Introduction to Wireless Sensors Networks (WSN)

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ICT Summer School
Fiuggi, Italy July 9th, 2015

Wireless Sensor Nodes

- Wireless networks of thousands of inexpensive miniature devices capable of computation, communication and sensing
- A self-configuring network of small sensor nodes communicating among themselves using radio signals, and deployed in quantity to sense, monitor and understand the physical world.

"motes"

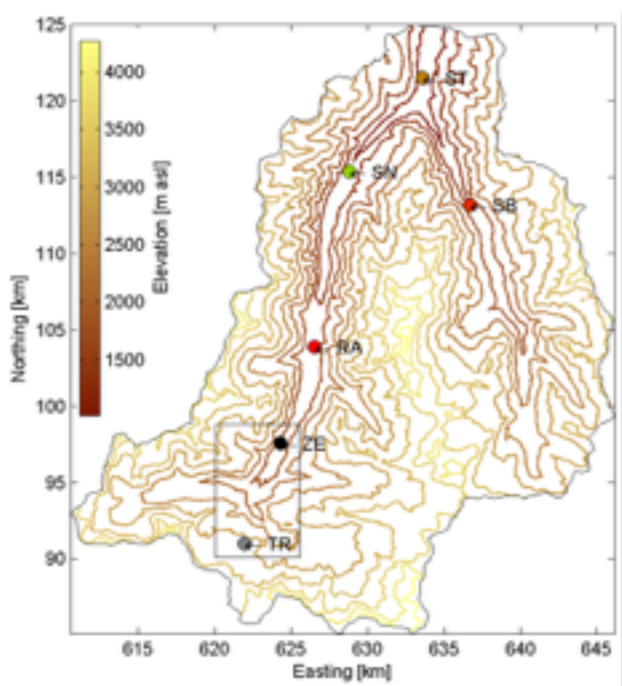
Their use throughout society "could well dwarf previous milestones in the information revolution"
U.S. National Research Council Report, 2001.

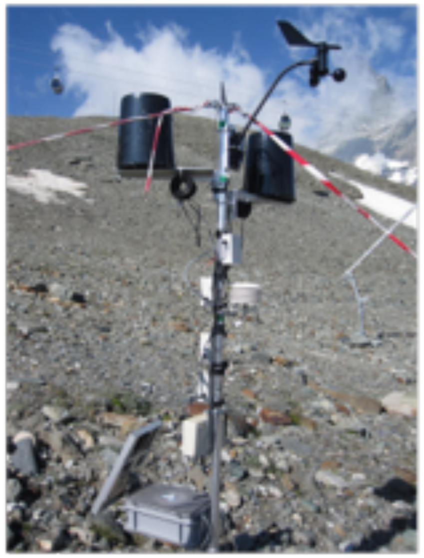
Timeline of WSNs

- 1970’s: Wired sensors connected to central location
- 1980’s: Distributed wired sensor networks
- 1999-2003: DARPA SensIT project: UC Berkeley, USC, Cornell etc.
- 2001: Intel Research Lab at Berkeley focused on WSN
- 2001-2002: Emergence of sensor networks industry; startup companies including Sensoria, Crossbow, Ember Corp, SensiCast plus established ones: Intel, Bosch, Motorola, General Electric, Samsung.
- 2003-2004: IEEE 802.15.4 standard, Zigbee Alliance.

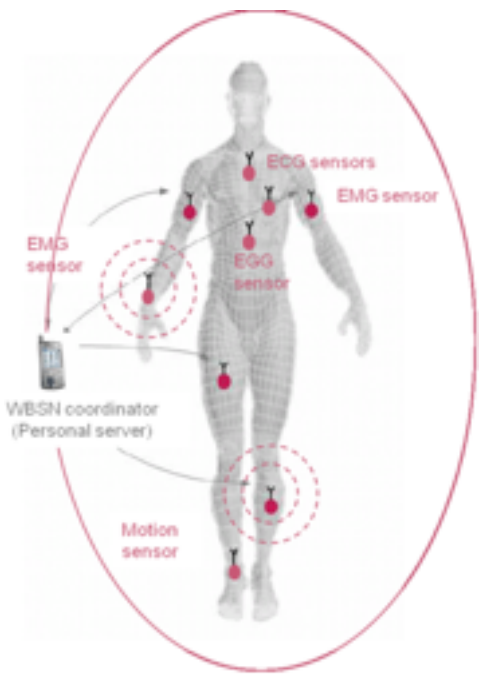
Why (and Who) we needs WSNs?

- WSN provide a bridge between the real physical and virtual worlds.
- Allow the ability to observe the previously unobservable at a fine resolution over large spatio-temporal scales.
- Have a wide range of potential applications to industry, medical, science, transportation, civil infrastructure, and security.

