leti

innovation for industry

07/04/2014

Wireless Sensor Networks, IoT and Platforms

R&D activities @ CEA-LETI
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MINATEC CAMPUS

Outline

I. LESC & LSP Lab
II. WSN & WBAN & IoT
III. BAN Protocols
    A. Design and Specification
    B. Implementation
IV. WSN Protocols
    A. Design and Specification
    B. Implementation
V. Routing protocols
VI. Conclusion

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Key skills in LESC Lab

- Domains of expertise
  - Radio communications systems
  - Signal processing for digital communications
  - Wireless communication protocols
- Main applications
  - Radio Cellular Networks: 3GPP LTE and 3GPP LTE-A
  - Short range radio and Wireless Sensor Networks: 60 GHz systems, ULP radio (IEEE 802.15.4), LDR UWB Systems, WBAN
- Main technical skills
  - Modulation, channel coding, equalization, synchronization, MIMO techniques, multicarrier systems, …
  - Information theory
  - MAC protocols, Radio Resource management and interference mitigation
  - Localization/tracking algorithms
  - Link Level Simulations (PHY), System level simulations (MAC/RRM)
  - System specifications and studies
- 17 people: 2 Dr, 7 Ing, 5 PhD students, 3 post-docs

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Key skills in LSP Lab

- Domains of expertise
  - Research and develop digital architectures
  - Optimize algorithm/architecture tradeoffs
  - Implement prototypes to prove novel algorithm and architecture concepts
- Main applications
  - Short range radio and Wireless Sensor Networks: ULP radio, LDR UWB Systems
  - Very High Data contactless
  - Flexible radio for TVWS
- Main technical skills
  - Digital HW architecture for wireless systems
    - Synchronization, channel coding, estimation, equalization, MIMO…
    - Algorithm Architecture Tradeoffs
    - Multi-mode reconfigurable
  - PHY/MAC system architectures
    - HW/SW partitioning and optimization for low power, real-time, high performance
  - HW/SW prototype design and implementation
    - State of the art FPGA based design, high complexity designs
    - Low power embedded CPU
- 13 people: <u>11 Researchers</u>, 2 PhD students

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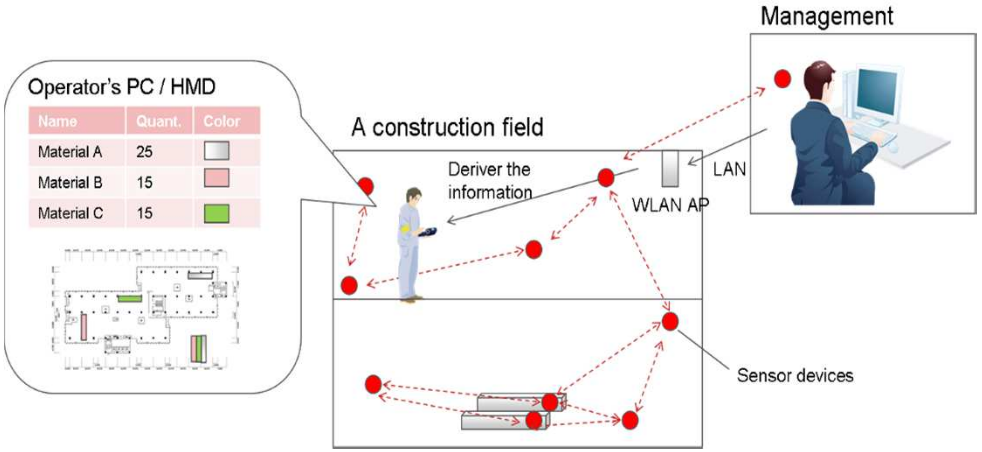
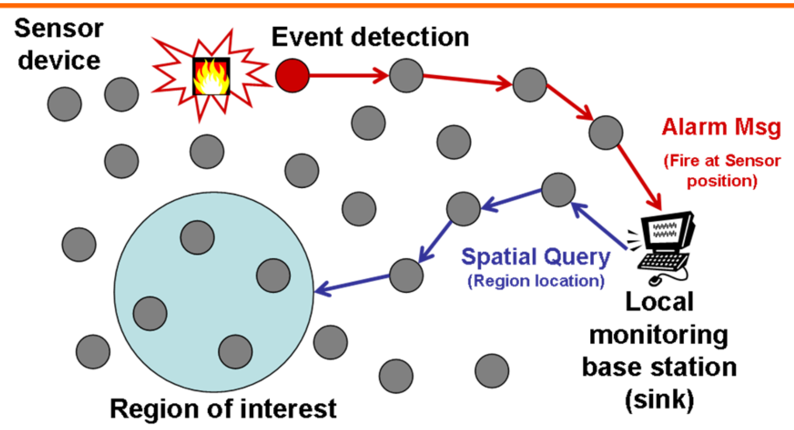
Wireless Sensor Network Scenario (1)



1st example:
Smart inventory of materials and tools on construction fields



2nd example:
Environmental monitoring, event detection and spatial queries

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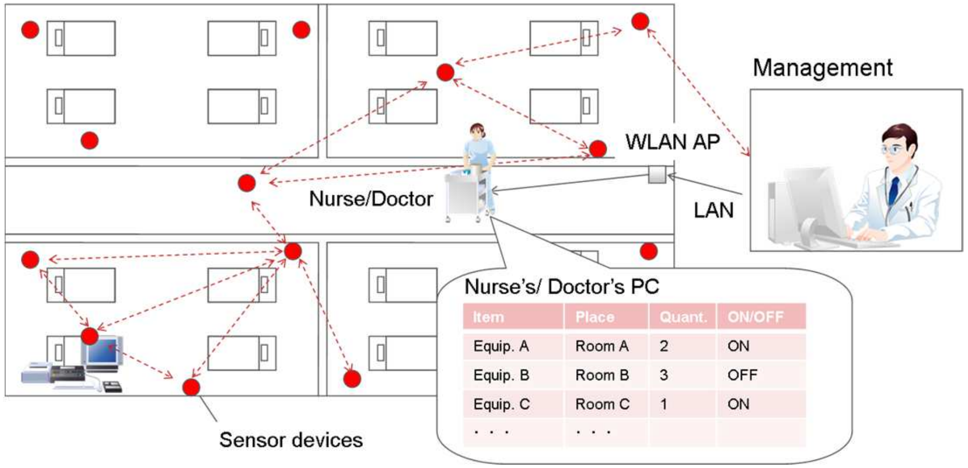
Wireless Sensor Network Scenario (2)



3rd example:
Tracking of medical / surgical instruments and equipments in hospitals

- Main benefits
- ➔ Costs and delays reduction
- ➔ Enhanced operator efficiency and responsiveness
- ➔ Enhanced ergonomics
- ➔ Improved security

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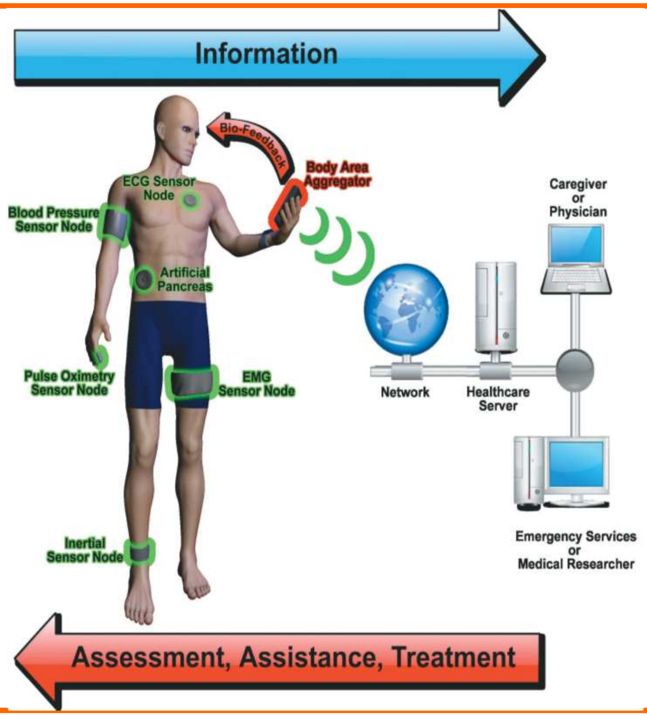
Body Area Network



4st example:
Healthcare, Fitness, Entertainment

Source: M.A. Hanson, H.C. Powell, A.T. Barth, K. Ringgenberg, B.H. Calhoun, J.H. Aylor, et J. Lach, “Body Area Sensor Networks: Challenges and Opportunities,” Computer, vol. 42, Jan. 2009, pp. 58-65.

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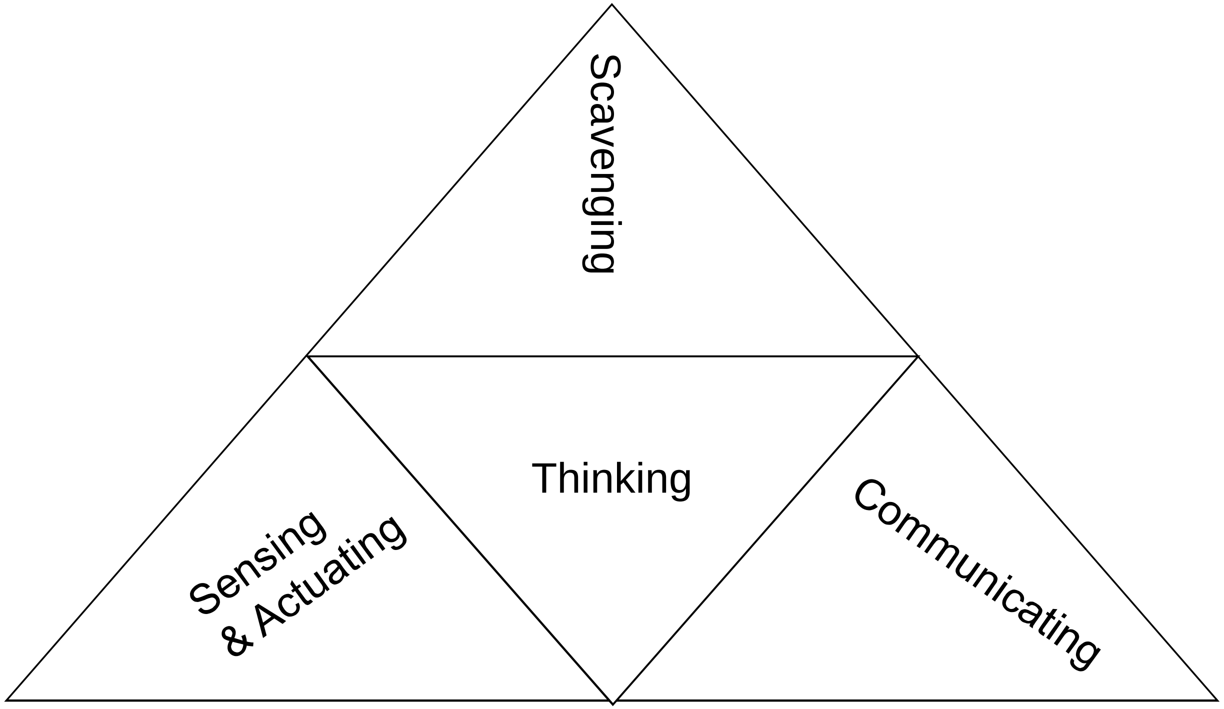
Device Definition (1)

- 1 Device = 4 Functions (cf. Internet of Things)



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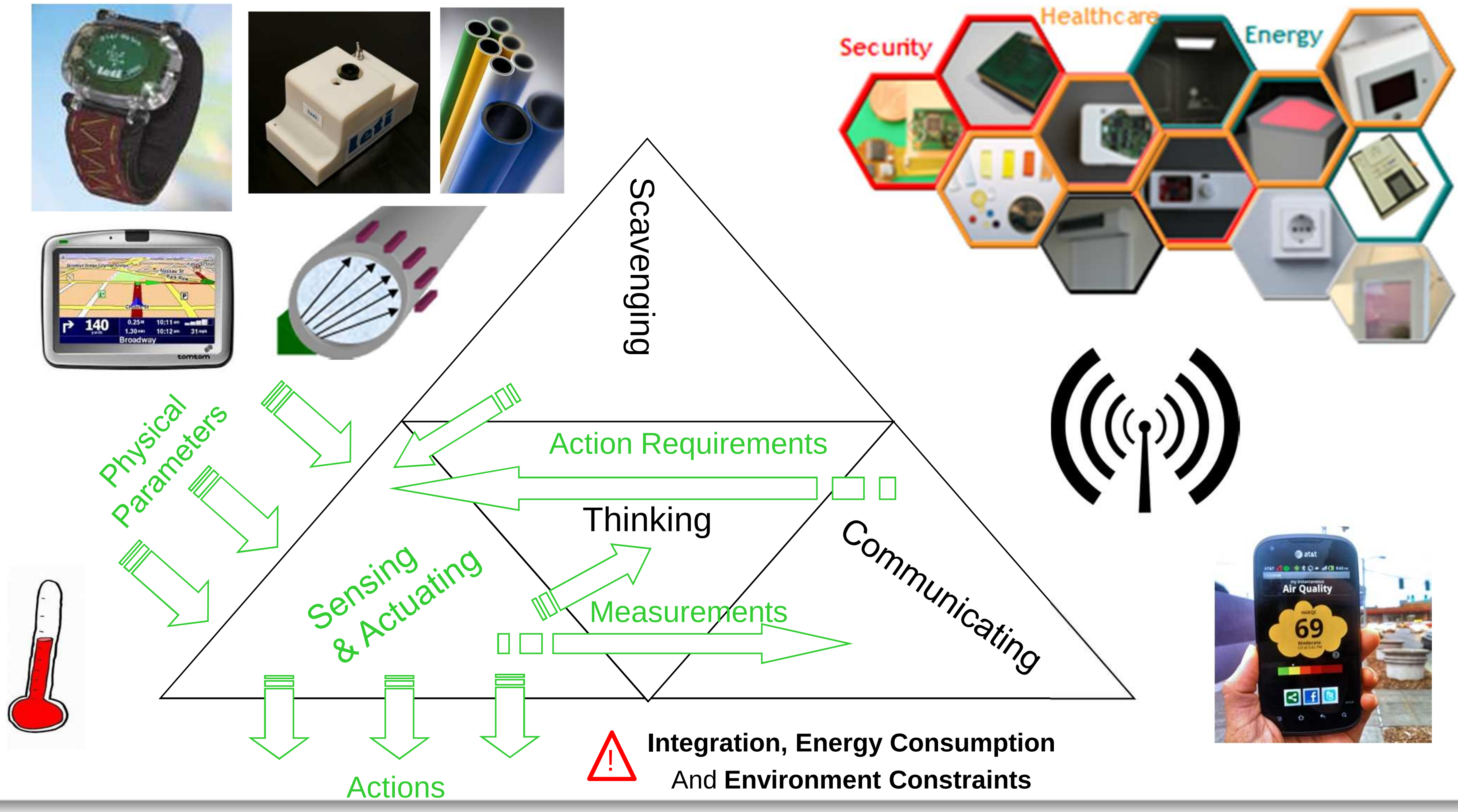
Device Definition (2)

