Real-Time and wireless sensor networks: are they compatible ?

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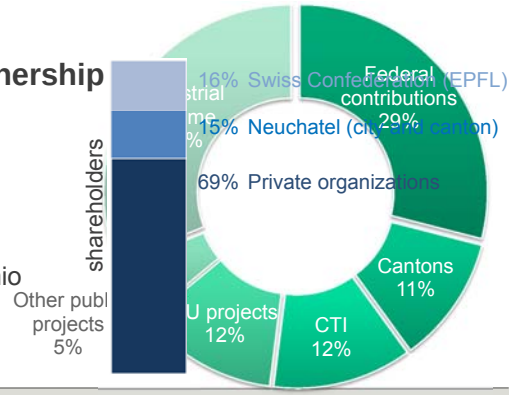
CSEM – Swiss Centrer for Electronics and Microtechnology, Neuchâtel, Switzerland (www.csem.ch)

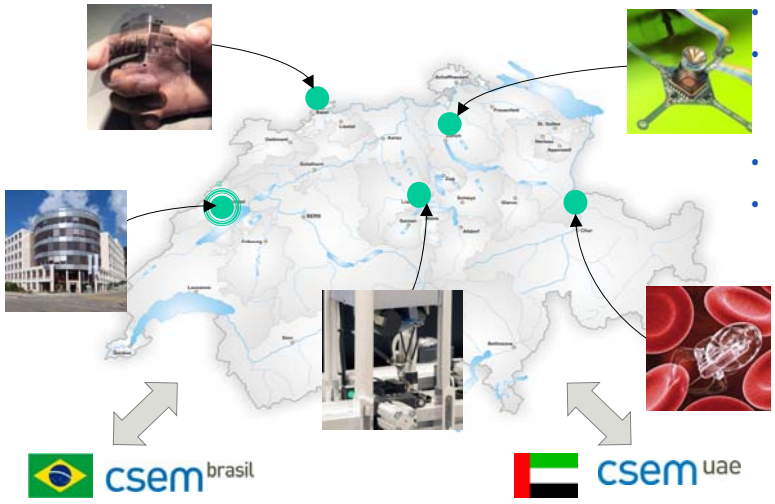
CSEM at a glance

- Incorporated, not-for-profit ***Research and Technology Organization (RTO)***, supported by the Swiss Government
- **A public-private partnership**
  - 31 % public
  - 69 % private
- **Key figures** (2010)
  - Revenues ~ CHF 70 mio
  - Employees ~ 400



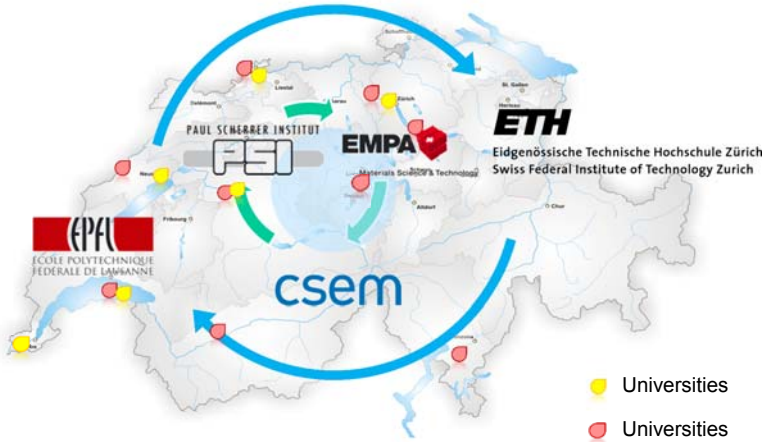
Centre Suisse d'Electronique et de Microtechnique SA

Close to industry ...

