Wireless Sensor Networks

25th Lecture

13.02.2007

CoNe Freiburg

University of Freiburg
Computer Networks and Telematics
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Final Meeting (before the exams)

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- **Meeting Point: Waldkirch, main station**
- **Date: Tuesday 27.02.2006 14:01 (Train departs Freiburg main station at 13:40)**

- **Plan**
  - Hike the Kastelburg
  - Picknick
- **BYOF**
  - Order drinks on-line
- **Don‘t forget**
  - Food
  - Umbrella
  - Matches

Data-centric and content-based networking

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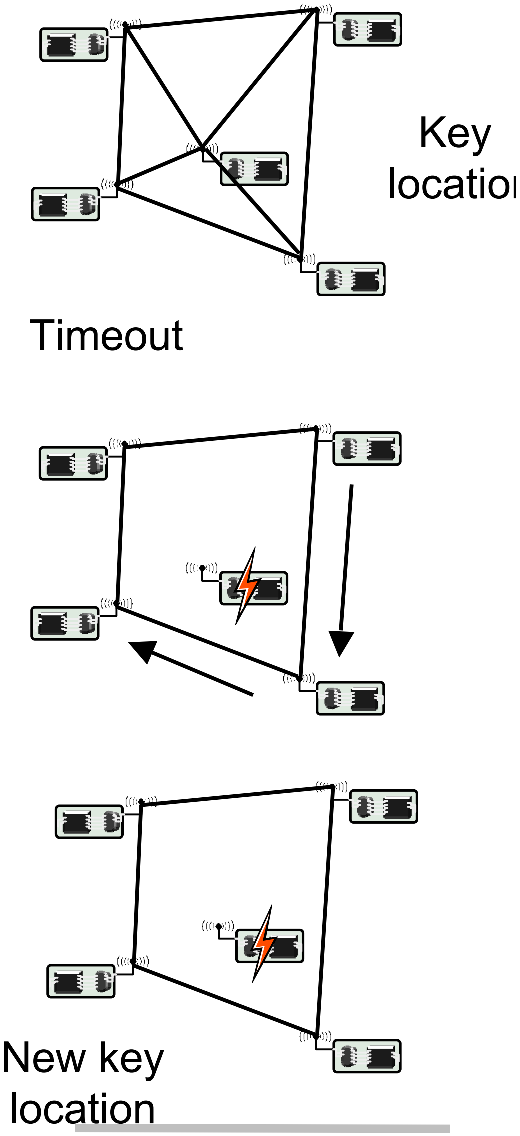
- **Interaction patterns and programming model**
- **Data-centric routing**
- **Data aggregation**
- *Data storage*

Data-centric storage

- **Problem: Sometimes, data has to be stored for later retrieval – difficult in absence of gateway nodes/servers**
- **Question: Where/on which node to put a certain datum?**
  - Avoid a complex directory service
- **Idea: Let name of data describe which node is in charge**
  - Data name is hashed to a geographic position
  - Node closest to this position is in charge of holding data
  - Akin to peer-to-peer networking/distributed hash tables
  - Hence name of one approach: ***Geographic Hash Tables*** (***GHT***)
  - Use geographic routing to store/retrieve data at this "location" (in fact, the node)

Geographic hash tables – Some details

- **Good hash function design**
- **Nodes not available at the hashed location – use "nearest" node as determined by a geographic routing protocol**
  - E.g., the node where an initial packet started circulating the "hole"
  - Other nodes around hole are informed about node taking charge
- **Handling failing and new nodes**
  - Failure detected by timeout, apply similar procedure as for initially storing data
- **Limited storage per node**
  - Distribute data to other nodes on same face



Conclusion

- **Using data names or predicates over data to describe the destination of packets/data opens new options for networking**
- **Networking based on such "data-centric addresses" nicely supports an intuitive programming model – publish/subscribe**
- **Aggregation a key enabler for efficient networking**
- **Other options – data storage, bradcasting aggregates – also well supportable**

Naming and Indexing

- **Non-standard options for denoting the senders/receivers of messages**
  - Traditional (fixed, wireless, ad hoc): Denote individual nodes by their identity
  - WSN: Content-based addresses can be a good complement
- **When addresses are not given a priori, they have to be determined "in the field"**
  - Some algorithms are discussed

