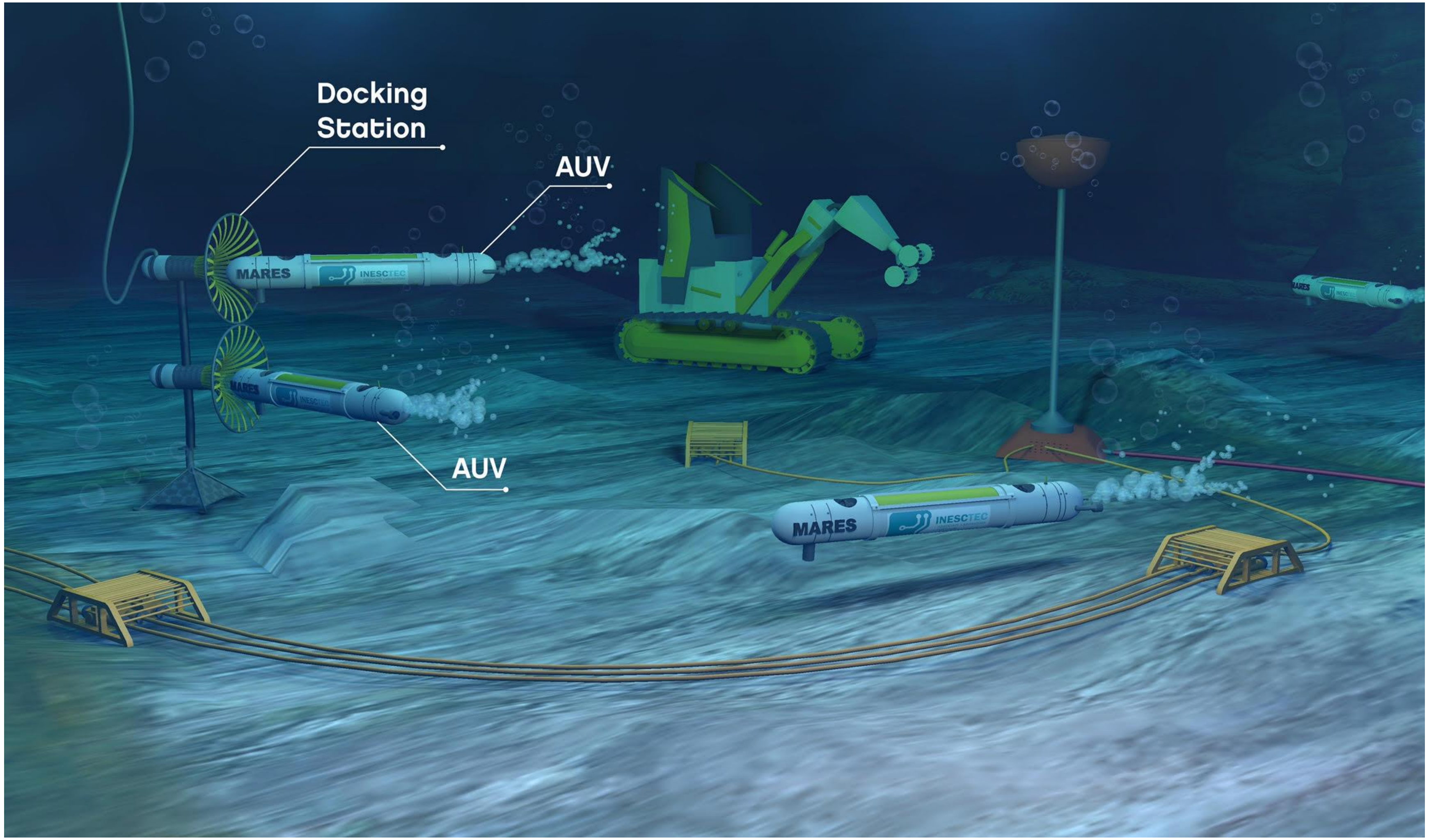
BLUECOM+

Connecting Humans and Systems at Remote Ocean Areas using Cost-effective Broadband Communications



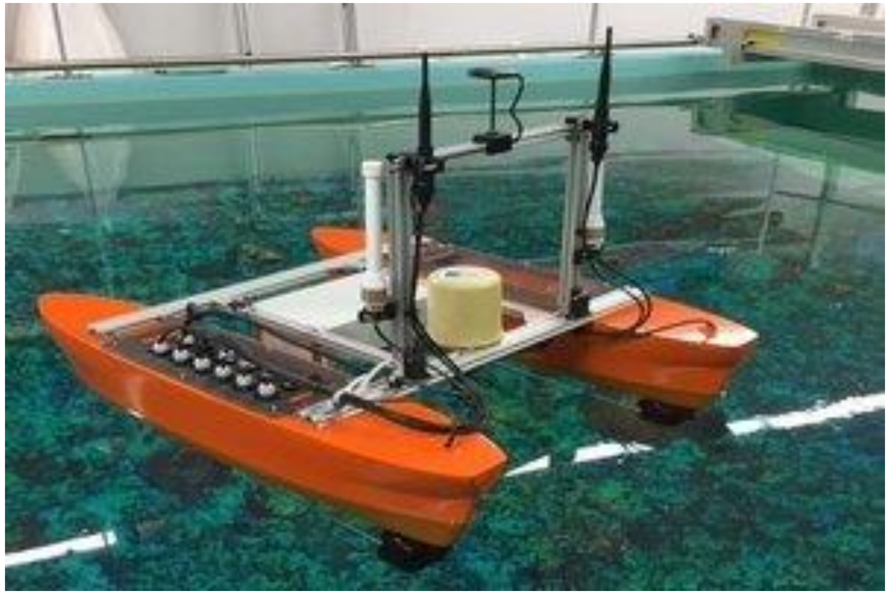
ENDURE

Enabling Long-Term Deployments of Underwater Robotic Platforms in Remote Oceanic Locations



FLEXUS

Flexible Unmanned Surface Vehicles for the Internet of Moving Things



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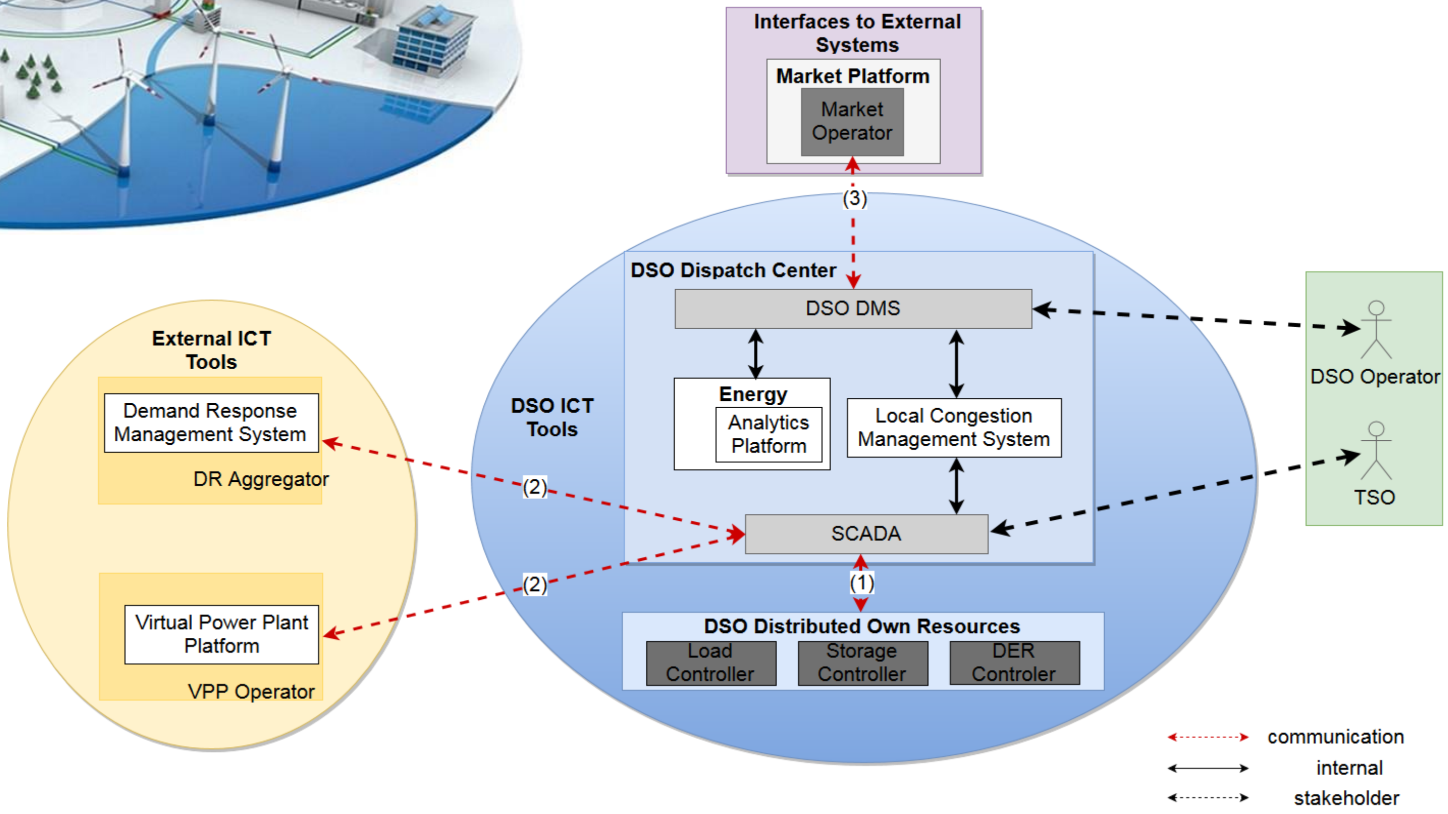
SmartEMC2

Empowering SG Market Actors through Information and Communication Technologies



More information

http://win.inesctec.pt

Evaluation of an RPL/6LoWPAN/IEEE 802.15.4g Solution for Smart Metering in an Industrial Environment

Jaime Dias, Filipe Ribeiro, Rui Campos, Manuel Ricardo,
Luís Martins, Fernando Gomes, António Carrapatoso

