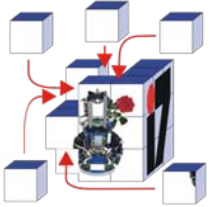

Self-Organization in Autonomous Sensor/Actuator Networks [SelfOrg]

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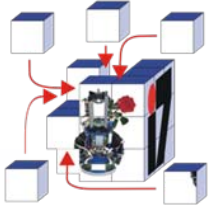
Overview

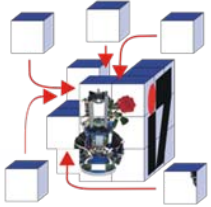


- **Self-Organization**
  Introduction; system management and control; principles and characteristics; natural self-organization; methods and techniques

- **Networking Aspects: Ad Hoc and Sensor Networks**
  Ad hoc and sensor networks; self-organization in sensor networks; evaluation criteria; medium access control; ad hoc routing; data-centric networking; clustering

- **Coordination and Control: Sensor and Actor Networks**
  Sensor and actor networks; coordination and synchronization; in-network operation and control; task and resource allocation

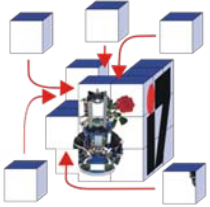
- **Bio-inspired Networking**
  Swarm intelligence; artificial immune system; cellular signaling pathways



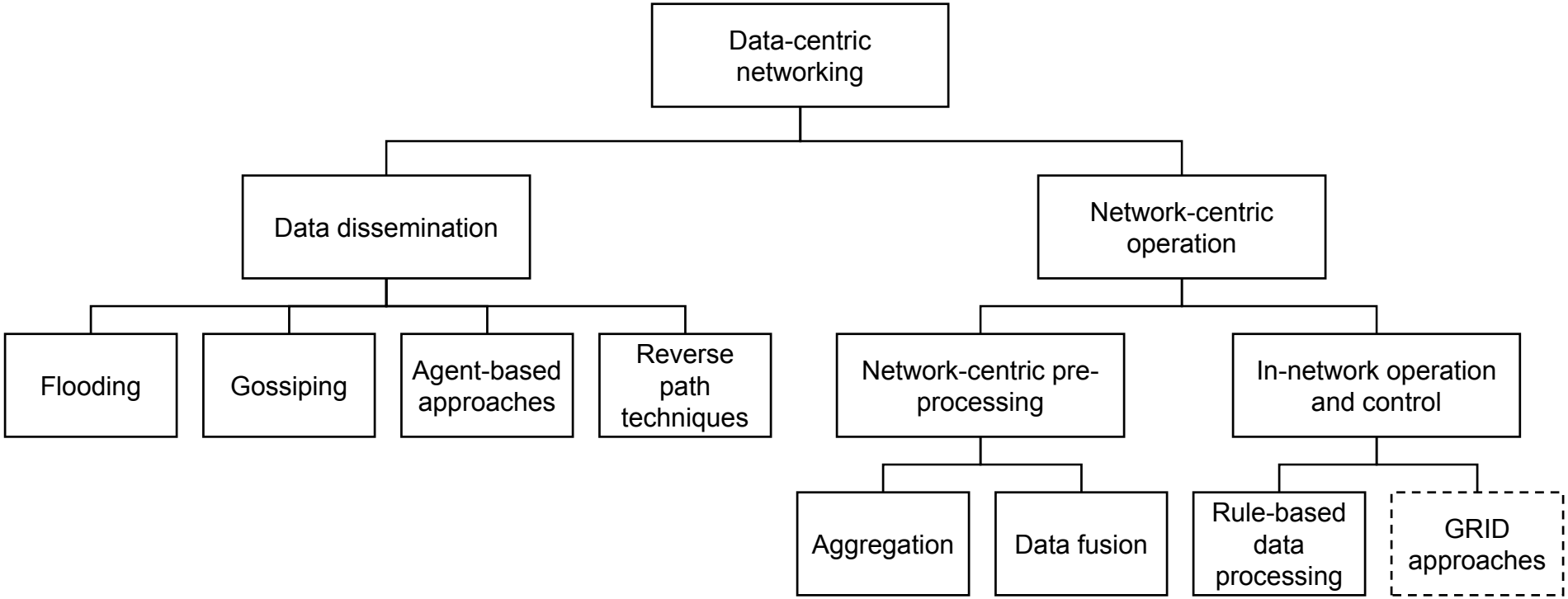
Data-Centric Communication

- Flooding / Gossiping / WPDD
- Rumor routing
- Directed Diffusion
- Data aggregation and data fusion

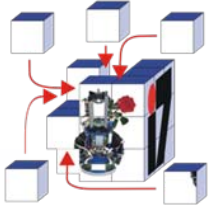
Overview and classification



- Data dissemination – forwarding of data though the network
- Network-centric operation – data manipulation and control tasks
  - Network-centric pre-processing, e.g. data aggregation and fusion
  - In-network operation and control, e.g. rule-based approaches

