Some key research and challenges in building IoT infrastructures

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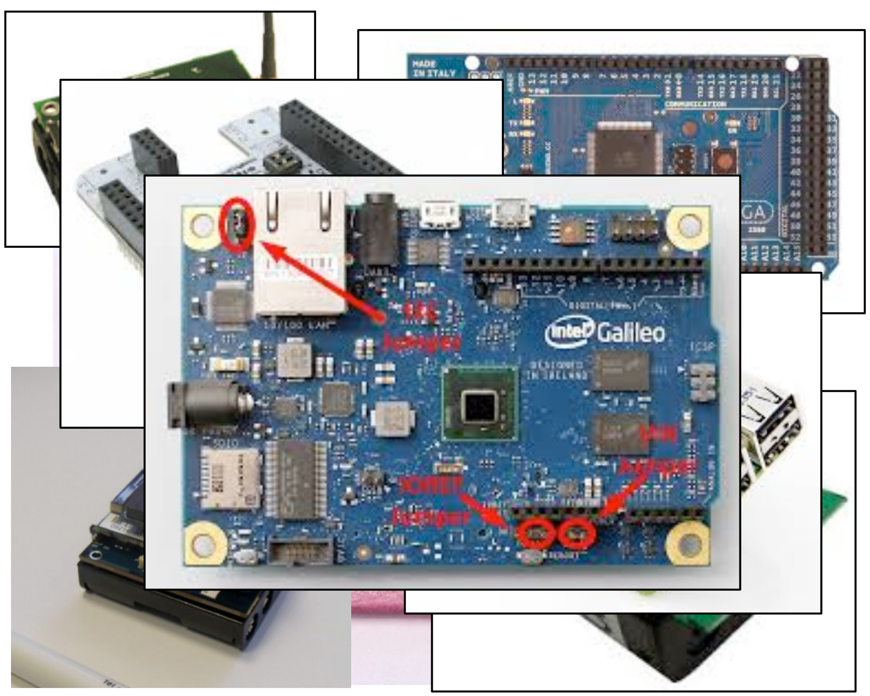
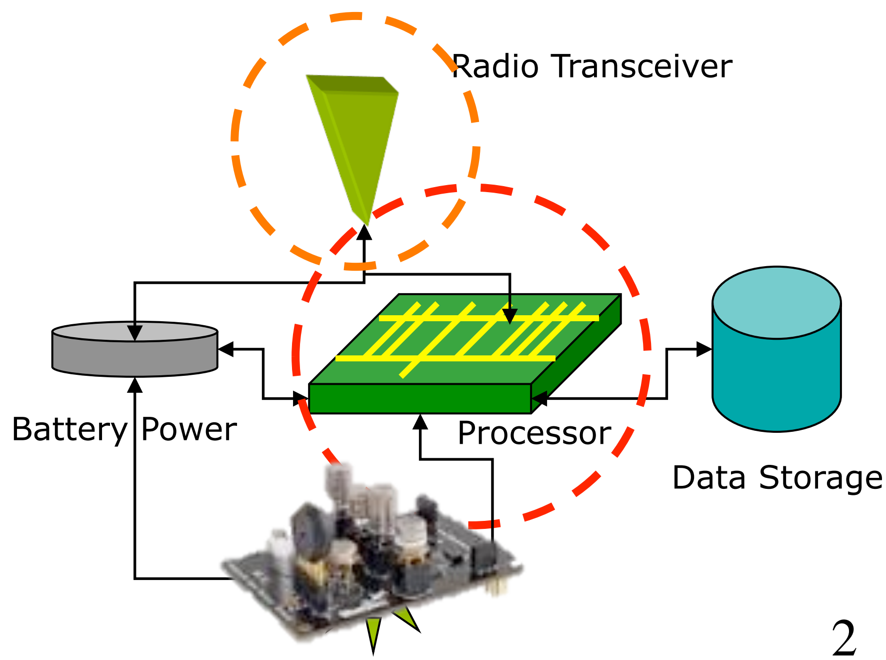
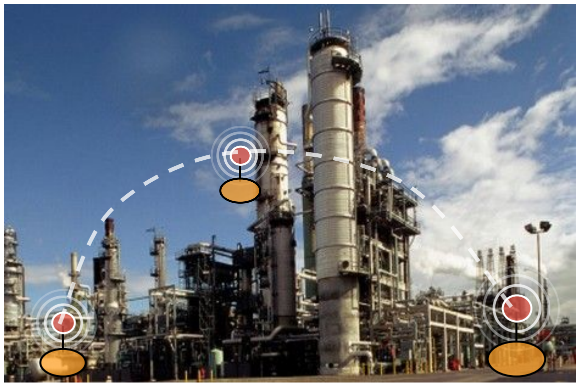
Before IoT: Wireless autonomous sensor

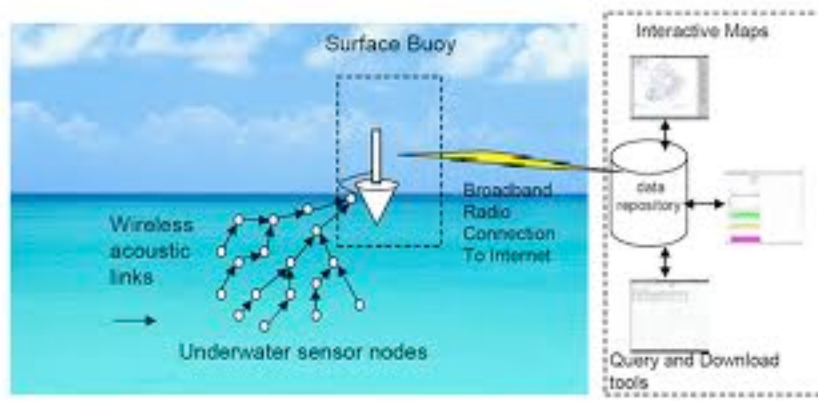
- Wireless Sensor Nodes or embedded Linux still remain the main IoT development platform
- In general: low cost, low power (the battery may not be replaceable), small size, prone to failure, possibly disposable



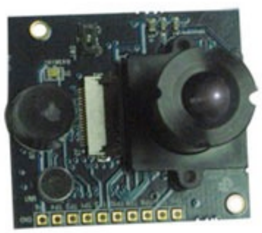


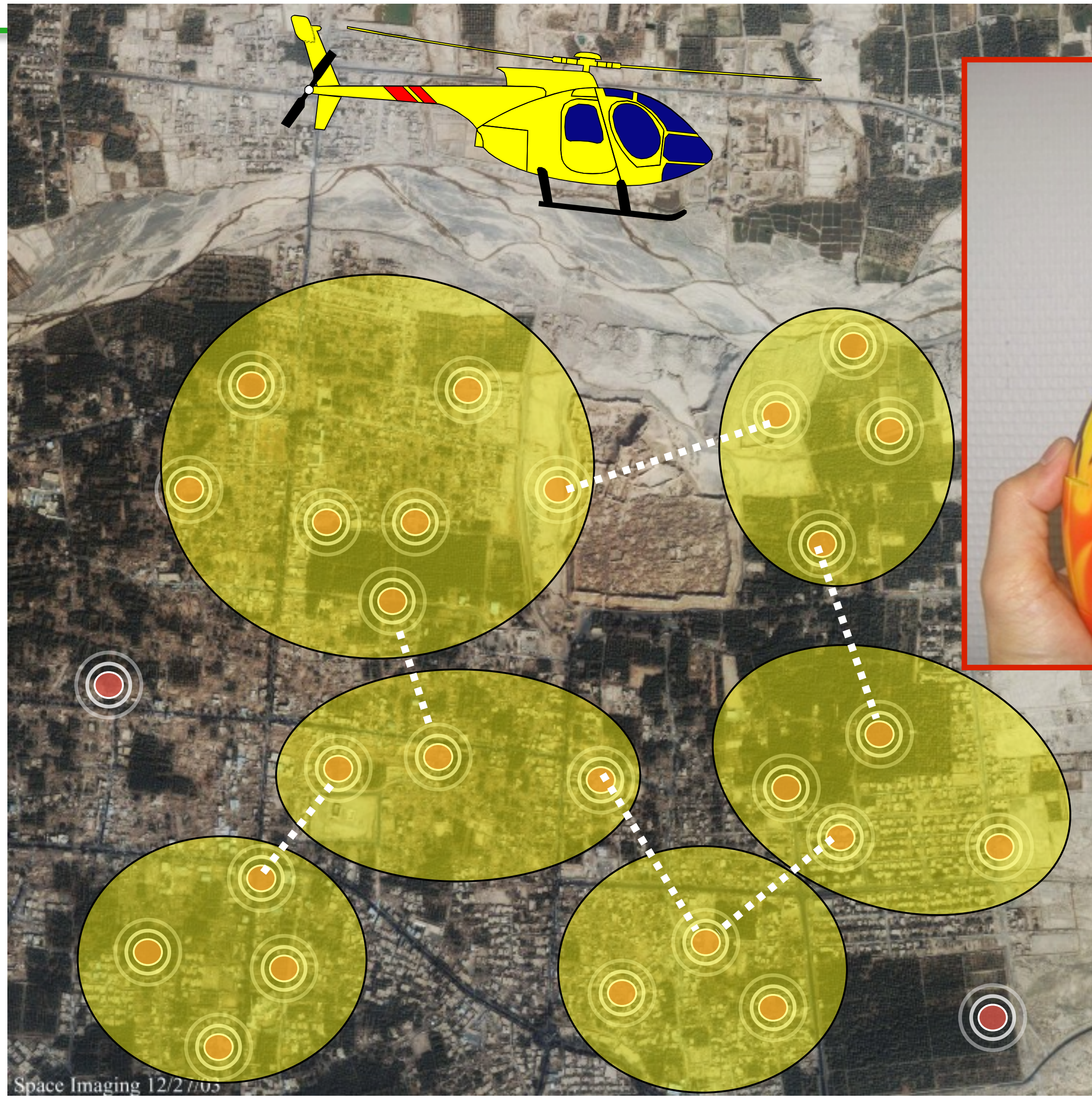
« Naturally » well suited for Monitoring/Surveillance



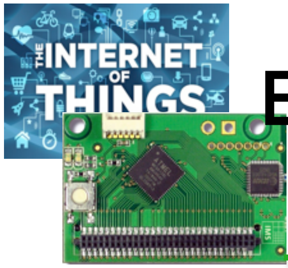


Safety, disaster relief



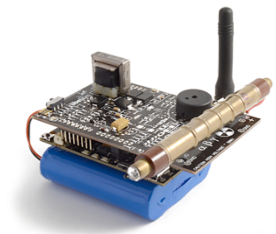


The digital ecosystem



Beyond Sensor Networks: Communicating Objects!

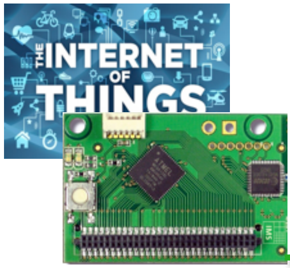
- Native communication:



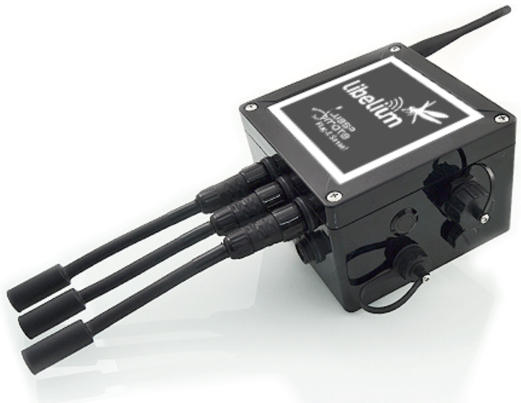
- Added communication
  - Active communication

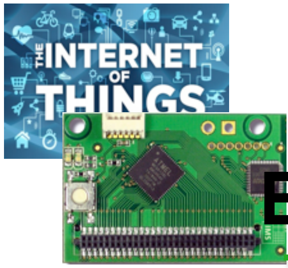
  - Passive communication

Wireless Communication made easy

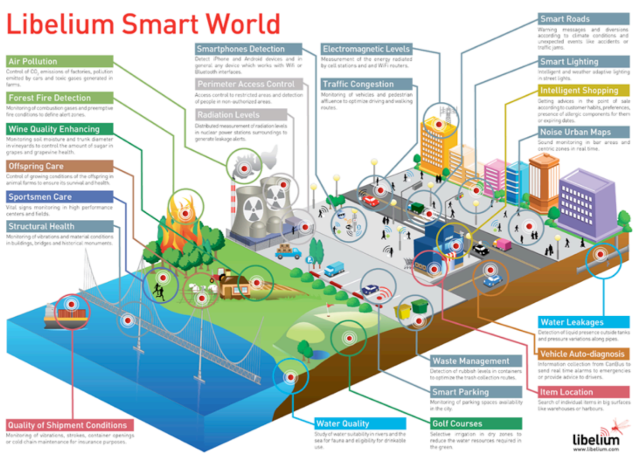


Maturation of the market: WSN→IoT



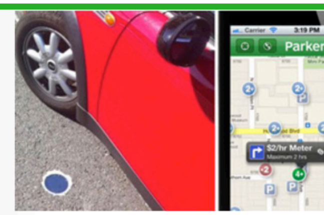


Smart Cities with real business model behind!



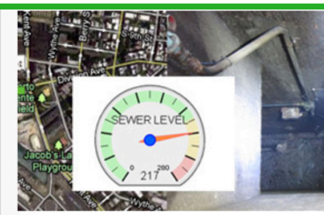
KEEP STREETS CLEAN

Products like the cellular communication enabled Smart Belly trash use real-time data collection and alerts to let municipal services know when a bin needs to be emptied. This information can drastically reduce the number of pick-ups required, and translates into fuel and financial savings for communities service departments. // Visit



STOP DRIVING IN CIRCLES

With the use of installed sensors, mobile apps, and real-time web applications like those provided in Streetline's ParkSight service, cities can optimize revenue, parking space availability and enable citizens to reduce their environmental impact by helping them quickly find an open spot for their cars. // Visit

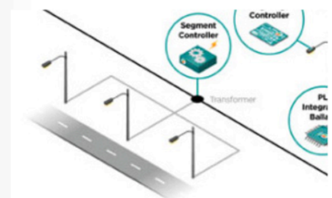


RECEIVE POLLUTION WARNINGS

The DontFlushMe project by Leif Percifield is an example that combines sensors installed in Combined Sewer Overflows (CSOs) with alerts to local residents so they can avoid polluting local waterways with raw sewage by not flushing their toilets during overflow events. // Visit

USE ELECTRICITY MORE EFFICIENTLY

The SenseNET system uses battery-powered clamp sensors to quickly measure current on a line, calculate consumption levels, and send that data to a hosted application for analysis. Significant financial and energy resources are saved as the clamps can easily identify meter tampering issues, general malfunctions, and any installation issues in the system. // Visit



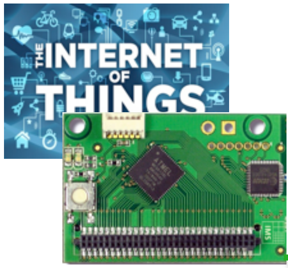
LIGHT STREETS MORE EFFECTIVELY

This smart lighting system from Echelon allows a city to intelligently provide the right level of lighting needed by time of day, season, and weather conditions. Cities have shown a reduction in street lighting energy use by up to 30% using solutions like this. // Visit

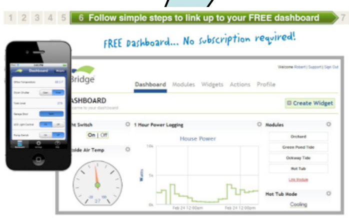
SHARE YOUR FINDINGS

AirCasting is a platform for recording, mapping, and sharing health and environmental data using your smartphone. Each AirCasting session lets you capture real-world measurements (Sound levels recorded by their phone microphone; Temperature, humidity, carbon monoxide (CO) and nitrogen dioxide (NO2) gas concentrations), and share it via the CrowdMap with your community. // Visit

http://www.postscapes.com/internet-of-things-examples/



Control, optimize & Instrument



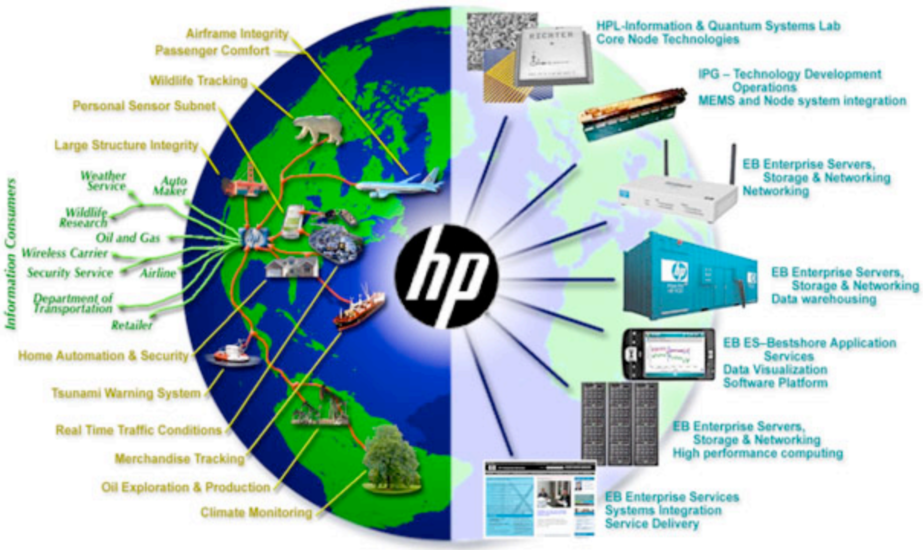
Pervasive Systems

Sensing

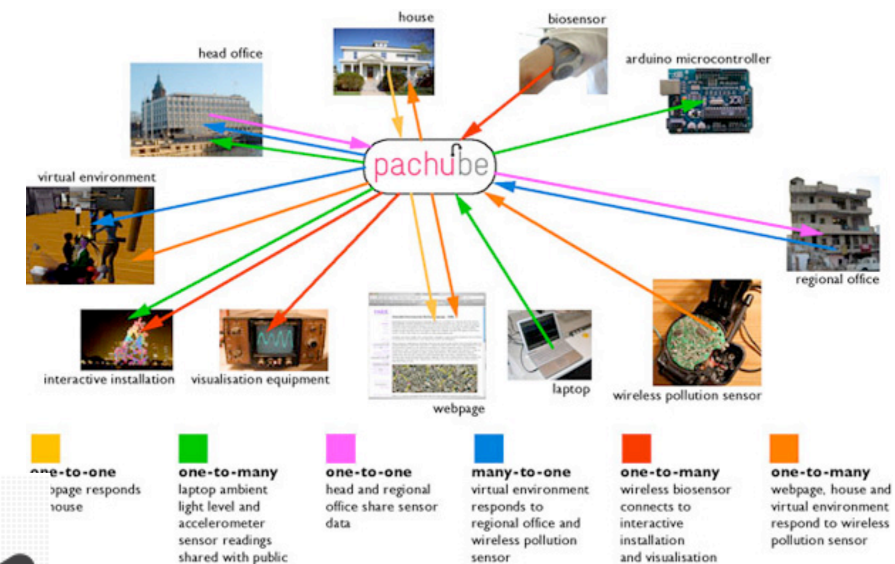
Peoples, infrastructures, buildings, vehicules

Big actors for big data

HP CeNSE

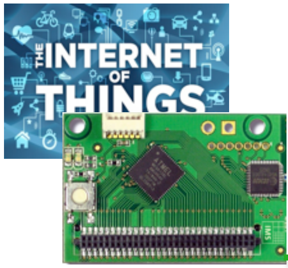


Pachube/Cosm

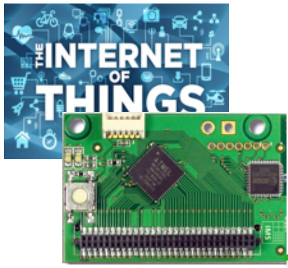


IBM Smarter Planet

cosm
Connect to your world

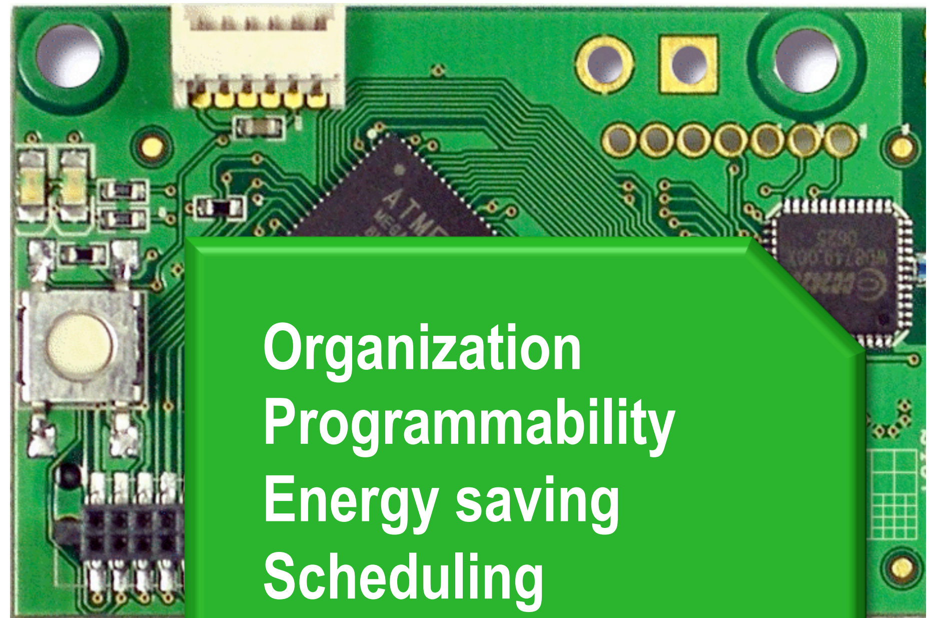


- OPEN SOURCE MIDDLEWARE FOR GETTING INFORMATION FROM SENSOR CLOUDS, WITHOUT HAVING TO WORRY ABOUT WHAT EXACT SENSORS ARE USED.
- EXPLORES EFFICIENT WAYS TO USE AND MANAGE CLOUD ENVIRONMENTS FOR IOT "ENTITIES" AND RESOURCES (SUCH AS SENSORS, ACTUATORS AND SMART DEVICES) AND OFFERING UTILITY-BASED, PAY-AS-YOU-GO, IOT SERVICES.
- ENABLES THE CONCEPT OF "SENSING-AS-A-SERVICE", VIA AN ADAPTIVE MIDDLEWARE FRAMEWORK FOR DEPLOYING AND PROVIDING SERVICES IN CLOUD ENVIRONMENTS



Are you IoT or WSN?