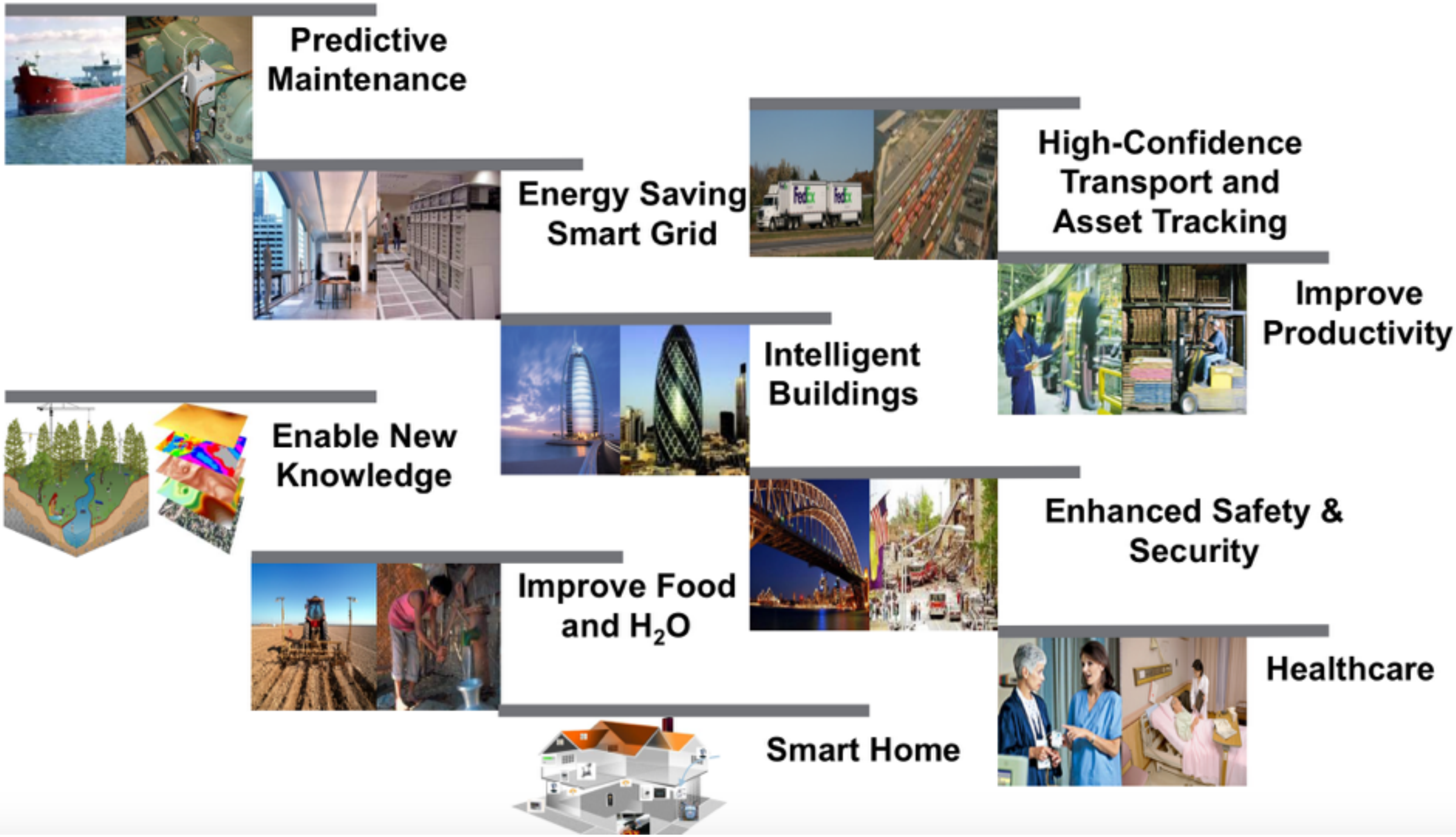



SensorScope Station


Reference Station

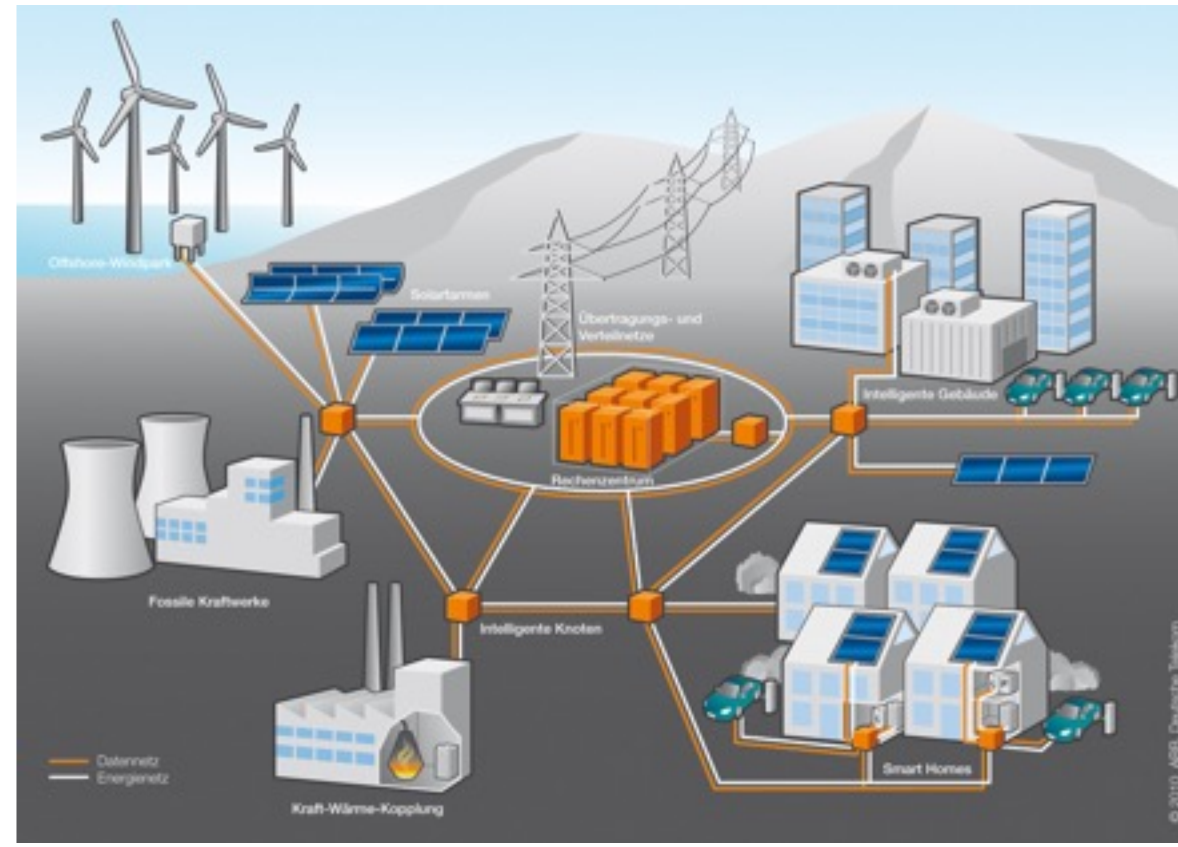


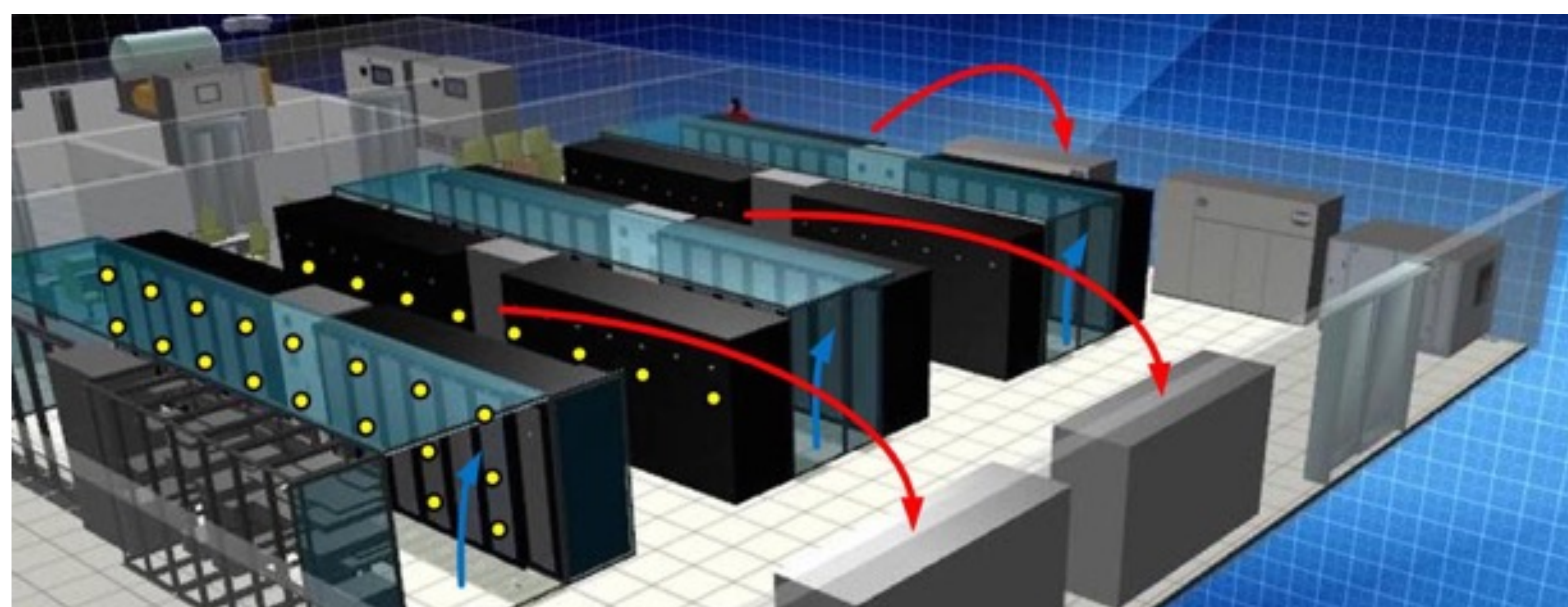
World of sensors!



Applications

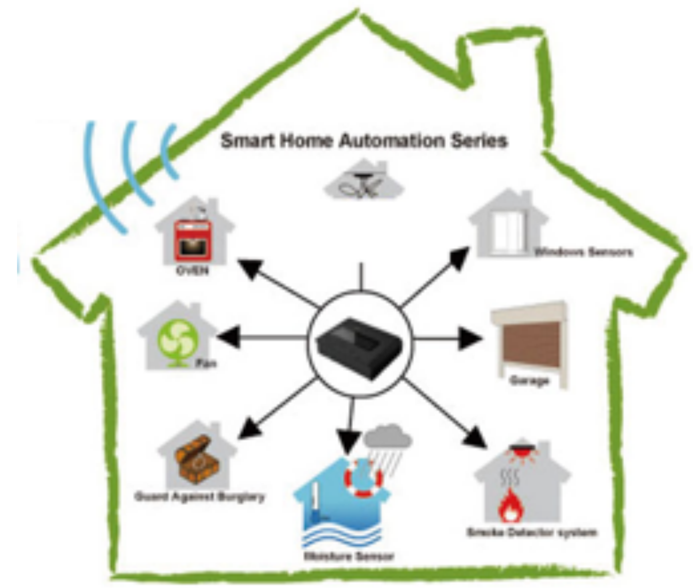
- SmartGrid
- Industrial Automation
  - Industrial Process Monitoring





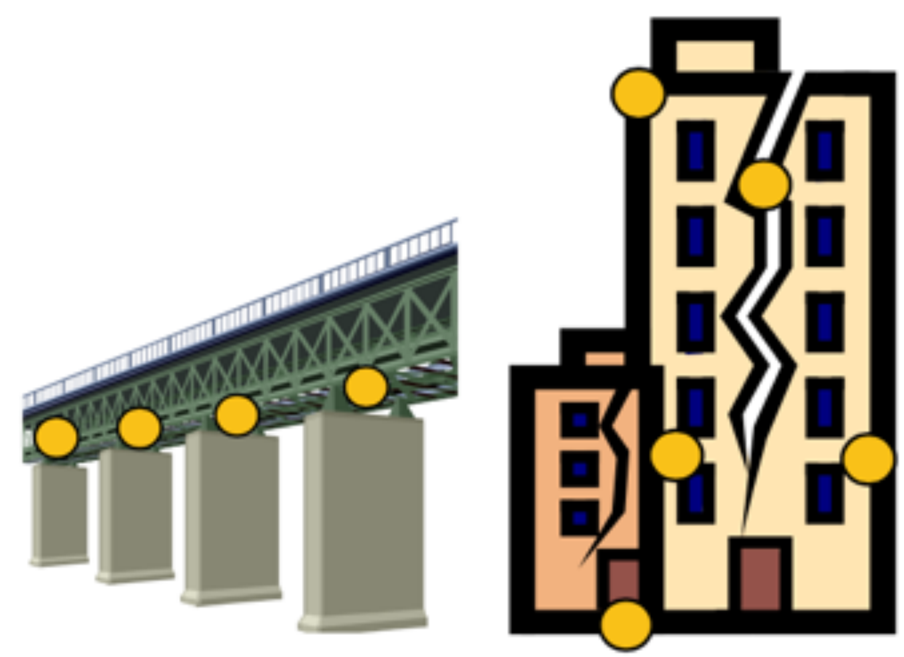
Applications

- Smart Cities and Urban Networks
  - Habitat and Ecosystem Monitoring
  - Monitoring Groundwater Contamination
  - Building & Home Automation
  - Automated Climate Control,…
    - Reduces energy waste



