SENSORCOMM 2017 @ROME

Energy-efficient Wireless Rechargeable Sensor Networks : Architecture, Medium Access Control and Energy Provision

2017. 09. 13
Dongsoo Har

Special thanks to Luiz for his assistance
In preparing this presentation

CONTENTS

CONTENTS

Sensors for various missions

Pressure sensor: Sensing trans-membrane pressure

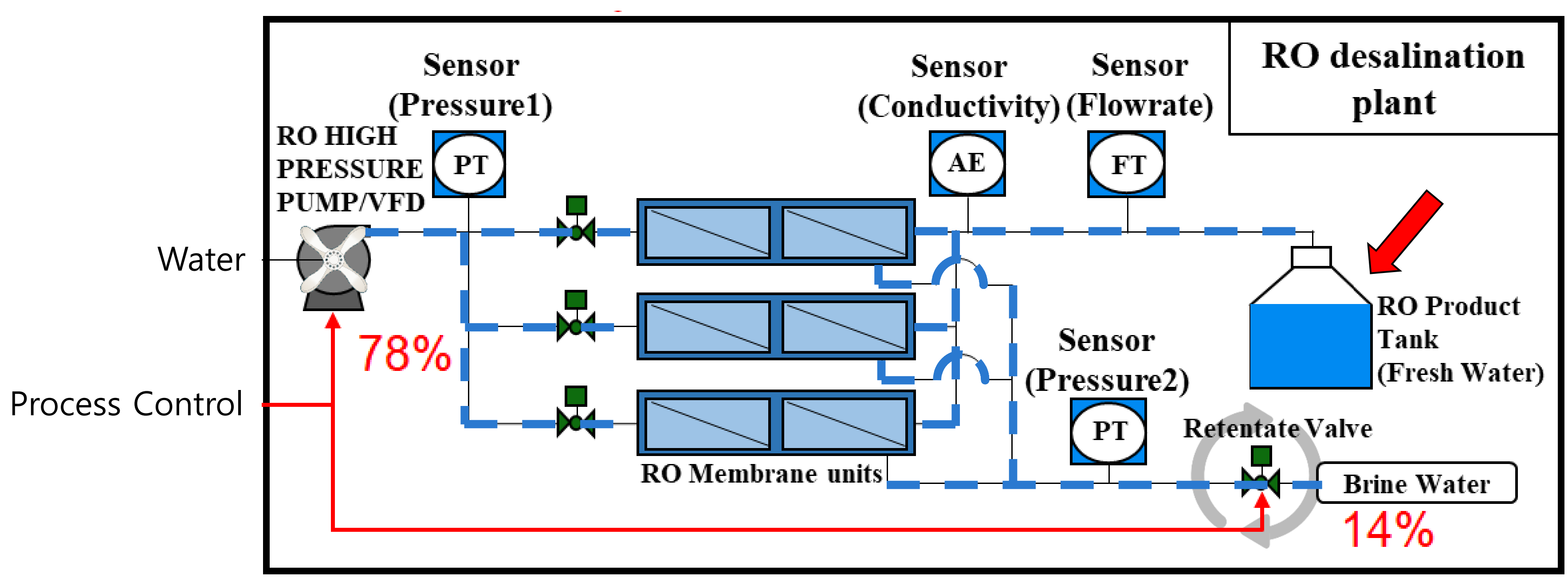
Flow-rate sensor: Measuring permeate production rate

Conductivity sensor: Measuring the quality of permeate water

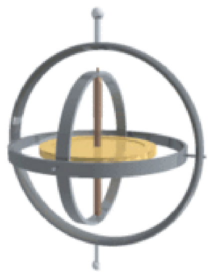
Desalination

Sensors for various missions

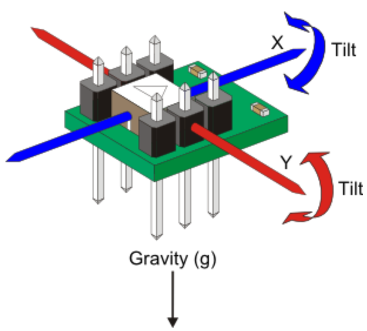
Operation scheme to achieve high energy efficiency using sensor networks



Sensors for various missions



Gyroscope: Sensing angular velocity



Accelerometer: Sensing acceleration

Drones

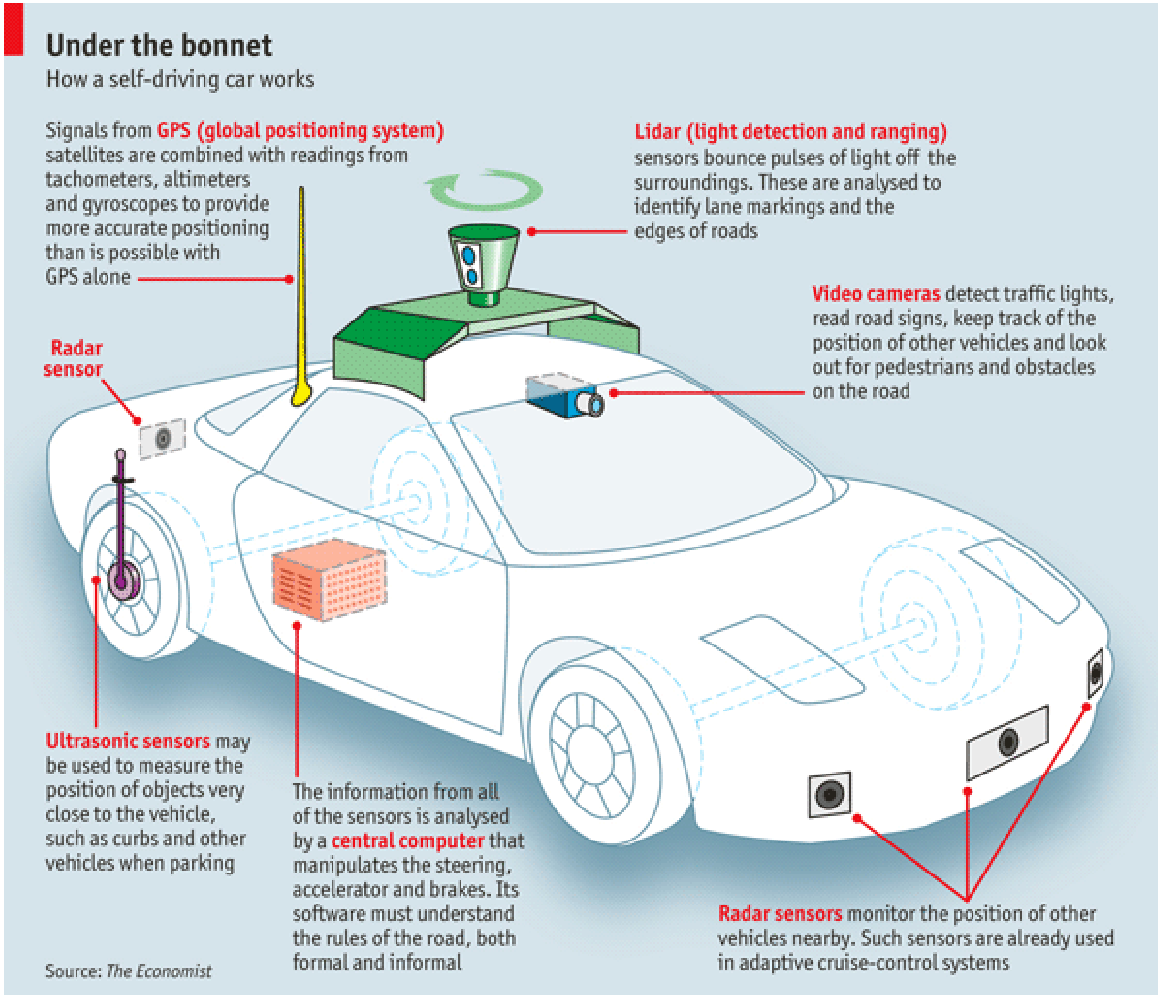
Source: https://www.dji.com/newsroom/news/drone-manufacturers-alliance-looks-to-next-steps-on-drone-registration

