with special guest:

OpenWSN: Building the Internet of (Important) Things

Thomas Watteyne
Inria-EVA

Xavier Vilajosana
Universitat Oberta de Catalunya

Grand Challenge

"A wireless network that performs like a wired network"

Determinism	**Manageability**	**Ease of use**
• <1ppm packet loss	• Flow isolation	• Off-the-shelf hardware
• <10ppm latency miss ratio	• Scheduling	• No installation
• <100uA average current	• Resource management	• No programming

Industry 4.0, "Factory of the Future", urban, building, environmental applications

Research Challenges
• What are the limits (throughput, latency, reliability, power consumption)?
• Which scheduling approach: Centralized? Distributed? Hybrid?

standardization

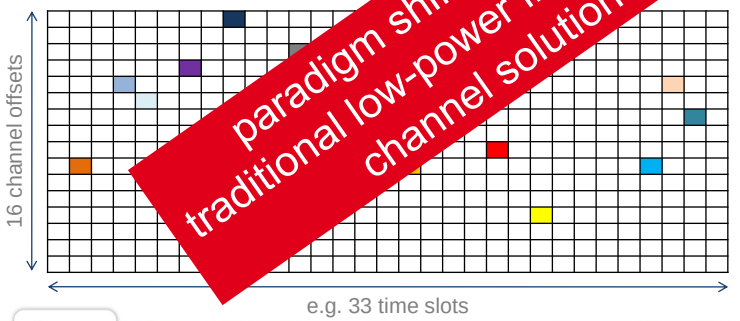
open-source implementation

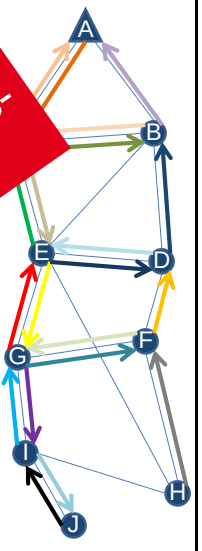
large-scale experimentation

Time Synchronized Channel Hopping

- Motes are synchronized
- Communication follows a schedule
- Schedule gives tunable trade-off between
  - packets/second
  - latency
  - robustness

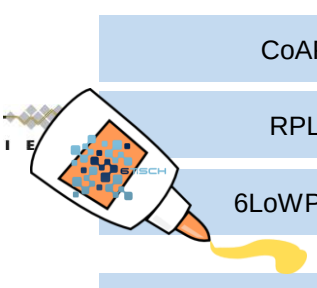
…and energy





paradigm shift compared to traditional low-power listening single-channel solutions!

We Want The Best of Both Worlds!



Ease-of-use of IPv6
- global addressing
- web-like interactions

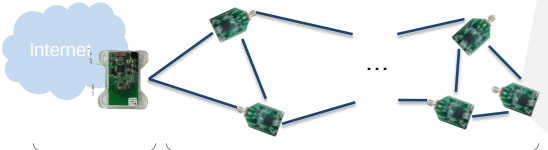
2012

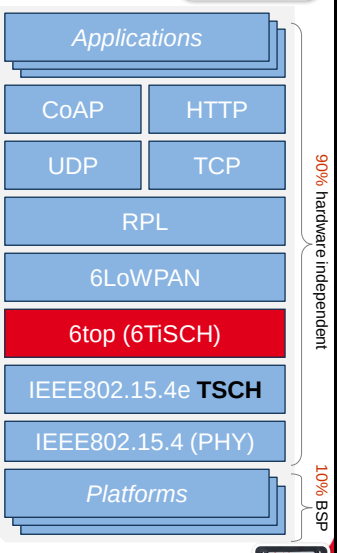
IEEE802.15.4e
Time
Slotted
Channel
Hopping