Names vs. addresses

- *Name:* **Denote/refer to "things"**
  - Nodes, networks, data, transactions, …
  - Often, but not always, unique (globally, network-wide, locally)
  - Ad hoc: nodes – WSN: Data!
- *Addresses:* **Information needed to *find* these things**
  - Street address, IP address, MAC address
  - Often, but not always, unique (globally, network-wide, locally)
  - Addresses often hierarchical, because of their intended use in, e.g., routing protocols
- **Services to map between names and addresses**
  - E.g., DNS
- **Sometimes, same data serves as name and address**
  - IP addresses are prominent examples

Issues in address management

- **Address allocation: Assign an entity an address from a given pool of possible addresses**
  - Distributed address assignment (centralized like DHCP [Dynamic Host Configuration Protocol] does not scale)
- **Address deallocation: Once address no longer used, put it back into the address pool**
  - Because of limited pool size
  - Graceful or abrupt, depending on node actions
- **Address representation**
- **Conflict detection & resolution (*Duplicate Address Detection*)**
  - What to do when the same address is assigned multiple times?
  - Can happen e.g. when two networks merge
- **Binding**
  - Map between addresses used by different protocol layers
  - E.g., IP addresses are bound to MAC address by ARP (Address Resolution Protocol)

Distributed address assignment

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- **Option 1: Let every node randomly pick an address**
  - For given size of address space
  - risk of duplicate addresses
- **Option 2: Avoid addresses used in local neighborhood**
- **Option 3: Repair any observed conflicts**
  - Temporarily pick a random address from a dedicated pool and a proposed fixed address
  - Send an ***address request*** to the proposed address, using temporary address
  - If ***address reply*** arrives, proposed address already exists
  - Collisions in temporary address unlikely, as only used briefly
- **Option 4: Similar to 3, but use a neighbor that already has a fixed address to perform requests**

Content-based addresses

- **Recall: Paradigm change from id-centric to data-centric networking in WSN**
- **Supported by content-based names/addresses**
  - Do not described involved nodes (not known anyway), but the ***content*** itself the interaction is about
- **Classical option: Put a naming scheme on top of IP addresses**
  - Done by some middleware systems

Geographic addressing

- **Express addresses by denoting physical position of nodes**
  - Can be regarded as a special case of content-based addresses
  - Attributes for x and y coordinates (and maybe z)
- **Options**
  - Single point
  - Circle or sphere centered around given point
  - Rectangle by two corner points
  - Polygon/polytope by list of points
  - …

ISO/OSI 7-layer reference model (complete network)