Disaster relief

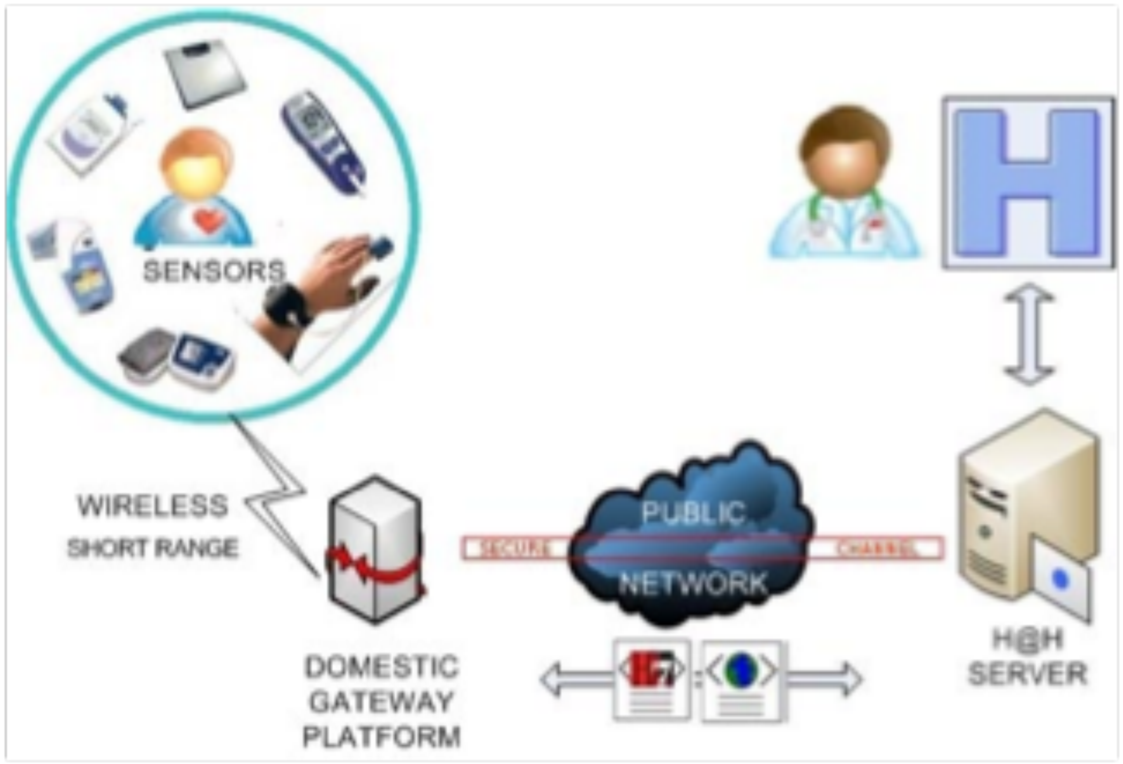
wildlife observation



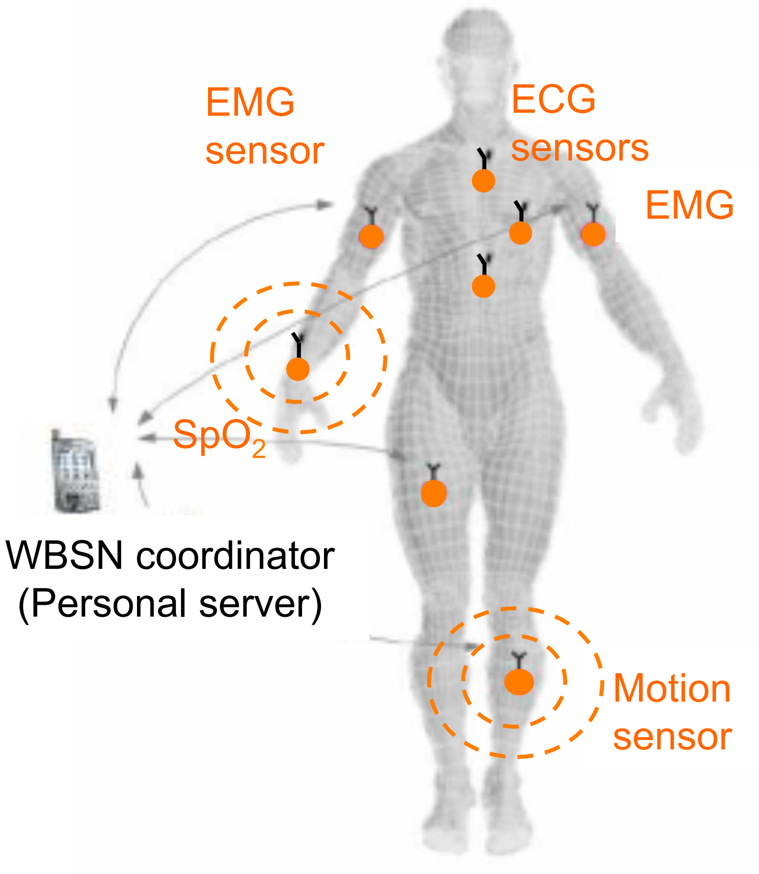
Monitoring stress

Applications

- Structural Health Monitoring
  - Body Sensor Networking
    - Health: monitor & assist disabled, Rapid Emergency response



Health@Home



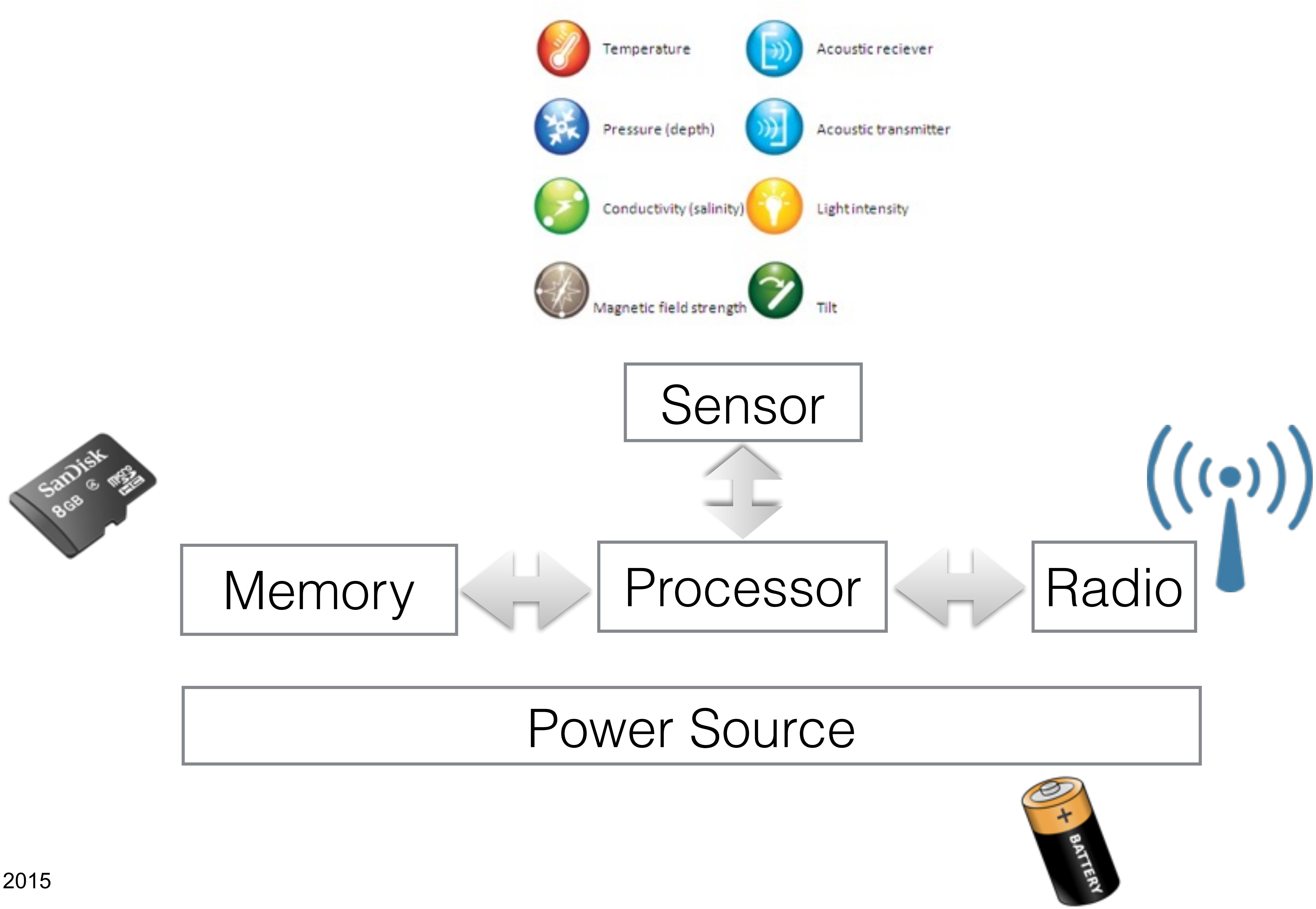
Main Challenges

- Fault tolerance
  - Be robust against node failure (running out of energy, physical destruction, …)
- Lifetime
  - The network should fulfill its task as long as possible – definition depends on application
  - Lifetime of individual nodes relatively unimportant
- Scalability
  - Support large number of nodes
  - Wide range of densities
  - Vast or small number of nodes per unit area, very application-dependent