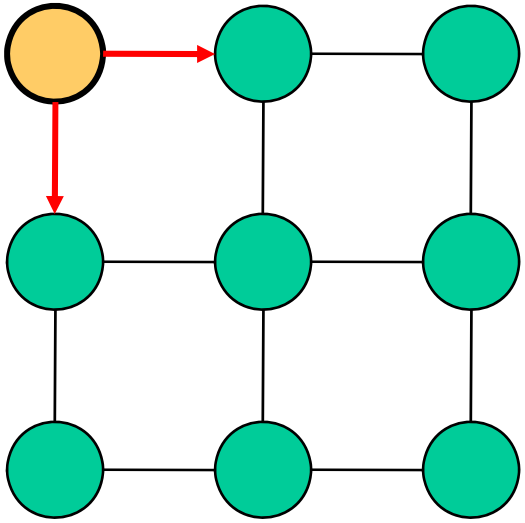


Flooding

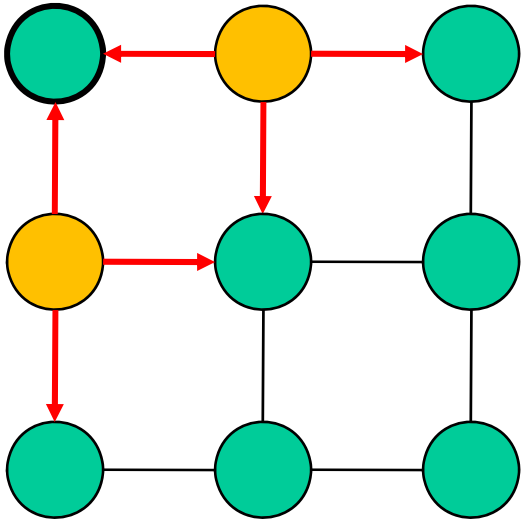


- Basic mechanism:
  - Each node that receives a packet re-broadcasts it to all neighbors
  - The data packet is discarded when the maximum hop count is reached

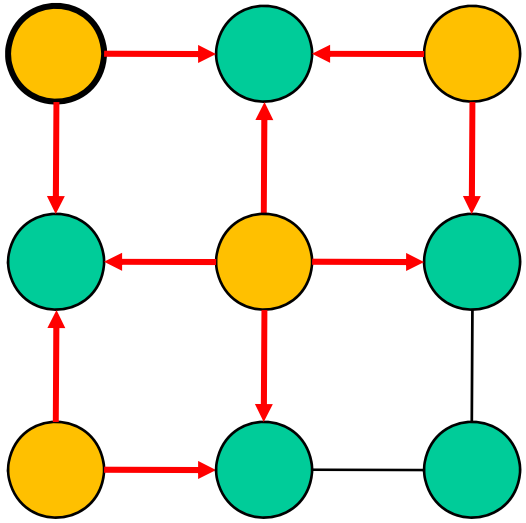
Step 1



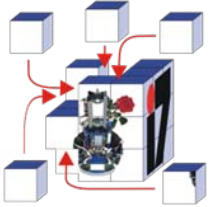
Step 2



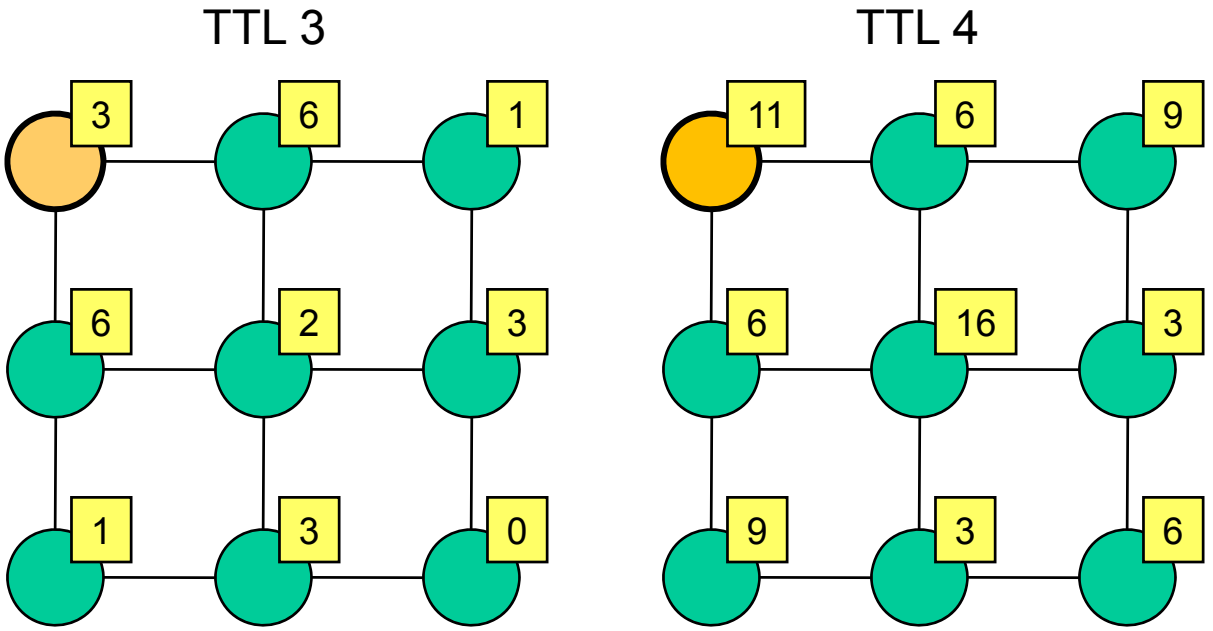
Step 3



Flooding

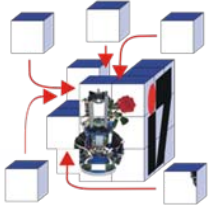


- Advantages
  - No route discovery mechanisms are required
  - No topology maintenance is required



- Disadvantages
  - ***Implosion:*** duplicate messages are sent to the same node
  - ***Overlap:*** same events may be sensed by more than one node due to overlapping regions of coverage → duplicate report of the same event
  - ***Resource blindness:*** available energy is not considered and redundant transmissions may occur → limited network lifetime

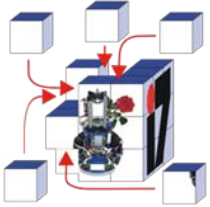
Topology assisted flooding



- Exploiting overhearing in wireless networks

while Receive a new flooding packet P **do**
    Start a process on packet P
    Wait for T time units – overhearing period
    if Each one-hop neighbor is already covered by at least one broadcast of P **then**
        terminate process on packet P
    else
        Re-broadcast packet P
    end if
end while

