Chapter 3:
Network architecture

For use in conjunction with *Protocols and Architectures for Wireless Sensor Networks,* by Holger Karl, Andreas Willig (http://www.wiley.com)

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Goals of this chapter

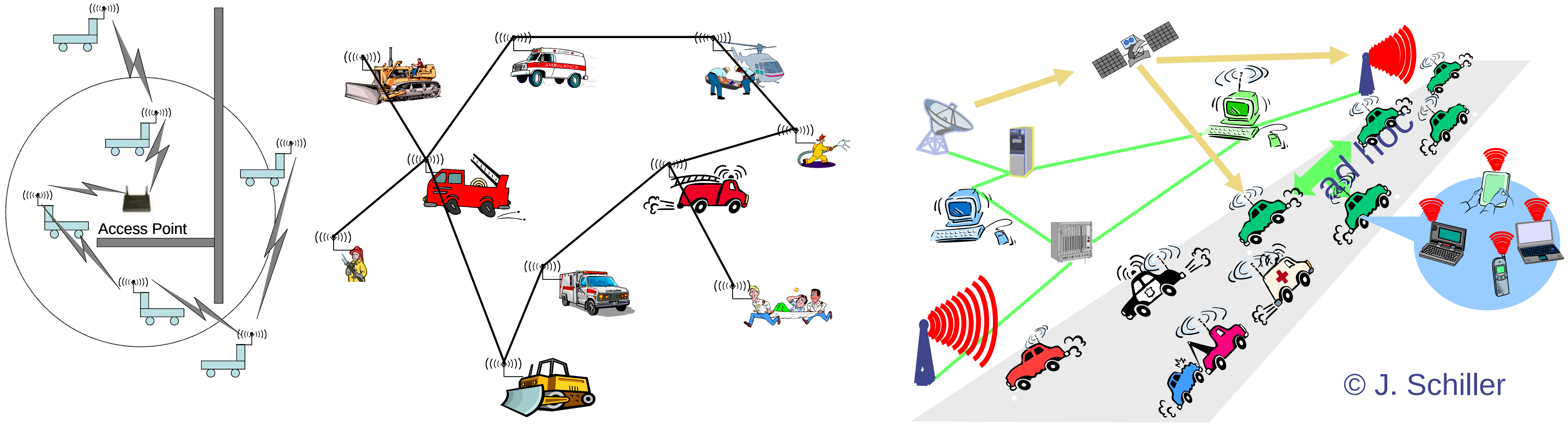
- Having looked at the individual nodes in the previous chapter, we look at general principles and architectures how to put these nodes together to form a meaningful network
- We will look at design approaches to both the more conventional ad hoc networks and the non-standard WSNs

Outline

- ***Network scenarios***
- Optimization goals
- Design principles
- Service interface
- Gateway concepts

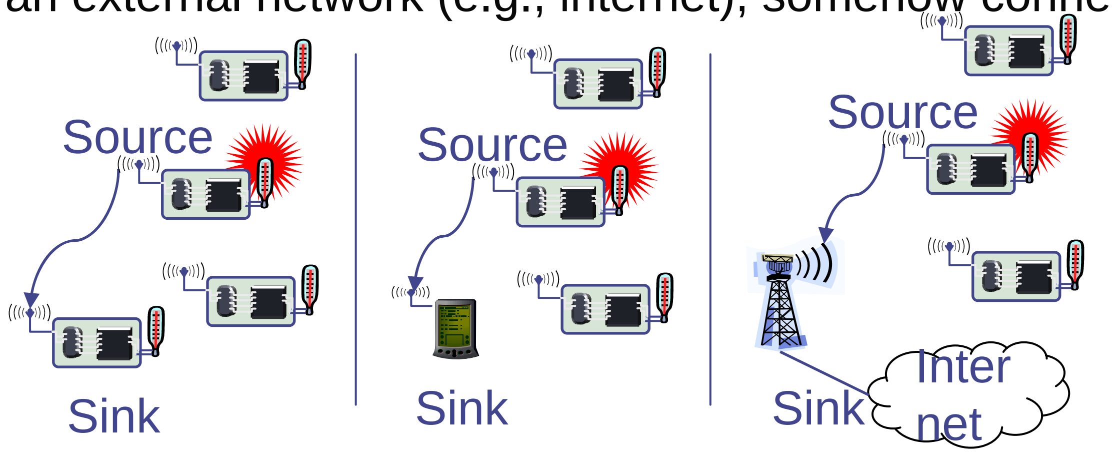
Basic scenarios: Ad hoc networks

- (Mobile) ad hoc scenarios
  - Nodes talking to each other
  - Nodes talking to “some” node in another network (Web server on the Internet, e.g.)
    - Typically requires some connection to the fixed network
  - Applications: Traditional data (http, ftp, collaborative apps, …) & multimedia (voice, video) → humans in the loop