Main Challenges

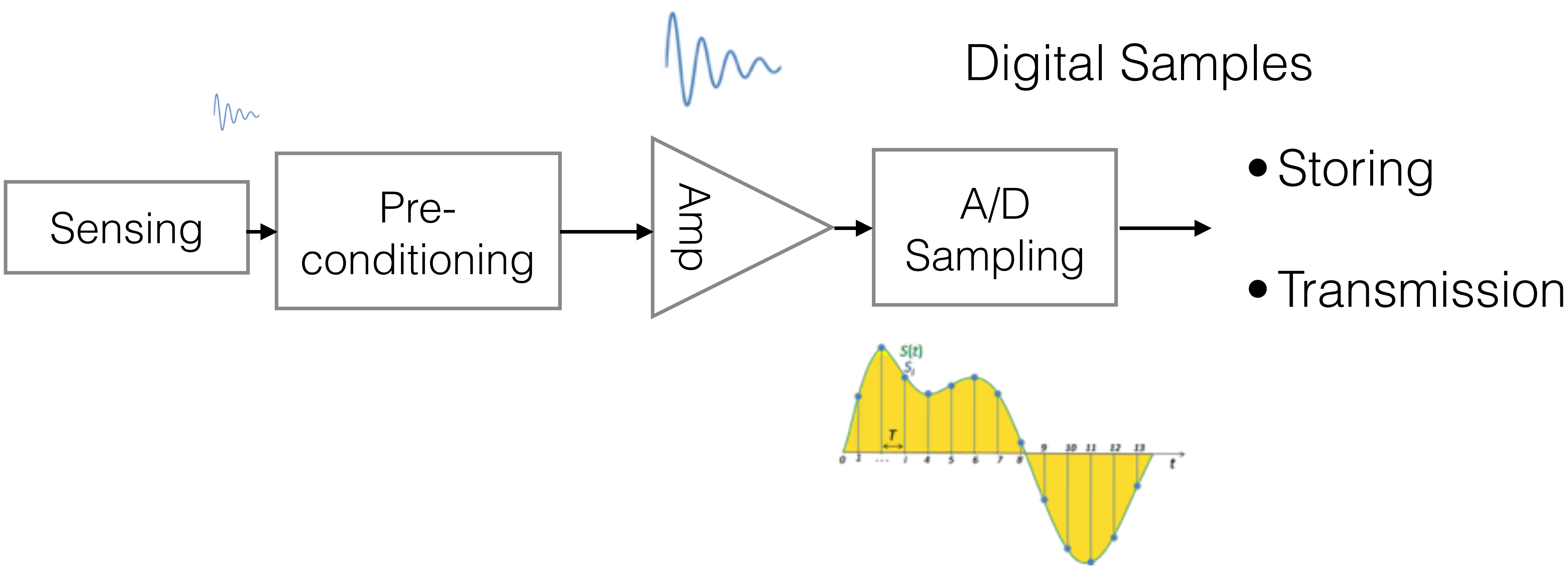
- Programmability
  - Self-Configuration and Adaptation
  - Re-programming of nodes in the field might be necessary, improve flexibility
- Maintainability
  - WSN has to adapt to changes, self-monitoring, adapt operation
  - Incorporate possible additional resources, e.g., newly deployed nodes

Building Blocks of a WSNodes



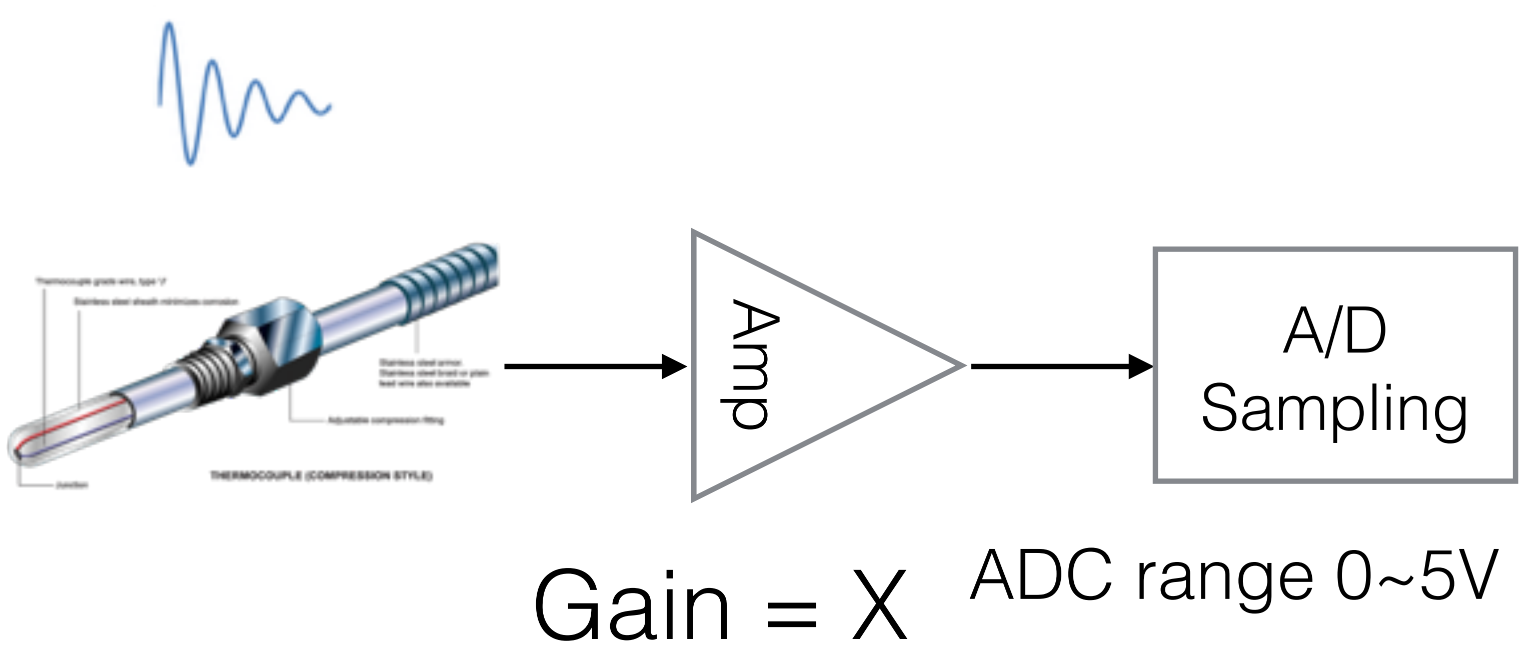
Sensors in detail

- Sensors are transducers to sense characteristics of environment: temperature, humidity, light, ...
- Sensors mainly translate these characteristics into electrical “signals”: current, voltage, resistance, time interval or frequency



Properties of sensors

- **Input range:** the operating range to which the sensor is sensing
  - E.g. Temperature sensor operating reliably from − 5°C to 40°C.
  - Outside this range the sensor's fault tolerance is exceeded.
- **Output range:** range of the output value
  - E.g. Temperature sensor returns voltage between 0 and 5V



- **Sensitivity:** How is a change in input signal mapped to the output signal?
  - E.g. an inclination sensor produces in output voltage of 1mv for every 2.30°.
- **Latency**: Speed with which sensor reacts to change
  - E.g. A temperature sensor having a latency of 14s per 10°C
- **Stability:** insensitivity to factors other then measured physical quantity.
  - Noise: undesired change from ideal output value. E.g. thermal noise in the circuitry
  - Distortions. E.g. electromagnetic radiation influencing the sensor.
  - Environmental influences. E.g. temperature, air pressure, ...

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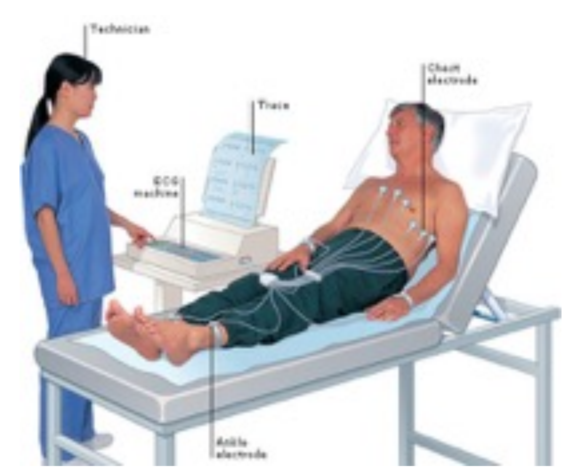
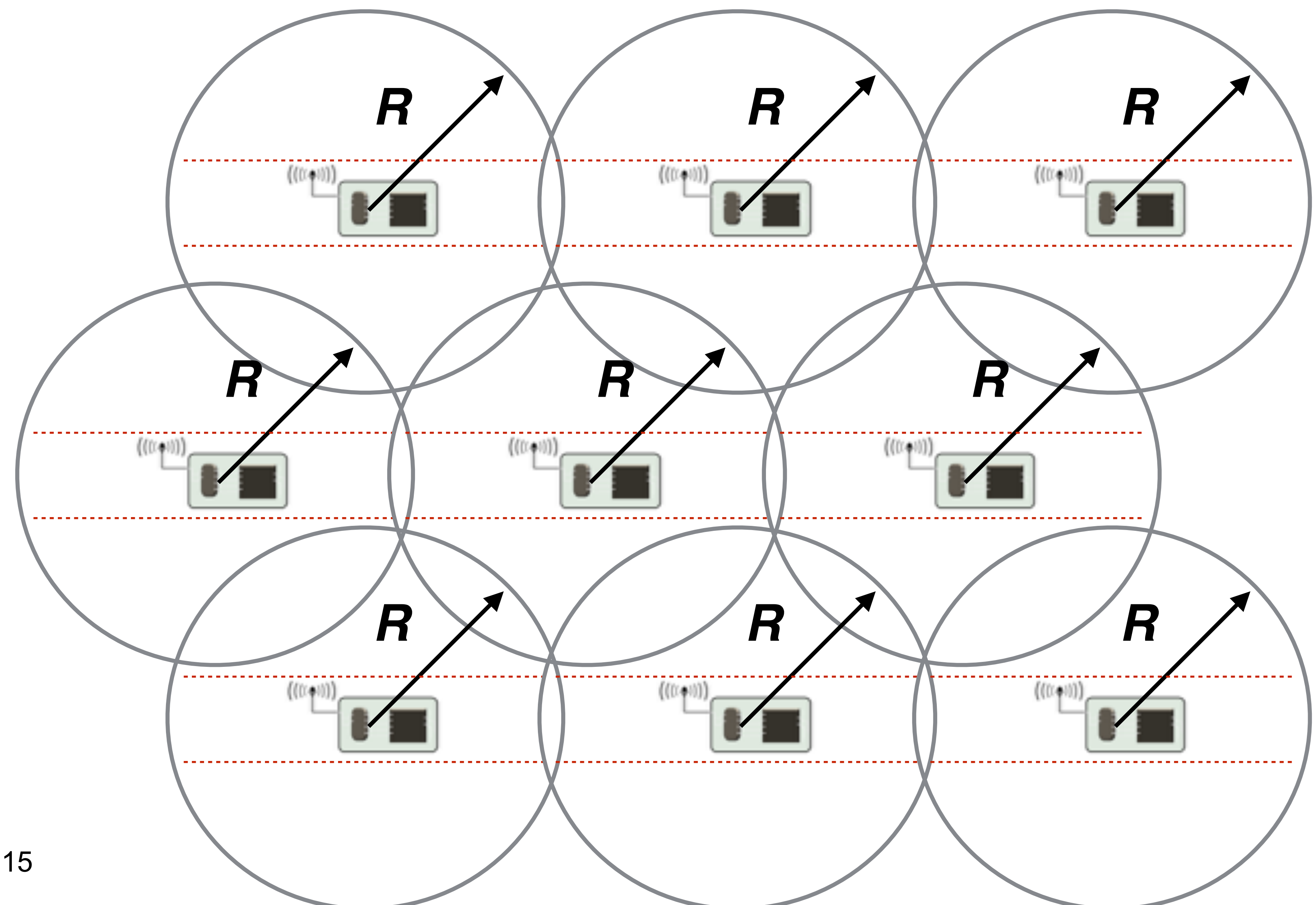
Sensors: examples