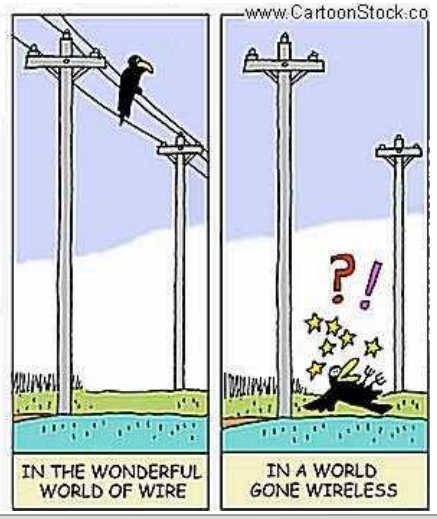


- MEMS
- Surface engineering technologies
- Systems
- Ultra-low-power integrated systems

CSEM's national network



It's all about wireless

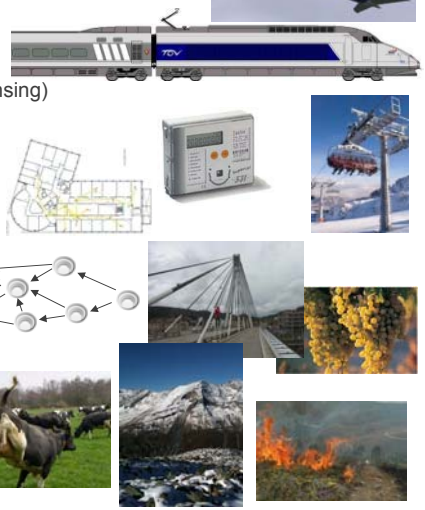


Outline

- **A few of our deployments**
- Lessons Learned
- Myths and realities
- What about real-time ?
- Conclusion

WSN applications and our deployments

- Industrial control and automation
  - ✓ Energy positive buildings (eg distr. sensing)
  - ✓ Transportation
  - ✓ Object tracking
- Security and public safety
  - ✓ Structural health monitoring
  - ✓ Surveillance (eg fire)
- Agricultural monitoring
  - ✓ Sensor-based growth optimization
  - ✓ Animal telemetry
- Environmental monitoring
  - ✓ Air & water quality monitoring
  - ✓ Hazard detection (fire, slides…

WiseNet: the deployed technology

- No planning, no configuration
- Ultra low power (downto 500µW average with COTS) for all nodes including relays (routers/coordinators)
  - ➢ Much less with our own ICs (IcyCom)

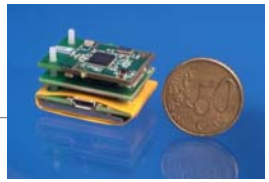
	XE1203	IcyCom SoC
WiseMAC	10x	reference
S-MAC	70x	5x
ZigBee -MAC	250x	36x

- forwarding 32 bytes every 30 seconds
- wake-up period of 250 ms

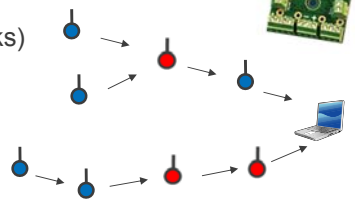
- High reactivity (down to 50ms)
- Low delay (down to 25ms per hop)

"the WiseMAC protocol showed a remarkable consistent behavior across a wide range of operational conditions, always achieving the best, or second-best performance." Langendoen & Meier. ACM Trans. Sensor Networks 7(1), 2010.