- Function 1: Sensors and Actuators



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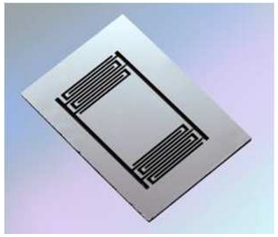
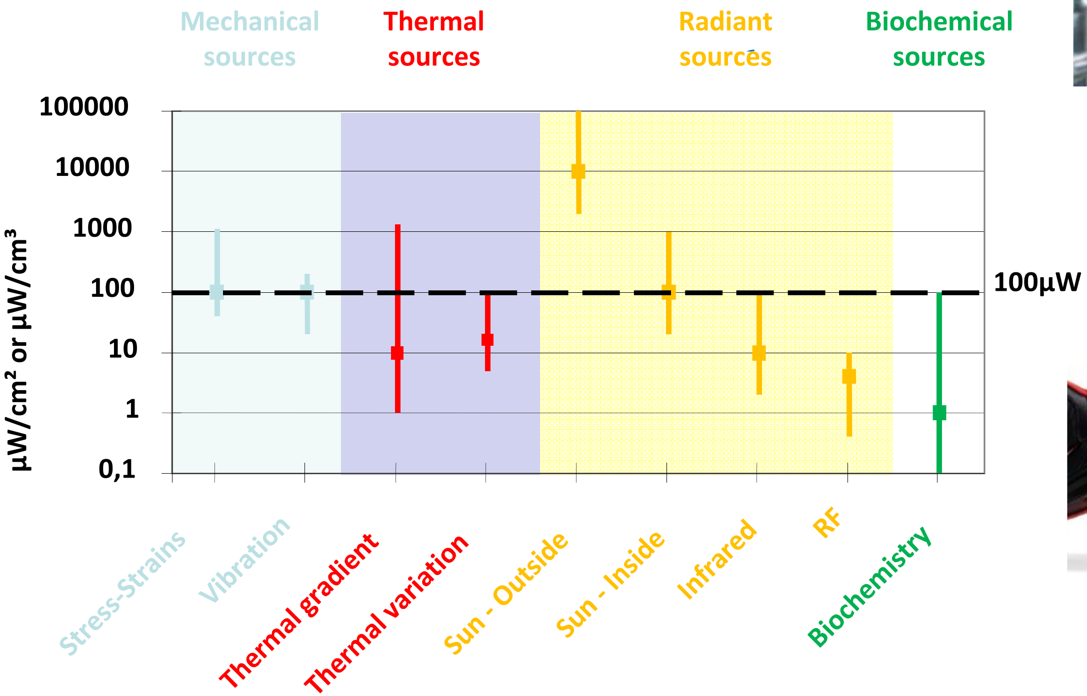
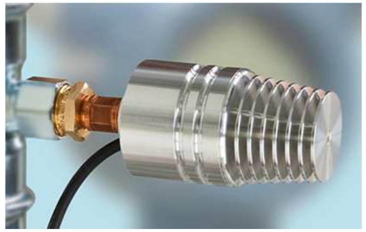
Device Definition (3)

- Function 2: Energy Scavenging







Availability of **Matured** solutions

Good Timing : Energy consumption ≈ Energy Scavenging

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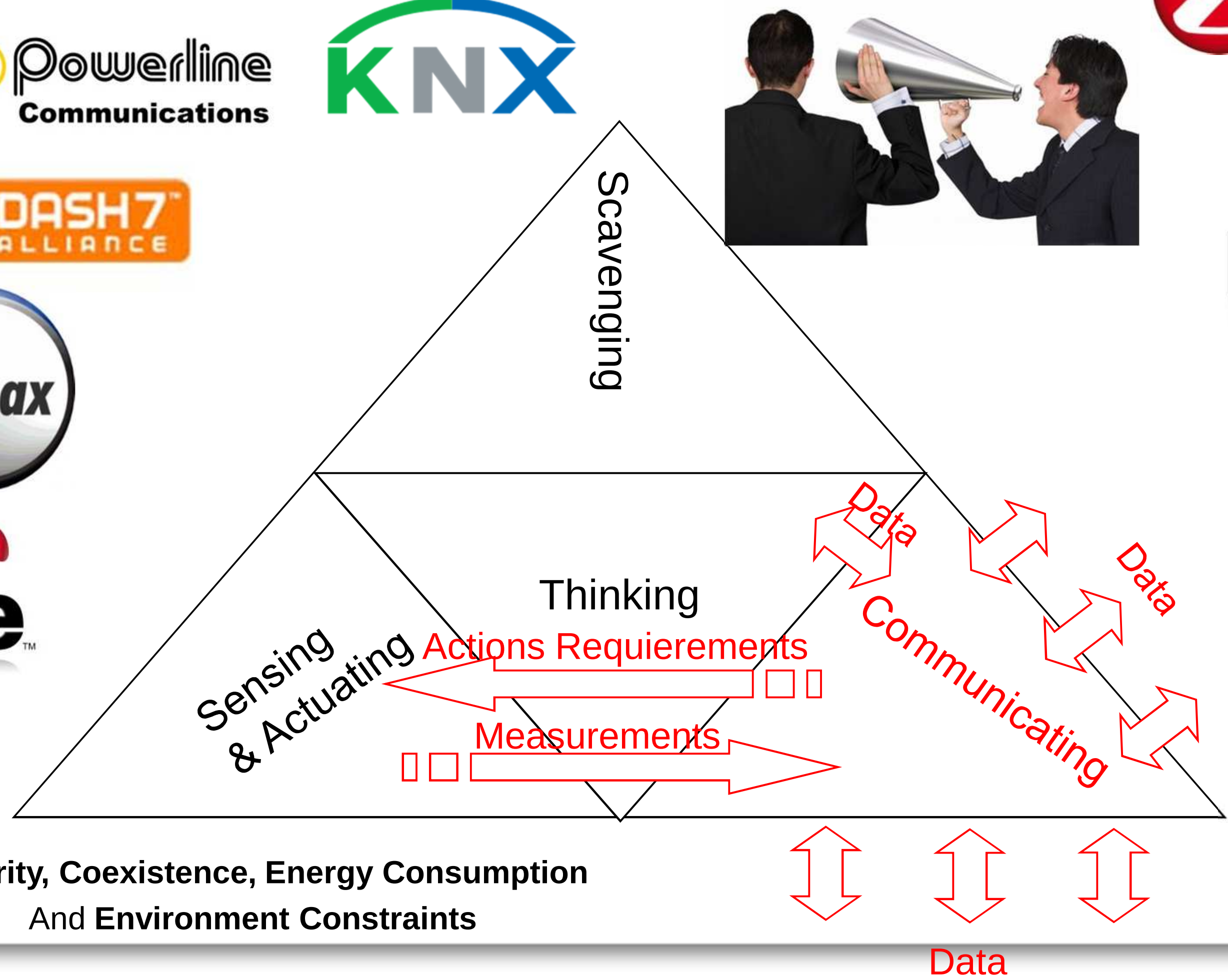
Device Definition (4)

- Function 3: Communications



⚠ **Security, Coexistence, Energy Consumption**
And **Environment Constraints**

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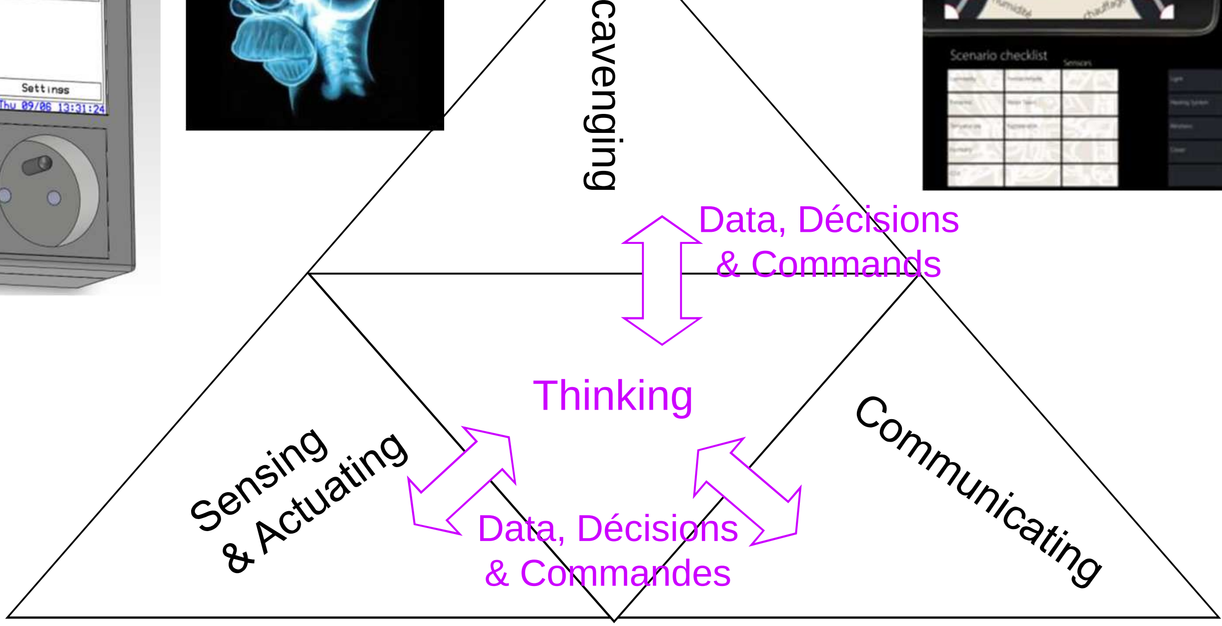
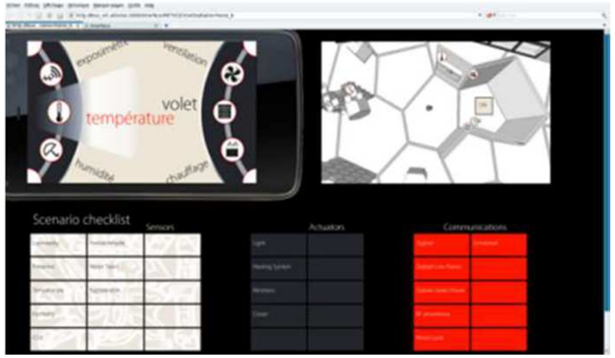
Device Definition (5)

- Function 4: Middleware, Computation, Data Storage





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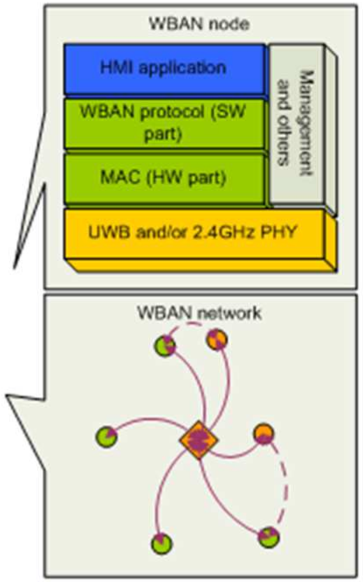
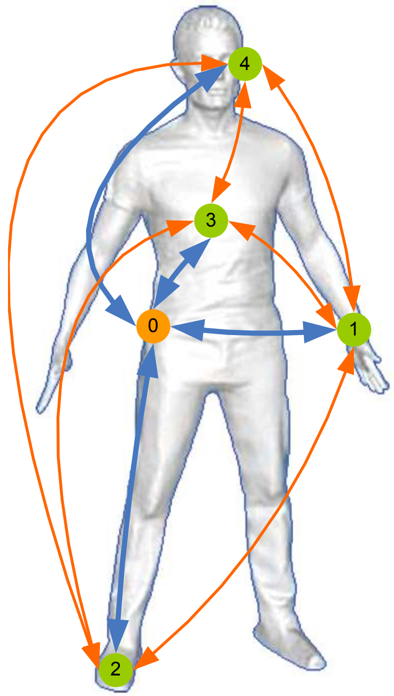
Design innovating functionalities

- An adaptive and low-power communication protocols for Body Area Networks
  - Unique : a common protocol architecture for several applications
  - Flexible (Network size, topology, communication…)
  - Adapted to Body Area Networks
  - Guaranteeing good QoS (reliability, latency,…)
    - Several MACs supporting different traffics.
    - Dynamic and Automatic relaying mechanisms mitigating the shadowing impact on PER
  - Optimized low power consumption for a long autonomy
  - Providing network functionalities (association, self-organizing, data collection…)
  - Transparent for the application thanks to several profiles
    - Autonomously and dynamically adaptive
    - Trade off between QoS and energy consumption
    - Adapted to several applications
    - Adapted to heterogeneous traffics





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Robust On-Body communications (1)

- MAC specification requires specific BAN investigations and optimizations due to the closeness of the human body and its environment.