- IP integration, WWW
- IPv6
- Inter-operability
- Interactions (all kind)
- Semantic, Ontology
- Data representation
- Data logging
- WebServices, RDF, OWL, …



- Organization
- Programmability
- Energy saving
- Scheduling
- Efficient MAC, routing
- Congestion control
- Data transmission

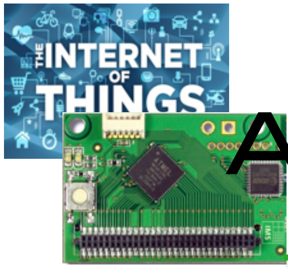
1ST ISSUE: COLLECT DATA

DATA ANALYSIS, OPTIMIZATION & CONTROL

PERVASIVE SYSTEMS

SENSING

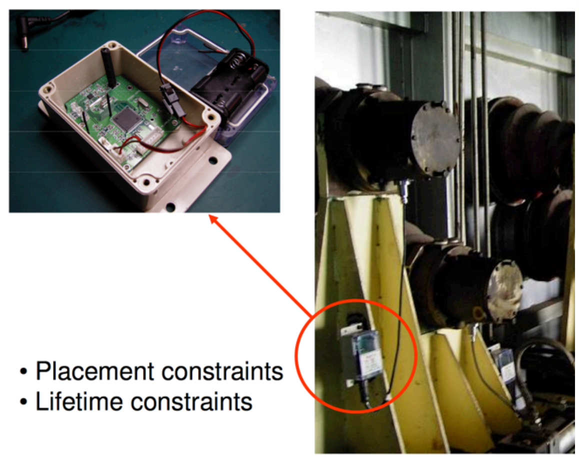
PEOPLES, INFRASTRUCTURES, BUILDINGS, VEHICULES



Academics vs Industries

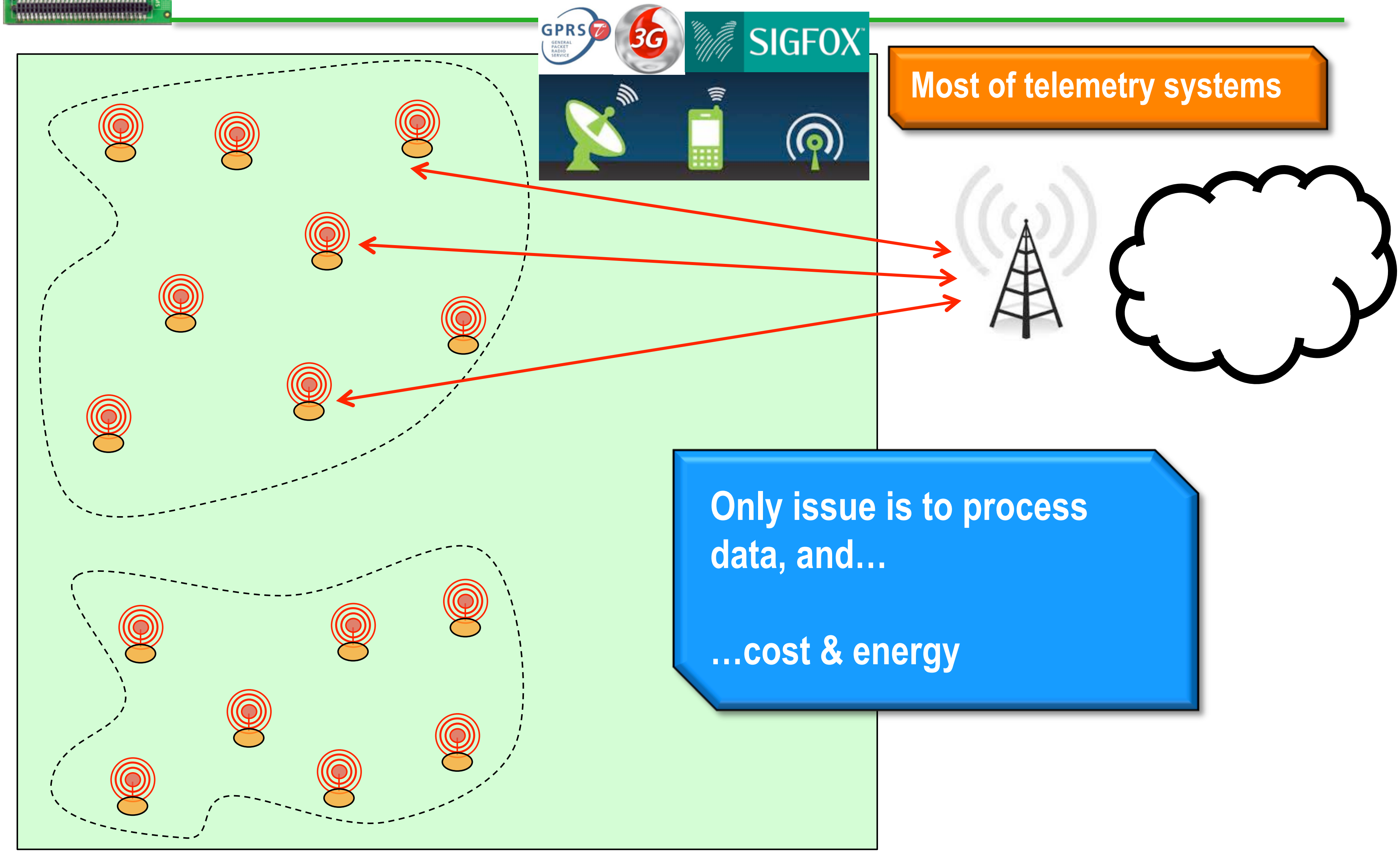
Millions of sensors, self-organizing, self-configuring, with QoS-based multi-path routing, mobility, and …

50 sensors, STATIC deployment, but need to have RELIABILITY, GUARANTEED LATENCY for monitoring and alerting. MUST run for 3 YEARS. No fancy stuff! CAN I HAVE IT?



From Peng Zeng & Qin Wang

1-HOP COMMUNICATION

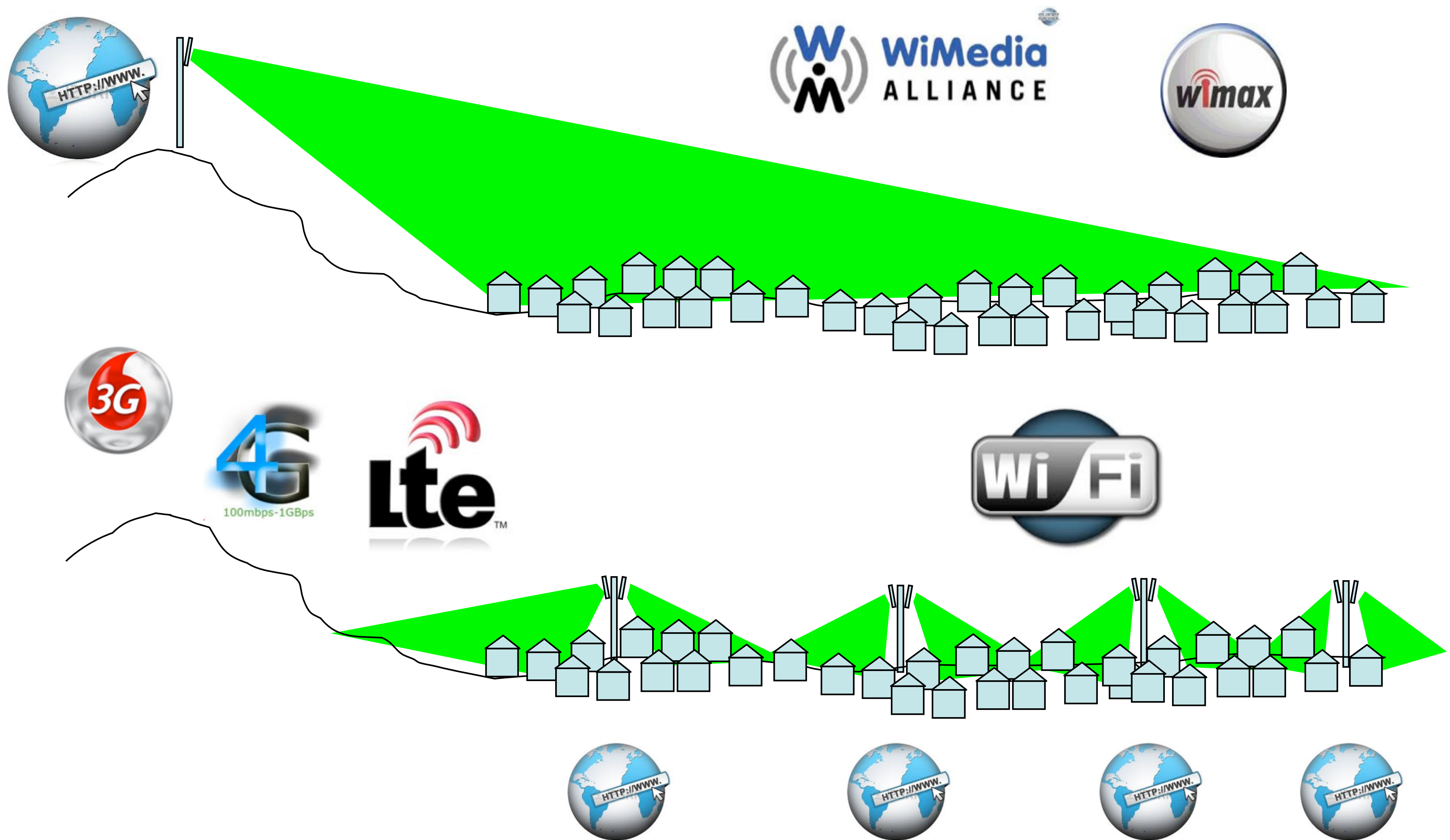


Most of telemetry systems

Only issue is to process data, and…

…cost & energy

Cellular model



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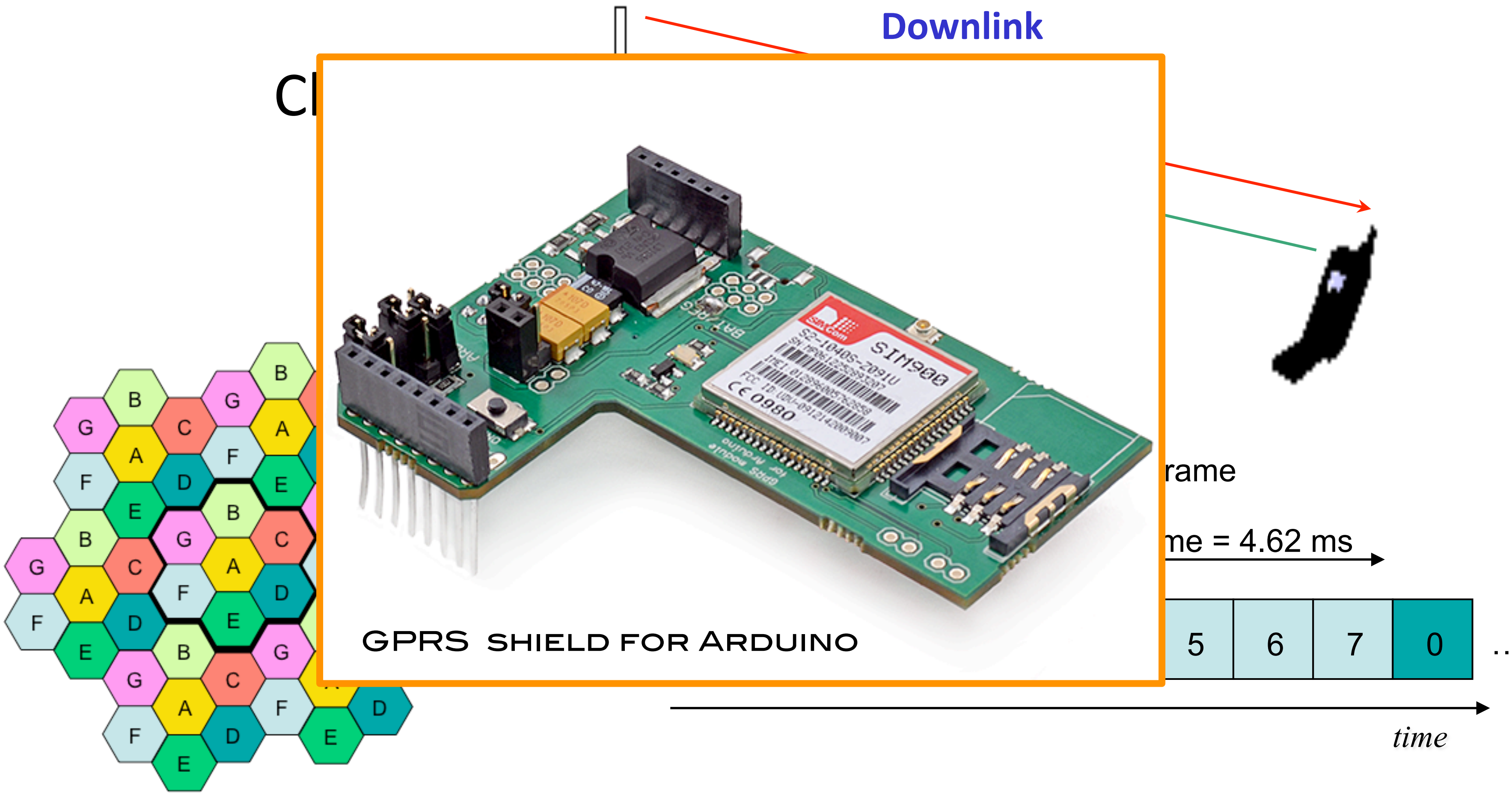
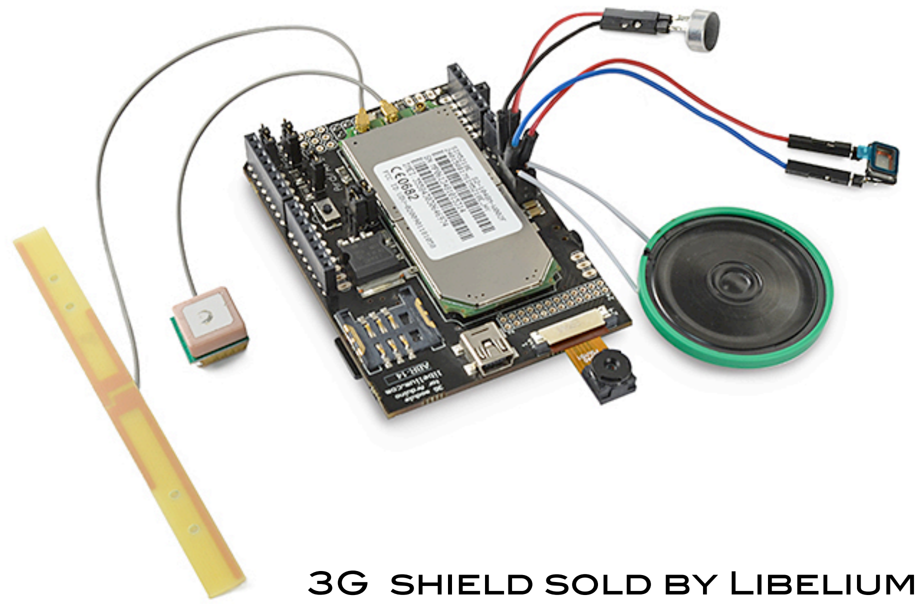
GSM (2G)/GPRS



GPRS shield for Arduino

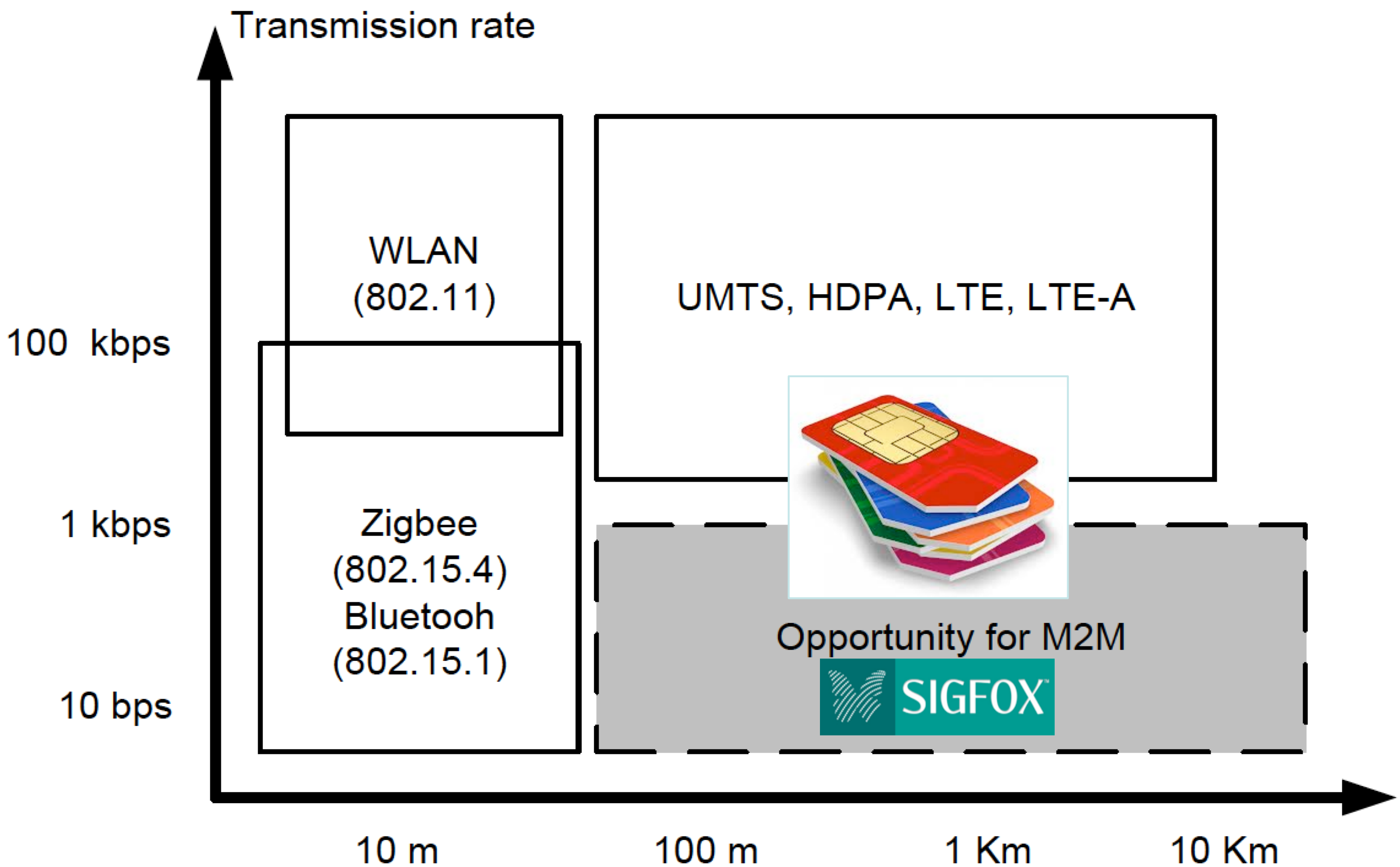
3G and Beyond

- 3G and beyond use CDMA techniques



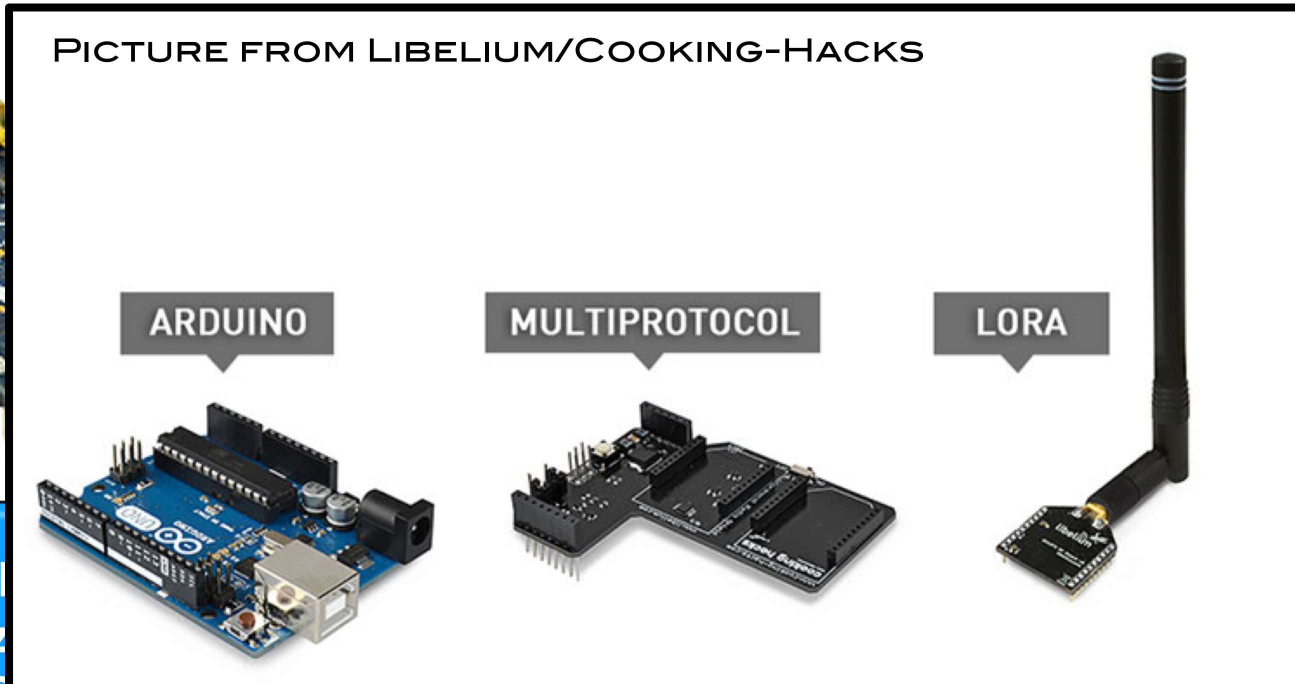
3G shield sold by Libelium

Opportunities for Telco operators & more...



Enhanced from M. Dohler "M2M in SmartCities"

Private long distance communications

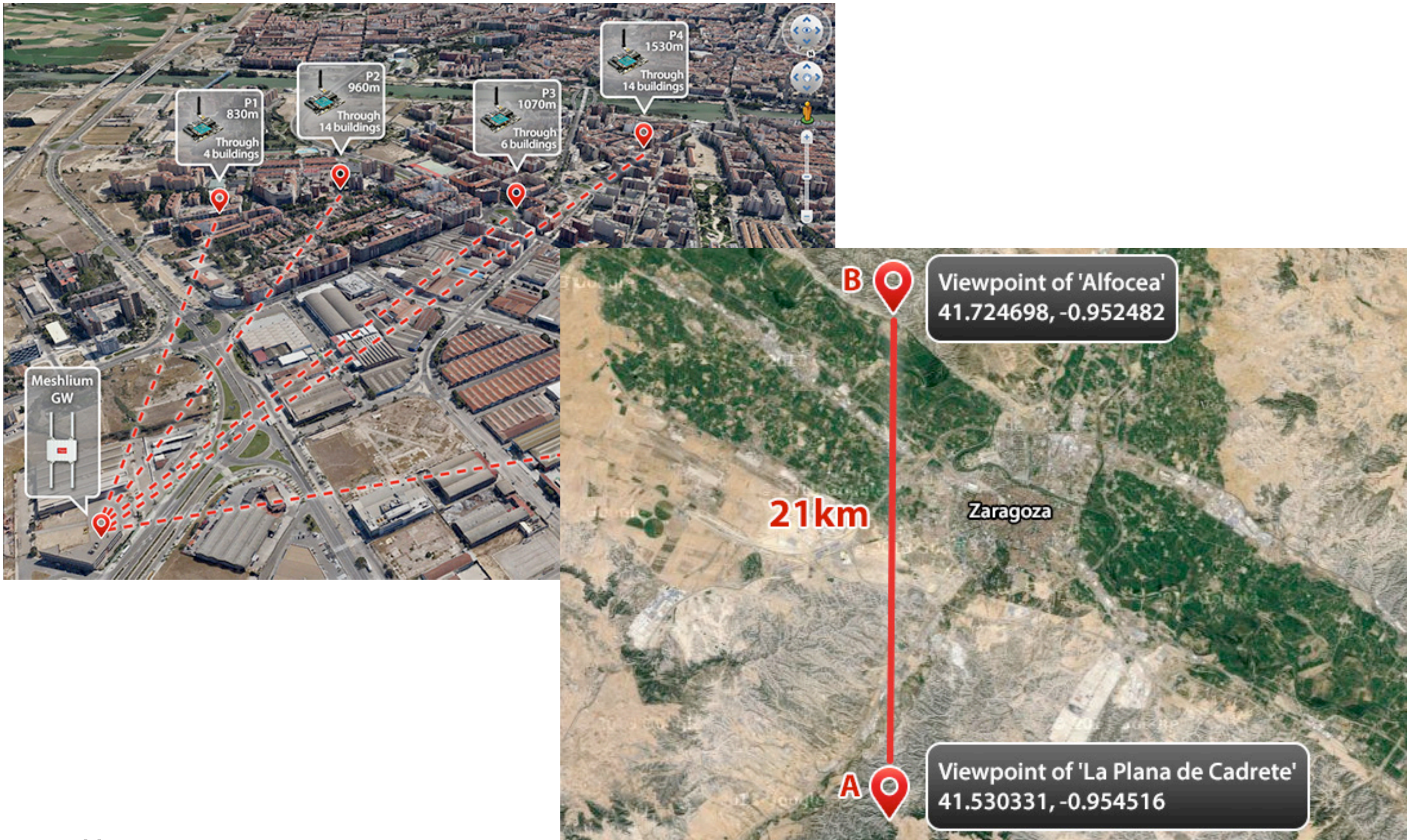


Picture from Libelium/Cooking-Hacks

XBEE—I
868 MHz
device G3 band for Europe
Outdoor RF line-of-sight
range up to 40 km
Data rate of 24 Kbps

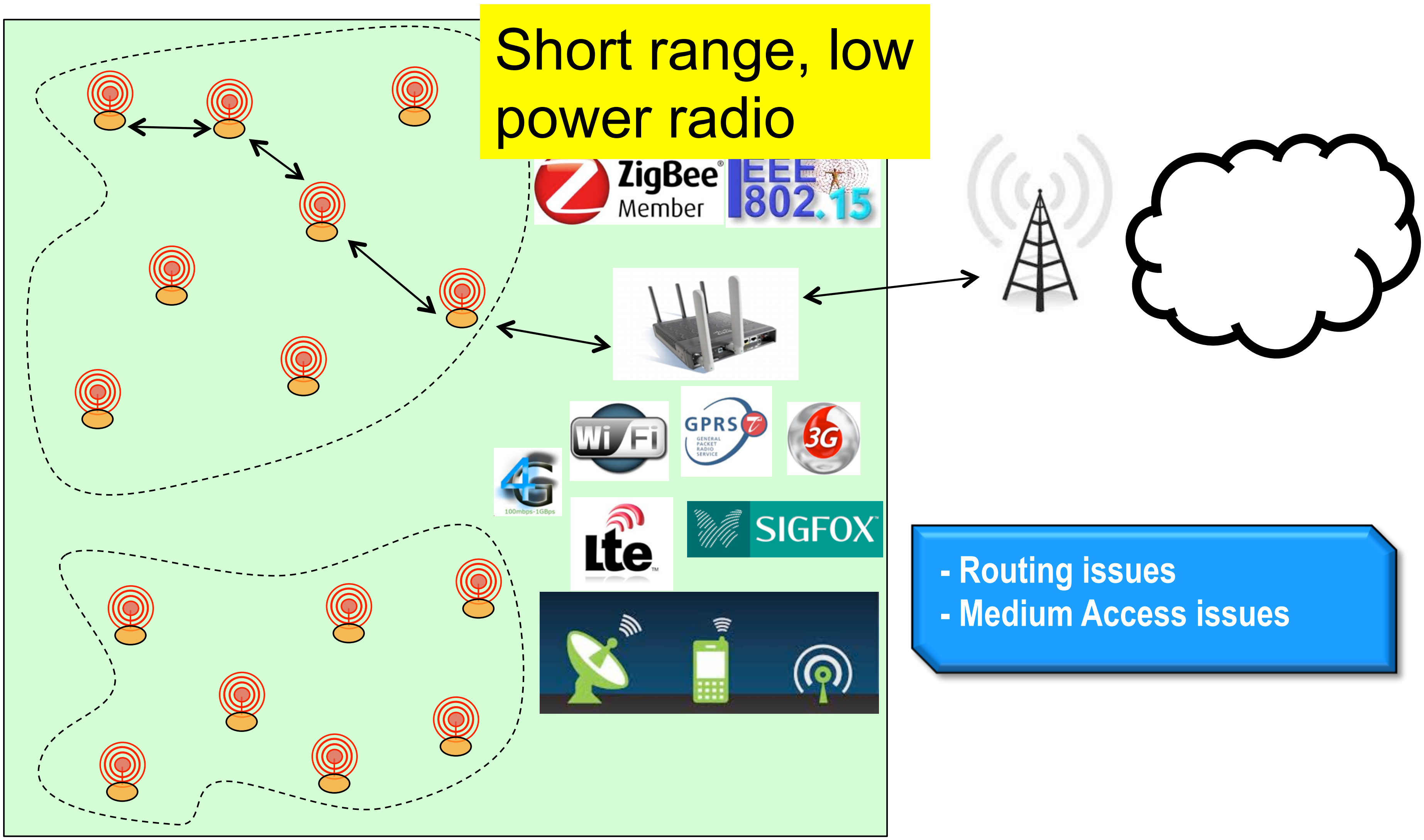
on
863-870 MHz for Europe
Outdoor RF line-of-sight
range up to 22 km in LOS
and 2km in NLOS
Data rate?

