Important!

The Internet of Things

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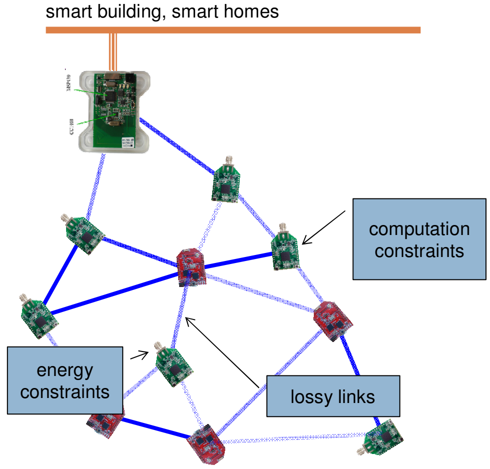
DREAM seminar
8 April 2014, UC Berkeley

Low-Power Wireless Mesh Networks

Smart plants, smart cities,
smart building, smart homes



Outline

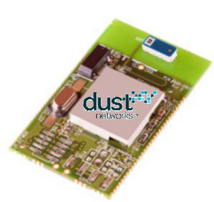
- Wireless Challenges
- Technological Solutions
- A proven Technology
- Latest Trends

Constrained Devices

MICA2 (2003)
sub-GHz

MICAZ (2003)
IEEE802.15.4

TelosB (2004)
IEEE802.15.4



LTC5800 (2011)
IEEE802.15.4

- Micro-controller
  - 8-, 16-, 32-bit
  - 1s-10s kB RAM
  - 10s-100s kB flash
- Radio
  - IEEE802.15.4 based
    - 127B MTU
    - 16 frequencies (2.4GHz)
- Power
  - Radio on: 5-25mA @3.6V
  - Radio off: 1-100uA @3.6V

The IoT Business Index: A quiet revolution gathers pace

The Economist, 29 October 2013

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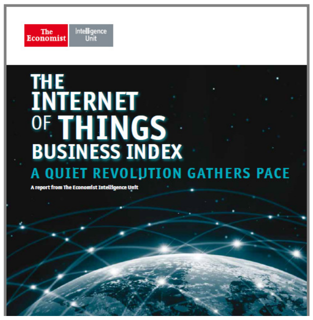

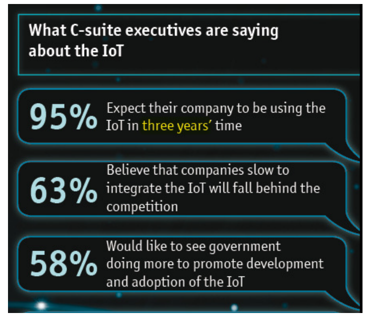

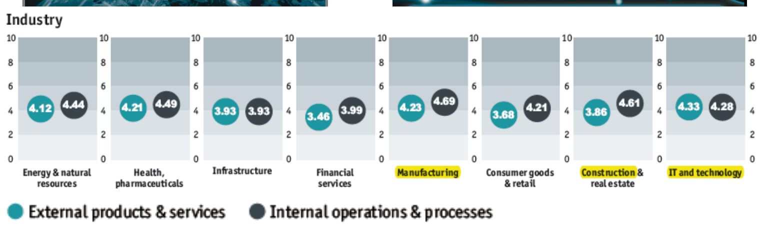

Challenges

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reliability

lifetime

Multi-path Fading

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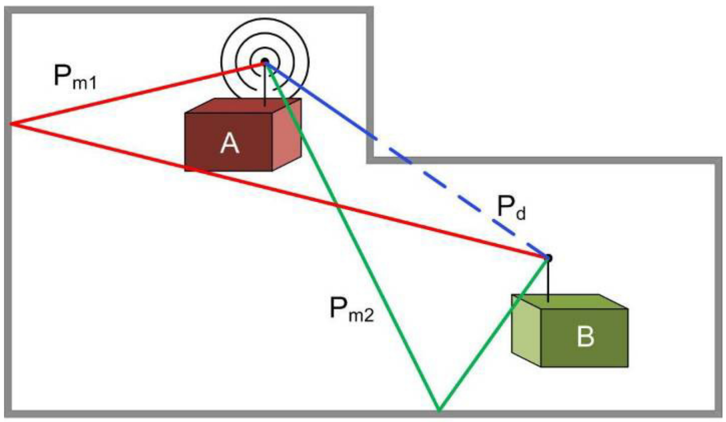