- The star topology is unstable for BANs

- To face to broken/weak links existence, 3 approaches are possible:
  - Increase transmission power
  - Retransmit when the channel is better (to prevent fast fading)
  - Take advantage of other nodes and asking them for acting as relays (to prevent shadowing effect)

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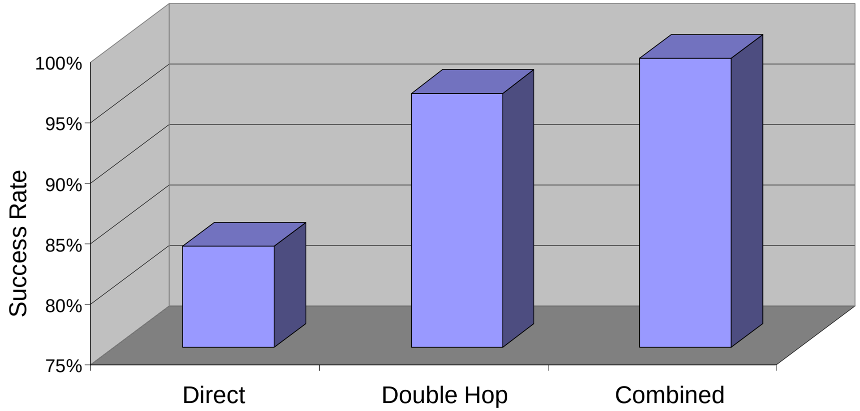
Robust On-Body communications (2)

- Retransmission → No systematic PER improvement
- Spatial diversity through cooperation → Enhanced PER & power performances
- Benefits of relaying functionalities and protocols implemented on complete platforms.



- Relaying mechanisms
  → Same performance with a lower transmission power.
  → Save energy & less pollute the other surrounding communications

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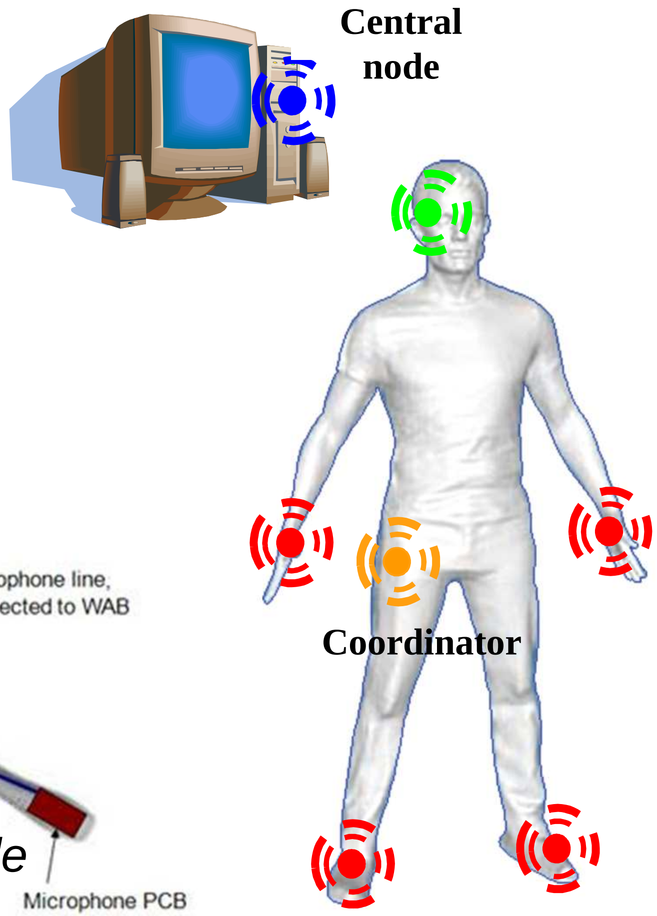
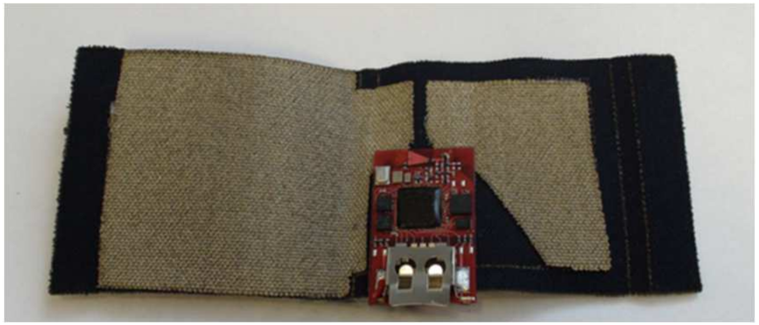
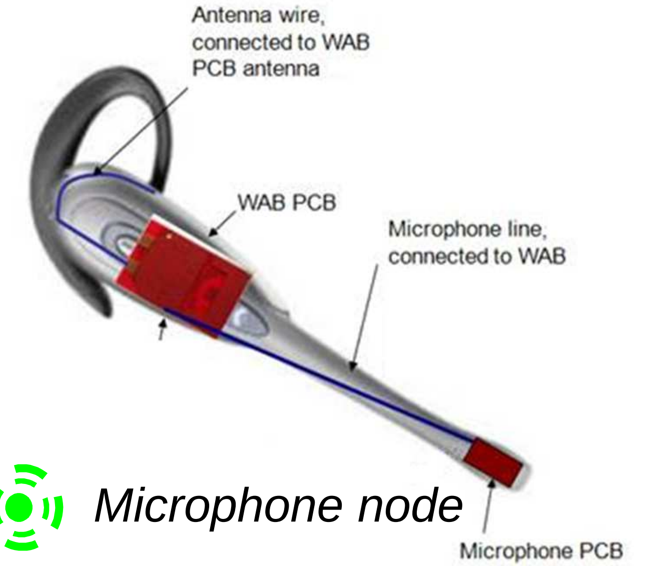
Ex. of implementation & prototyping (1)

- A BAN of heterogeneous modules
  - The motional (e.g. 3D accelerometer, 3D magnetometer and 3D gyrometer) and emotional (e.g. microphone) sensors
  - 868 MHz Radio SoC
  - Adaptive and low-power communication protocol
  - Several application profiles for:
    - Robotics based rehabilitation
    - Daily life physical activity monitoring
    - Gaming





Wear-A-BAN project node with textile antenna



Microphone node

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Ex. of implementation & prototyping (2)

- Protocols extension to fit with more application requirements.
  - 2 different MAC protocols:
    - Low Power Listening-based (LPL), used for low energy consuming, aperiodic and loose traffic
    - Superframe-based MAC, useful for periodic traffic and streaming
  - Management of 3 different PHY Layers:
    - 802.15.4-like PHY (MSK with spreading) with a bit rate of 250 kbit/s
    - Bluetooth-LE PHY (GMSK) with a bit rate of 1 Mbit/s.
    - Proprietary PHY (MSK without spreading) with a bit rate of 2 Mbit/s
  - Definition of new profiles
  - Dynamic selection of the best solution depending on the application requirements
  - Trade off between the QoS and Energy consumption in real time depending on the environment conditions and users activities and needs

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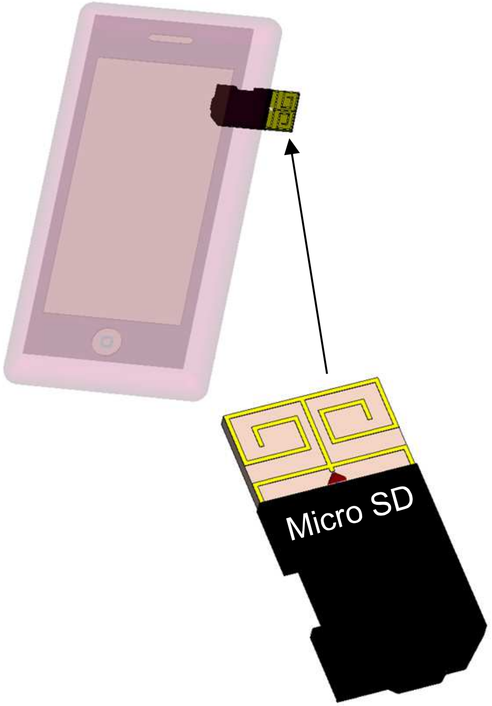
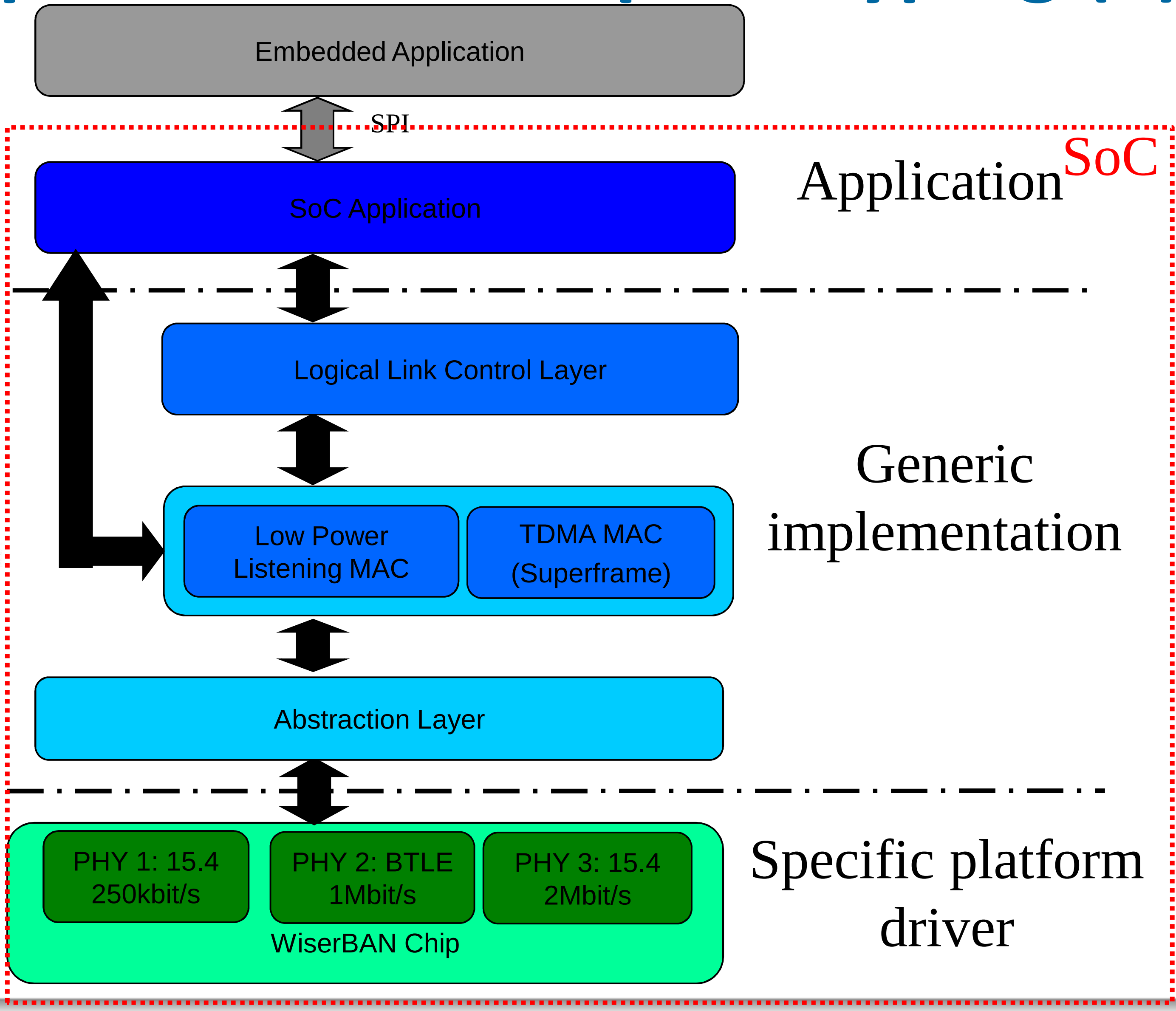
Ex. of implementation & prototyping (3)



2D-SiP
4.2mmx4.3mmx0.770mm



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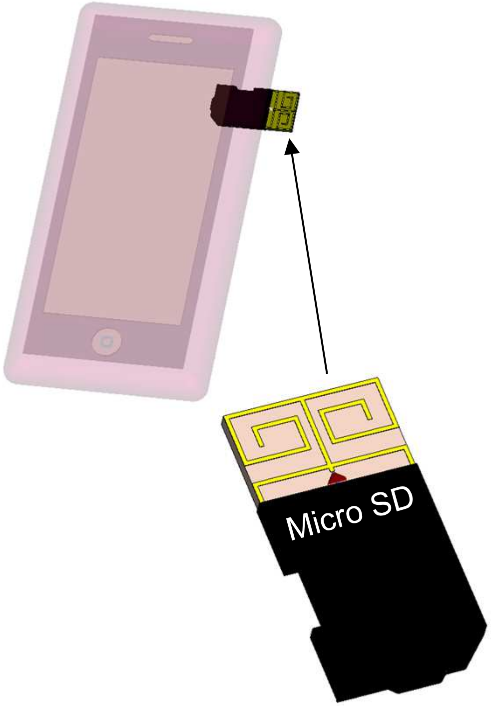