Tests from Libelium



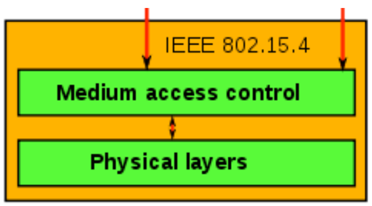
http://www.libelium.com

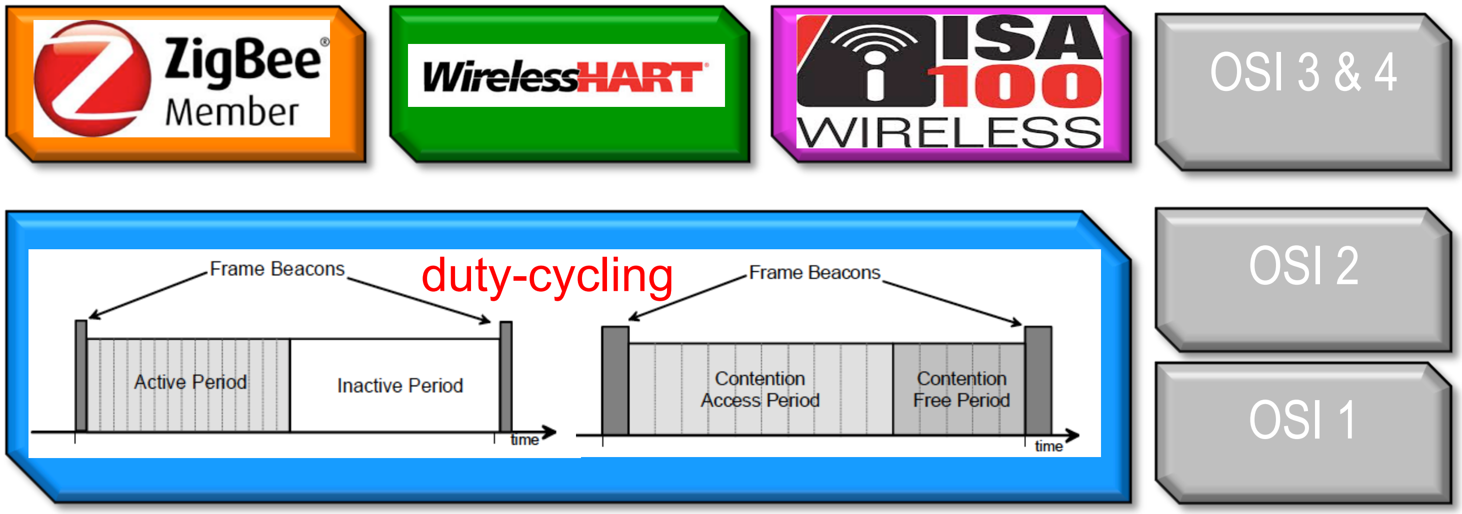
Multi-hop to gateways



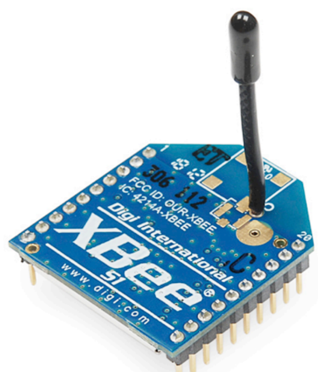
- Routing issues
- Medium Access issues

IEEE 802.15.4





CC2420 (TI)



XBee (Digi)

MRF24J40MA (Microchip)

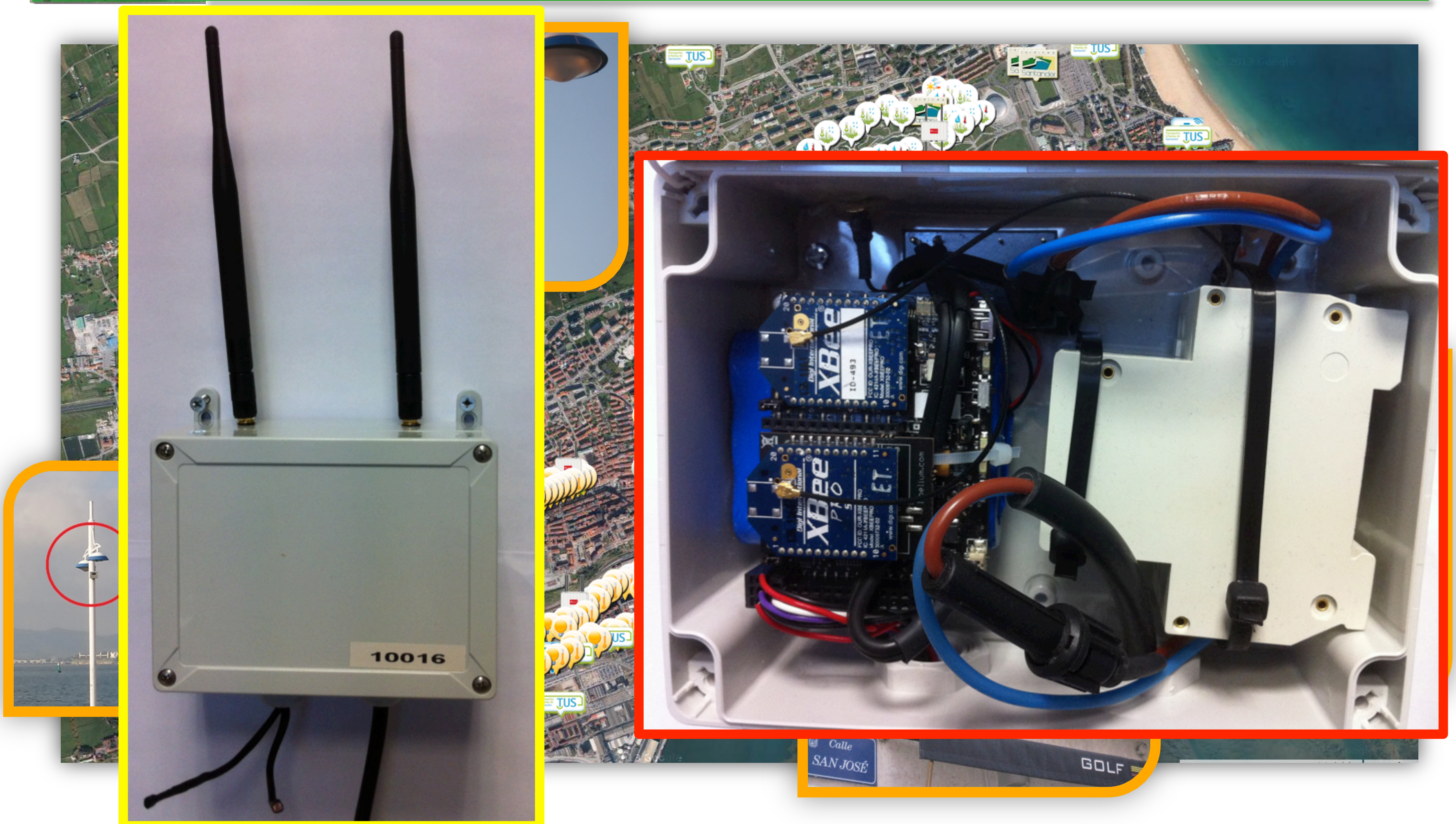
ZigBit AT86RF230 (Atmel)

SmartSantander testbed

www.smartsantander.eu

SmartSantander test-bed

Sensor motes / IoT node



Pictures are taken in the context of the EAR-IT project

SmartSantander test-bed

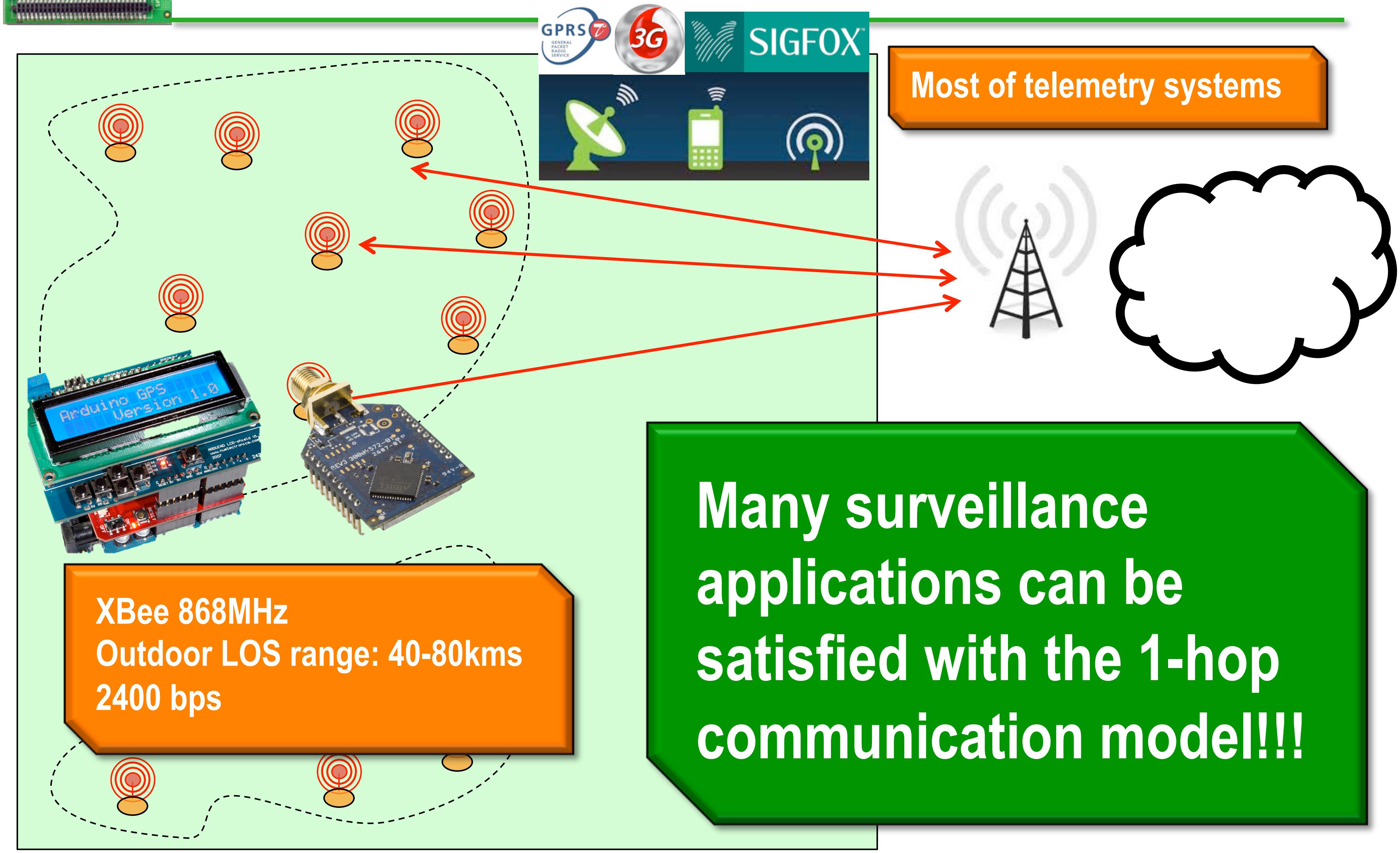
Gateways

Pictures are taken in the context of the EAR-IT project

Limit the number of hops to gateways

3 to 5 hops maximum

Do I need multi-hop for my app?



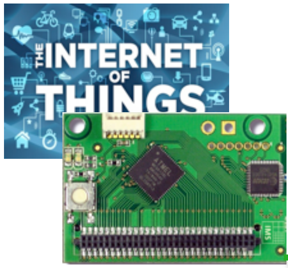
Most of telemetry systems

XBee 868MHz
Outdoor LOS range: 40-80kms
2400 bps

Many surveillance applications can be satisfied with the 1-hop communication model!!!

Multi-hop routing is still interesting!

- 1-hop model is not economically tractable in large scale deployment
- 1-hop model is usually not energy-efficient
- 1-hop model is hard to optimize in terms of radio access methods
- Routing in WSN is fundamentally different from routing in other type of networks, even other wireless networks



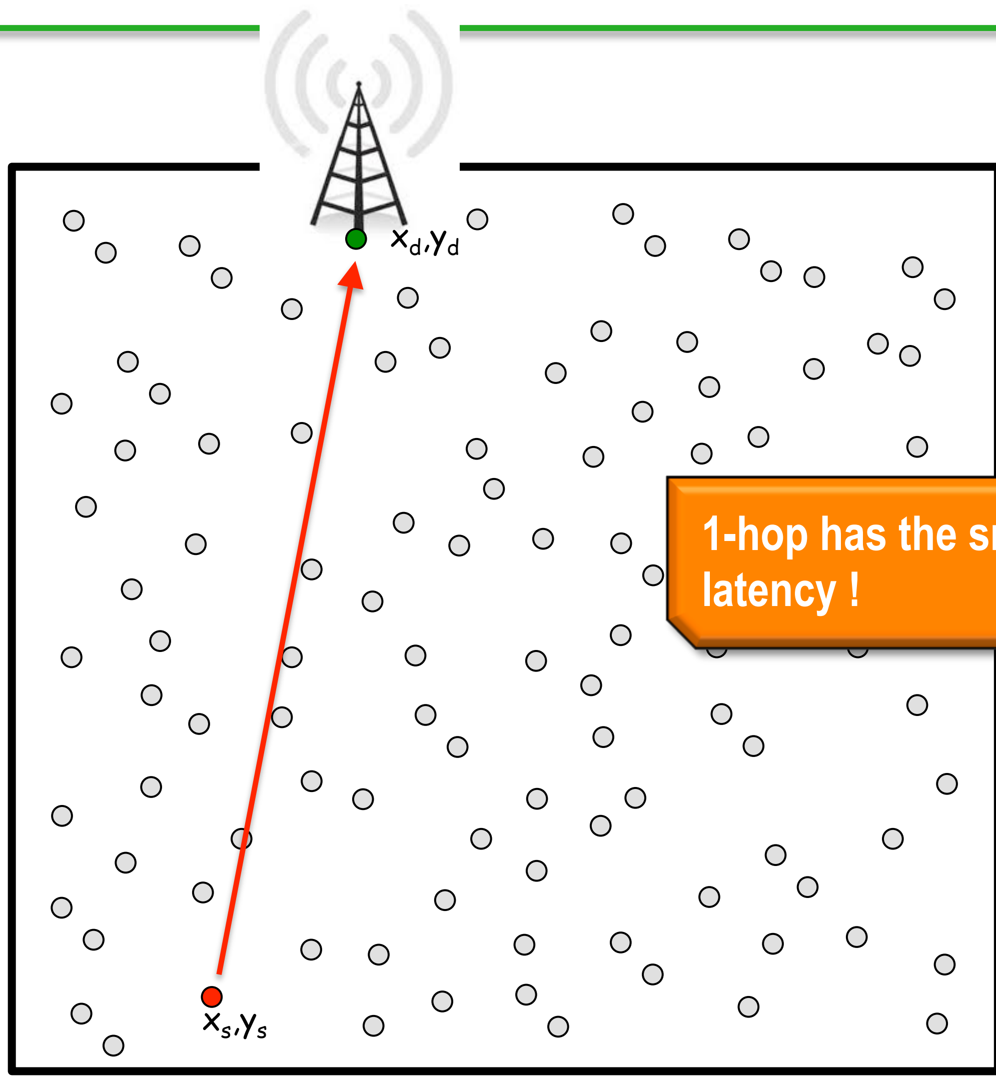
Why is it so different?

1. WSN/IoT are mainly deployed for surveillance →coverage & Latency is important

2. WSN/IoT are deployed to get data from remote areas or to react to events → mainly data-centric

3. WSN/IoT run on battery → energy saving is important, if not managed correcty, see item 1

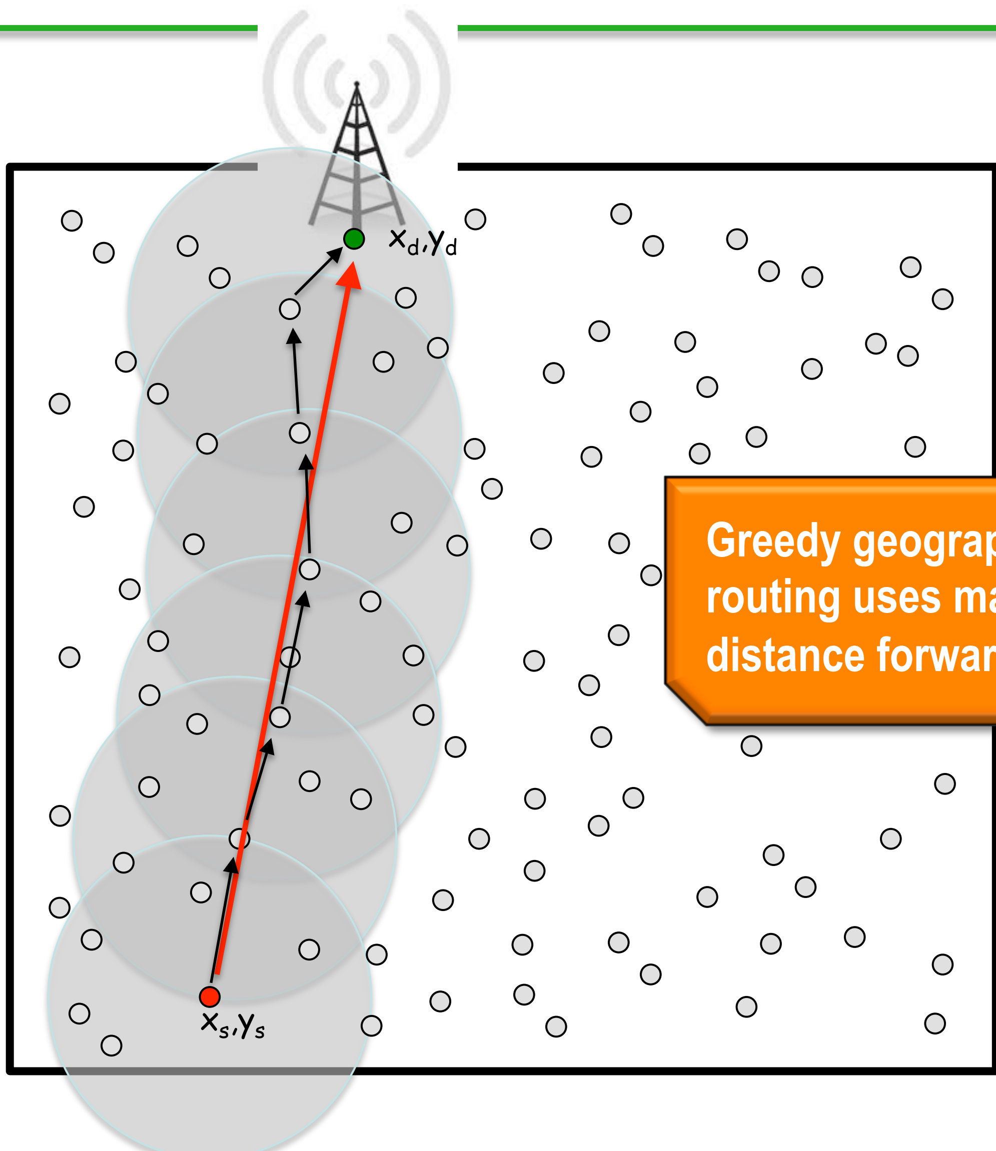
Energy vs Latency
1-hop



1-hop has the smallest latency !

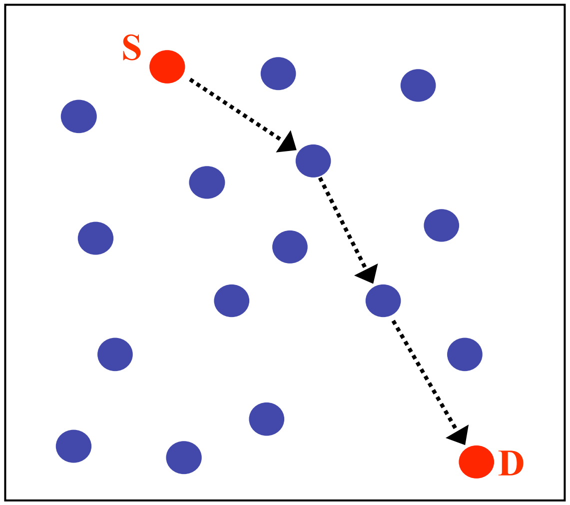
Energy vs Latency

Multi-hop - greedy

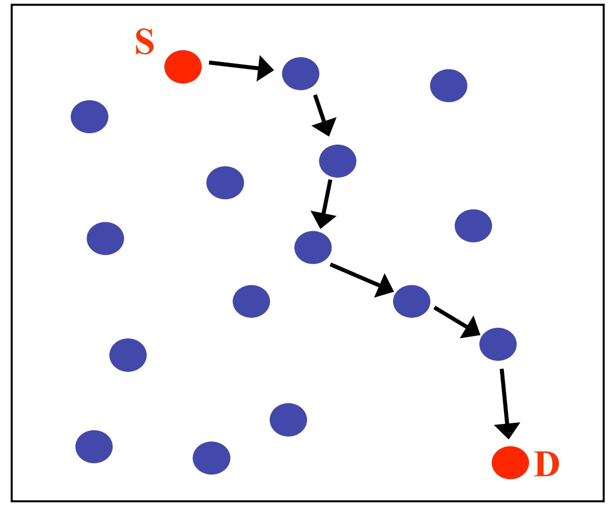


Greedy geographic routing uses maximum distance forwarding

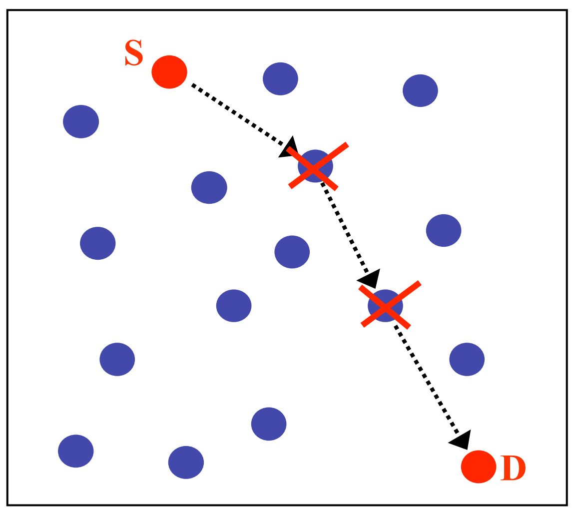
Is maximum distance always good?