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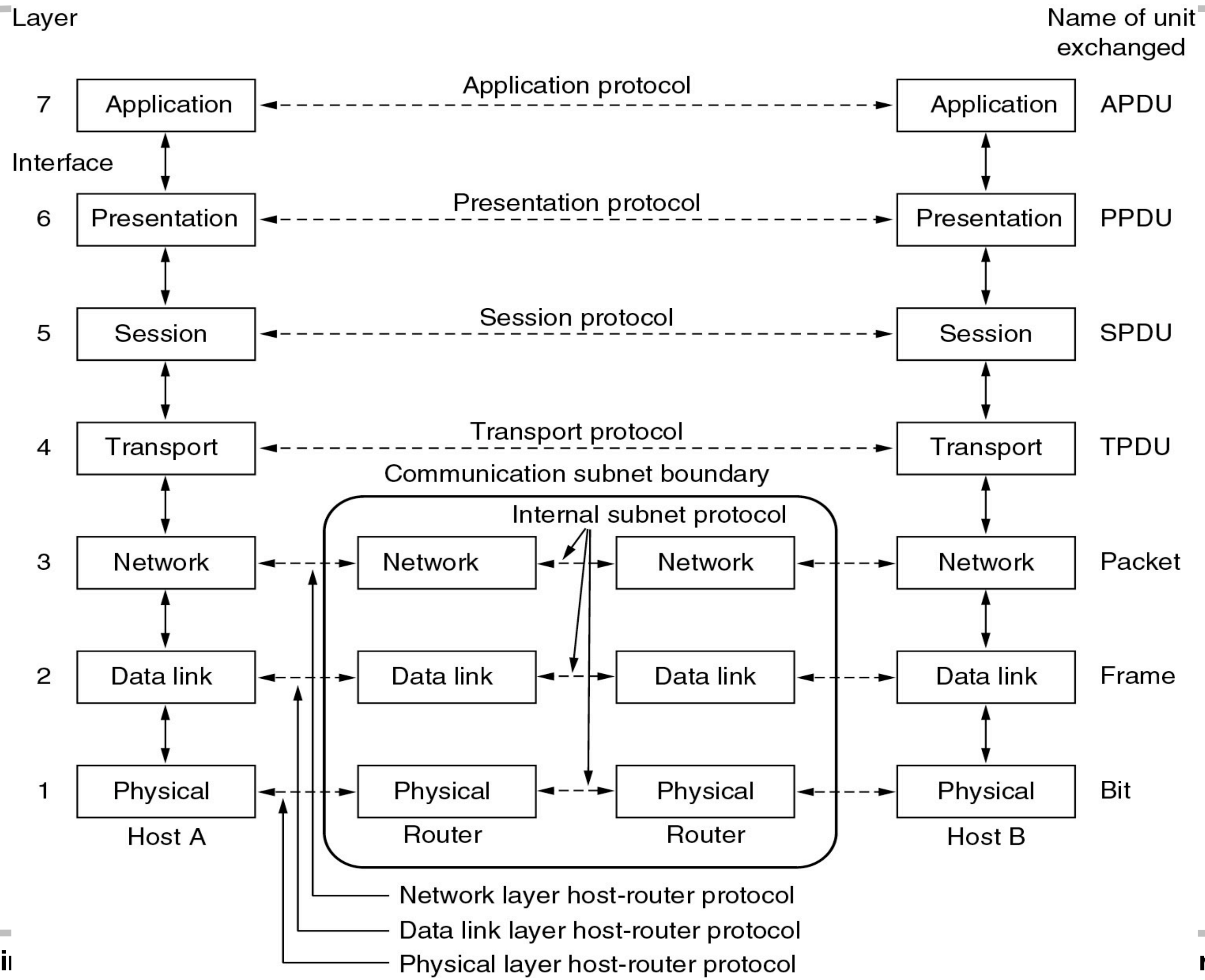

Protocols for dependable data transport

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- **Dependability requirements**
- **Delivering single packets**
- **Delivering blocks of packets**
- **Delivering streams of packets**

Dependability aspects

- *Coverage & deployment*
  - Is there a sufficient number of nodes such that an event can be detected at all? Such that data can accurately measured?
  - How do they have to be deployed?
- *Information accuracy*
  - Which of the measured data have to be transported where such that a desired accuracy is achieved?
  - How to deal with inaccurate measurements in the first place?
- *Dependable data transport*
  - Once it is clear which data should arrive where, how to make sure that it actually arrives?
  - How to deal with ***transmission errors*** and ***omission errors/congestion***?

Dependability: Terminology

- **“Dependable” is an umbrella term**
- **Main numerical metrics**
  - ***(Steady state) availability*** – probability that a system is operational at any given point in time
    - Assumption: System can fail and will repair itself
  - ***Reliability at time t –*** Probability that system works correctly during the entire interval [0,t)
    - Assumption: It worked correctly at system start t=0
  - ***Responsiveness –*** Probability of meeting a deadline
    - Even in presence of some – to be defined – faults
  - ***Packet success probability*** – Probability that a packet (correctly) reaches its destination
    - Related: packet error rate, packet loss rate
  - ***Bit error rate –*** Probability of an incorrect bit
    - Channel model determines precise error patterns

Dependability constraints

- **Wireless sensor networks (WSN) have unique constraints for dependable data delivery**
  - Transmission errors over a wireless channel
  - Limited computational resources in a WSN node
  - Limited memory
  - Limited time (deadlines)
  - Limited dependability of individual nodes

- **Standard mechanisms: Redundancy**
  - Redundancy in nodes, transmission
  - Forward and backward error recovery
  - Combinations are necessary!