2D-SiP
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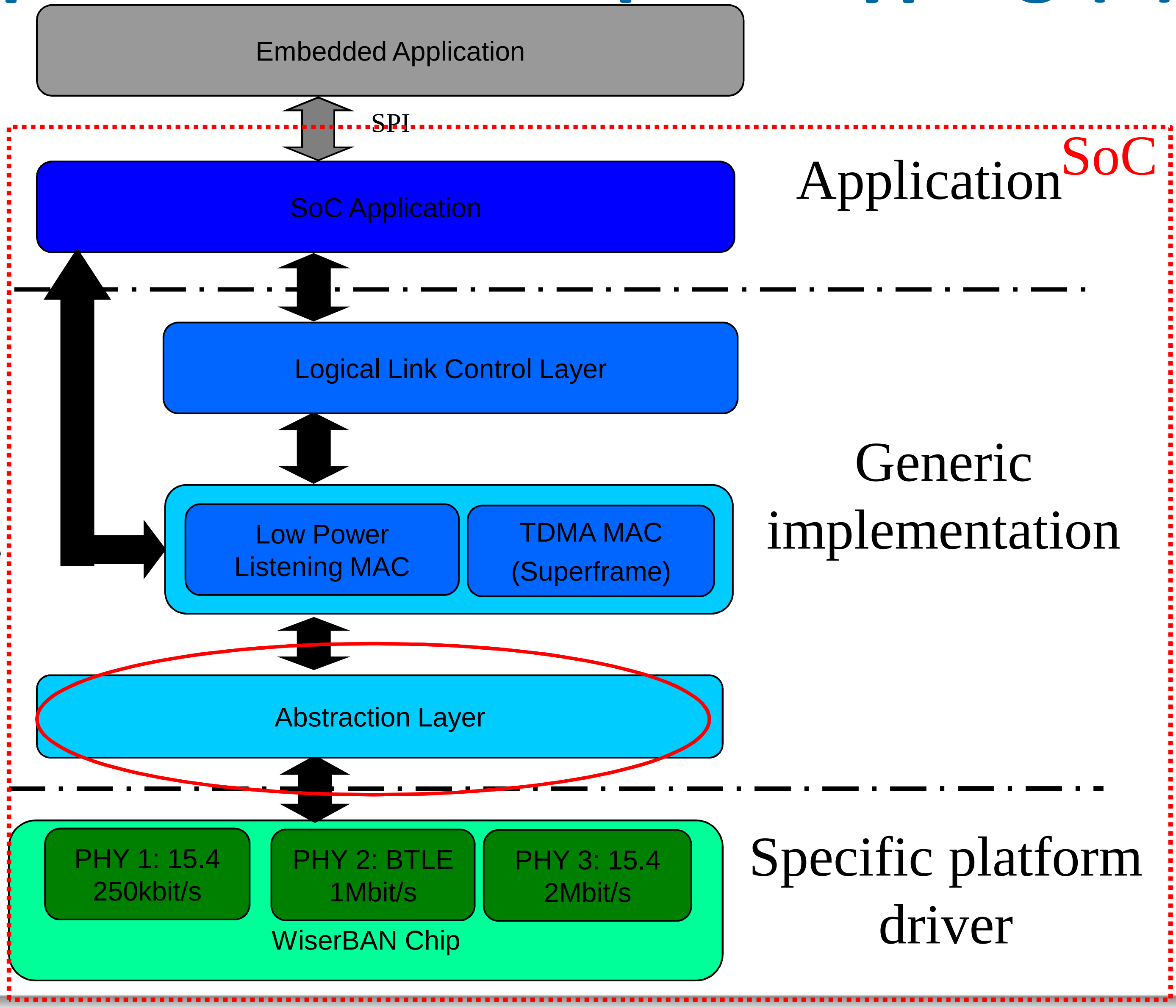

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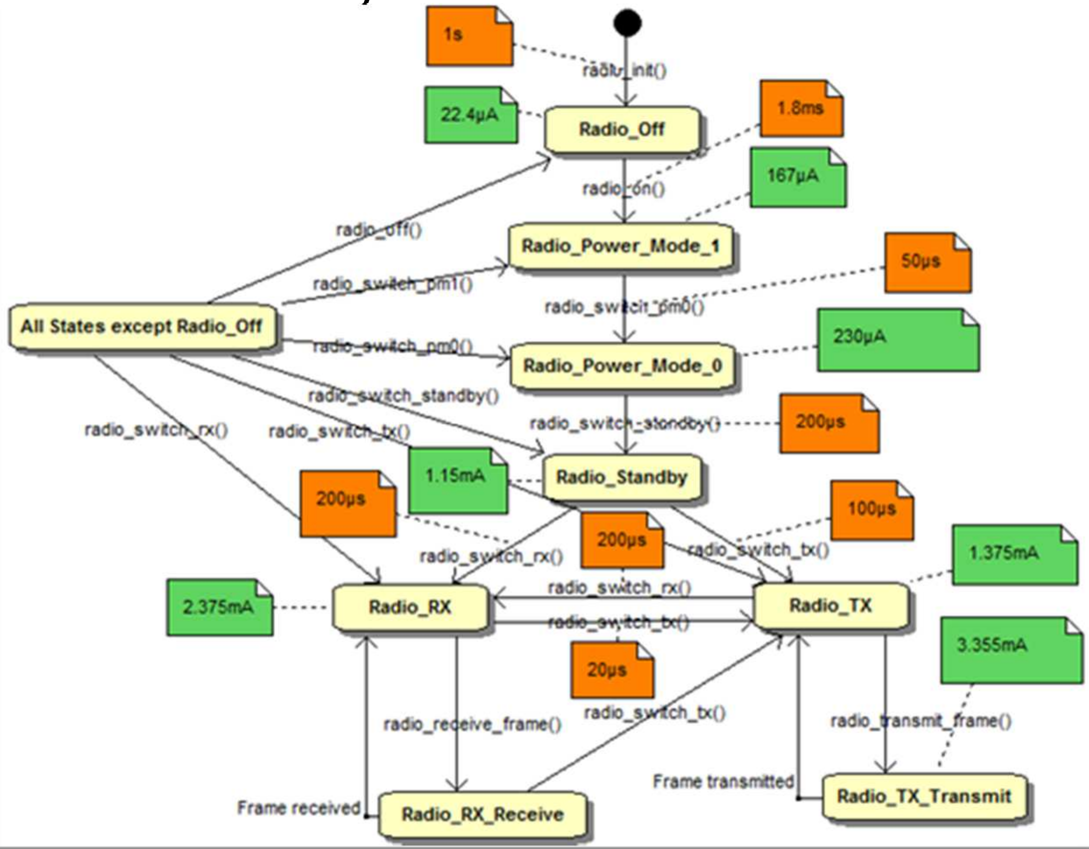
Abstraction Layer

- The Hardware Abstraction Layer provides a programming interface (API) between the protocol stack and the drivers for a specific platform.

⇒ Separating the protocol stacks and the hardware significantly reduces the software portage efforts to another platform.

⇒ Simplify the management of the different PHY layers

- With this Radio state machine, we define a trade off between the energy efficiency and the radio latency.
- Depending on its latency constraint, the MAC layer can choose the most energy efficient radio state.



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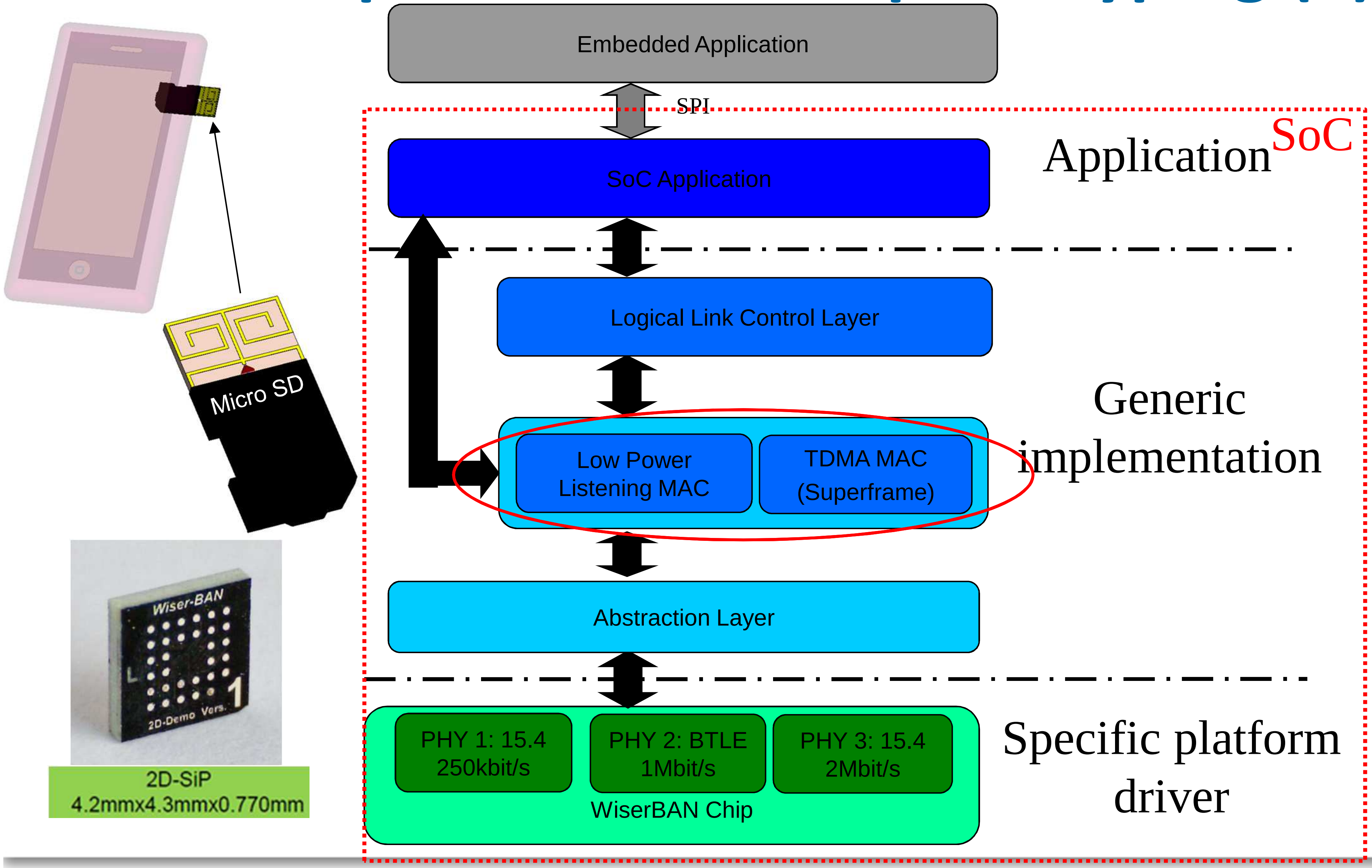
Ex. of implementation & prototyping (3)



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MAC protocol layer

- The Medium Access Control (MAC) Layer provides channel access control mechanisms to several communicating devices.
- The MAC layer is responsible for:
  - The network formation
    - The association and disassociation of devices to the network,
  - The maintenance of the network
    - Manage the list of the node in the BAN
  - The management of the access to the radio channel.
    - A TDMA, centralized and beacon based protocol, inspired from the IEEE802.15.4 standard and, more recently, from the IEEE802.15.6 standard.
    - Dynamic and Automatic Relaying Procedure
    - Low Power Listening-based (LPL) protocol for aperiodic traffic
  - The management of the traffic:
    - Traffic allocation/deallocation and expiration
    - Acknowledgment and retransmission policies
    - Time to live
    - Data relaying
    - Manage the duplicate data

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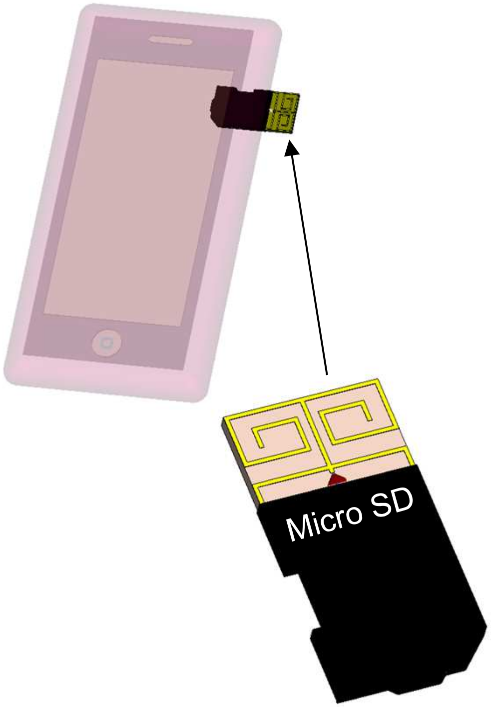
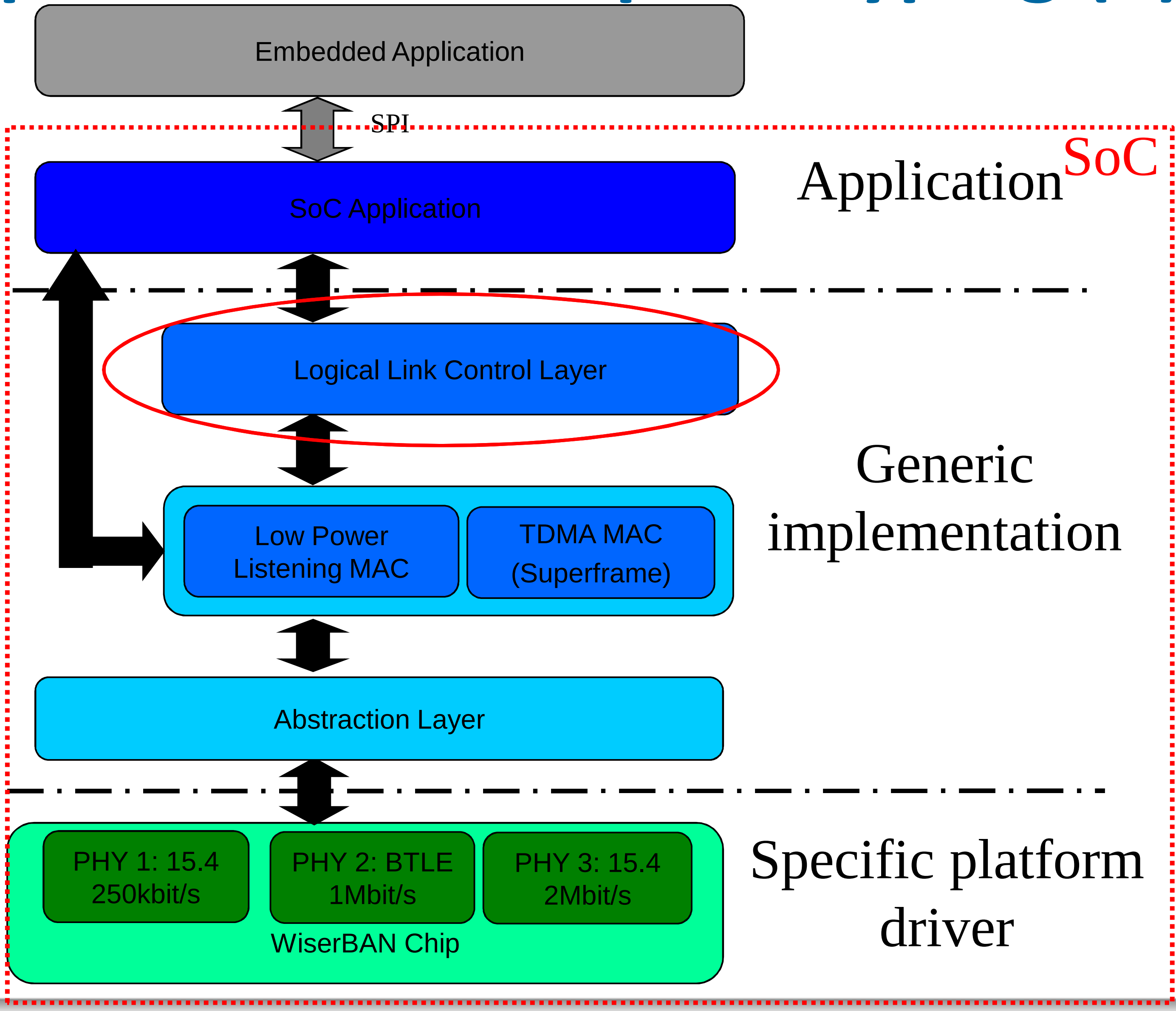
Ex. of implementation & prototyping (3)



2D-SiP
4.2mmx4.3mmx0.770mm



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Logical Link Control Layer

- The Logical Link Control (LLC) sublayer provides an interface between upper sublayers (e.g. Application layer) and the MAC data communication protocol sublayer.

