Low-power and Lossy Networks (LLNs)

Giuseppe Anastasi

Executive Director, Industry 4.0 CrossLab

Dept. of Information Engineering, University of Pisa

E-mail: giuseppe.anastasi@unipi.it

Website: www.iet.unipi.it/g.anastasi/

UNIVERSITÀ DI PISA

DEPARTMENT OF INFORMATION ENGINEERING

CROSSLAB Innovation for industry 4.0

Roadmap

- Low-power and Lossy Networks (LLNs)
  - Definition
  - Communication patterns
- Wireless Sensor/Actuator Networks
  - Classification
  - Application Areas
  - Networking Issues

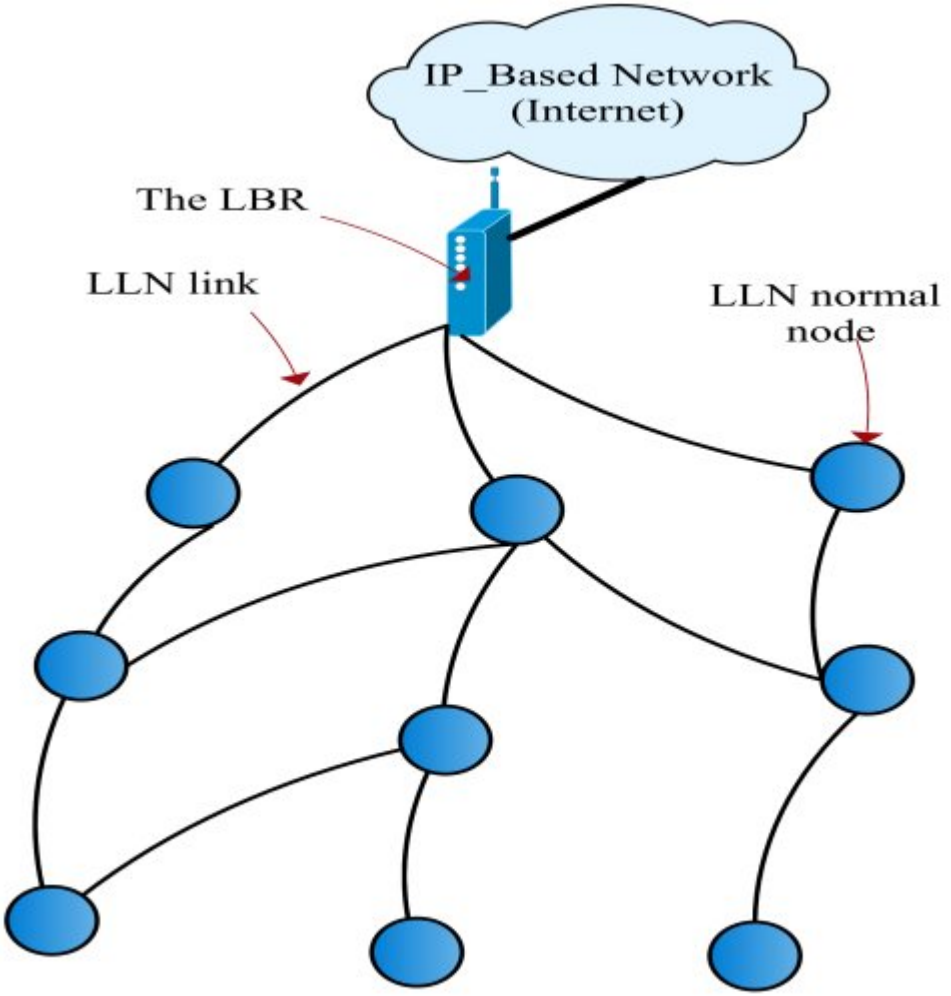
LLN

- A network composed by many embedded devices with **limited power**, **memory and processing resources**, interconnected through wired/wireless link
  - IEEE 802.15.4
  - Bluetooth Low Energy (BLE)
  - Low-power WiFi
  - PLC
  - …
- LLNs often exhibit considerable **loss**, significant **variability** in the delivery rate, and some short-term **unreliability**
- LLNs are typically characterized by **limited and unpredictable bandwidth**

LLN

- Constrained Nodes
  - low power
  - limited memory
  - scarce processing resources
- Constrained Networks
  - Lossy networks
  - Limited and unpredictable bandwidth
  - Dynamic topology
- LLN=Constrained Network of Constrained Nodes

LLN



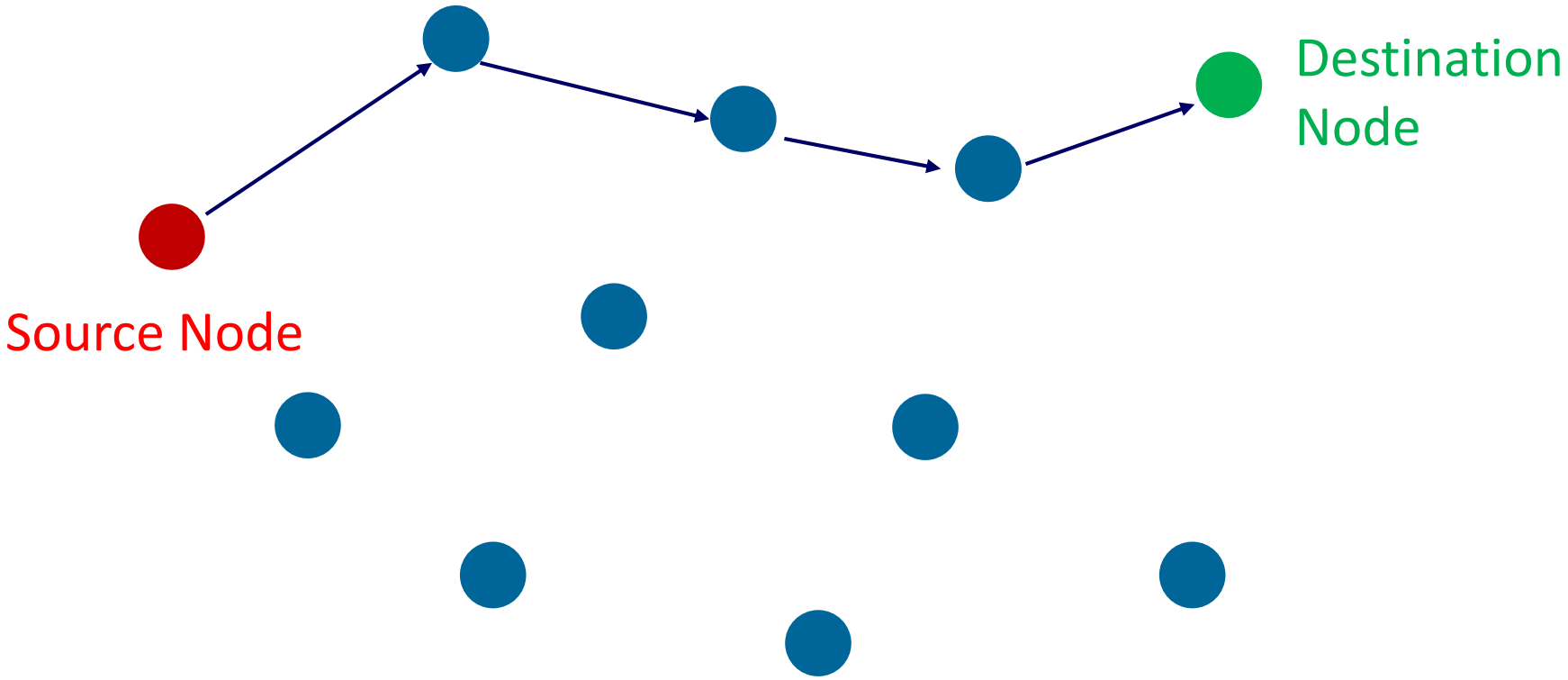
Communication in LLNs

- The communication pattern depends on the specific application scenario
- Unreliable links
- Shared communication medium
  - collisions
- Dynamic network topology
  - Meteorological conditions
  - Power management
  - Obstacles
- Limited power
  - Energy-efficient communication