Basic scenarios: sensor networks

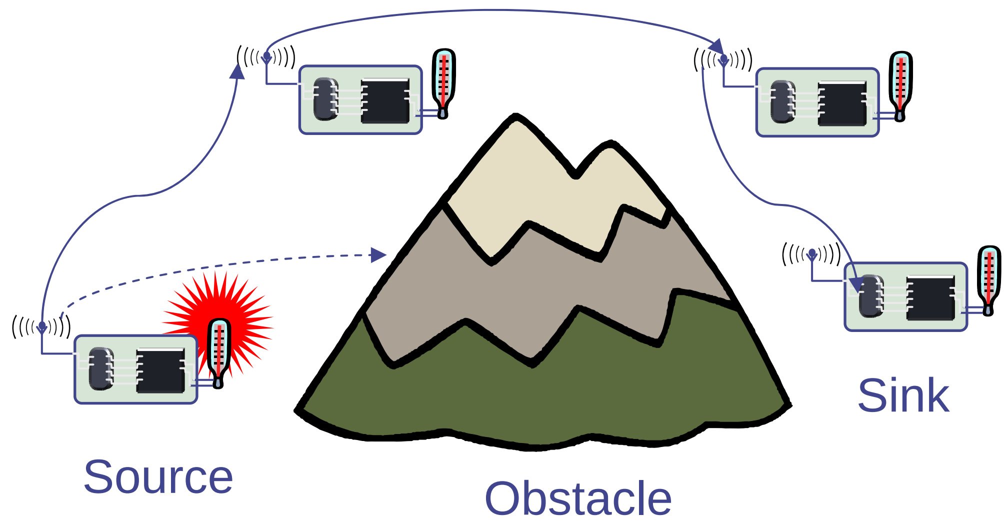
- Sensor network scenarios
  - ***Sources***: Any entity that provides data/measurements
  - ***Sinks***: Nodes where information is required
    - Belongs to the sensor network as such
    - Is an external entity, e.g., a PDA, but directly connected to the WSN
      - Main difference: comes and goes, often moves around, …
    - Is part of an external network (e.g., internet), somehow connected to the WSN



  - 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
- Basic technique applies to both WSN and MANET
- Note: Store&forward multi-hopping NOT the only possible solution
  - E.g., collaborative networking, network coding
  - Do not operate on a per-packet basis

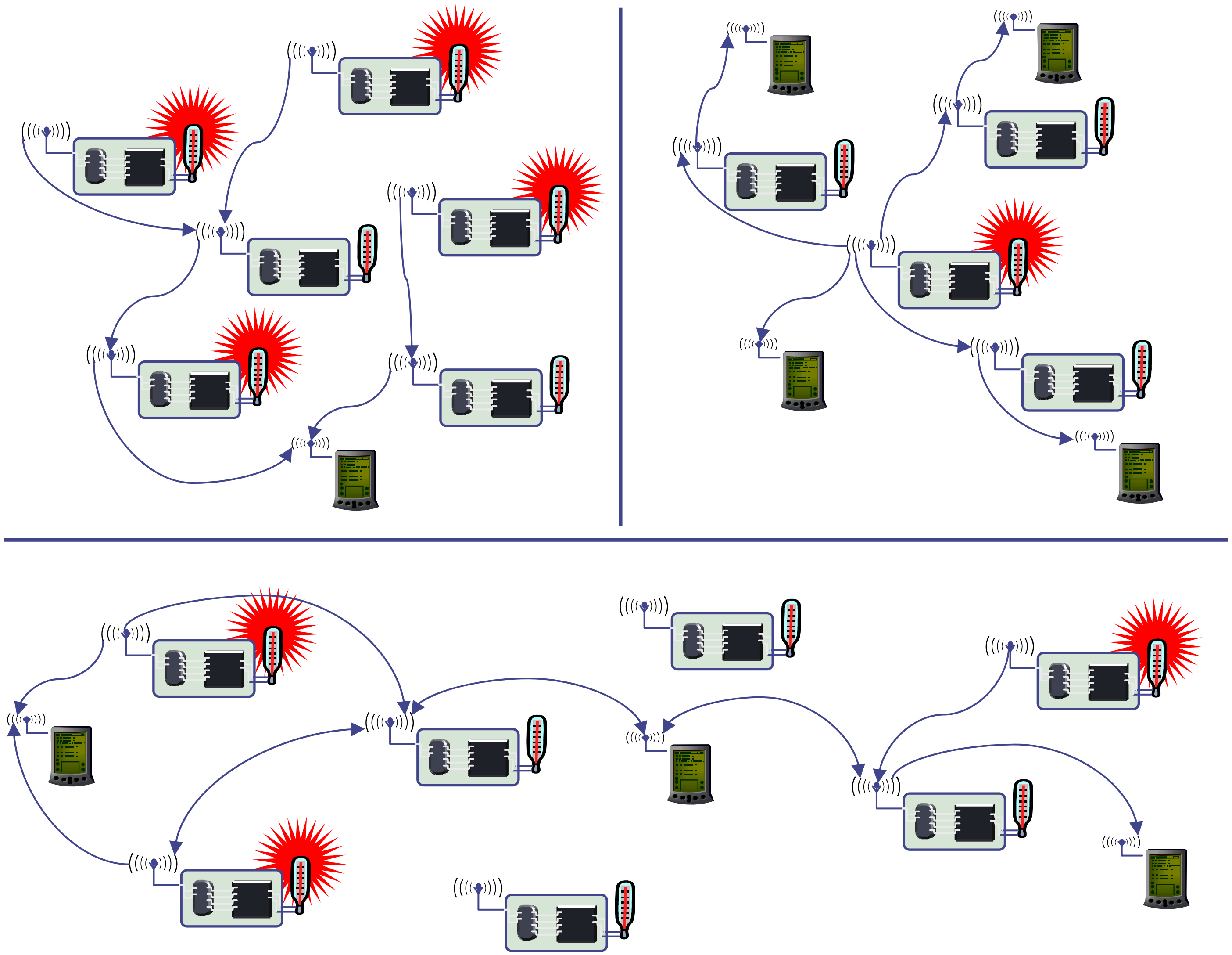


Energy efficiency of multi-hopping?