Few long links with low quality



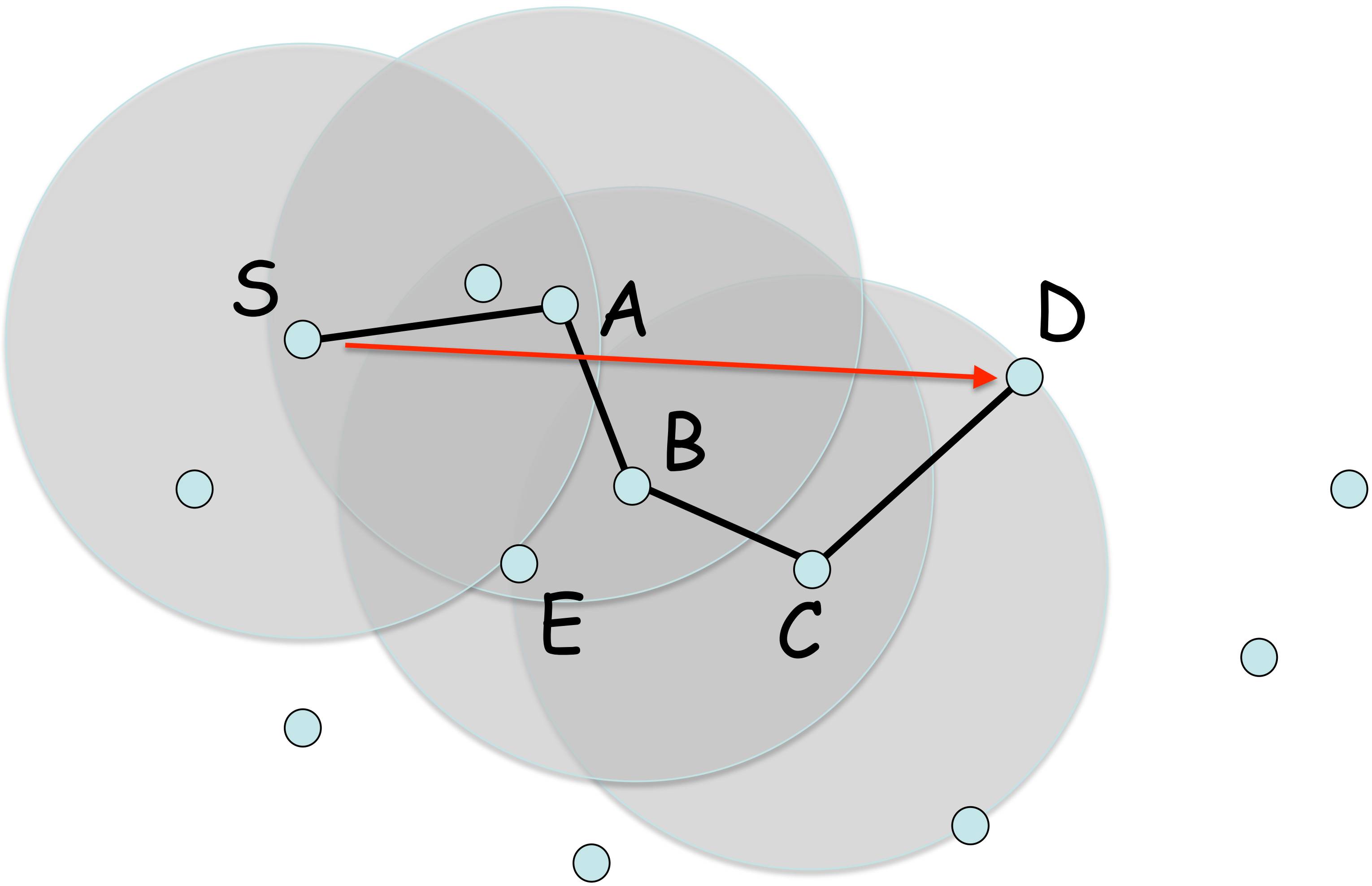
Many short links with high quality



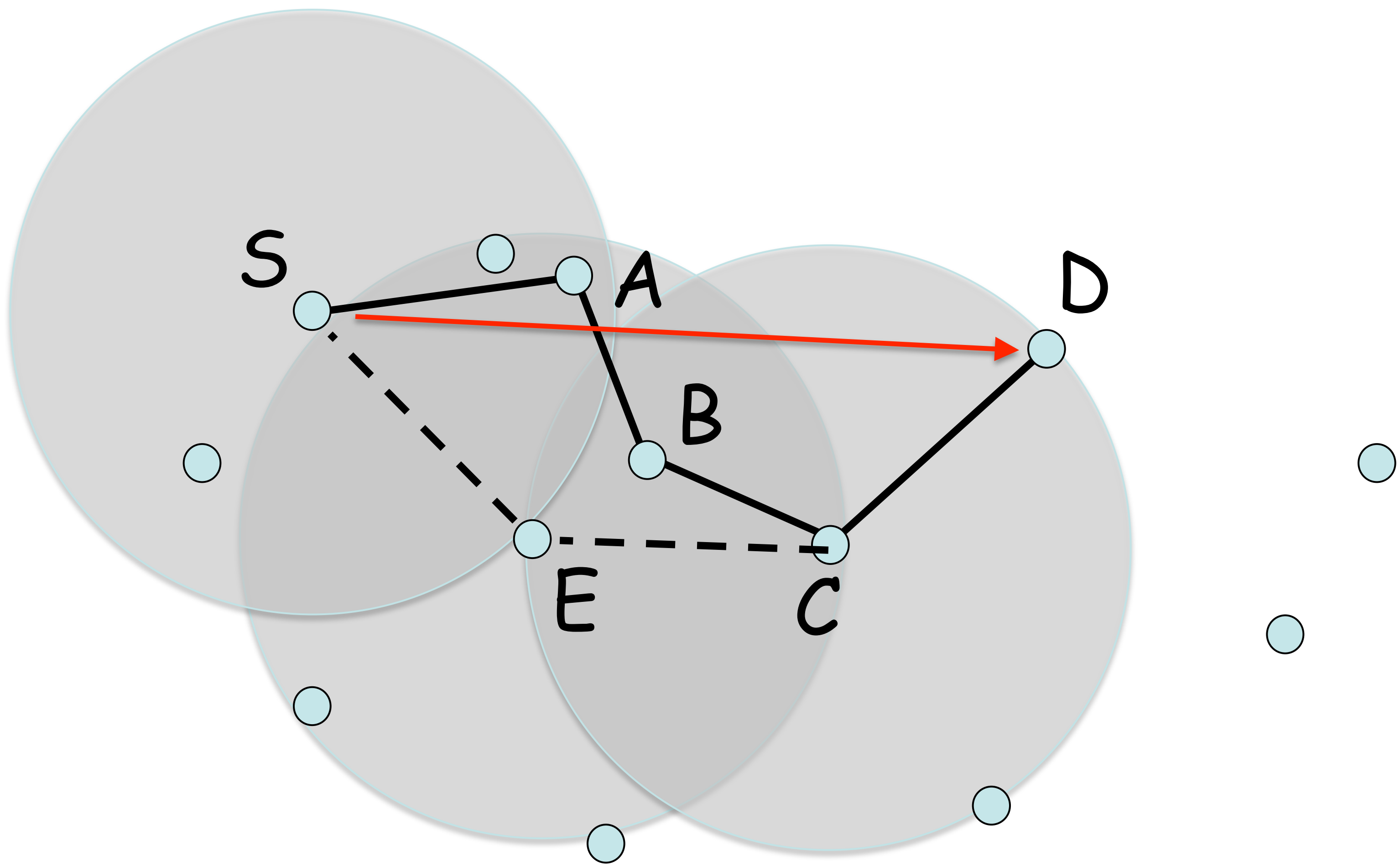
Intermediate nodes that are more sollicited die first

Adapted from Ahmed Helmy, “Robust Geographic Routing and Location-based Services”

Greedy=shortest path?



Greedy=shortest path?

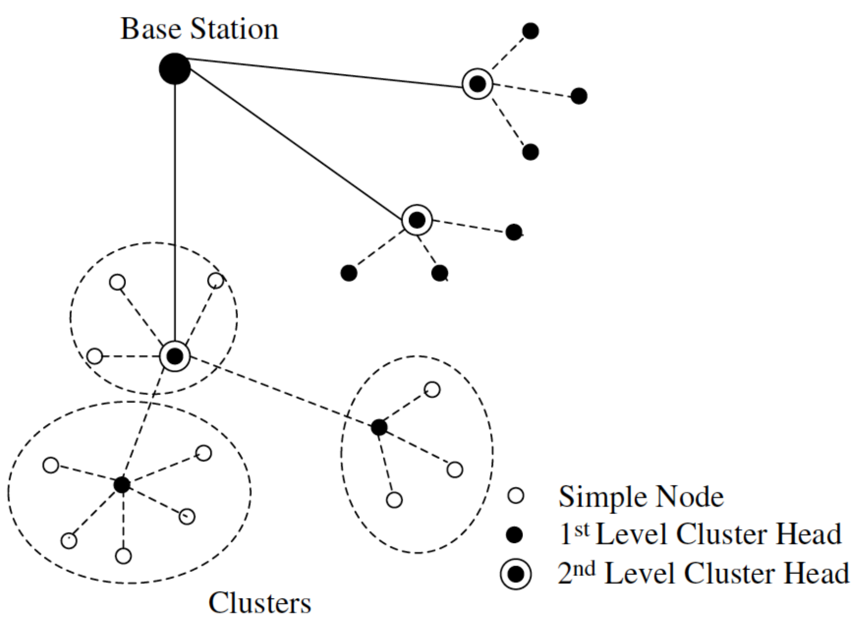


Organizing the Network

- The network is no longer useful when node's battery dies
- Organizing the network allows for spacing out the lifespan of the nodes
- Hierarchical routing protocols often give priority to energy
- Ex: Low-Energy Adaptive Clustering Hierarchy (LEACH)

Clustering

- A cluster-head collect data from their surrounding nodes and pass it on to the base station
- The job of cluster-head rotates



LEACH cluster-head

- Cluster-heads can be chosen *stochastically* (randomly based) on this algorithm:

$$T(n) = \frac{P}{1 - P \times (r \bmod P^{-1})} \qquad \forall n \in G$$

$$T(n) = 0 \qquad \forall n \notin G$$

Where n is a random number between 0 and 1
P is the cluster-head probability and
G is the set of nodes that weren't cluster-heads the previous rounds

- If n < T(n), then that node becomes a cluster-head
- The algorithm is designed so that each node becomes a cluster-head at least once

W.B. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, Application specific protocol architecture for wireless microsensor networks, IEEE Transactions on Wireless Networking (2002).

Example

```
p=0.05,
draw N a random number [0,1[ at each
round

N < 0.0500 = 0.05/(1-0.05*0) ?
N < 0.0526 = 0.05/(1-0.05*1) ?
N < 0.0555 = 0.05/(1-0.05*2) ?
N < 0.0588 = 0.05/(1-0.05*3) ?
N < 0.0625 = 0.05/(1-0.05*4) ?
N < 0.0666 = 0.05/(1-0.05*5) ?
N < 0.0714 = 0.05/(1-0.05*6) ?
N < 0.0769 = 0.05/(1-0.05*7) ?
N < 0.0833 = 0.05/(1-0.05*8) ?
N < 0.0909 = 0.05/(1-0.05*9) ?
N < 0.1000 = 0.05/(1-0.05*10) ?

N < 0.5000 = 0.05/(1-0.05*18) ?
N < 1.0000 = 0.05/(1-0.05*19) ?
```

- Number of clusters may not fixed in any round.

$$T(n) = \begin{cases} \dfrac{P}{1 - P[r \bmod (1/P)]} & \text{if } n \in G, \\ 0 & \text{otherwise,} \end{cases}$$

Optimize selection

- A modified version of this protocol is known as LEACH-C (or LEACH Centralized)
- This version has a *deterministic* threshold algorithm, which takes into account the amount of energy in the node

$$T(n)_{new} = \frac{P}{1 - P \times (r \bmod P^{-1})} \frac{E_{n\_current}}{E_{n\_max}}$$

Where $E_{n\_current}$ is the current amount of energy and
E_{n_max} is the initial amount of energy

IoT: « I » for Internet

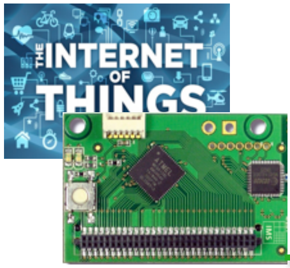
From ad-hoc to standardized protocols

Don't reinvent the wheel!

RFC 768	UDP - User Datagram Protocol	[1980]
RFC 791	IPv4 – Internet Protocol	[1981]
RFC 792	ICMPv4 – Internet Control Message Protocol	[1981]
RFC 793	TCP – Transmission Control Protocol	[1981]
RFC 862	Echo Protocol	[1983]
RFC 1101	DNS Encoding of Network Names and Other Types	[1989]
RFC 1191	IPv4 Path MTU Discovery	[1990]
RFC 1981	IPv6 Path MTU Discovery	[1996]
RFC 2131	DHCPv4 - Dynamic Host Configuration Protocol	[1997]
RFC 2375	IPv6 Multicast Address Assignments	[1998]
RFC 2460	IPv6	[1998]
RFC 2765	Stateless IP/ICMP Translation Algorithm (SIIT)	[2000]
RFC 3068	An Anycast Prefix for 6to4 Relay Routers	[2001]
RFC 3307	Allocation Guidelines for IPv6 Multicast Addresses	[2002]
RFC 3315	DHCPv6 - Dynamic Host Configuration Protocol for IPv6	[2003]
RFC 3484	Default Address Selection for IPv6	[2003]
RFC 3587	IPv6 Global Unicast Address Format	[2003]
RFC 3819	Advice for Internet Subnetwork Designers	[2004]
RFC 4007	IPv6 Scoped Address Architecture	[2005]
RFC 4193	Unique Local IPv6 Unicast Addresses	[2005]
RFC 4291	IPv6 Addressing Architecture	[2006]
RFC 4443	ICMPv6 - Internet Control Message Protocol for IPv6	[2006]
RFC 4861	Neighbor Discovery for IP version 6	[2007]
RFC 4944	Transmission of IPv6 Packets over IEEE 802.15.4 Networks	[2007]

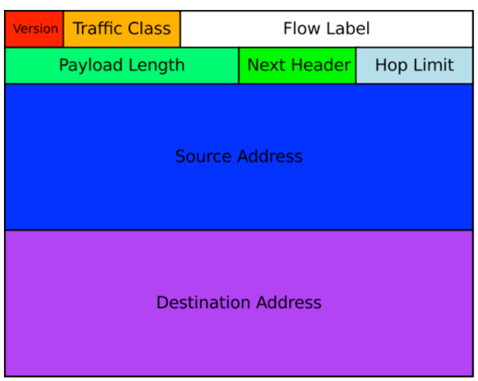
RFC6282 Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks [2011]

From ArchRock "6LowPan tutorial"

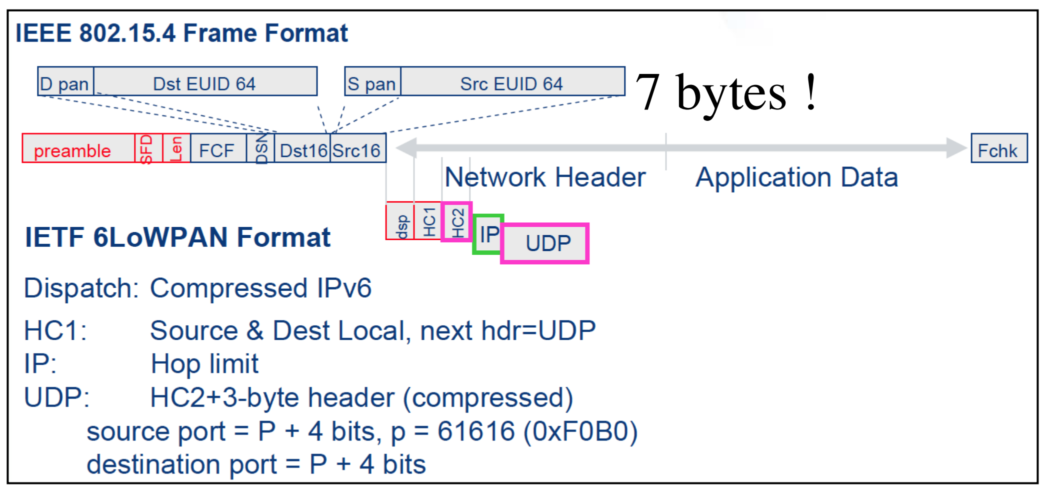


IP need IP addresses!

- IPv4 has no more addresses!
- IPv6 gives plenty of addresses
  - 128bit address=16bytes!
- 6LowPan adapts IPv6 to resource-constrained devices
  - Compressed IPv6 header



40 bytes



From ArchRock "6LowPan tutorial"

IPv4 vs. IPv6 Addressing

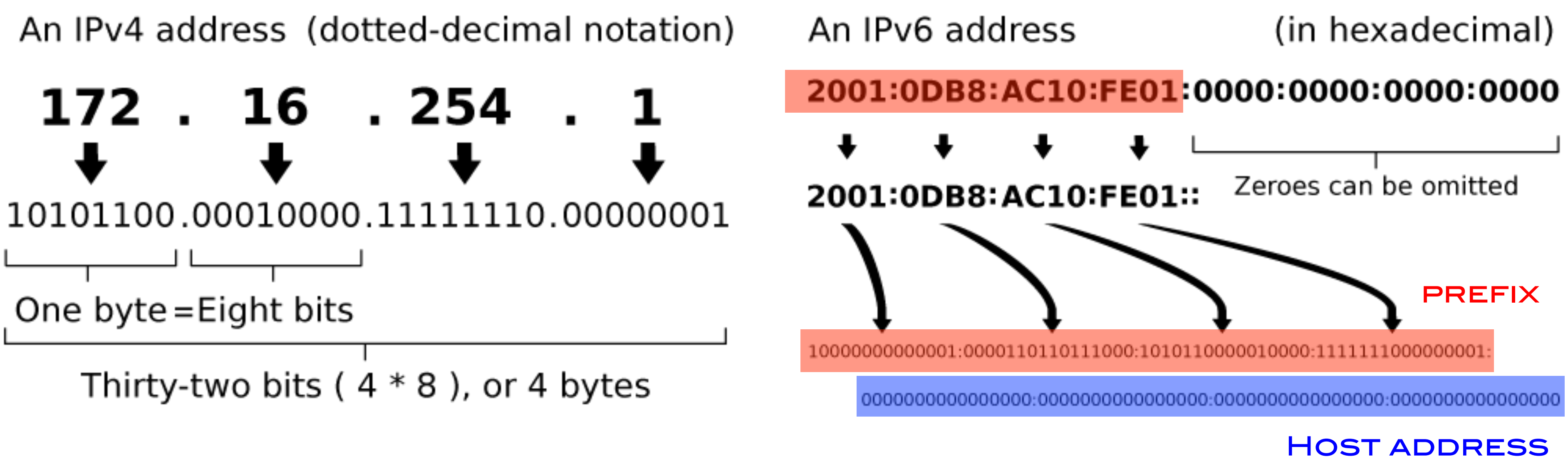


Image source: Indeterminant (Wikipeida) GFDL

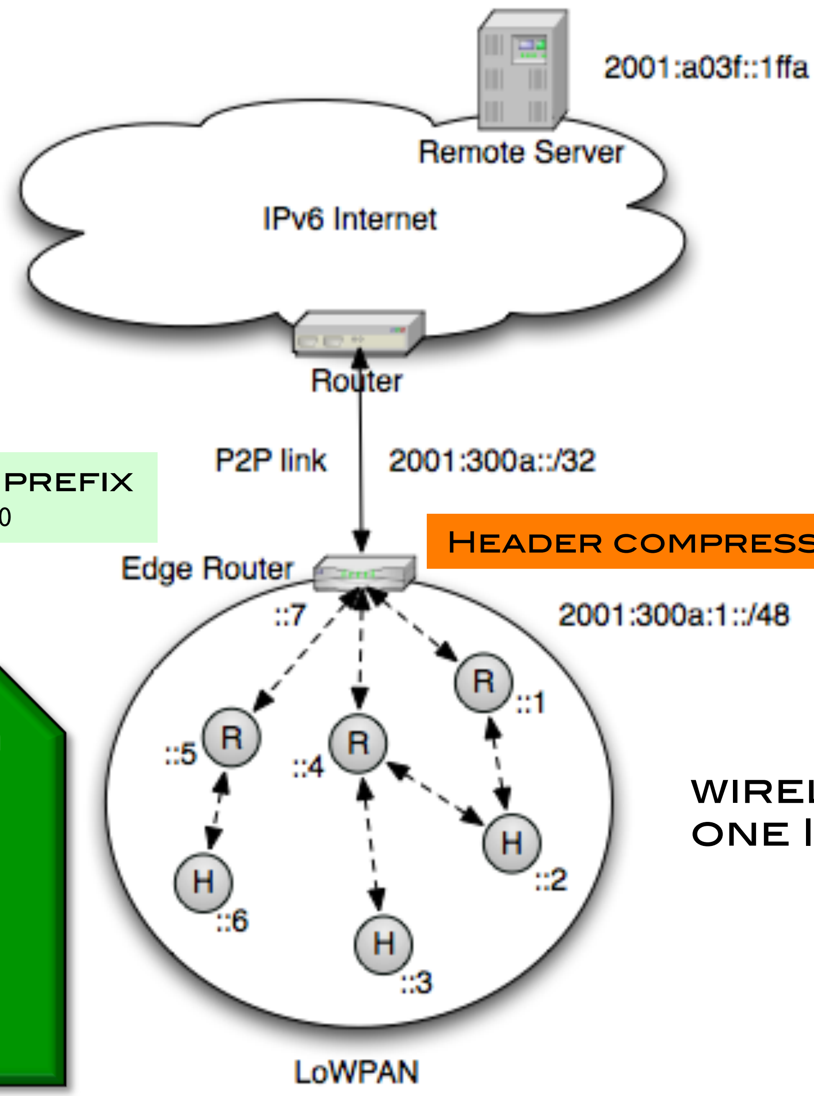
From "6LoWPAN: The Wireless Embedded Internet, Shelby & Bormann"

6LoWPAN Addressing

- IPv6 addresses are compressed in 6LoWPAN
- A LoWPAN works on the principle of
  - flat address spaces (wireless network is one IPv6 subnet)
  - with unique MAC addresses (e.g. 64-bit or 16-bit: 0x0013A20040568B34 or 0x0220)
- 6LoWPAN compresses IPv6 addresses by
  - Eliding the IPv6 prefix
    - Global prefix known by all nodes in network
    - Link-local prefix indicated by header compression format
  - Compressing the Interface ID
    - Elided for link-local communication
    - Compressed for multihop dst/src addresses
  - Compressing with a well-known "context"
  - Multicast addresses are compressed

From "6LoWPAN: The Wireless Embedded Internet, Shelby & Bormann"

Addressing Example



Advertise prefix
2001:300a:1:0

Header compression

Build an IPv6 address with prefix and a combination of 802.15.4:
- PANID
- 16-bit address

or
- 64-bit address

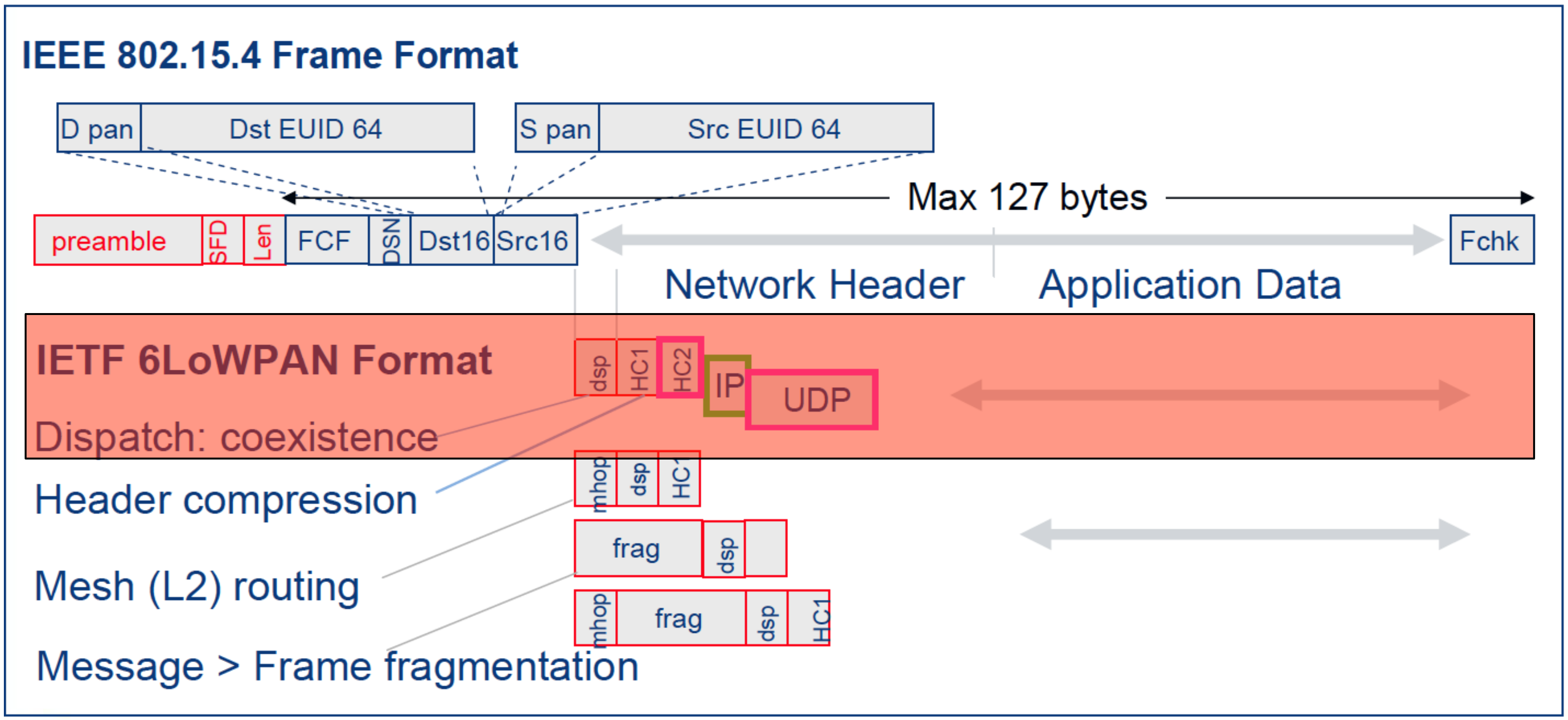
Wireless network is one IPv6 subnet

Based from "6LoWPAN: The Wireless Embedded Internet, Shelby & Bormann"