- Contact sensor
- Force sensors
- Light sensing
  - Photo diode, Photo transistors, Light dependent resistors (LDR)
- Proximity sensors
- Medical Sensors
  - ECG (Electrocardiogram): Monitor the heart activity
  - Pulse oximeter: Pulse and oxygen level
  - Pressure measurement – Blood pressure, Lung capacity
  - Accelerometer: Stroke, Alzheimers

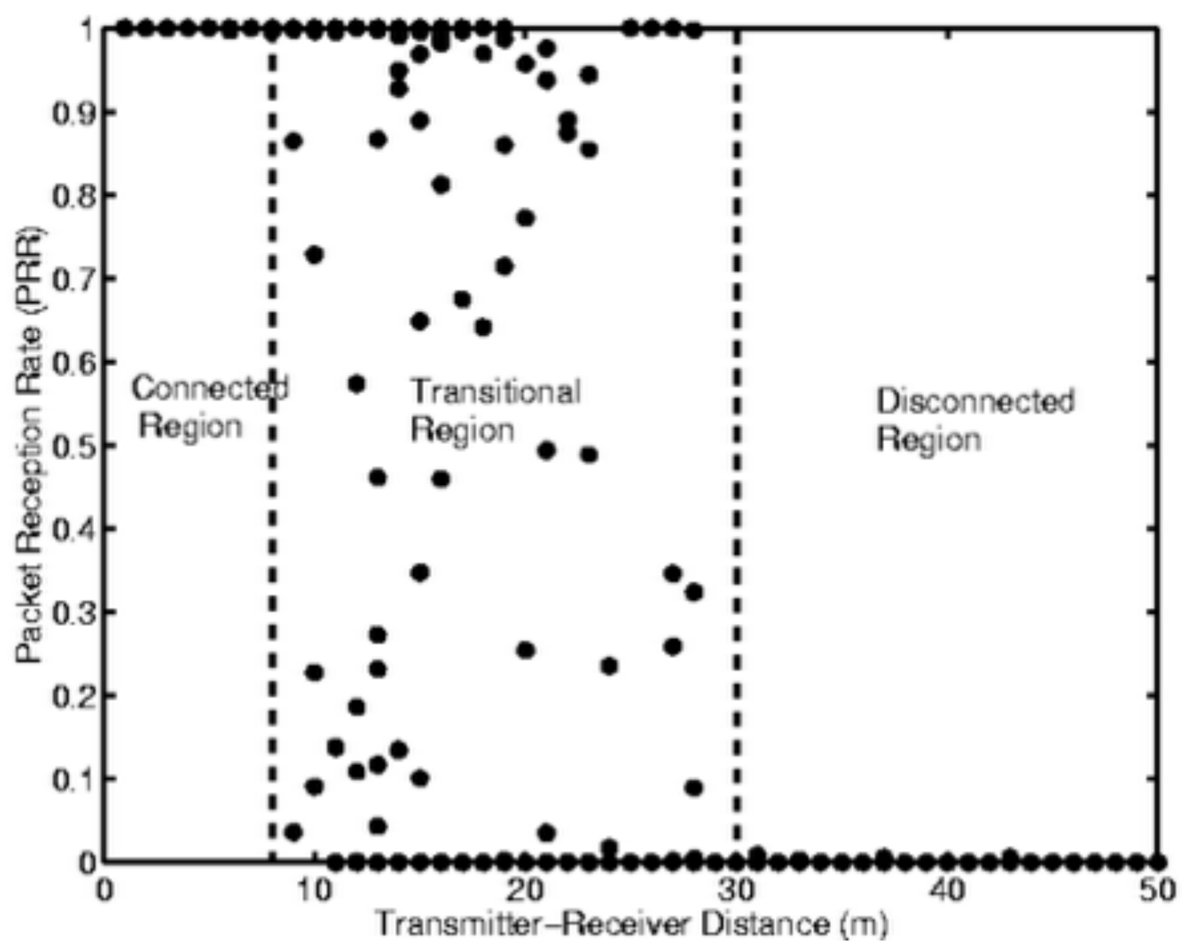
Wireless Networks

- Early studies all assumed a simple perfect-connectivity-within-range model for simulations and analysis.
  - But this is not case in real-life scenarios



Wireless Networks

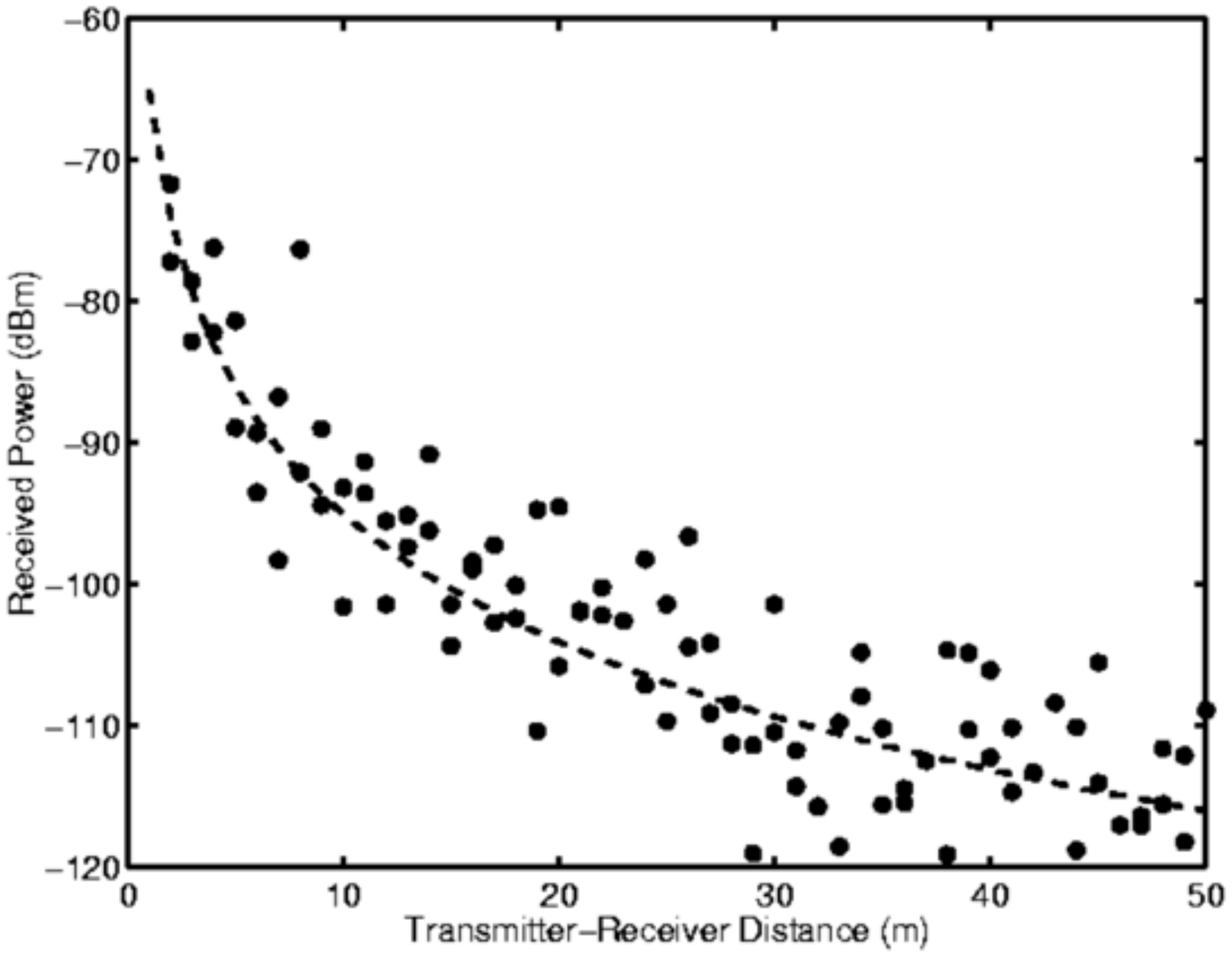
- Links fall into three regions: connected, transitional and unconnected.