Multi-path Fading

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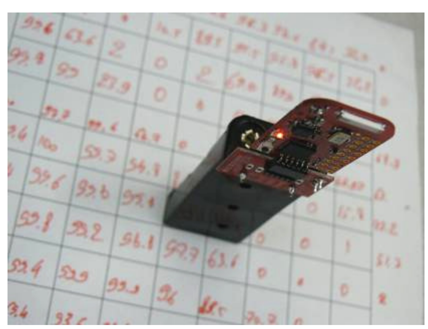
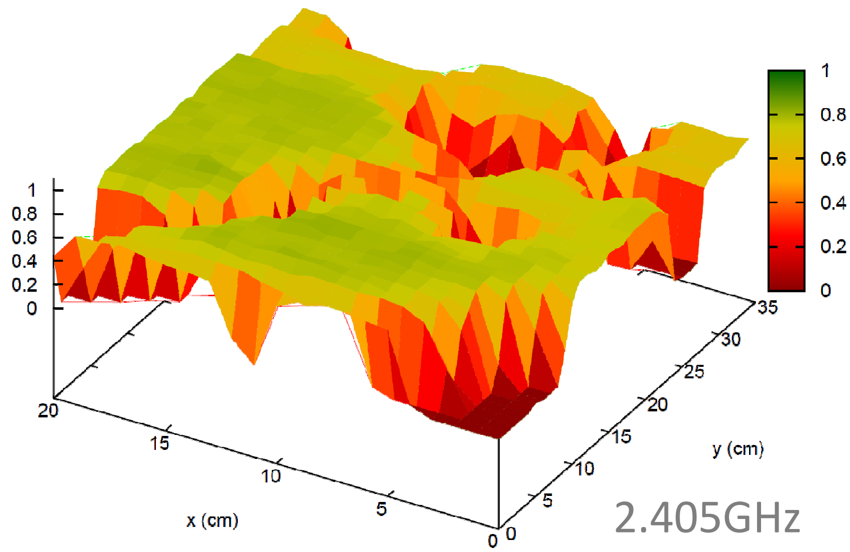
- Separate sender and receiver by 100cm
- Have sender send bursts of 1000 packets
- Have receiver count the number of received packets
- Move transmitter around in a 20cmx35cm square and start over



Multi-path Fading

9



Multi-path Fading

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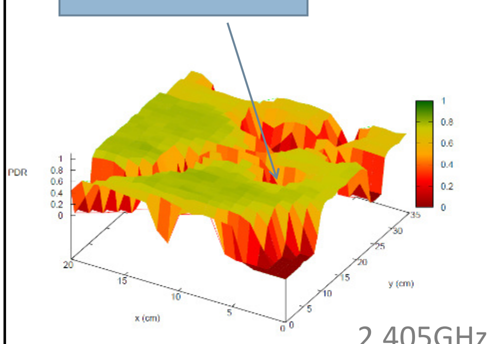
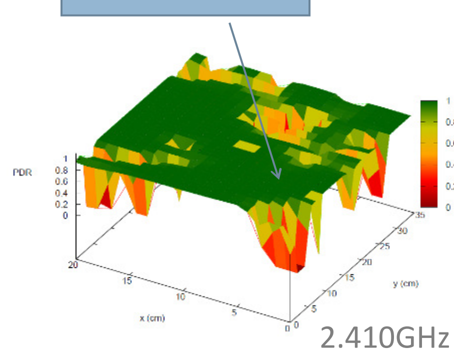
0% reliability