Industrial Performance
- wire-like reliability
- "deploy and forget" lifetimes

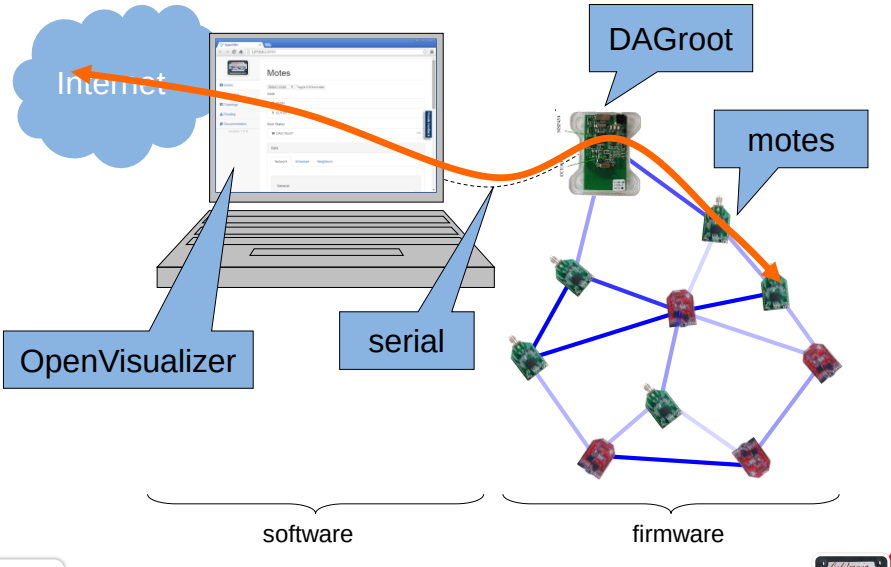
www.OpenWSN.org

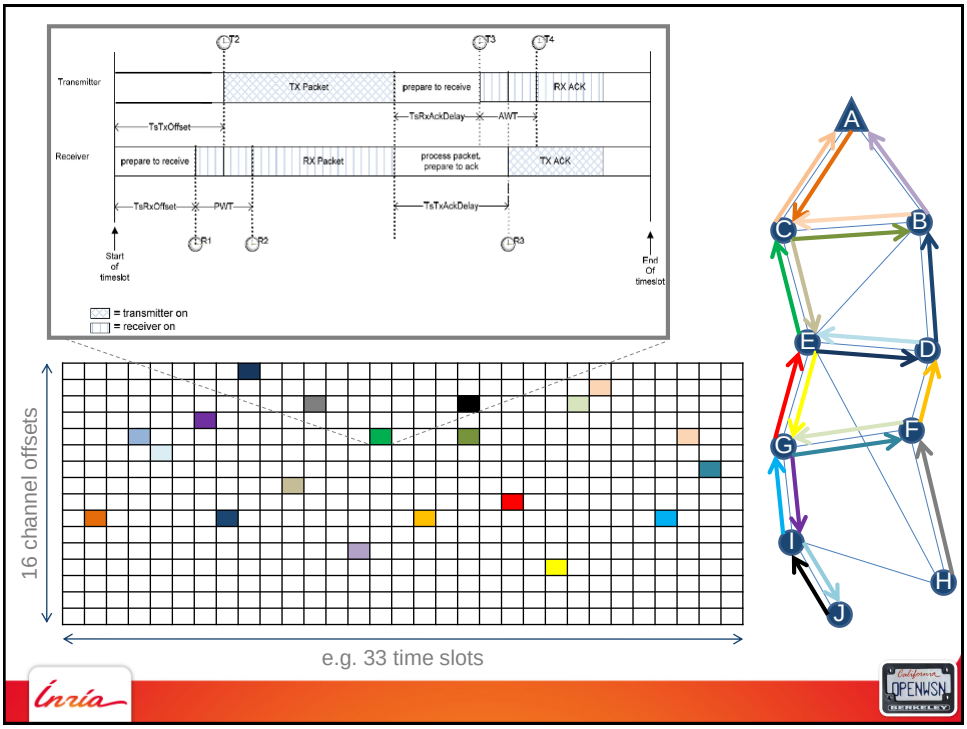
- modular:
  - a port simply means implementing a new BSP (81 functions)
  - 11 platforms supported
- community-based:
  - 60+ direct contributors
  - catalyst for research around TSCH networks.
- Open-source (BSD license)