- Obvious idea: Multi-hopping is more energy-efficient than direct communication
  - Because of path loss $\alpha > 2$, energy for distance d is reduced from cd^{α} to $2c(d/2)^{\alpha}$
    - c some constant
- However: This is usually wrong, or at least very over-simplified
  - Need to take constant offsets for powering transmitter, receiver into account
  - Details see exercise, chapter 2

$\rightarrow$ Multi-hopping for energy savings needs careful choice

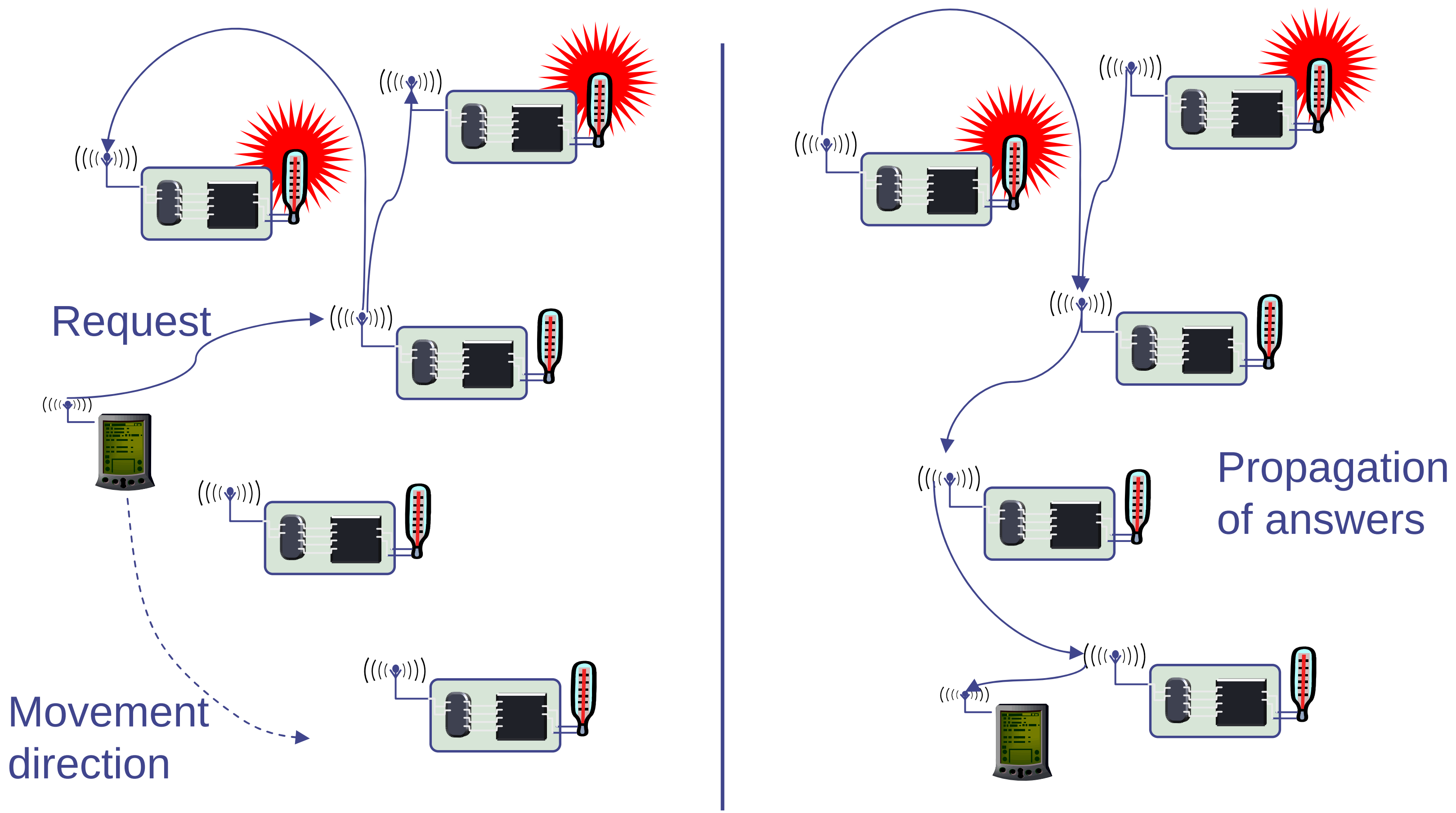
WSN: Multiple sinks, multiple sources



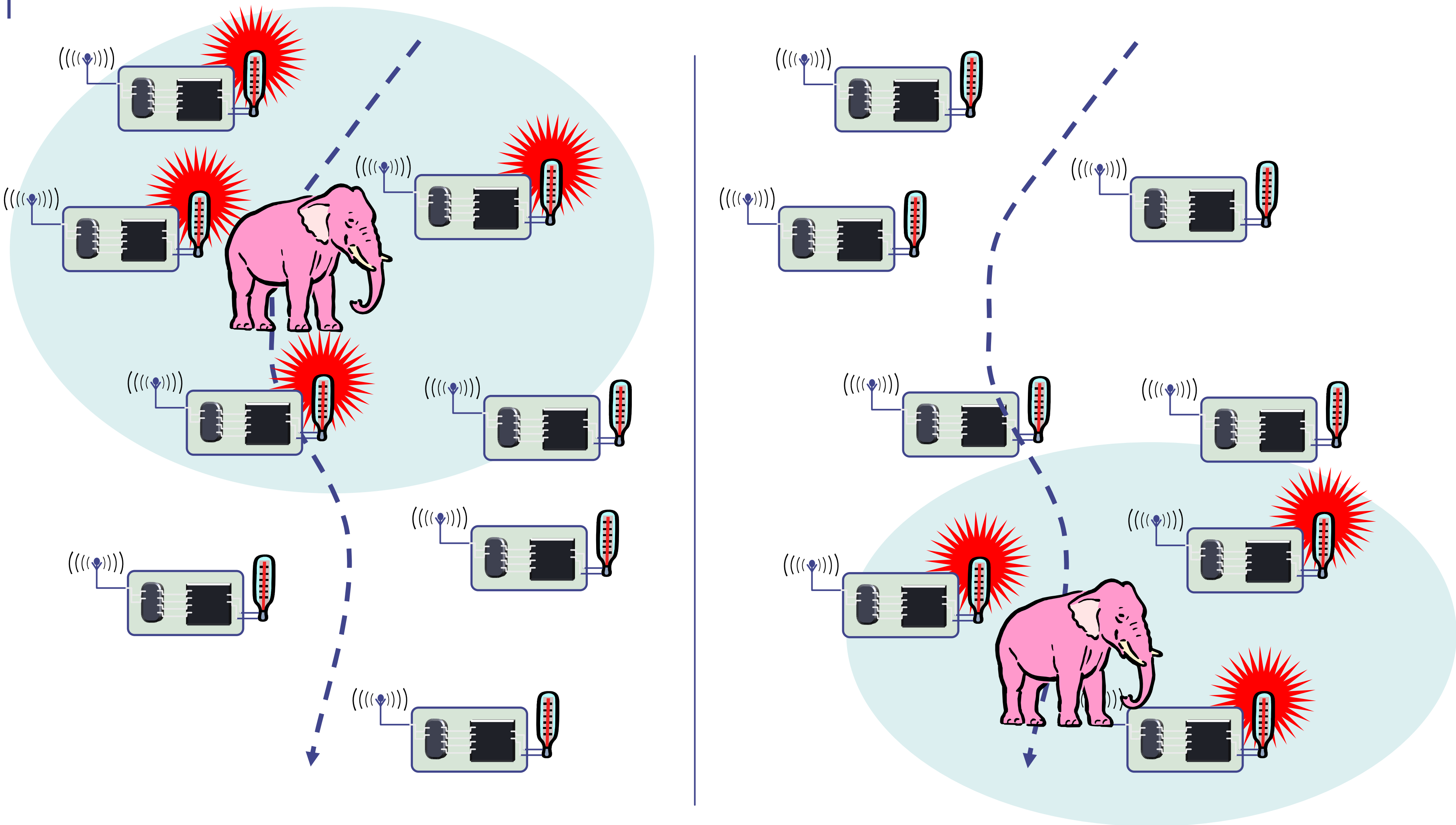
Different sources of mobility

- Node mobility
  - A node participating as source/sink (or destination) or a relay node might move around
  - Deliberately, self-propelled or by external force; targeted or at random
  - Happens in both WSN and MANET
- Sink mobility
  - In WSN, a sink that is not part of the WSN might move
  - Mobile requester
- Event mobility
  - In WSN, event that is to be observed moves around (or extends, shrinks)
  - Different WSN nodes become “responsible” for surveillance of such an event

WSN sink mobility



WSN event mobility: Track the pink elephant



Here: Frisbee model as example

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Optimization goal: Quality of Service

- In MANET: Usual QoS interpretation
  - Throughput/delay/jitter
  - High perceived QoS for multimedia applications
- In WSN, more complicated
  - Event detection/reporting probability
  - Event classification error, detection delay
  - Probability of missing a periodic report
  - Approximation accuracy (e.g, when WSN constructs a temperature map)
  - Tracking accuracy (e.g., difference between true and conjectured position of the pink elephant)
- Related goal: robustness
  - Network should withstand failure of some nodes

Optimization goal: Energy efficiency

- Umbrella term!
- Energy per correctly received bit
  - Counting all the overheads, in intermediate nodes, etc.
- Energy per reported (unique) event
  - After all, information is important, not payload bits!
  - Typical for WSN
- 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

- Network should be operational regardless of number of nodes
  - At high efficiency
- Typical node numbers difficult to guess
  - MANETs: 10s to 100s
  - WSNs: 10s to 1000s, maybe more (although few people have seen such a network before…)

- 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 $n \rightarrow \infty$ solutions!