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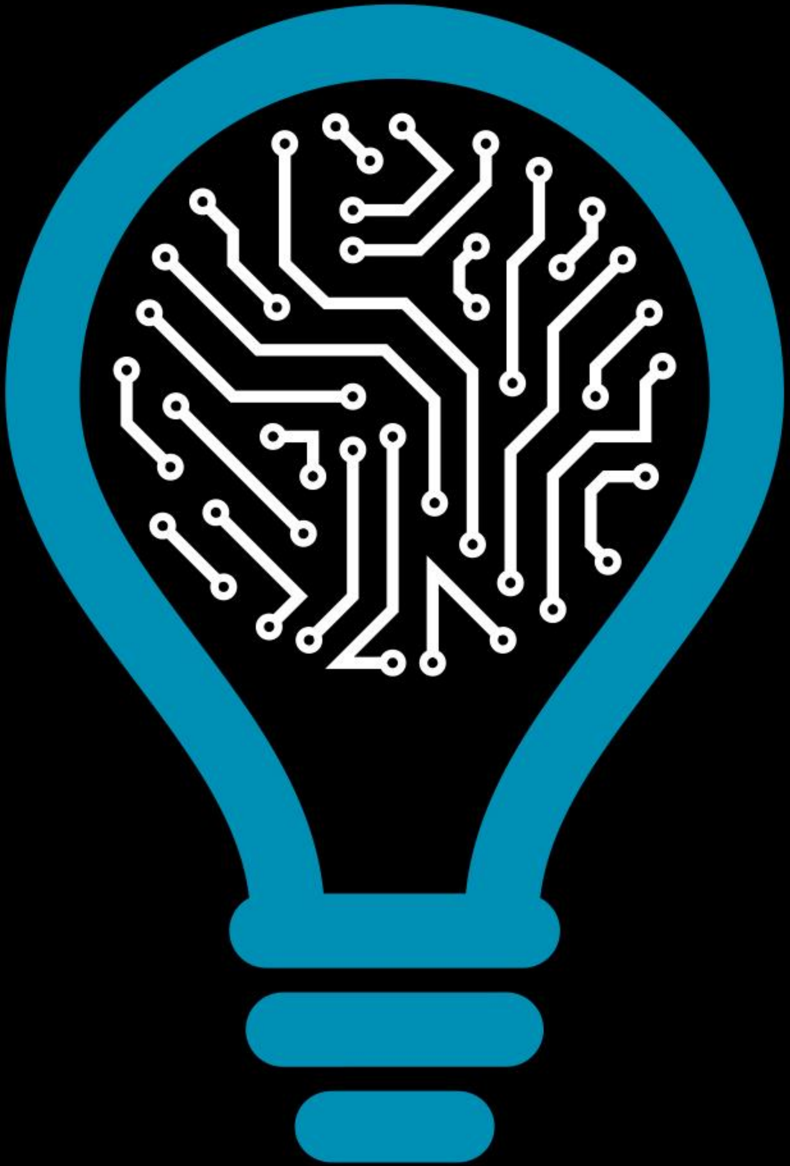
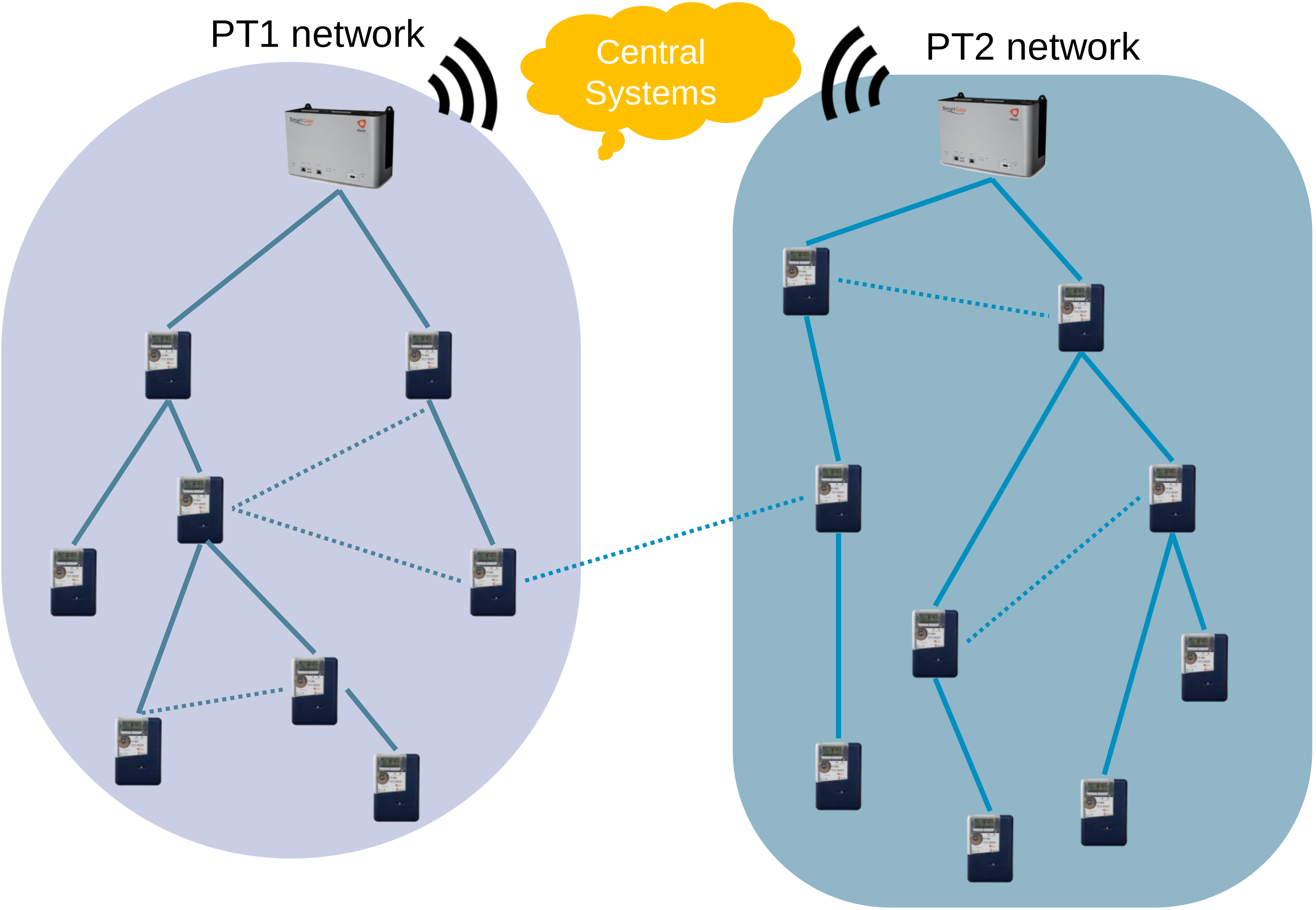


Developed Solution

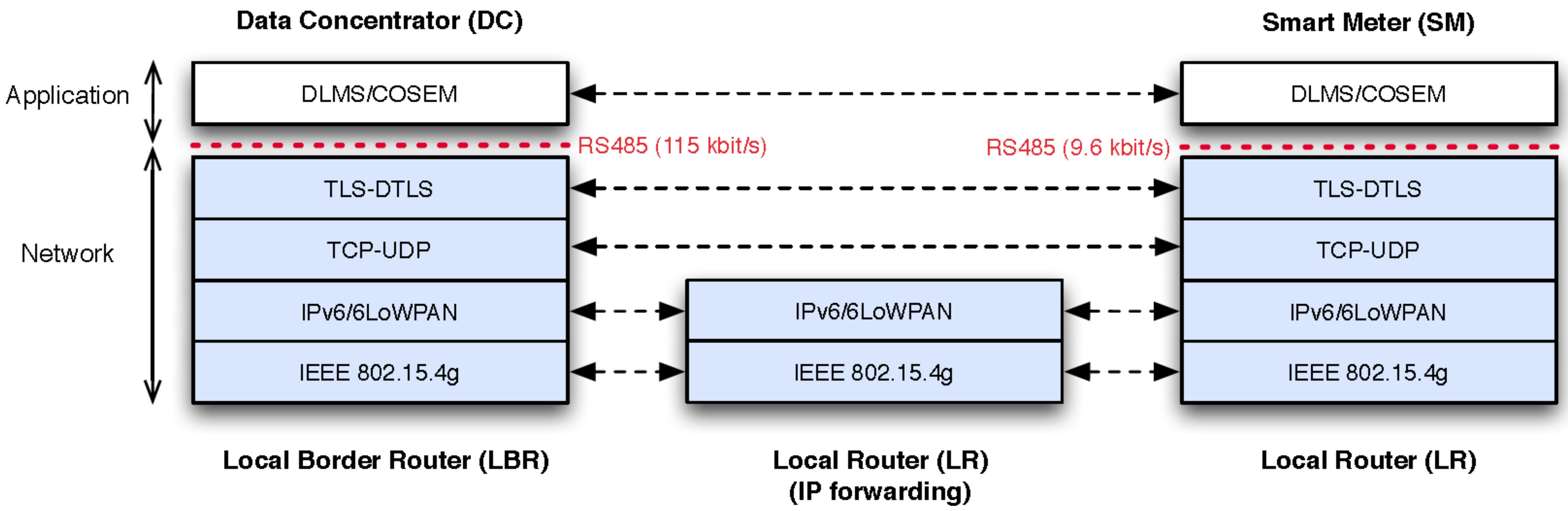
- Multi-hop wireless network
  - IEEE 802.15.4g technology (layer 1 and 2)
  - IETF Low-Power and Lossy-Networks (LLNs) protocol suite
- IETF LLNs
  - 6LoWPAN (IPv6 over Low-Power Wireless Personal Area Networks)
  - RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks)
- Transport of DLMS/COSEM Smart Grid metering
  - DLMS/COSEM TCP/IP communication profile

Network Topology

Up to 500 SMs per PT network



Protocol Stack



Software / Hardware

- Operating System and TCP/IP Stack
  - FreeRTOS
  - IPv6 stack based on Lightweight TCP/IP stack (LwIP)
- Hardware
  - LBR: ARM926@400 MHz, 16 Mbytes of SDRAM
  - LR: Cortex-M4@120 MHz, 160 kbytes of SDRAM
  - IEEE 802.15.4g transceiver
    - Atmel RF215 (prototype)
    - Sub-GHz and 2.4 GHz frequency bands
    - Transmission power: 14 dBm
    - Antenna: 2 dBi omnidirectional for the 900 MHz band

Prototype

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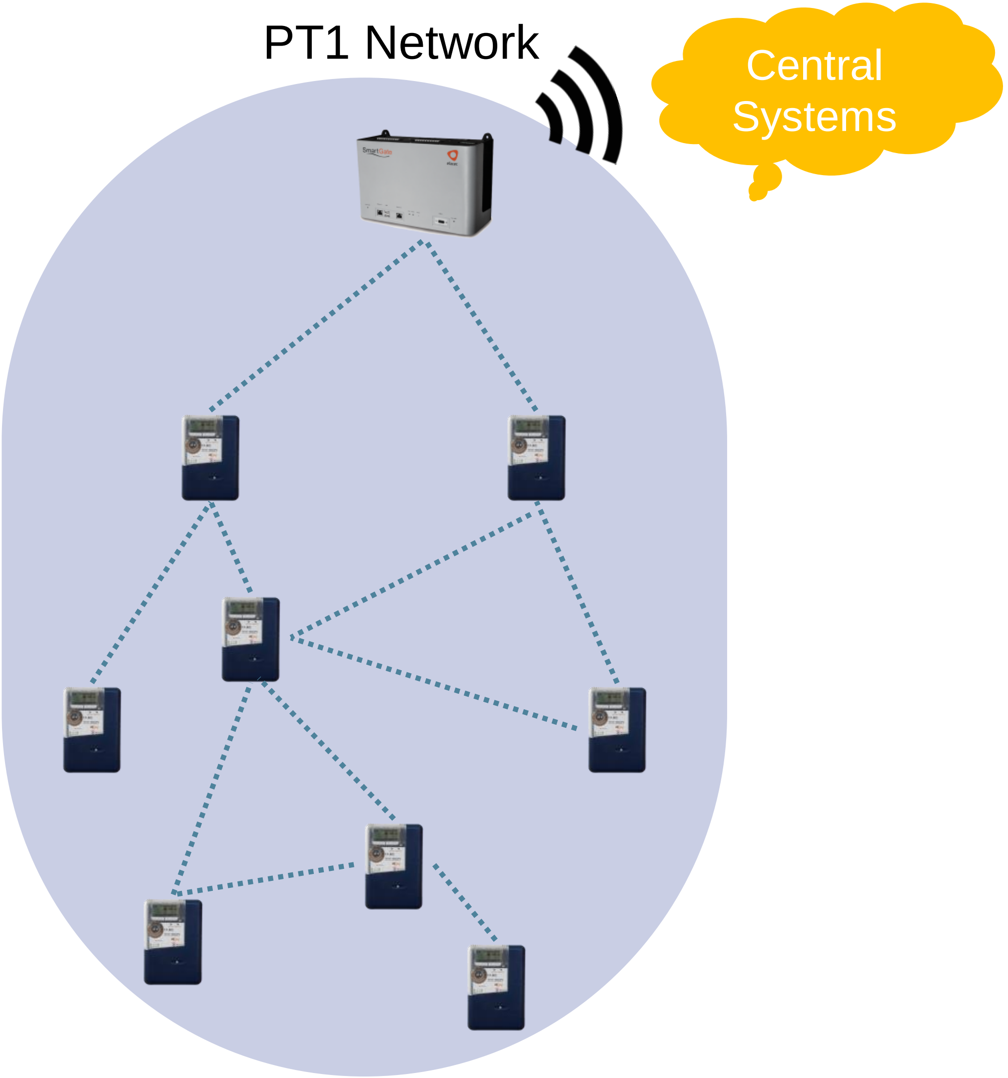
Prototype