Use RFC4944 compression scheme for simplicity. New scheme should follow RFC6282

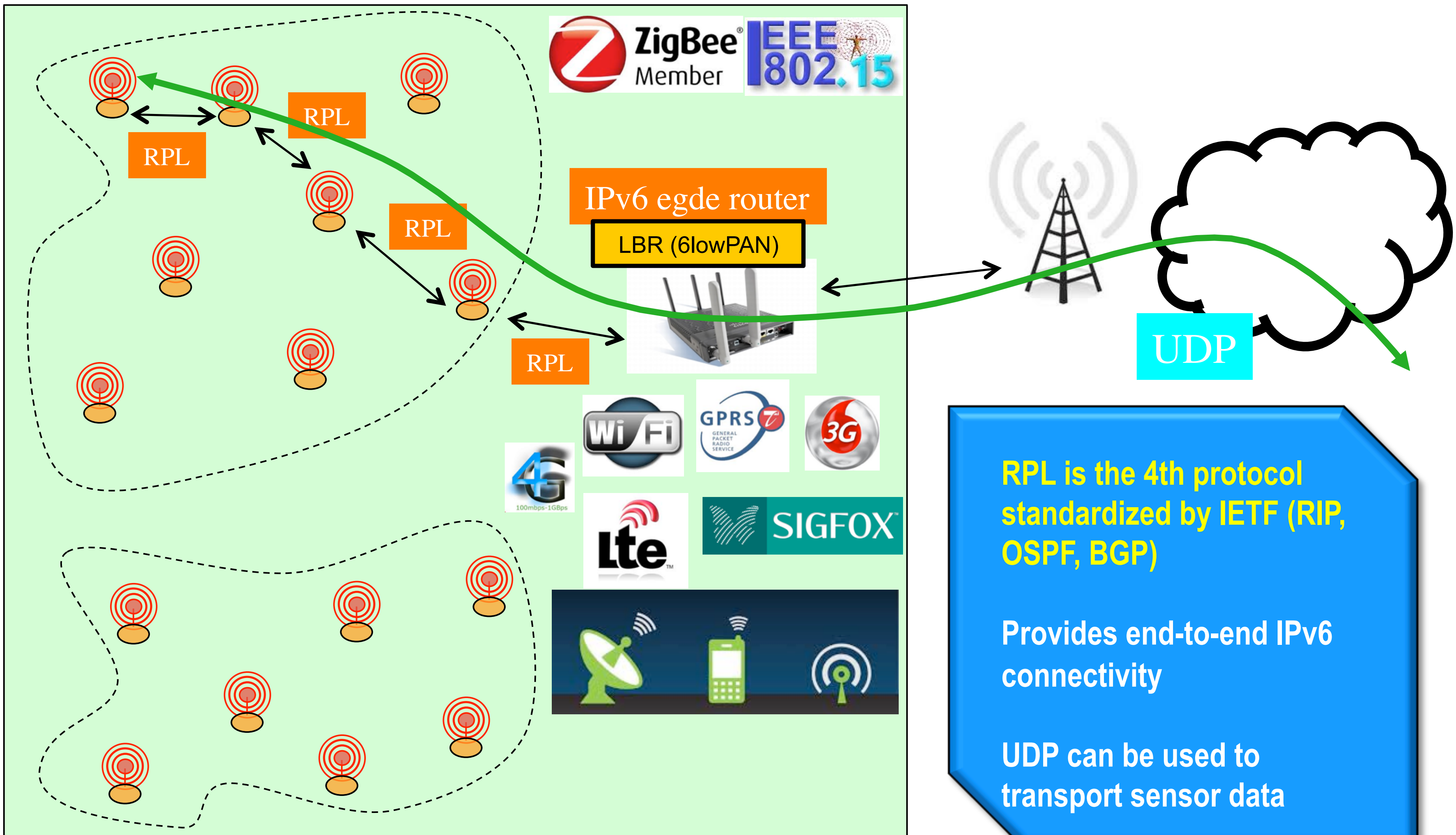
6LoWPAN Format Design

- Orthogonal stackable header format
- Almost no overhead for the ability to interoperate and scale.
- Pay for only what you use



From ArchRock "6LowPan tutorial"

Routing over Low Power & Lossy Networks (RPL)



RPL is the 4th protocol standardized by IETF (RIP, OSPF, BGP)

Provides end-to-end IPv6 connectivity

UDP can be used to transport sensor data

RPL (ripple)
Routing Protocol for Low Power and Lossy Networks

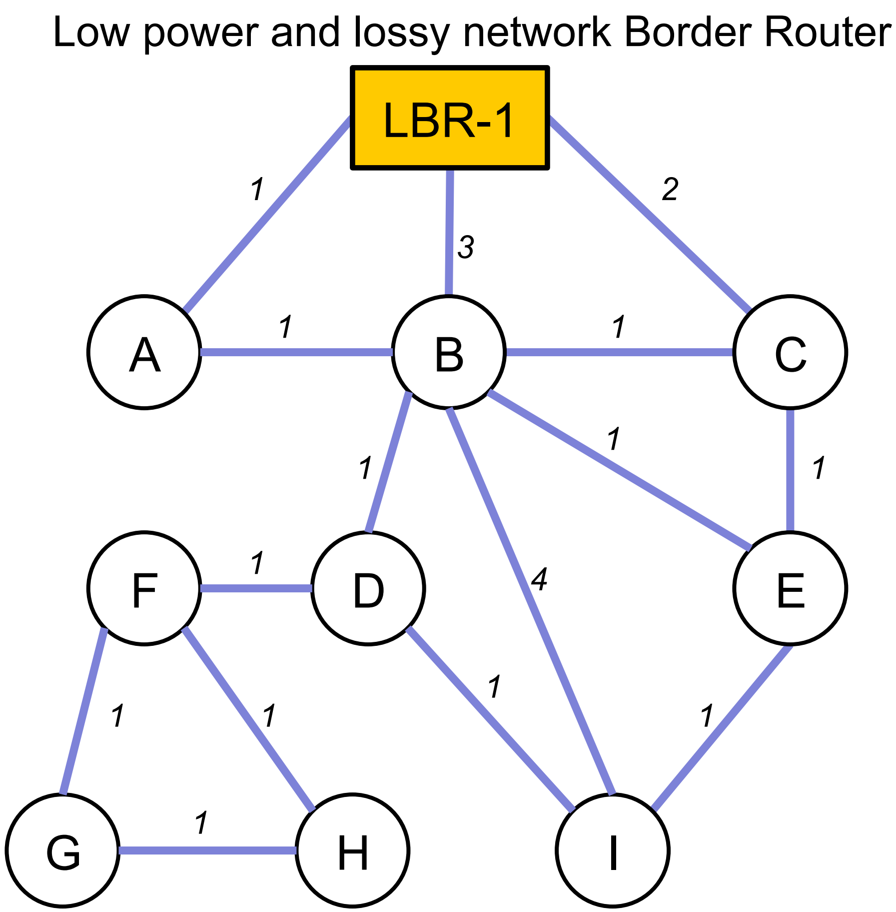
Walkthrough

draft-dt-roll-rpl-01.txt

Anders Brandt
Thomas Heide Clausen
Stephen Dawson-Haggerty
Jonathan W. Hui
Kris Pister
Pascal Thubert
Tim Winter

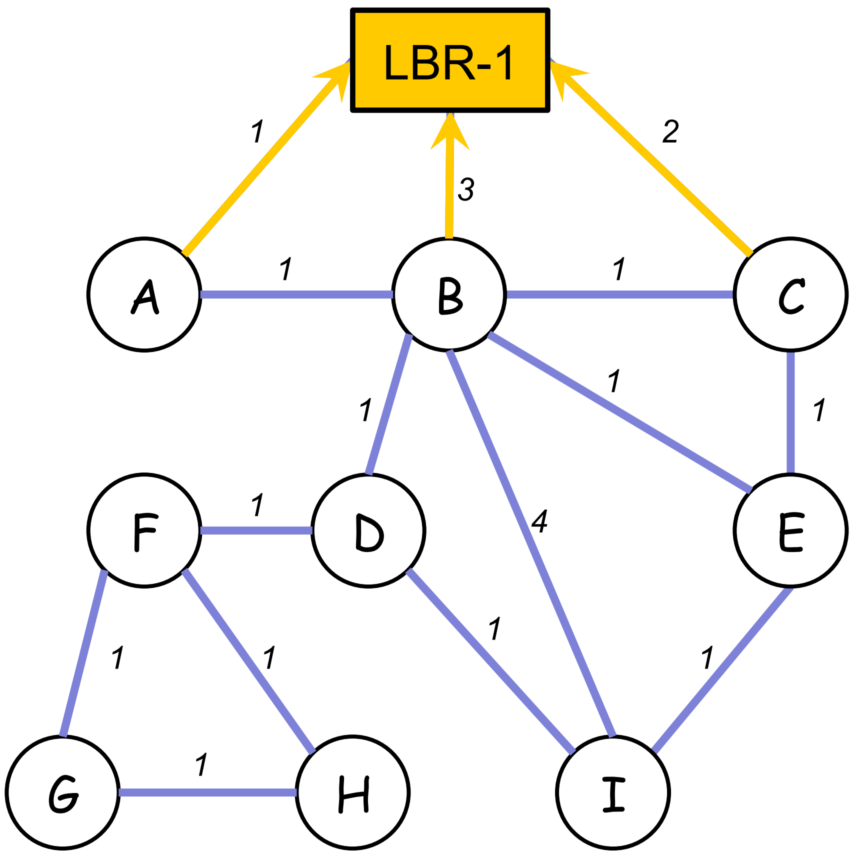
IETF 75 – Roll WG – July 2009

DAG Construction



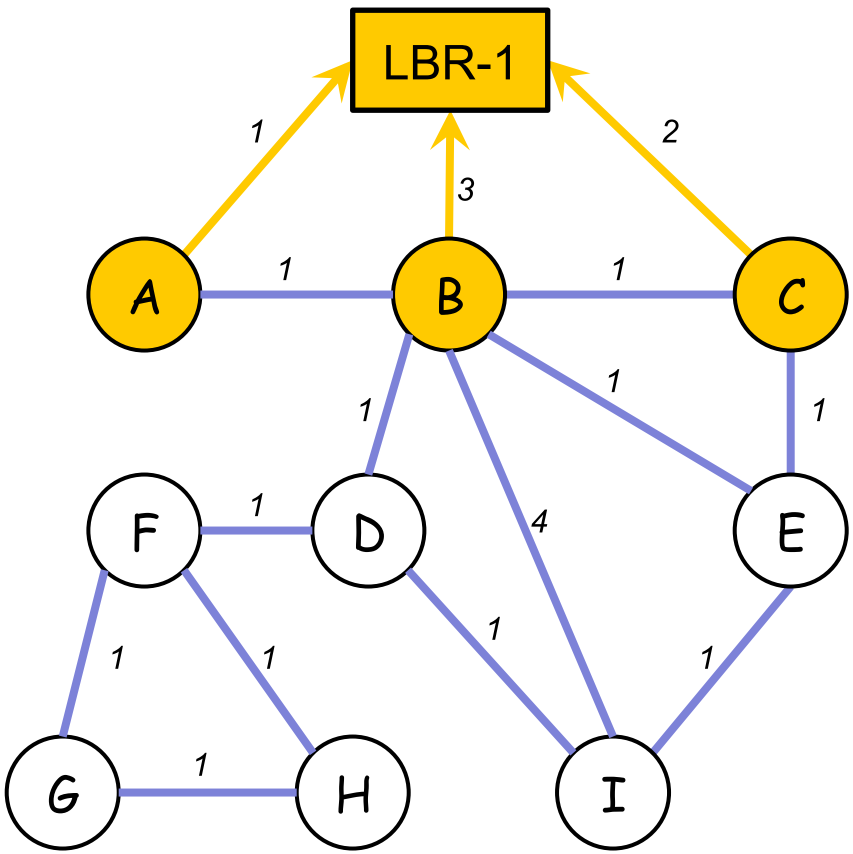
- LLN links are depicted
- LBR form a Destination Object DAG (DODAG)
- Links are annotated w/ ETX (Expected Transmission Count)
- It is expected that ETX variations will be averaged/filtered as per [ROLL-METRICS] to be stable enough for route computation

DAG Construction



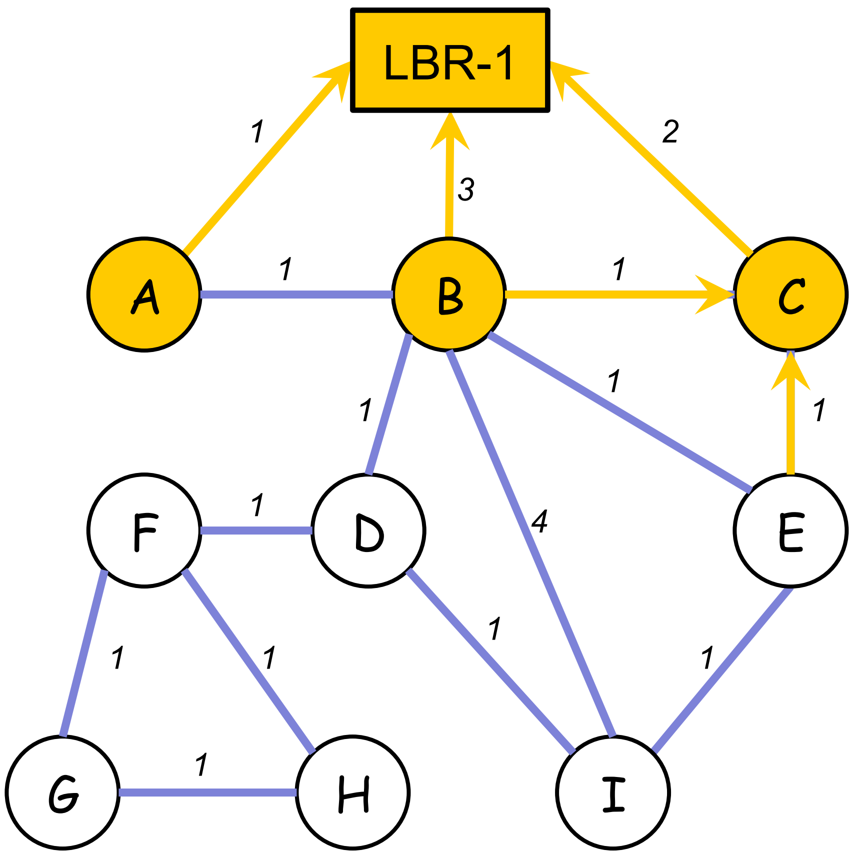
- LBR-1 multicasts RA-DIO (Router Advertisement DODAG Information Object)
- Nodes A, B, C receive and process RA-DIO
- Nodes A, B, C consider link metrics to LBR-1 and the optimization objective
- The optimization objective can be satisfied by joining the DAG rooted at LBR-1
- Nodes A, B, C add LBR-1 as a DAG parent and join the DAG

DAG Construction



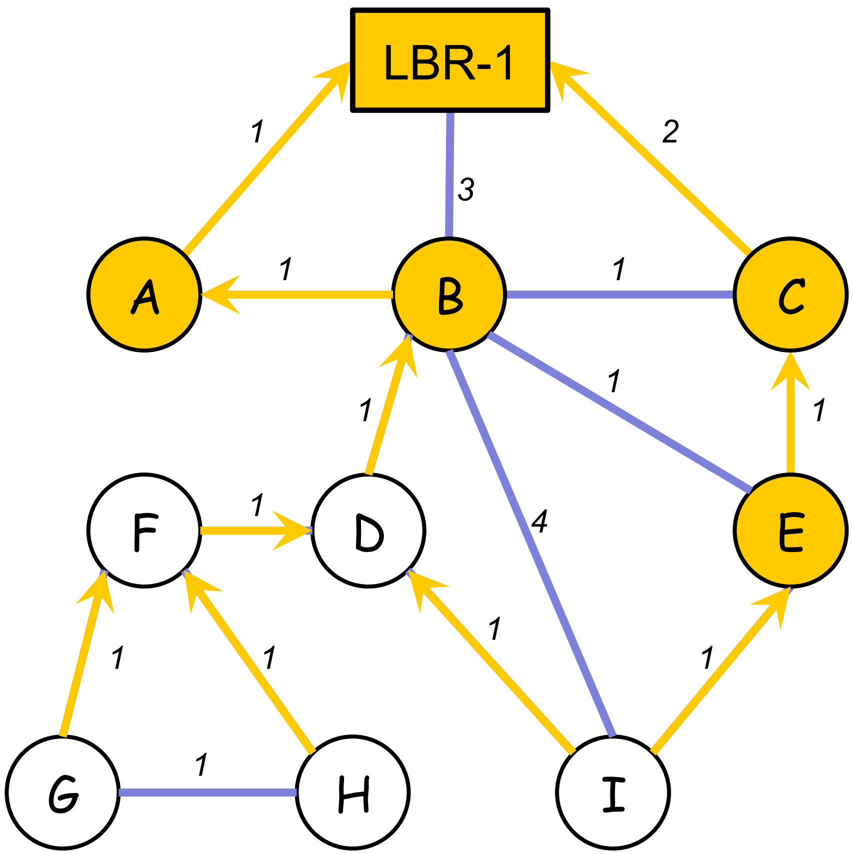
- Node A is at Depth 1 in the DAG, as calculated by the routine indicated by the example OCP (Depth ~ ETX)
- Node B is at Depth 3, Node C is at Depth 2
- Nodes A, B, C have installed default routes (::/0) with LBR-1 as successor

DAG Construction

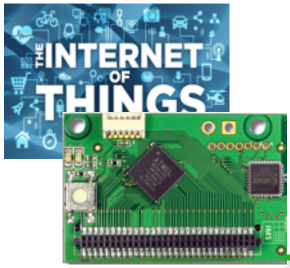


- The RA timer on Node C expires
- Node C multicasts RA-DIO
- LBR-1 ignores RA-DIO from deeper node
- Node B can add Node C as *alternate* DAG Parent, remaining at Depth 3
- Node E joins the DAG at Depth 3 by adding Node C as DAG Parent

DAG Construction



- DAG Construction continues…
- And is continuously maintained



Internet for things

UDP, TCP?

RPL
Routing Protocol for Low power & Lossy Networks

6LowPan
802.15.4

IPv6 egde router

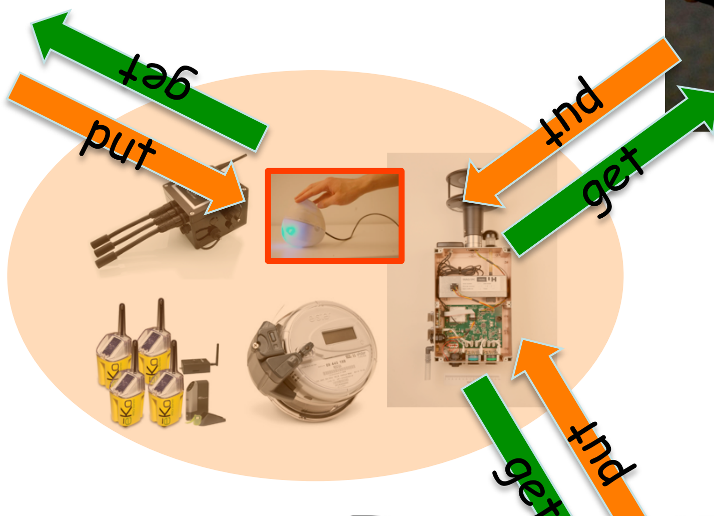
LBR (6lowPAN)

TCP, UDP

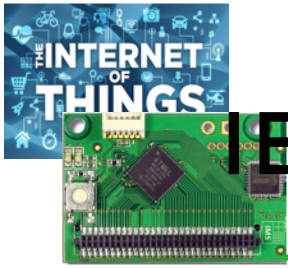
Internet Routing Protocols: RIP, OSPF, BGP,…

IPv4, IPv6

IoT for human



Internet of Things for you & me



IETF Internet for things

CoAP: Constrained Application Protocol

UDP, TCP?

RPL
Routing Protocol for Low power & Lossy Networks

6LowPan
802.15.4

CoAP HTTP

TCP, UDP

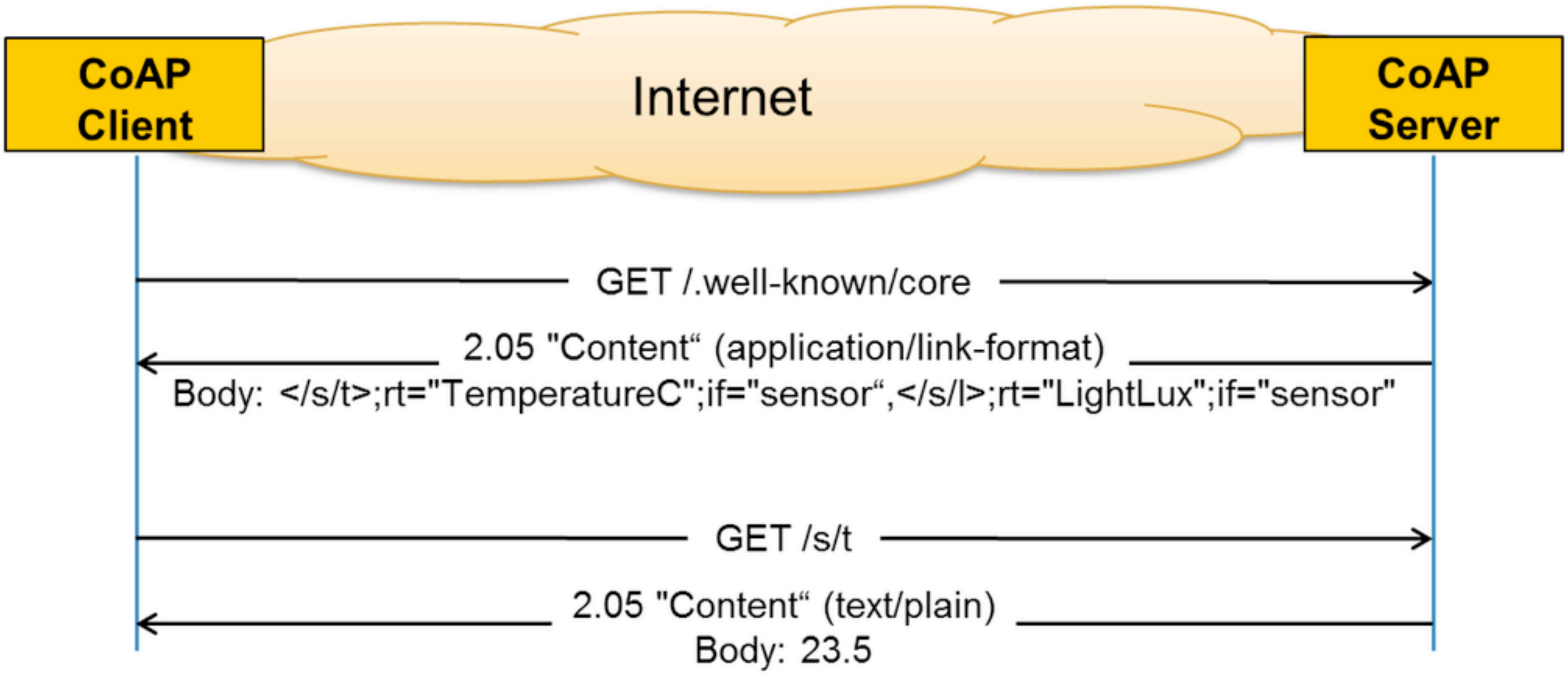
Internet Routing Protocols: RIP, OSPF, BGP,…