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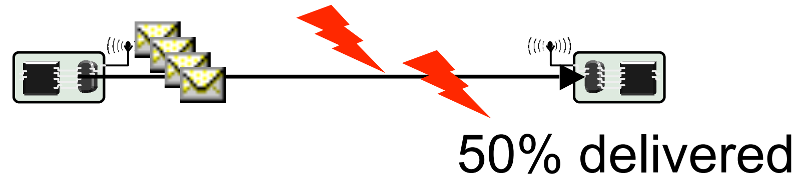
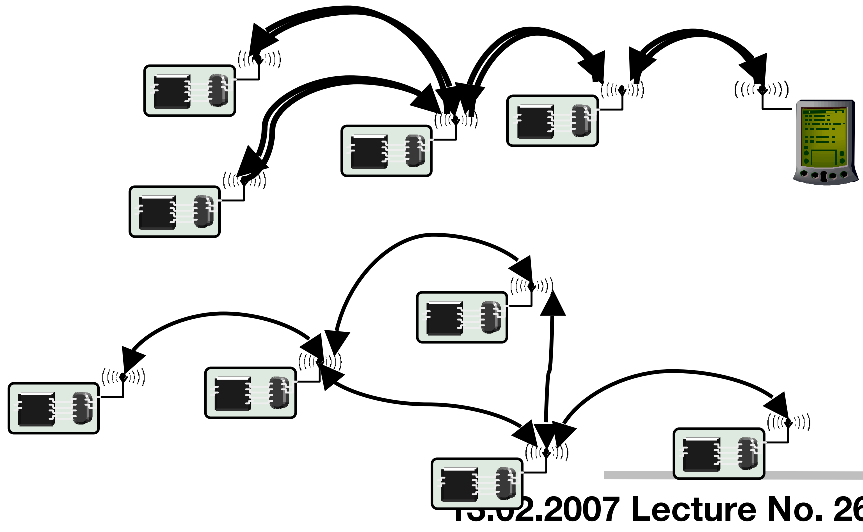
Dependable data transport – context

- **Items to be delivered**
  - Single packet
  - Block of packets
  - Stream of packets

- **Level of guarantee**
  - Guaranteed delivery
  - Stochastic delivery



- **Involved entities**
  - Sensor(s) to sink
  - Sink to sensors
  - Sensors to sensors



Constraints

- **Energy**
  - Send as few packets as possible
  - Send with low power $\rightarrow$ high error rates
  - Avoid retransmissions
  - Short packets $\rightarrow$ weak FEC
  - Balance energy consumption in network
- **Processing power**
  - Only simple FEC schemes
  - No complicated algorithms (coding)
- **Memory**
  - Store as little data as briefly as possible

Overview

- **Dependability requirements**
- *Delivering single packets*
  - Single path
  - Multiple paths
  - Gossiping-based approaches
  - Multiple receivers
- **Delivering blocks of packets**
- **Delivering streams of packets**

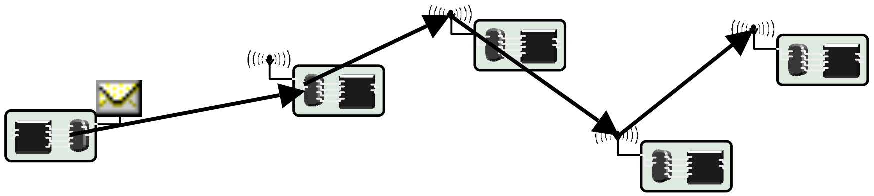
Delivering single packets – main options

- **What are the intended receivers?**
  - A ***single receiver***?
  - ***Multiple receivers***?
    - In close vicinity? Spread out?
  - Mobile?

- **Which routing structures are available?**
  - Unicast routing along a ***single path***?
  - Routing with ***multiple paths*** between source/destination pairs?
  - No routing structure at all – rely on ***flooding/gossiping***?

Single packet to single receiver over single path

- **Single, multi-hop path is giving by some routing protocol**



- **Issues: Which node**
  - Detects losses (using which indicators)?
  - Requests retransmissions?
  - Carries out retransmissions?

