Lecture

Network Architecture of WSN

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Goal of this chapter

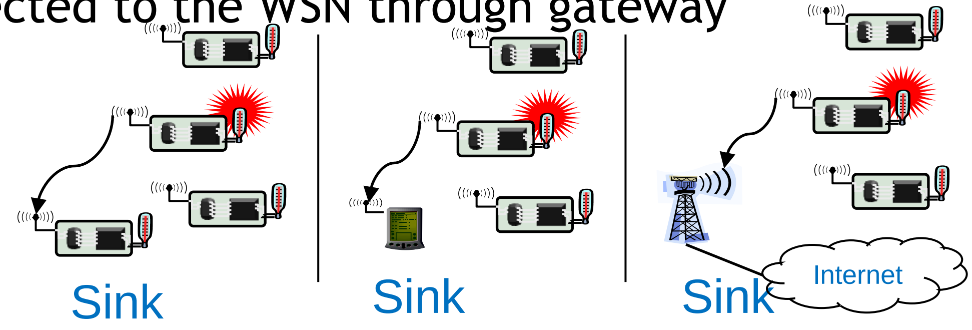
- Having looked at the individual nodes in the previous chapters, we look at general principles and architectures how to put these nodes together to form a meaningful network

Outline

- ***Network scenarios***
- Optimization goals
- Design principles

Basic scenarios: sensor networks

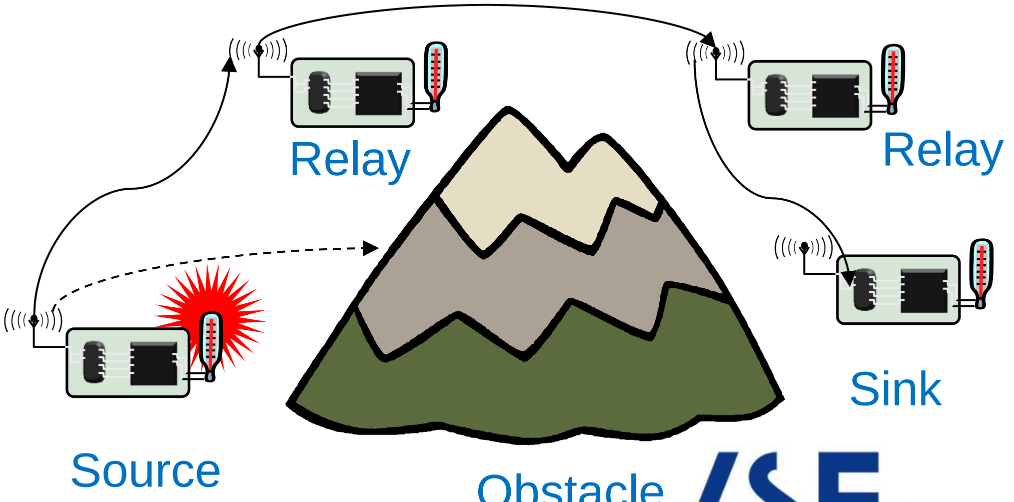
- Sensor network scenarios
  - ***Sources***: Any entity that provides data/measurements
  - ***Sinks***: Nodes where information is required
    - just a sensor or actuator
    - Not a sensor but more powerful device, e.g., a smartphone, but directly connected to the WSN
      - Main difference: comes and goes, can move around, …
    - Located in an external network (e.g., internet), indirectly connected to the WSN through gateway



  - Applications: Usually, machine to machine, often limited amounts of data, different notions of importance

Single-hop vs. multi-hop networks

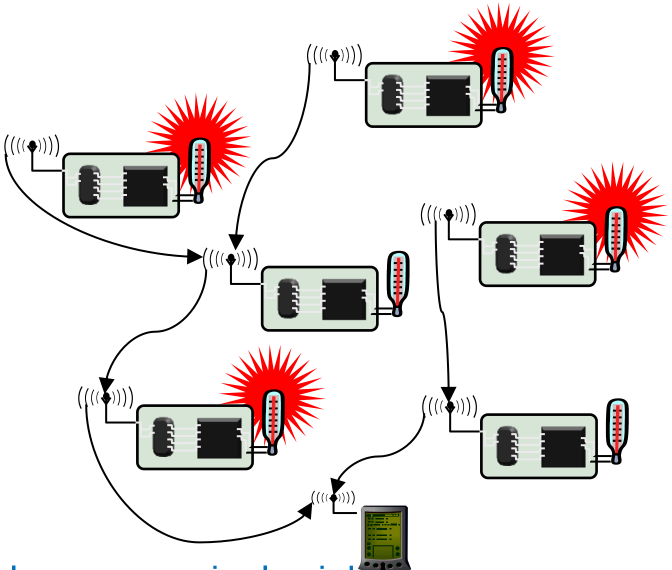
- One common problem: limited range of wireless communication
  - Essentially due to limited transmission power, path loss, obstacles
- Option: multi-hop networks
  - Send packets to an intermediate node
  - Intermediate node forwards packet to its destination
  - ***Store-and-forward*** multi-hop network
  - Tackle problems in communication with large distance or obstacles



