SENSOR NETZE :

Entwicklungstendenzen und Perspektiven

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Acknowledgements are due to

Acknowledgements are due to:

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- Partners form the past end ongoing research projects: EU EYES and Embedded WiSenTs, BMBF AVM
- Co-Members of numerous PCs, with whom I have had hours of discussions…

Outline

- Some issues in Sensor Networks design
- Connecting the “virtual” and “real” world.
- Ways to use SN: service interface?
- Real experiments with sensor networks?

Consequences of the hardware development

- Nodes will be cheap – and could be easily destroyed – better use redundancy!!!
- A new paradigm appears: do not care about the node, you might have a lot of them...
- Note: the main difference between a SENSOR NODE and an RFID tag is PERSISTENCE!!!
  - RFIDs should be unique and have a lifetime not shorter than the marked artifact
  - Redundant usage of sensor nodes of rather limited lifetime is attractive!

  This is a “logical split”...

Typical scenarios

- **Data Collection**: with a frequency specific for the physics of the plant. Some aggregates: Like averages over short time and pre-defined space are expected.

  Long term operation (years!) is crucial!

- **Alarm monitoring:** Pre-defined events have to be identified and signaled ASAP. Permanent self-testing of the sensors required.

  Reliability of the operation and short delay are crucial!

- **Object tracking:** Objects (people, cars) emitting some specific values have to be tracked.

  Position estimation in spite of changing dynamics…

YES, actuation comes in addition….

But... there is even a bigger dimension...

- Computer networks are NOT only for “pushing data from ***host A*** to ***host B*** ” over the “dumb internet” !!!

  They are for extracting and providing information...

- Today's information systems care mostly about distributing information (WWW) to HUMAN BEINGS!
  - We use only the information we (human beings) have **put** there (Web page editors)
  - With lousy support for recognizing that information is there! (crawlers)
  - And only slightly better for **selection** (Google)
- The challenge: Coupling the information systems to the real world : BOTH WAYS!

Power consumption: let us talk numbers!

Typical Receive: Rx ~ 15-30 mW ***(see 802.15.4 radio - EM 420)***

Typical Transmit: Tx ~ 1.1- 1.3 of receive power.

Perspective : 1-3mW ….(BWRC)

Typical microcontroller: Atmel (MICA2) - 16.5mW,

Will go down to around 1-3mW…

Sensors do also need energy...

Compare: Typical AA Battery (Alkaline) – 2000 mA-Hr

Reality: with 45 mW = 40 hours continuous operation on a typical AA (Alkaline) Battery

Sensors Today and Tomorrow… (Jason Hill, UCB)

Commonly avilable sensors

	Current	Discrete Sample Time	Voltage Requiremet	Manufacturer
Photo	1.9 mA	330 uS	2.7-5.5V	Taos
Temperature	1 mA	400 mS	2.5-5.5V	Dallas Semiconductor
Humitidy	550 uA	300 mS	2.4-5.5V	Sensirion
Pressure	1 mA	35 mS	2.2V-3.6V	Intersema
Magnetic Fields	4 mA	30 uS	Any	Honeywell
Acceleration	2 mA	10 mS	2.5-3.3V	Analog Devices
Acoustic	.5 mA	1 mS	2-10 V	Panasonic
Smoke	5 uA	--	6-12 V	Motorola
Passive IR (Motion)	0 mA	1 mS	Any	Melixis
Photosynthetic Light	0 mA	1 mS	Any	Li-Cor
Soil Moisture	2 mA	10 mS	2-5 V	Ech2o

Energy lessons lerned…

- Discontinuous operation of the nodes: Nodes go to sleep for as long as possible – wake up shortly!!
- Sensing rate dependent on the nature of observed phenomena
  - We can use the Nyquist theorem to determine sensing rate - tuning on the **maximum** expected frequency of changes…☹
  - Better: adopt the sensing rate to the real dynamics? Variable sensing rates help save energy..

Regular operation is not necessarily optimal from the energy viewpoint… deviation from regularity implies more complex network design and operation….