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Distributed organization

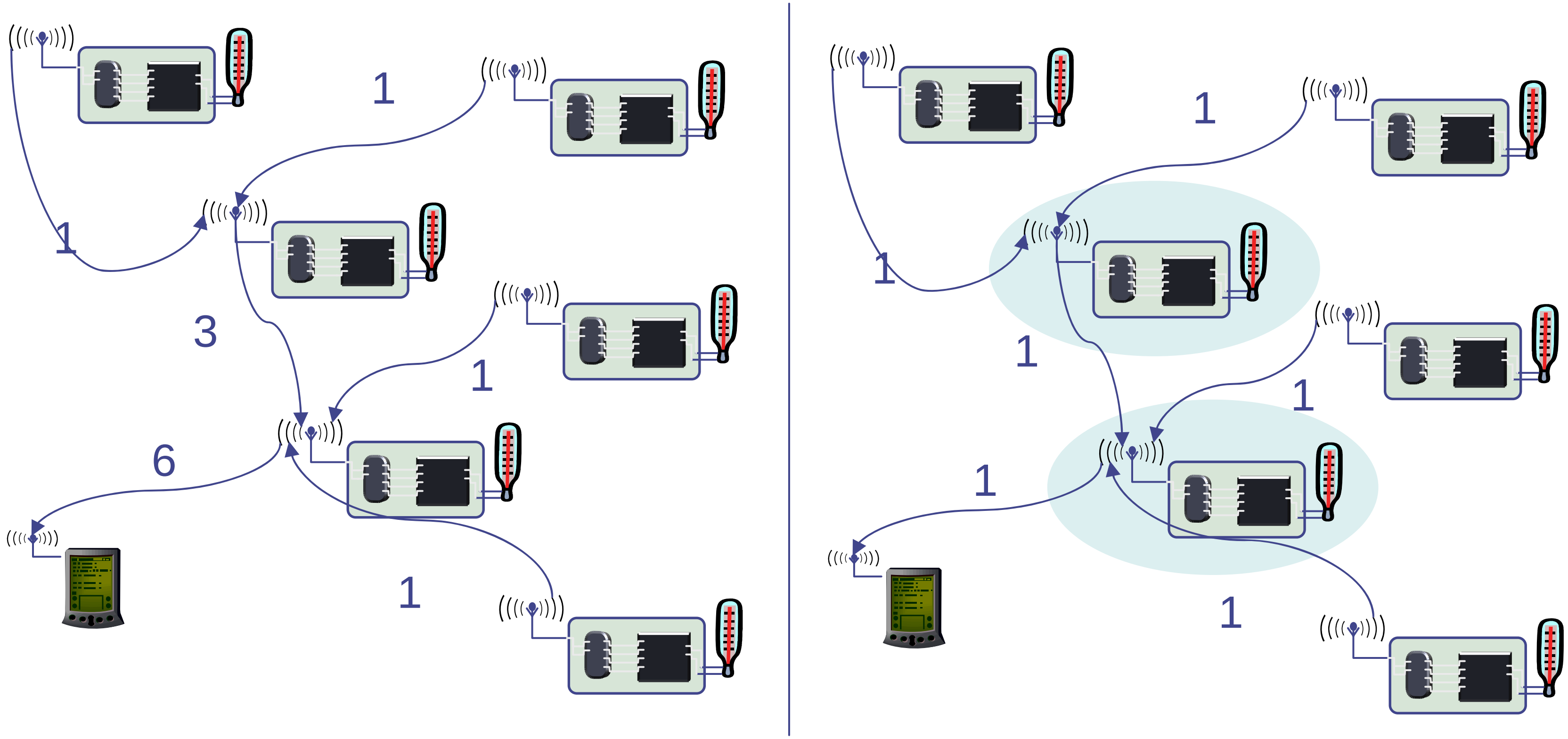
- Participants in a MANET/WSN should cooperate in organizing the network
  - E.g., with respect to medium access, routing, …
  - Centralistic approach as alternative usually not feasible – hinders scalability, robustness
- Potential shortcomings
  - Not clear whether distributed or centralistic organization achieves better energy efficiency (when taking all overheads into account)
- Option: "limited centralized" solution
  - Elect nodes for local coordination/control
  - Perhaps rotate this function over time

In-network processing

- MANETs are supposed to deliver bits from one end to the other
- WSNs, on the other end, are expected to provide information, not necessarily original bits
  - Gives addition options
  - E.g., ***manipulate*** or ***process*** the data in the network
- Main example: aggregation
  - Apply composable aggregation functions to a convergecast tree in a network
  - Typical functions: minimum, maximum, average, sum, …
  - Not amenable functions: median

In-network processing: Aggregation example

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



In-network processing: signal processing

- Depending on application, more sophisticated processing of data can take place within the network
  - Example edge detection: locally exchange raw data with neighboring nodes, compute edges, only communicate edge description to far away data sinks
  - Example tracking/angle detection of signal source: Conceive of sensor nodes as a distributed microphone array, use it to compute the angle of a single source, only communicate this angle, not all the raw data
- Exploit ***temporal*** and ***spatial correlation***
  - Observed signals might vary only slowly in time → no need to transmit all data at full rate all the time
  - Signals of neighboring nodes are often quite similar → only try to transmit differences (details a bit complicated, see later)

Adaptive fidelity

- Adapt the effort with which data is exchanged to the currently required accuracy/fidelity
- Example event detection
  - When there is no event, only very rarely send short “all is well” messages
  - When event occurs, increase rate of message exchanges
- Example temperature
  - When temperature is in acceptable range, only send temperature values at low resolution
  - When temperature becomes high, increase resolution and thus message length