- The LLC manages Data flow to MAC sublayer, Traffic (Bandwidth) and Quality of service :
  - A flow is composed of one or several profiles and each profile corresponds to a set of configuration parameters managing the MAC layer
  - If the QoS configurable by the application is not respected, a flow can switch to the next profile with more functionalities but more consuming.
  - Several flows can be managed simultaneously by the LLC depending on the traffic generated

⇒ This scheme permits to a higher flow priority to used bandwidth to a lower flow priority (e.g. emergency data used bandwidth to monitoring data)

⇒ Thank to the definition of flow with several profiles, the MAC layer becomes adaptive and transparent from Applications viewpoint.

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Logical Link Control Layer

- Each profile is characterized by the following parameters:
  - Priority: This parameter could permit to a higher flow priority to have priority in the access to the channel with respect to a lower flow priority
  - Transmission period (TX period): This parameter indicates the MAC protocol used, and in case of Superframe MAC protocol, the portion of the superframe.
  - Acknowledgement policy (ACK): several policies could be considered:
  - Traffic mode: This parameter selects the type of traffic used
  - Retransmission and Relaying policies
  - Maximum Packet Loss Rate tolerable
  - Packet Time-to-Live (TTL): Time before discarding the data at the MAC layer
  - Packet Rate: Nb of packets per second that the application expects to send
  - Maximum tolerable delay.

Flow category	Fixed parameters								Configurable parameters			
	Profile	Priority	Period	Ack	Permanent traffic	Switched traffic	Retransmit period	Relaying	Packet TTL	Loss rate acceptable	Packet rate	Recipient
Monitoring	Periodic normal data are sent to the Central node in order to analyze and report sensed data											
	1	251	CAP	X	X				X	X	X	X
	2	251	CFP	X	X				X	X	X	X
	3	251	CFP	X	X		CAP		X	X	X	X
	4	251	CFP	X	X		CFP		X	X	X	X
	5	251	CFP	X	X		CAP	X	X	X	X	X

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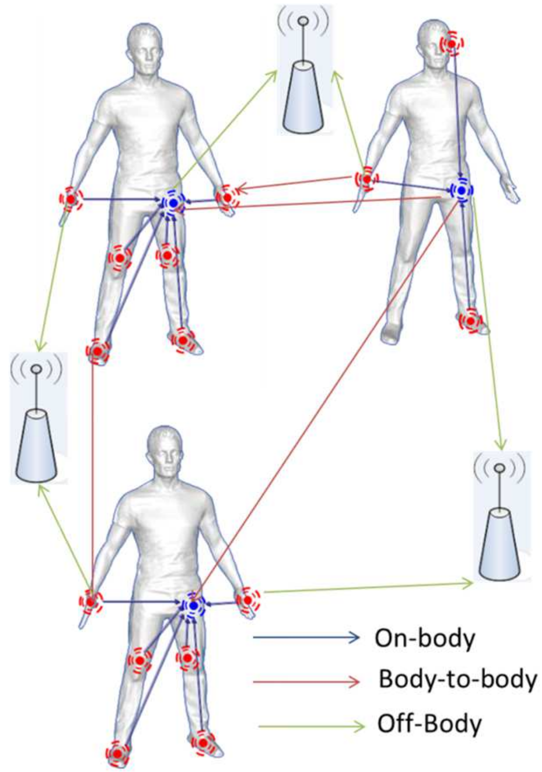
Next Step

- BANs extension to cooperative Body-to Body Networks
  - New requirements imposed by coexistence and collective mobility
  - Robustness of the communication between WBANs and between a WBAN and the deployed infrastructure/surrounding IoTs.
  - Coexistence and interoperability towards the ”Man” integration into the digital world (e.g. smart cities and social networks).



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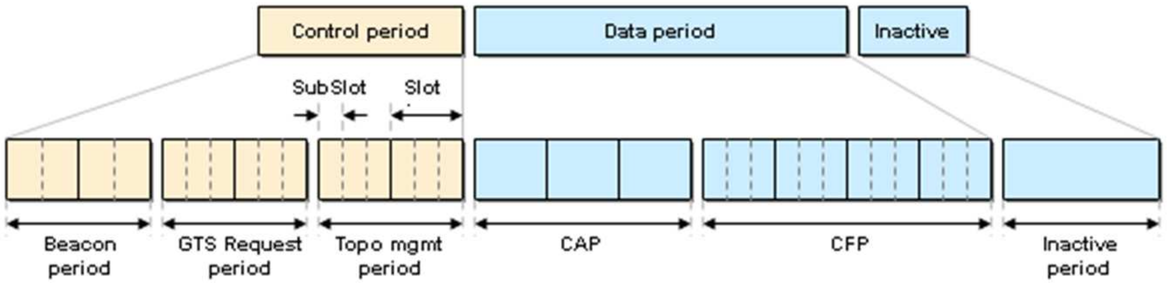
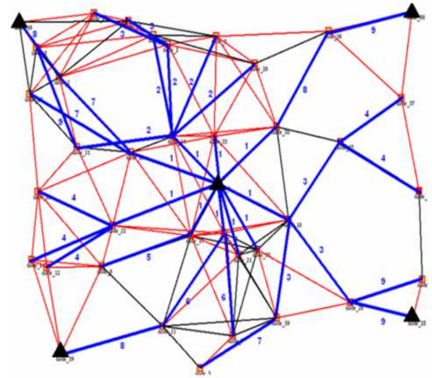
Design innovating functionalities and protocols

- Beacon-based (IEEE802.15.4) + slotted Aloha + tree topology
  - Medium Access Control adapting communication protocols for mesh networks.
  - Adaptation of IEEE 802.15.4 Standard for UWB LDR-LT networks.





- Flexible MAC to allow several classes of applications
  - Control period: beacon period (relaying), GTS request period (CAP), topology management period (hello, tree updates)
  - Data period: CAP (command and associations frames) and CFP (data and ranging frames)
  - The beacon entirely specifies the superframe (Size of different periods, Number of subslots per slot per period, ID of nodes communicating in the guaranteed slots…)

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Localization Platforms

Techno	*Ultra-Large Bande Impulsionnel*		*Zigbee*
Réalisation	« TCR »	« Loreleï »	« Letibee »
Modulation/ Débit	f_0=4.5GHz, BW: 500MHz DBPSK, détection d'NRJ 0.347Mbps à 1Mbps	f_0=3.5 - 4 - 4.5 GHz, BW: 500MHz DBPSK, démod cohérent 0.5Mbps à 64Mbps	f_0=2.4GHz, BW: 5MHz OQPSK + half sinc 250kbps
Précision radioloc	< 30cm @20m < 50 cm @40m	< 5 cm	< 60 cm@10m < 5 m @100m
Portée	40m	50m à 100m	50m à 100m
Mesure	Temps de Vol	Temps de Vol	Puissance Reçue
Maturité d'Intégration	Circuit Tx/Rx + Plateforme complète (SW)	Circuit Rx + Plateforme en cours de développement	Circuit Tx/Rx + Plateforme complète (SW)
Standard & Régulation	Standard (IEEE 802.15.4a)	Standard (IEEE 802.15.4a)	Standard (IEEE 802.15.4)
Consommation	Radio. 20mW(Tx) & 50mW(Rx)	Radio. 50mW (Rx)	Radio. 15mW (Tx)& 9mW (Rx)
Applications & Marchés	Capteurs, Domotique, Automobile	Logistique Précise, Sports	Capteurs, Logistique, Inventaires

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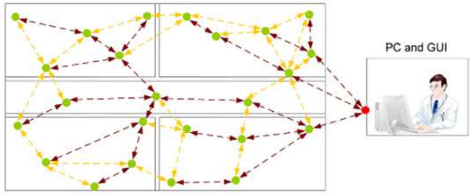
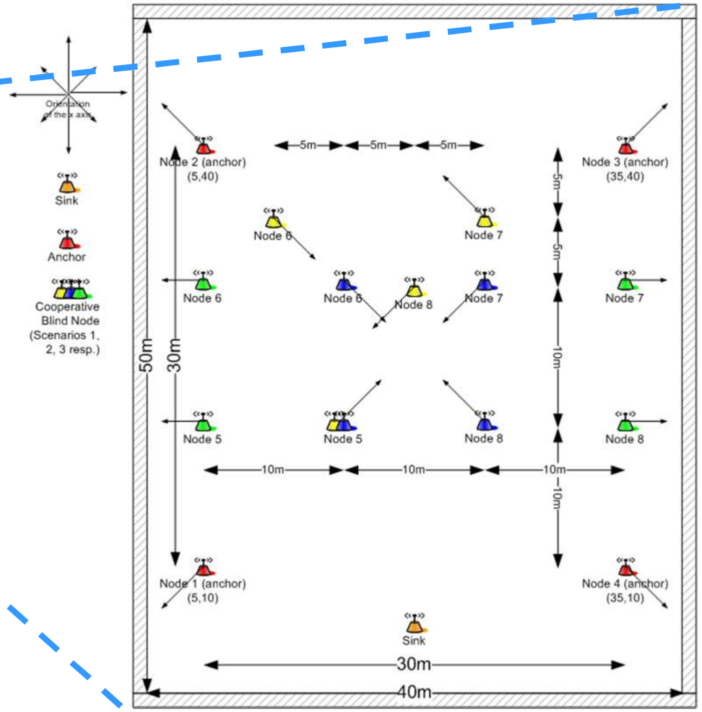
Localization Platform (LETIBEE)



Application
Localization,
Physical measurements…

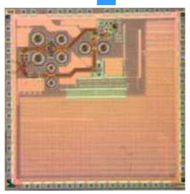
DEMONSTRATION

Validation platforms
« Letibee » Node



INTEGRATION

\+ Location-enabled Higher Layers (MAC/NWK)
Neigh./Route discrvery, Multi-hop, Mesh, CSMA-CA



IEEE 802.15.4 ULP Radio
« Letibee » Chip

Ex. Self-calibrating cooperative positioning with a mesh network topology and very low anchors density…

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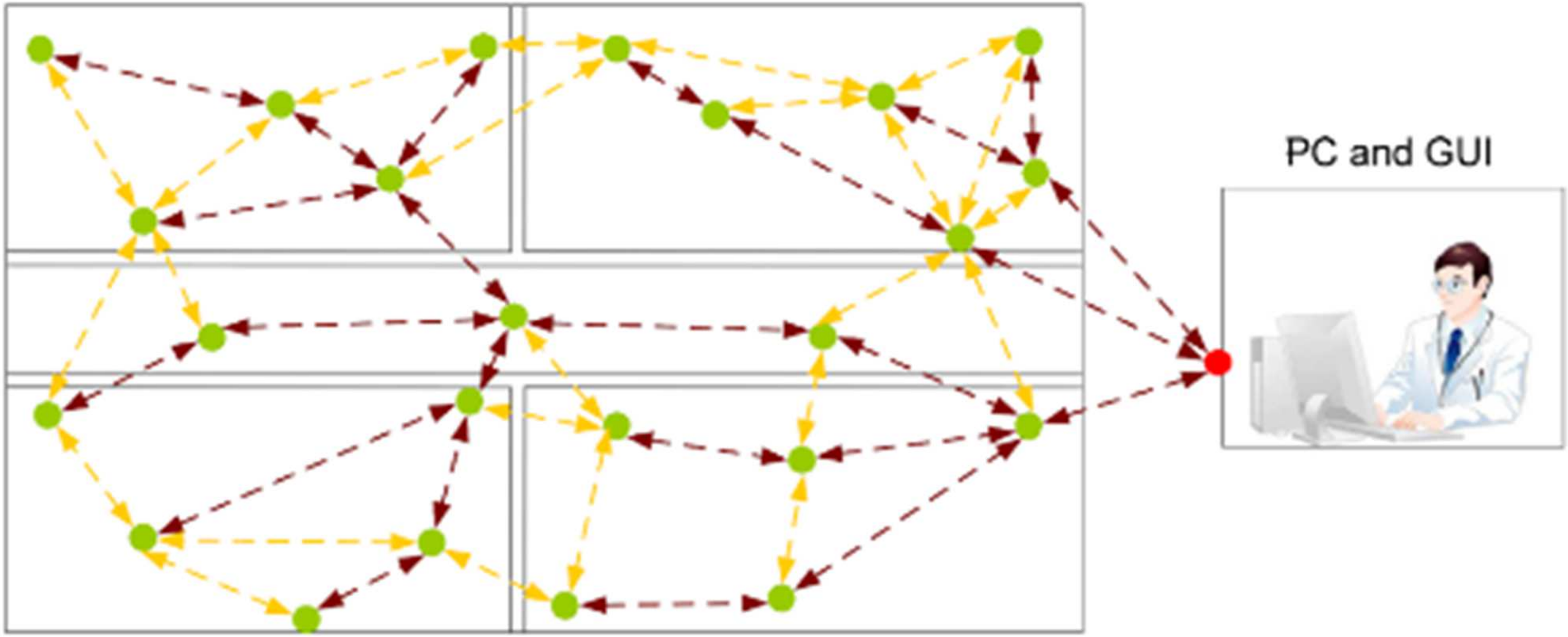
Wireless Sensor Network Validation