RPL

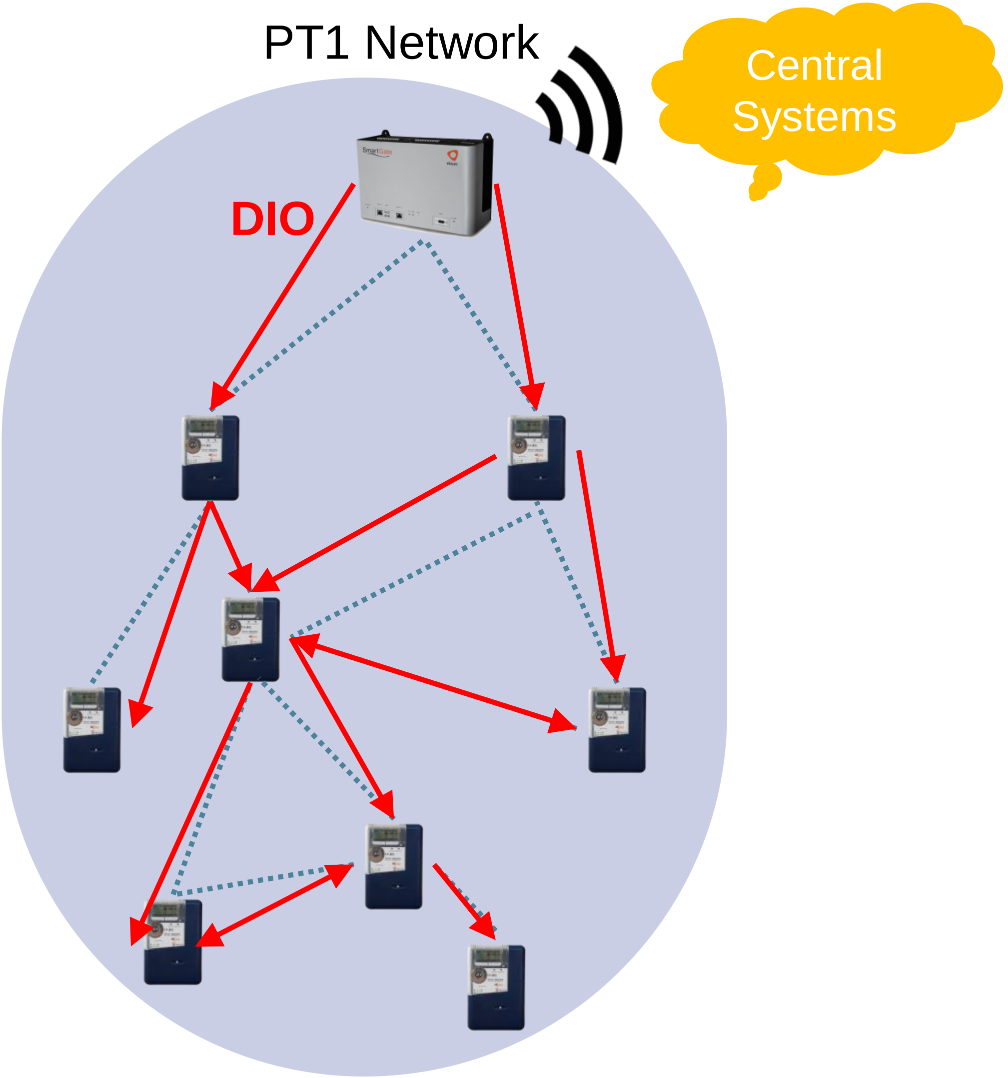
Storing vs. Non-storing modes

Storing Mode



Storing Mode

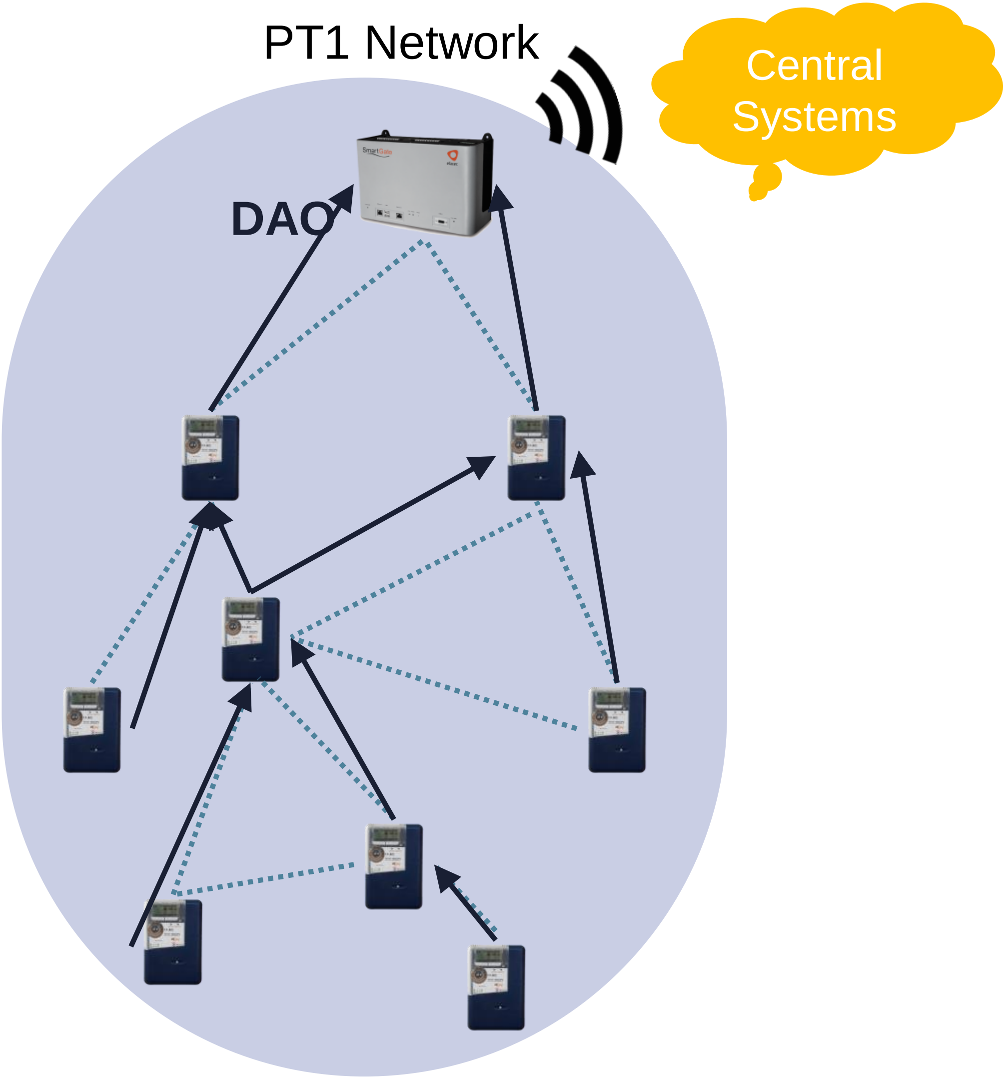
Upward routes



Each node presents itself as a parent candidate if it can forward packets to the root (LBR)

Storing Mode

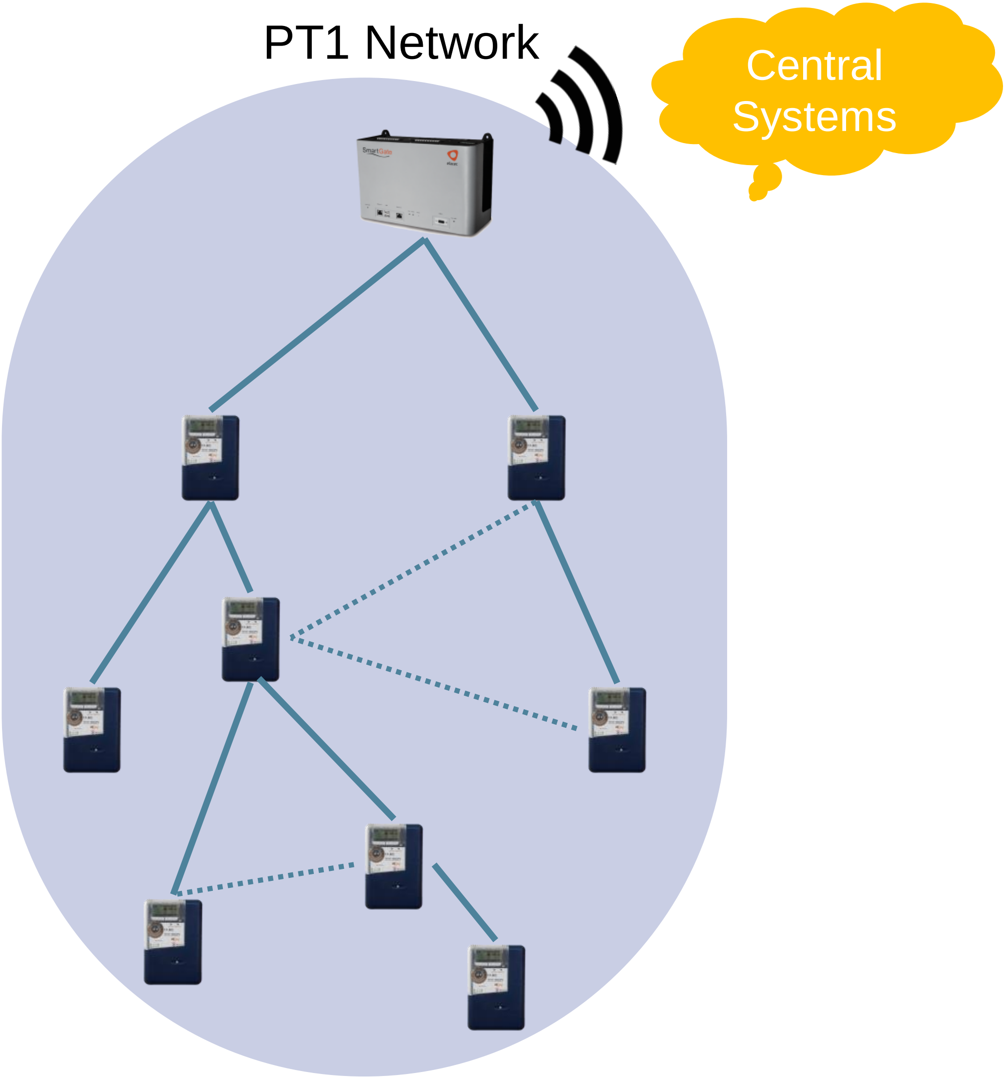
Downward routes



Each node (child) notifies the selected parent and then becomes accessible through it.