Protocols

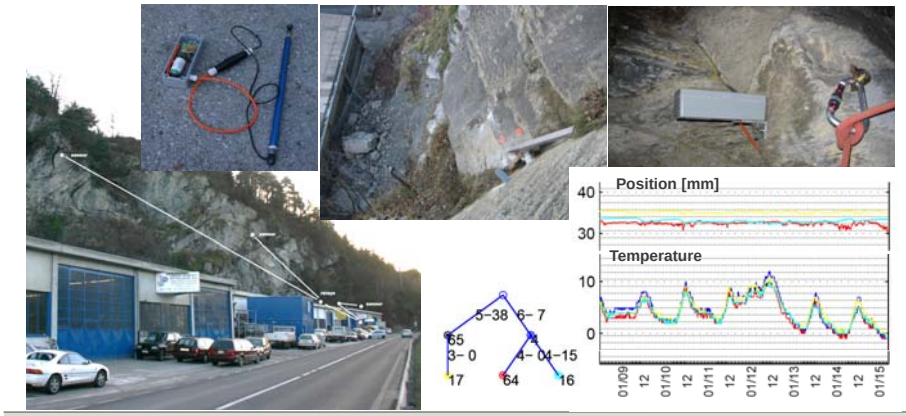


- MAC : WiseMAC – LPL type
- Routing (self configuring)
  - Cluster-tree (small number of sinks)
  - Opportunistic (mobile nodes)
- Application layer
  - SNMP like (Set / Get / Event)
- Code update
  - Reliable, patch based, OS independent
- Localisation
- Local data logging (delay tolerance)



Rock movements monitoring

- Pilote test network (2006): Chandoline, Vallis, Switzerland, in cooperation with Crealp (Research center on alpine environment)

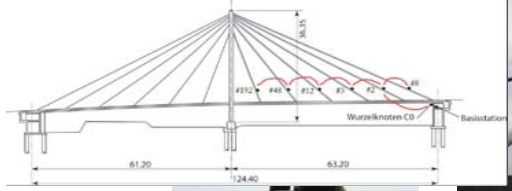


Fire and Flood detection at Wild Urban Interface

- Detection & prediction of fire, flood & their evolution
- network of temperature, rain, wind, humidity sensors
- Multiple sinks in urban premisses

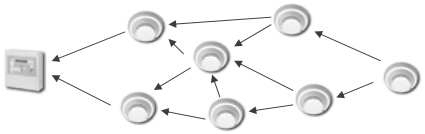
Bridge health monitoring

- with the Swiss Federal Laboratories for Materials Science and Technology (EMPA)
- 6 nodes in line (25 ultimately), co-processor for measuring vibrations
- Single sink with relay to EMPA premises through GSM/GPRS



Safety Critical Sensor Networks for Building Applications

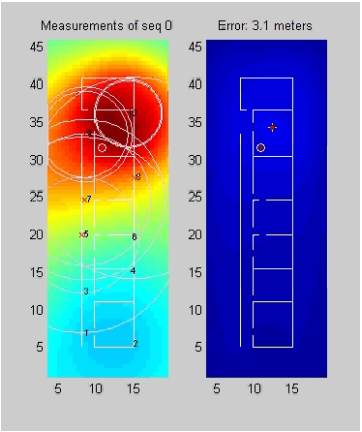
- 3 partners SIEMENS ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich csem centre suisse d'électronique et de microtechnique
- Project goal: Develop an ultra-low power wireless multi-hop communication system providing high reliability and low delay transmissions. Application to Wireless Fire Detection.



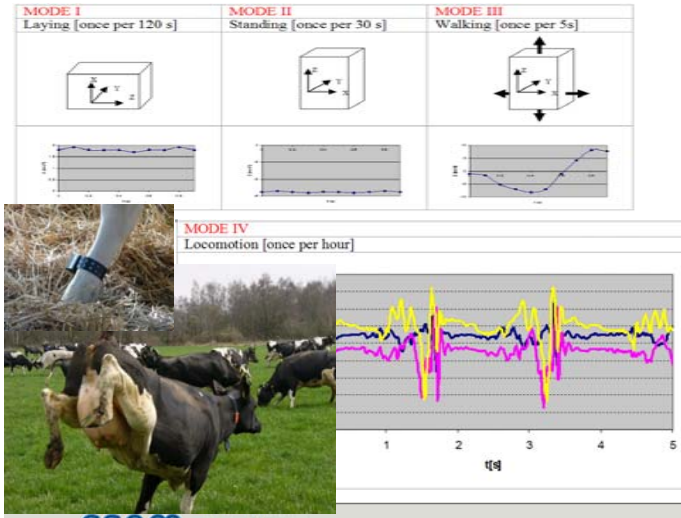
- Contributions from CSEM :
  - ultra-low power medium access control (MAC) for low latency and dependable mesh networking