- Experimental Wireless Sensor Network
  - A complete IEEE802.15.4 compliant network composed of commercial nodes (Sensinode with TI CC2431 radio module) and Letibee nodes
  - The implementation of routing protocols
  - Real-time performance of data collection and localisation algorithms.
- Thanks to WSNet simulation, we extend our network to large scale wireless sensor networks in order to evaluate the global gathering time of measurements



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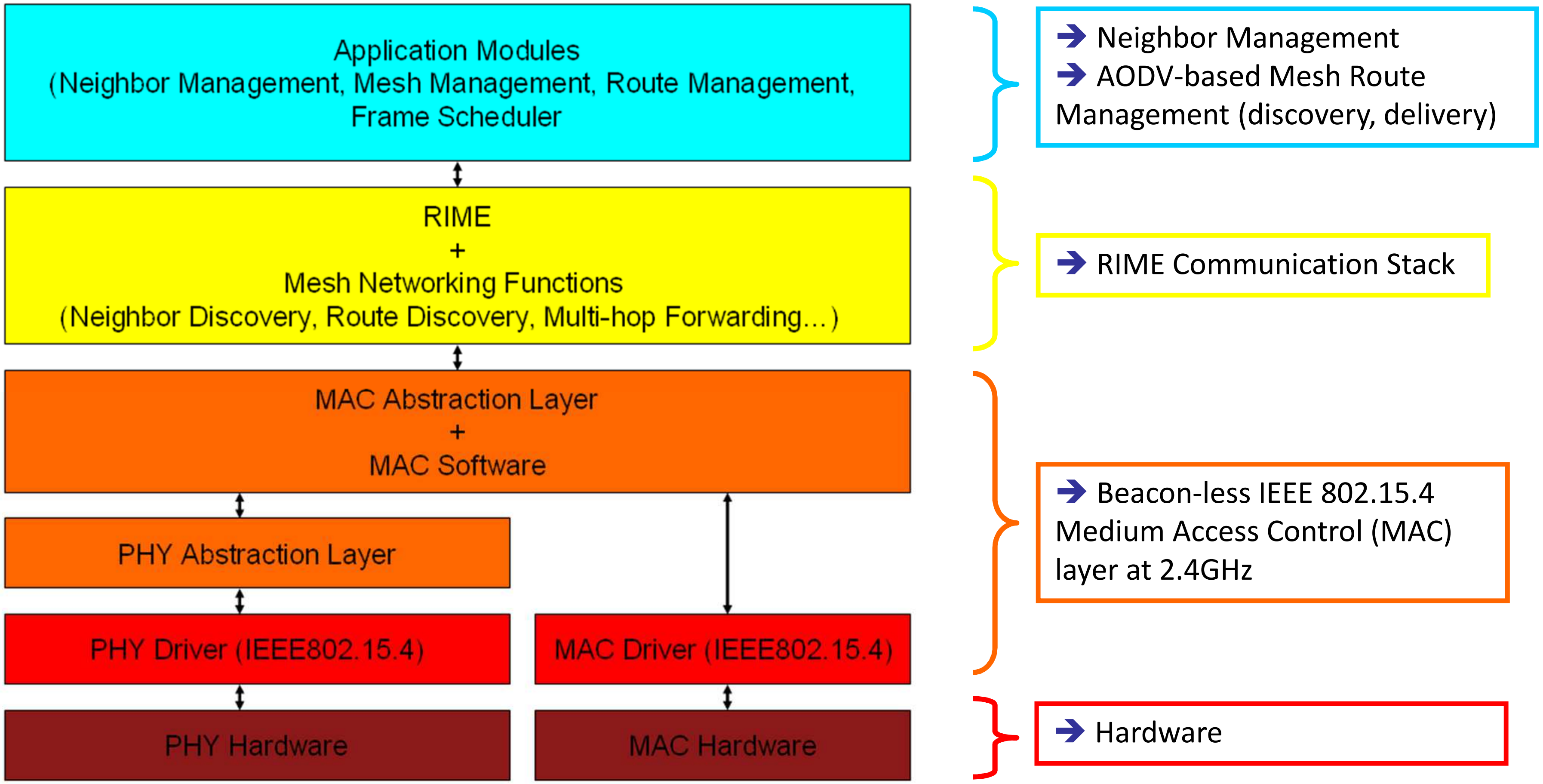
Implementation

- The implementation of the HW platform is based on the RIME protocol stack and Contiki v2.4 operating system:



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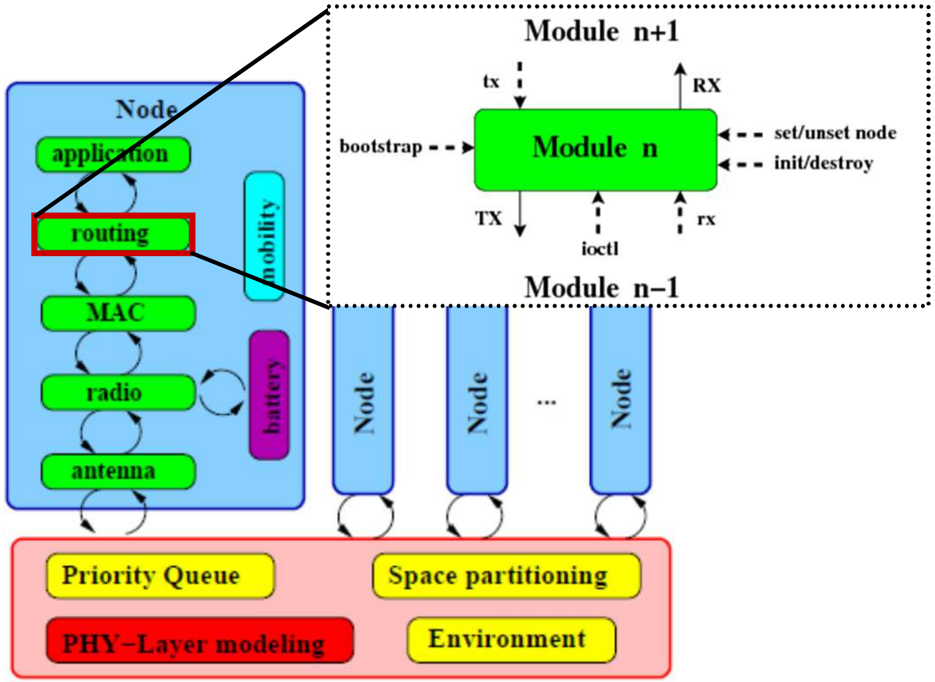
Simulation

- WSNet is a complete and modular simulation environment for large scale and mobile wireless networks (sensor, adhoc, mesh, etc.) :
  - Written in C for Linux/Unix based OS
  - Under the CeCILL Free Software License
- Node modeling:
  - Mobility and battery model
  - From Application to MAC protocols
- Realistic PHY modeling:
  - Pathloss, fading, shadowing
  - Full interference modeling
  - SNR/PER PHY Abstraction



- Network/Routing layer
  - Evaluation of the Network/routing layer implemented in the HW platform
  - Comparison to evolved WSN specific data dissemination and collection protocols (from the literature) and compatibles with the RIME stack

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Outline

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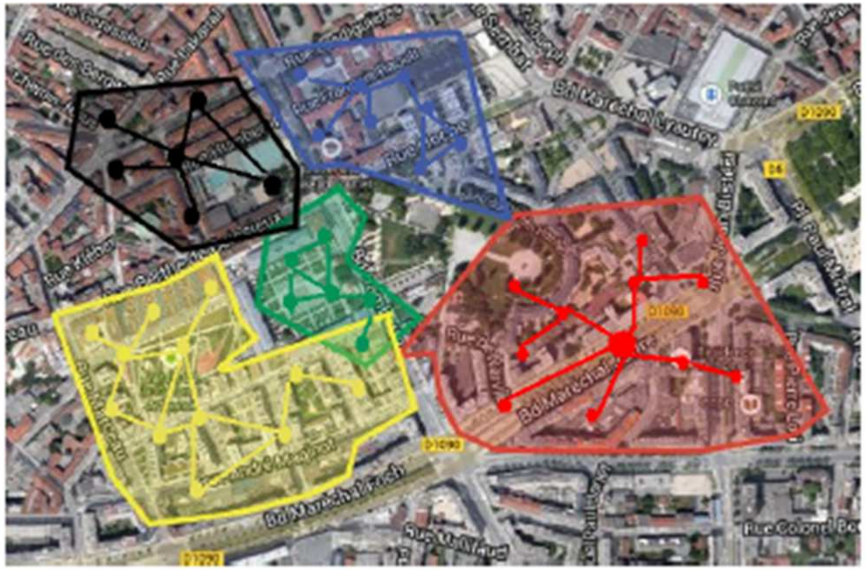
Context

- Wireless Sensor Networks are self-organized and multi-hop networks which need high throughput, QoS support, scalability and low energy consumption.
- No universal routing solution that outperforms all the others. It is necessary to select the protocols that are best fitted to some particular requirements.
- In smart cities context, the main drawbacks of wireless sensors networks are the lack of mechanisms for managing communications between different networks and the limited coverage for a given target reliability.



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Objective

- **Autonomous Routing protocol** i.e. self configurable, self maintenance and self healing
  - Provide satifying QoS
    - Robust data delivery
    - Low latency
  - Minimize energy consumption
  - Interact with deployed architectures
  - Manage heterogeneity of applications
  - Support node mobility without communication interruption
  - Real-time selection of the best conditions of communication
  - Self configuration of the network
  - Self healing in all situation (normal, failure…) i.e. discover diagnostic and react to dysfunctions.

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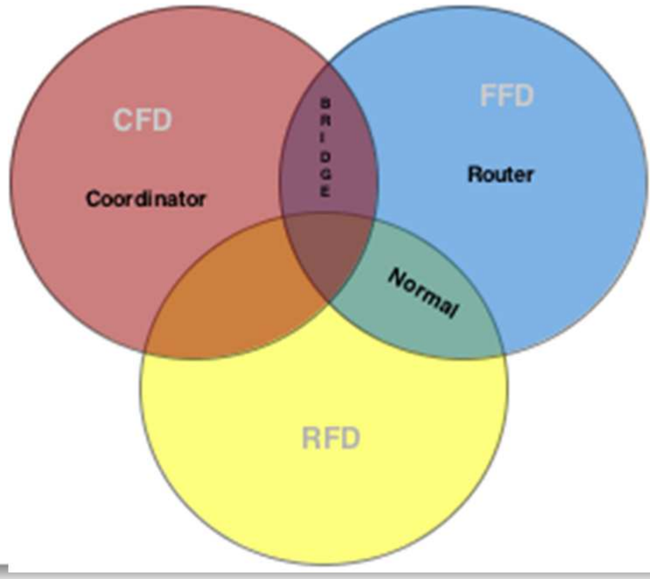
Cross-layer MAC&Routing protocol (1)

- CLUster Based CROss layer Multi-channel protocol (CLUBCROM)
  - Several roles
    - Coordinator: only one CFD per cluster. responsible for association management, beacon scheduling and periods scheduling.
    - Router: Relay beacons and association messages and increase the cluster coverage
    - Bridge: Communicate with other clusters through dedicated channels
    - Normal



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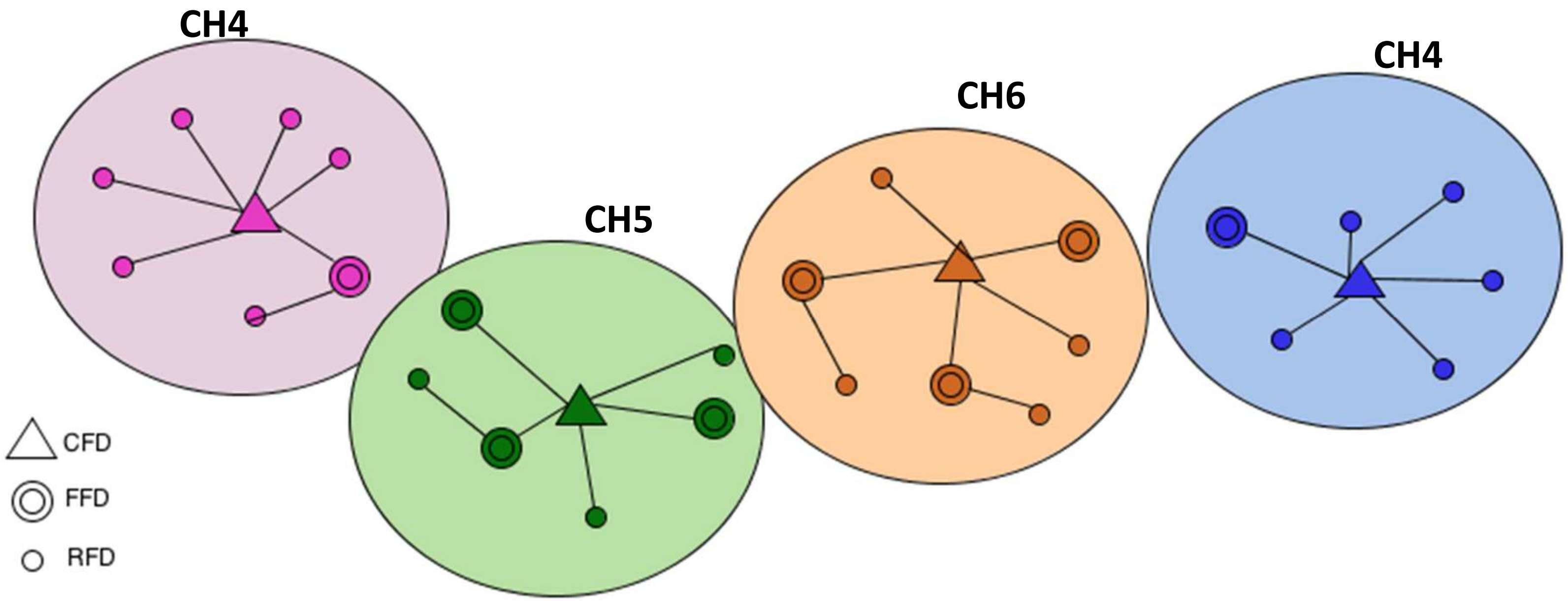
Cross-layer MAC&Routing protocol (2)