IPv4, IPv6

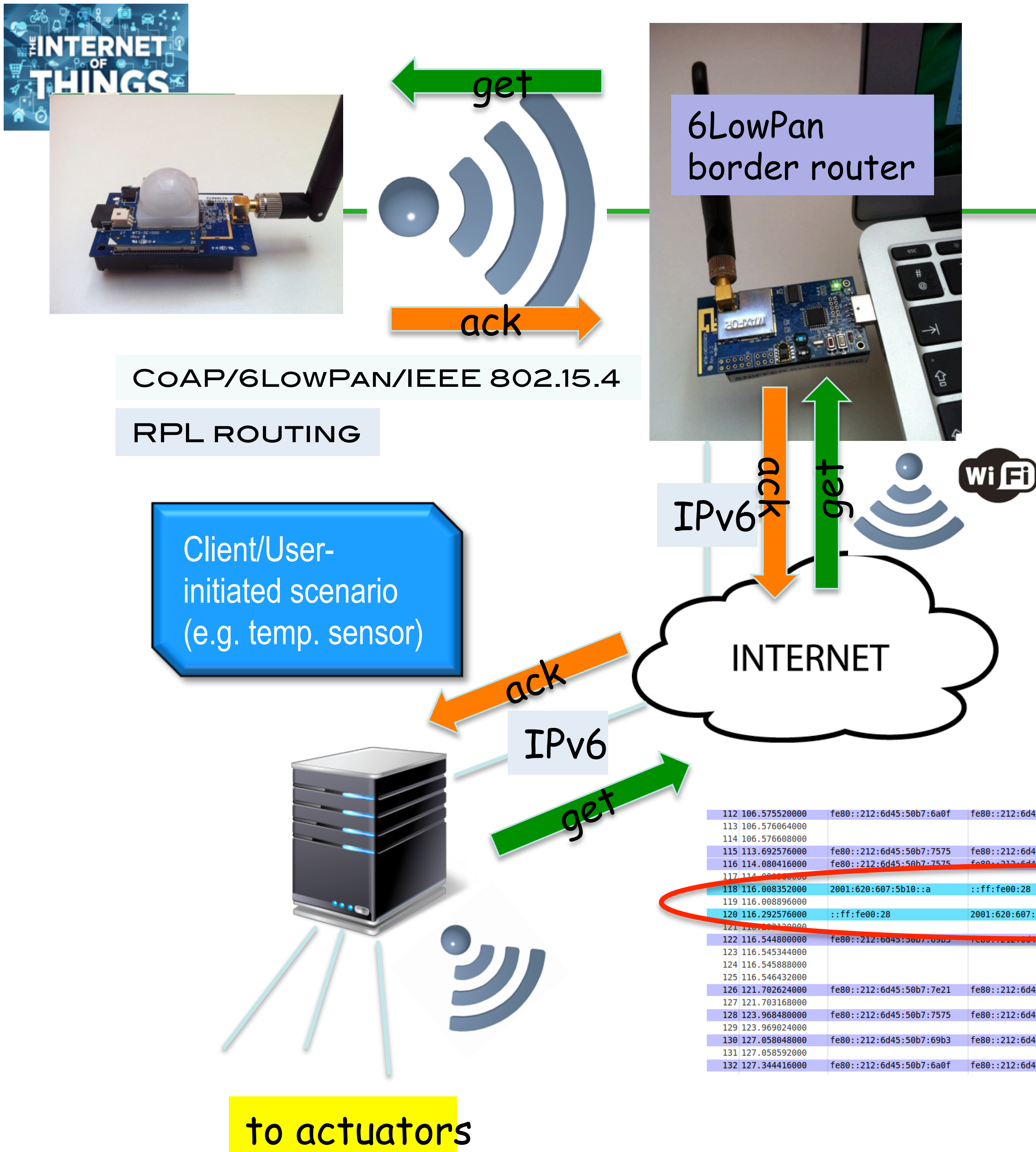
IPv6 egde router

LBR (6lowPAN)

DATA = RESOURCES

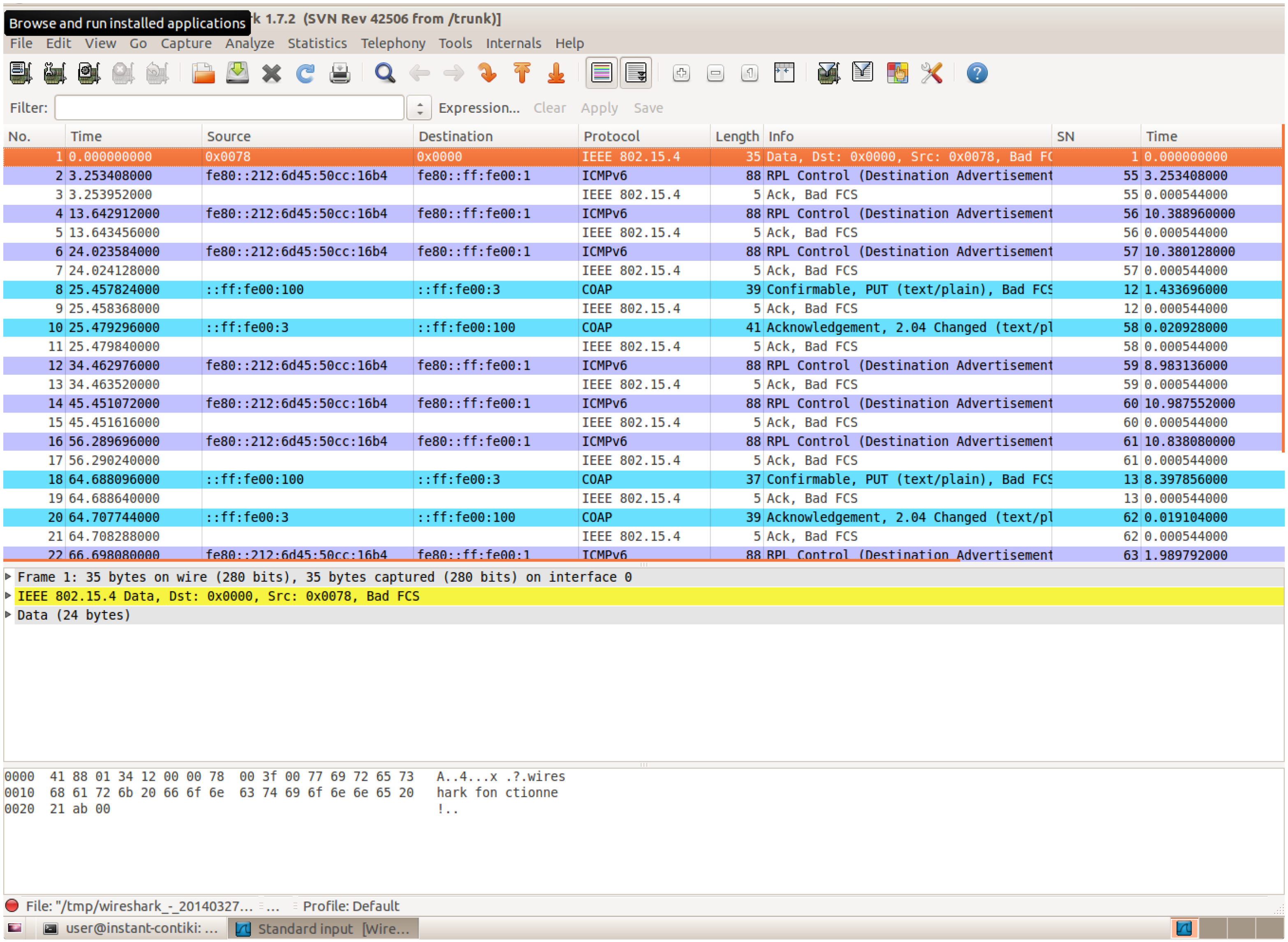


From Isam Ishaq et al. "Flexible Unicast-Based Group Communication for CoAP-Enabled Devices", MDPI *Sensors* **2014**, *14*(6), 9833-9877



112	106.575520000	fe80::212:6d45:50b7:6a0f	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
113	106.576064000			IEEE 802.15.4	5	Ack, Bad FCS
114	106.576608000			IEEE 802.15.4	5	Ack, Bad FCS
115	113.692576000	fe80::212:6d45:50b7:7575	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
116	114.080416000	fe80::212:6d45:50b7:7575	[illegible]	[illegible]	94	RPL Control (Destination Advertisement Object),
117	[illegible]			IEEE 802.15.4	5	Ack, Bad FCS
118	116.008352000	2001:620:607:5b10::a	::ff:fe00:28	COAP	60	Confirmable, GET, End of Block #15, Bad FCS
119	116.008896000			IEEE 802.15.4	5	Ack, Bad FCS
120	116.292576000	::ff:fe00:28	2001:620:607:5b10::a	COAP	65	Acknowledgement, 2.05 Content, End of Block #15
121	[illegible]			IEEE 802.15.4	5	Ack, Bad FCS
122	116.544800000	fe80::212:6d45:50b7:69b3	fe80::212:6d45:50b7:6a0f	ICMPv6	94	RPL Control (Destination Advertisement Object),
123	116.545344000			IEEE 802.15.4	5	Ack, Bad FCS
124	116.545888000			IEEE 802.15.4	5	Ack, Bad FCS
125	116.546432000			IEEE 802.15.4	5	Ack, Bad FCS
126	121.702624000	fe80::212:6d45:50b7:7e21	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
127	121.703168000			IEEE 802.15.4	5	Ack, Bad FCS
128	123.968480000	fe80::212:6d45:50b7:7575	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
129	123.969024000			IEEE 802.15.4	5	Ack, Bad FCS
130	127.058048000	fe80::212:6d45:50b7:69b3	fe80::212:6d45:50b7:6a0f	ICMPv6	94	RPL Control (Destination Advertisement Object),
131	127.058592000			IEEE 802.15.4	5	Ack, Bad FCS
132	127.344416000	fe80::212:6d45:50b7:6a0f	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),

RPL and CoAP exchanges



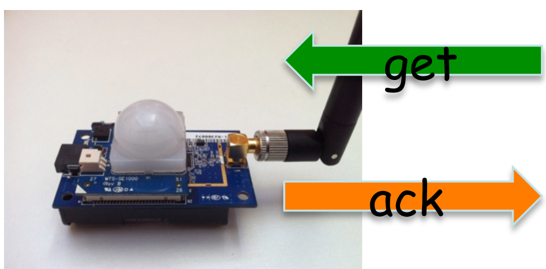
No.	Time	Source	Destination	Protocol	Length	Info	SN	Time
1	0.000000000	0x0078	0x0000	IEEE 802.15.4	35	Data, Dst: 0x0000, Src: 0x0078, Bad FC	1	0.000000000
2	3.253408000	fe80::212:6d45:50cc:16b4	fe80::ff:fe00:1	ICMPv6	88	RPL Control (Destination Advertisement	55	3.253408000
3	3.253952000			IEEE 802.15.4	5	Ack, Bad FCS	55	0.000544000
4	13.642912000	fe80::212:6d45:50cc:16b4	fe80::ff:fe00:1	ICMPv6	88	RPL Control (Destination Advertisement	56	10.388960000
5	13.643456000			IEEE 802.15.4	5	Ack, Bad FCS	56	0.000544000
6	24.023584000	fe80::212:6d45:50cc:16b4	fe80::ff:fe00:1	ICMPv6	88	RPL Control (Destination Advertisement	57	10.380128000
7	24.024128000			IEEE 802.15.4	5	Ack, Bad FCS	57	0.000544000
8	25.457824000	::ff:fe00:100	::ff:fe00:3	COAP	39	Confirmable, PUT (text/plain), Bad FCS	12	1.433696000
9	25.458368000			IEEE 802.15.4	5	Ack, Bad FCS	12	0.000544000
10	25.479296000	::ff:fe00:3	::ff:fe00:100	COAP	41	Acknowledgement, 2.04 Changed (text/pl	58	0.020928000
11	25.479840000			IEEE 802.15.4	5	Ack, Bad FCS	58	0.000544000
12	34.462976000	fe80::212:6d45:50cc:16b4	fe80::ff:fe00:1	ICMPv6	88	RPL Control (Destination Advertisement	59	8.983136000
13	34.463520000			IEEE 802.15.4	5	Ack, Bad FCS	59	0.000544000
14	45.451072000	fe80::212:6d45:50cc:16b4	fe80::ff:fe00:1	ICMPv6	88	RPL Control (Destination Advertisement	60	10.987552000
15	45.451616000			IEEE 802.15.4	5	Ack, Bad FCS	60	0.000544000
16	56.289696000	fe80::212:6d45:50cc:16b4	fe80::ff:fe00:1	ICMPv6	88	RPL Control (Destination Advertisement	61	10.838080000
17	56.290240000			IEEE 802.15.4	5	Ack, Bad FCS	61	0.000544000
18	64.688096000	::ff:fe00:100	::ff:fe00:3	COAP	37	Confirmable, PUT (text/plain), Bad FCS	13	8.397856000
19	64.688640000			IEEE 802.15.4	5	Ack, Bad FCS	13	0.000544000
20	64.707744000	::ff:fe00:3	::ff:fe00:100	COAP	39	Acknowledgement, 2.04 Changed (text/pl	62	0.019104000
21	64.708288000			IEEE 802.15.4	5	Ack, Bad FCS	62	0.000544000
22	66.698080000	fe80::212:6d45:50cc:16b4	fe80::ff:fe00:1	ICMPv6	88	RPL Control (Destination Advertisement	63	1.989792000

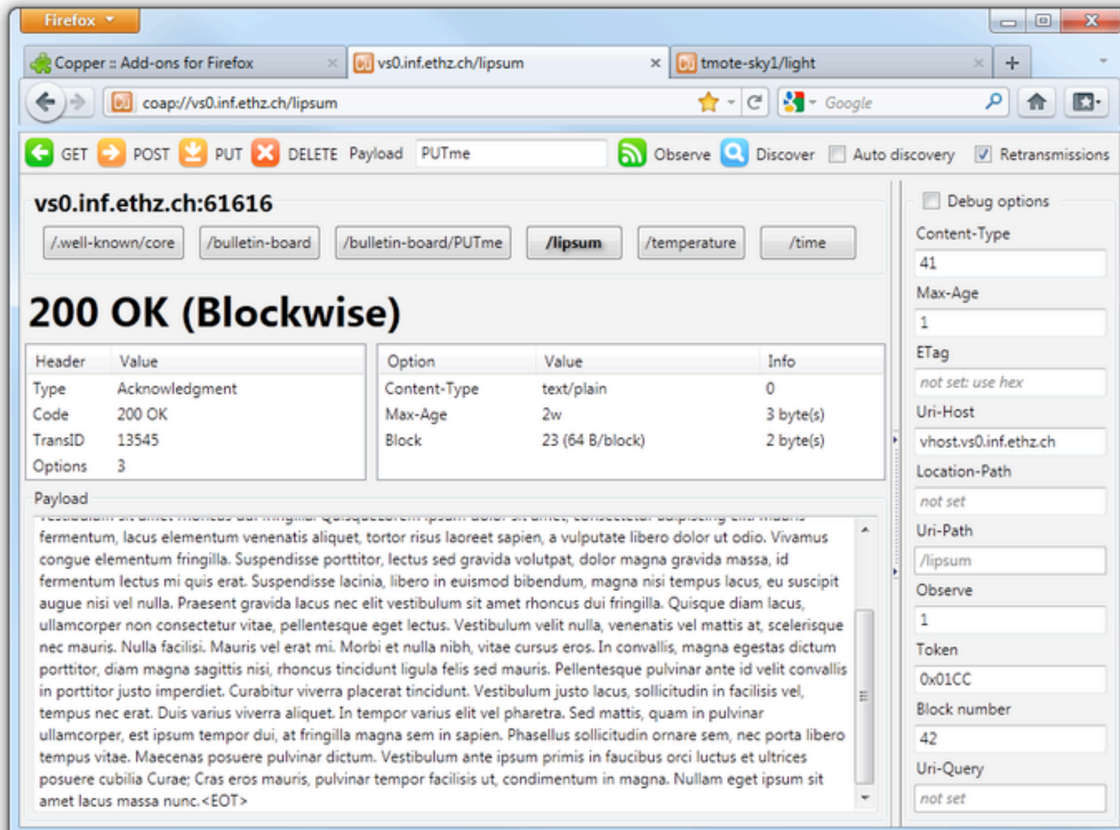
Frame 1: 35 bytes on wire (280 bits), 35 bytes captured (280 bits) on interface 0
IEEE 802.15.4 Data, Dst: 0x0000, Src: 0x0078, Bad FCS
Data (24 bytes)

```
0000  41 88 01 34 12 00 00 78  00 3f 00 77 69 72 65 73   A..4...x .?.wires
0010  68 61 72 6b 20 66 6f 6e  63 74 69 6f 6e 6e 65 20   hark fon ctionne
0020  21 ab 00                                           !..
```

Copper for Firefox

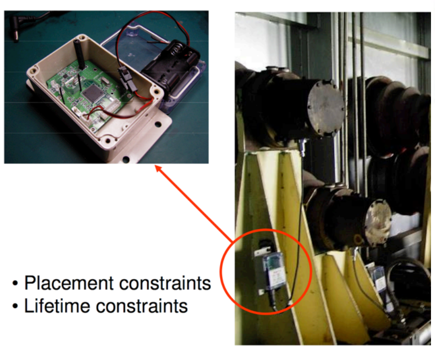
- CoAP pluggin to query CoAP nodes in an HTTP-like fashion

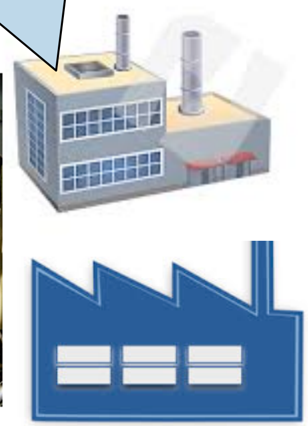




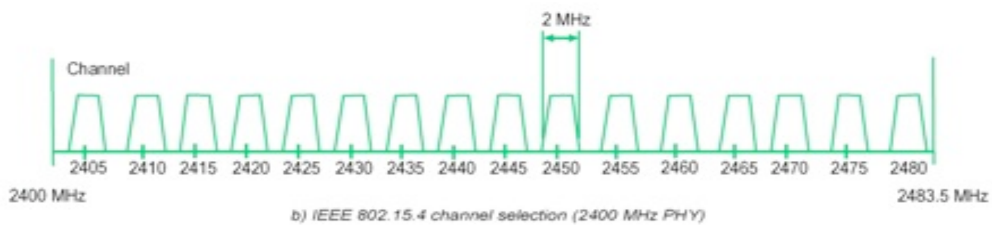
Back to Industrial

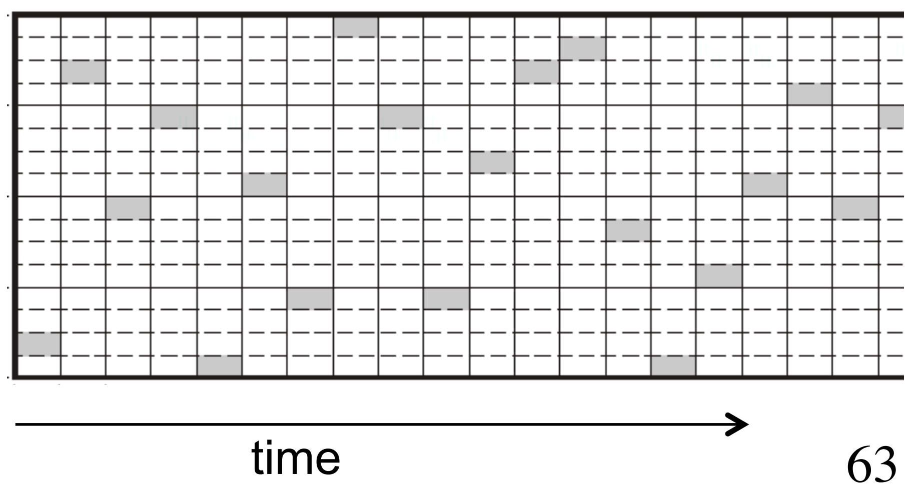
50 sensors, STATIC deployment, but need to have RELIABILITY, GUARANTEED LATENCY for monitoring and alerting. MUST run for 3 YEARS. No fancy stuff! CAN I HAVE IT?



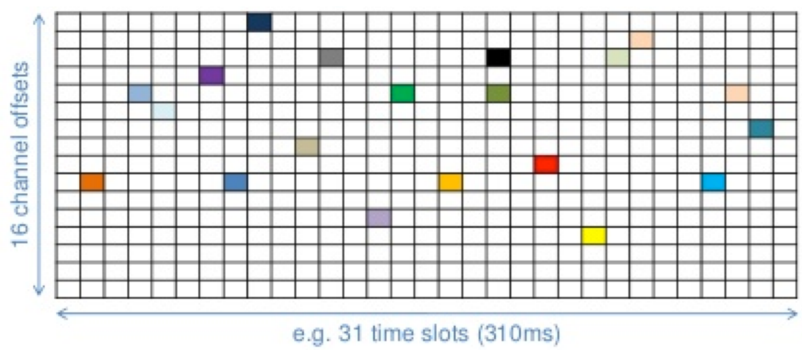


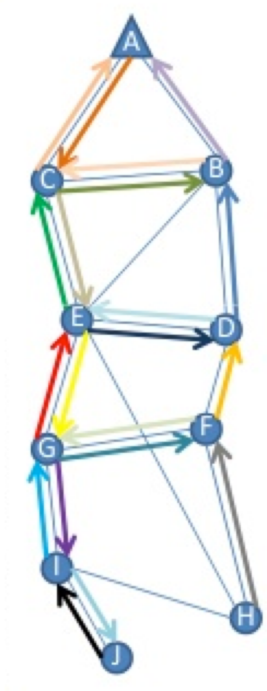
IEEE 802.15.4 has been enhanced to provide more reliability with channel hopping technologies - TSCH



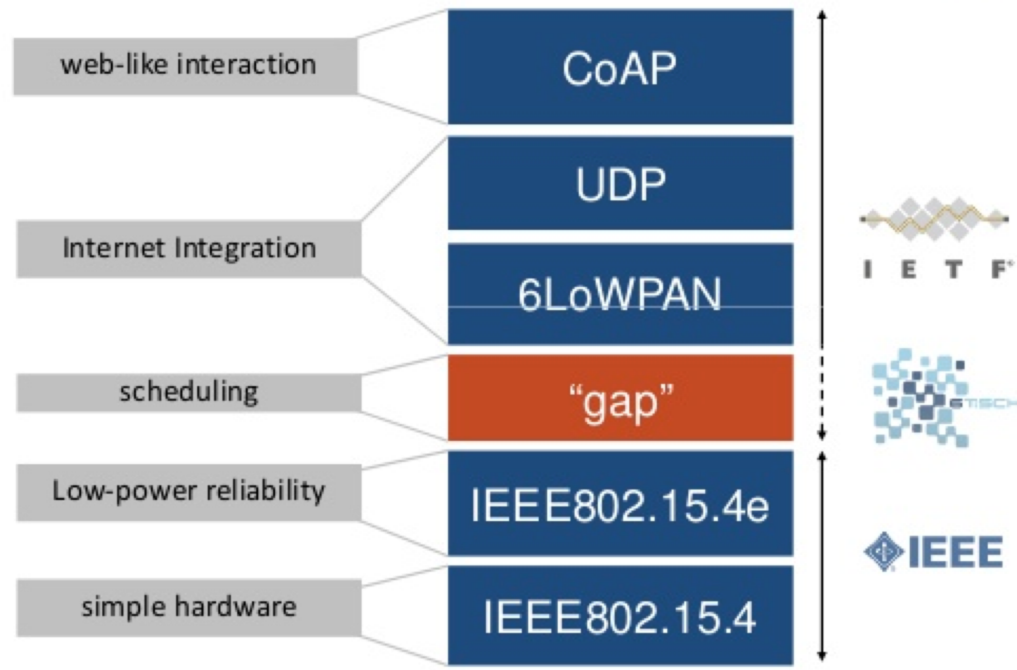


6LowPan / TSCH



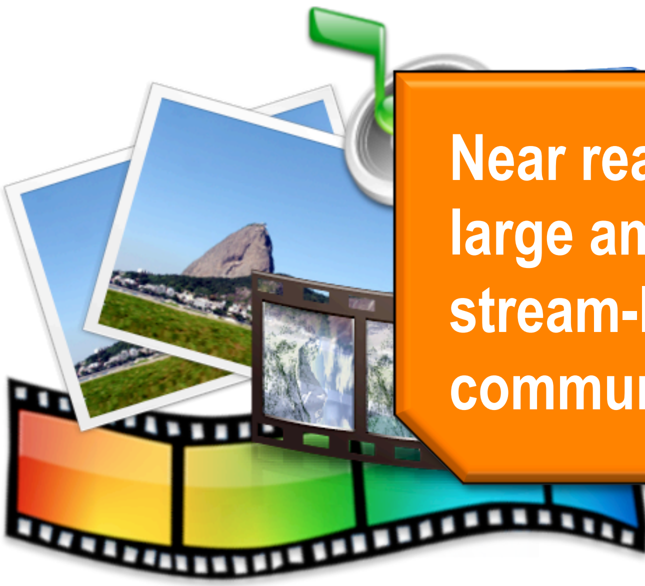


Figures from X. Vilajosana, "IETF 6TiSCH, a new standardization effort to combine IPv6 connectivity with industrial performance