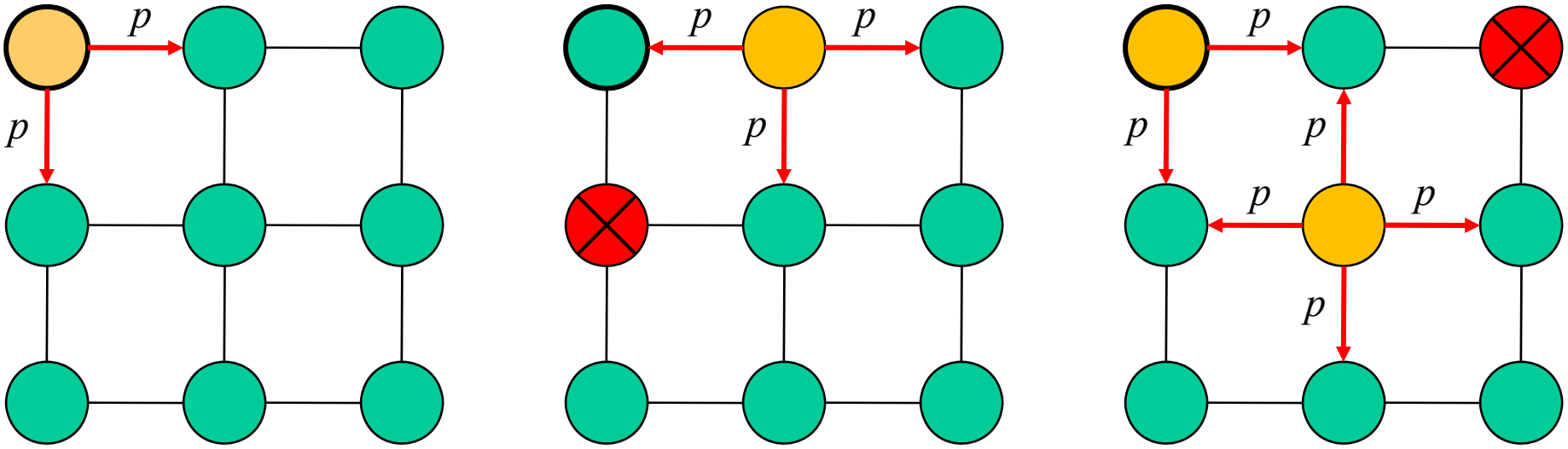
Simple gossiping



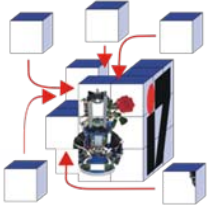
- GOSSIP(p) – Probabilistic version of flooding
- Packets are re-broadcasted with a gossiping probability p

for each message m
    if random(0,1) < p **then** message m

Step 1 Step 2 Step 3

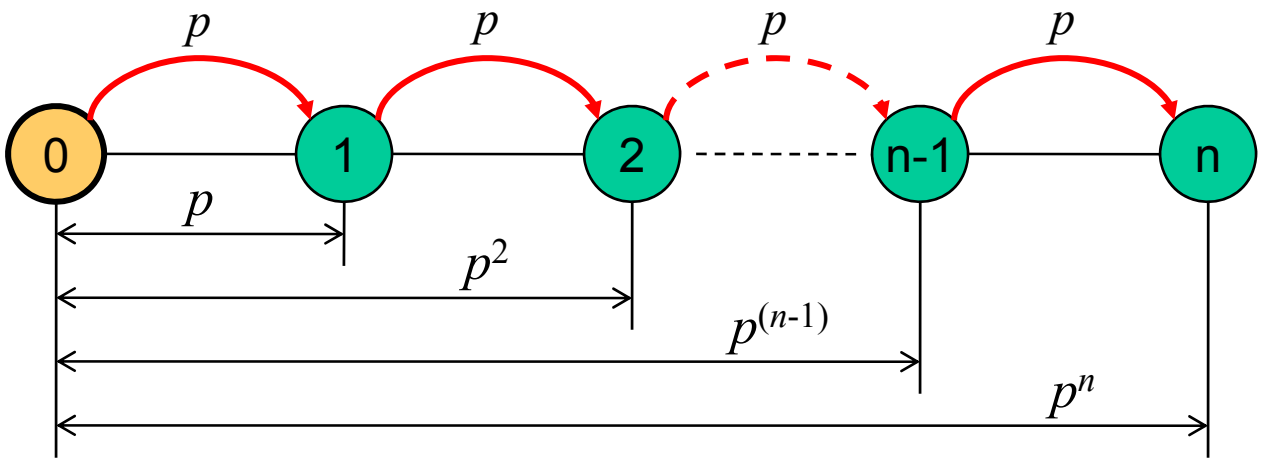


Simple gossiping

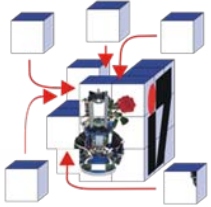


- Advantages
  - Avoids packet implosion
  - Lower network overhead compared to flooding

- Disadvantages
  - Long propagation time throughout the network
  - Does not guarantee that all nodes of the network will receive the message (similarly do other protocols but for gossiping this is an inherent “feature”)



Optimized gossiping



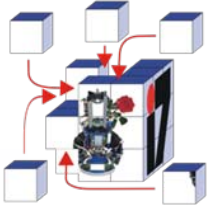
- Two-threshold scheme
  - GOSSIP(p, k) – Flooding for the first k hops, then gossiping with probability p
    - GOSSIP(1, k) → flooding
    - GOSSIP(p, 0) → simple gossiping

- Destination attractors
  - Weighted gossiping probability according to the distance of the current node to the final destination