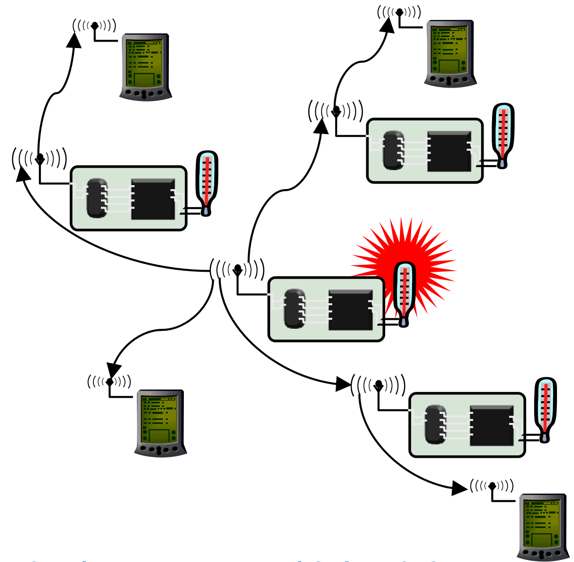
Is multi-hopping more energy efficient?

- Conventional argument: Multi-hopping is more energy-efficient than direct communication
  - Because of path loss $\alpha > 2$,
  - Energy for direct transmission of distance d is cd^{α}
  - Energy of two-hop transmission with relay is $2c(d/2)^{\alpha}$
    - *c* denotes some constant, *d* is distance, α is attenuation exponent
- However: This is usually wrong, or at least very over-simplified
  - The above calculation only considers ***radiated energy***
  - Need to take into account the complete energy consumption
    - Radiated energy
    - Transmission and receiver electronic
  - Note: Multi-hopping for energy savings might not be true, needs careful consideration
  - To select single-hop or multi-hop solution depends on the system and application requirements