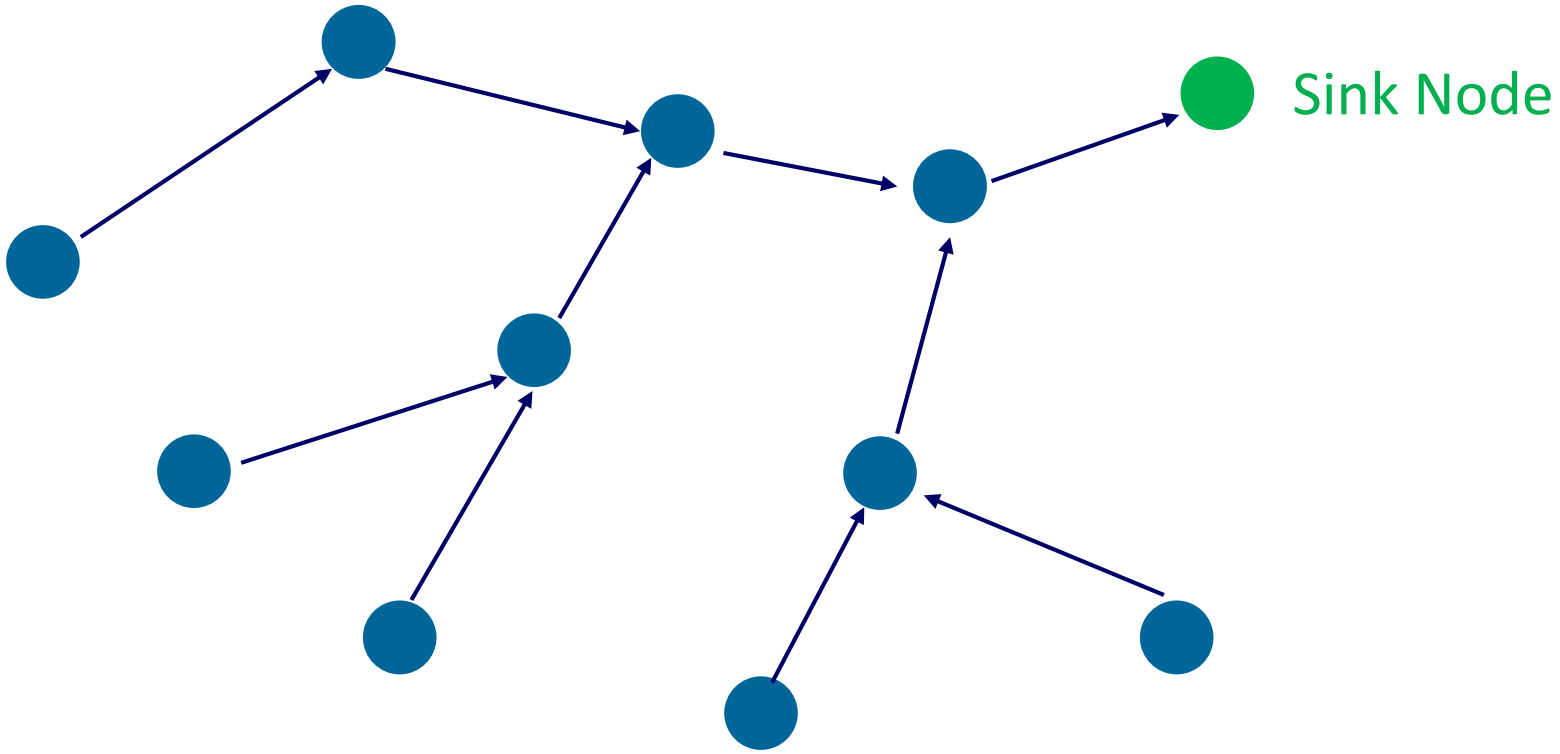
Communication Patterns

- One-to One
- Many-to-one
- One-to-many

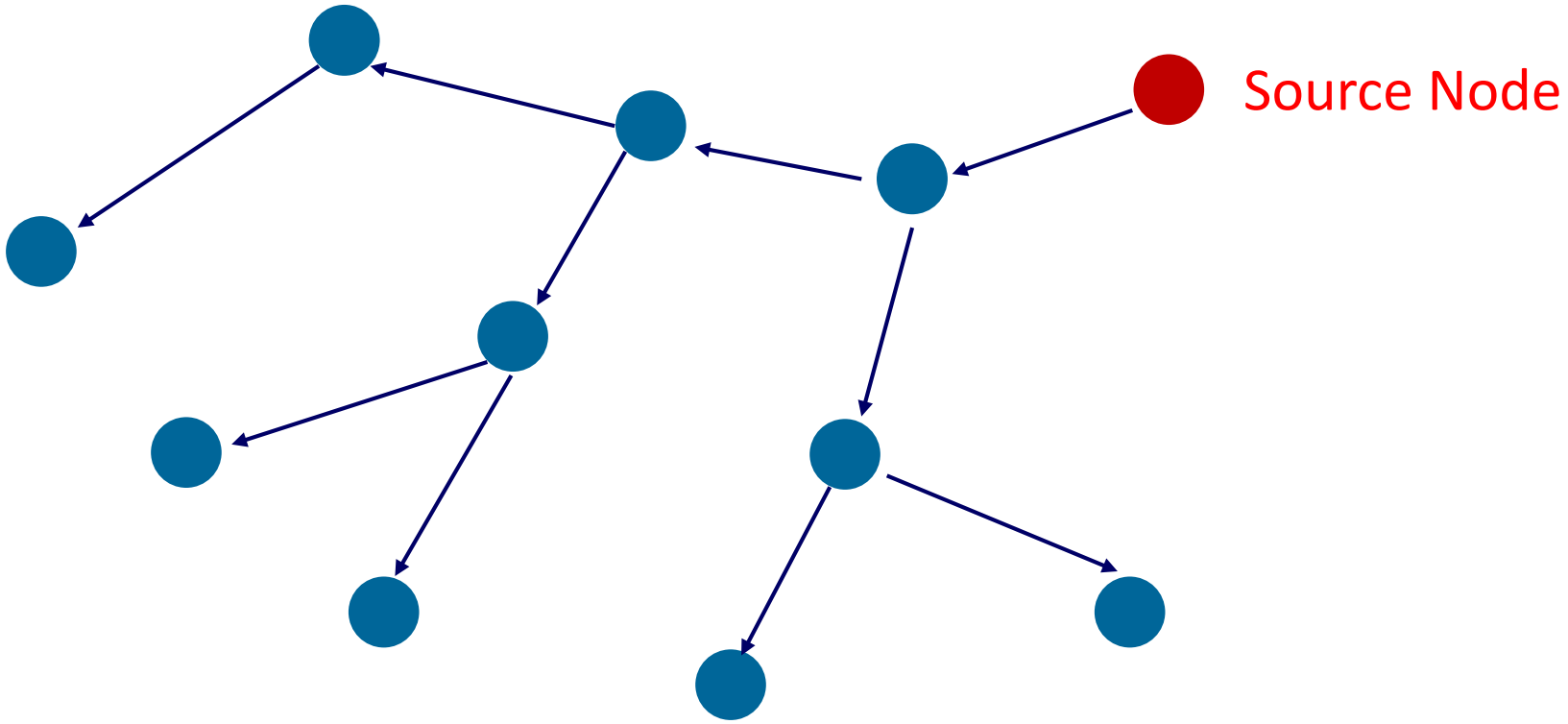
One-to-One Communication



Many-to-One Communication



One-to-Many Communication

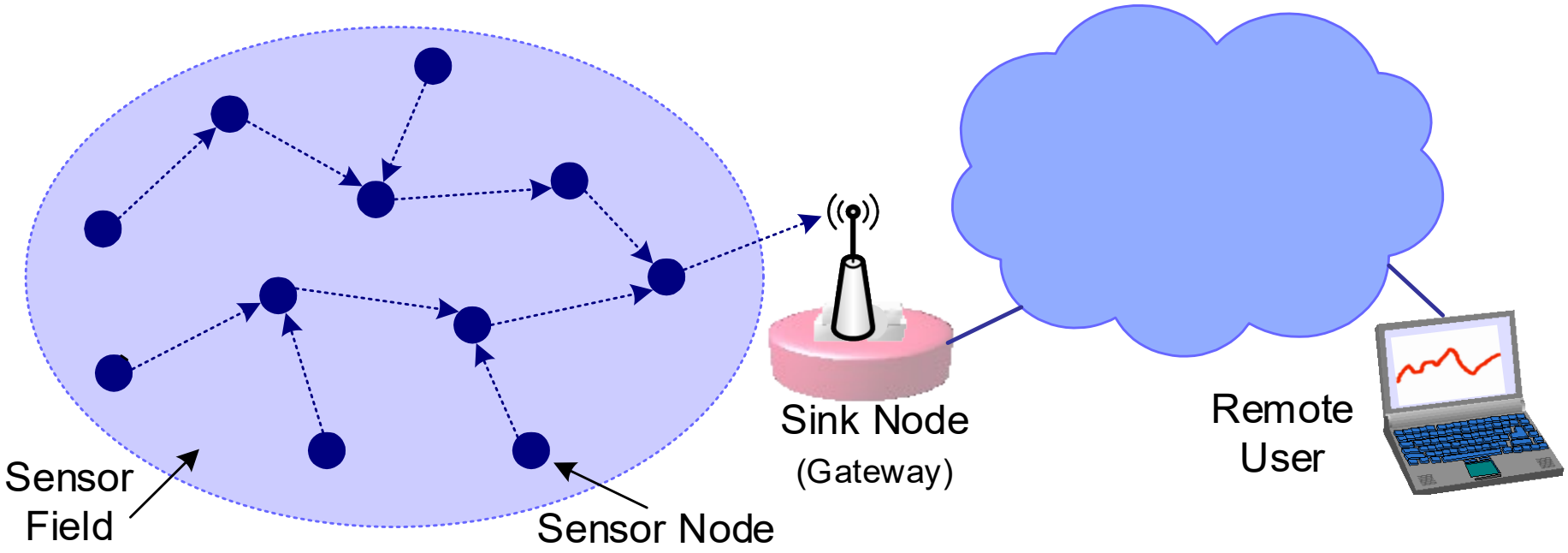


Wireless Sensor/Actuator Networks

Sensor Networks

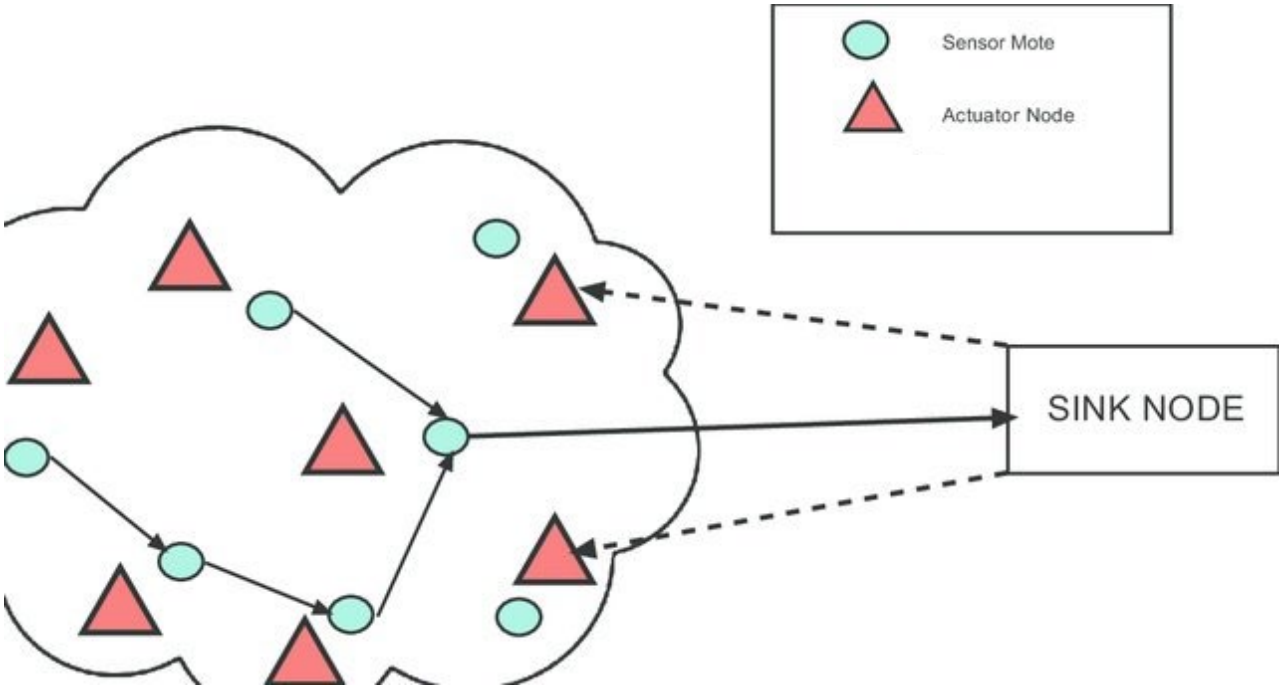
- A large number of tiny sensor nodes
  - deployed over a geographical area
- Sensor nodes integrate three different capabilities
  - *Sensing*, *computing*, and *communication*
- Distributed Sensing Infrastructure
  - Sensor nodes sense physical information …
    - ⇨ e.g., temperature, pressure, vibrations, pollution level
  - … process the data locally …
  - … and/or send them to one or more collection points
    - ⇨ Sink node| base station |gateway | border router

Sensor Networks



Sensor/Actuator Networks

- Include Sensors and/or Actuators
- Actuators allows to act on the external environment



Wireless Sensor/Actuator Networks

- Sensor/Actuator node typically communicate through wireless links
  - Wired communication is also used
    - ⇨ E.g. for emergency and critical applications
    - ⇨ E.g. PLC
  - More flexibility
  - Easy of deployment

- Wireless Sensor Networks (WSNs)
- Wireless Sensor/Actuator Networks (WSANs)

WSN Classification

Topology

- *Static WSN*
  - all sensor nodes are stationary
- *Quasi-static* WSN
  - (some) sensor nodes have limited mobility
    - ⇨ E.g., reloctable nodes
- *Mobile*
  - Some (or even all) sensor nodes are mobile
    - ⇨ Mobile relays/mobile sinks
    - ⇨ Mobile peers