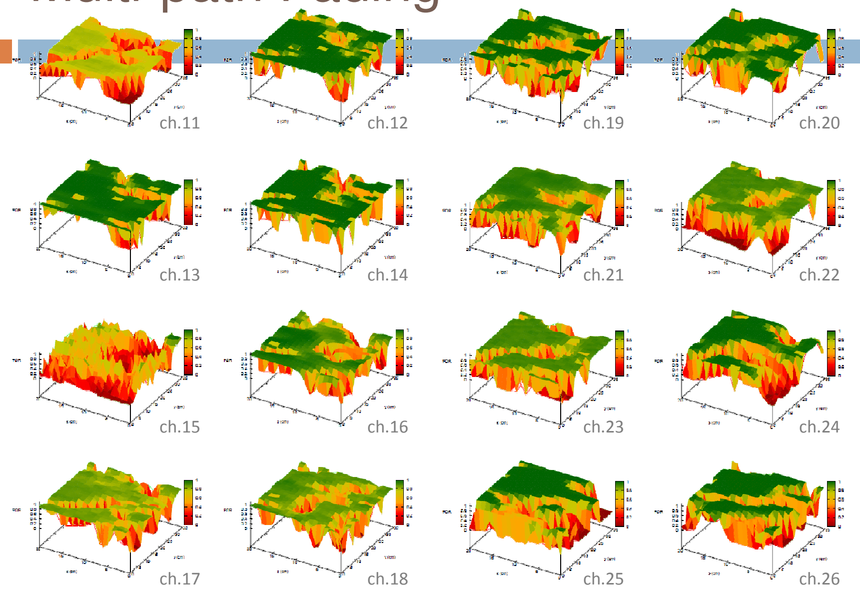
100% reliability





Multi-path Fading

11



Measured Packet Performance

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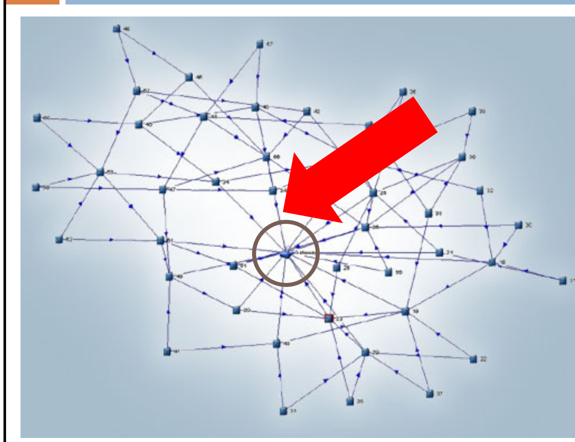

- Sensor nodes deployed across entire facility (44 Nodes)
- 2.5 hop average
- Measure performance of:
  - 33 packets (80 bytes) per 15 min per mote
  - 3.6 million packets over 26 days

$$\text{Path stability} = \frac{\#\text{ packets received}}{\#\text{ packets sent}}$$

16 Channels on Single Path

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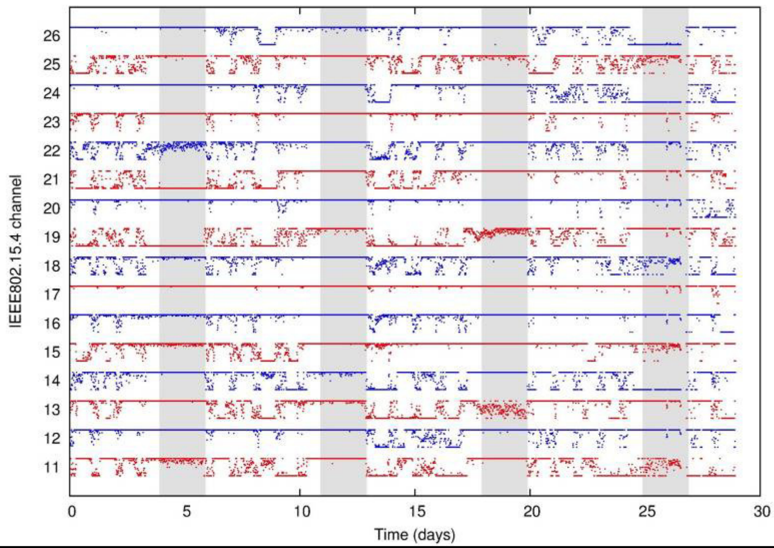