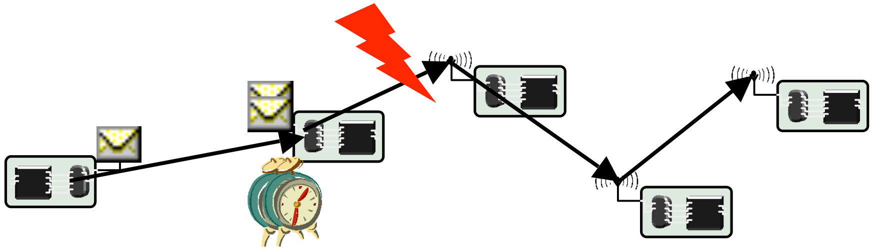
Detecting & signaling losses in single packet delivery

- **Detecting loss of a *single packet*:**
  Only positive acknowledgements (ACK) feasible
  - Negative acks (NACK) not an option – receiver usually does not know a packet should have arrived, has no incentive to send a NACK

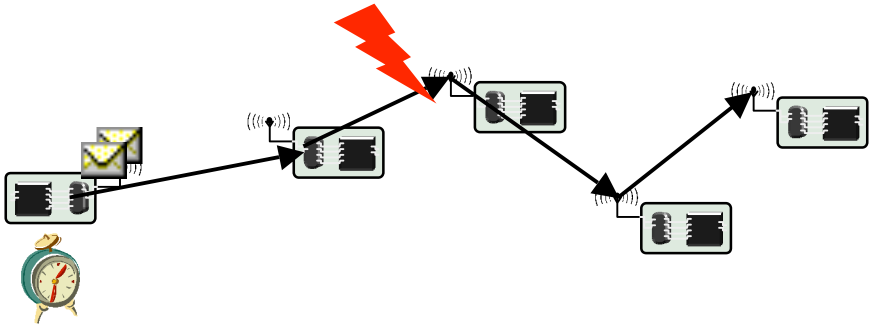
- **Which node sends ACKs (avoiding retransmissions)?**
  - At each intermediate node, at MAC/link level
    - Usually accompanied by link layer retransmissions
    - Usually, only a bounded number of attempts
  - At the destination node
    - Transport layer retransmissions
    - Problem: Timer selection

Carrying out retransmissions

- **For link layer acknowledgements: Neighboring node**



- **For transport layer acknowledgements:**
  - Source node → end-to-end retransmissions



Example schemes: HHR and HHRA

- *Hop-by-hop reliability (HHR)*
  - Idea: Locally improve probability of packet transmission, but do not use packet retransmission
  - Instead, simply repeat packet a few times – a repetition code
  - Choose number of repetitions per node such that resulting end-to-end delivery probability matches requirements
- *Hop-by-hop reliability with Acknowledgements (HHRA)*
  - Node sends a number of packets, but pauses after each packet to wait for acknowledgement
  - If received, abort further packet transmissions

Multiple paths

- **Types of : disjoint or braided**
- **Usage: default and alternative routes**
- **Usage: simultaneous**
  - Send same packet
  - Send redundant fragments
- **Example: ReInForM**