WSN Classification

Density

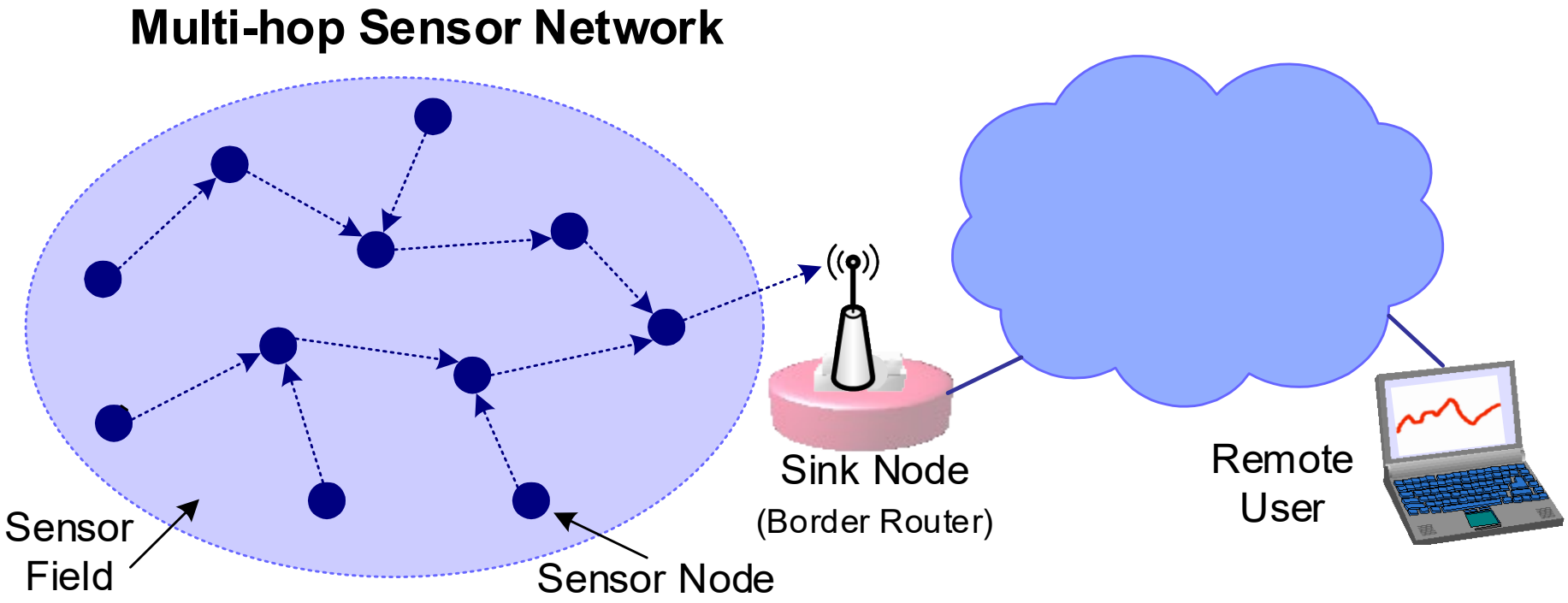
- *Dense WSN*
  - the distance between sensor neighboring nodes is below the transmission range
  - High density, large number of sensor nodes
- *Sparse*
  - the distance between sensor neighboring nodes is much larger than the transmission range
  - The number of deployed sensor depends on the application needs

WSN Classification

Data Collection Paradigm

- *Multi-hop Communication*
  - *Flat*
  - *Hierarchical*
- *Mobile Data Collectors*

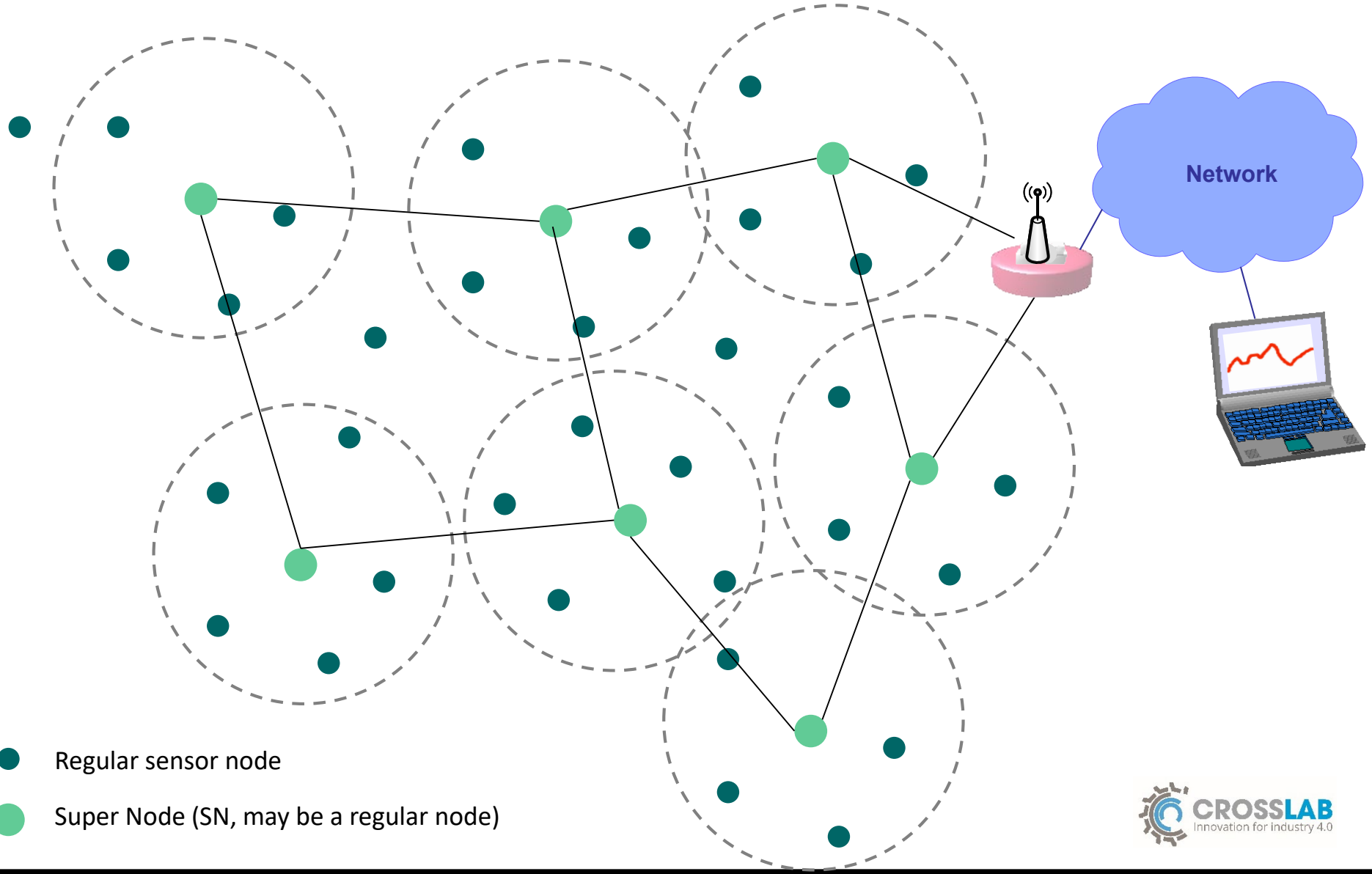
WSN Architecture: Flat Multi-hop



WSN Architecture: Flat Multi-hop

- Dense Network, Static Topology
  - Typically random deployment
  - Multi-hop communication
- *Long paths* from sensors to sink
  - Large sensor-to-sink delay
  - Low reliability
  - High energy consumption
  - Funneling effect
- Application areas
  - Military applications, environmental monitoring, structural monitoring