- CLUster Based CROss layer Multi-channel protocol (CLUBCROM)
  - Several roles
  - Clusters
    - On different channels
    - Channel reuse possible



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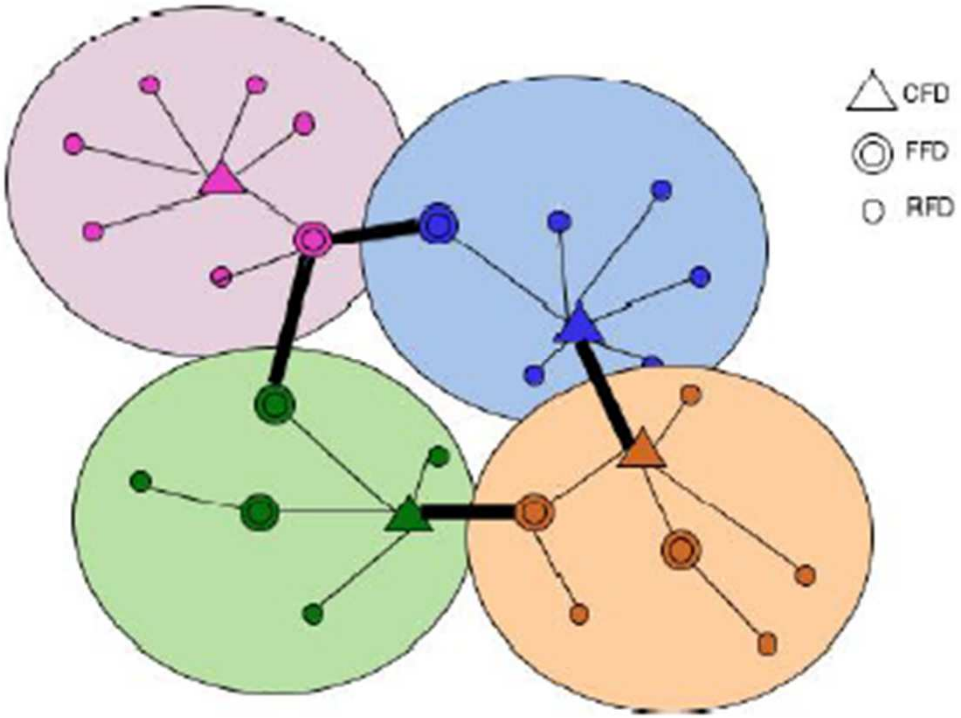
Cross-layer MAC&Routing protocol (3)

- CLUster Based CROss layer Multi-channel protocol (CLUBCROM)
  - Several roles
  - Clusters
  - Bridge method



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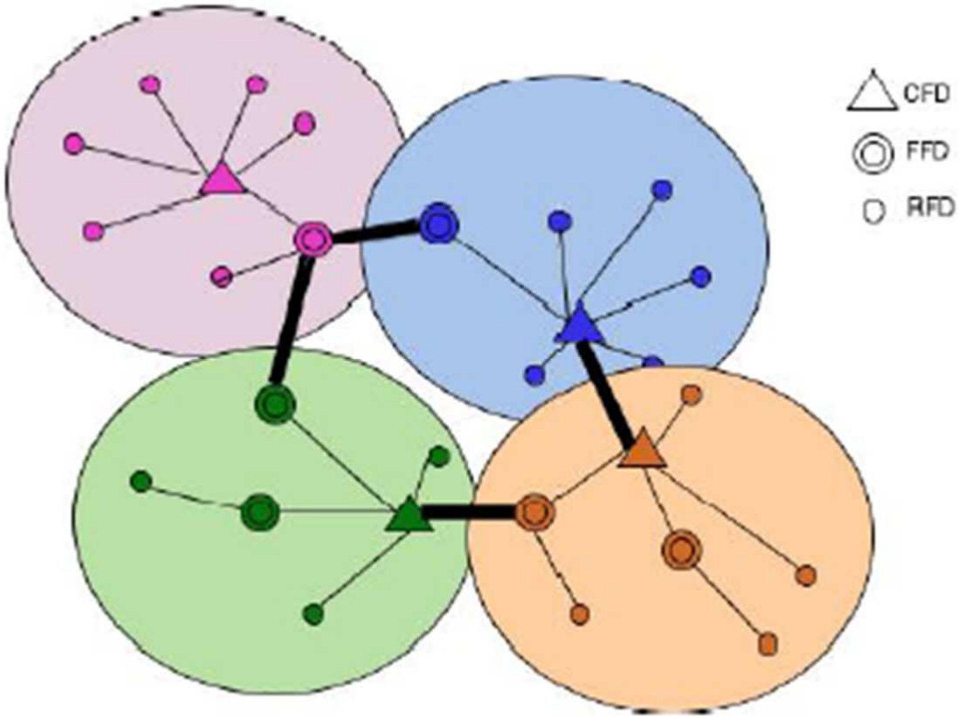
Cross-layer MAC&Routing protocol (4)

- CLUster Based CROss layer Multi-channel protocol (CLUBCROM)
  - Several roles
  - Clusters
  - Bridge method



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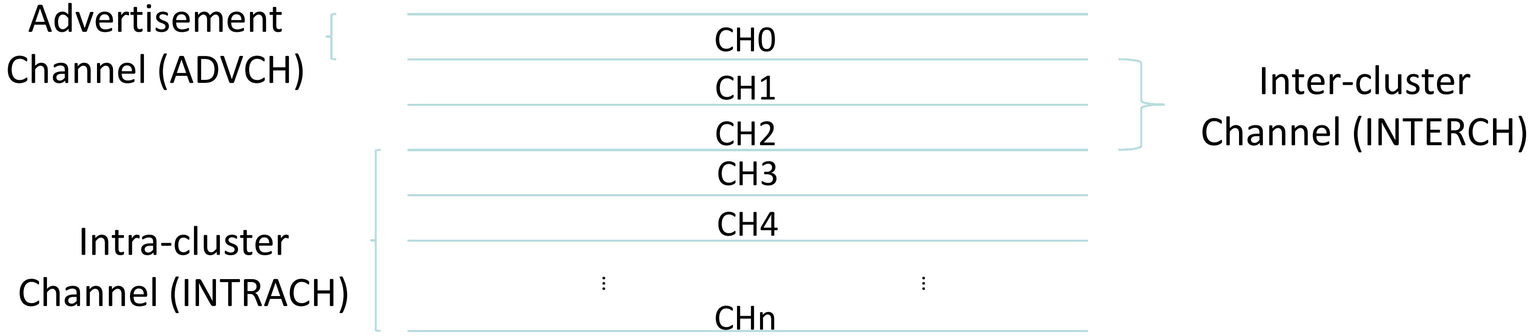
Cross-layer MAC&Routing protocol (5)

- CLUster Based CROss layer Multi-channel protocol (CLUBCROM)
  - Several roles
  - Clusters
  - Bridge method
  - Simple and flexible
  - 3 communication schemes
    - Intra-cluster communications
    - Advertisement communications on a dedicated channel for coexistence
    - Inter-cluster communications for cooperation



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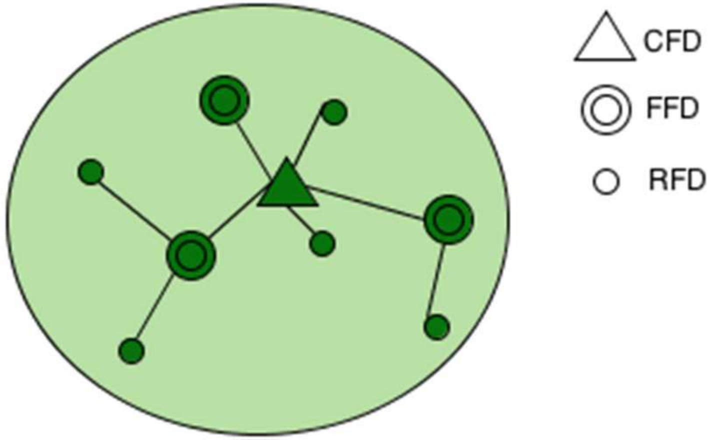
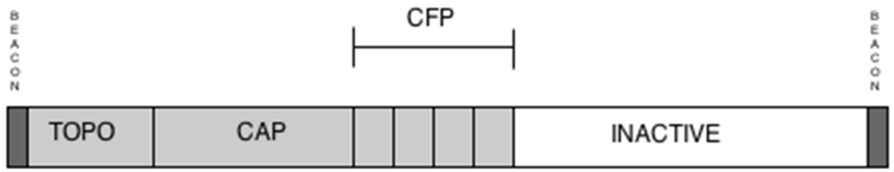
Cross-layer MAC&Routing protocol (6)

1. Intra-cluster communications
   - Ordinary Intra-cluster Channel (INTRACH)
   - Superframe (IEEE802.15.4)
   - Beacon
   - Association (Normal, Router, Bridge)





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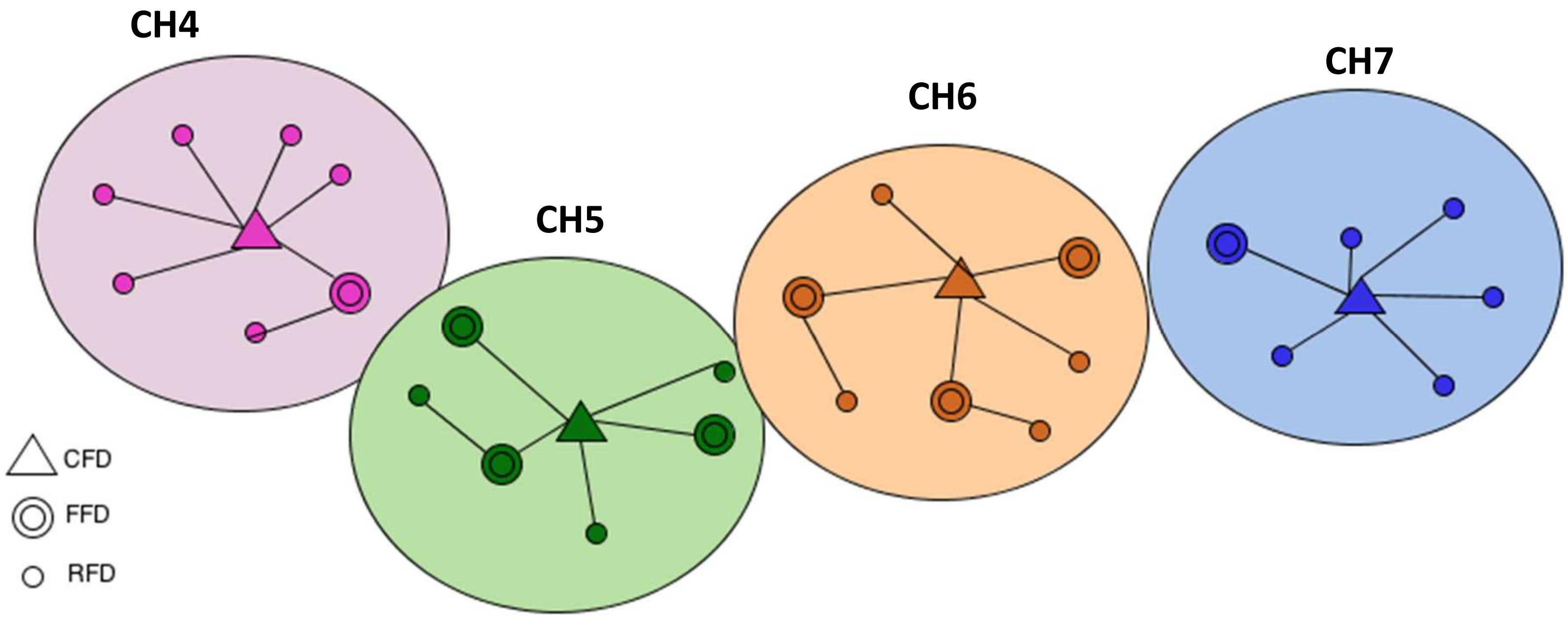
Cross-layer MAC&Routing protocol (6)

1. Intra-cluster communications
   - Each network on a different channels (Coexistence)
   - Intra-cluster routing based on scheduling tree and on-demand (Centralized)



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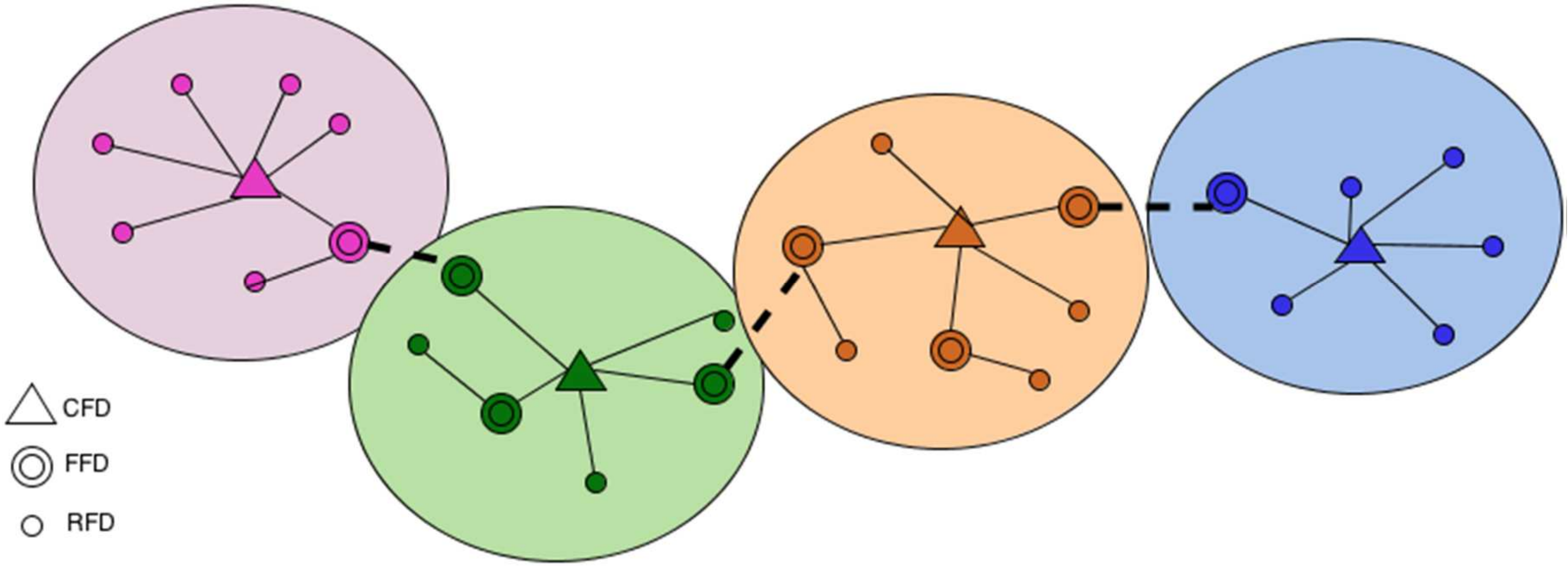
Cross-layer MAC&Routing protocol (7)