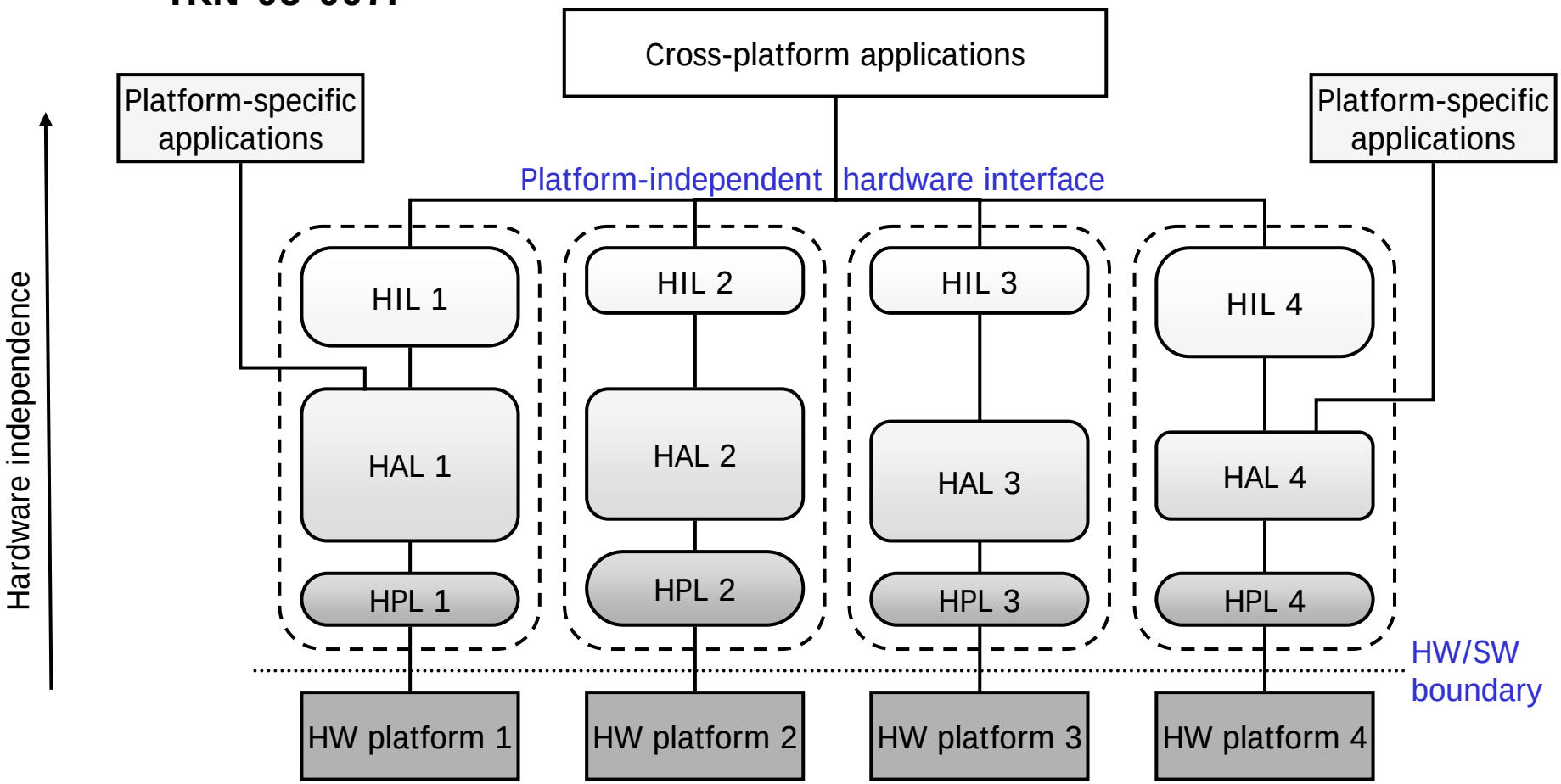
- Tradeoff between measurements, computation and communication is not trivial. Individual parameters of the available platform must be precisely known.

Knowledge of hardware details ?...

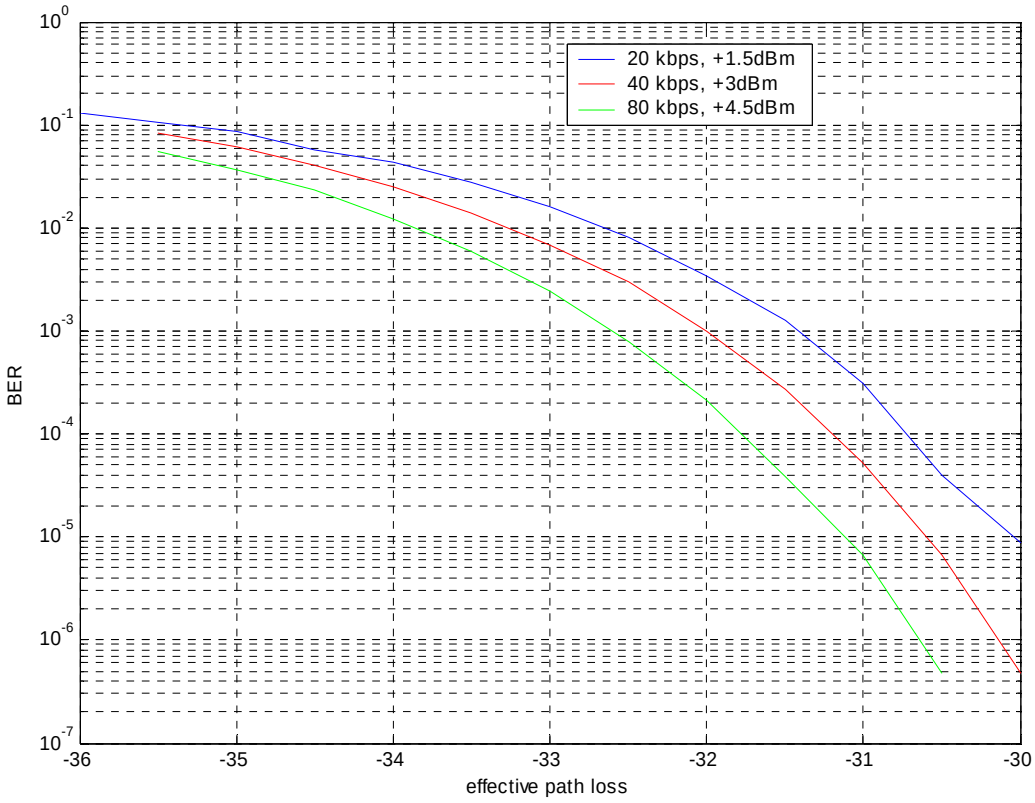
- What is the most appropriate level of *hardware abstraction* ?
- Two seemingly conflicting requirements
  - Rapid application development → high level of abstraction
  - Energy-efficient implementation → low level of abstraction
- How to effectively reconcile this gap ?
  - Flexible, reconfigurable operating system architectures
  - More like a component library then a monolithic structure
  - Let the application choose the appropriate level of abstraction
- T2 - TinyOS 2.0 – a big step towards this goal
  - Joint research TKN/UCB (group David Culler)
  - Activities in the TinyOS Community/**emerging TinyOS Alliance**