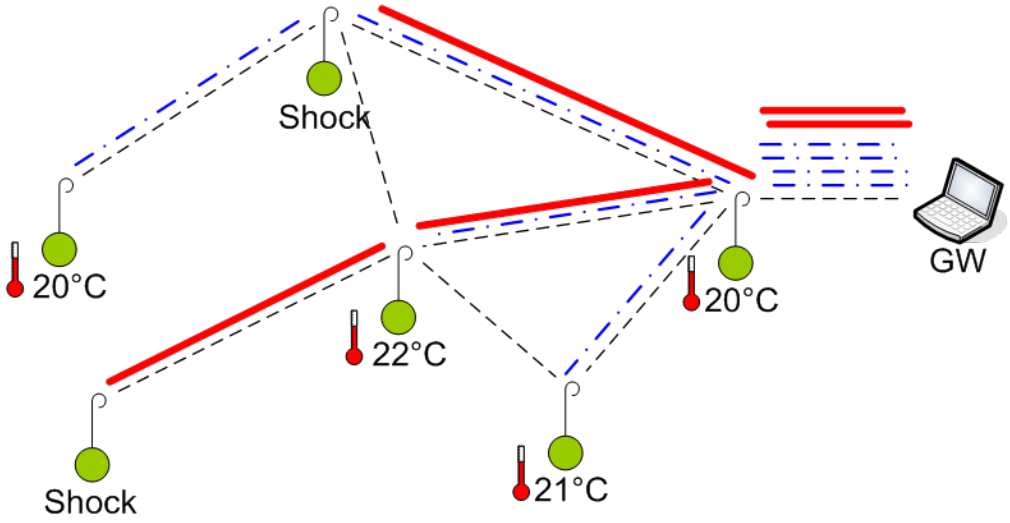
$$P_{Ri} = \begin{cases} (1+k)P_{Ri-1} & \text{closer to destination} \\ (1-k)P_{Ri-1} & \text{further to destination} \\ P_{Ri-1} & \text{same or indeterminate} \end{cases}$$

P_{Ri} is the gossiping probability for a packet at the i^{th} node R_i in its path to the destination, k can be used to scale the probability

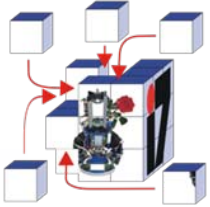
Weighted Probabilistic Data Dissemination (WPDD)



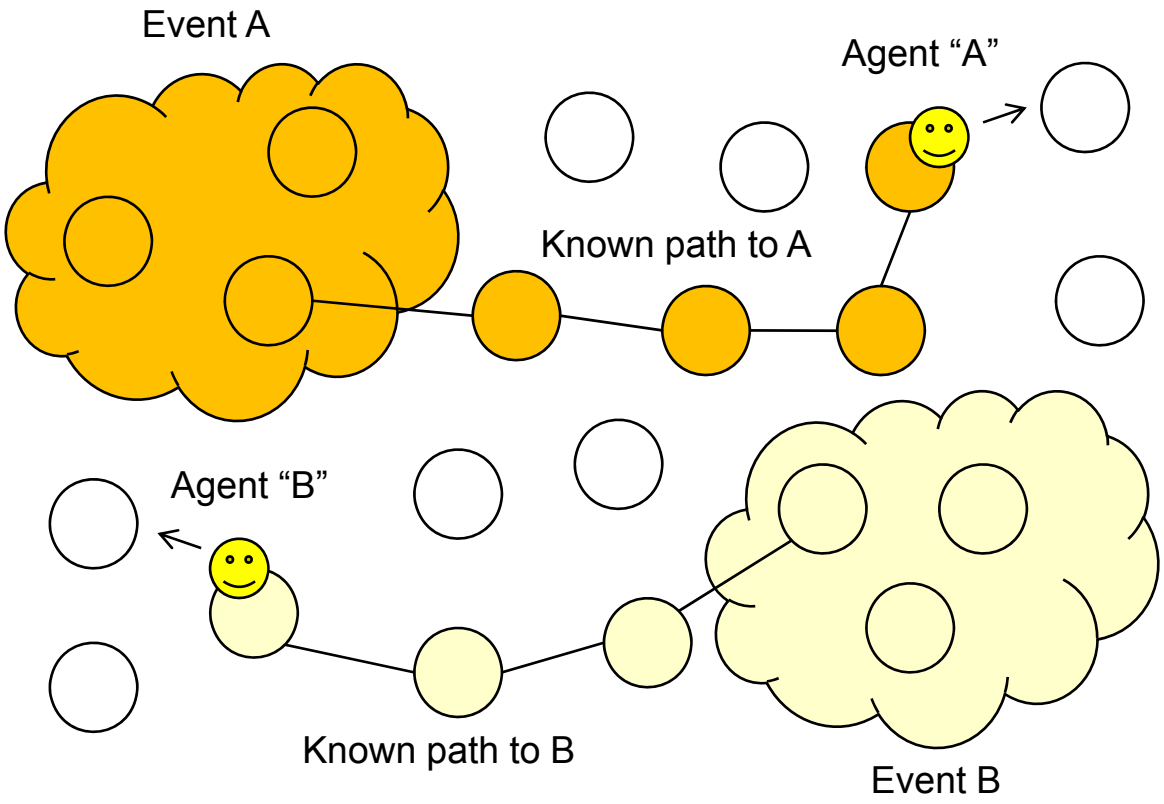
- Optimized gossiping
  - Each message (data value) to be sent is given a priority *I(msg)*
  - The message is processed according to the message-specific gossiping probability *G(I(msg))* and a node-specific weighting $W(S_i)$ for each node S_i
  - Message forwarding condition: $G(I(msg)) > W(S_i)$