Data centric networking

- In typical networks (including ad hoc networks), network transactions are addressed to the ***identities*** of specific nodes
  - A “node-centric” or “address-centric” networking paradigm
- In a redundantly deployed sensor networks, specific source of an event, alarm, etc. might not be important
  - Redundancy: e.g., several nodes can observe the same area
- Thus: focus networking transactions on the data directly instead of their senders and transmitters → ***data-centric networking***
  - Principal design change

Implementation options for data-centric networking

- Overlay networks & distributed hash tables (DHT)
  - Hash table: content-addressable memory
  - Retrieve data from an unknown source, like in peer-to-peer networking – with efficient implementation
  - Some disparities remain
    - Static key in DHT, dynamic changes in WSN
    - DHTs typically ignore issues like hop count or distance between nodes when performing a lookup operation
- Publish/subscribe
  - Different interaction paradigm
  - Nodes can ***publish*** data, can ***subscribe*** to any particular kind of data
  - Once data of a certain type has been published, it is delivered to all subscribes
  - Subscription and publication are decoupled in time; subscriber and published are agnostic of each other (decoupled in identity)
- Databases

Further design principles

- Exploit location information
  - Required anyways for many applications; can considerably increase performance
- Exploit activity patterns
- Exploit heterogeneity
  - By construction: nodes of different types in the network
  - By evolution: some nodes had to perform more tasks and have less energy left; some nodes received more solar energy than others; …
- Cross-layer optimization of protocol stacks for WSN
  - Goes against grain of standard networking; but promises big performance gains
  - Also applicable to other networks like ad hoc; usually at least worthwhile to consider for most wireless networks

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Interfaces to protocol stacks

- The world's all-purpose network interface: sockets
  - Good for transmitting data from one sender to one receiver
  - Not well matched to WSN needs (ok for ad hoc networks)
- Expressibility requirements
  - Support for simple request/response interactions
  - Support for asynchronous event notification
  - Different ways for identifying addressee of data
    - By location, by observed values, implicitly by some other form of group membership
    - By some semantically meaningful form – "room 123"
  - Easy accessibility of in-network processing functions
    - Formulate complex events – events defined only by several nodes
  - Allow to specify accuracy & timeliness requirements
  - Access node/network status information (e.g., battery level)
  - Security, management functionality, …
- No clear standard has emerged yet – many competing, unclear proposals

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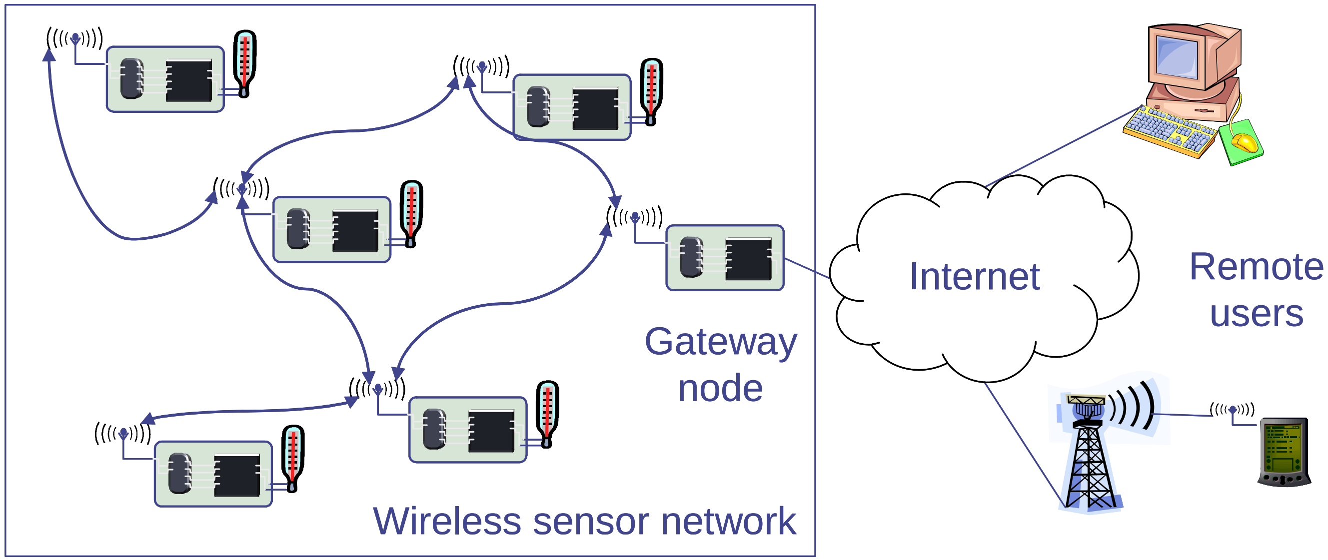
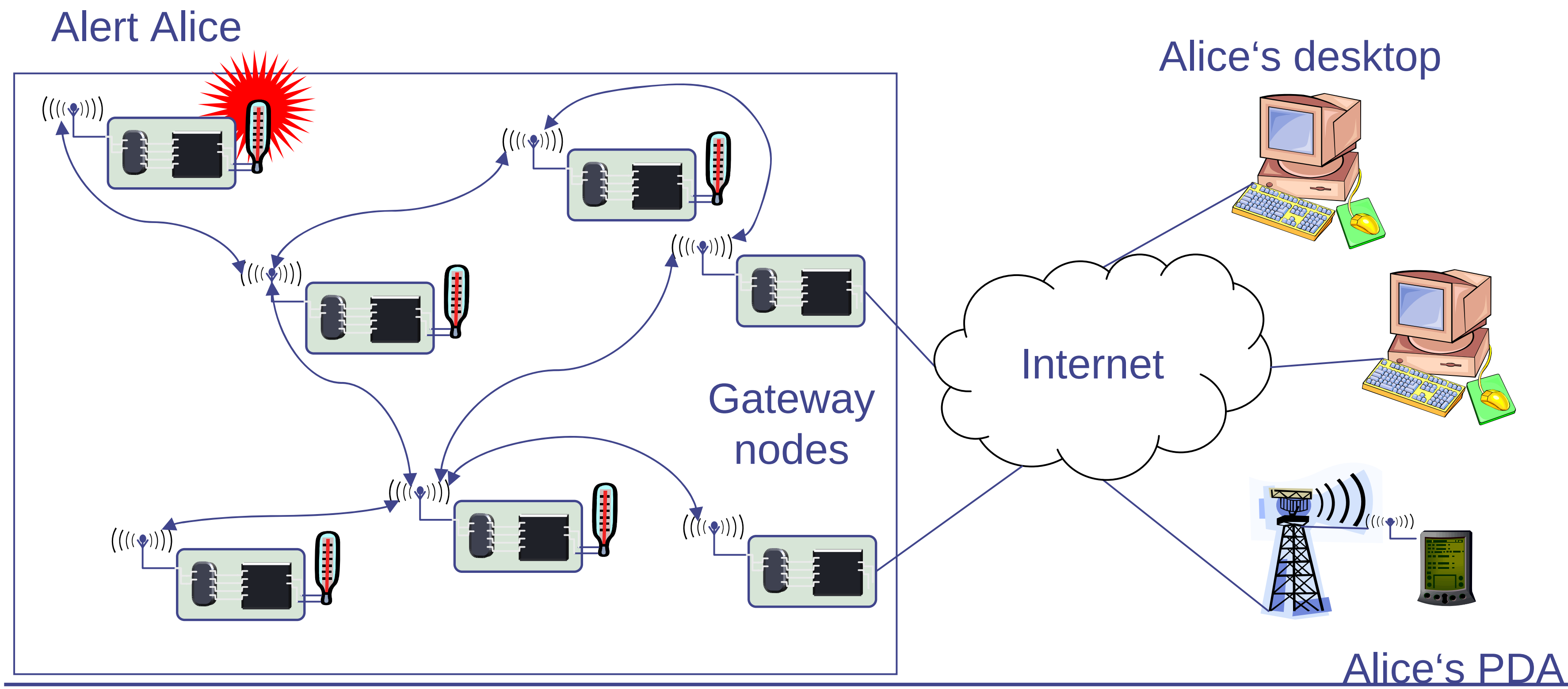
Gateway concepts for WSN/MANET