WSN Architecture: Hierarchical Multi-hop

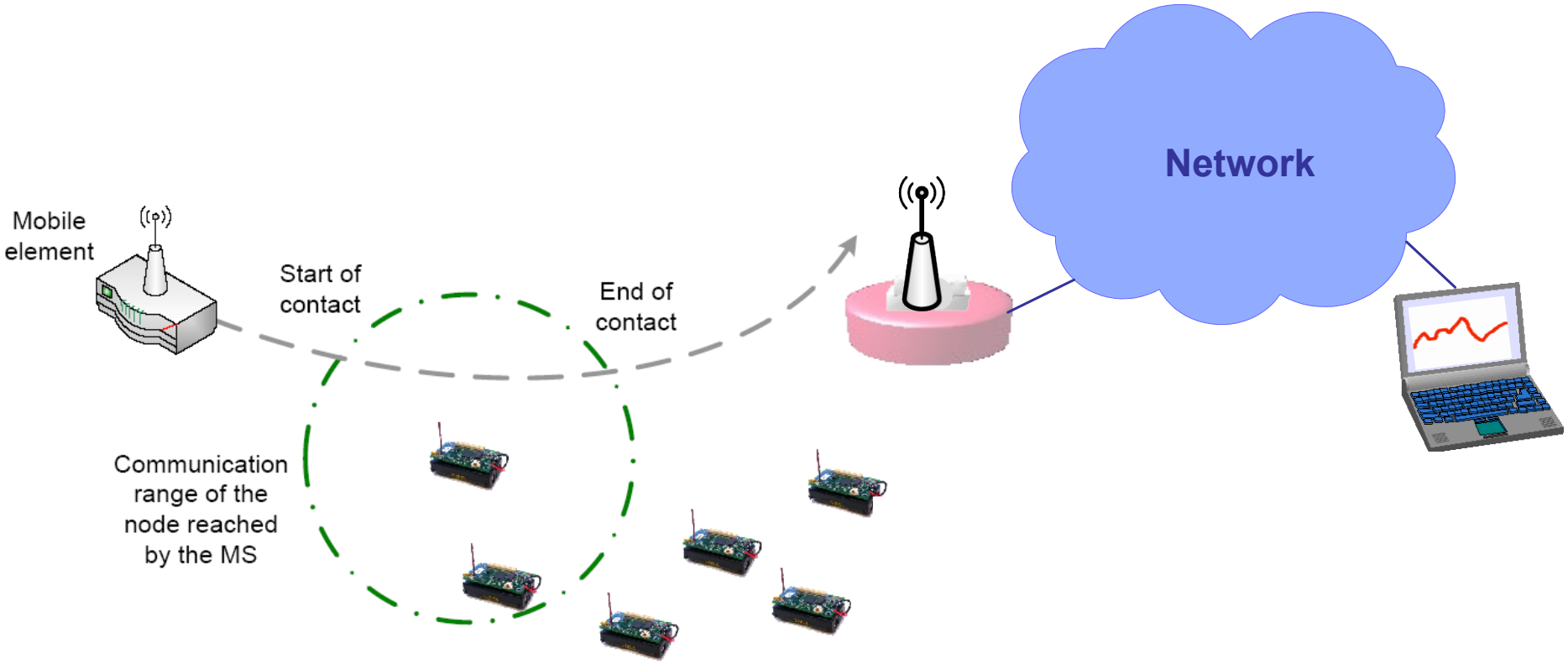


WSN Architecture: Hierarchical Multi-hop

- Dense Network, Static Topology
  - Typically strategic deployment
- Hierarchical Multi-hop communication
  - Sensor-to-SN routing
  - SN-to-Sink routing
- *Short paths* from sensors to sink
  - Typically 1-hop from sensors to SNs
  - Limited sensor-to-sink delay
  - Increased reliability
  - No funneling effect
- Application areas
  - Industrial applications, critical applications, building automation, …

CROSSLAB
Innovation for Industry 4.0

WSN Architecture: Mobile Data Collector

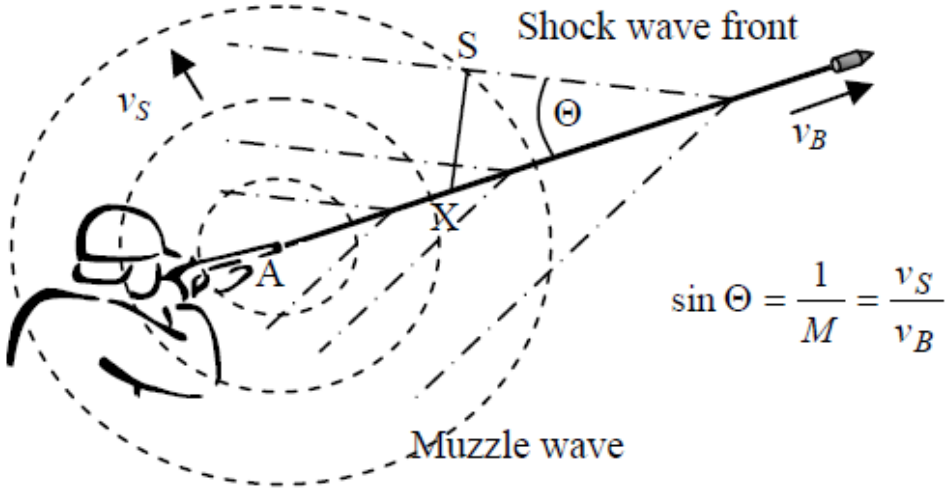


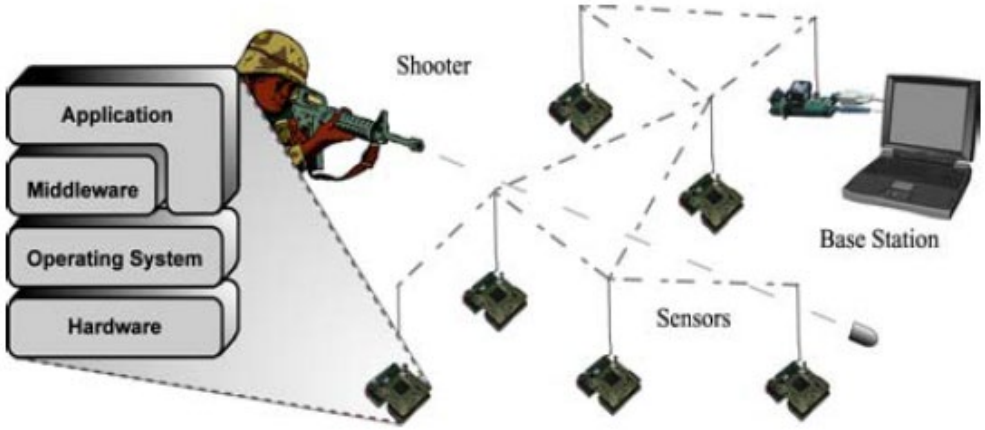
WSN Application Areas

- Military Applications
- Environmental Monitoring
- Precision Agriculture
- Location/Tracking
- Industrial applications
- Health Monitoring
- Smart Buildings
- Smart Grid
- Smart Cities
- Smart *
- …