Hardware Abstraction Architecture...

Details in: V.Handziski et al. "Flexible Hardware Abstraction for Wireless Sensor Networks", In *Proc of EWSN 2005*, Istanbul; more in: P.Levis et al, "T2: A Second Generation OS For Embedded Sensor Networks",Tech Rep. TKN-05-007.



The Disadvantage of Simple Radio's



Factor 10^5 in error rate

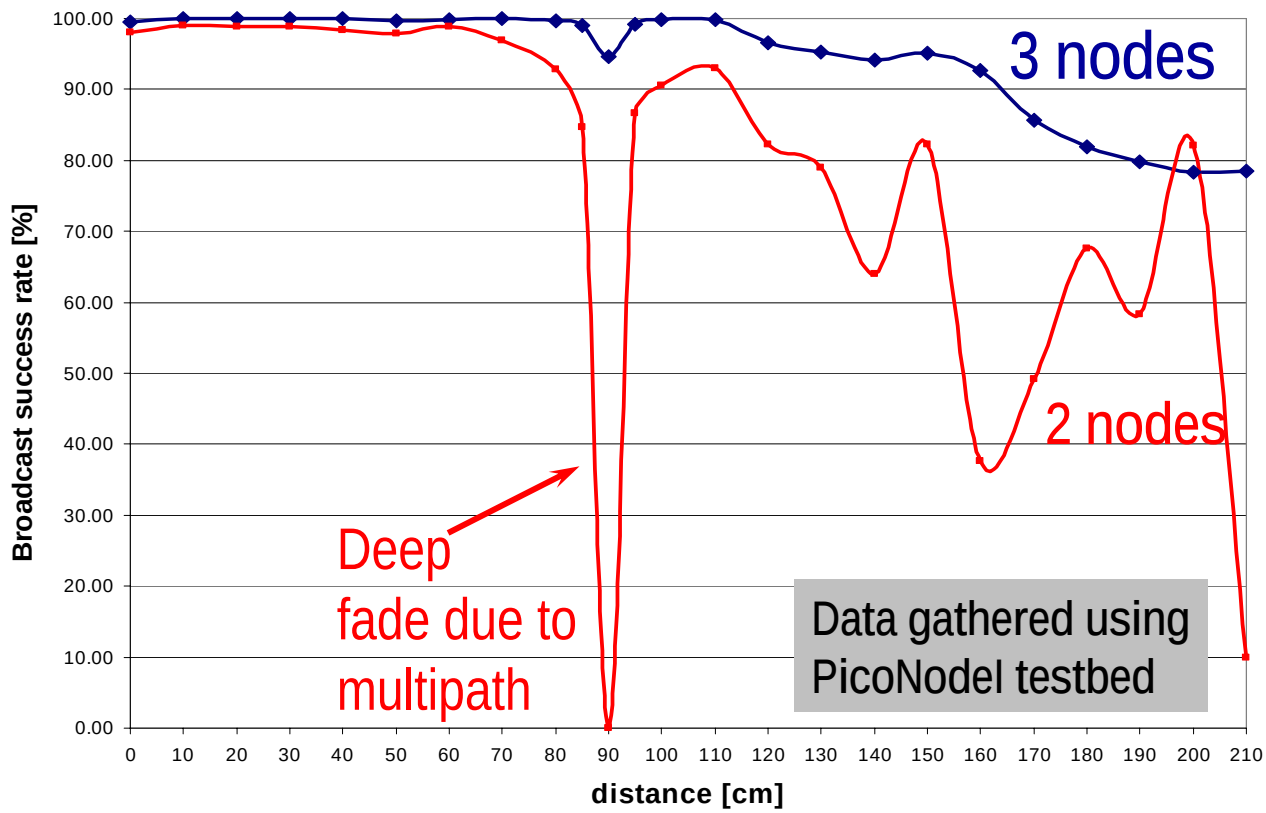
6 db

Small Change in Path Loss Has Dramatic Impact on Transmission Quality

- Channel is either "good" or "bad"
- Increasing Symbol Time (or reducing Data Rate) offers *limited* help…

Simulated response of PicoNode radio (BWRC; UCBerkeley)

The Impact of Spatial Diversity (BWRC measurement)



Adding a single node already changes dramatically the success probability– spatial diversity is the preferred way to provide robustness in sensor networks

A lot can be done with single-hop configuration...