Rumor Routing

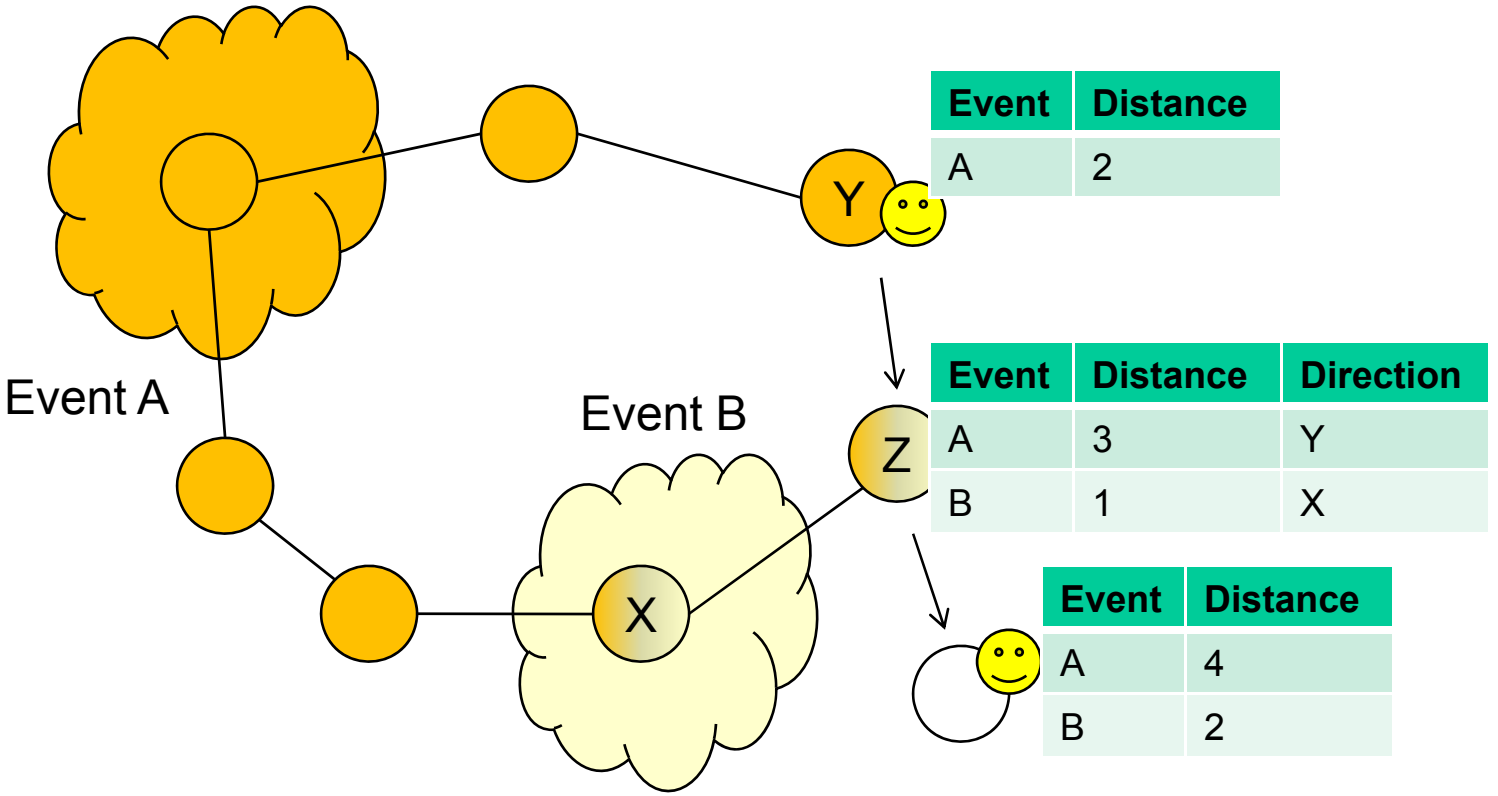


- Agent-based path creation algorithm
  - Agents, or “ants” are long-lived entities created at random by nodes
  - These are basically packets which are circulated in the network to establish shortest paths to events that they encounter

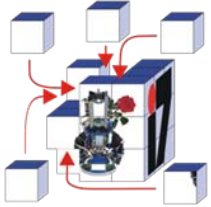


Rumor Routing

- Agent-based path creation algorithm
  - Can also perform path optimization at nodes that they visit
  - When an agent finds a node whose path to an event is longer than its own, it updates the node‘s routing table



Directed Diffusion

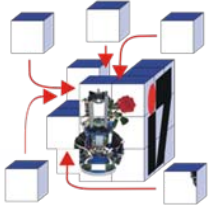


- Diffusion routing protocol
- Improves on data diffusion using interest gradients

- Basic behavior
  - Each sensor node **names its data** with one or more attributes
  - Other nodes **express their interest** depending on these attributes
  - The sink node has to periodically refresh its interest if it still requires data to be reported to it
  - Data is propagated along the reverse **path of the interest propagation**

- Optimizations
  - Nodes are allowed to cache or locally transform (aggregate) data
  - → increases the scalability of communication and reduces the number of required transmissions