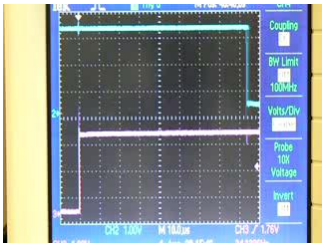
Architecture



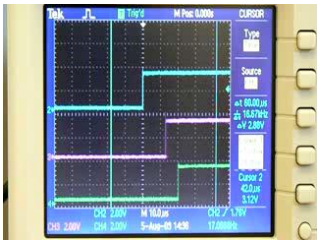

T2
T3
T4
Transmitter
TX Packet
prepare to receive
RX ACK
TsTxOffset
TsRxAckDelay
AWT
Receiver
prepare to receive
RX Packet
process packet, prepare to ack
TX ACK
TsRxOffset
PWT
TsTxAckDelay
R1
R2
R3
Start of timeslot
End Of timeslot
= transmitter on
= receiver on
16 channel offsets
e.g. 33 time slots
A
B
C
D
E
F
G
H
I
J


TX
8/19/2011 6:38 PM
state
TXDATA OFFSET
TXDATA PREPARE
TXDATA READY
TXDATA DELAY
TXDATA
RXACK OFFSET
RXACK PREPARE
RXACK READY
RXACK LISTEN
RXACK
TX PROC
SLEEP
variables
*dataToSend
*dataReceived
*ackToSend
*ackReceived
lastCapturedTime
syncCapturedTime
timing & events
pins
fsm
task
isr
radio
timeslot template
RX
RXDATA OFFSET
RXDATA PREPARE
RXDATA READY
RXDATA LISTEN
RXDATA
TXACK OFFSET
TXACK PREPARE
TXACK READY
TXACK DELAY
TXACK
RX PROC
SLEEP
waste!

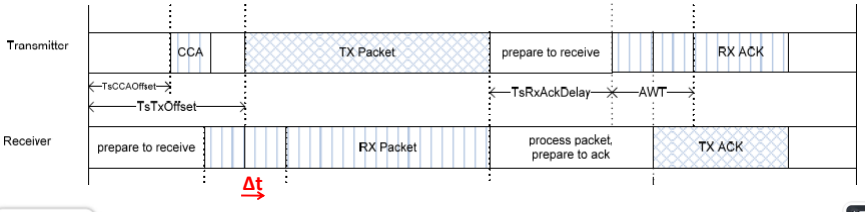
Synchronization



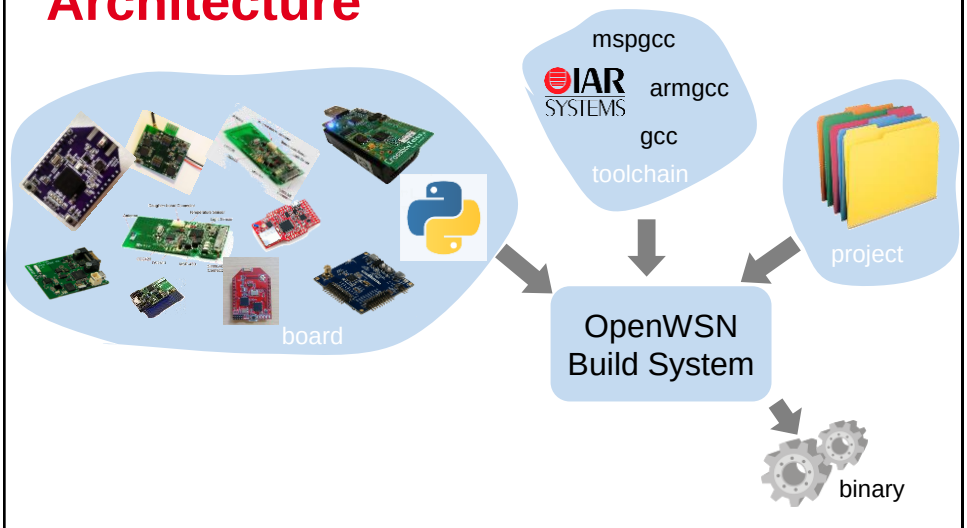
clocks drift
(10ppm typical)



Periodic realignment
(within a clock tick)

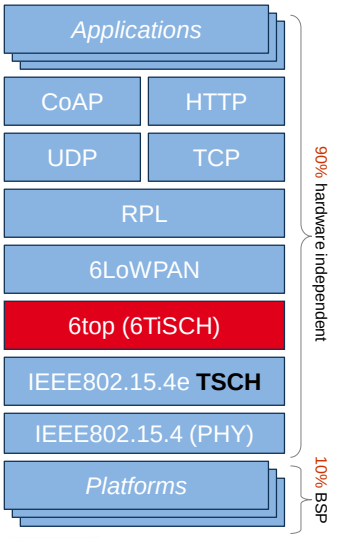


Architecture

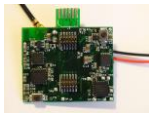



```
scons board=<board> toolchain=<toolchain> <project>
```