- Assume having a “hub node” and several satellites
- The hub has any amount of power....
- Transmission down-link: you USE a lot of power on your antenna, use directional antennas... etc.
- Transmission up-link....this is tricky...
  - What about going “close to Shannon” ? Use efficient coding ...
  - Take LDPC-code: it is asymmetric: low complexity of coding high for decoding
  - Up to 150 meters seems reasonable...
- Single hop NOT equal to single route!! (multiple BS?)

See: C. Zhong,et al. , "Does Proper Coding Make Single Hop Wireless Sensor Networks Reality", In *Proc. of WCNC*2005, New Orleans, LA, USA

A lot could be done... (better antennas) *

- Let us use a standard Telos Tmote Sky with 2.4 GHz 802.15.4 radio...
- One could use better antennas at the base station...
  - a 24 dBi parabolic grid
  - a 17 dBi 90o sector antenna,
  - 8 dBi omni-directional antenna.
- Unmodified end –system
- 500-800m (LoS) or up to 80 m in significant foliage environment!

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*/``Implications of Link Range and (In)Stability on Sensor Network Architecture'', Bhaskaran Raman & al., WiNTECH 2006, Sept. 06.

What if we go multi-hop?

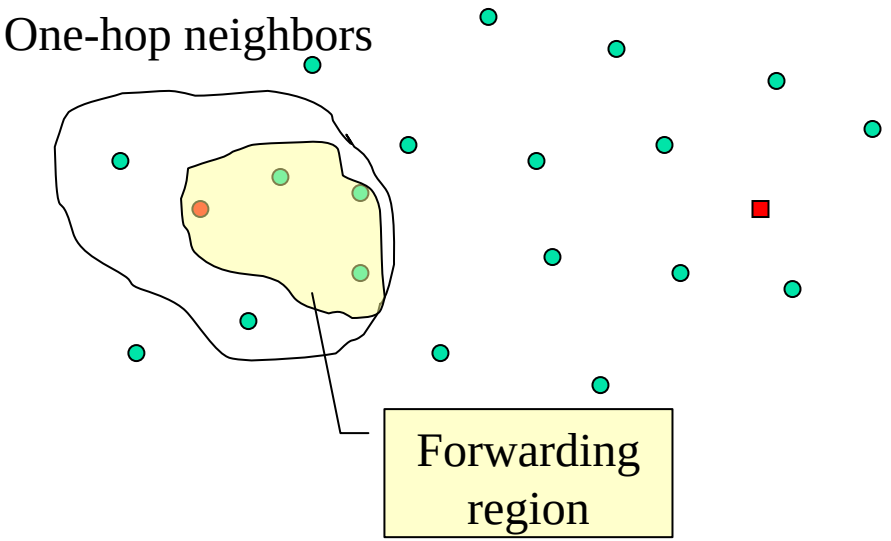
- Routes are NOT stable
  - If route is pre-computed, possibly numerous repetitions will be necessary - until a temporarily unavailable route becomes available again... or several pre-computed routs are needed!
  - Or: on demand routing might be the better choice

    (eg. geographic routing...) ➔**opportunistic routing!!**
- Cooperation “rendezvous schemata” in case of cycling nodes not trivial!
  - Synchronous schema (like S-MAC)? *strong time sync.needed!*
  - Asynchronous schema (wake-up radio)?

    low power – high precision wake –up mechanism...?
  - Pseudo- asynchronous approach...

Routing: the Opportunistic Approach (R.Shah, UCB)

Research by numerous researchers: Notably M. Zorzi, Ferrara/UCSD, and MIT; Joint research UCB/TKN papers by R.Shah et al, e.g. R. C. Shah, S. Wiethölter, A. Wolisz, and J. M. Rabaey, "When does opportunistic routing make sense?", In *Proc. of PerSeNS 2005*..



~~Path-based routing:~~

~~Network specifies next hop~~

List-based routing:

- Network specifies *forwarding region*
- MAC chooses next-hop based on connectivity

What is long term operation??

- Usually formulated as: Maximize the lifetime of the network.
  - Not precise: Until the first node collapses? Until a percentage of nodes does?

    Until some functionality will fail!!

- How to organize the activities over redundant equivalent nodes to assure that?
  - Some, alternating, representative of “clusters” should be active?
  - Monitor the energy level and adapt the activity level of individual nodes?

    How can the energy level be correctly known? How can operational measures be enforced? How to make decisions in a distributed way? Preferably with limited (or better none!) information exchange ?

We just wanted to find information

- Well, but do we really have to sense everything using some type of motes?
- Let us assume I am interested in Temperature in Barcelona, now. What do I do ?

  Ask Google.... “weather in Barcelona”

Google search: weather in Barcelona (excerpt...)