Military Applications

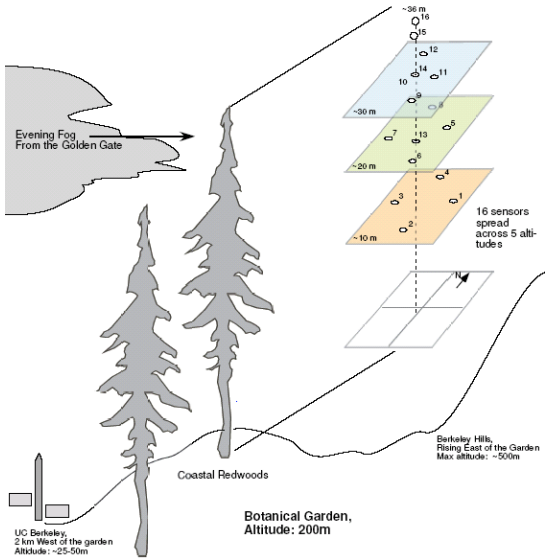
- Monitoring
  - friendly forces, equipment, ammunition
- Battlefield surveillance
- Reconnaissance of opposite forces
  - sniper detection
- Targeting
- Battle damage assessment
- Attack detection
  - nuclear, biological, chemical





Environmental Monitoring

- Environmental Monitoring
  - Temperature, humidity, pollution level
  - Habitat monitoring
    - ⇨ monitoring of petrel habitat (Great Duck Island project)
  - Microclimate monitoring
    - ⇨ Berkeley botanical garden



- Alert systems
  - fire detection
  - flood detection
  - seismic events

Precision Agriculture

- Temperature
- Humidity
- Wind Speed and Direction
- Soil moisture

Location/Tracking

- Location/Tracking of moving objects
  - Surveillance
  - Presence assessment
  - Animals' movements
- Inventory Control
  - easy localization of items
  - smart management of items
- Vehicles
  - tracking and detection
  - car theft detection
  - remote monitoring of parking places

E-Health

- Remote monitoring
  - chronicle patients
    - ⇨ physiological data monitoring
  - elderly people
    - ⇨ fall detection
- Hospital
  - monitoring of patients
  - tracking of doctors and attendants
  - drug administration
    - ⇨ minimize adverse drug events (e.g., allergies to a specific medicine)

Smart Factory

- Distributed Intelligent Sensing System for
  - Factory automation
  - Process Control
  - Real-time monitoring of machinery's health
  - Detection of liquid/gas leakage
  - Remote monitoring of contaminated areas
  - Real time inventory management
  - …

CROSSLAB
Innovation for Industry 4.0

Smart Buildings

- Building Automation
  - temperature and air flow control
  - light level control
  - energy efficiency
- Smart Home
  - Smart appliances
    - ⇨ sensors and actuators inside appliances
  - easy management of home devices
    - ⇨ both local and remote

Smart Cities

- Environmental Monitoring
  - Temperature, Noise, Pollution
- Parks and Gardens Irrigation
- Parking Area Management
- Guidance to free Parking Slots
- Traffic Intensity Monitoring
  - Intelligent traffic management
- Mobile Environmental Monitoring
  - Better coverage than static monitoring
- …

Environmental Monitoring

Measured Parameters

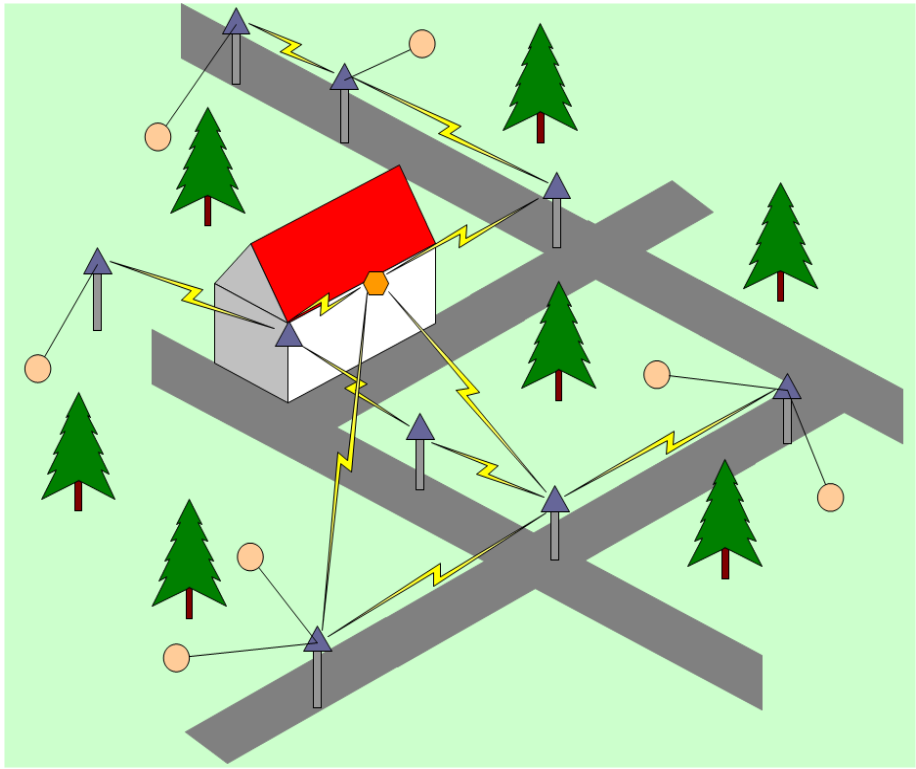
- Temperature
- Light
- Noise
- CO
- …

Light intensity can be used for *smart lighting*

If some critical parameters goes above a threshold the system sends an alarm.

Parks and Gardens Irrigation

- Goal
  - to control and make more efficient the irrigation in certain parks and gardens
- Sensors
  - Anemometer, pluviometer.
  - Atmospheric pressure, solar radiation, air humidity and temperature sensors.
  - Soil temperature and humidity sensors.
  - Evaluation of water consumption sensor