Sensors for various missions

- Sensors used for Drones

Sensors for various missions

- Sensors used for Autonomous Cars



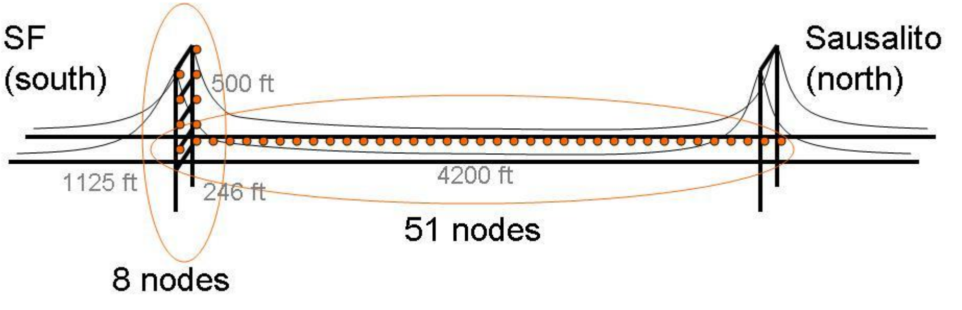
Sensors for various missions

- **Sensors used for Autonomous Cars**

Source: https://www.youtube.com/watch?v=rmY1irCK3iw

Sensors for various missions

- **Golden Gate Bridge**
  - **Structural Health Monitoring using Wireless Sensor Networks**
    - Collect ambient structural vibrations synchronously at 1kHz rate
    - Low Cost
    - Compare data with theoretical models and previous studies



Source: suhunkim.com/research/ggb

Sensors for various missions

- **Golden Gate Bridge**
  - **Structural Health Monitoring using Wireless Sensor Networks**

Source: https://www.youtube.com/watch?v=S8xDXYMdh6I

CONTENTS

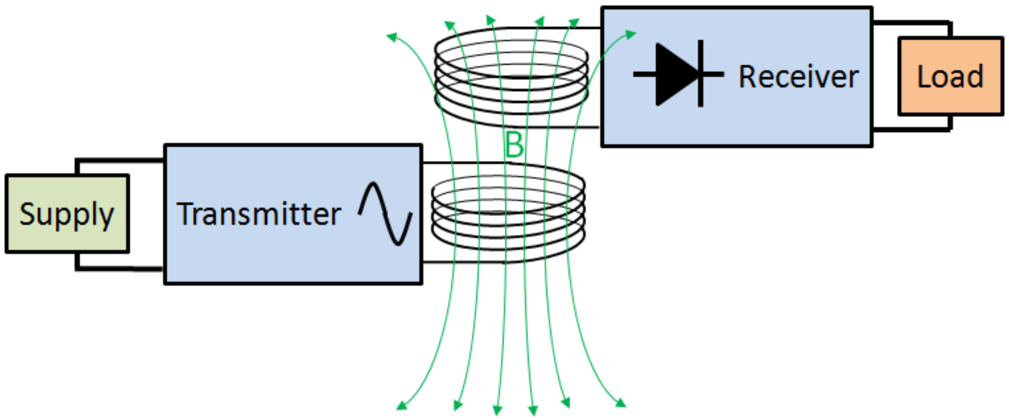
Charging sensors

- **Wired charging and Energy Harvesting**

Source: https://saultonline.com/2016/07/electric-vehicle-charging-stations-coming-soon-to-the-sault
https://tti.tamu.edu/2013/06/01/plane-spotting-sensors-assist-general-aviation-airports-with-plane-traffic-counts/

Charging sensors

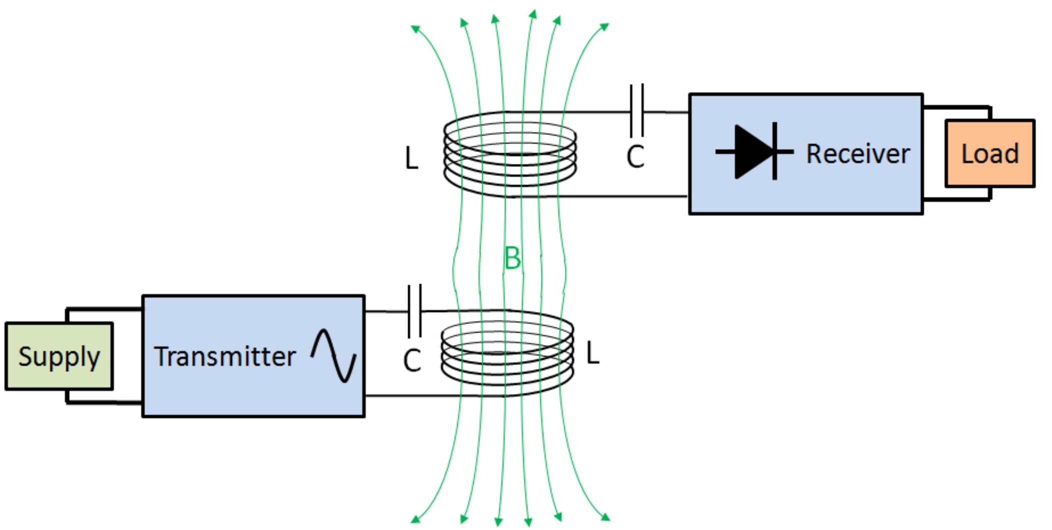
- **Wireless charging : Magnetic induction**
  - Considerable power(energy) can be transferred
  - Two coupled inductors