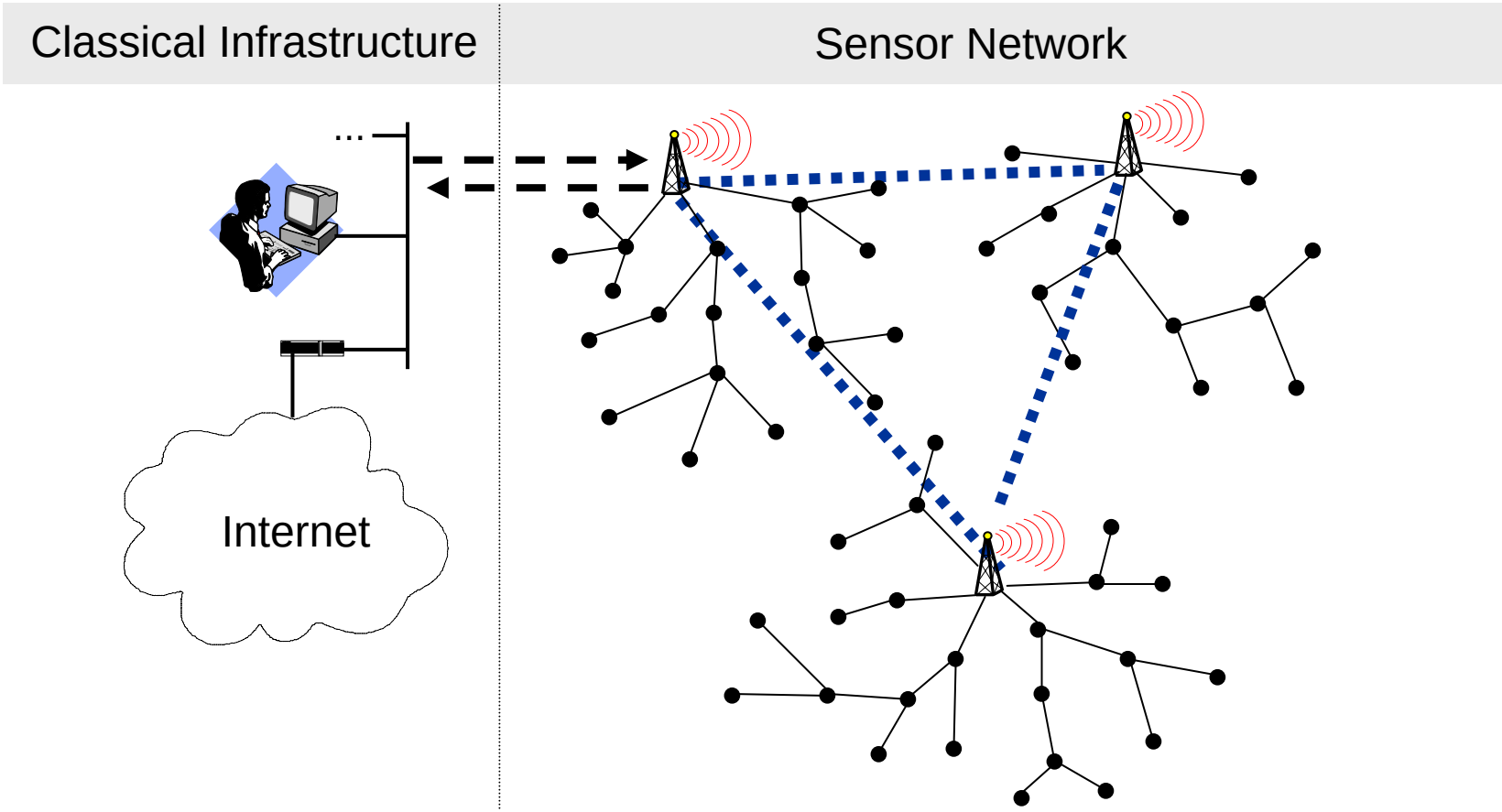
- Yahoo! **Weather** uk.**weather**.yahoo.com/SPXX/SPXX0015/index_c.html
- **Weather Barcelona** www.1st**barcelona**hotels.com/travel/Weather.htm
- **Weather** Underground: www.wunderground.com/global/stations/08181.html
- CNN.com - **Weather**- **Barcelona**, www.cnn.com/WEATHER/eu/Spain/BarcelonaLEBL.html
- BBC - **Weather** Centre www.bbc.co.uk/**weather**/5day.shtml?world=0042&links
- **Weather** Online **Barcelona** Spain. www.**weather**online.co.uk/Spain/Barcelona.htm -
- **WeatherBarcelona** hotels www.worldexecutive.com/ cityguides/**barcelona**/**weather**.shtml
- The **weather** in **Barcelona** www.bcn.es/temps/english/
- **Weather Barcelona** storm1.herald.com/auto/miamiherald/ global/stations/80419.html
- Cityvox **Barcelona**: www.cityvox.com/ciw_page_meteo/ 0,6666,BARENGMETCIT,00.html
- Europe **Weather** www.online**weather**.com/v4/world/owac/EU/
- The **Weather** Network www.the**weather**network.com/**weather**/cities/intl/pages/ESCT0001.htm
- Boston.com / **Weather** / **Barcelona**, **weather**.boston.com/?code=LELL
- Wetter Online **Barcelona** www.wetteronline.de/Spanien/Barcelona.htm -
- **barcelona** / aeropuerto www.asinah.net/**weather**/**weather**.html?pands=LEBL
- **Barcelona Weather**, www.about**barcelona**.com/**barcelona**/**weather**.asp
- InfoMet www.infomet.fcr.es/
- AccuWeather.com - www.accu**weather**.com/adcbin/intlocal_index?wxcity2=BARCELONA&wxcountry=EU;SP
- Met Office: **Barcelona** current **weather** www.metoffice.com/worldcity/**barcelona**now.html