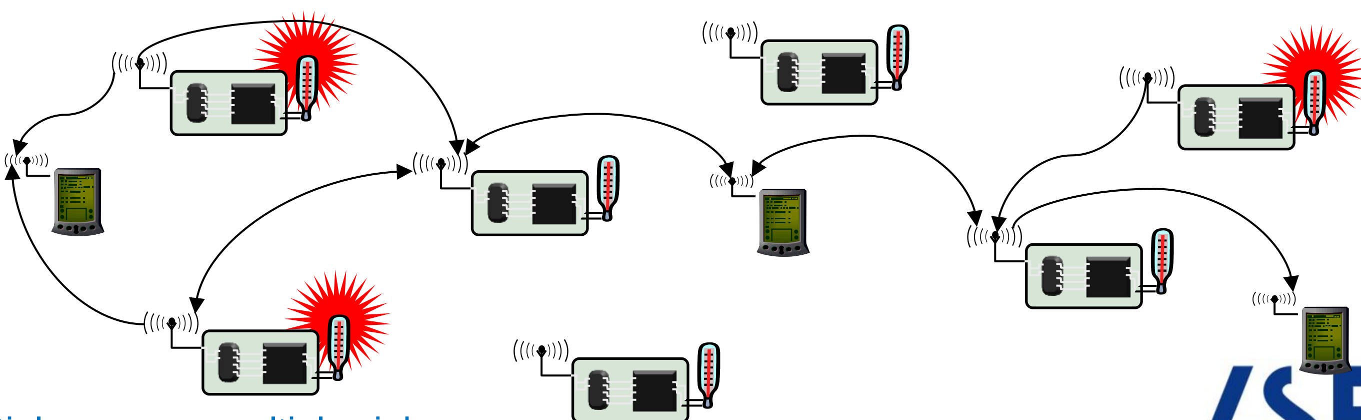
WSN: Multiple sinks, multiple sources



Multiple sources-single sink



Single source-multiple sinks

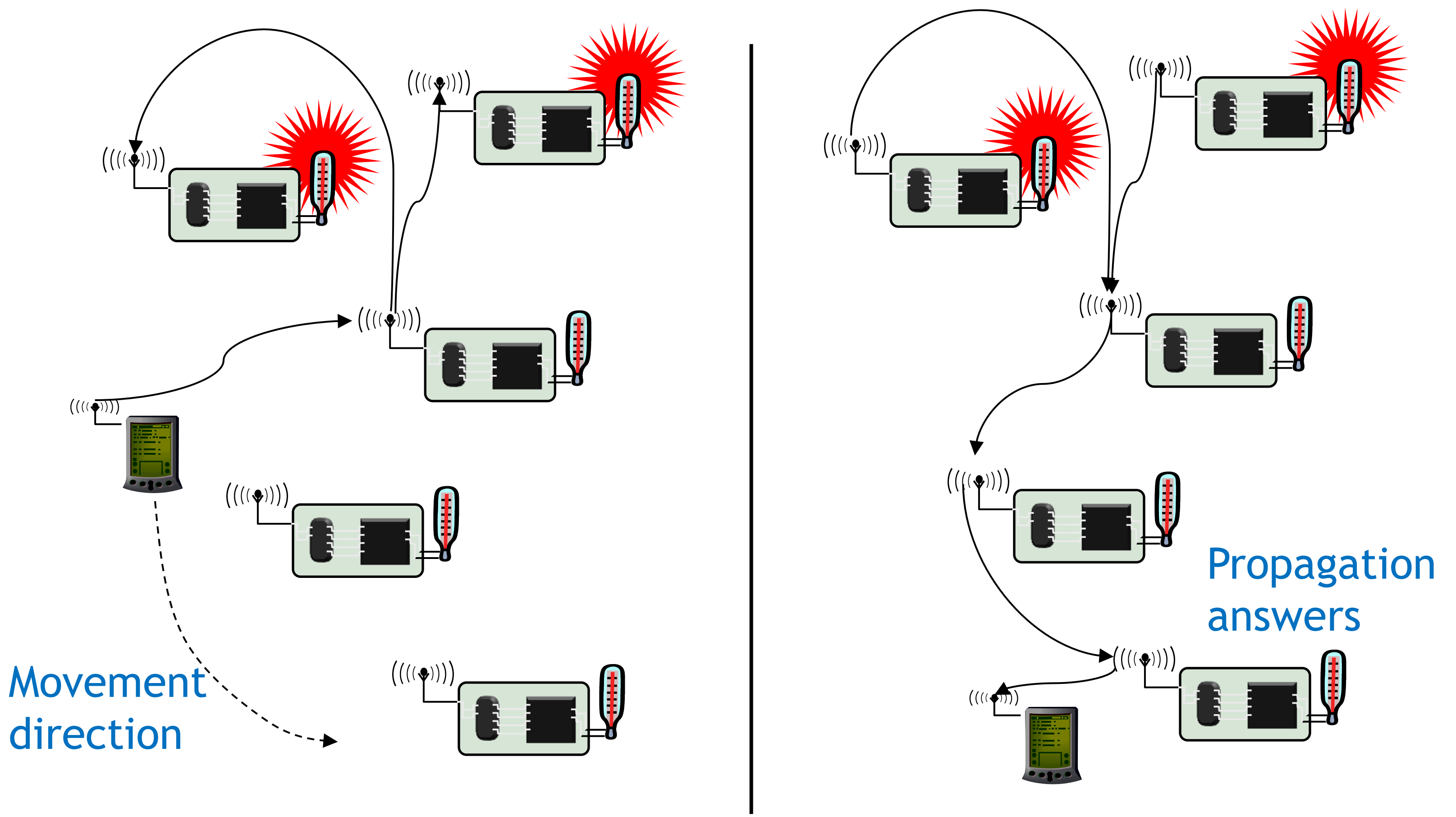


Multiple sources-multiple sinks

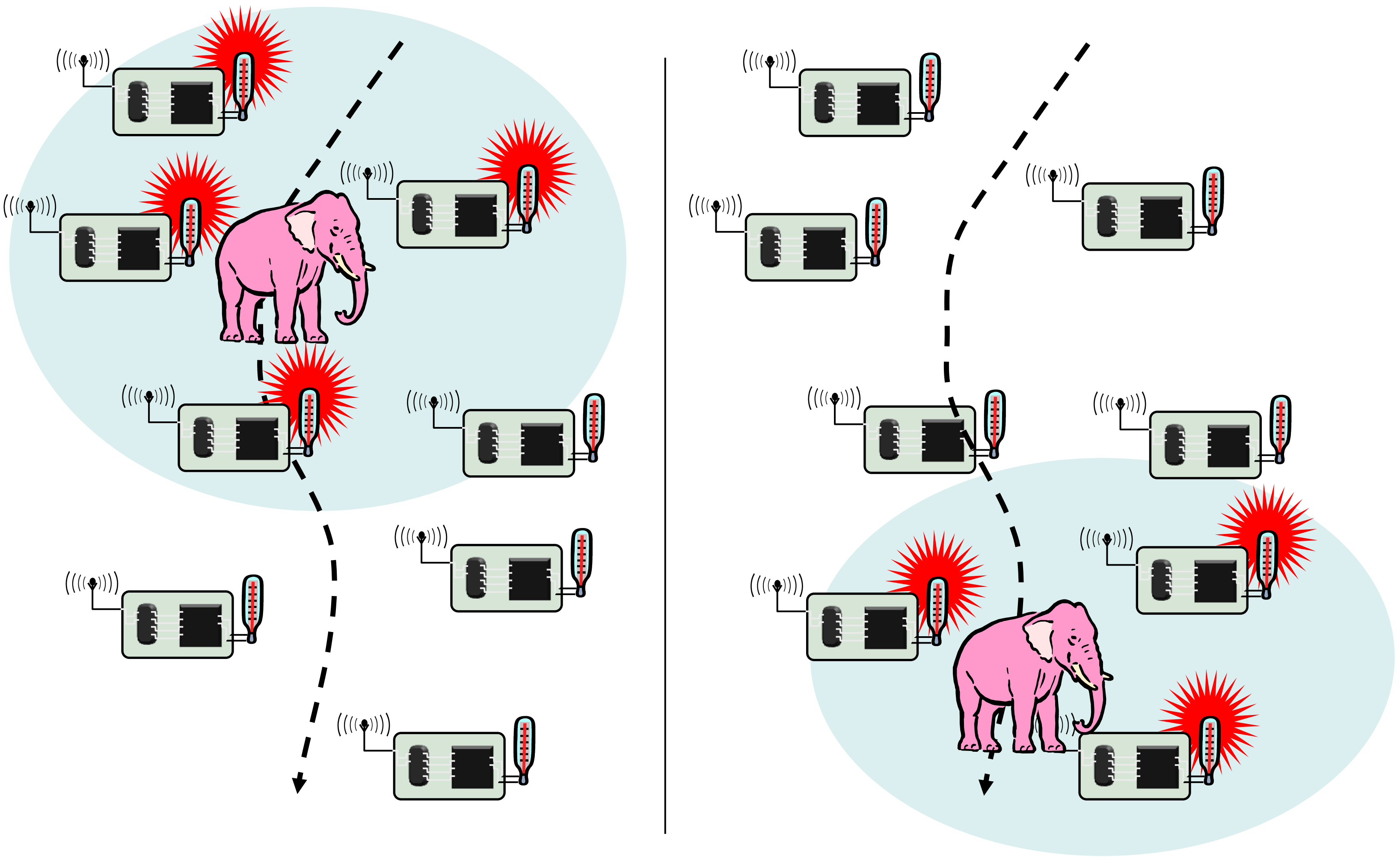
Different types of mobility

- Node mobility
  - A node participating as source/sink (or destination) or a relay node might move around
  - self-propelled or by external force;
  - targeted or at random
- Event mobility
  - In event detection or object tracking applications, event or object can move around
  - Sensors in the vicinity of event or object become active
  - The rest sensors can usually switch to lower sleep states

WSN sink mobility



WSN event mobility: Track the pink elephant



Frisbee model as example

Outline

- Network scenarios
- ***Optimization goals***
  - ***Quality of Service***
  - ***Energy Efficiency***
  - ***Scalability***
  - ***Robustness***
- Design principles

Optimization goal: Quality of Service (QoS)

- QoS in WSN is different from traditional wireless networks
- Generic QoS properties in WSN:
  - Event detection/reporting probability
    - Miss detection probability
  - Event classification error
  - Event detection delay
  - Probability of missing a periodic report
  - Approximation accuracy
    - What is the average/ maximum absolute or relative error with respect to the actual function?
  - Tracking accuracy
    - E.g. difference between reported and real position of the pink elephant