Channel Hopping

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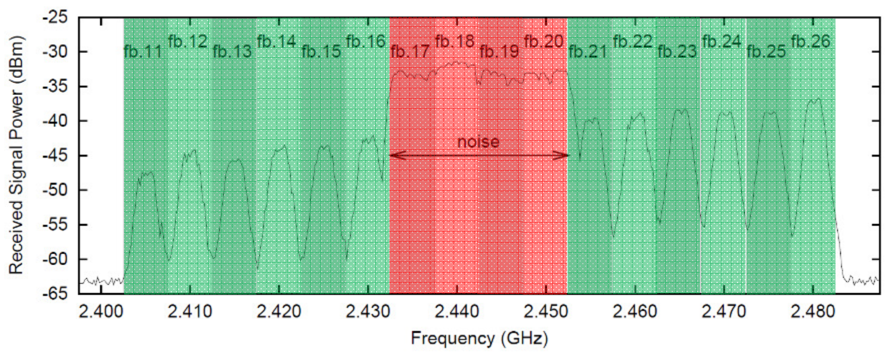
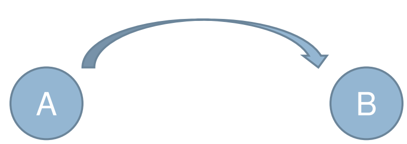
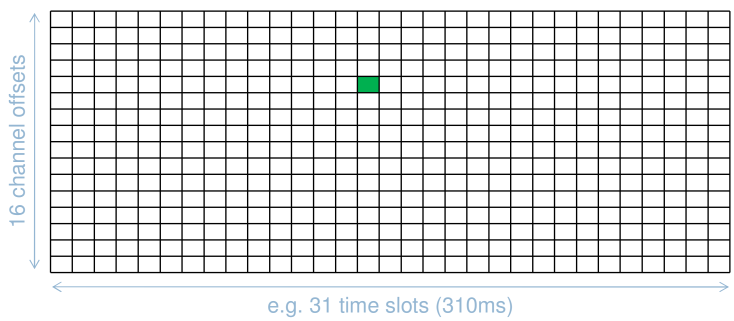
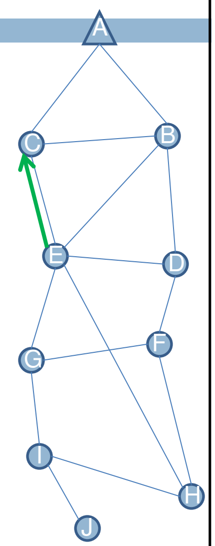




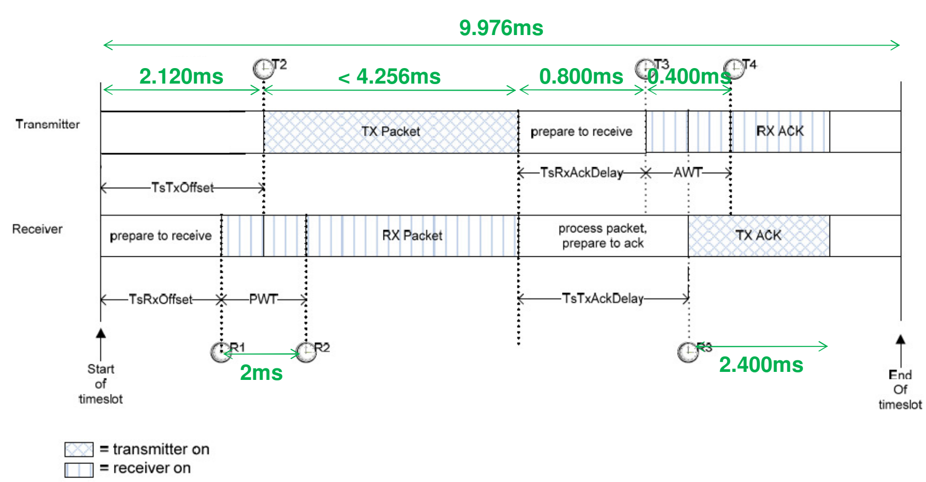
Time Sync. Channel Hopping

- A slotframe repeats over time
  - Number of slots in a slotframe is tunable
  - Each cell can be assigned to a pair of motes, in a given direction





TSCH: A (time) slot



TSCH: Synchronization

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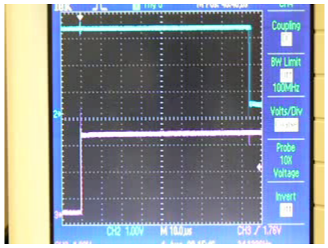
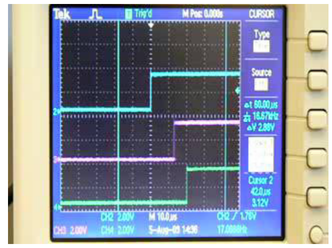
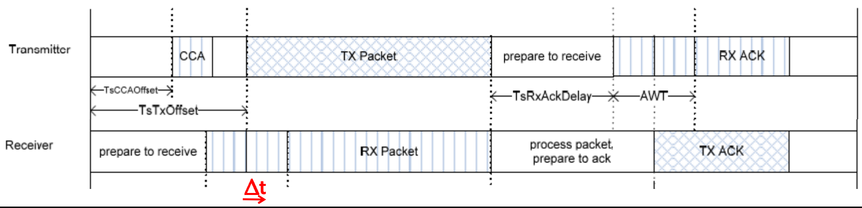


clocks drift
(10ppm typical)