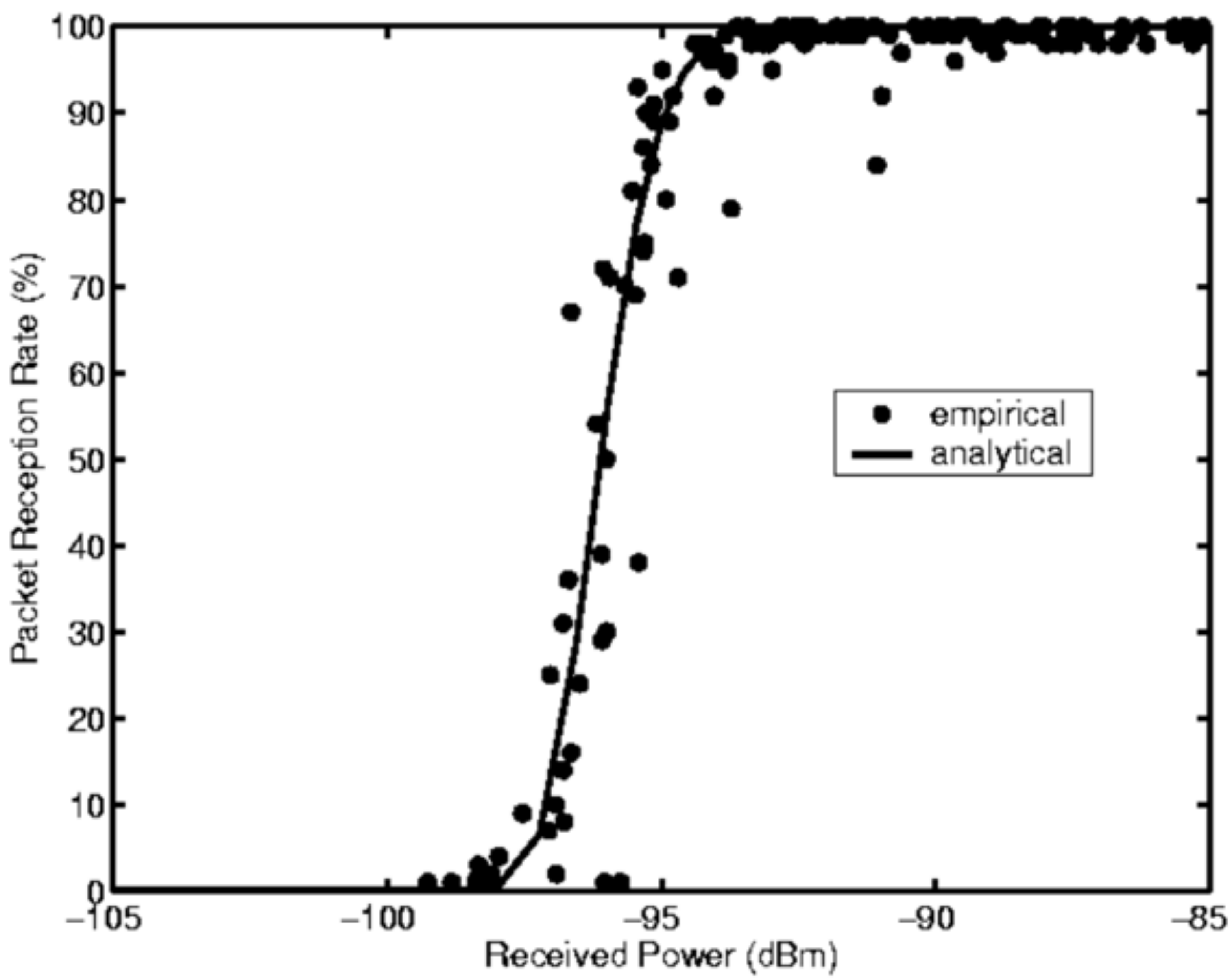
- The transitional region will contain a large number of unreliable links.

Wireless Networks

- Received Signal Strength (RSSI)
  - Represented with “dBm”: power unit in decibels (dB), referenced to 1 milliwatt (mW).

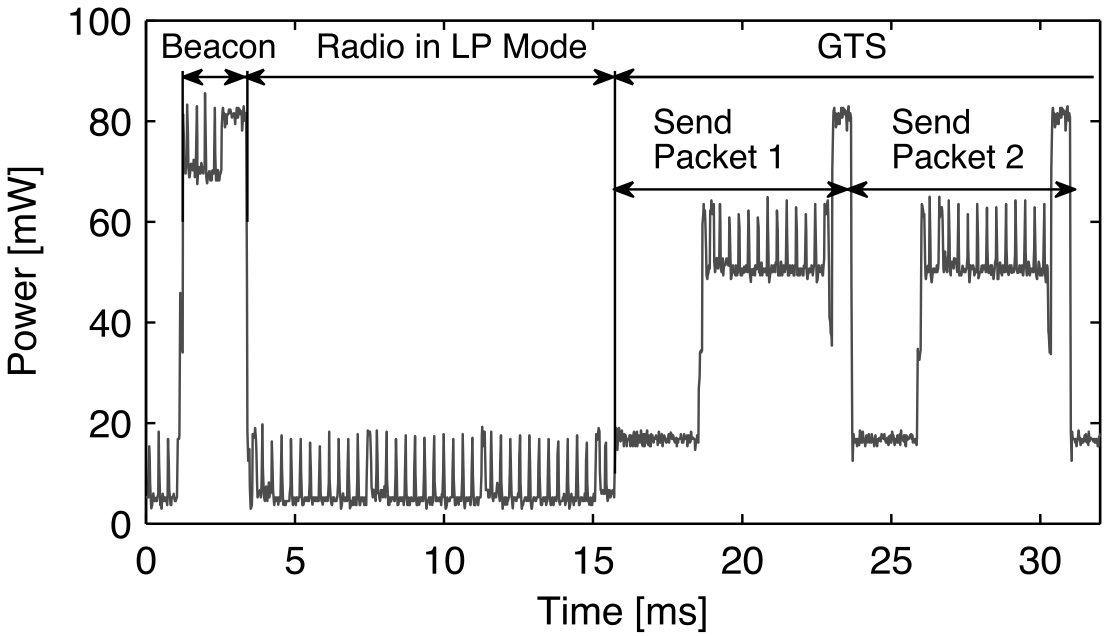


- Radio Reception



Power consumption of radio links

- Transmit and Receive energy costs are typically the same for most radios.
  - Sleep is the only energy efficient mode.
- Startup times and costs vary from radio to radio, but can be quite significant.

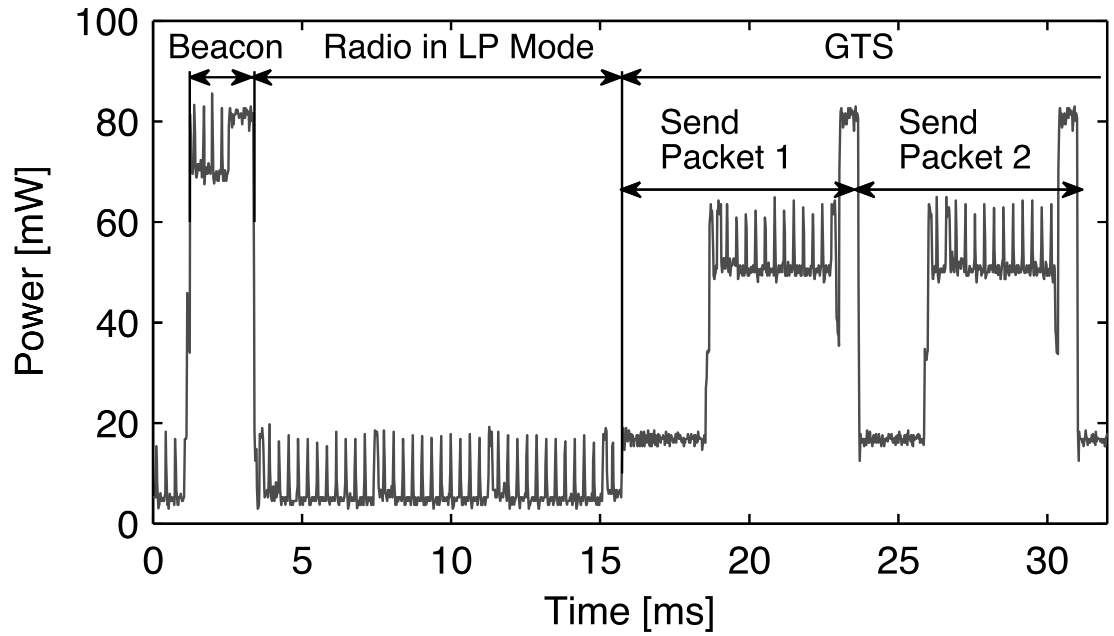


Radio	Freq.	Data rate	Sleep	Tx	Rx	Startup
CC2420	2.4G	250kbps	60uW	52mW	59mW	0.6msec

Wireless Personal Access Networks (WPAN)

- The two main wireless standards used by WSNs are **802.15.4** and **Zigbee**
- Low power/ Low rate protocols
- 16 channels in the 2450 MHz band,
- Max distance is around 100 m (@ 2.4Ghz)
- Over-the-air data rates of 250 kb/s,
- Star or peer-to-peer operation
- Energy detection (ED) and Link quality indication (LQI)
- CSMA/CA channel access and allocation of guaranteed time slots, ACKS

IEEE 802.15.4



- **Carrier Sense Multiple Access-Collision Avoidance (CSMA-CA)**
  - each node listen the medium prior to transmit. If the energy found is higher than a specific level, the transceiver waits for a random time (in an interval) and tries again.
- **Guarantee Time Slots (GTS):**
  - This systems uses a centralized node (PAN coordinator) which gives slots of time to each node so that any knows when they have to transmit. There are 16 possible slots of time.