Source: http://www.richtek.com/en/Design%20Support/Technical%20Document/AN036

Charging sensors

- **Wireless charging : Magnetic Resonant Coupling**
  - Capable of transfer energy at high efficiency over a large gap
  - Magnetically coupled coils at the transmitting and receiving sides



Source: http://www.richtek.com/en/Design%20Support/Technical%20Document/AN036

Charging sensors

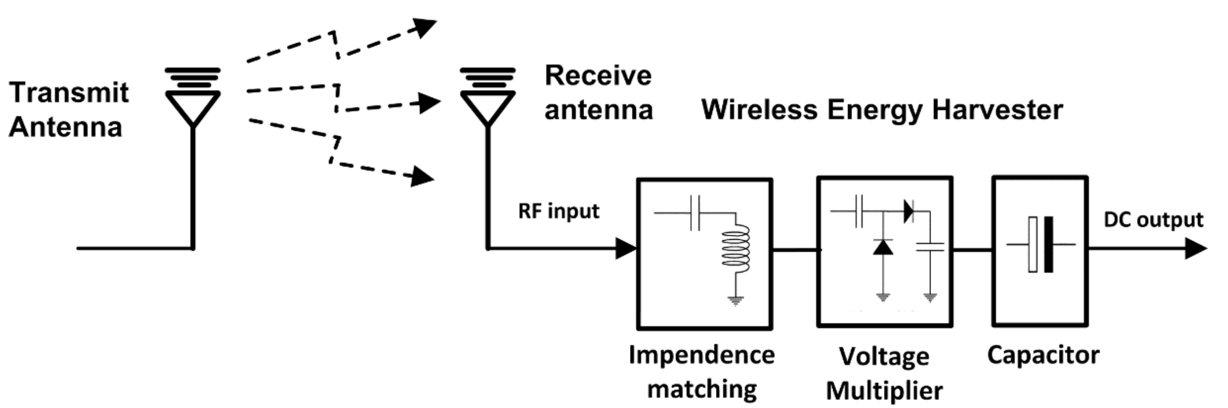
- **Wireless charging : Magnetic induction**
  - KAIST On-Line Electric Vehicle (OLEV):

Source: https://www.youtube.com/watch?v=6626Hi_h_K8

Charging sensors

Radio Frequency Charging

- It uses electromagnetic waves, rather than induced magnetic fields
- Can be used to charge low-power devices
- No need for precise placement



Source: Lu, Xiao et al. “Wireless Charging Technologies: Fundamentals, Standards, and Network Applications.”

CONTENTS

Energy efficiency in charging

Energy Efficiency

- **Definition might depend on specific application.**

General Definition by Dr. W. Irrek: Energy Efficiency=Benefits / Expenses

(Electrical) Energy Efficiency=Amount of useful output / Electrical energy consumed

Energy Efficiency (in Desalination)=Rate of Fresh(Permeate) Water Production / Electrical power consumed

Why we want high Energy Efficiency ?

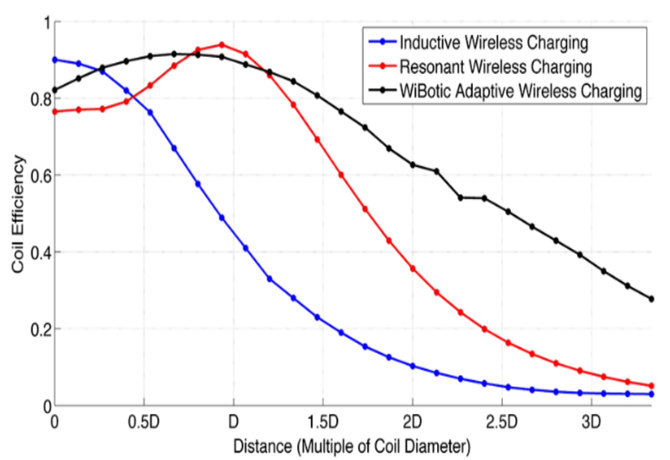
- More Benefits and less Expenses are important as critical economic issues
- Top priority for Sensor Networks design

Energy efficiency in charging

- **Energy efficiency in charging = charging efficiency**

  Charging efficiency = Energy transferred to the battery / Electrical energy consumed for charging