Optimization goal: Energy efficiency

- Energy per correctly received bit
  - Counting all the overheads (e.g., protocol overhead, lost packets or retransmission, energy expenditure in intermediate nodes), etc.
- Energy per reported (unique) event
  - After all, information is important, not payload bits!
  - Smart design of representation of event
- Delay/energy tradeoffs
- Network lifetime
  - Time to first node failure
  - Network half-life (how long until 50% of the nodes died?)
  - Time to partition
  - Time to loss of coverage
  - Time to failure of first event notification

Optimization goal: Scalability

- Scalability:
  - The ability to maintain performance characteristics irrespective of the size of the network.
- Difficult to guess typical node numbers
  - WSNs: 10s to 1000s, maybe more
- Requiring to scale to large node numbers has ***serious*** consequences for network architecture
  - Might not result in the most efficient solutions for small networks!
  - Carefully consider actual application needs before looking for solutions!

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Optimization goal: Robustness

- Robustness is related to QoS and Scalability
  - Robustness is often defined as invariance degree of state, behaviour, and function or the adaptation/flexibility degree under interference of perturbations.

- WSN should withstand:
  - Failure of some nodes
    - E.g. Reconstruct routing table when some nodes run of energy
  - Environment changes
  - Radio links change (e.g., due to mobility, interference)
  - Etc.
- Precise evaluation of robustness in practice is lacking due to the difficulties, however, it is of paramount importance for safety-critical or mission critical applications.

Outline

- Network scenarios
- Optimization goals
- ***Design principles***
  - ***Distributed Organization***
  - ***In-Network processing(chapter 12)***
  - ***Adaptive fidelity and accuracy***
  - ***Data-centricity (chapter 12)***

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Distributed organization

- Scalability and robustness optimization goal requires to organize WSN in a distributed fashion.
  - Centralized approach usually not feasible
    - e.g., introducing exposed points of failures hinders robustness
    - e.g., large number of sensor nodes all need to talk to central entity hinders scalability
  - Nodes in WSN should cooperate in organizing the network
    - e.g., in medium access, topology control and routing, nodes can take decision based on local observation
- Potential shortcomings
  - e.g., maybe is not energy efficient
- Option: “limited centralized” solution
  - Elect nodes for local coordination/control, e.g., cluster header
  - Perhaps rotate the role of sensors over time

In-network processing

- Nodes in WSNs are not only passing on packets or executing application programs, but also
  - Involving in taking decisions
    - Expected to provide information
    - How to operate the network
    - E.g., ***manipulate*** or ***process*** the data in the network
- Typical example: aggregation
  - Apply aggregation functions to a convergecast tree in a network
  - Typical functions: minimum, maximum, average, sum, …
- Challenges:
  - e.g., how to determine where to aggregate results
  - e.g., how long to wait for results