We just wanted to find information

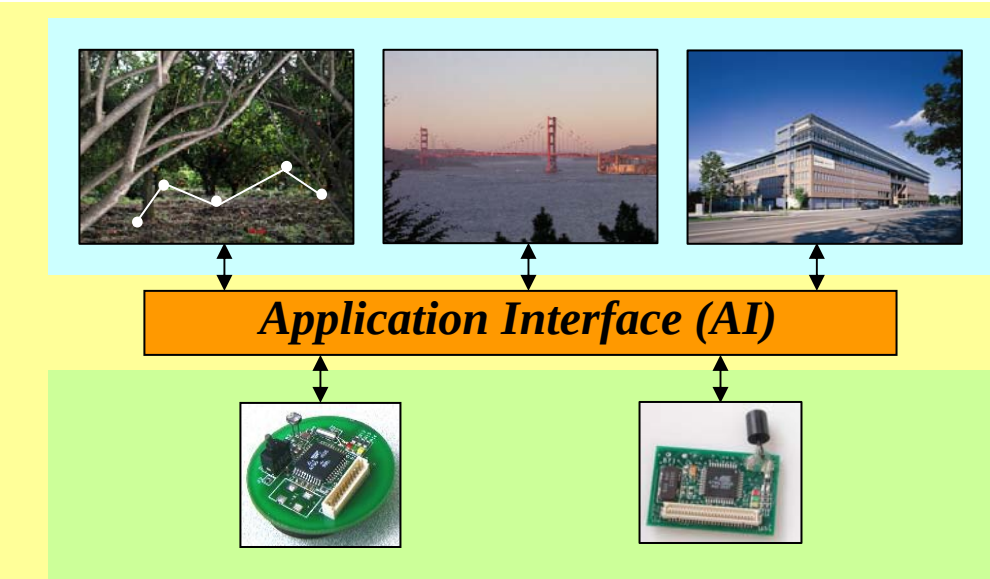
- Well, but do we really have to sense everything using some type of motes?
- Let us assume I am interested in Temperature in Barcelona, now. What do I do ?

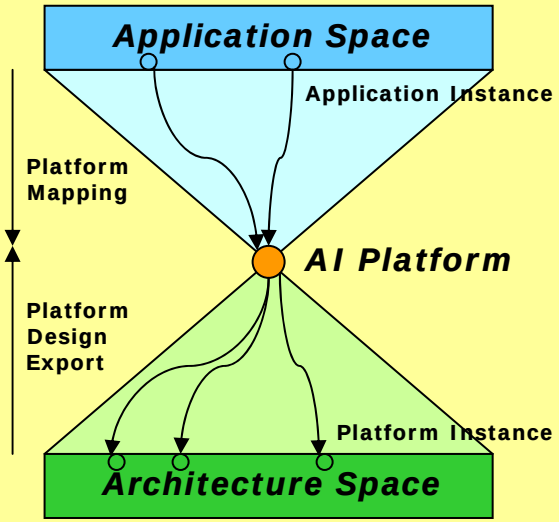
  Ask Google.... “weather in Barcelona”
- What did we get? Just a new set of sensors... let us call them “virtual sensors”.
- Note: they have very similar features to “classical” sensor nodes:
  - Are highly redundant
  - Might disappear, new might come
  - Each node might be temporarily unavailable
  - Problems with trust, with non-proper information...

General Sensor Network Topology (snapshot)



A case for Service-based Application **Interface**





- Focus is on the information (or the service), remaining independent of the Implementation on any present and future Sensor Network Platform
- Service-based: standard set of ***Services*** and ***Interface Primitives*** available to Applications
- Significance similar to the significance of the **Socket interface** in the Internet development

Data Centric Adressing

- **Interest in** : temperature in the Kitchen

  NOT referring to node A20 (or 10.32.117.241)

- Address (not unique!!) consists of a pair:
  - ***Attribute specification*** : Attribute and value selector

    ((temperature, > 25 degrees) OR (humidity, = 70 %))
  - ***Scope****:* description of an *organization* or *region*

    Org. : Utility company (electricity provider), Fire Dept..
    Region: Kitchen, courtyard; **or**: 30 meters around XXX

- How to?

  Possibly by flooding the request and collecting the answers (see for example Directed Diffusion, Estrin et al. UCLA)

Aggregation ...

- Because of
  - Node redundancy
  - Similarity of sensing results due to constraints of physical values variability in space or time..

  redundant data might easily be generated...
- Aggregate data while forwarding messages by intermediate nodes!

  using computation to reduce number of sent messages
- Or at least numerous sensor readings passing a single node might be put into a single data packet – saving the overhead on headers... but increasing delay...
- What about reliability of aggregated data transmission?