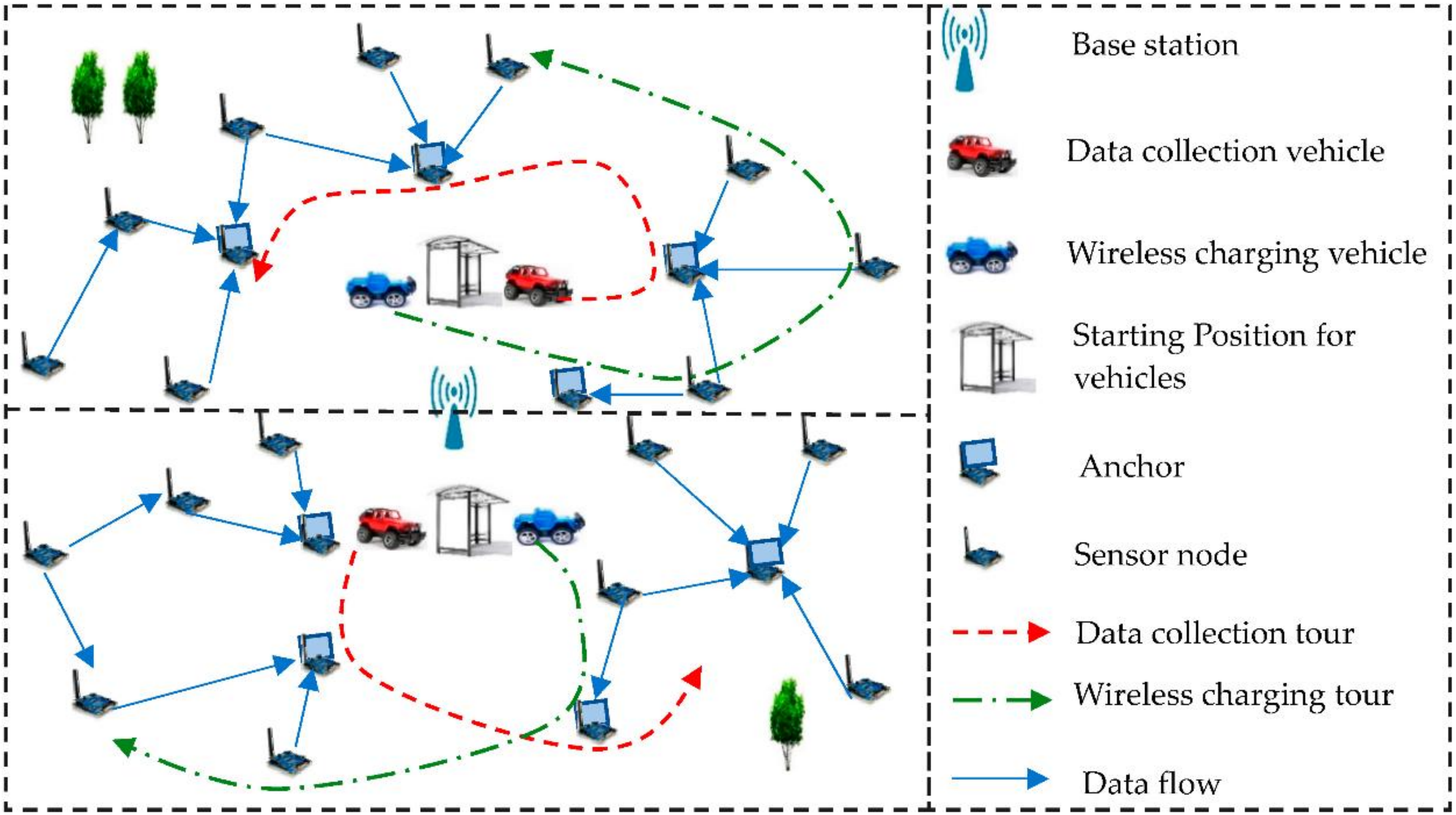
- **Charging efficiency in wireless charging**
  - **Magnetic Induction and Magnetic Resonance:**
    - Limited charging distance
  - **RF charging:**
    - Power of RF source
    - Distance from RF source
    - Parameters of receiving antenna
    - Transmission frequency
    - Spreading of wave power+low receiving antenna gain
    - (+electronic circuit conversion loss) lead to low charging efficiency



Source: http://www.wibotic.com/wireless-power/

CONTENTS

Wireless Rechargeable Sensor Networks (WRSN)



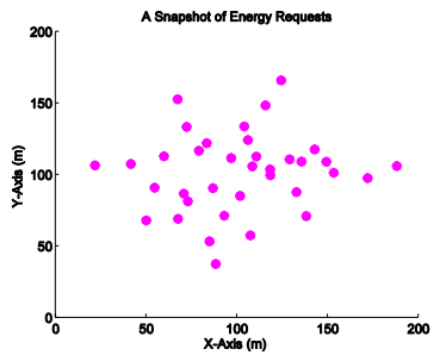
Source: Zhong, Ping et al. “Joint Mobile Data Collection and Wireless Energy Transfer in Wireless Rechargeable Sensor Networks.”

Wireless Rechargeable Sensor Networks (WRSN)

- Spatially distributed sensors to monitor a pre-determined condition and to cooperatively pass their data through the network to other locations.
- Each sensor node has: transceiver, microcontroller, electronic circuit for interfacing with the sensors, and energy storage.
- Energy is the scarcest resource of WRSN nodes.
- Recharging vehicles are used to recharge the sensor nodes in a WRSN. Their recharging capacity and recharging path are important to energy efficiency.

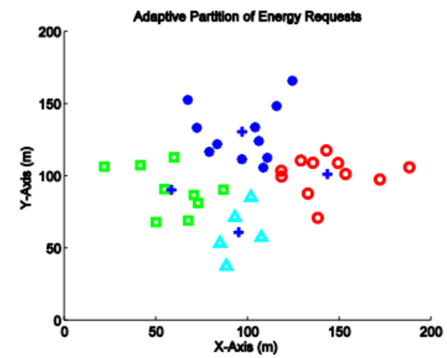
Wireless Rechargeable Sensor Networks (WRSN)

Recharging Schedule

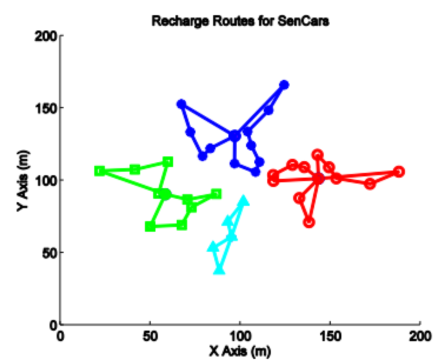


(a) A snapshot of energy requests

grouping



(b) Adaptive partition of energy requests



(d) Improve recharge routes to capture sensor's battery deadlines

group-based charging

Source: Yang, Yuanyuan et al. "Wireless Rechargeable Sensor Networks – Current Status and Future Trends."