IEEE 802.15.4

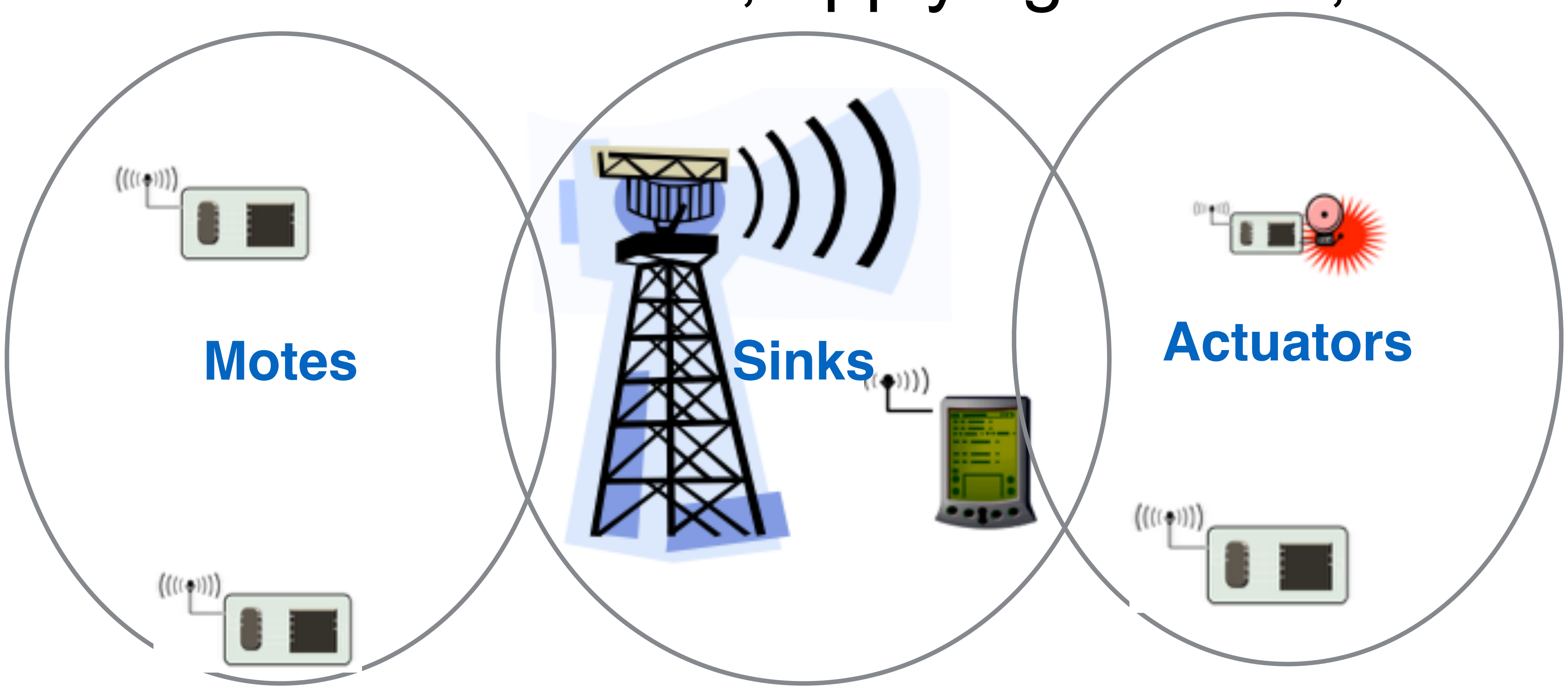
- A highly configurable MAC protocol
  - implemented on TinyOS/RTOS/Motes
- Highly customizable
  - Many independent components that can be turned off if not needed for a particular application
- Highly Low Power:
  - wake up the radio only when needed to transmit, and periodically to check for preamble from transmitter.
  - transceiver can go to sleep most of the time (up to 99% on average), depends on the kind of communication model used.

Zigbee Protocol

- Network Protocol created by a set of companies which form the **ZigBee Alliance**
- Basically offers four kinds of different services:
- **Encryption services**
- **Association and authentication:** only valid nodes can join to the network.
- **Routing protocol:** Reactive adhoc protocol has been implemented to perform the data routing and forwarding process to any node in the network.
- **Application Services:** Each node belongs to a predefined cluster and can take a predefined number of actions.
  - Example: the "house light system cluster" can perform two actions: "turn the lights on", and "turn the lights off".

Nodes in a WSNs

- **Motes or Sources**: Measure data, report them“somewhere”
  - Typically equip with different kinds of actual sensors
- **Coordinators or Sinks**: receiving data, analyzing, and coordinating
  - May be part of the WSN or external entity, PDA, gateway, ...
- **Actuators**: Control devices, applying actions,



Structure os WSNs

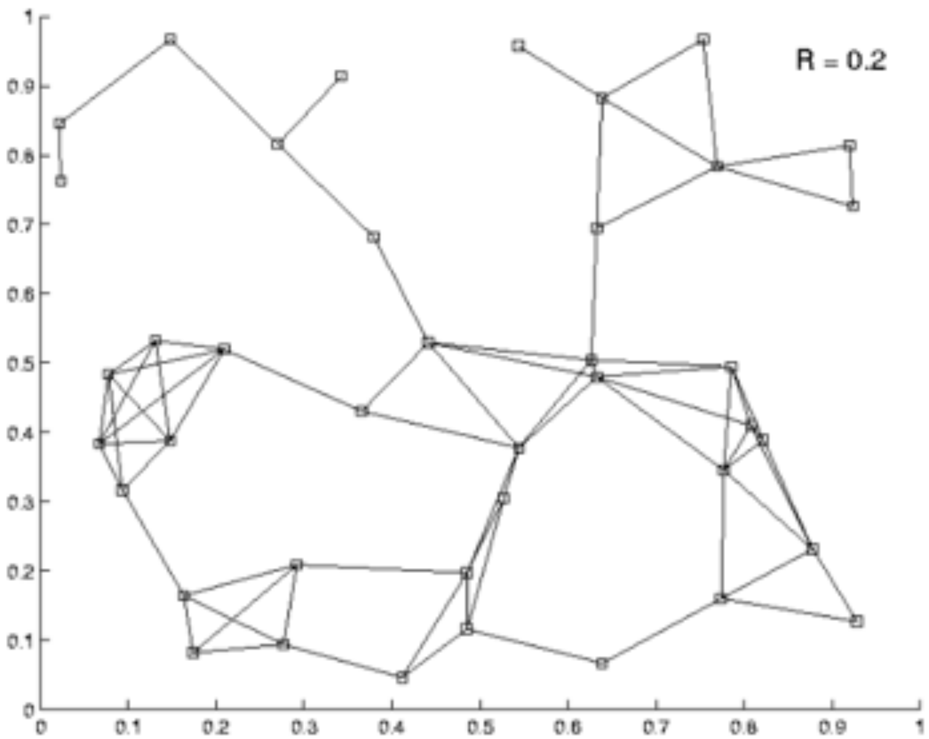
- Interaction patterns between sources and sinks classify application types
- **Event detection:** Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks
- **Periodic measurement**
- **Function approximation**: Use sensor network to approximate a function of space and/or time (e.g., temperature map)
- **Tracking:** Report (or at least, know) position of an observed intruder ("pink elephant")

Deployment and Network topology

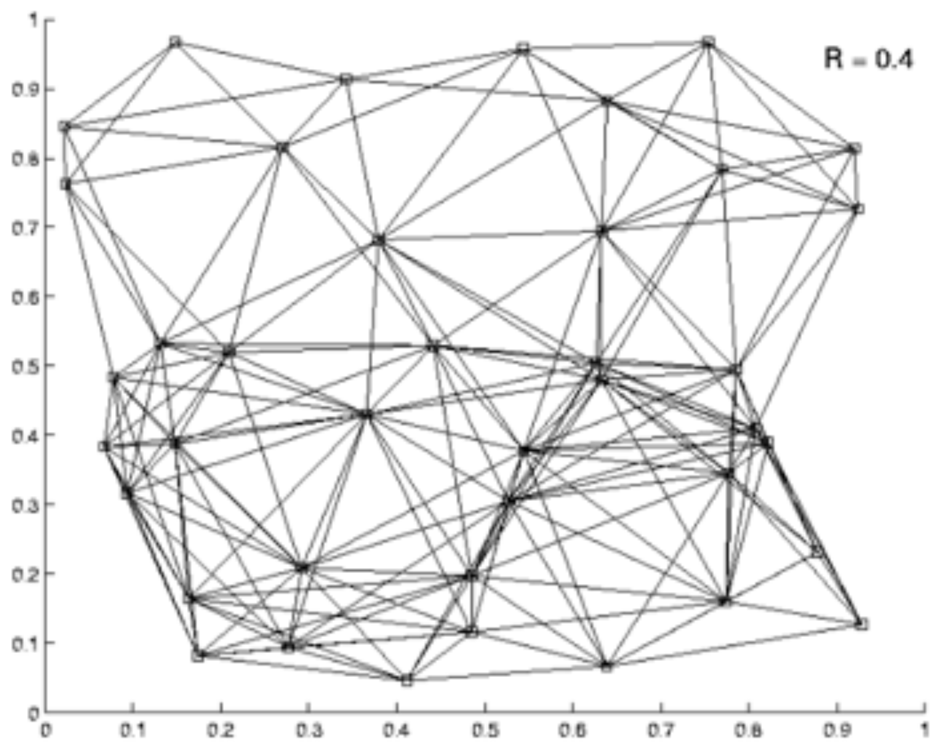
- **Random deployment**
  - For some applications, WSN nodes could be scattered randomly (e.g. from an airplane)
- Random Graph Theory is useful in analyzing such deployments

Random Deployment

- The most common random graph model is G(n,R): deploy n nodes randomly with a uniform distribution in a unit area, placing an edge between any two that are within Euclidean range R.