Periodic realignment
(within a clock tick)



TSCH: Channel Hopping

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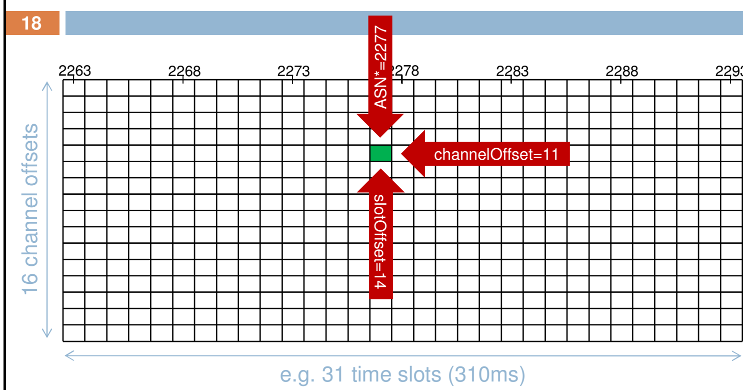

frequencyChannel=(channelOffset+ASN)%16+11

Now:
Ch. 11 (**2.405GHz**)

Next slotframe:
Ch. 26 (**2.480GHz**)

*Absolute Slot Numbe

TSCH: Trade-off

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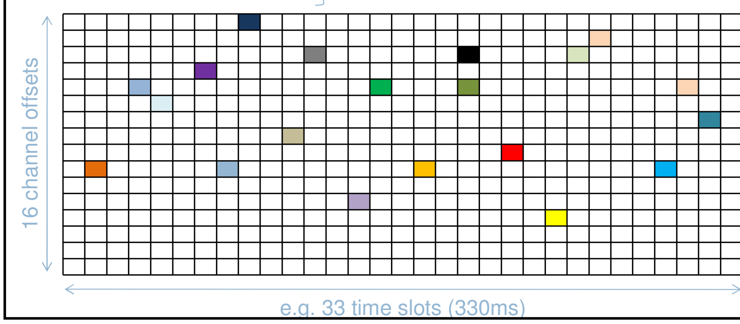
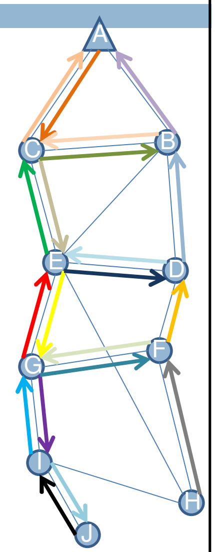
- Cells are assigned according to application requirements
- Tunable trade-off between
  - packets/second
  - latency
  - robustness

  …and energy consumption





TSCH: Energy Consumption

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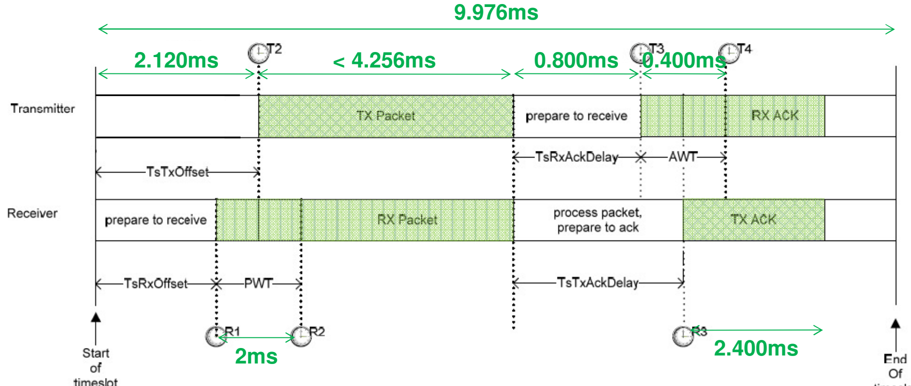