Wireless Rechargeable Sensor Networks (WRSN)

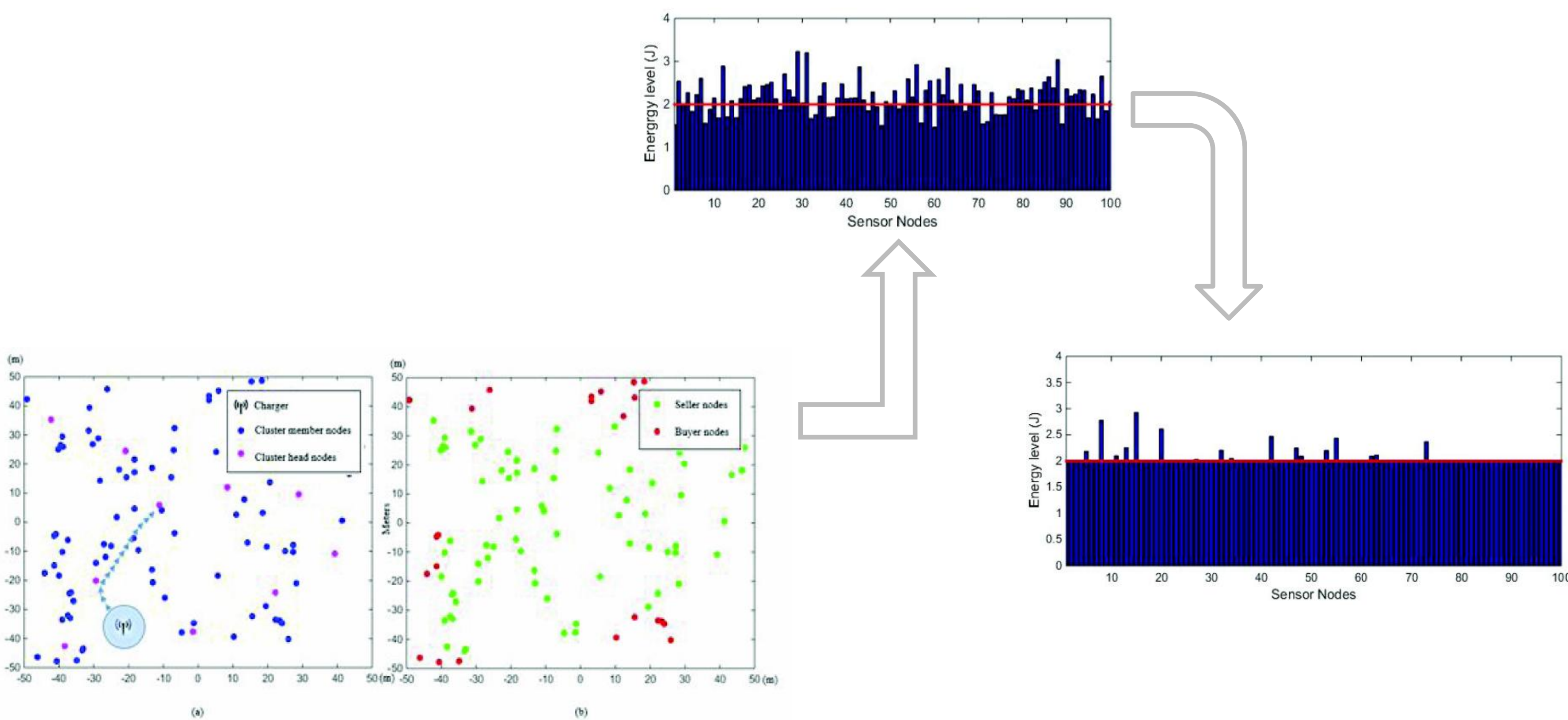
- **Wireless RF charging for Sensor Networks**

Source: https://www.youtube.com/watch?v=cHf1Dkbw410

Energy efficiency in charging

Energy Trading

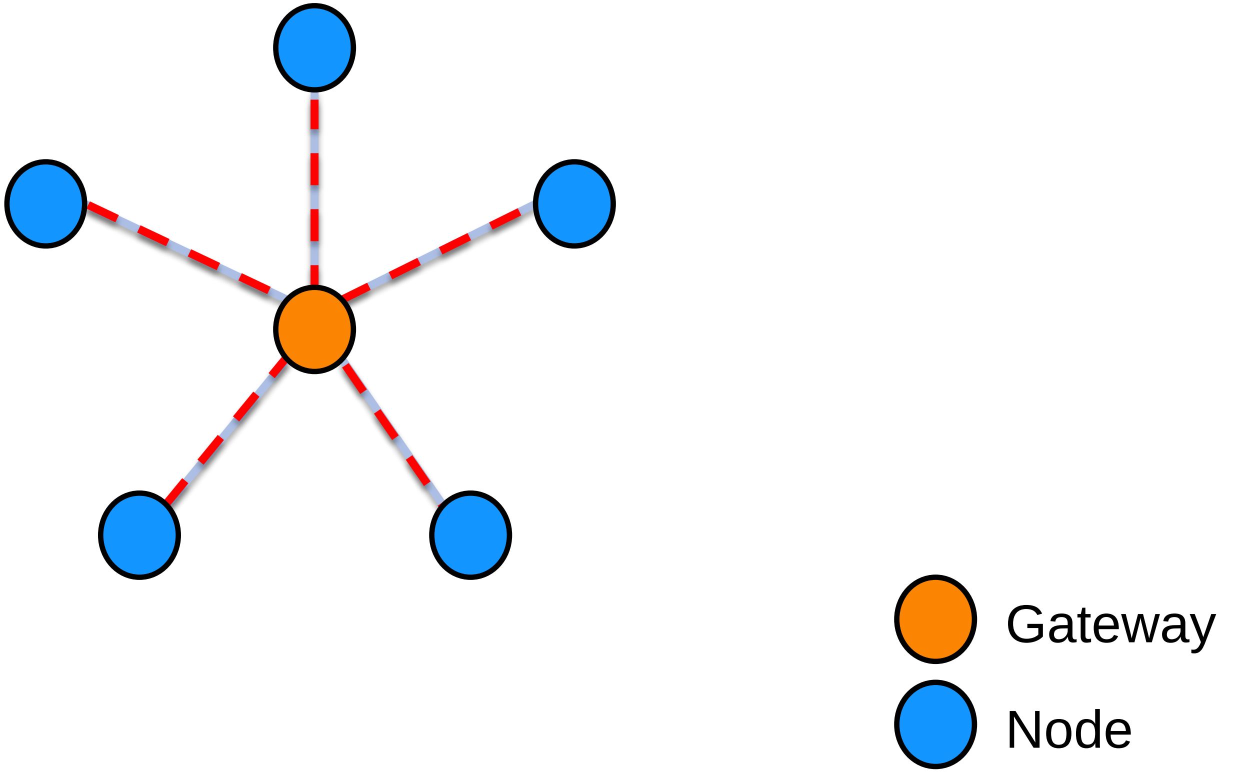
- Two-stage charging scheme for Sensor Networks : charging and trading
- Overcharged sensors transmit energy to undercharged nearby sensors