Directed Diffusion



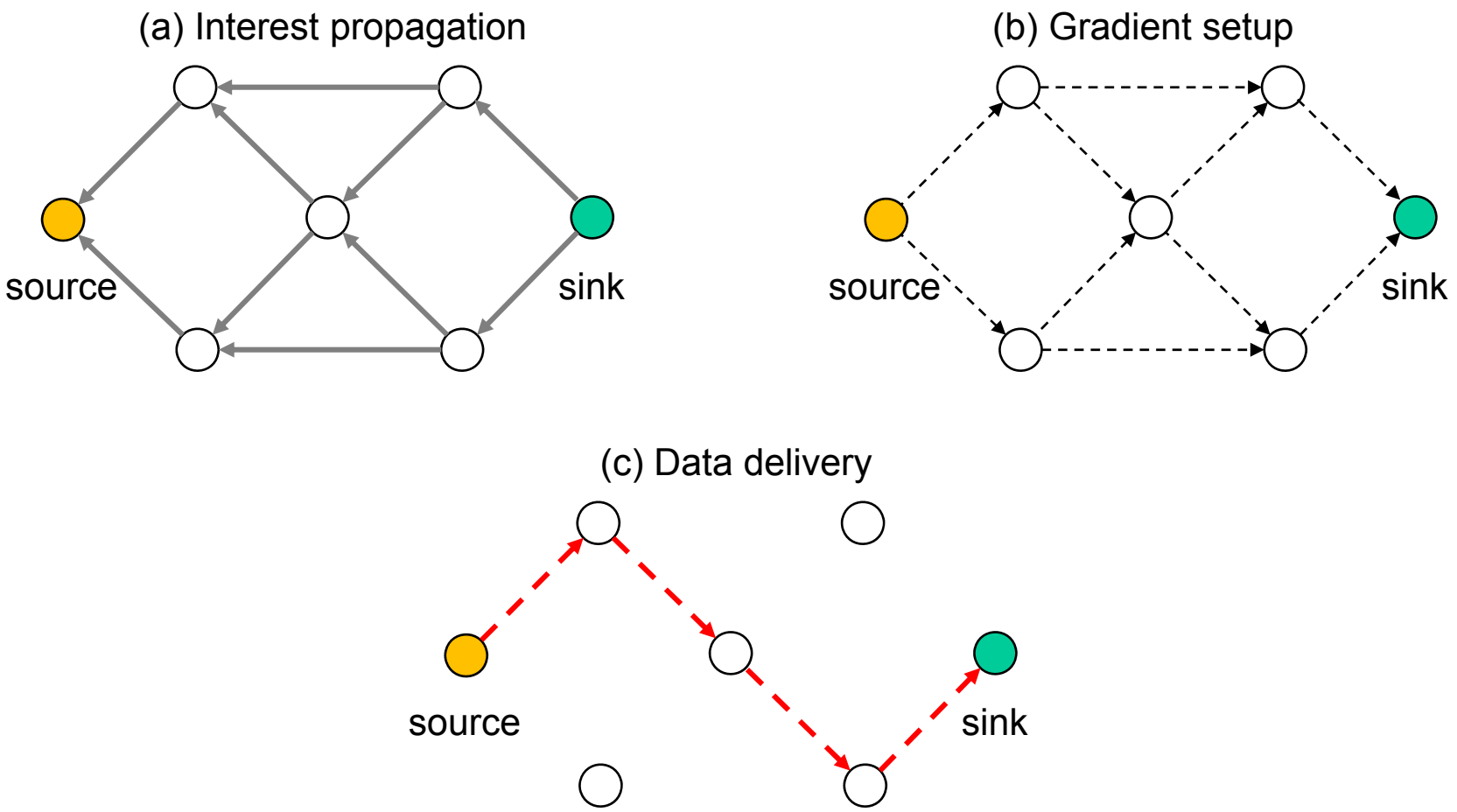
- Interest propagation

```
type = four-legged animal
interval = 1s
rect = [-100, 200, 200, 400]
timestamp = 01:20:40
expiresAt = 01:30:40
```

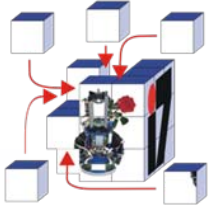
- Data transmission

```
type = four-legged animal   // type of animal seen
instance = elephant         // instance of this type
location = [125, 220]       // node location
intensity = 0.6             // signal amplitude measure
confidence = 0.85           // confidence in the match
timestamp = 01:20:40        // event generation time
```

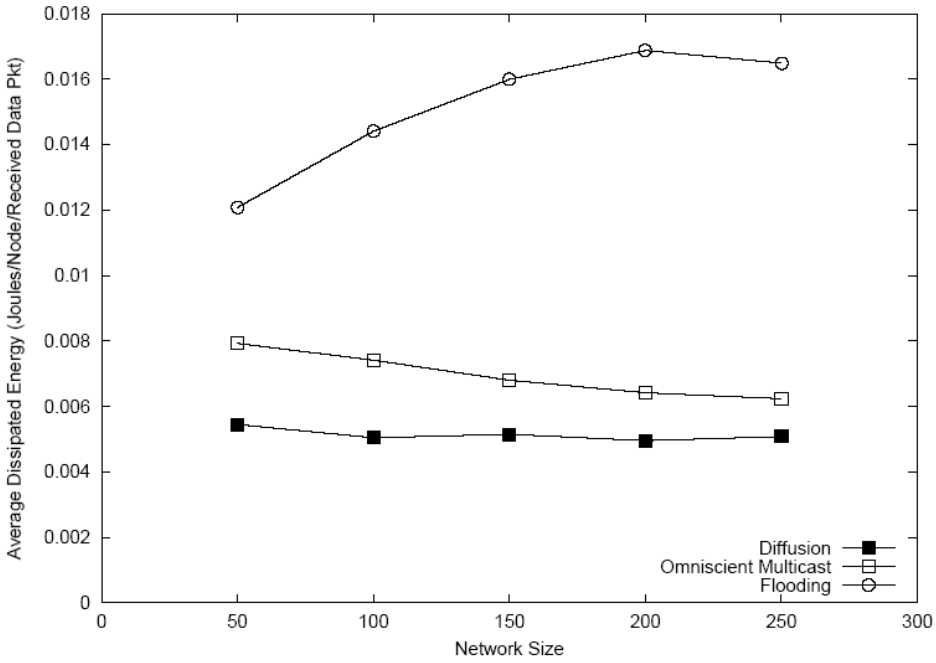
Directed Diffusion



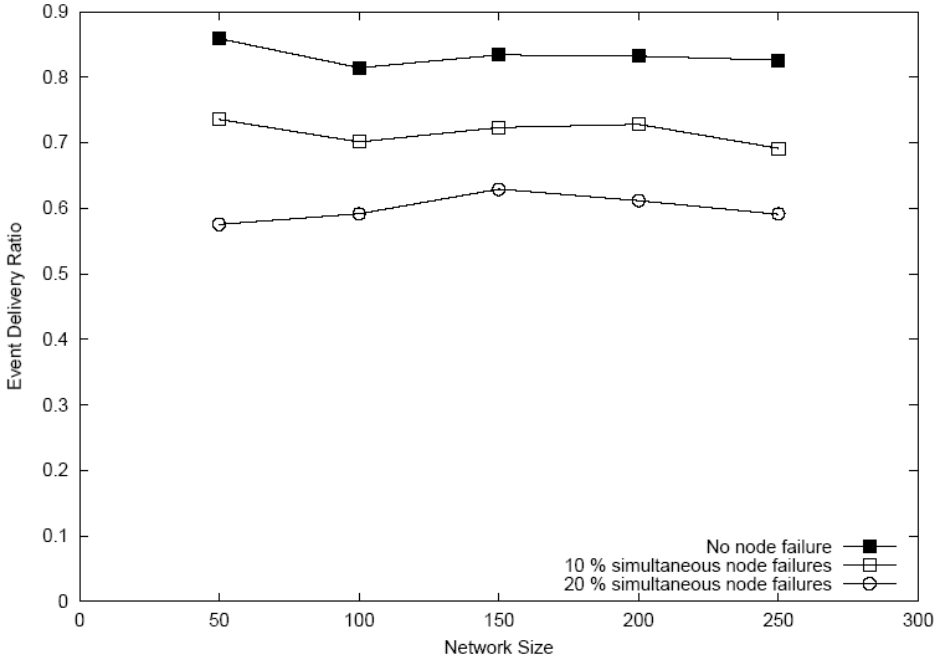
Directed Diffusion – Performance Aspects