WSN based In/Out-door localization

- In-door results
  - Accuracy better than 3m (80% of time)
  - Grid of 10 reference nodes that are also used for communication
  - Movie shows raw measurement (left) and final result (right)*
  - Demo kit is available from CSEM

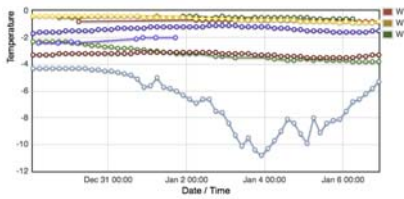


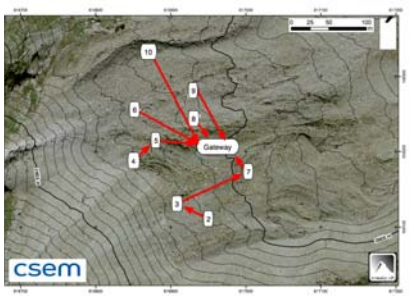
Herd control (FP6 WASP)

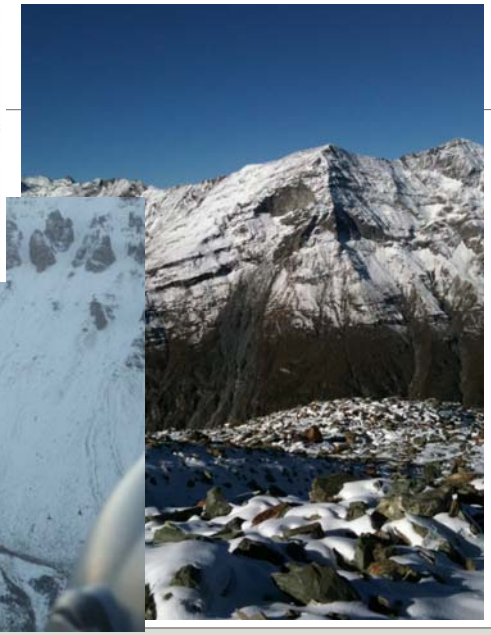


Monitoring glaciers

- 2800 m altitude
- 5 years planned
- Continuous monitoring via GSM

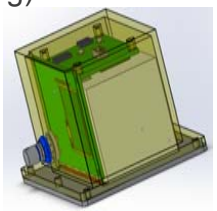






Strain sensing on planes

- an autonomous wireless platform for data acquisition of strain gauges on planes (structural monitoring)
  - ➢ Self sustained thanks to energy harvesting
    - ✓ Autonomous operation for the lifetime of the plane
    - ✓ Lack of constant source of energy
  - ➢ Reliable and ultra low power communication
    - ✓ Difficult propagation environment
      - E.g. landing gear
    - ✓ Absence of pre-configuration
- Need for a solution that is fast and ultra low power at same time



Outline

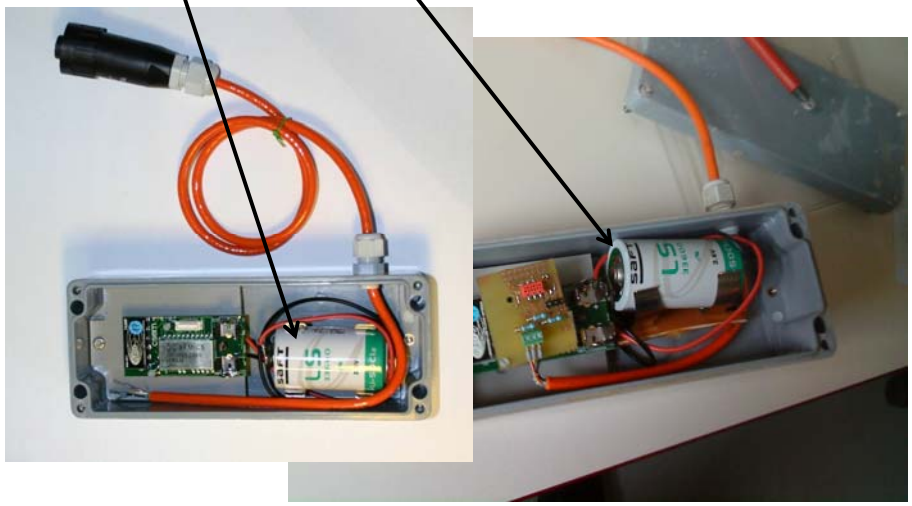
- Deployments
- **Lessons Learned**
- Myths and realities
- What about real-time ?
- Conclusion