OpenWSN ports




OpenMote-CC2538


GINA


WSN430v13b


WSN430v14


Z1


TelosB

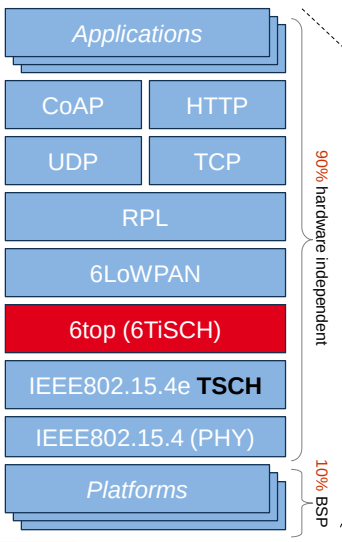

OpenMoteSTM

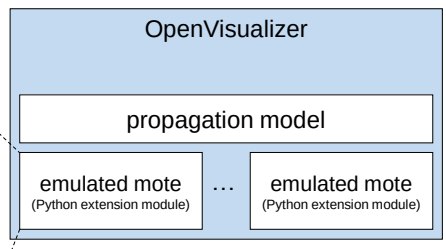

SAM R21


IoT-LAB_M3


AgileFox

OpenSim Emulator



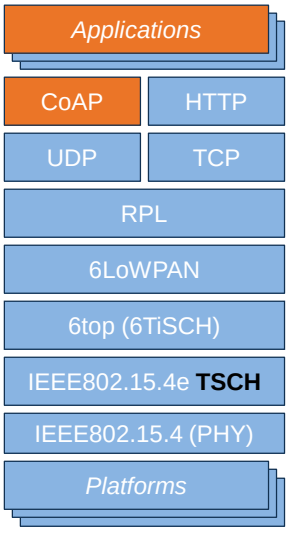


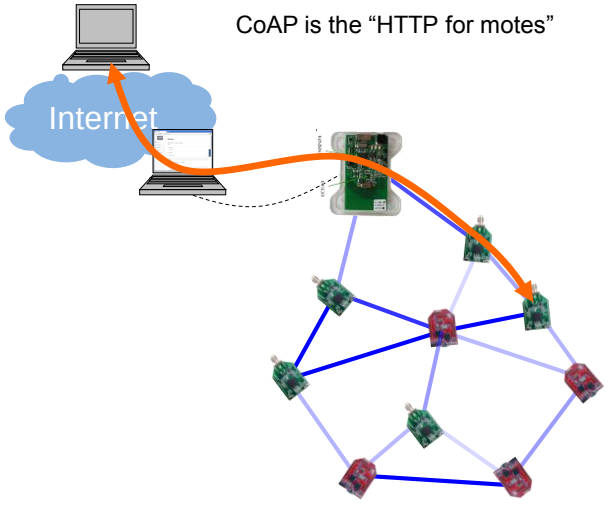
- same interface as real motes
- omniscient debugging:
  - see all packets (Wireshark)
  - see all pin activity (logic analyzer)
- models:
  - clock
  - propagation/topology

```
scons board=python toolchain=gcc oos_openwsn
```

```
openVisualizerWeb.py --sim --simCount=3
```

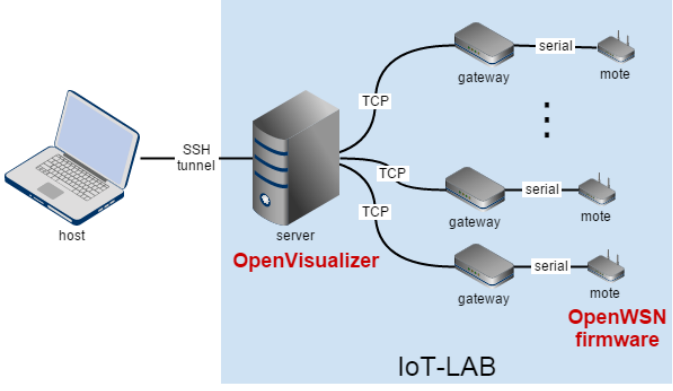
Internet Integration





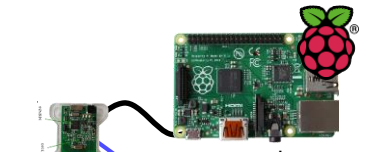
CoAP is the “HTTP for motes”