- Gateways are necessary to the Internet for remote access to/from the WSN
  - Same is true for ad hoc networks; additional complications due to mobility (change route to the gateway; use different gateways)
  - WSN: Additionally bridge the gap between different interaction semantics (data vs. address-centric networking) in the gateway
- Gateway needs support for different radios/protocols, …



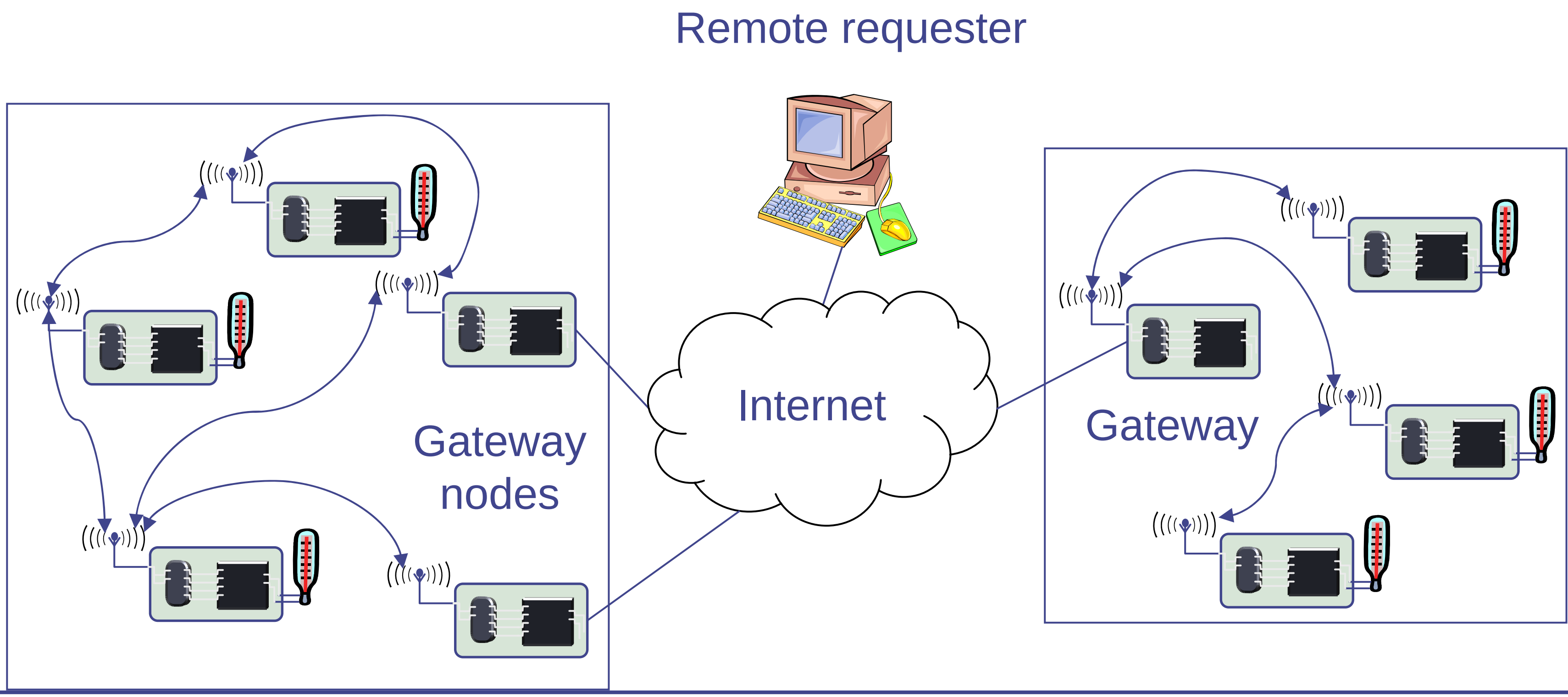
WSN to Internet communication

- Example: Deliver an alarm message to an Internet host
- Issues
  - Need to find a gateway (integrates routing & service discovery)
  - Choose “best” gateway if several are available
  - How to find Alice or Alice’s IP?



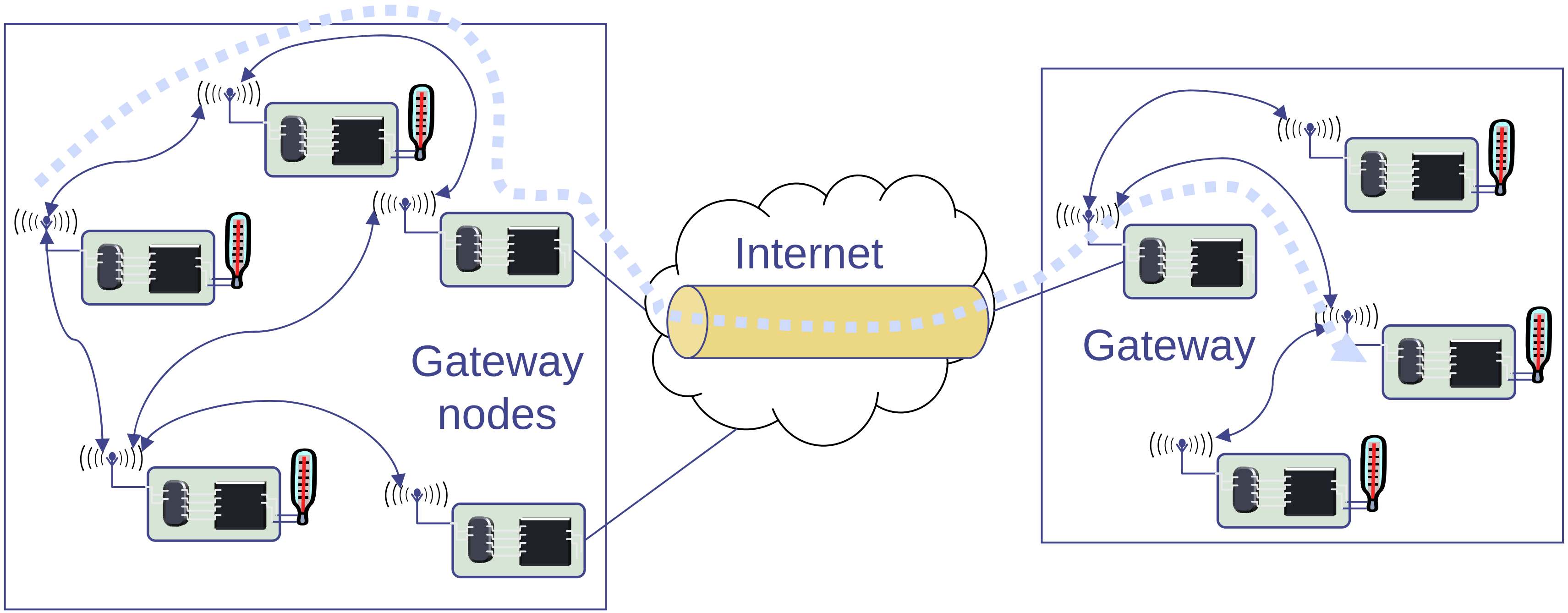
Internet to WSN communication

- How to find the right WSN to answer a need?
- How to translate from IP protocols to WSN protocols, semantics?



WSN tunneling

- Use the Internet to “tunnel” WSN packets between two remote WSNs



Summary

- Network architectures for ad hoc networks are – in principle – relatively straightforward and similar to standard networks
  - Mobility is compensated for by appropriate protocols, but interaction paradigms don't change too much
- WSNs, on the other hand, look quite different on many levels
  - Data-centric paradigm, the need and the possibility to manipulate data as it travels through the network opens new possibilities for protocol design
- The following chapters will look at how these ideas are realized by actual protocols

Homework #3:

1. Discuss with the node mobility, sink mobility, event mobility.
2. What’s ‘in-network processing’ ?