Lessons learned

- Tools, tools, tools,…
  - To simulate
  - To install physically
  - To observe (congestions, drops, missing nodes, …)
  - To diagnose (LEDs)
  - To modify (network parameters, code, …)
- Anything that may fail, will.
  - Beware of connections between sensors and transmitters
  - Batteries
  - RF links

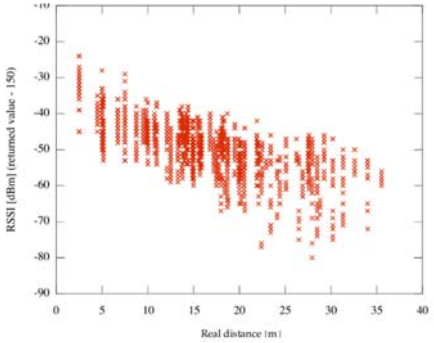
Changing a sensor !!!

Before and after !!!



Lessons learned (2)

- Propagation is never as planned
  - Very difficult to forecast
  - Distances are always as long as possible
    - ✓ Link quality is always close to its limit
  - Link quality may change
  - Nodes may disappear
- It is never easy enough to install
  - Too big, too heavy, Cannot fixture it !
  - Not the right place for propagation or not the right place for sensing or the right place for hooking
  - Tools missing (screw driving, plastic ties, adhesive tape, ….)



Propagation

Outline

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7 assumptions about wireless transmission

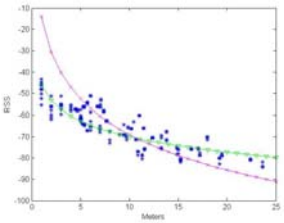
The world is flat & radio transmission area is circular

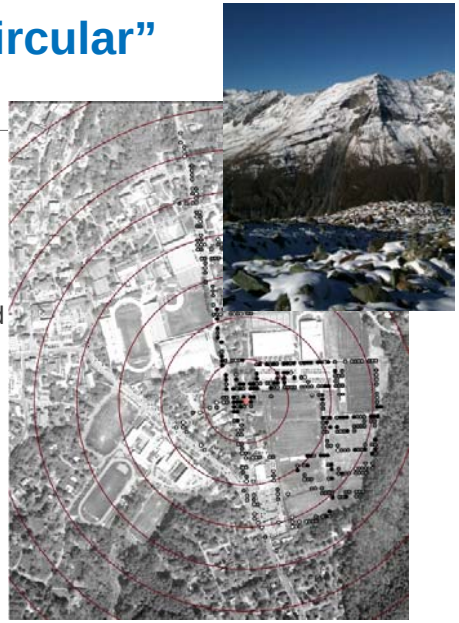
- signal strength is a simple function of distance

- All radios have equal range
- Link quality does not change
  - if I can hear you, you can hear me & if I can hear you at all, I can hear you perfectly
- The only source of packet loss is collision
- Broadcast is for free
- Energy is proportional to the number of packets and their size
- Duty cycling is the only way to reduce energy consumption

"transm. area is circular" "the world is flat"

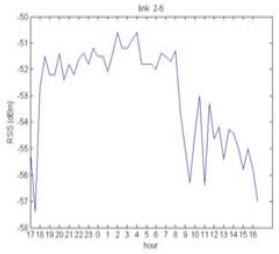
- radio coverage is not at all circular
  - ✓obstacles, height, fading, …
- signal strength is loosely related with distance