CONTENTS

Architecture and Medium Access Control for energy-efficient WRSN

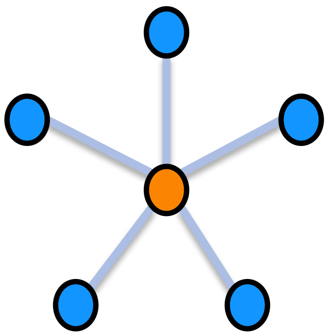
- **Architecture**
  - > **Star network(topology)**



Architecture and Medium Access Control for energy-efficient WRSN

Architecture

> Star network



Advantages:

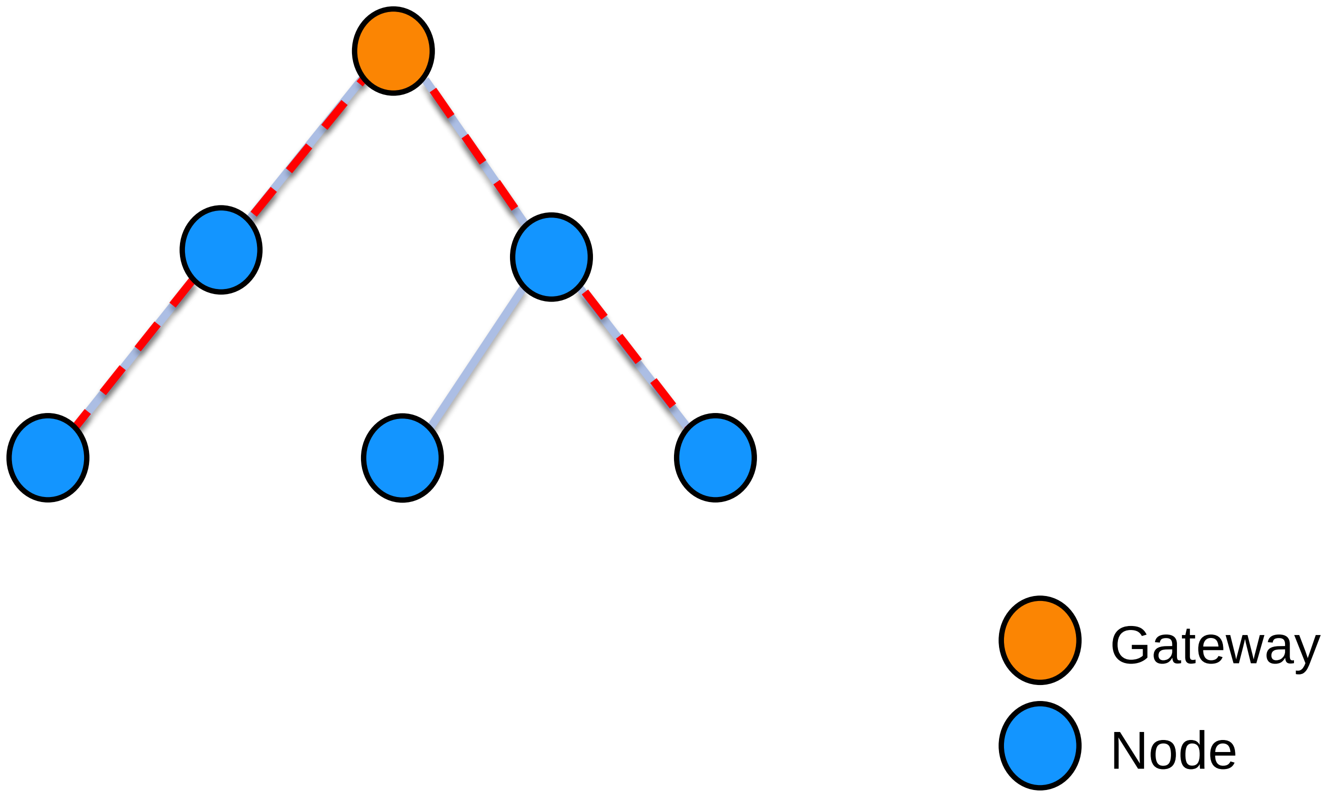
- Devices can be added without disturbing the network
- If one node breaks it does not affect the other connections

Disadvantages:

- Infeasible in large geographic areas
- Central hub: single point of failure

Architecture and Medium Access Control for energy-efficient WRSN

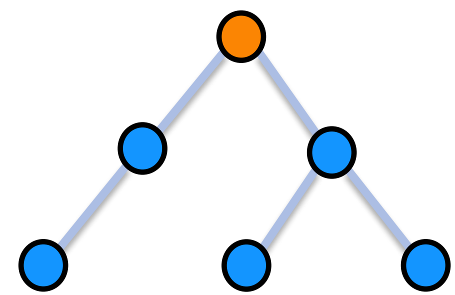
- **Architecture**
  - > **Tree network**



Architecture and Medium Access Control for energy-efficient WRSN

Architecture

> Tree network



Advantages:

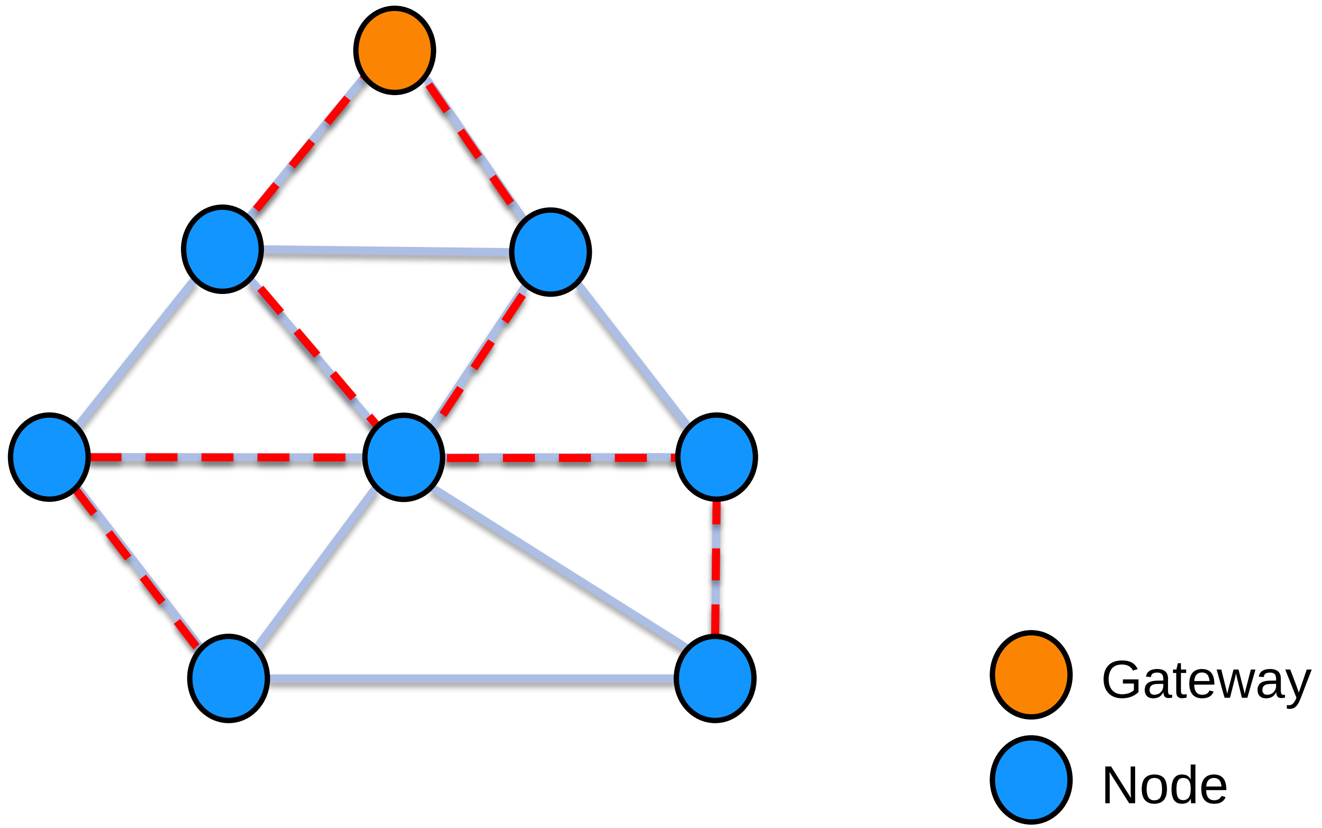
- Extended communication range
- Scalable

Disadvantages:

- Requires time synchronization
- Failure at relay nodes cut the connection with its children nodes

Architecture and Medium Access Control for energy-efficient WRSN

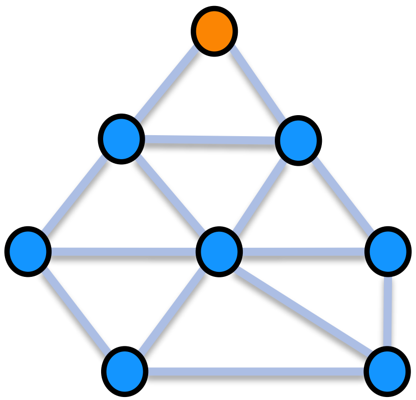
- **Architecture**
  - > **Mesh network**



Architecture and Medium Access Control for energy-efficient WRSN

Architecture

> Mesh network



Advantages:

- Easy to expand to adapt time-varying local demand
- Highly fault tolerant

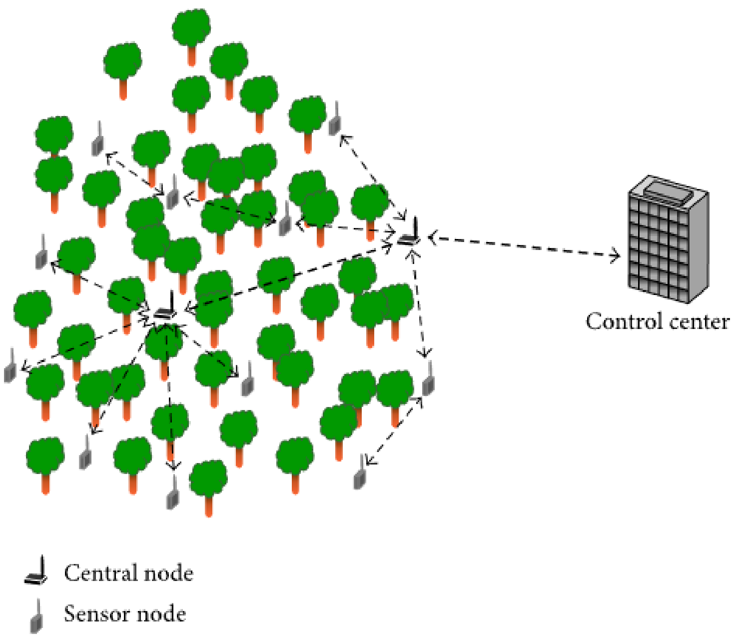
Disadvantages:

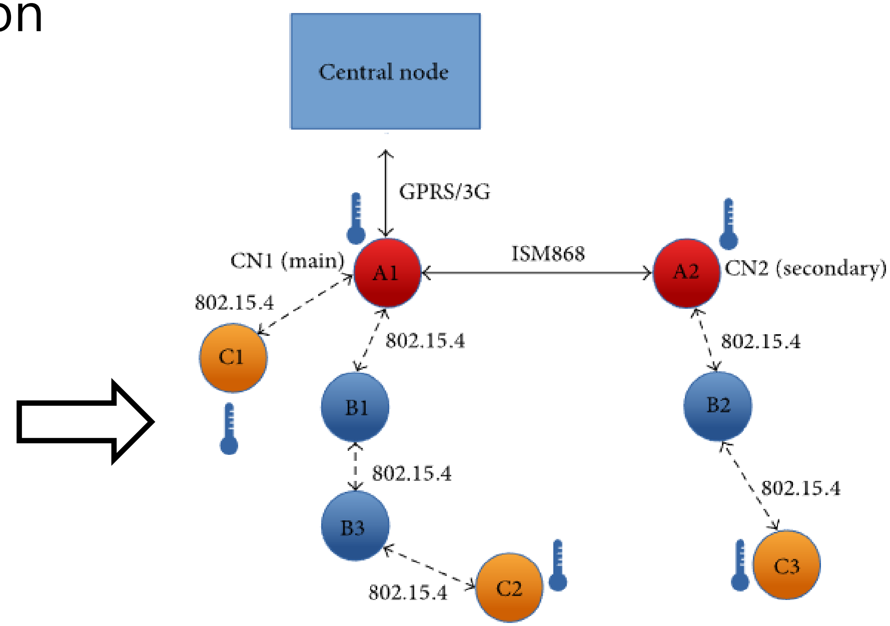
- Maintenance cost with large number of sensor nodes

Architecture and Medium Access Control for energy-efficient WRSN

Architecture

- **Application:** Forest Fire Detection





A: nodes are directly connected to central nodes.
B: nodes have sensing and routing functionalities.
C: nodes only have sensing capabilities.