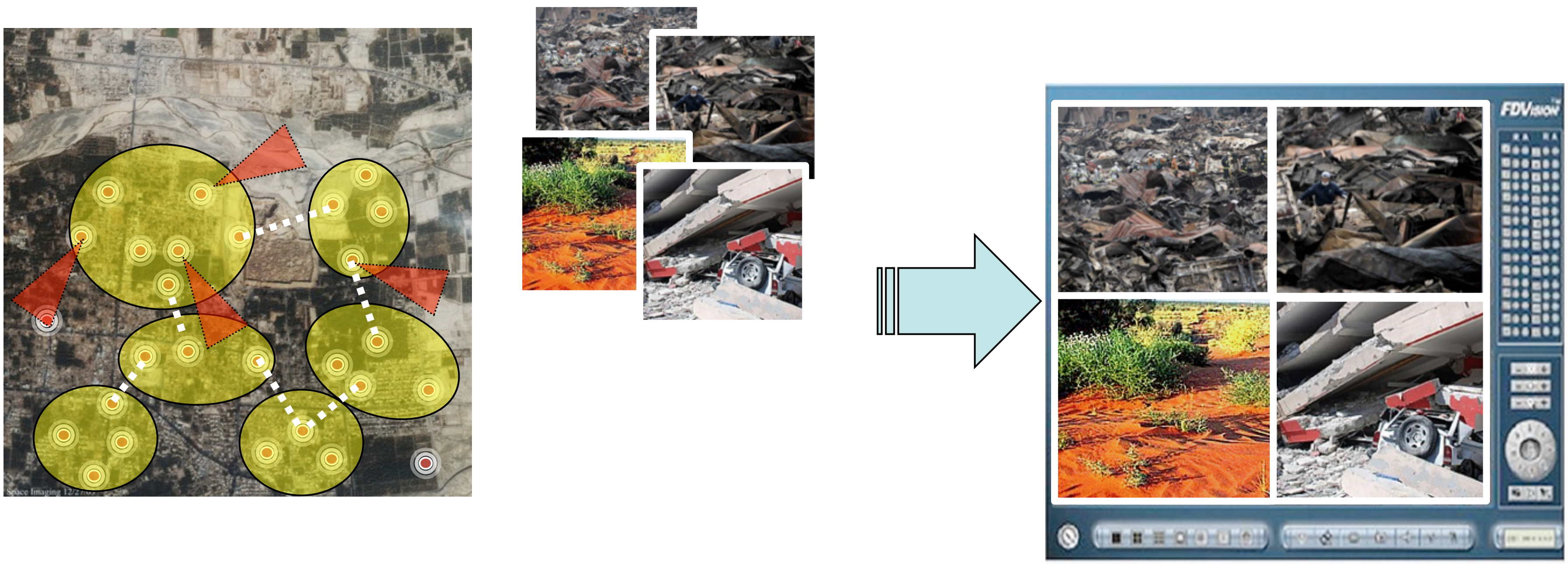
IETF 6TiSCH addresses the issues of IPv6 over TSCH MAC

Towards Multimedia Information



Near real-time constraints, large amount of data, stream-like communication,…

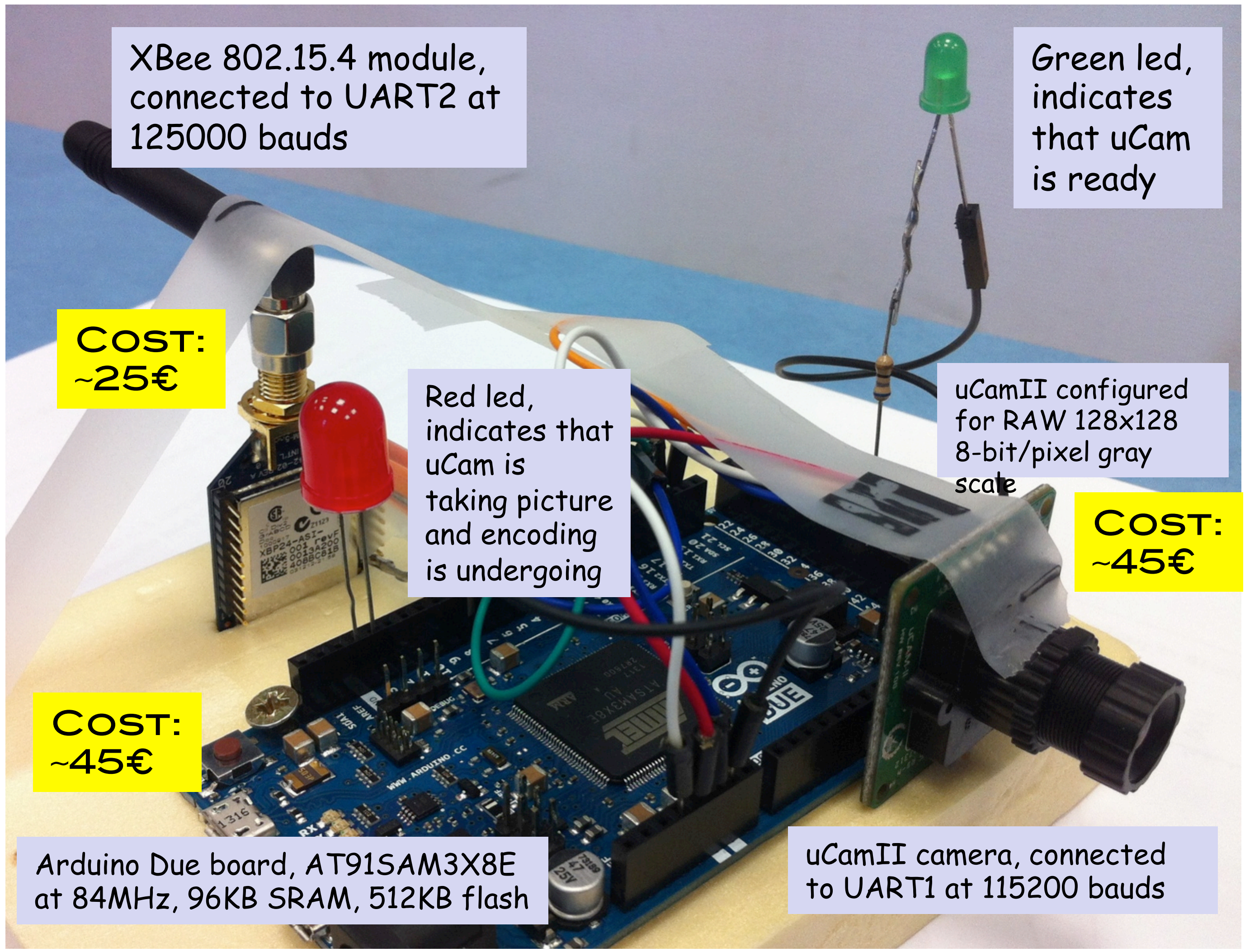
Visual data for situation-awareness

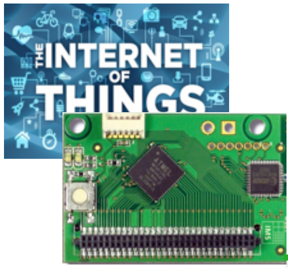


Collect data to improve the responsiveness of rescue operations

Arduino + uCamII
128x128 images

Can be controlled wirelessly to capture, take reference image, compare image, transmit image, define packet size, image quality factor,…

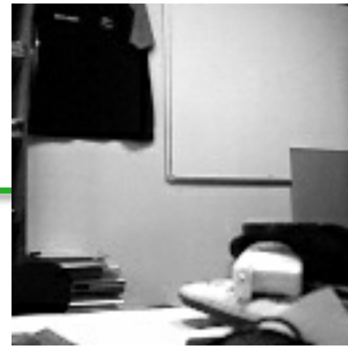




ADJUSTABLE IMAGE QUALITY FACTOR Q

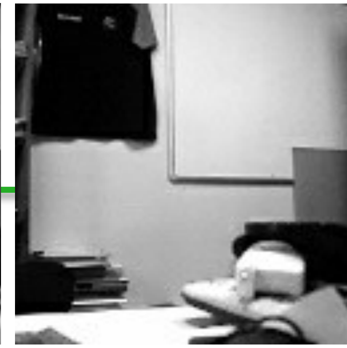
BMP 16384b

Q=100; 9768b



PSNR=51.344

Q=90; 5125b



PSNR=29.414

Q=80; 3729b

PSNR=28.866

Q=70; 2957b

PSNR=28.477

Q=60; 2552b

PSNR=28.024

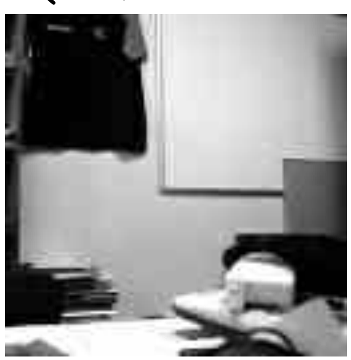
Q=50; 2265b

PSNR=27.912

Q=40; 2024b

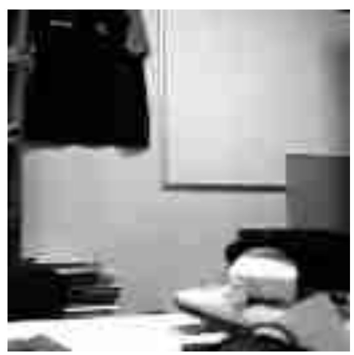
PSNR=27.423

Q=30; 1735b



PSNR=26.933

Q=20; 1366b



PSNR=26.038

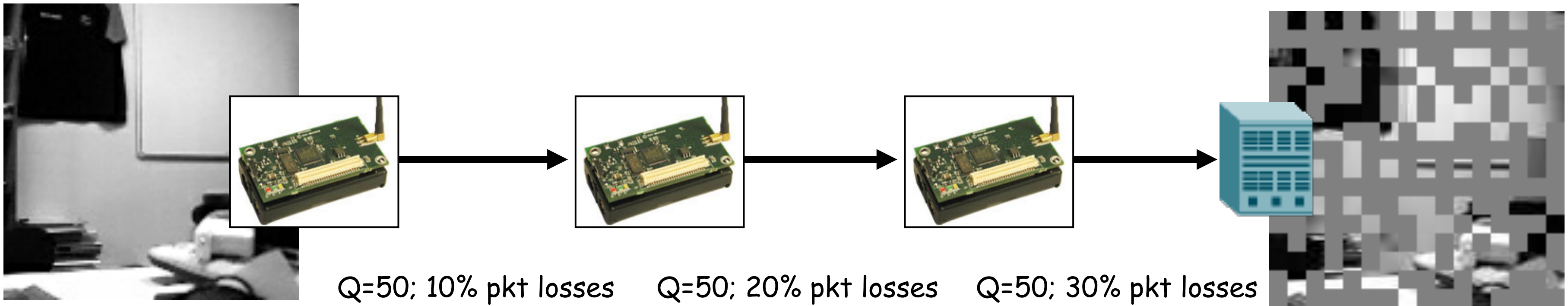
Q=10; 911b

PSNR=25.283

Q=5; 576b

PSNR=23.507

Robust to packet losses, Out of order reception



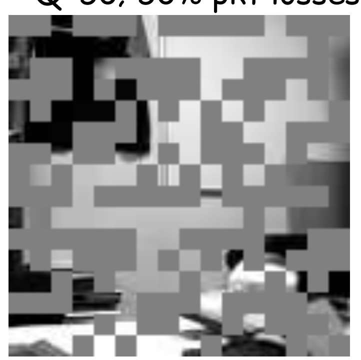
Q=50; 10% pkt losses

Q=50; 20% pkt losses

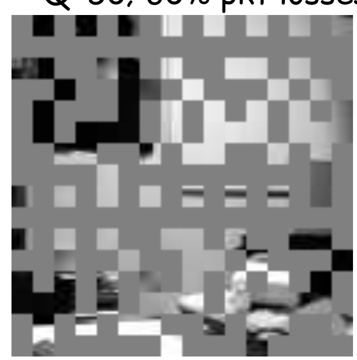
Q=50; 30% pkt losses

Q=50; 40% pkt losses

Q=50; 50% pkt losses

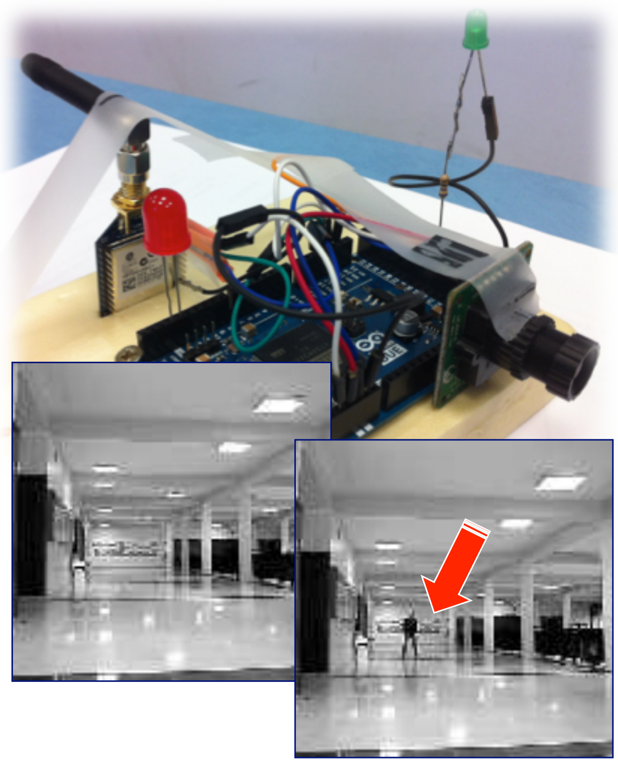


Q=50; 60% pkt losses



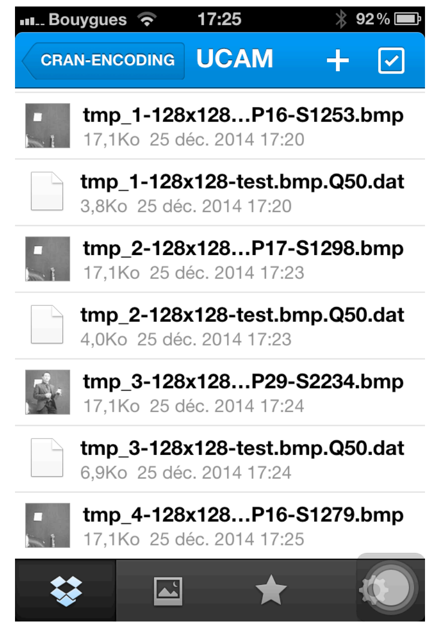
Scientific cooperation with V. Lecuire from CRAN laboratory for the optimized image encoding algorithm

Intrusion detection

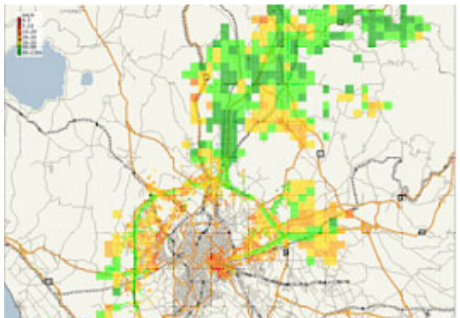


Sends image to gateway on intrusion detection

Real-time synchronization with your smartphone through cloud applications, e.g. DropBox



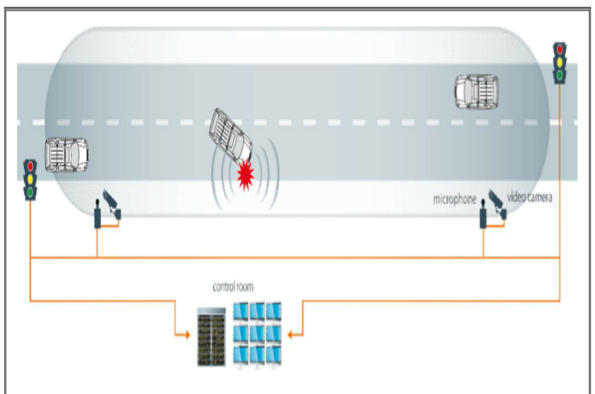
EXPLOITING ACOUSTIC DATA



[redacted]

[redacted]
Management

[redacted]
efficiency



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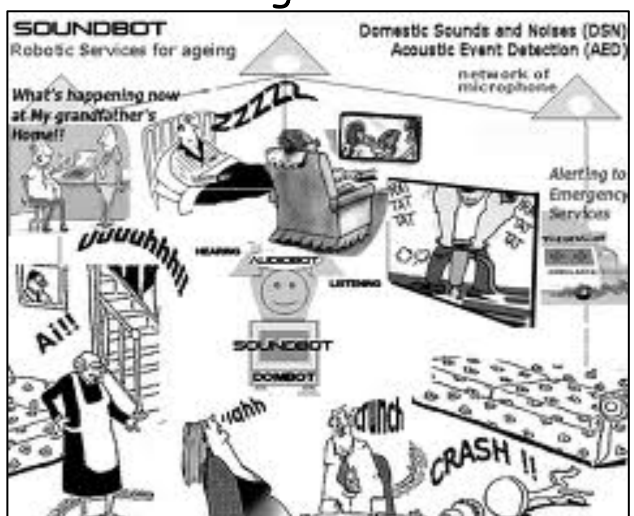

[redacted]

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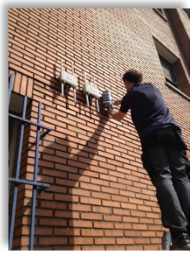
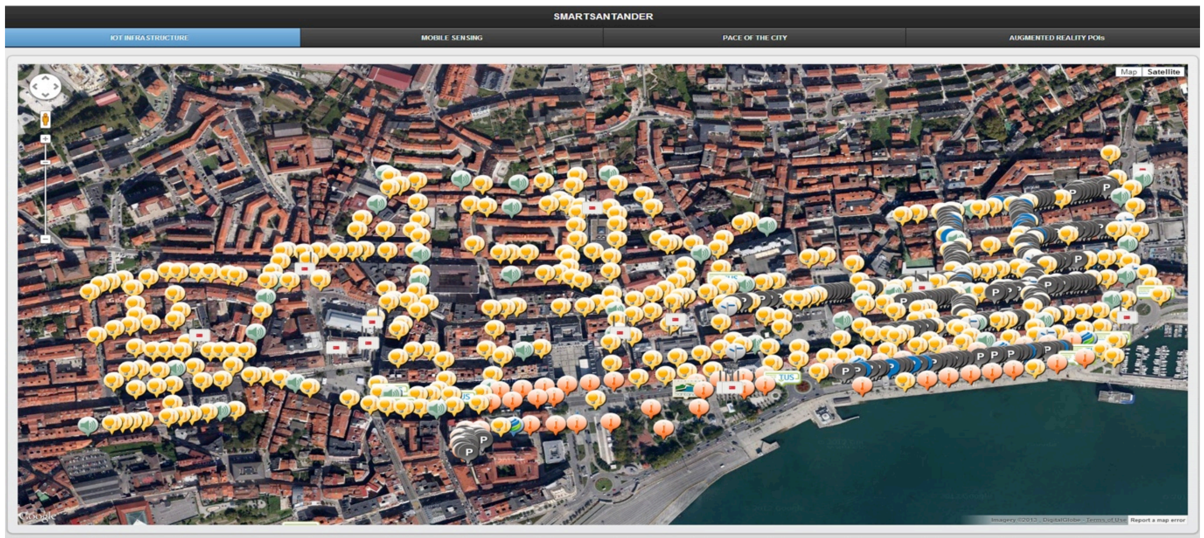
Surveillance

SmartSantander meets EAR-IT

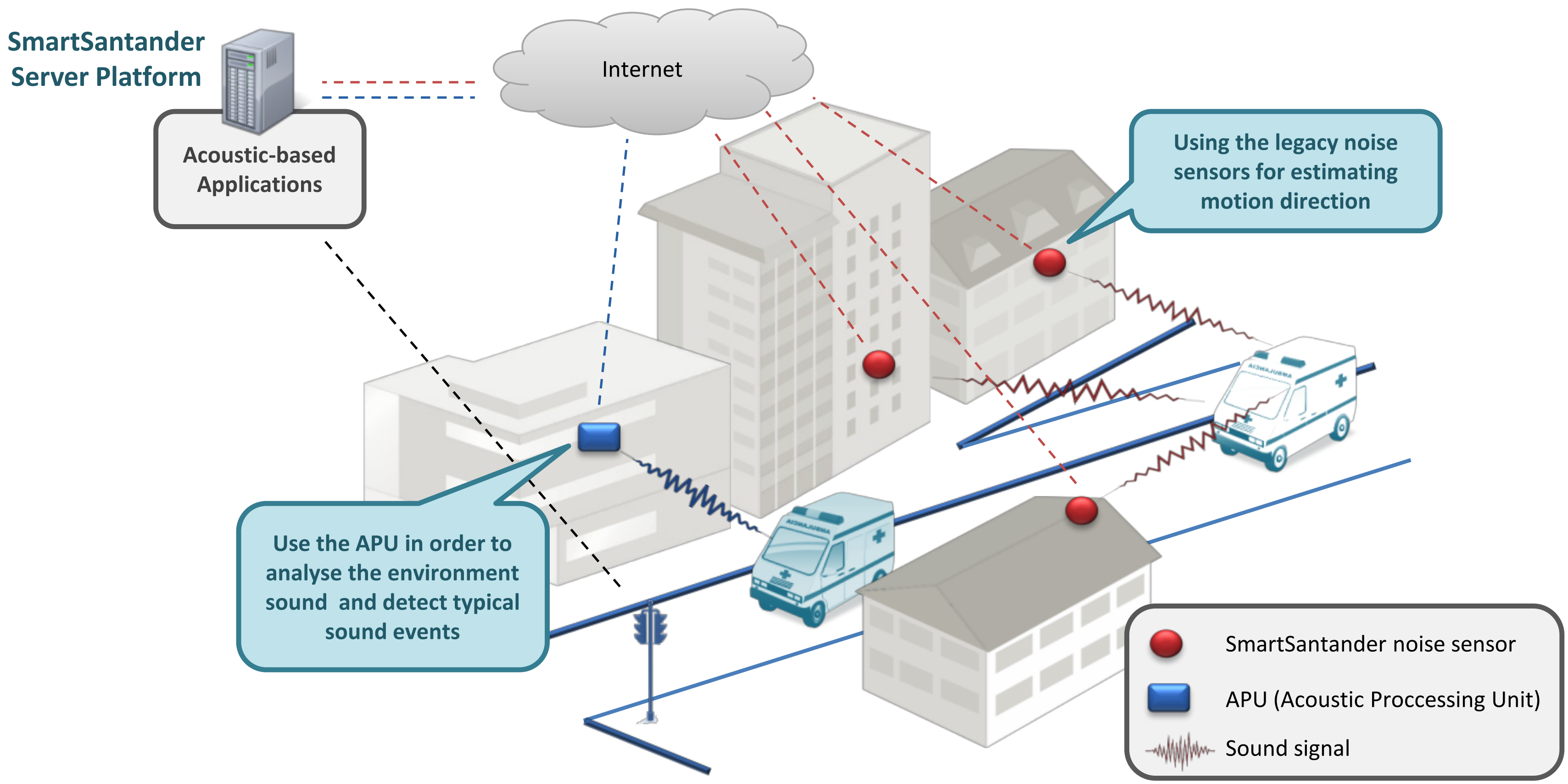
Upon concrete noise pattern detected by the APU, legacy sensors collect data for several purposes ⇒ Two use cases as a starting point.



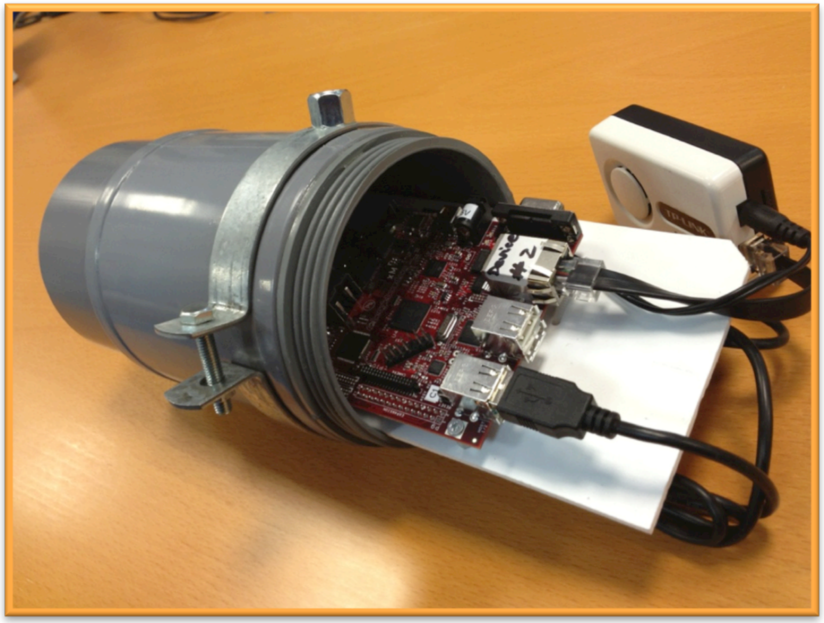


EAR-IT Use Case 1: Emergency Detection

Use the APU to detect an alarm ⇒ Legacy SmartSantander noise sensors to get the direction of such an event (police car, ambulance,…).