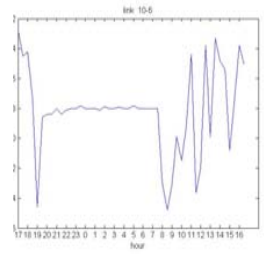


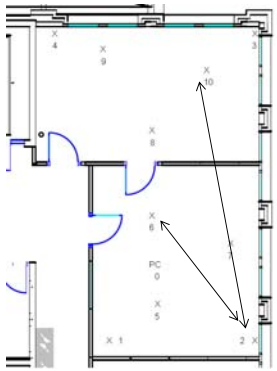


source: D. Kotz et al., 2003

"link quality does not change"



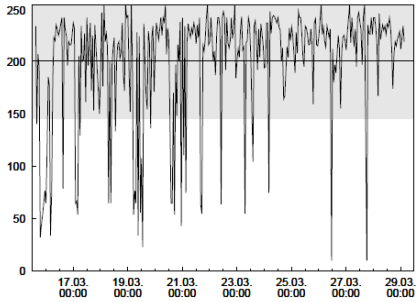




- links fall into 3 categories
  - ➢connected, transitional, disconnected
- transitional links are often unreliable and asymmetric (even for static nodes)

“The only source of packet loss is collision”

- packet error does not mean collision
  - Coexistence: What if there are other people on the earth ????
  - Link quality change
- It is often counterproductive to retry immediately
  - At least on same channel
- There are other techniques than retry to correct errors
- Hidden / exposed terminal



Source: V. Turau et al., INSS 2006

A few words about energy

- sources of energy waste at the MAC layer:

idle listening	➔ listening when no data is available
overhearing	➔ listening to data dedicated to others
oversending	➔ emitting while there is no receiver
collisions	➔ two parties are sending at the same time
protocol overhead	➔ data that is not directly used for the application

“Broadcast is for free” / “Energy ~ to number of packets & their size”

- Broadcast means all nodes must be synchronized in time (and frequency)
  - Synchronization is not free
- Packet transmission means synchronization between sender and receiver(s)
  - There is an overhead per packet (can be large)
  - It varies with sending interval
- Turning off nodes for long periods of time
  - Introduces long latencies
  - There are other techniques (e.g. preamble sampling)

In addition

- Severe resource constraints
  - energy, bandwidth, memory size, processing
- Network dynamics
  - Nodes come and go, link go up and down
- Scalability (along number of nodes, traffic, errors, etc)
- Multiple traffic requirements
  - periodic, sporadic, critical, non critical, …
  - Often unbalanced (to sink)
  - and also changing with time
- Regulations (e.g. ETSI)
- Dependability (many sources of failure)



Outline

- Deployments
- Lessons Learned
- Myths and realities
- **What about real-time ?**
- Conclusion

So what's new for RTN research ?

- Not only MAC
  - mulithop (routing) must be taken into account
- Impossible to ignore errors
- It is the first transmitted byte that costs
  - Concatenation and aggregation are tempting
- Highly dynamic traffic
- With limited resources
  - Energy (means good models for that)
  - Memory (buffers)

A few standard proposals

- Industrial wireless communications
  - Wireless HART, ISA 100.11a, WIA-PA
    - ✓ Pure TDMA with retries, channel hopping and route redundancy
- Consumer market
  - IEEE 802.11e
    - ✓ Statistically higher chance for high priority traffic
    - ✓ Little care about energy

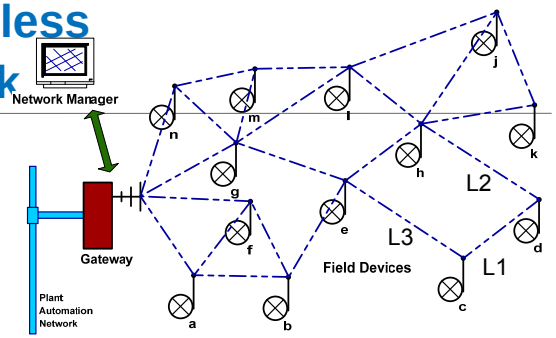
	ZigBee	WirelessHART
Robustness	Low	High
Co-existence	Low	High
Power consumption	High	Low
Security	Low	High