A testbed for controlled experiments

- We need better understanding about what is happening at the network level
- The complexities of the wireless communication and the massive scales involved, render our traditional tools inadequate
  - Analysis
  - Simulations
  - Limited deployments with debug info sent over the wireless channel

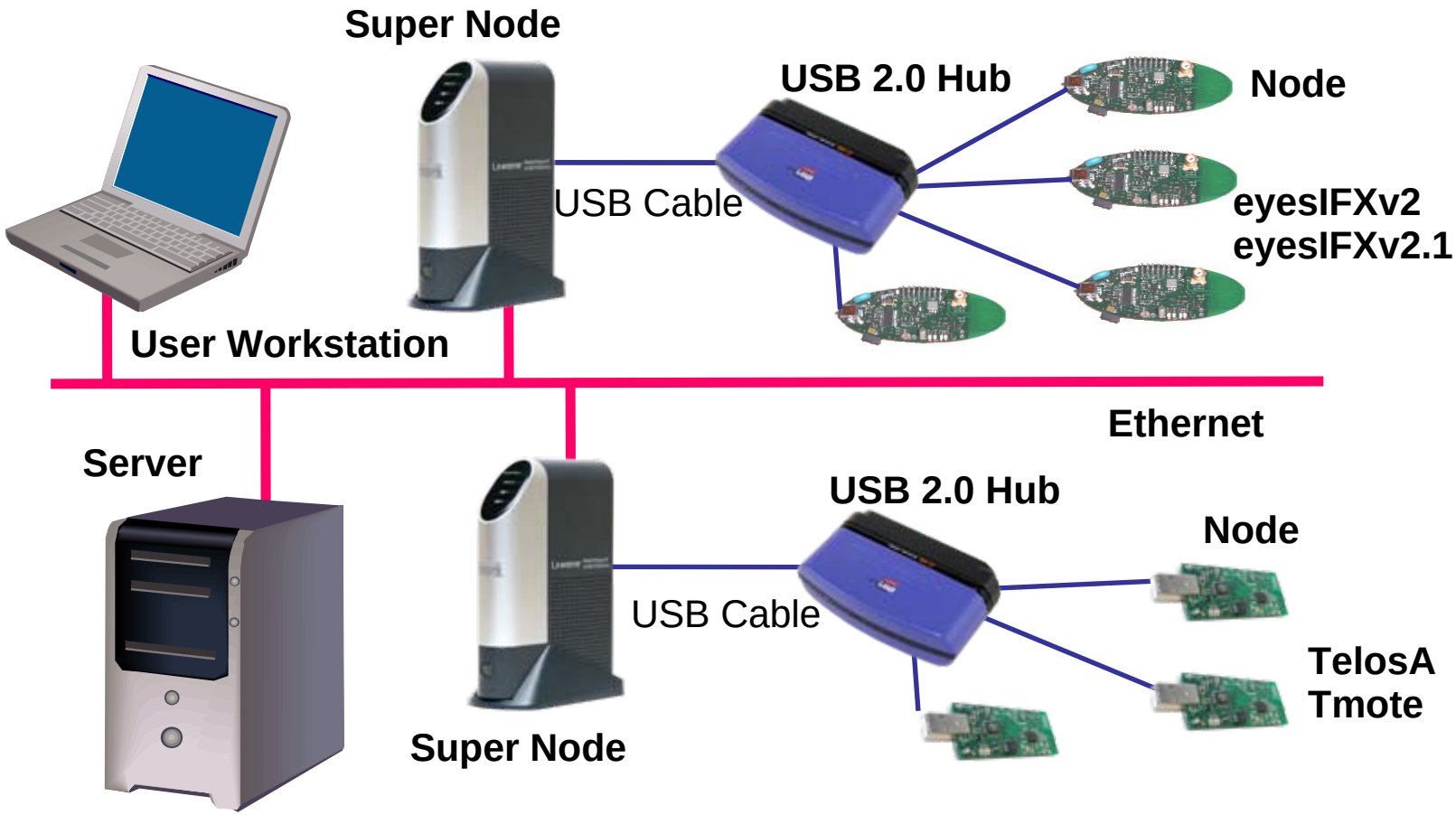
Use a large-scale controlled experimental testbed with out-of-band signaling

For details see: V.Handziski et al: "TWIST: A scalable and reconfigurable Testbed for Wireless Indoor Experiments with Sensor Networks" to appear in Proceedings of REALMAN; Florence, May 2006