Parking Area Management

Parking areas equipped with sensors

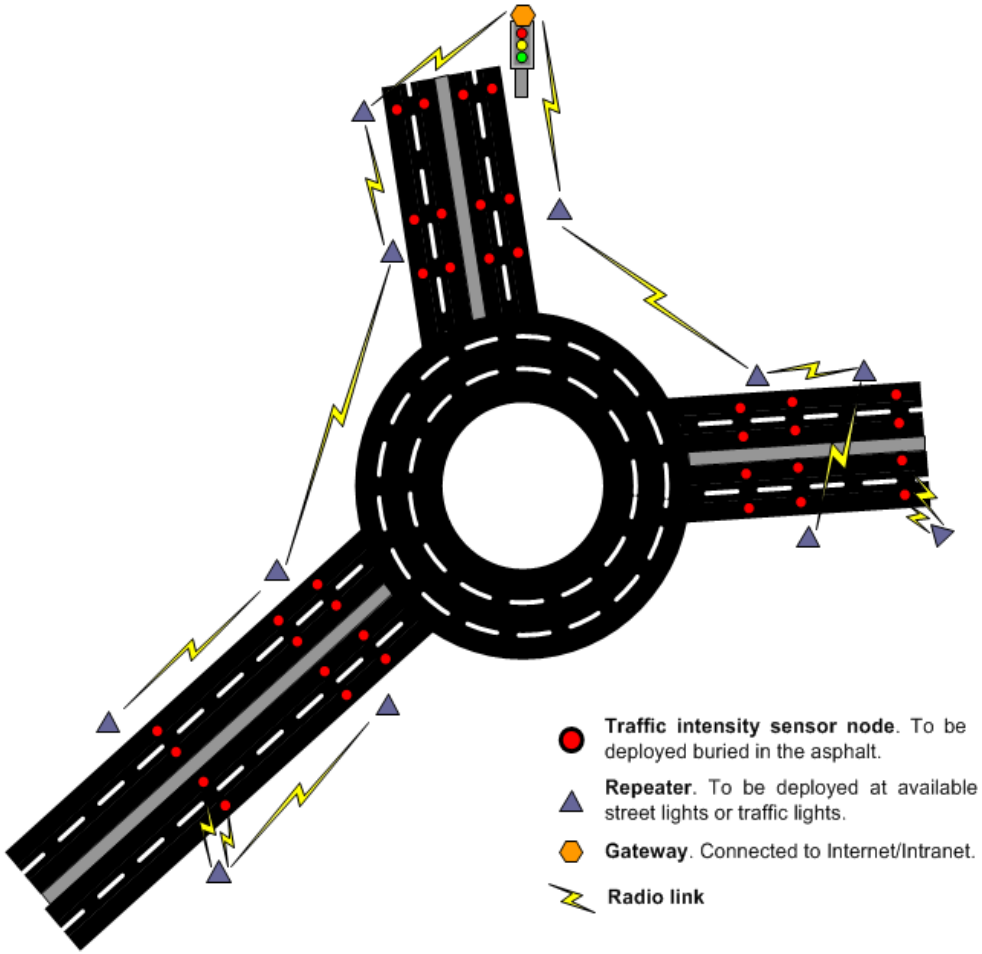
- based on ferromagnetic technology
- buried under the asphalt in the main parking areas.
- provided with one transceiver
- send their parking state (free or occupied), to a gateway through the repeaters.

Traffic Intensity Monitoring

- Sensors buried under the asphalt at the main entrance of the city
- Measure traffic parameters:
  - Traffic volumes
  - Vehicle Speed
  - Queue length

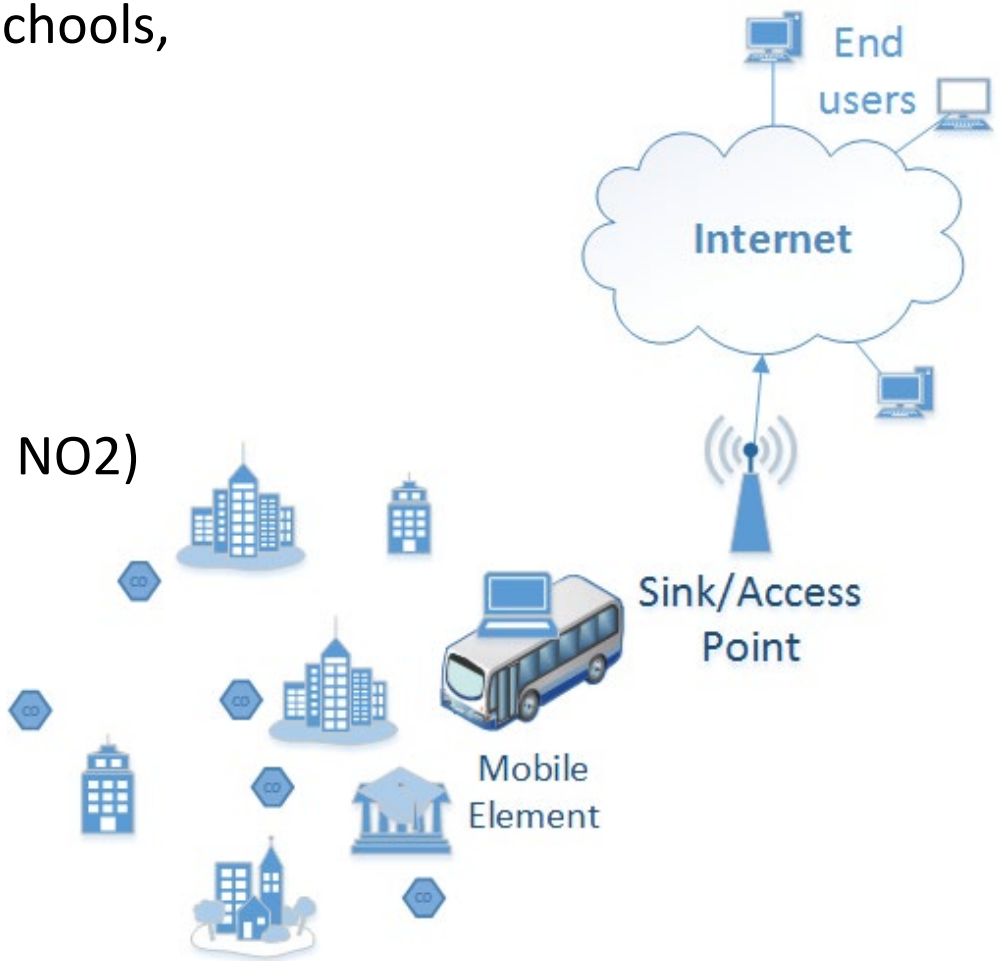
Architecture:

- Traffic Sensors
- Repeaters
- Gateway



Mobile Environmental Monitoring

- Sensors deployed in strategic (fixed) points
  - Crosses, bus stops, homes, schools, …
- Measured Parameters
  - Temperature
  - Humidity
  - Air Pollution (PM10, CO, O3, NO2)
- Data collection through mobile elements
  - public buses, taxis
  - people



Networking Issues

Features and Challenges

- Application specific
  - protocols should adapt to the application behavior
- Environment-driven
  - The data traffic is expected to be different from human-driven traffic
- Scalability
  - The number of sensor nodes can be very high (hundreds, thousands, …)
- Energy-efficiency
  - Sensor nodes are limited in power, computational capabilities, and memory
  - Power sources cannot be replenished as in smart phones

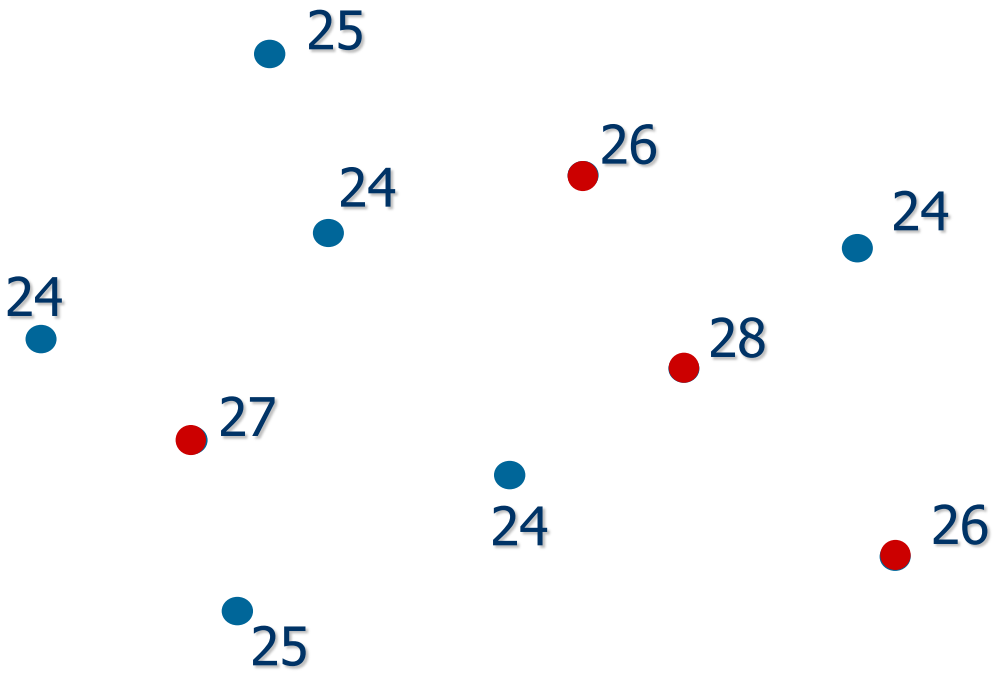
CROSSLAB
Innovation for Industry 4.0

Features and Challenges

- Dependability
  - sensor nodes prone to failures
  - frequent topology changes
    - ⇨ due to failures, energy limitations, mobility
- Quality of Service (QoS)
  - heterogeneous, strictly tied to data transfer type
- Simplicity
  - limited computational resources
- Data-centricity
  - the importance of a particular node is considerably reduced (due to redundancy)