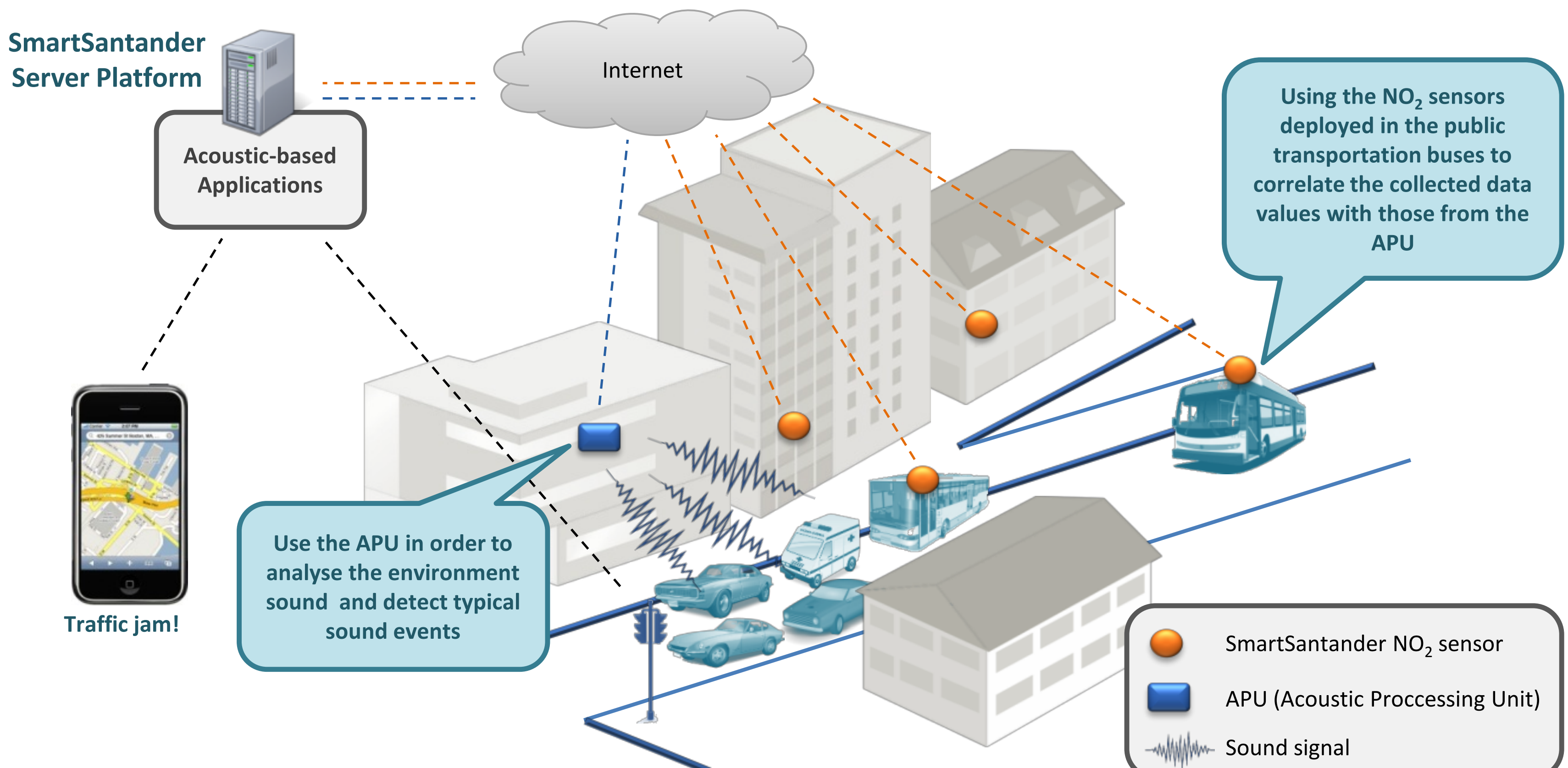
Emergency Detection Deployment



EAR-IT *the sounds of smart environment*

EAR-IT Use Case 2 : Traffic Monitoring

Use the APU to measure the traffic density and correlating it with pollution values (NO_2, CO,…) collected by legacy fixed and mobile nodes in the area.



EAR-IT Use Case 2 : Traffic density estimation

- The whole SmartSantander infrastructure is used in the deployment (IoT-s, APU, database, remote control)
- Traffic monitoring IoT-s are used for development and validation
- The examined street is a one-way road with 3 lanes

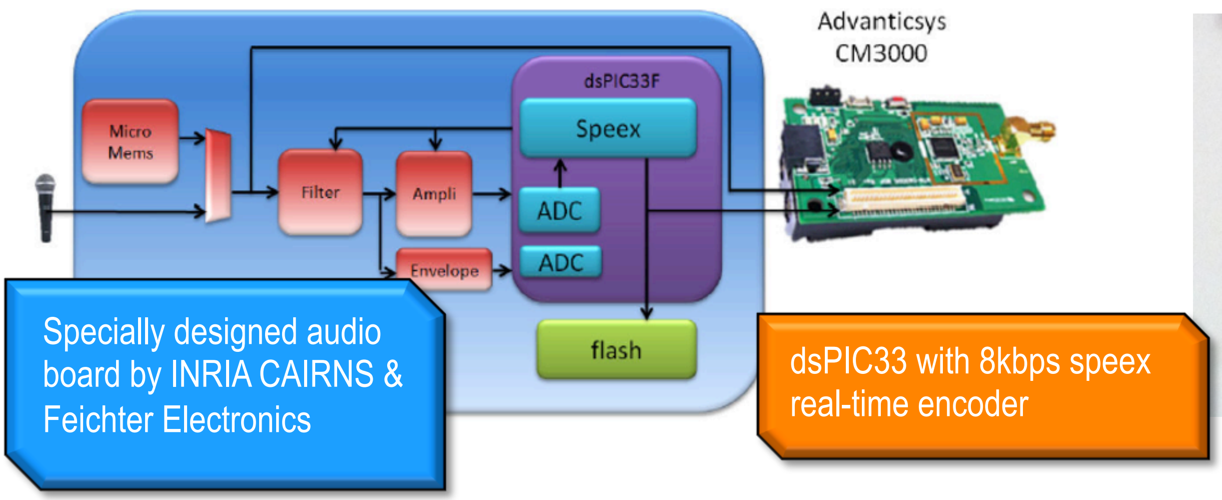
Traffic Density Monitoring Deployment

Low-resource IoT node to enhance acoustic services

Play/store received audio data

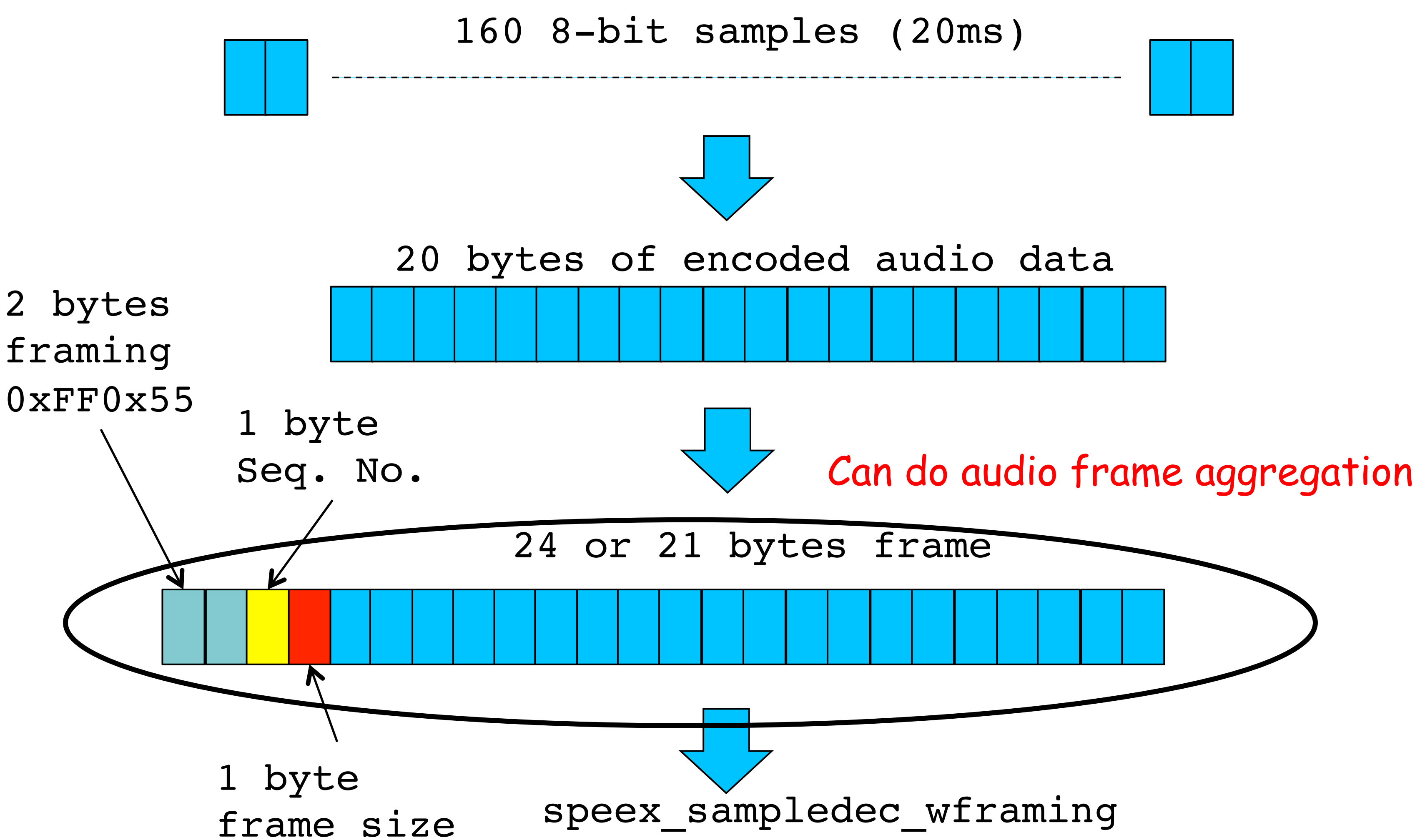
Development of Audio Board

- Use dedicated audio board for sampling/storing/encoding



- Encoding scheme is Speex at 8kbps
- Designed for multi-platform motes
- Can be plugged to other boards (UART)

Speex at 8kbps



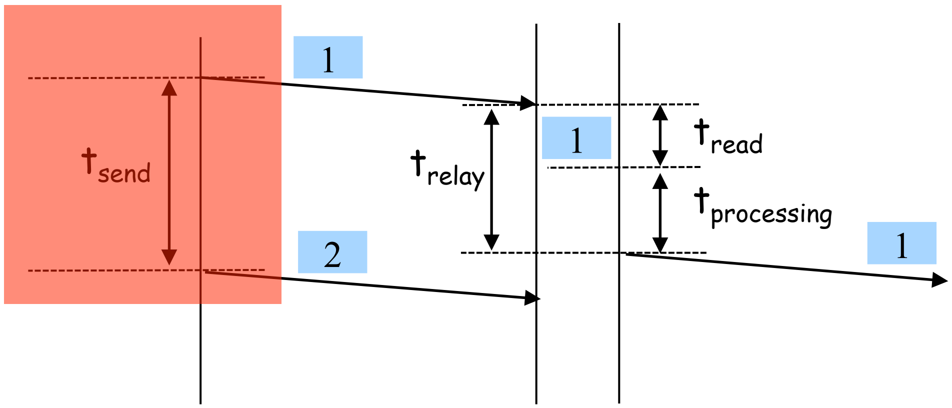
Communication performance issues?

- Application level performances depends on OS, API, hardware architecture
- Usually much lower than radio performances!
- What are min. latencies & max. throughput?
  - For sending?
  - For receiving?
  - For relaying?

C. Pham, "Communication performance of low-resource sensor motes for data-intensive applications ", Proceedings of the IFIP Wireless Days International Conference (WD'2013), Valencia, Spain, November 2013.

C. Pham, "Communication performances of IEEE 802.15.4 wireless sensor motes for data-intensive applications: a comparison of WaspMote, Arduino MEGA, TelosB, MicaZ and iMote2 for image surveillance", Journal of Network and Computer Applications (JNCA), Elsevier, Vol. 46, Nov. 2014

Sending performances



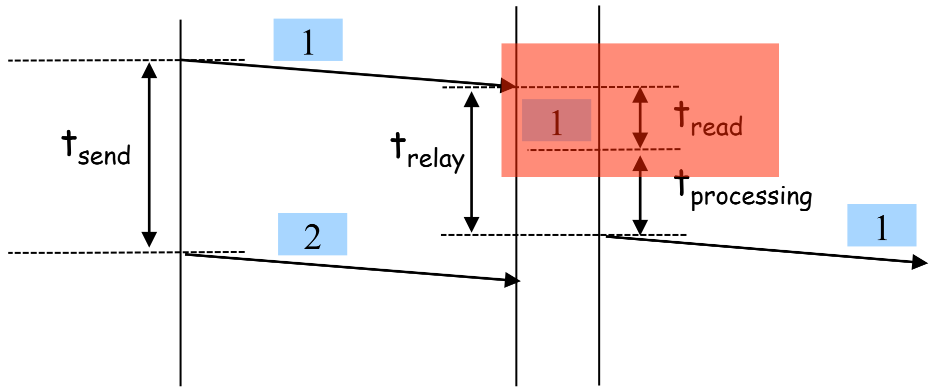
Traffic Generator

```
void loop() {
        T0;
        L0=T0;
        ...
        T1;
        send(buf);
        T2;
        ...
}
```

Measure the time in various part of API `send()` when possible.

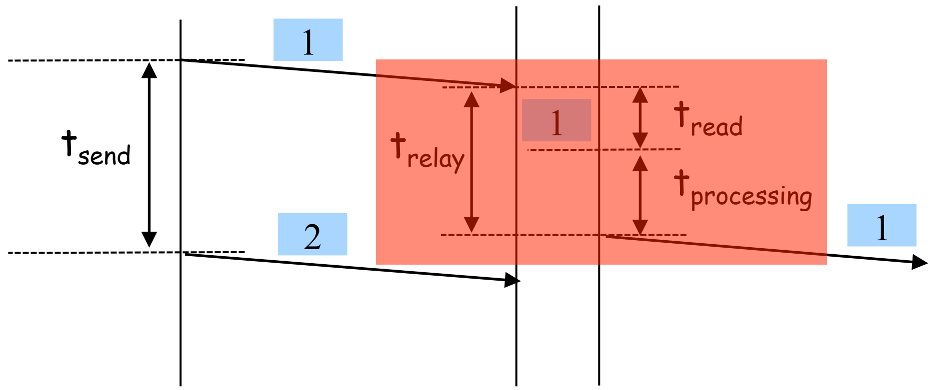
« Time in send() » is T2-T1
« Time between 2 pkt generation » is T0-L0
Time resolution is millisecond
Minimum data manipulation

Receive performances



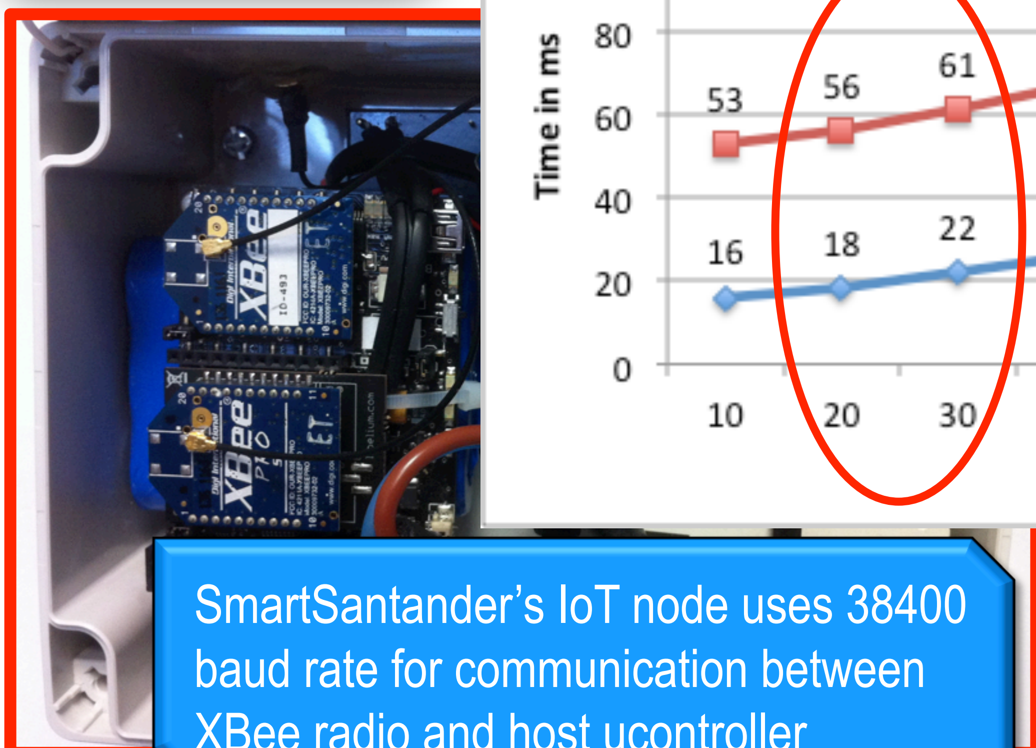
- At sender side, send as fast as possible
- At receiver side, determine t_{read}
- ... and also compute the maximum receive throughput per packet size

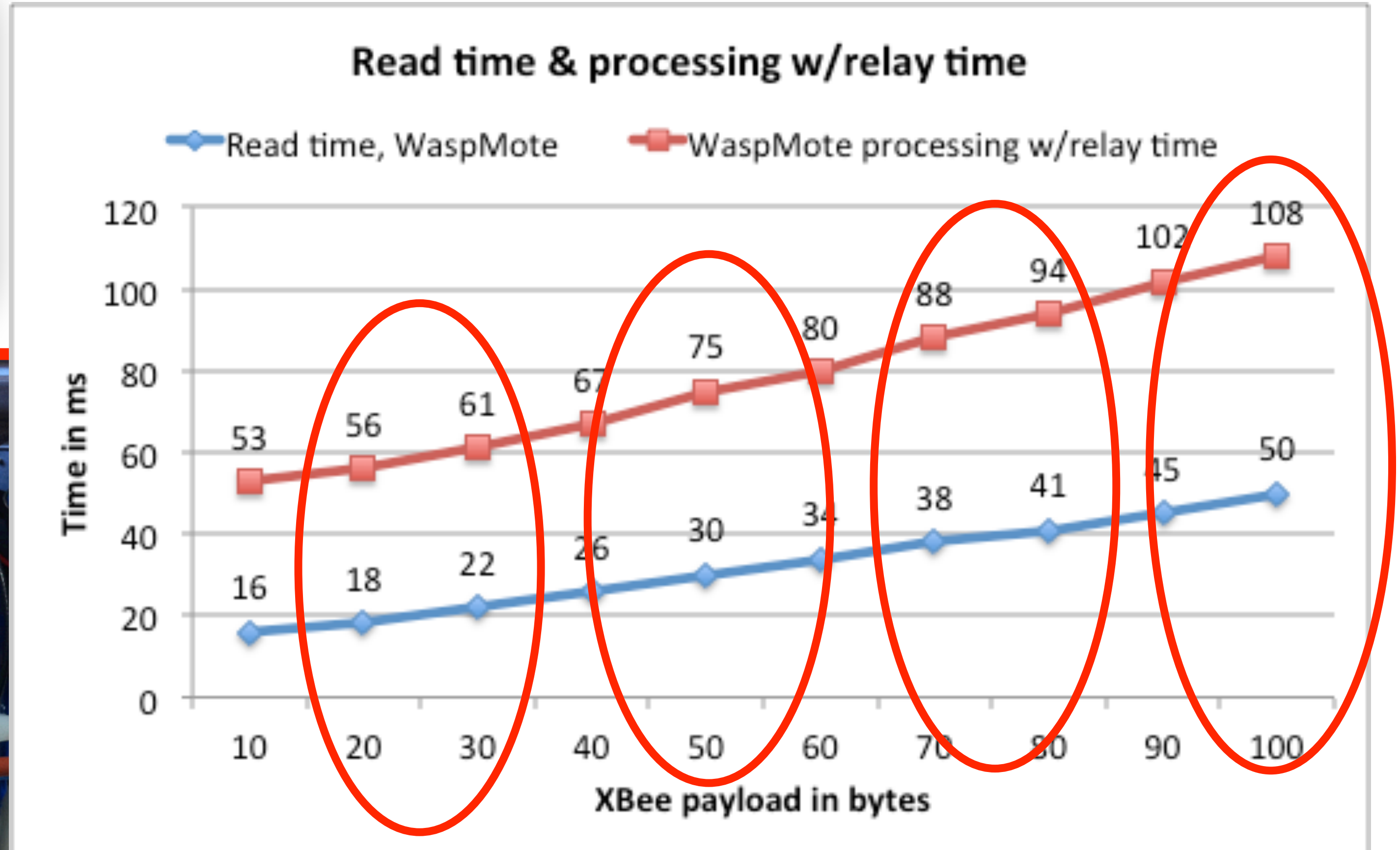
Relay performances



- Relaying are usually done at application-level (even OS level is considered app-level for the mote)
- Relaying means:
  - Read the packet in memory
  - Send the packet to next hop

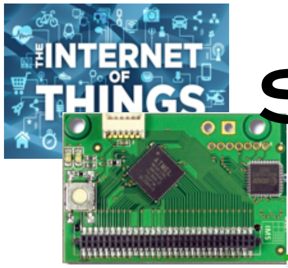
Santander's Limitations



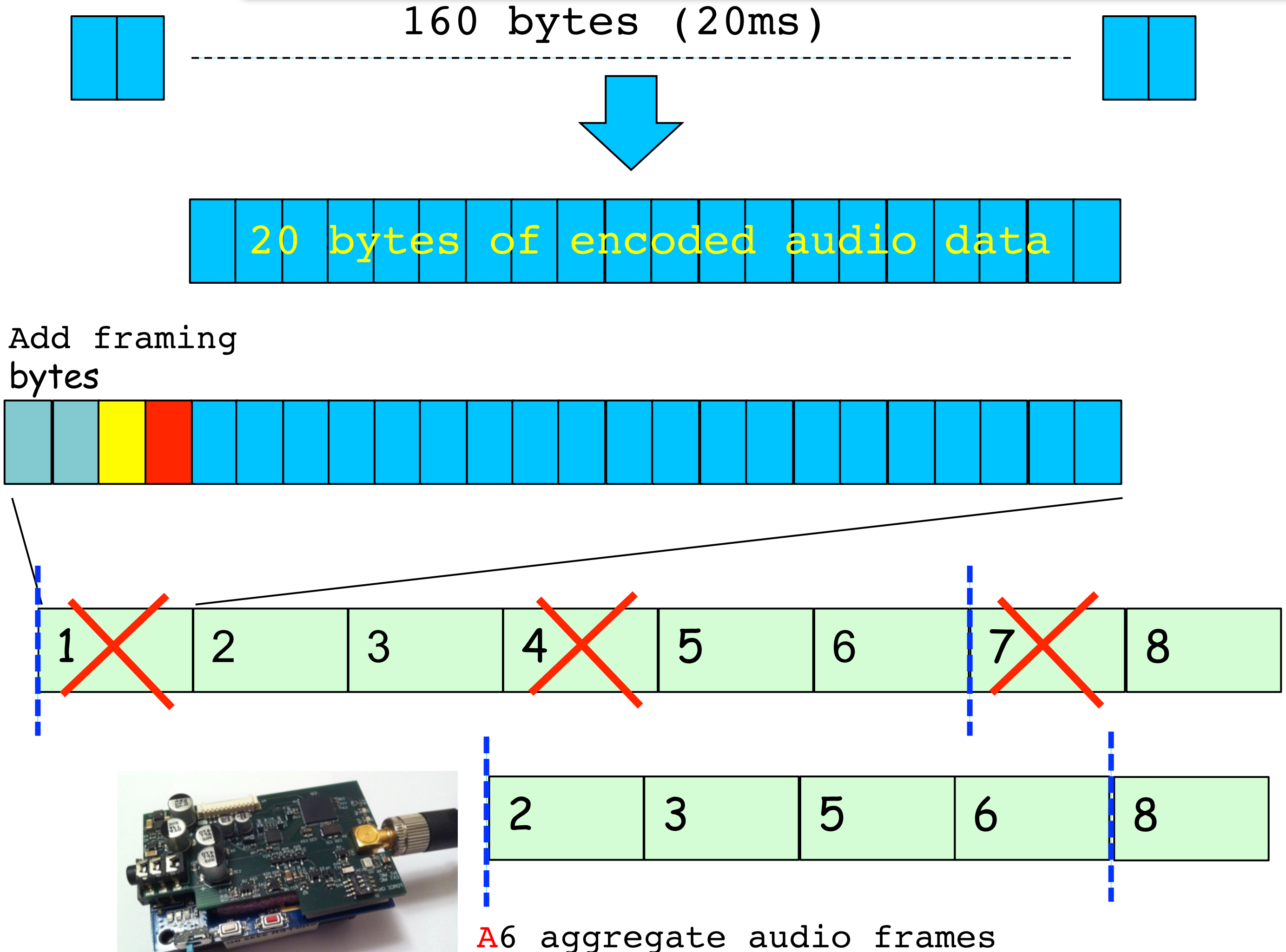


SmartSantander's IoT node uses 38400 baud rate for communication between XBee radio and host ucontroller

Needs to discard audio frame at the source to increase the time window

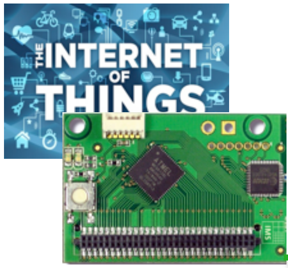


Speex at 8kbps on slow relay nodes



Capture 6 audio frames (120ms) but only send 4

Need to be able to relay 96-byte pkt every 120ms



Conclusions

- Internet of Things, like Wireless Sensor Networks are the foundation of pervasive surveillance infrastructures
- Connecting them, collecting data and providing seamless internet connectivity is challenging but many standards have emerged
- Going beyong « simple » data to multimedia is still challenging on these low-resource platforms