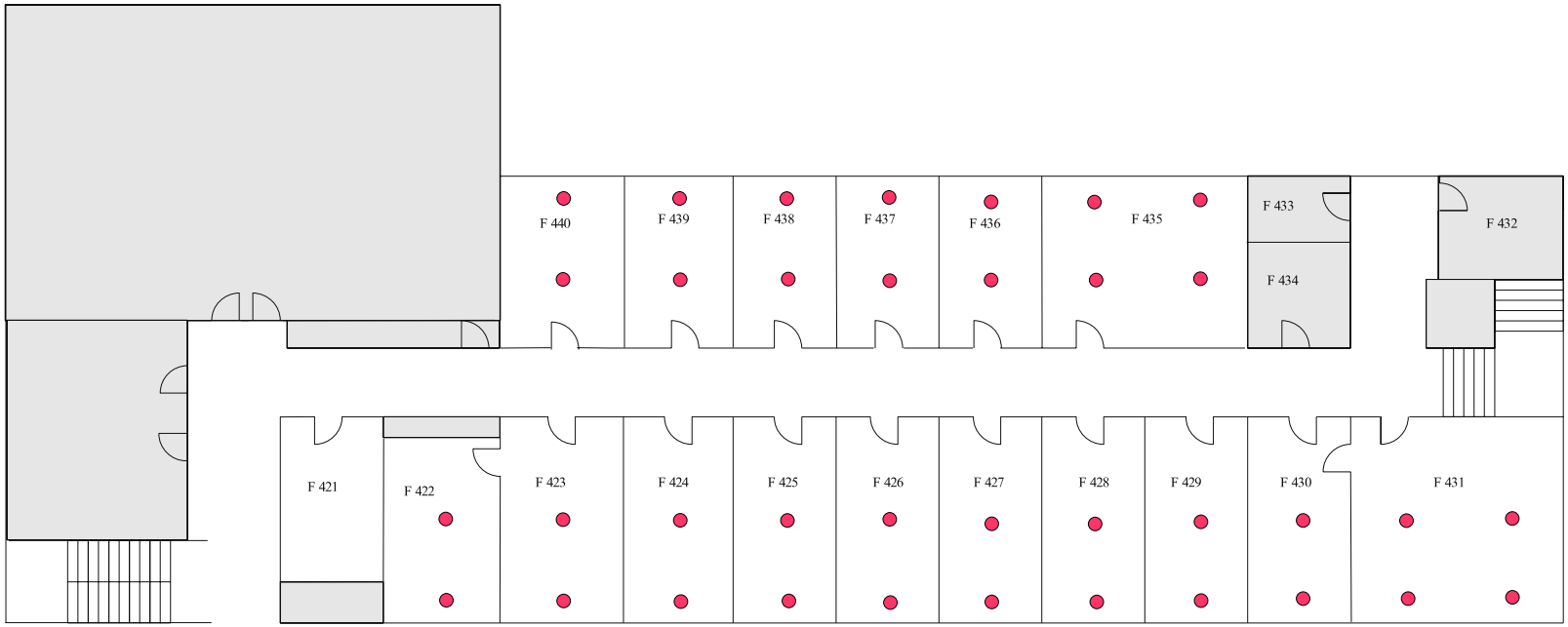
Desired WSN Testbed Features

- Support for hosting different SUE architectures
  - Flat, single platform WSNs
  - Segmented, multi-platform WSNs with gateways in-between
  - Hierarchical WSNs with high-performance nodes for dedicated tasks
- Support for testing and debugging
  - reliable and fast out-of-band reprogramming of nodes
  - out-of-band signalling of debug information
  - time synchronization for “happened-before” event ordering
- Support for running experiments
  - power control to simulate node failures, arrival of new nodes
  - synchronous switch to batteries - estimate consumed energy
- Support for easy management
  - identification of malfunctioning nodes
  - automatic inventory control and configuration

TWIST Instance at the TKN Building



The TKN Wireless Sensor Networks testbed



Close to 150 nodes covering 3 floors of the FT building

Making large-scale WSN testing affordable

- Hardware costs significantly lower then “classical” WSN-testbed setups
  - WSN Node ~ $100
  - USB hub ~ $30
  - Gateway node ~ $80
- Total cost for 100-node testbed (without cabling):

  100 x 100+25 x (30+80) = **$12750**

  vs. *100 x 100 + 100 x 350* = ***$45000***
- State-of-the art software infrastructure completely based on Open Source solutions that we plan to make available in an easy to use package
- Further development in progress: Talk to me if interested in cooperation...☺

WS**Networks** design paradigms ...

- **Cheap**, (non-reliable, redundant?) nodes/Routes!!!
- Keep operation of the system in spite of the failure of components!! *Over long, long periods of time...*
  - Nodes are mostly sleeping, might be lost...
  - Signal deteriorate... Interference...
- *Redundant* objects can replace each other in their functionality: Care about *Role* not about *Identity*
- *Self-organizing* capability, cooperative problem solving
- *In-network Processing* rather than “Internet Style” dumb network with all intelligence in the end systems (e.g. in network data aggregation!!).

More White Spots

- Deployment planning and execution...

  How many nodes do we need? **Where** should they be deployed, how to do it...

- Plug&Play operation of nodes:

  No turn-key solutions, application functions and devices will be incrementally added to existing systems. Seamless extension needed!

- SECURITY; **PRIVACY**!!

- Business Models!!!

  There are generally not developed. A significang share of the applications might easily be in the space of „infrastructure“ which is always pretty hard ...

Thank You !

Questions?

Ask now!

Alternatively :

Talk to me after this talk

or drop me an

e-mail: awo@ieee.org