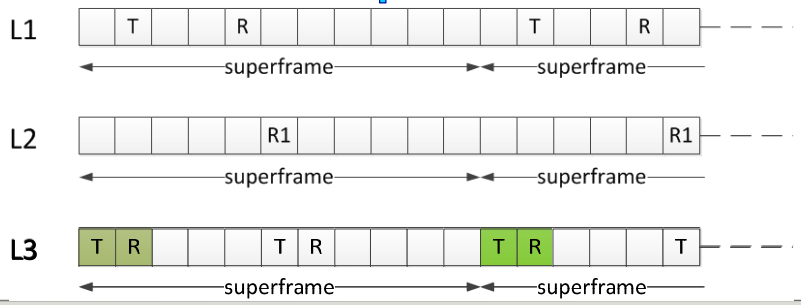
Table 1. Overview of comparison

Source: Lennvall, WFCS 2008

A simple wireless HART network

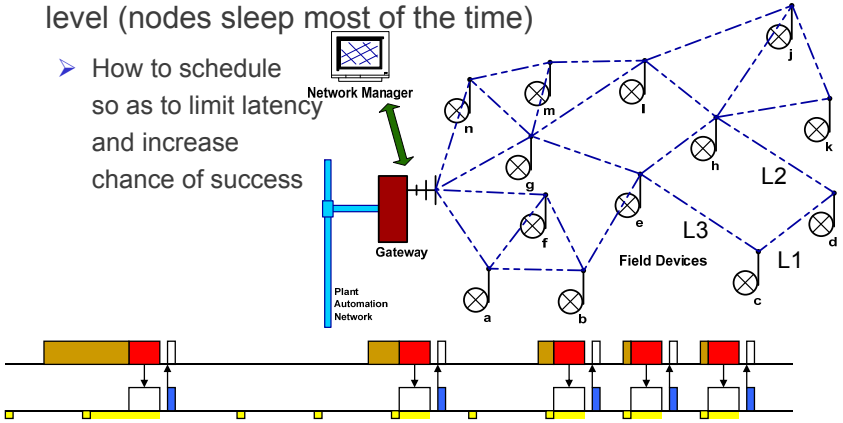
- Pure TDMA
- Traffic from Node d





Another simple network

- A simple network that is exploited at ultra low energy level (nodes sleep most of the time)
  - How to schedule so as to limit latency and increase chance of success



To make a long story short

there is no way to provide HRT guarantees in WSNs

it is unlikely that pure TDMA can be the most efficient solution in WSNs

Possible ways forward

- rethink the model
- have a clear and reasonable fault model
- select the right metrics
- design protocols that adapt
- use application properties

Rethink the model

- are we sure that applications care about deadlines ?
  - ✓ what about accuracy of detection, coverage, …
- do we need end-to-end guarantees ?
  - ✓ what about other models
- what about the publish-subscribe model
  - ✓ WSNs are data centric not client centric
  - ✓ this is a way to decouple the entities
- other models such as (m,k)-firm

Fault model

- classical FT assumes crash failure
- sensing part may fail but not routing
- there is redundancy in sensing (multimodal)

- we need to clearly state which kind of faults we tolerate
  - link / nodes / sensors
  - at which degree (link may come and go)
- which kind of mobility

The right metrics

- If it is not possible to provide HRT guarantees
- what about
  - the probability that a given message reaches its destination
  - within a given deadline
  - with some energy consumption

RFC 1925 Fundamental Truths of Networking

- (3) With sufficient thrust, pigs fly just fine. However, this is not necessarily a good idea. It is hard to be sure where they are going to land, and it could be dangerous sitting under them as they fly overhead.

RFC 1925 Fundamental Truths of Networking (2)

- (7a) (corollary). Good, Fast, Cheap: Pick any two (you can't have all 3).
- (12) In protocol design, perfection has been reached not when there is nothing left to add, but when there is nothing left to take away.

Conclusion

- Real-time and WSNs are certainly compatible
  - Provided we use the right definition of RT
- Plenty of challenging scheduling (and other) problems ahead of us
- It is good to make assumptions ….. provided they are reasonable

Thanks very much for your attention