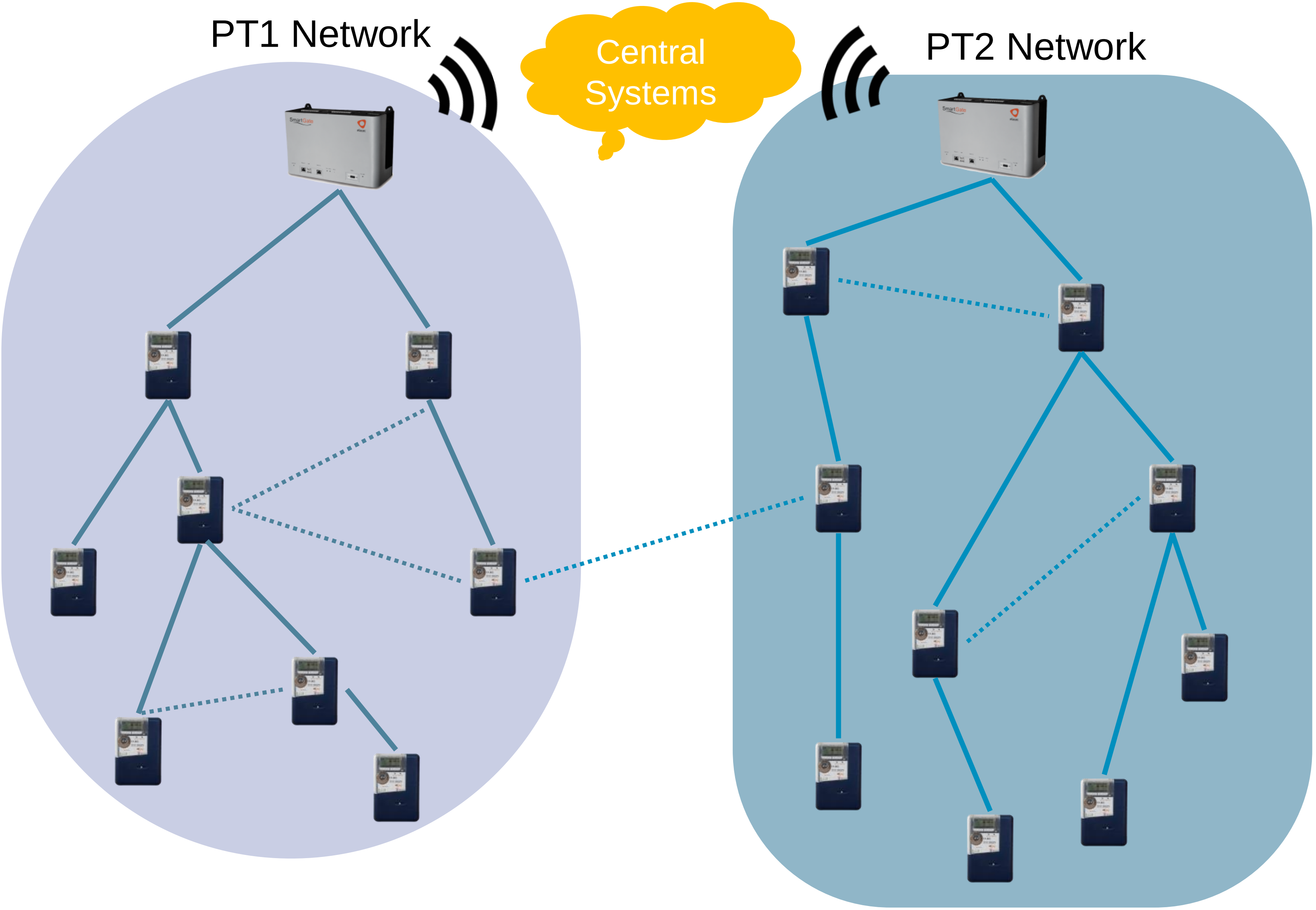
Storing Mode

Tree



Storing Mode

LR connecting to another network



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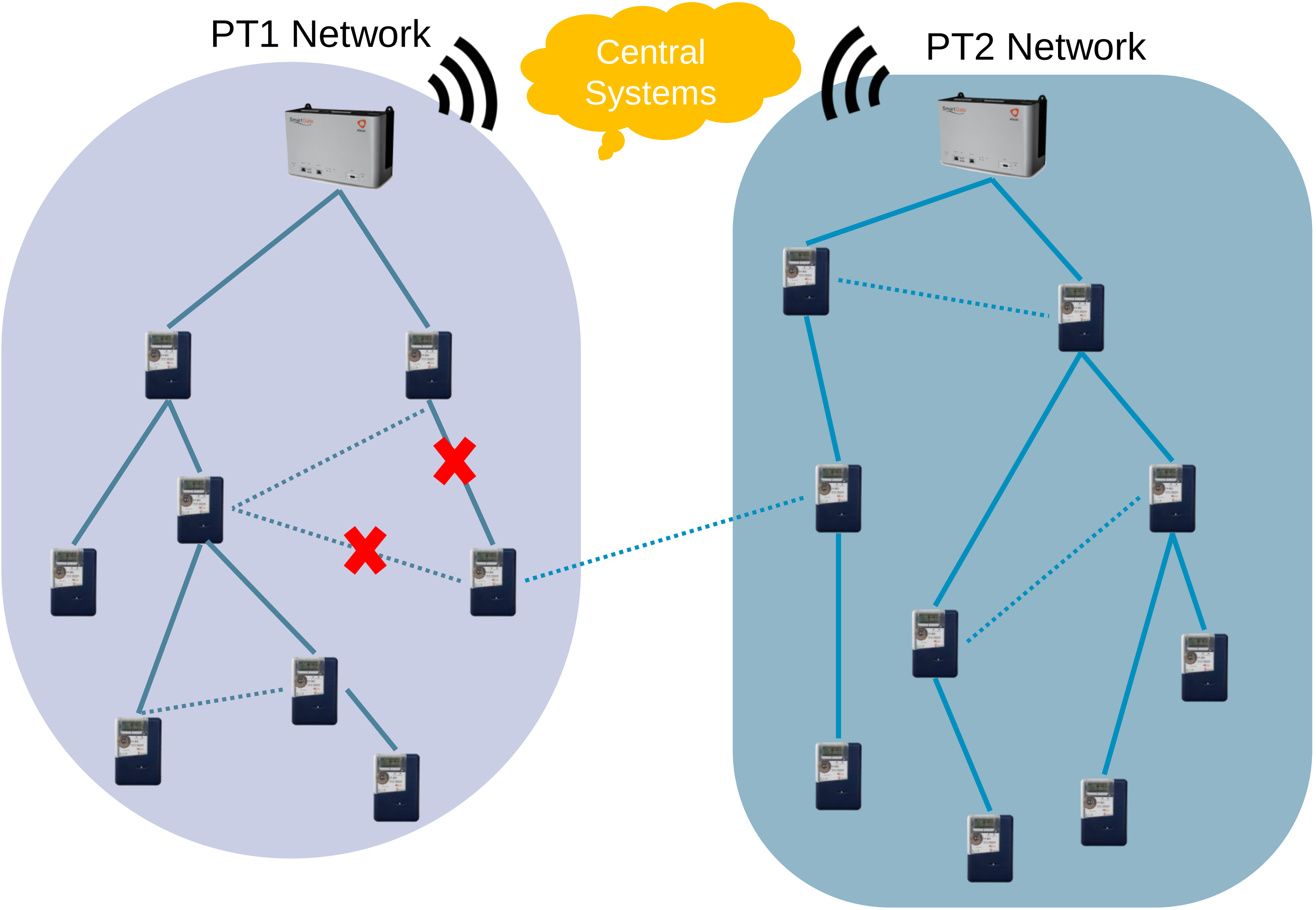
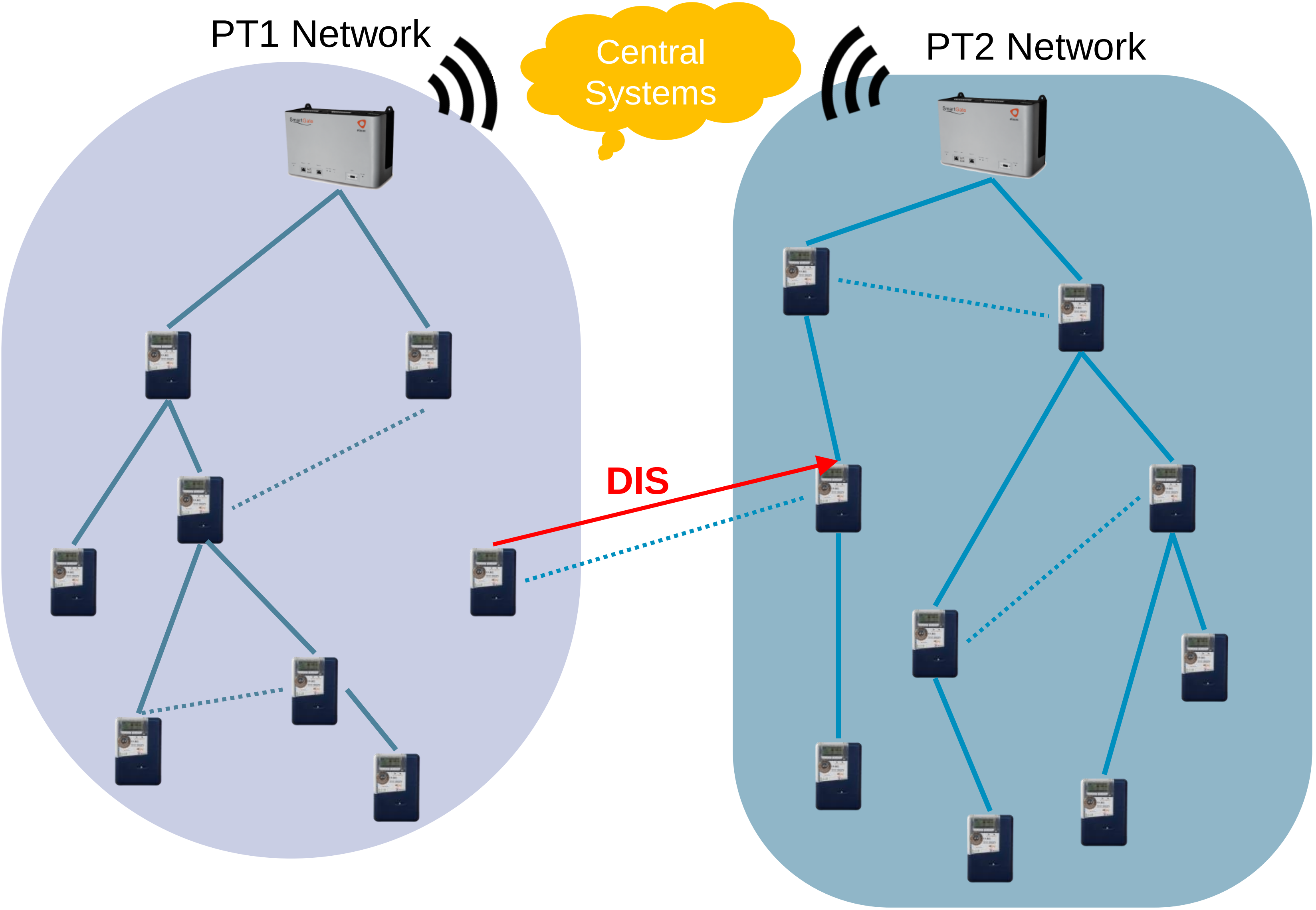
Storing Mode