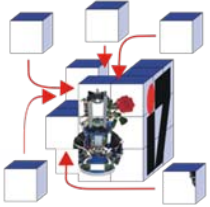
Average Dissipated Energy



Node Failures – Event Delivery Ratio

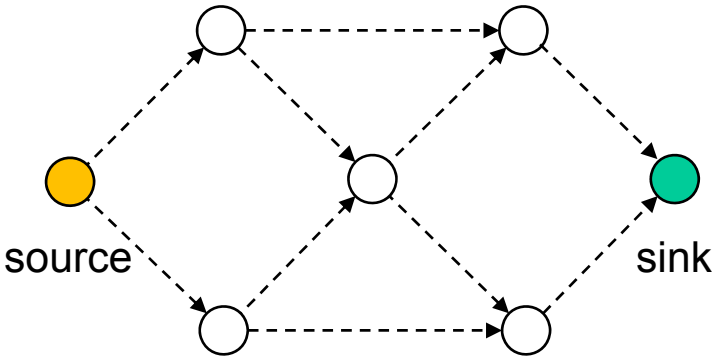


Improving directed diffusion

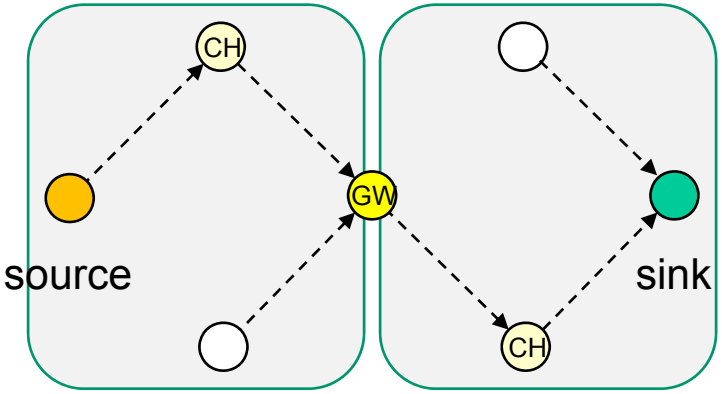


- Node mobility
  - Aggressive diffusion – improved ***timeout*** handling
  - Handoff and proxies – similar to handoff in mobile communication
  - Anticipatory diffusion – setting up paths ***before*** node movements
- Energy efficiency
  - Based on passive clustering techniques

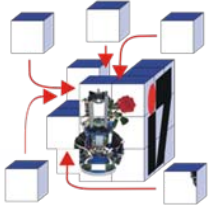
Gradient setup w/o clustering



Gradient setup w/ clustering



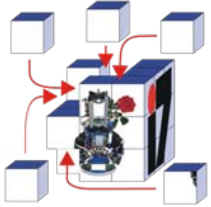
Data aggregation – Motivation



- Energy constraints and network congestion
  - Data transmission in sensor networks is much more energy expensive compared to local computation efforts
  - The reduced number of transmitted messages towards the base station helps reducing network congestion (especially near the base station)

- Redundancy and correlation
  - A certain degree of overlap and redundancy is created as measured sensor data is often generated by nearby nodes
  - Measured data can be expected to be highly correlated allowing further improvements of the information quality by using data fusion approaches (possibly exploiting further available meta information)

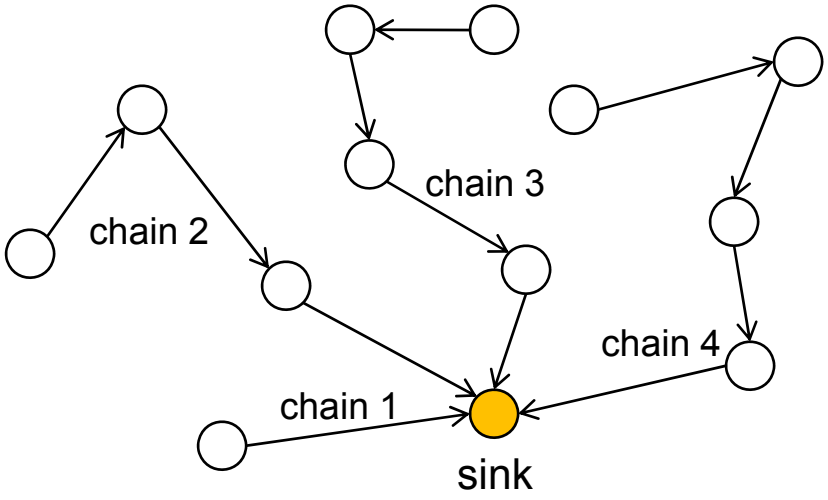
Data aggregation – Terminology



- ***Data aggregation*** – Data aggregation is the process of combining multiple information particles (in our scenario, multiple sensor messages) into a single information that is representing all the original messages. Examples of aggregation methods are statistical operations like the mean or the median.