Multiple paths: Disjoint or braided

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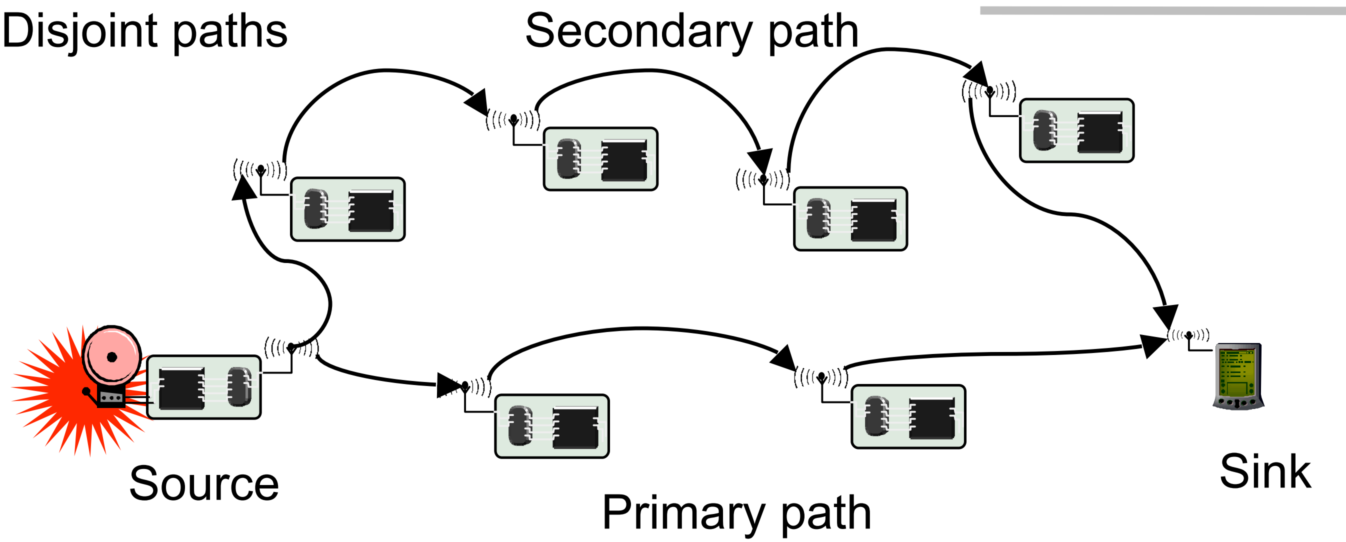
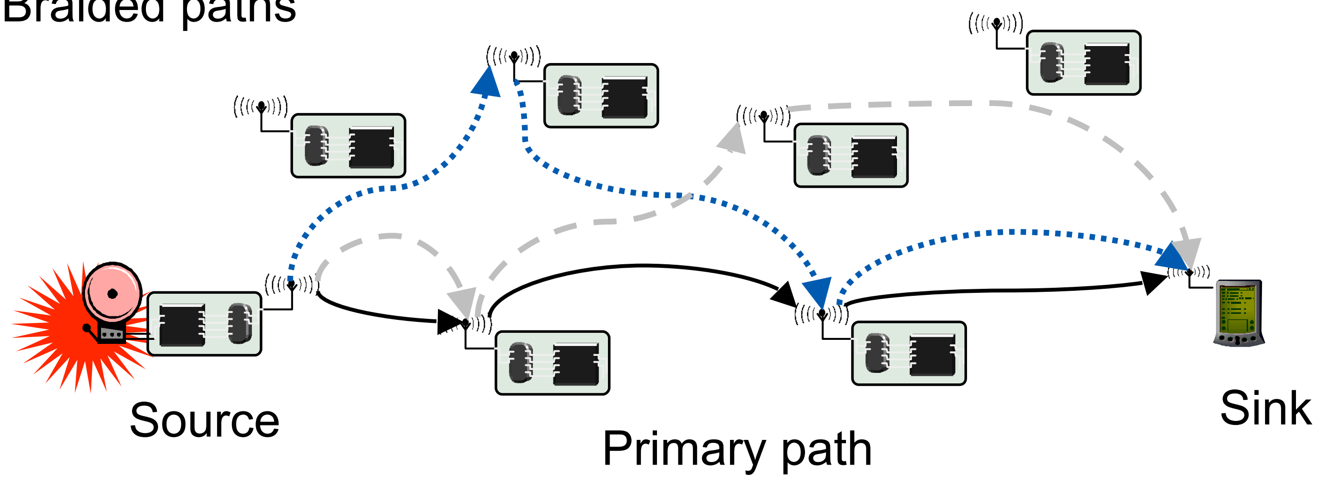
Disjoint paths



Braided paths



Using multiple paths

- **Alternating use**
  - Send packet over the currently “selected” path
  - If path breaks, select alternative path
  - Or/and: repair original path locally

- **Simultaneous use**
  - Send the complete packet over some or all of the multiple paths simultaneously
  - Send packet fragments over several paths
    - But endow fragments with redundancy
    - Only some fragments suffice to reconstruct original packet

Conclusion

- **Transport protocols have considerable impact on the service rendered by a wireless sensor networks**
- **Various facets – no “one size fits all” solution in sight**
- **Still a relatively unexplored areas**

- **Items not covered**
  - Relation to coverage issues
  - TCP in WSN? Gateways?
  - Aggregation? In-network processing?

Thank you

and thanks to Holger Karl for the slides

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