LR connecting to another network



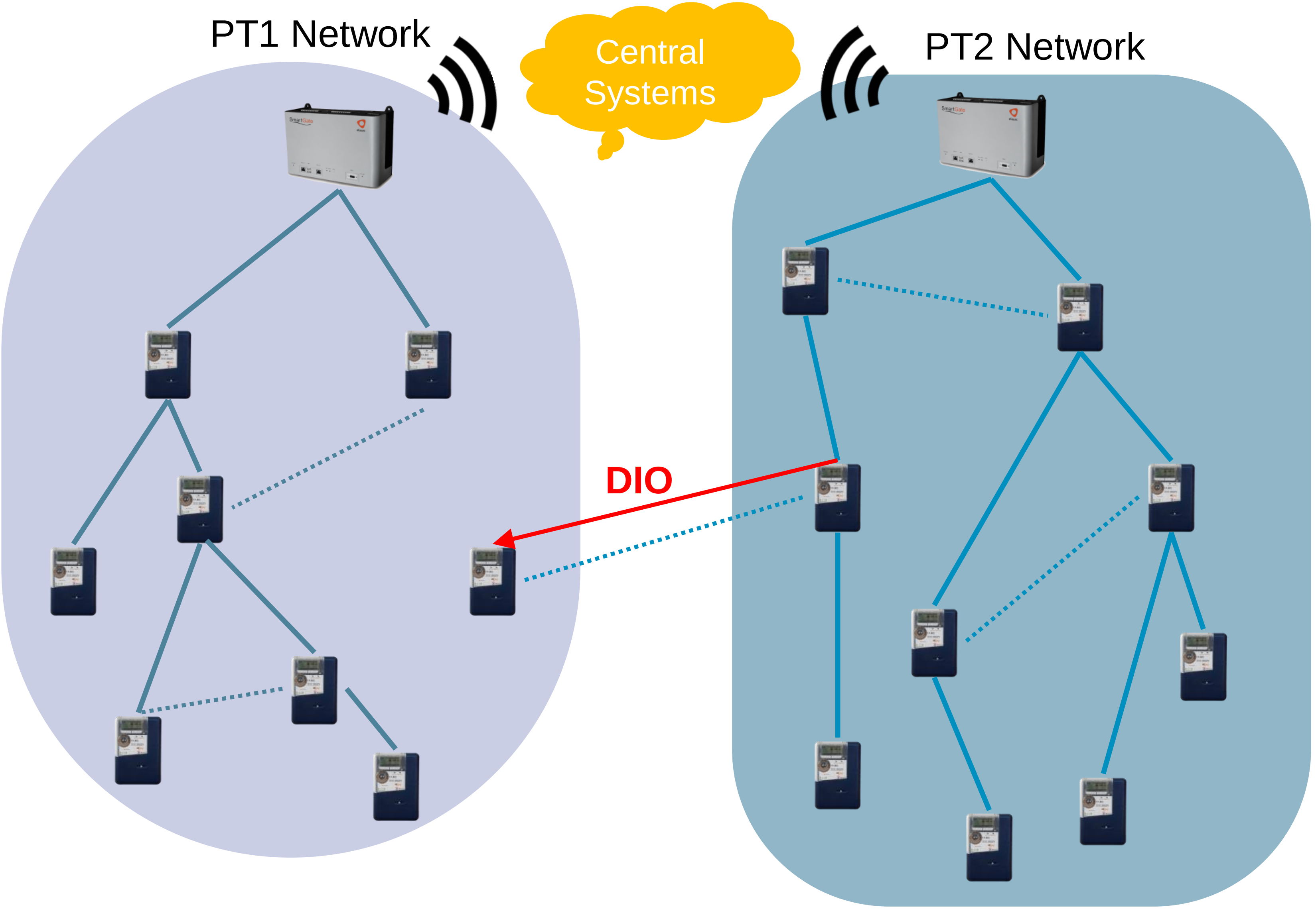
Storing Mode

LR connecting to another network



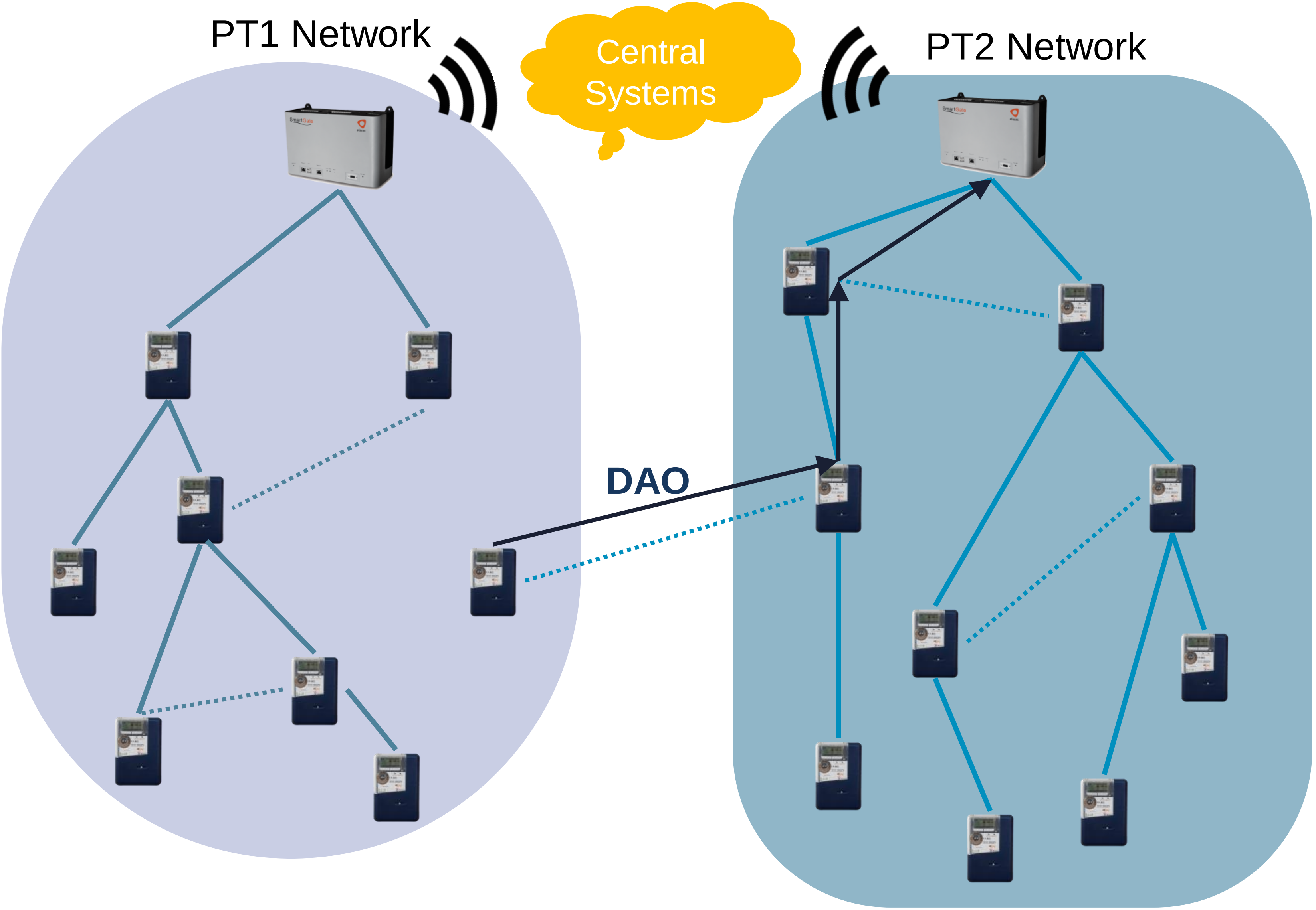
Storing Mode

LR connecting to another network



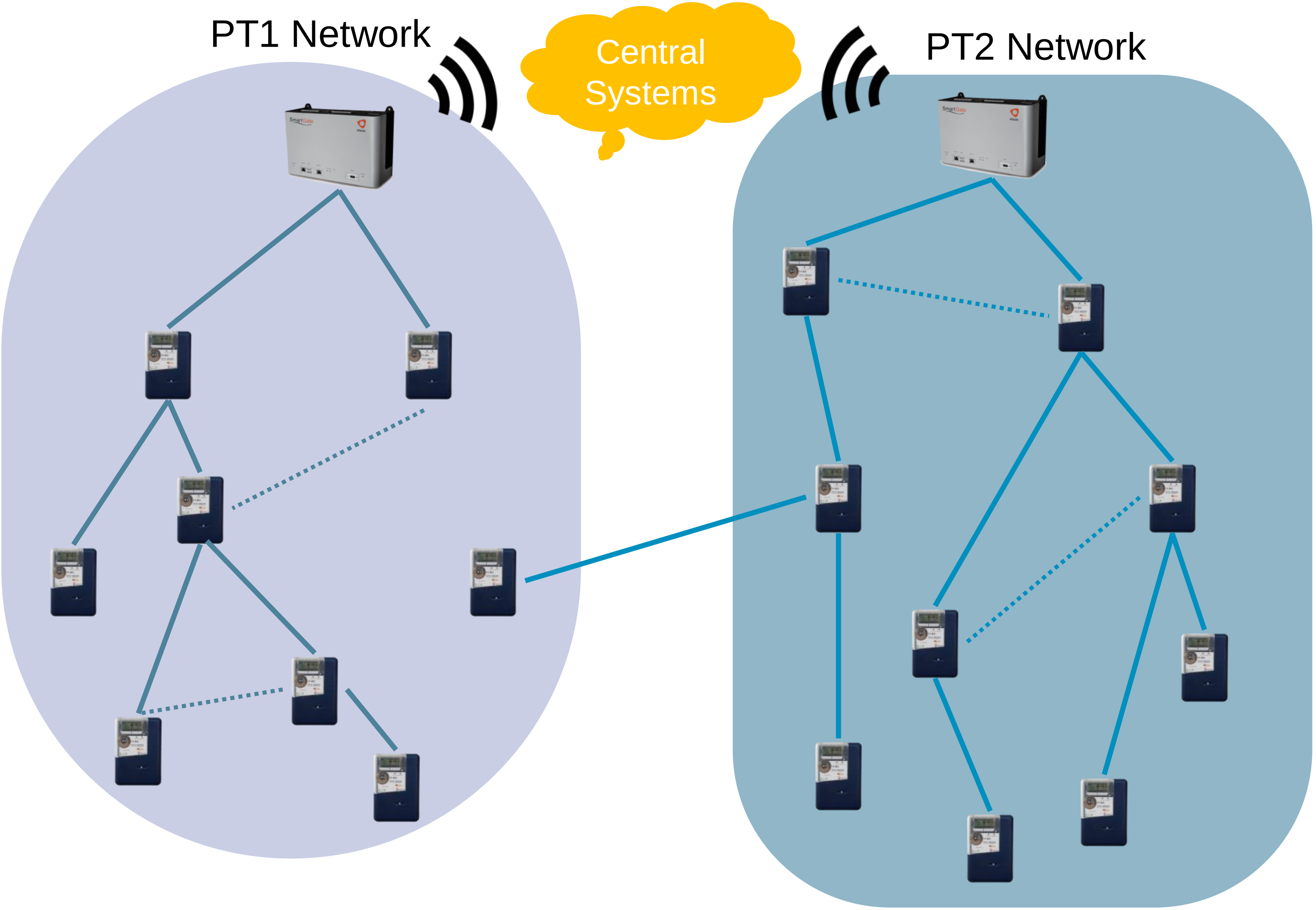
Storing Mode

LR connecting to another network



Storing Mode

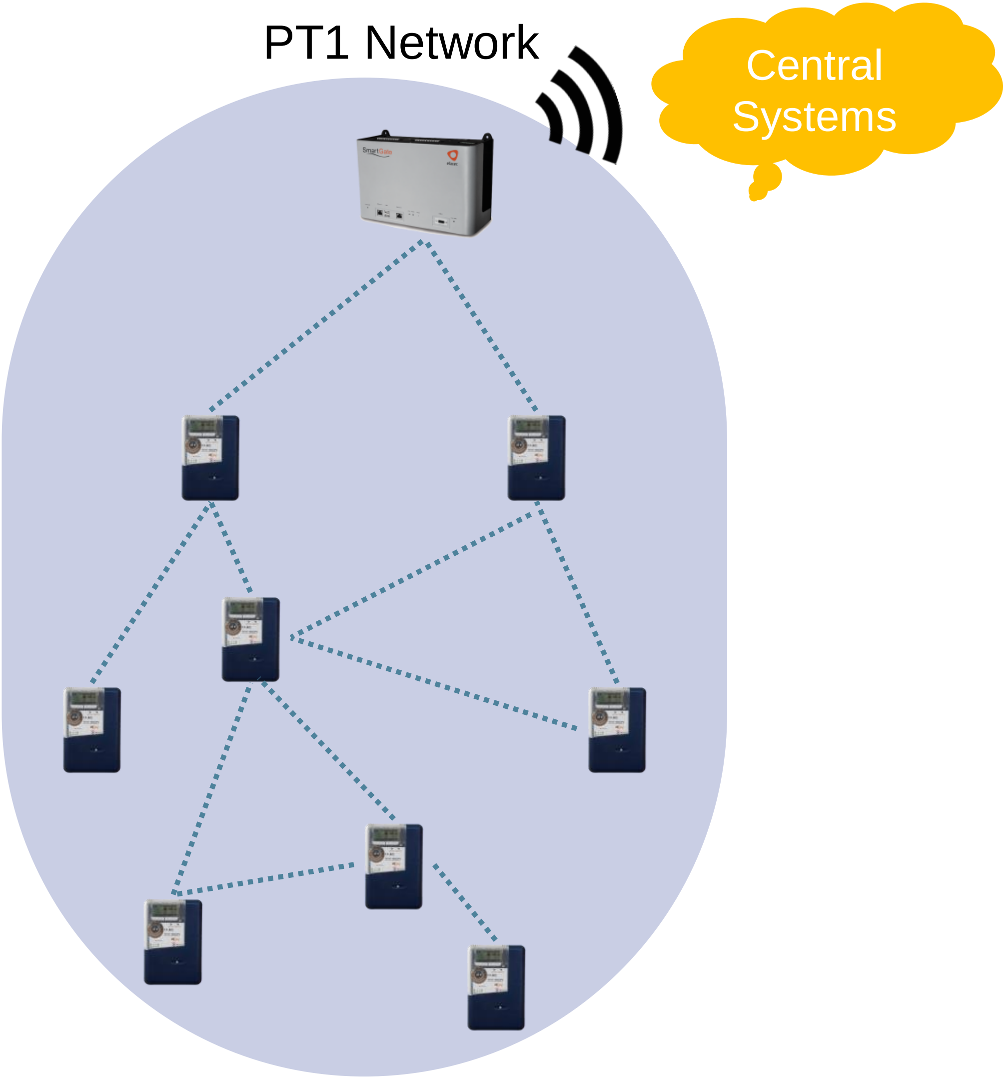
LR connecting to another network



Storing Mode - Disadvantages

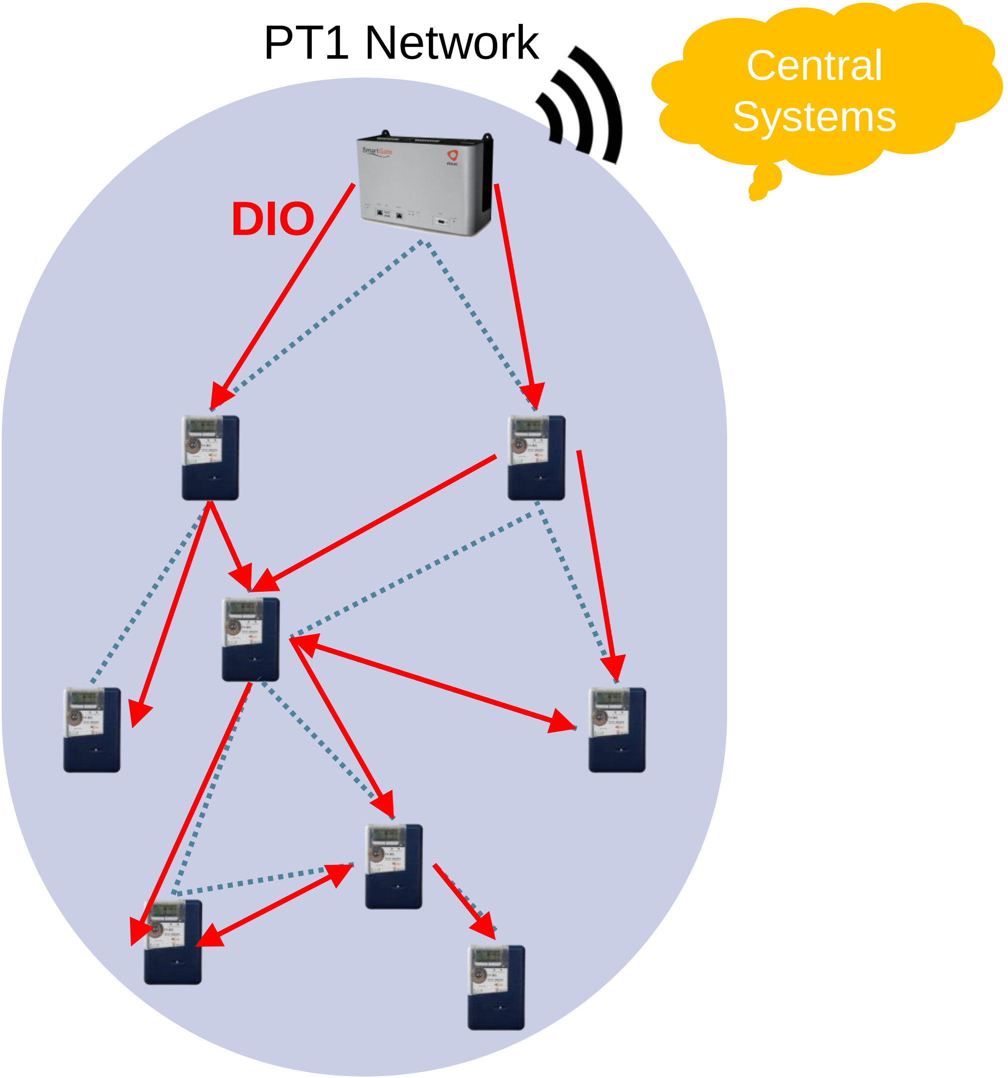
- Node’s routing table
  - must have an entry for each child node in the tree below
- Requires RAM
  - LR near the LBR may store up to 500 entries
  - Single entry: ~47 bytes
  - 500 entries: ~24 kbytes of RAM
- Packet forwarding can be slow
  - Routing table lookup
  - Higher CPU usage → forwarding delay + power consumption