Type of slot	Transmitter	Receiver

= transmitter on
= receiver on

"atomic" operations

TSCH: Standardization

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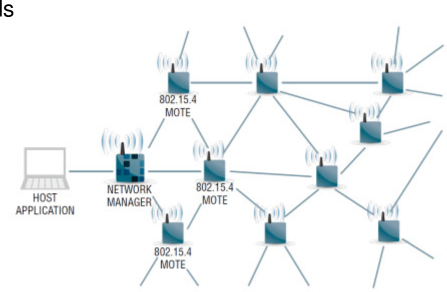
- 2006: Dust Networks's Time Sync. Mesh Protocol (TSMP)
  - Break-through technology
    - 26 days
    - 3.6 million packets generated
    - only 17 packets lost
    - 99.9995% end-to-end reliability
  - Applicable to industrial application
- 2008: WirelessHART
  - Wireless extension of HART, the *de-facto* standard for industrial monitoring
  - Foundation of the SmartMesh WirelessHART product line
- 2012: IEEE 802.15.4e
  - Amends MAC protocol of IEEE 802.15.4-2011
  - Foundation of the SmartMesh IP product line

WirelessHART

IEEE

Linear Technology, Dust Networks® Product Group

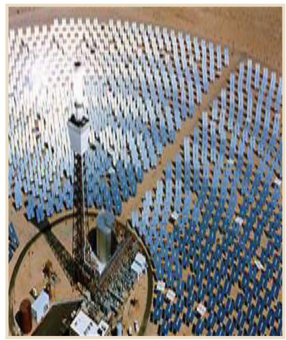
- Dust Networks® has been part of Linear Technology since Dec 2011
- Pioneer and inventor of highly reliable, low power time synchronized wireless sensor network protocols, and the market leader for WirelessHART
- Core technology for WirelessHART and IEEE 802.15.4e standards
- 99.999% reliability, <50uA average current draw
- LTC®5800 is the world's lowest power 802.15.4 system-on-chip
- Latest product line, SmartMesh IP, is built for IP compatibility, and is based on 6LoWPAN and 802.15.4e standards



TSCH: proven technology

Over 30,000 Dust networks in 120 countries

Industrial
- Equipment health/condition monitoring
- Process monitoring and control



Energy
- Energy Management
- Data Center Monitoring & Control
- Utility Scale Solar Monitoring and Control

Smart Infrastructure
- City infrastructure
- Transportation

IETF 6TiSCH

CoAP

UDP

6LoWPAN

"gap"

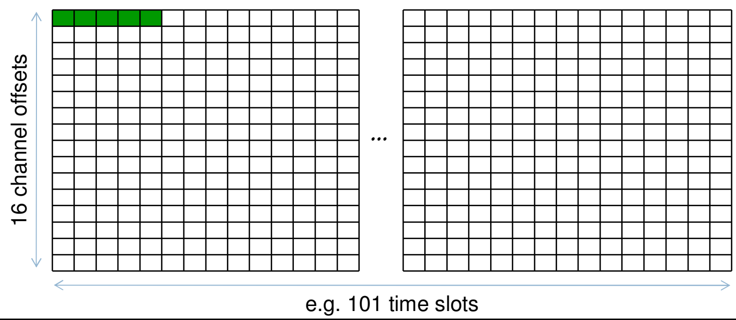
IEEE802.15.4e

IEEE802.15.4

- New IETF Working Group
  - http://tools.ietf.org/wg/6tisch/
  - 6tisch@ietf.org
- *IPv6 over the TSCH mode of IEEE 802.15.4e*
- Define mechanisms to manage TSCH schedule, "building blocks"

6TiSCH: Static Schedule

- "Minimal" approach
  - draft-ietf-6tisch-minimal
  - Static schedule, slotted-Aloha access
  - **Questions**: energy/latency/throughput limits?