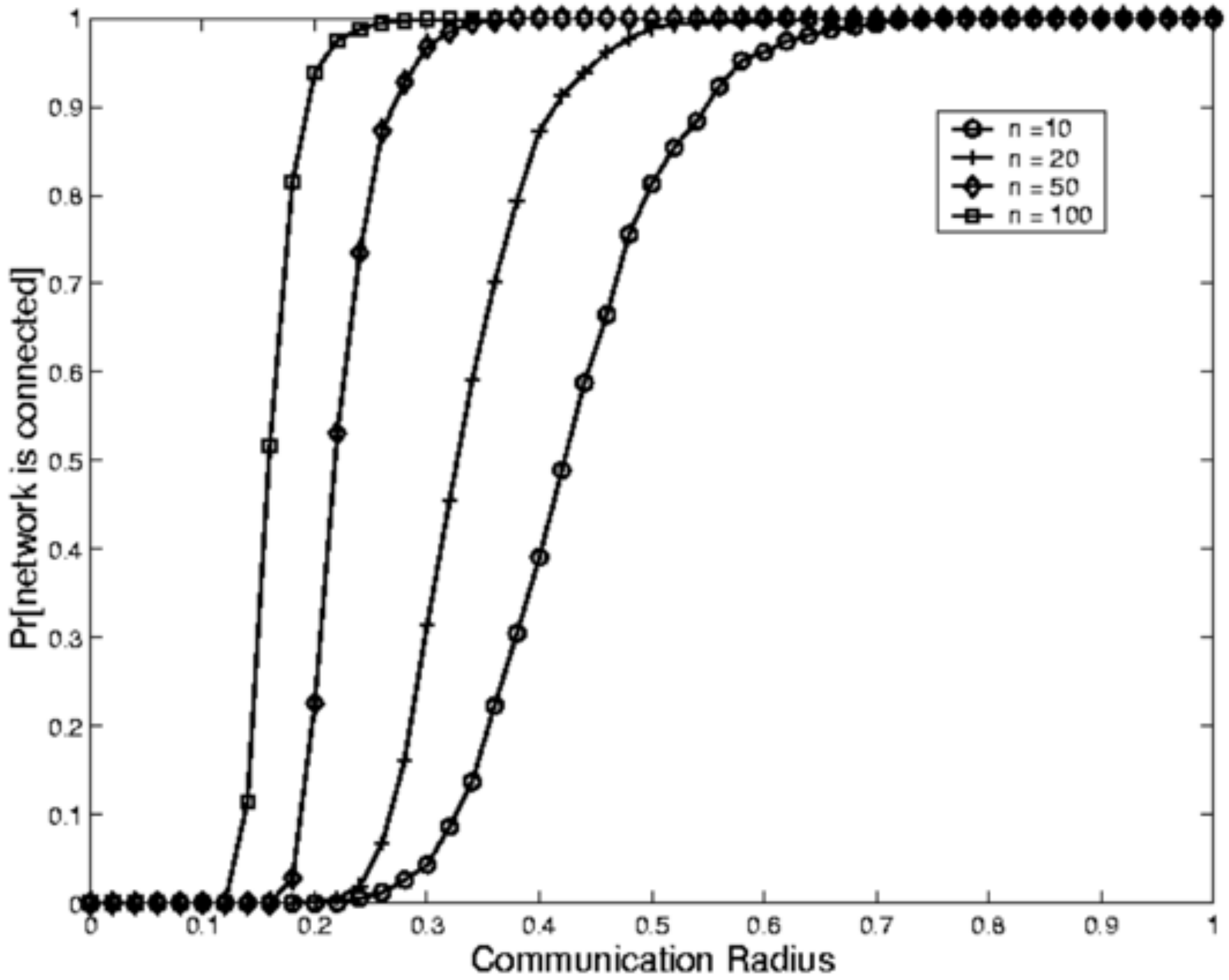
Sparse



dense

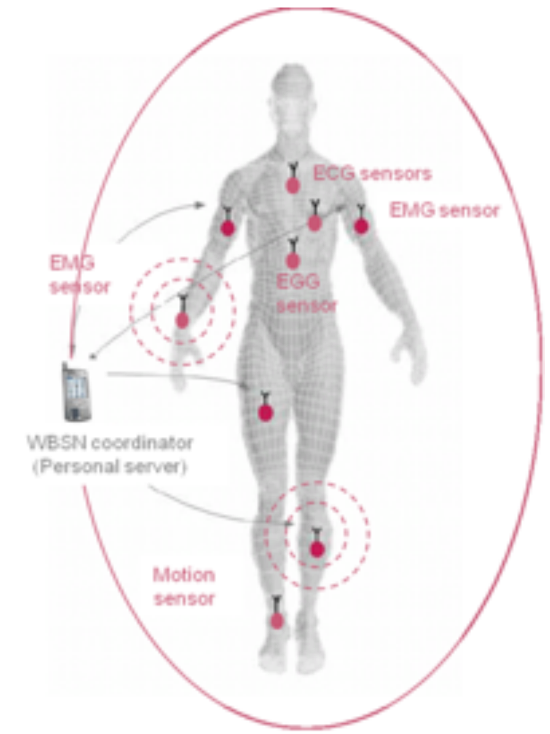
Random Deployment

- Connectivity in a Random graph with G(n,R)



Deployment and Network topology

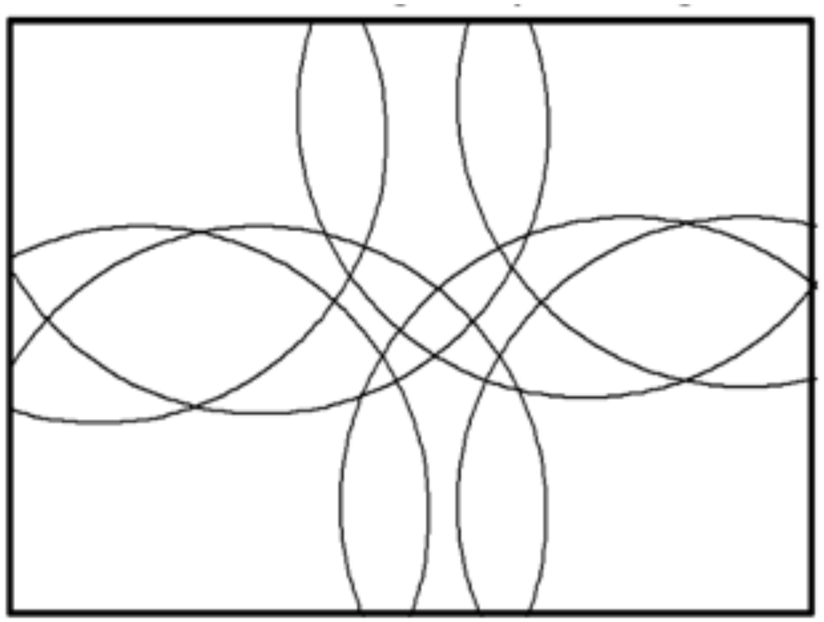
- **Fixed: Regular deployment**
  - in preventive maintenance or similar
  - Not necessarily geometric structure, but that is often a convenient assumption



- **Mobile sensor nodes**
  - Can move to compensate for deployment shortcomings
  - Can be passively moved around by some external force (wind, water)

Key definitions

- All monotone graph properties have an asymptotic critical range R beyond which they are guaranteed with high probability (*Goel, Rai, and Krishnamachari ’04*)
- **K-covered field:** if and only if all intersection points between sensing circles are at or inside the boundary of K+1 sensing circles.
- **The critical range for connectivity:** The critical range to ensure that all nodes have at least k neighbors also ensures k-connectivity.

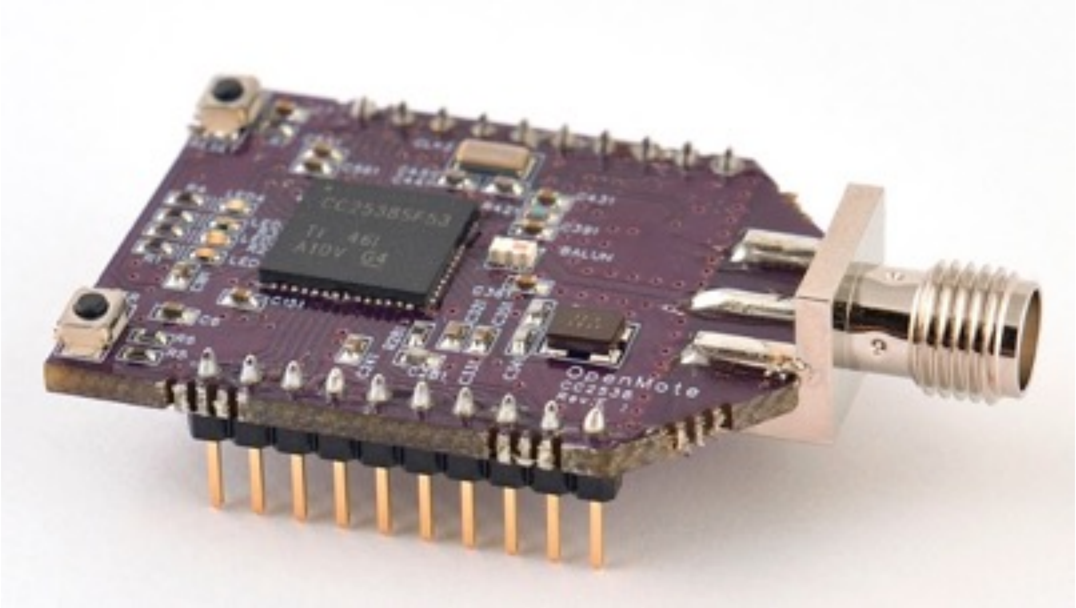


2-covered field

Open Wireless Sensors

- Open Wireless Sensors are devices that are open both in software as in hardware
- They have many advantages on proprietary ones:
  - Cost
  - Personalization

Shimmer



OpenMote

Intel Edison

Conclusions

- WSN are a widely applicable, major emerging technology.
- They bring a whole host of novel research challenges pertaining to energy efficiency, robustness, scalability, self-configuration, etc.
- These challenges must be tackled at multiple levels through different protocols and mechanisms.
- Existing partial solutions offer much hope for the future, but much work remains to be done.

References

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