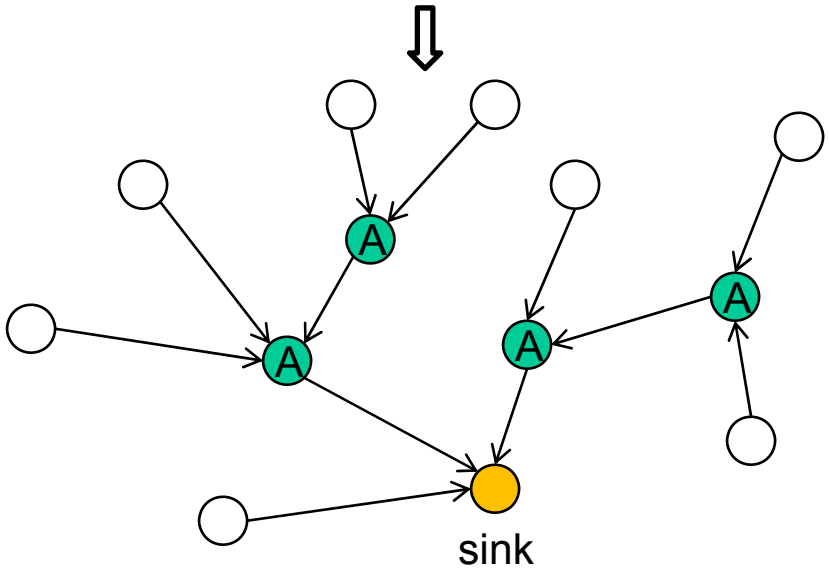
- ***Data fusion*** – Data fusion is the process of annotating received information particles with meta information. Thus, data from different is combined to produce higher quality information, e.g. by adding a timestamp or location information to received sensor readings.

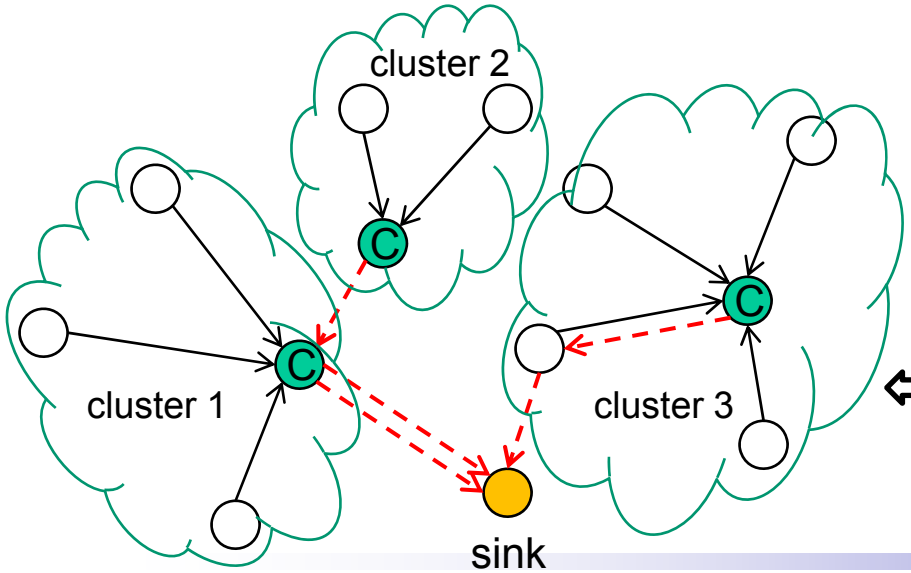
Aggregation techniques



⇦ Chain-based aggregation

Tree-based aggregation

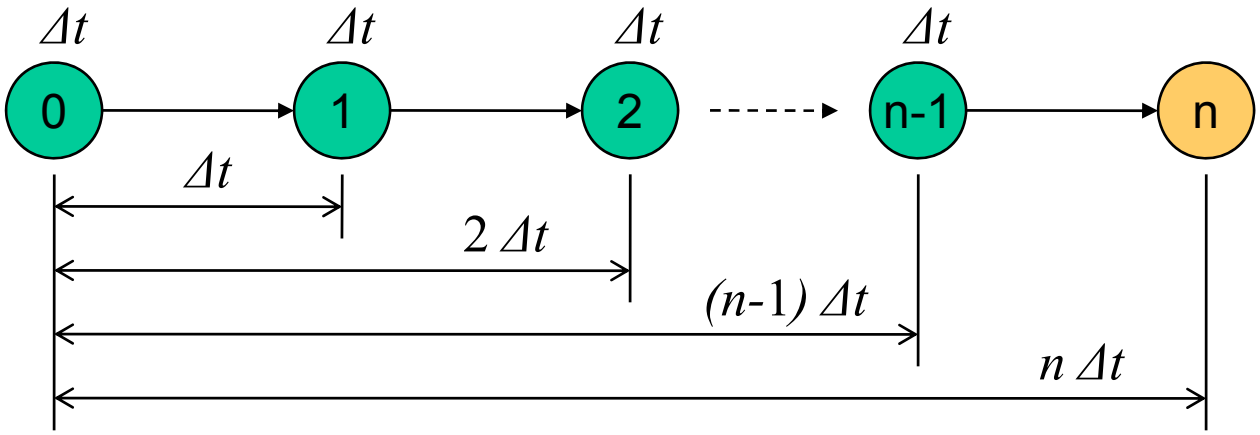




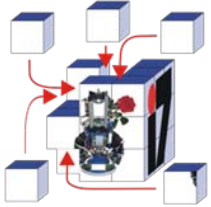
⇦ Grid-based aggregation

Limitations

- Optimization latency vs. efficiency
  - High aggregation ratios require long aggregation delays Δt
  - Large Δt will obviously lead to increased message transmission delays

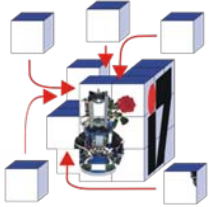


Summary (what do I need to know)



- ***Data-centric communication***
  - Main ideas and principles
- ***Data dissemination techniques***
  - Principles and limitations of
    - Flooding / Gossiping / WPDD
    - Rumor routing
    - Directed Diffusion
- ***Data aggregation and data fusion***
  - Differentiation aggregation vs. fusion
  - Advantages and limitations

References



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