6TiSCH: Dynamic Scheduling

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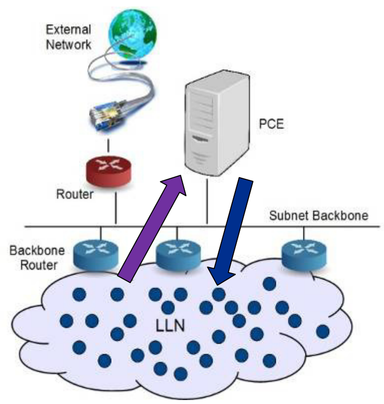
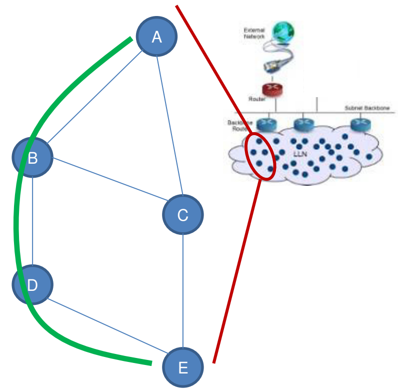
Centralized



vs.

Distributed



- **questions**: scalability, reactivity?

e.g. "On-The-Fly" scheduling
draft-dujovne-6tisch-on-the-fly-02.txt
- **questions**: reactivity, performance?

OpenWSN.berkeley.edu

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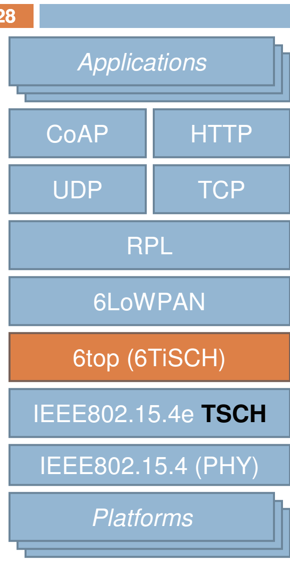

- Experimental platform for TSCH networks
  - Open-source reference TSCH implementation
  - Cloud-based Wiki and ticketing system
  - Source code on GitHub
  - Travis-based CI servers
- Catalyst for research on TSCH
  - OpenWSN team at UC Berkeley
    - 2 Master thesis
    - International visitors: 2 Professors, 3 PhD students
  - Over 30 international contributors
  - Ported to 10 platforms
- Has fostered research on topics such as scheduling, energy consumption modeling, switching, adaptive channel hopping, advanced synchronization techniques

Important!

The Internet of Things

Thomas Watteyne

Senior Networking Design Engineer

Linear Technology, Dust Networks product group

DREAM seminar

8 April 2014, UC Berkeley

Abstract

- The products and standards developed as part of the Internet of Things (IoT) revolution allow small embedded devices to appear as regular Internet hosts, thereby becoming the "fingers of the Internet". The manufacturing sector is leading the way in adopting IoT technology, where it is being applied to energy management, building automation, and industrial process control. While most IoT solutions offer seamless integration into the Internet, many lack the reliability, security and low-power operation required by most applications. This can cause pilot deployments to exhibit poor performance and security vulnerabilities, eventually leading to an adoption rate of the IoT slower than anticipated.
- To answer this situation, IoT technology adopts techniques coming from industrial networking. The networks resulting from this convergence enable data to flow over a traditional IP-based infrastructure, but exhibiting wire-like reliability, ultra-low power consumption, and the highest level of security. The resulting "Internet of Important Things" enables the true fusion of the cyber and physical worlds.
- This presentation will show how the Internet of Important Things is a reality today. We will start by listing the challenges of building highly reliable and ultra low-power wireless mesh networks. We will then discuss the technologies which can answer this challenge, with a particular focus on channel hopping. We will illustrate this discussion through numerous examples taken from existing commercial products and deployments, and open-source implementations. We will end by introducing the work being done in the new IETF 6TiSCH working group, and highlight the associated open research problems.

Bio

Thomas Watteyne is a Senior Networking Design Engineer at Linear Technology, in the Dust Networks product group, the leader in supplying low power wireless mesh networks for demanding industrial process automation applications. He serves as the co-chair of the new IETF 6TiSCH working group, which standardizes the use of IEEE802.15.4e TSCH in IPv6-enabled mesh networks. At UC Berkeley, Thomas coordinates OpenWSN, an open-source project of the Pister lab which promotes the use of fully standards-based protocol stacks in M2M applications. In 2009 and 2010, he was a post-doctoral research lead in Prof. Kristofer Pister's laboratory at UC Berkeley. Between 2005 and 2008, he was a research engineer at France Telecom, Orange Labs. He obtained his PhD in Computer Science (2008), and MSc and MEng in Telecommunications (both 2005) from INSA Lyon, France.