Non-Storing Mode



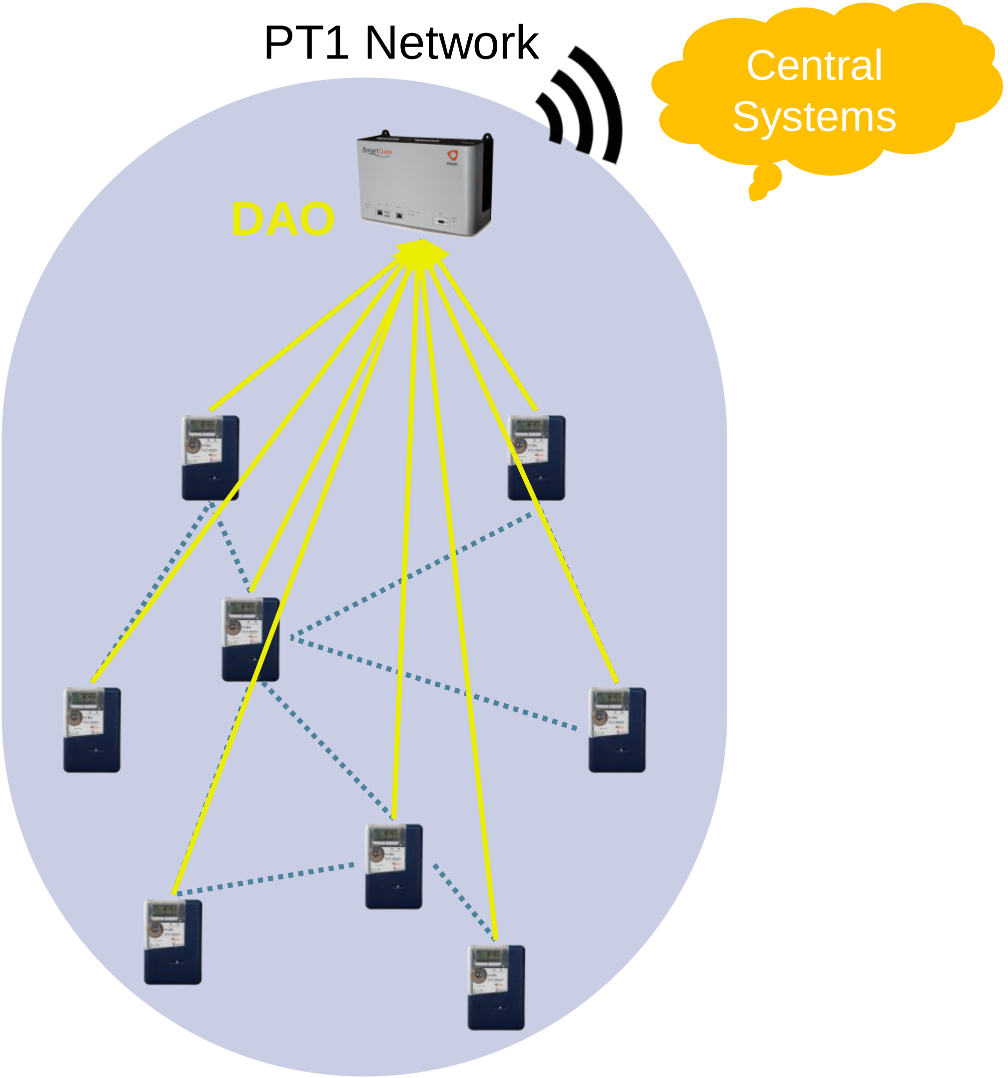
Non-Storing Mode

***Upward routes* (same as Storing mode)**



Non-Storing Mode

Downward routes

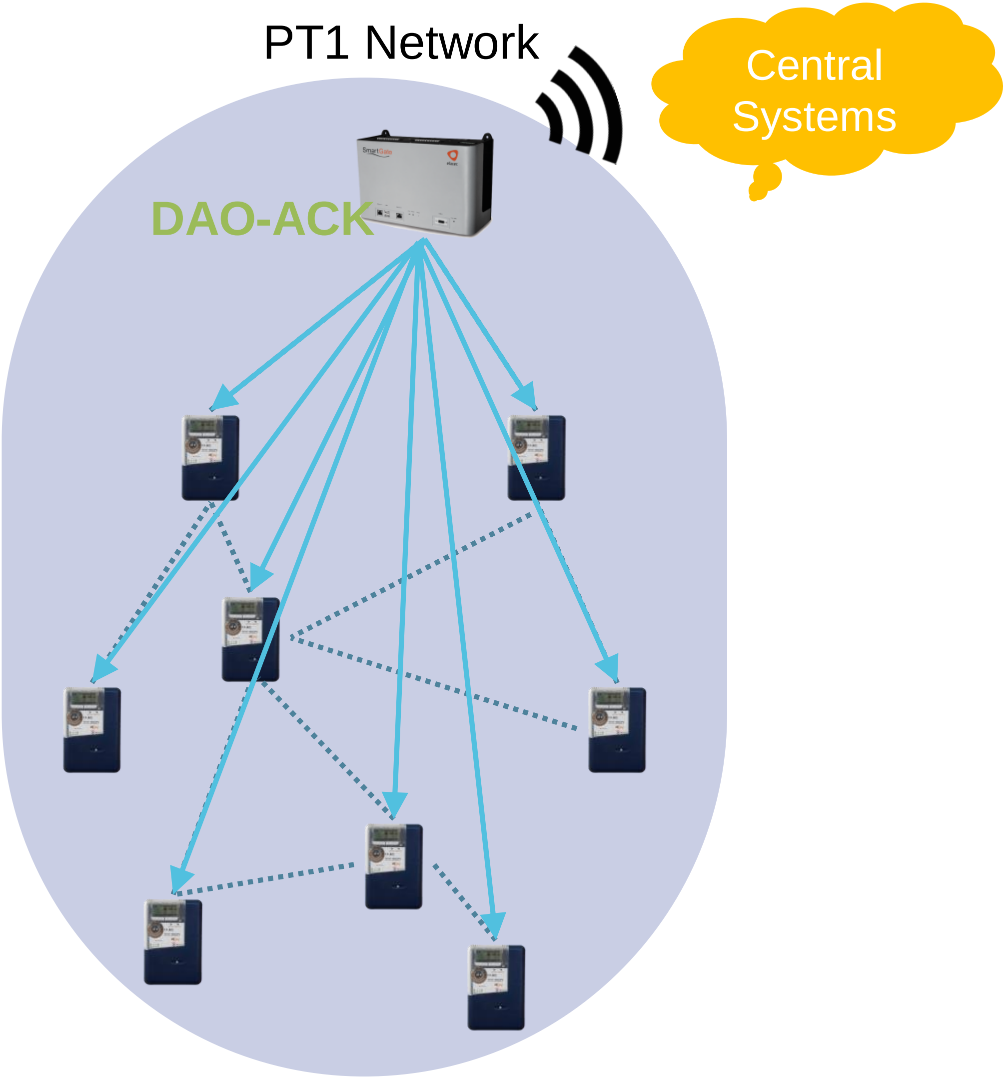


Each node notifies the LBR about selected parent

LBR knows the whole network topology

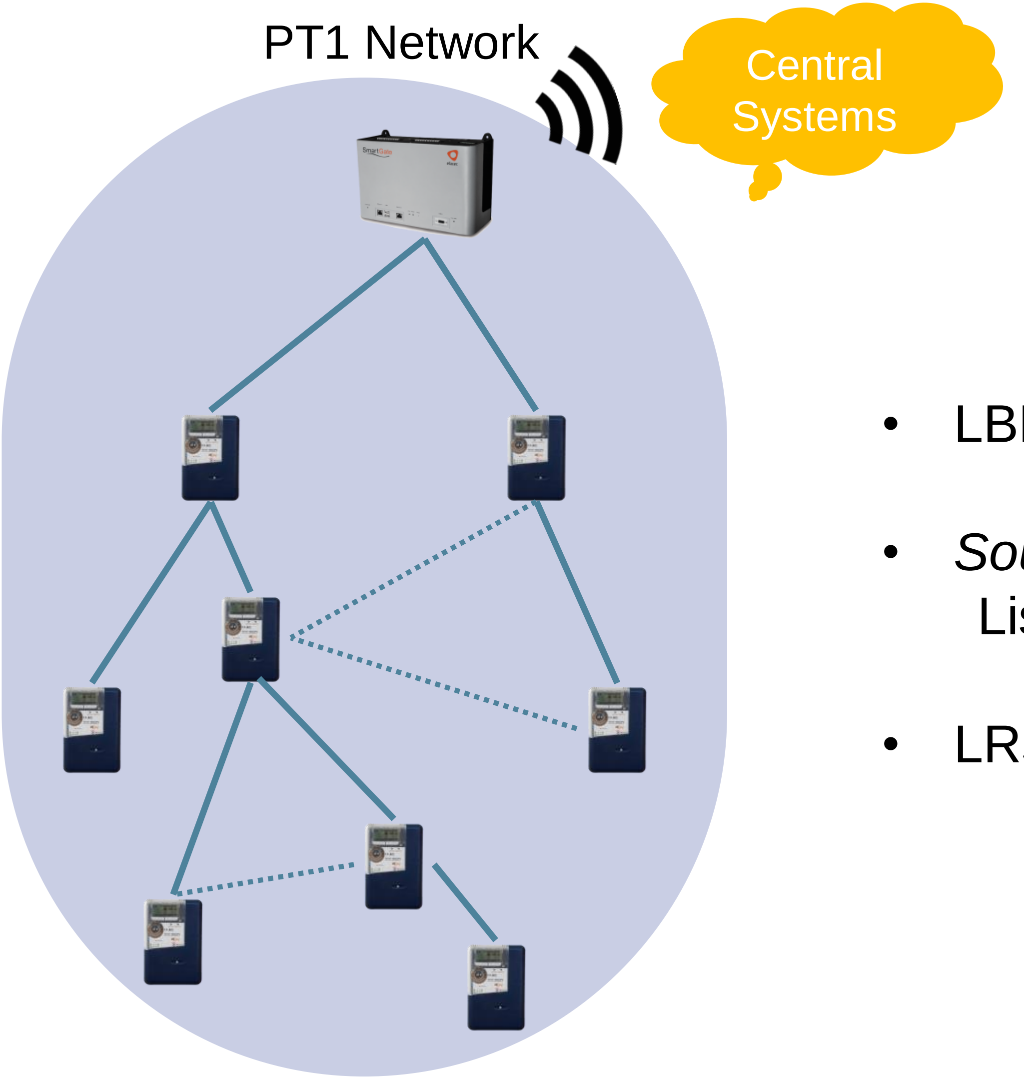
Non-Storing Mode

Downward routes



The LBR confirms the registration

Non-Storing Mode
Tree



- LBR knows whole topology
- *Source Routing Header* added to IP packet
  List of LRs visited by packet
- LRs have small routing table

Non-Storing Mode - Disadvantages

- Routing Header size (n hops) = 8*(n+1) bytes
- It is a problem for IEEE 802.15.4
  - 127 bytes maximum frame size
  - 3 hops → 32 bytes
- Not a problem for IEEE 802.15.4g
  - maximum frame size → 2047 bytes

Non-Storing Mode - Disadvantages

- Traffic between 2 LRs passes through root node
  - Unless LRs have same parent
  - Unlikely scenario in Smart Metering

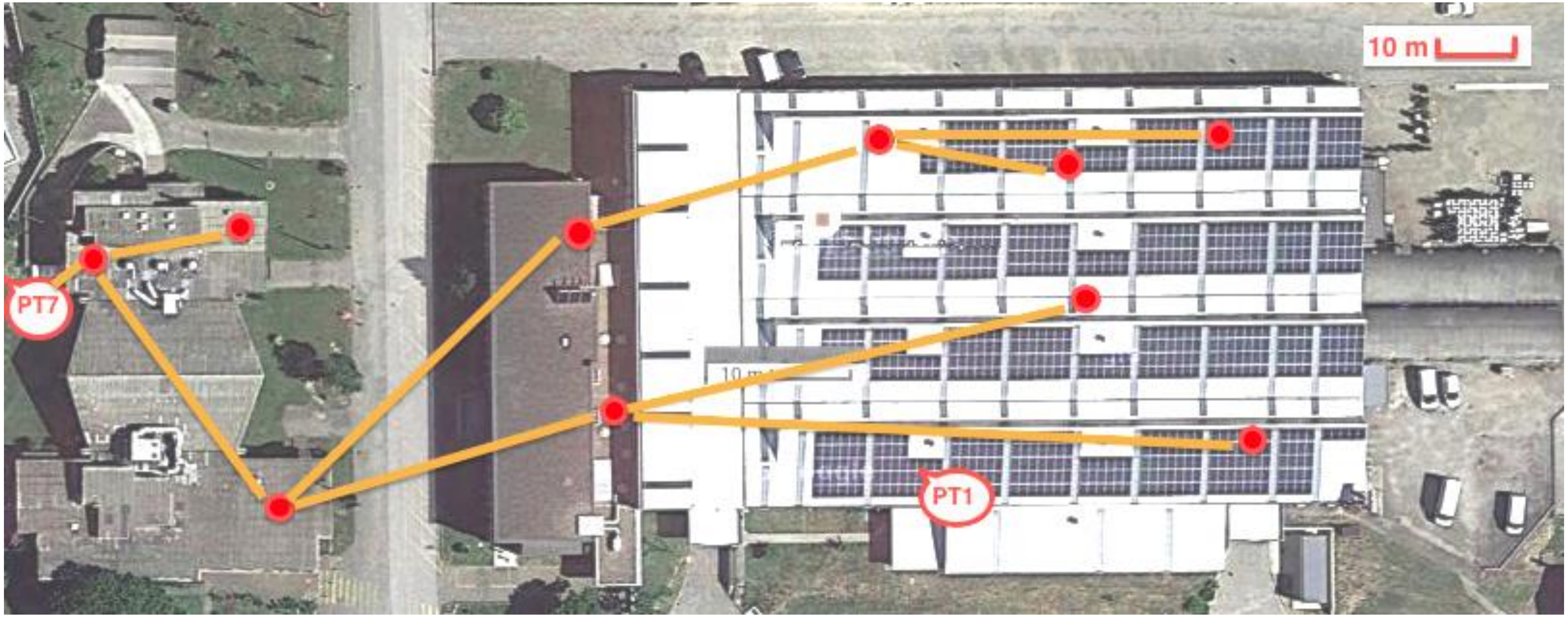
- **Non-storing mode was used**

Experimental tests

Testbed

- 2 PT(LBR), 10 SM (LR)
- Only 1 LBR used at time
- Security disabled → DLMS over TCP or UDP
- Transceivers
  - Channel 7 @ 915 MHz band, bandwidth of 2 MHz
  - O-QPSK with 250 kbit/s data rate
  - TX power: 14 dBm
  - Sensitivity: -102 dBm