OpenWSN on IoT-lab

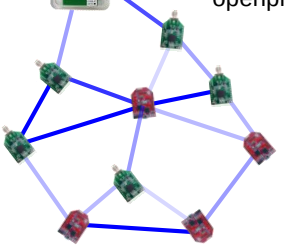


https://openwsn.atlassian.net/wiki/display/OW/OpenWSN+on+IoT-LAB
https://github.com/openwsn-berkeley/openwsn-on-iotlab

OpenPi



openpi



• OpenVisualizer pre-installed on Raspberry Pi image
• built nightly with latest OpenVisualizer

openpi.openwsn.org

OpenVM

vmware®

VirtualBox

• run with (free) vmware Player
• all toolchains pre-installed

openvm.openwsn.org

Open Source Collaboration Tools

source code
(GitHub)

Atlassian Confluence
documentation

Atlassian JIRA
ticketing

openwsn.berkeley.edu

continuous integration
(Travis-CI and Jenkins-CI)

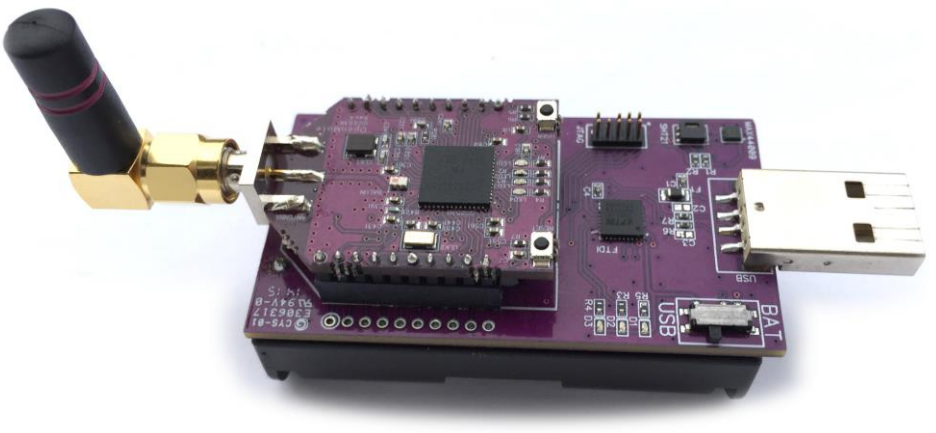
Doxygen
source code documentation

{Open}Projects

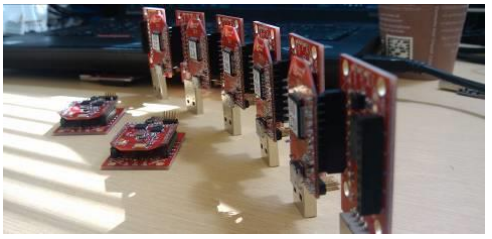
- Entrepreneurial
- Academic
- Standardization