Source: A., Molina-Pico et al. "Forest Monitoring and Wildland Early Fire Detection by a Hierarchical Wireless Sensor Network."

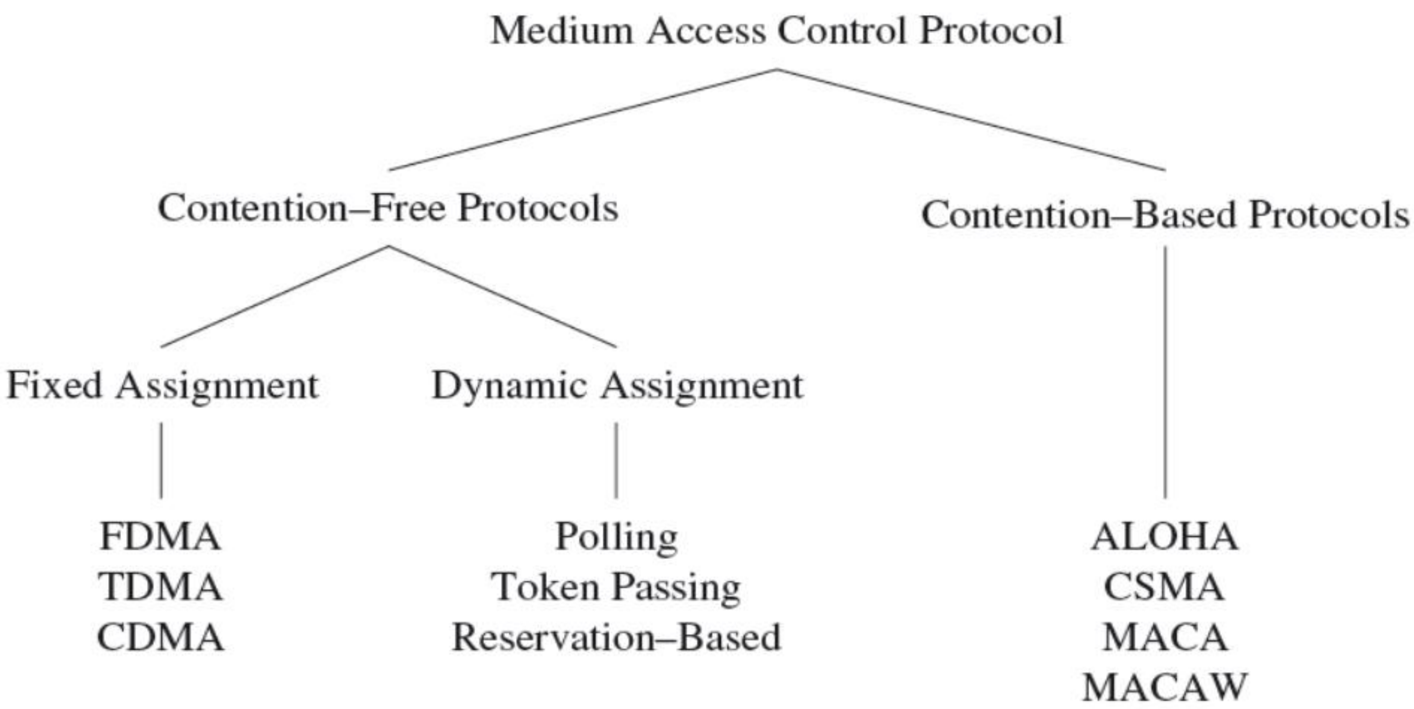
Architecture and Medium Access Control for energy-efficient WRSN

- **Medium Access Control (MAC)**

  - Multiple nodes can share a communication medium to transmit their data packets
  - The MAC protocol is responsible for deciding when a node access a shared medium
  - Energy efficiency also affects the design of the MAC protocol, especially for Wireless Rechargeable Sensor Networks

Architecture and Medium Access Control for energy-efficient WRSN

- **Categories:**



Source: https://www3.nd.edu/~cpoellab/teaching/cse40815

Architecture and Medium Access Control for energy-efficient WRSN

- **Characteristics of typical WRSN:**
  - Low data rates
  - Energy-constrained sensors

- **Common Technique: Dynamic Power Management (DPM)**
  - Status of a sensor is changed between different operational modes: active, idle and asleep.

Architecture and Medium Access Control for energy-efficient WRSN

- **Characteristics of typical radios used by state-of-the-art sensor nodes:**

	RFM TR1000	RFM TR3000	MC13202	CC1000	CC2420
Data rate (kbps)	115.2	115.2	250	76.8	250
Transmit current	12mA	7.5mA	35mA	16.5mA	17.4mA
Receive current	3.8mA	3.8mA	42mA	9.6mA	18.8mA
Idle current	3.8mA	3.8mA	800μA	9.6mA	18.8mA
Standby current	0.7μA	0.7μA	102μA	96μA	426μA

Characteristics of typical radios used by state-of-the-art sensor nodes

Source: https://www3.nd.edu/~cpoellab/teaching/cse40815

Architecture and Medium Access Control for energy-efficient WRSN

- **What can decrease the energy efficiency?**

  - Operation mode of sensors
  - Collisions while trying to send information
  - Protocol design: modulation scheme, transmission rate

Source: https://www3.nd.edu/~cpoellab/teaching/cse40815

Architecture and Medium Access Control for energy-efficient WRSN

- **Other desired properties of MAC Protocols for WRSN:**

  - Allow the efficient use of resources. For example, multi-hop mesh network architecture
  - Computationally efficient
  - Adapt to changes in the WRSN size, density and traffic characteristics
  - Low Latency for determined types of WRSN
  - Reliability in operation

Source: https://www3.nd.edu/~cpoellab/teaching/cse40815

CONTENTS

Conclusion

- **Wireless charging strategy, network architecture, and Medium Access Control protocol are crucial for the development of Energy-efficient Wireless Rechargeable Sensor Networks.**
- **Many applications to appear.**
- **Challenges:**
  - Network Scalability
  - Ultra-fast battery charging and extended charging range
  - Optimal recharging scheduling
- **Still have open issues and research topics for the coming years.**

Thank you