Testbed



Tests

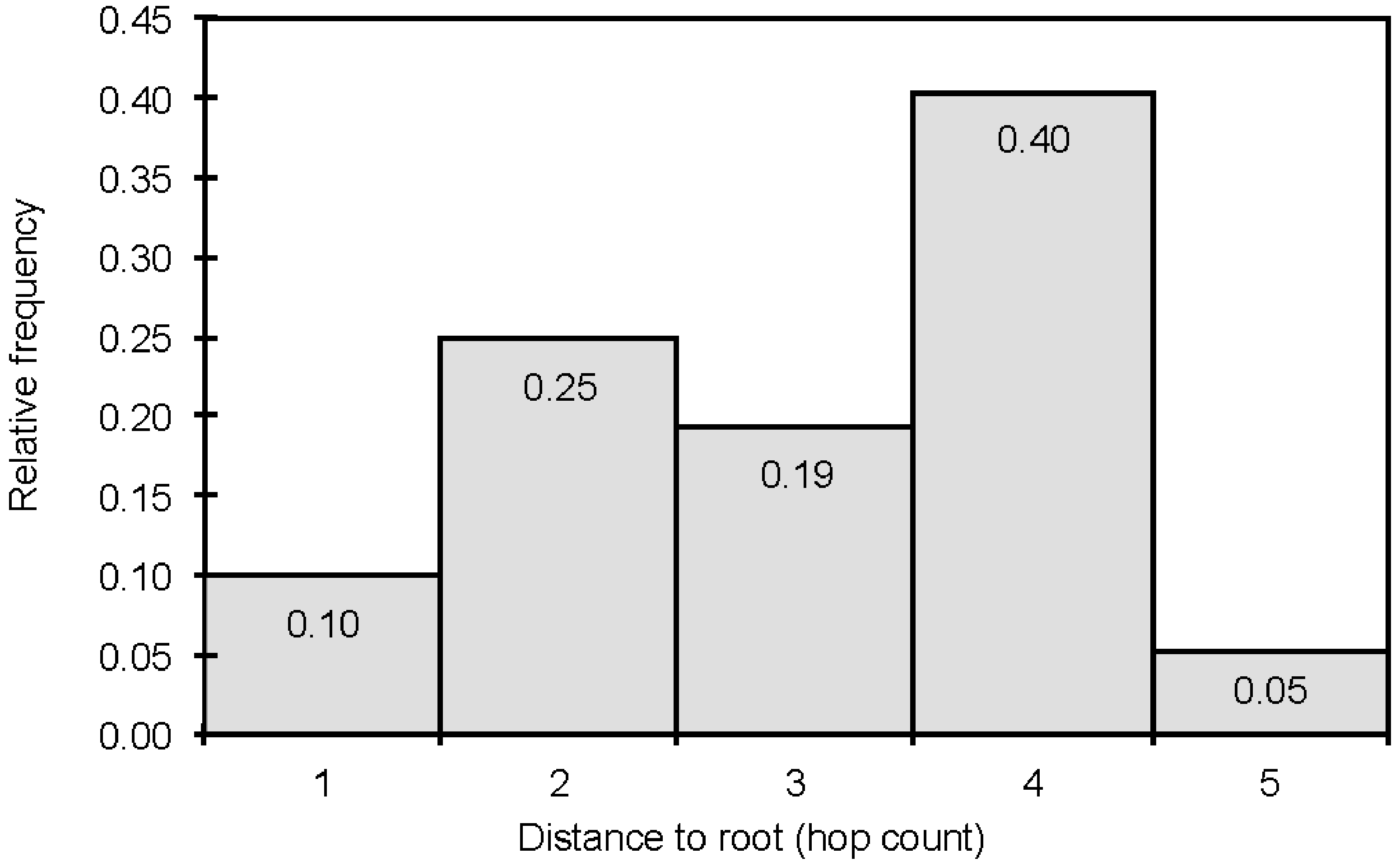
- 20 days of experimental testing
- Three stages

1. Ping tests to LRs during 11.5 days
2. DLMS/COSEM application tests over TCP and UDP during 7 days
3. IEEE 802.15.4 packet sniffing near LBR during 28 hours

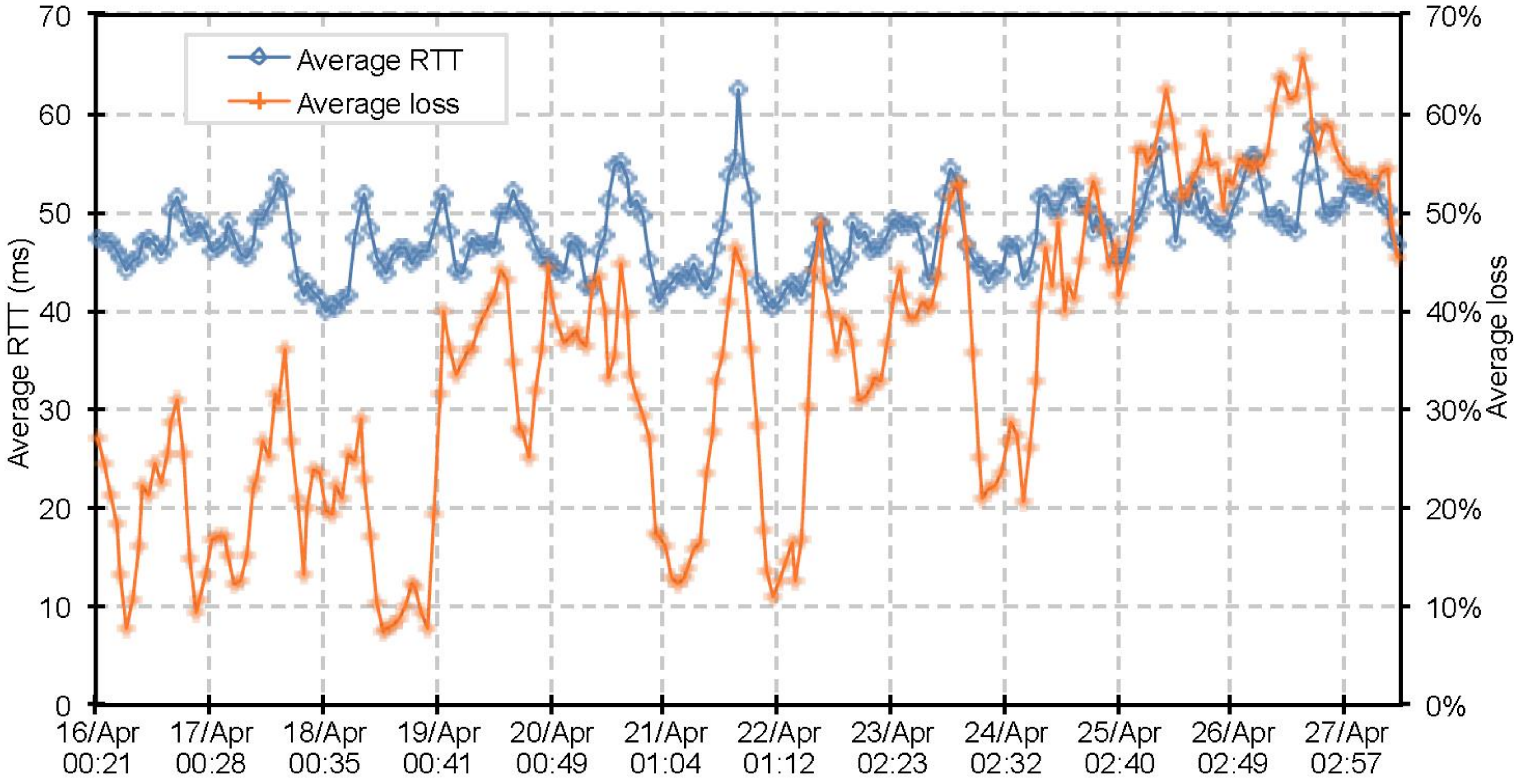
Stage 1: Ping to LRs

- Ping tool used to measure performance at the IP layer
- Duration: 11.5 days
- Procedure
  - Continuous rounds of pings to all LRs
  - 100 consecutive requests to each LR in each round

Hop distance between LRs and LBR



Average RTT and ping loss ratio



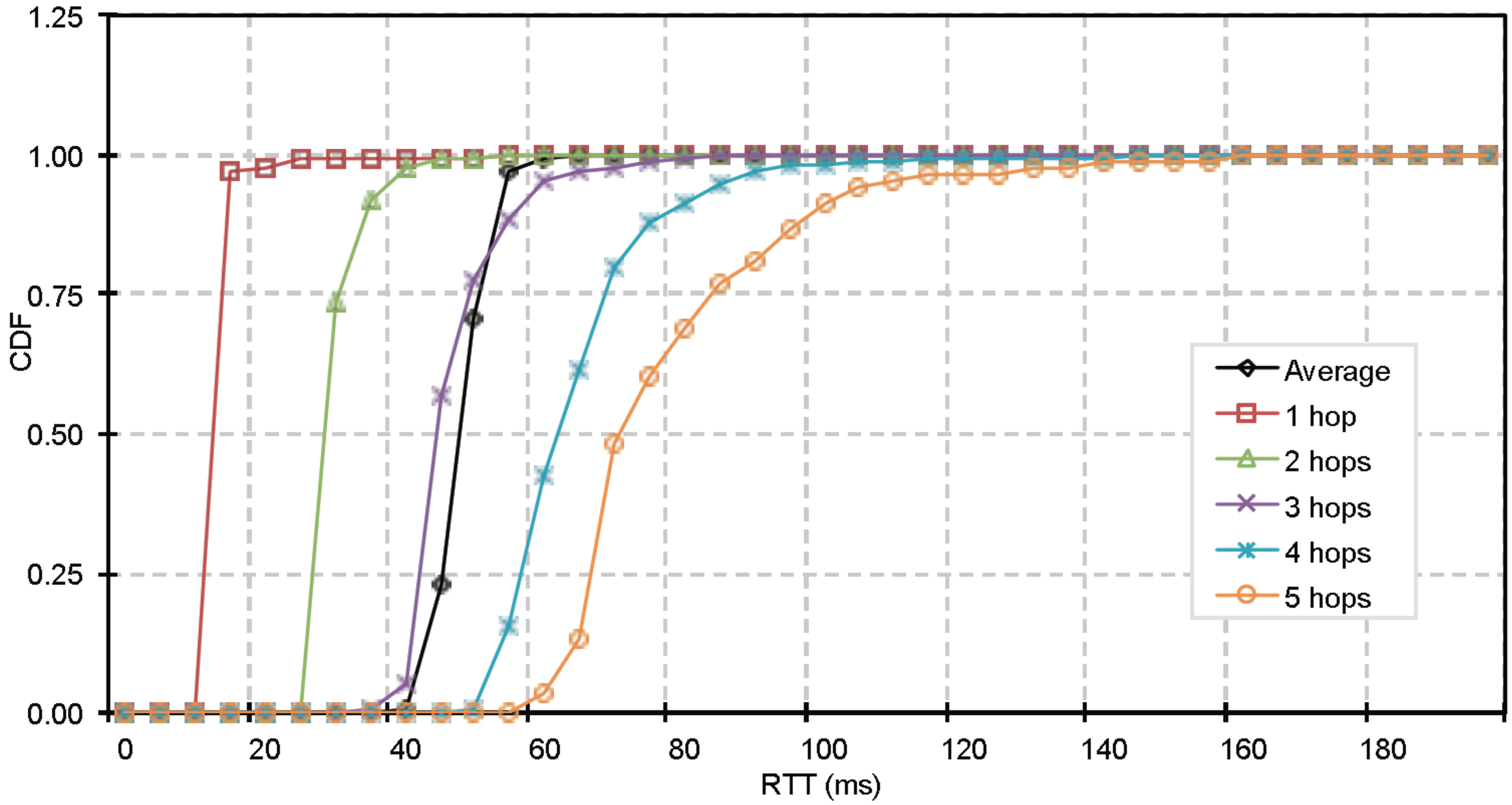
Average RTT and ping loss ratio

- Average RTT near 50 ms almost all the time
- Average ping loss ratio between 10% and 60%
  - Ping loss ratio (echo request + echo reply)
    is higher than packet loss ratio (one way)
- It is a Lossy Network!