2. Advertisement communications on a dedicated channel (ADVCH)
   - Detect the presence of different clusters



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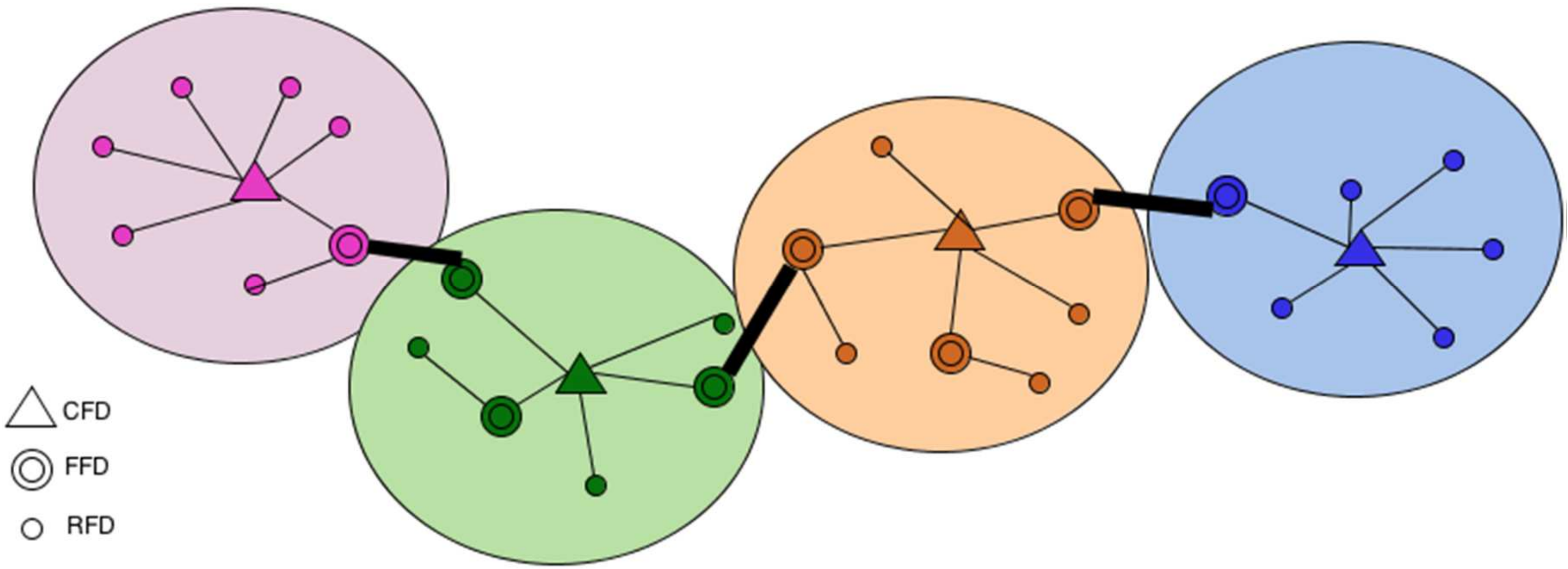
Cross-layer MAC&Routing protocol (8)

3. Inter-cluster communications
   - Dedicated cooperative Inter-cluster Channels (INTERCH)



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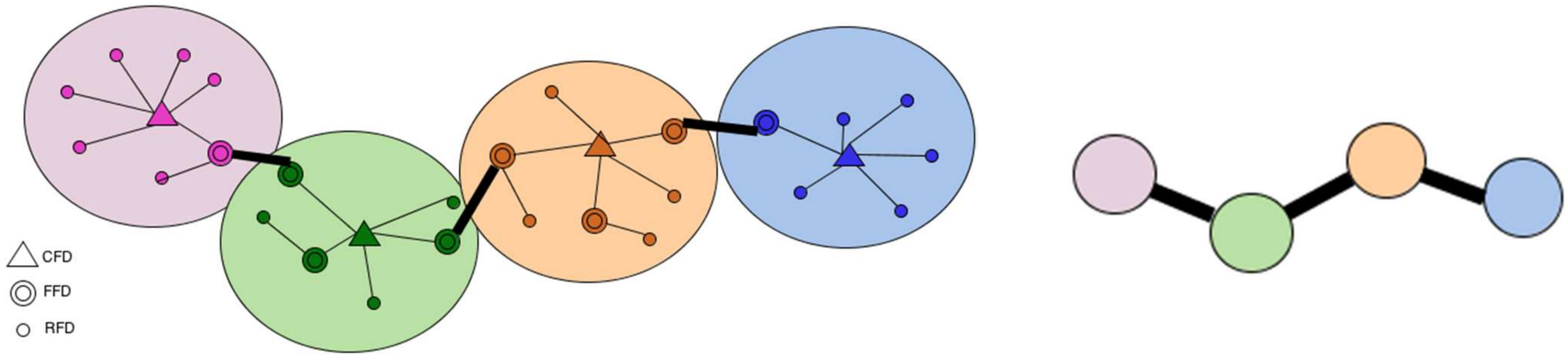
Cross-layer MAC&Routing protocol (8)

3. Inter-cluster communications
   - Dedicated cooperative Inter-cluster Channels (INTERCH)
   - Inter-cluster communication scheme based on preamble sampling
   - High level inter-cluster routing protocol (Distributed)
     - Cluster = primary cache “device” i.e. respond through bridge or coordinator on behalf of associated devices
     - Simple inter-cluster routing based on AODV (not multi-hop but multi-cluster)



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Outline

I. LESC & LSP Lab
II. WSN & WBAN & IoT
III. BAN Protocols
   A. Design and Specification
   B. Implementation
IV. WSN Protocols
   A. Design and Specification
   B. Implementation
V. Routing protocols
VI. Conclusion

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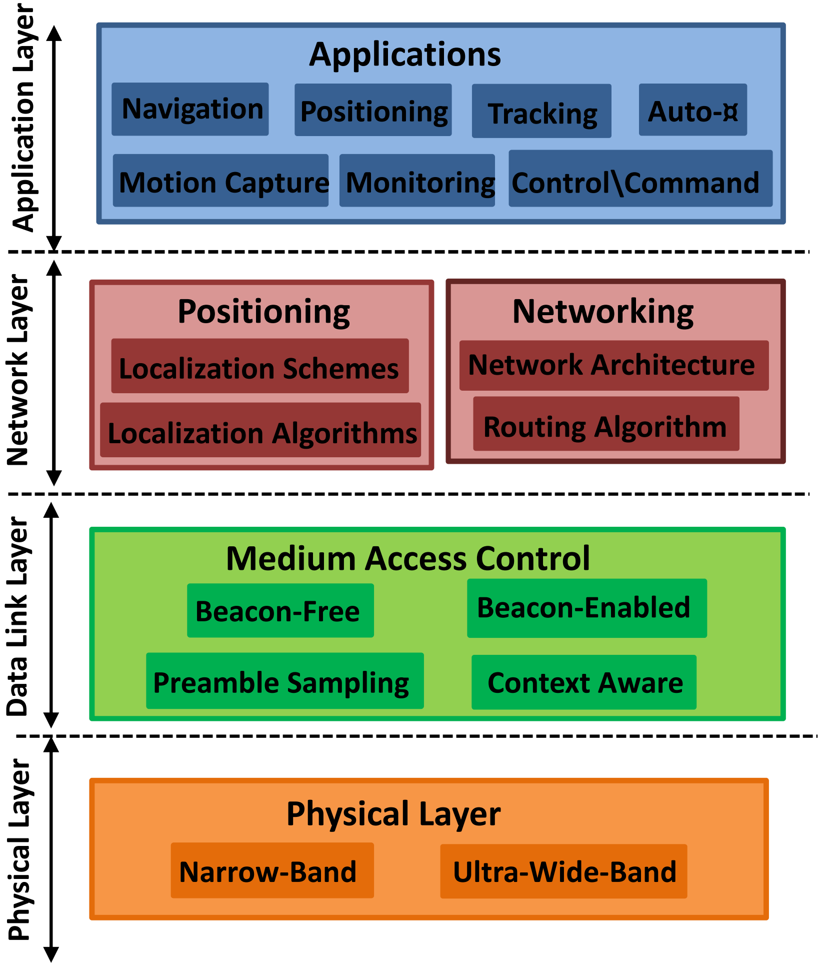
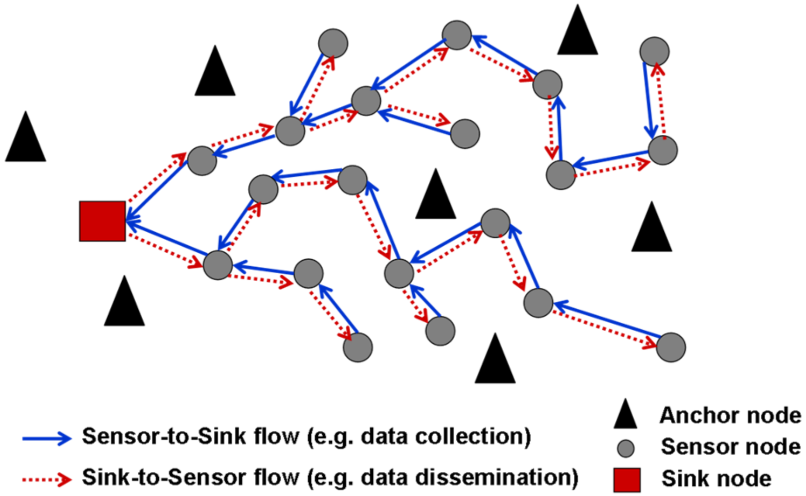
Conclusions



- A Wireless sensor networks consists in multiple tiny, low-power and hardware-constrained wireless sensor devices deployed, randomly or manually, over an area of interest to provide a wide range of applications, including weather/environment monitoring, intrusion detection, target tracking, surveillance, etc.



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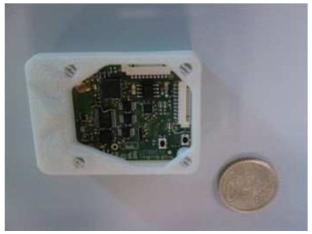
Platforms

		Traffic management, Profiles and Applications		Localg Applications		MOVEA Applications
PULSERS MAC**…		BATMAC*	BATMAC* and preamble sampling	RIME ou BATMAC* (soon)		Simple 2-hop relaying extension BlueSync [MOVEA] Centralized star topology
Linux OS	Linux OS	No OS		Contiki OS (open Source)		
ARM9 (ARM) [LETI] 32 bits DSP/MCU 16 MB RAM	ARM7TDMI (ARM) [LETI] 32 bits DSP/MCU 160 kB RAM	Icyflex [CSEM] 32 bits DSP/MCU 96 kB RAM	Icyflex [CSEM] 32 bits DSP/MCU 96 kB RAM	8051 (Oregano) [LETI] 8 bits MCU 64 kB RAM	8051 [TI] 8 bits MCU 128 kB RAM	8051 [Nordic] 8 bits MCU 128 kB RAM
TCR\Lorelei [LETI] UWB 4 GHz	TCR [LETI] 4 GHz, 350 kbit/s 40 mA RX, -85dBm sensi.	Icycom [CSEM] 868-915 MHz, 200 kbit/s 2 mA RX, -105dBm sensi.	WiserBAN [Leti+CSEM] 2.4 GHz, 250, 1000-2000 kbit/s tbd	Letibee [LETI] 2.4 GHz, 250 kbit/s 9mA RX, -85 dBm sensi.	CC2431 [TI] 2.4 GHz, 250 kbit/s 16mA RX, -92 dBm sensi.	nRF24L01 [Nordic] 2.4 GHz, 250 kbit/s 9mA RX, -85 dBm sensi
IR-UWB	IR-UWB IEEE 802.15.4**a**		IEEE 802.15.4 / BT-LE	IEEE 802.15.4	IEEE 802.15.4	IEEE 802.15.4
	3A3M3G	3A3M3G, Micro	3A3M3G, Micro	Light, Temp, 3A3M	Light, Temp	3A3M3G
	[LETI] TCR	[CSEM] Icycom HDK	WiserBAN Node	[LETI] LetiNode	[Sensinode] N711	[MOVEA] MotionPod

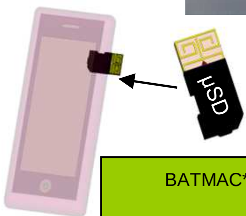
Colors Code

- Leti's Developments
- NWK+Application
- MAC (SW)
- Embedded OS
- Processor
- PHY Chip
- PHY Techno/Standard
- Sensors
- Platform name









BATMAC* for BAN = Centralized, star with 2-hop relaying extension, beacon, flexible superframe, TDMA+CFP+ALOHA access

PULSERS** for WSN = Centralized, beacon, flexible superframe, TDMA+CFP+ALOHA access

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Merci de votre attention