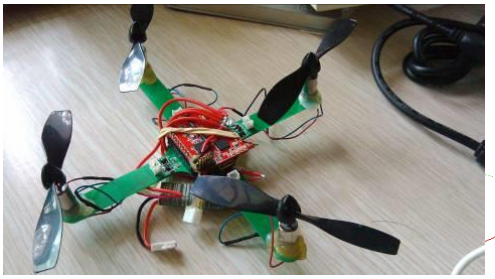
openmote

openhardwareforthe internetofthings



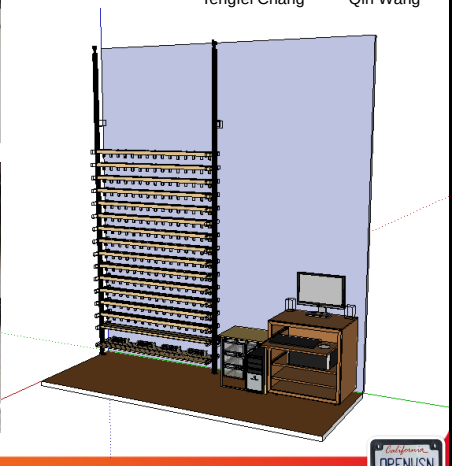
Univ. Science Tech. Beijing testbed





Tengfei Chang

Qin Wang



6TiSCH Plugtests

IETF89, London, March 2014

IETF90, Toronto, July 2014

6TiSCH/OpenWSN hackathon

19 July 2015, Prague

1. **Distributed blacklisting for improving FHSS**
   - Pedro Henrique Gomes (Univ. Southern California)
2. **6top-to-6top 6TiSCH negotiation in OpenWSN**
   - Tengfei Chang, Qin Wang (Univ. Sc. Techno. Beijing)
3. **OpenWSN on the IoT-lab**
   - Nicola Accettura (UC Berkeley)
4. **Contiki 6TiSCH implementation and hardcell allocation**
   - Sedat Gormus, YiChao Jin
5. **IEEE802.15.4e/6TiSCH dissectors**
   - Jonathan Munoz, Guillaume Gaillard, Dominique Barthel (Orange Labs)
6. **Node Monitoring framework**
   - Dominique Barthel, Quentin Lampin (Orange Labs)
7. **6TiSCH Scheduler-free prototype in Contiki**
   - Simon Duquennoy (SICS)
8. **Dust Networks/Linear Technology's SmartMesh IP**
   - Thomas Watteyne (Linear Technology/Dust)
9. **uPnP: Automatic recognition of connected sensors**
   - Prof. Danny Hughes (KU Leuven)
10. **Flexible HW/SW CCM* security implementations in OpenWSN**
    - Malisa Vucinic (ST Micro)
11. **6TiSCH layer-2 security implementation in OpenWSN**
    - Savio Sciancalepore, Giuseppe Piro (U. Bari)

ETSI 6TiSCH interop event

17-18 July 2015, Prague
2-4 February 2016, Paris
July 2016, Berlin

organizer: ETSI

sponsors: openmote, Inria

Preparation
- **OpenWSN** selected as **reference implementation**
- "Golden Device"

Participation and Tests
- 15 participating companies*
- 23 total test pairings, each 1:30 hours in duration
- 12 single-hop tests
- 8 multi-hop tests

Outcome
- 221 test cases performed
- 93.7% overall compliance!

* list of participants under NDA

Application Domains

Smart Factory

Control loops in a wireless process control network, in which high reliability and a fully deterministic behavior are required.

- Bounded latency
- Ultra-high reliability

Smart Building

Service Provider networks transporting data from different independent clients, and for which an operator needs flow isolation and traffic shaping.

- Flow isolation
- Traffic Engineering

Environmental Monitoring

Networks comprising energy harvesting nodes, which require an extremely low and predictable power consumption.

- Ultra low power operation
- Predictable battery lifetime

Flexibility & Customization

Road Ahead & Opportunities

REALMS team

Research

Next steps:

- conduct a rigorous study on the capabilities of TSCH technology, identify its performance bounds (latency, throughput, reliability, power consumption)
- Compare different scheduling approaches.
- Large-scale experimentation in environmental sensing and smart building applications.

Engineering

[Q2 2015] ~~6TiSCH minimal support~~
[Q3 2015] ~~FreeRTOS support~~
[Q4 2015] 6TiSCH dynamin support
[Q1 2016] ETSI interop
[Q2 2016] Cloud-based (re)programming

Standardization

Second ETSI 6TiSCH interop event

- Organized by ETSI
- 2-4 February 2016
- Hosted at Inria Paris *(tentative)*

Collaboration

- Research partners
  - Complementary technology
- Pilot deployments
  - Access to testbeds or environments for tests/pilots
- Grow the user base
  - End users *(Smart City, Industrial, Building, Environmental)*
  - Contributors

OpenWSN Tutorial!

Getting started
- Where to get information
- OpenVM Virtual Machine
- Cloning & Compiling

OpenWSN in simulation
- OpenSim Emulator
- CoAP interaction with nodes

OpenWSN on the OpenMote
- Compiling/Loading OpenMote (real hardware)
- Code Development with Eclipse+JTAG toolchain

Developing code and tuning the stack
- Adding a new application
- Changing the IEEE802.15.4e TSCH schedule
- Enable/Disabling Channel Hopping