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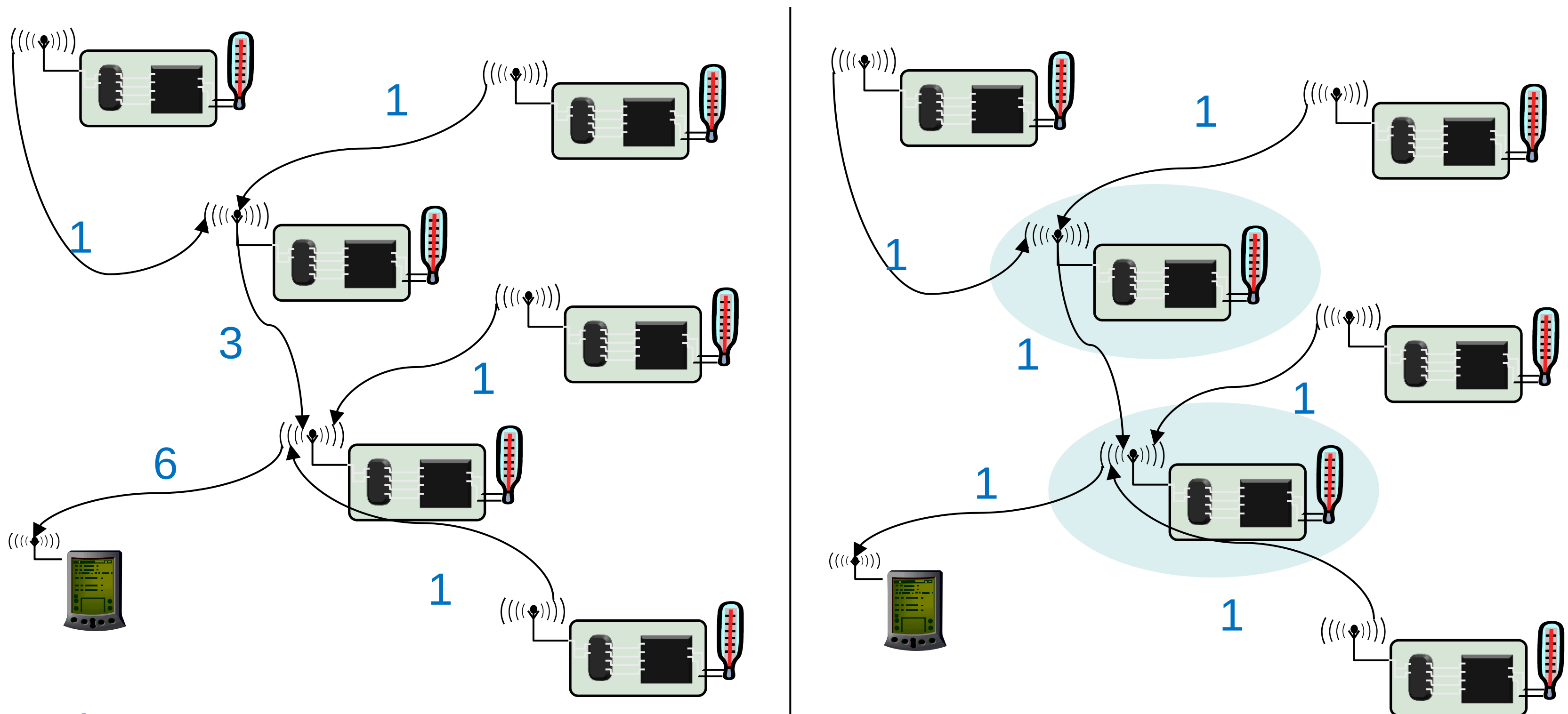
In-network processing: Aggregation example

- Reduce number of transmitted bits/packets by applying an aggregation function in the network



Without aggregation

With aggregation

In-network processing

- Exploit ***temporal*** and ***spatial correlation***
  - e.g. Observed signals might vary only slowly in time
    - It means no need to transmit all data at full rate all the time
  - e.g., Signals of neighboring nodes are often quite similar
    - It means it could only transmit the differences

- Distributed computation
  - E.g., compute an FFT in a distributed fashion, trade-offs between local computation complexity and communication cost

Adaptive fidelity and accuracy

- Degree of sensing accuracy depends on applications
  - Some applications can live with imprecise, approximate value
  - Some application is critical of the sensing value
- Communication protocols aim to achieve the required accuracy/fidelity as energy efficient as possible, e.g.
  - Event detection
    - When there is no event, only very rarely send short “all is well” messages
    - When event occurs, increase rate of message exchanges
  - Temperature monitoring
    - When temperature is in acceptable range or stable, it only sends temperature values at low resolution
    - When temperature becomes high or varies a lot, it increases the sensing resolution

Data centric networking

- In typical networks, network transactions are addressed to the ***identities*** of specific nodes
  - A “node-centric” or “address-centric” networking paradigm
- In WSN, sensors maybe don’t have an Identity.
- In a redundantly deployed sensor networks, it might not be important to know which sensor reports the event
  - Redundancy: e.g., several nodes can observe the same area
- Data-centric Networking: Not the identity of nodes but the data is the center of attention
- Data-centric Networking allows very different networking architectures compared to identity-based networking
  - Principal design change

Further design principles

- Exploit location information
  - Required anyways for many applications; can considerably increase performance
- Exploit activity patterns
- Exploit heterogeneity
  - Deploy different types of nodes in the network
  - Due to evolution: some nodes had to perform more tasks and have less energy left; some nodes received more solar energy than others; …
  - Opportunities in asymmetric assignment of task
    - E.g., nodes with more memory or faster processor are good for aggregation
    - Nodes with more energy are used for hierarchical coordination
    - Farther-reaching radio nodes for long-distances communication
  - Burden in dynamic of asymmetric re-assignment

Summary

- WSNs look quite different from traditional networks in
  - Optimization goals
  - Design principles
- We will look at how these ideas/principles are realized/used by actual communication protocols in the following lectures