Data centric interest

Interest in on specific data not on nodes

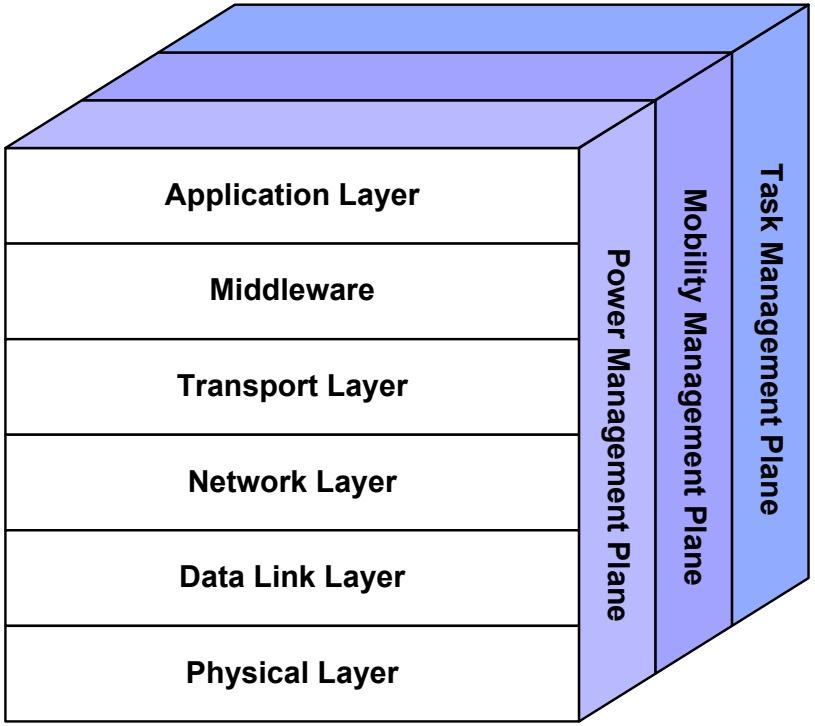


Query:

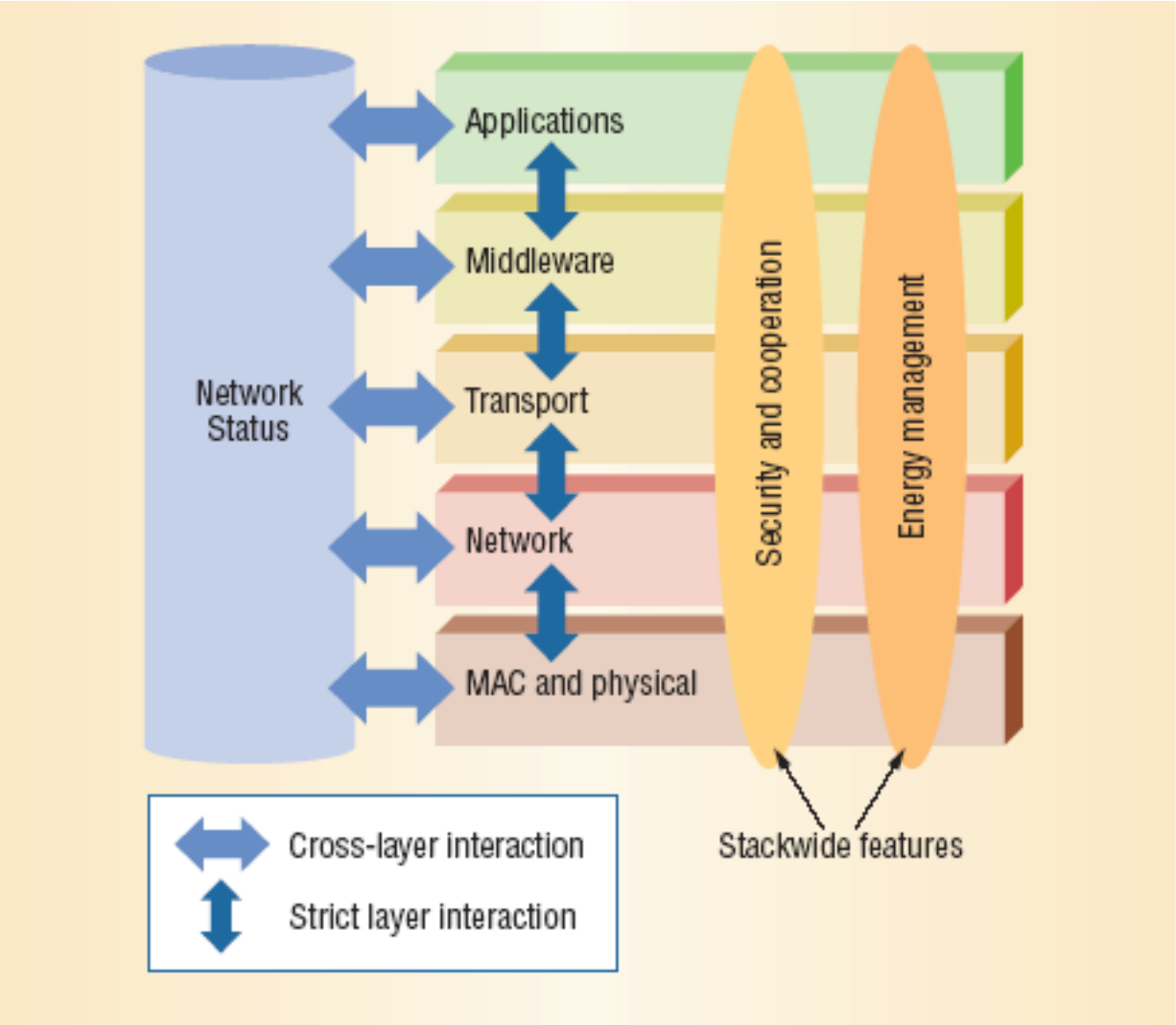
Temperature>25°C

Networking stack

- Networking stack
  - used by the sink and all sensor nodes
  - promotes cooperative efforts
- Layering
  - may be broken
  - abstractions typically cost time and space
  - cross-layering approach
    - ⇨ to reduce complexity, execution times, …
    - ⇨ to make networking protocols energy-efficient



Cross-layer networking stack



M. Conti, S. Giordano, G. Maselli, G. Turi, **Cross-Layering in Mobile Ad Hoc Network Design**, *IEEE Computer*, February 2004

Readings

- P. Baronti, P. Pillai, V. Chook, S. Chessa, A. Gotta, Y. Hu, **Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards,** Computer Communications, Vol. 30 (2007), pp. 1655–1695. http://www.sciencedirect.com/science/article/pii/S0140366406004749

Questions