OpenWSN on the IoT-lab

Contributors

- https://openwsn.atlassian.net/wiki/display/OW/Team
- Adilla Susungi, Ahmad Dehwah, Alaeddine Weslati, Andrew Pullin, Ankur Mehta, Anita Flynn, Boyang Zhang, Branko Kerkez, Constanza Pérez García, Cedric Adjih, Charles McParland, Chol Su Kang, Christopher Snyder, Chuang Qian, David Burnett, David Stanislowski, Diego Dujovne, Dominique Barthel, Edmund Ye, Emmanuel Baccelli, Emily Chen, Fabien Chraim, Fabrice Theoleyre, Franck Rousseau, Giuseppe Piro, Giuseppe Ribezzo, Guillaume Gaillard, Hilfi Alkaff, Isabel Vergara, Jonathan Simon, Jonathan Muñoz, Kazushi Muraoka, Ken Bannister, Keoma Brun, Kevin Weekly, Kris Pister, Laura Keys, Leonid Keselman, Marcelo Barros de Almeida, Mališa Vučinić, Mathivanan, Michael Lin, Min Ting, Nahir Sarmicanic, Nicola Accettura, Oleksiy Budilovsky, Oliver Hahm, Pascal Thubert, Pedro Issa Helou, Peng Du, Pere Tuset, Qin Wang, Quentin Lampin, Ricardo Cervera-Navarro, Russ Tremain, Sahar Mesri, Tengfei Chang, Thomas Eichinger, Thomas Watteyne, Vinoth Kumar, Vincent LadevezeVitor Garbellini, Xavi Vilajosana.
- *if I left you off the list, send me an email! It wasn't intentional.*

Thank you!

Thomas Watteyne

Research Scientist & Innovator
Inria-Paris, EVA team
thomas.watteyne@inria.fr

Xavi Vilajosana

Professor
Universitat Oberta de Catalunya
xvilajosana@uoc.edu

www.openwsn.org

About the Speakers

Thomas Watteyne (http://www.thomaswatteyne.com/) is an insatiable enthusiast of low-power wireless mesh technologies. He is a researcher at Inria in Paris, in the new EVA research team, where he designs, models and builds networking solutions based on a variety of Internet-of-Things (IoT) standards. He is Senior Networking Design Engineer at Linear Technology, in the Dust Networks product group, the undisputed leader in supplying low power wireless mesh networks for demanding industrial process automation applications. Since 2013, he co-chairs the IETF 6TiSCH working group, which standardizes how to use IEEE802.15.4e TSCH in IPv6-enabled mesh networks, and recently joined the IETF Internet-of-Things Directorate. Prior to that, Thomas was a postdoctoral research lead in Prof. Kristofer Pister's team at the University of California, Berkeley. He founded and co-leads Berkeley's OpenWSN project, an open-source initiative to promote the use of fully standards-based protocol stacks for the IoT. Between 2005 and 2008, he was a research engineer at France Telecom, Orange Labs. He holds a PhD in Computer Science (2008), an MSc in Networking (2005) and an MEng in Telecommunications (2005) from INSA Lyon, France. He is Senior member of IEEE. He is fluent in 4 languages.

Xavier Vilajosana (http://xvilajosana.org/), Entrepreneur and co-founder of Worldsensing. He is currently associate professor at the Open University of Catalonia (UOC), and senior firmware architect at the HP R&D labs. From January 2012 to January 2014, Xavier was visiting Professor at the University of California Berkeley holding a prestigious Fulbright fellowship. In 2008, he was visiting researcher of France Telecom R&D Labs, Paris. Xavier has been one of the main promoters of low power wireless technologies, co-leading the OpenWSN.org initiative at UC Berkeley, and promoting the use of low power wireless standards for the emerging Industrial Internet paradigm. He is also author of different Internet Drafts and RFCs, as part of his standardization activities for low power industrial networks. Xavier is contributing actively at the IETF 6TiSCH WG. He has an MsC degree on Computer Sciences from the Universitat Politècnica de Catalunya (UPC) and a PhD on Computer Science from the Universitat Obertat de Catalunya. At the moment, he holds a patent, more than 20 high impact journal publications and more than 40 International conference contributions. Technically Xavier has extensive experience in Distributed Systems, Wireless Networks, Delay Tolerant Networks and Cloud Computing. He is an IEEE member, and founding member of the IEEE Sensors Council in Spain. Also Xavier is chair in several prestigious international conferences. His research interests include low power communication protocols, routing, scheduling and optimization problems in distributed systems at large.