RTT as a function of distance

- RTT increases 15 ms/hop
- RTT variation increases with distance
- All RTTs below 160 ms
- Average RTT similar to RTTs for 3 hops
  consistent with average hop count (3.06 hops)

RTT as a function of distance



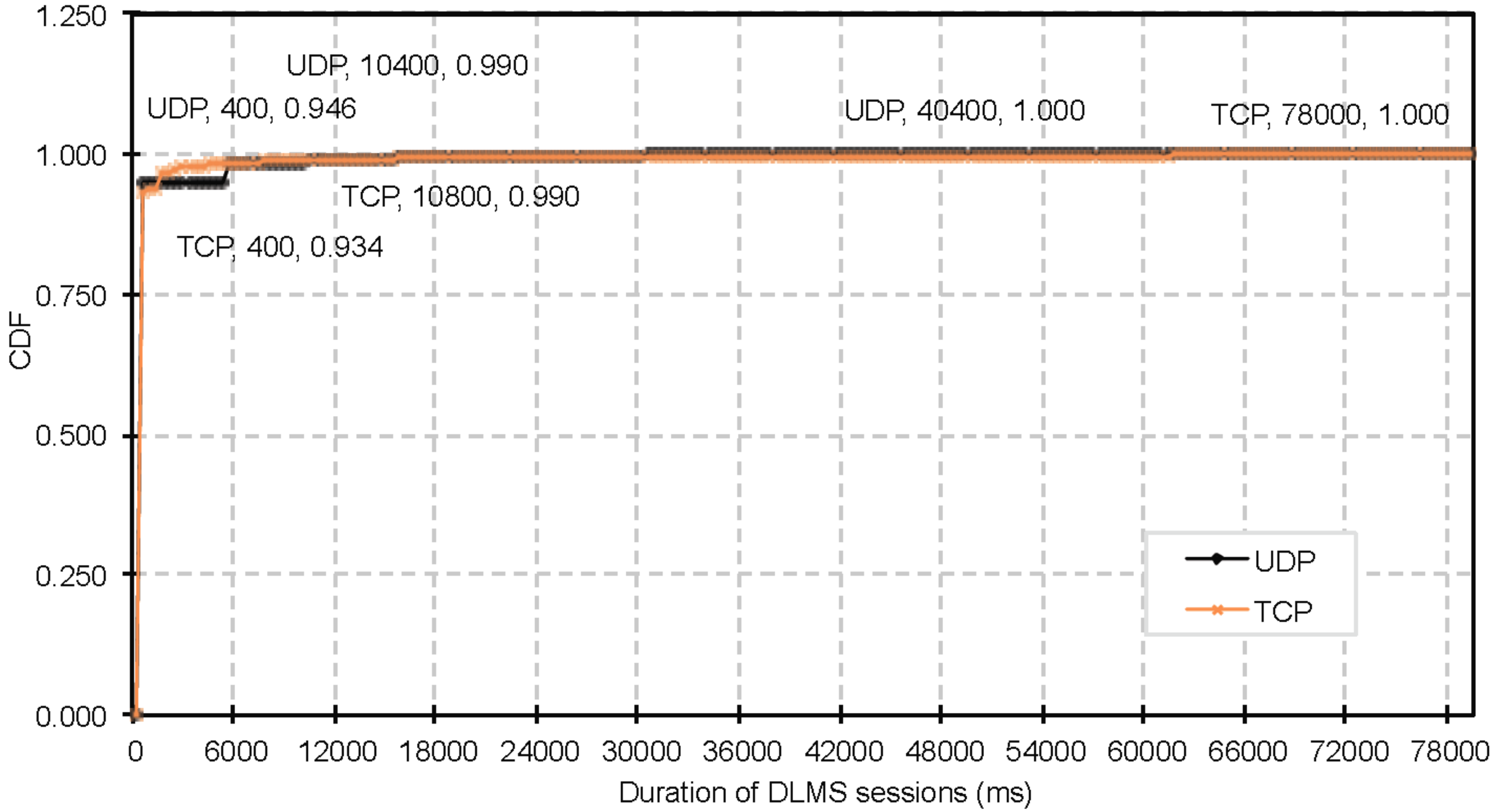
Stage 2: DLMS/COSEM over TCP and UDP

- DLMS/COSEM application used to measure performance of DLMS protocol over TCP and UDP
- Duration: 7 days
- From DLMS/COSEM client (DC) to servers (SMs)
- Measurements at the application layer
  - DLMS session duration
  - DLMS session failure ratio

Stage 2: DLMS/COSEM over TCP and UDP

- 20 000 DLMS rounds
- DLMS round: 3 consecutive DLMS sessions to each LR
- Transport switched between TCP and UDP every 30 minutes
- Timeout and maximum number of DLMS retransmissions
  - For UDP: timeout of 5 s and a 8 retransmissions
  - For TCP: timeout of 60 s and 1 retransmission
- DLMS messages length
  - Requests: 64 bytes
  - Responses: 128 bytes
- DLMS session duration includes UARTs delays
  - UART@LBR: 115.2 kbit/s
  - UART@LR: 9.6 kbit/s
  - 173 ms to Tx messages through UARTs

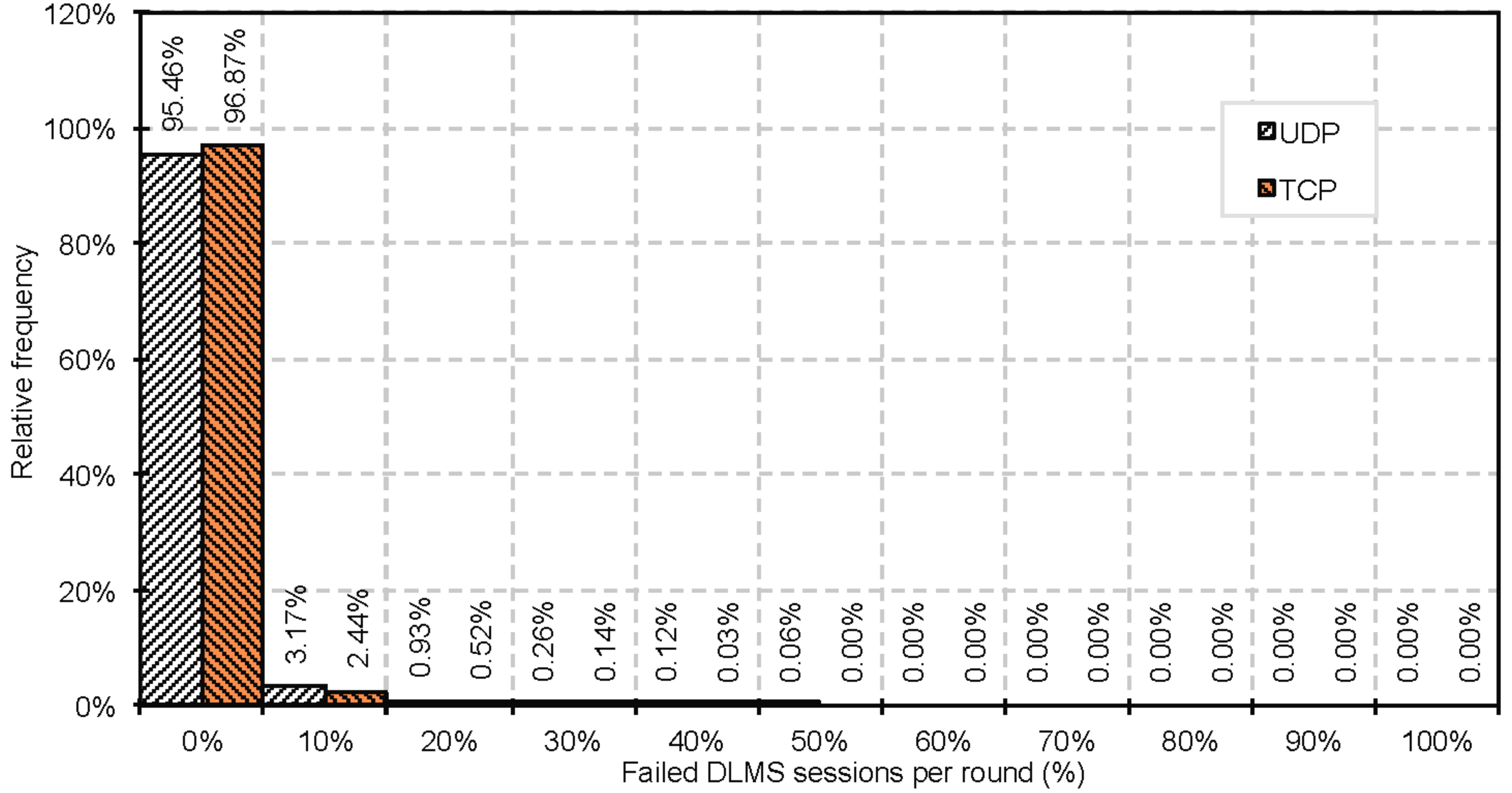
DLMS session duration



	Average	25^{th} percentile	Median	75^{th} percentile
TCP	779 ms	217 ms	243 ms	258 ms
UDP	695 ms	213 ms	237 ms	252 ms

+**90%** of successful DLMS sessions under **400 ms** (including UART delays)

Failed DLMS sessions per round



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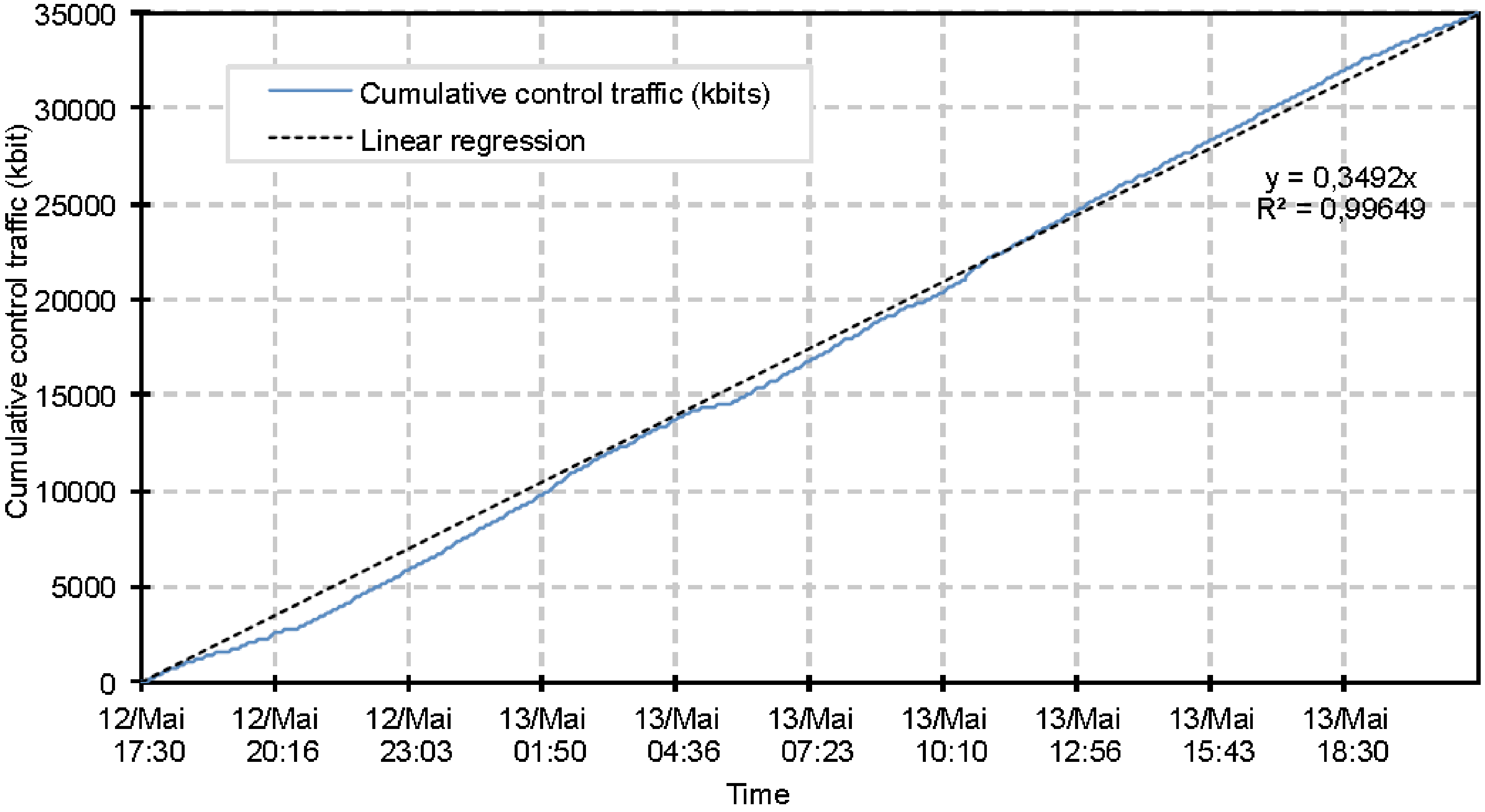
Stage 3: IEEE 802.15.4 packet sniffing

- Used to measure IP control traffic in the medium near the LBR
- Duration: 28 hours
- IEEE 802.15.4 packet sniffer near LBR
- Procedure
  - DLMS rounds made to all LRs
  - As in Stage 2

IP control traffic near the LBR



- Mainly RPL messages
- 350 bit/s (= 0.14% of medium capacity)

Conclusions

- IP packet loss ratio is high
- RTT increased 15 ms/hop
- **Repetition** helps overcoming packet loss
- Failed DLMS sessions/round
  - 0.25% for TCP
  - 0.47% for UDP
- +90% of DLMS sessions completed before 400 ms

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THE END