Retis
Real-Time Systems Laboratory

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Reconfigurability issues in MANETs

Mobile Wireless Networks

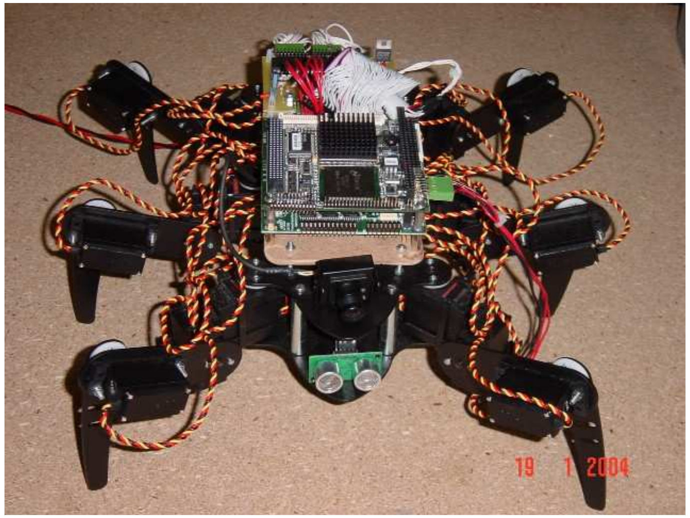
Wireless ad hoc networks of **mobile** nodes (MANETs) equipped with:

- sensors
- actuators
- processing units
- communication devices

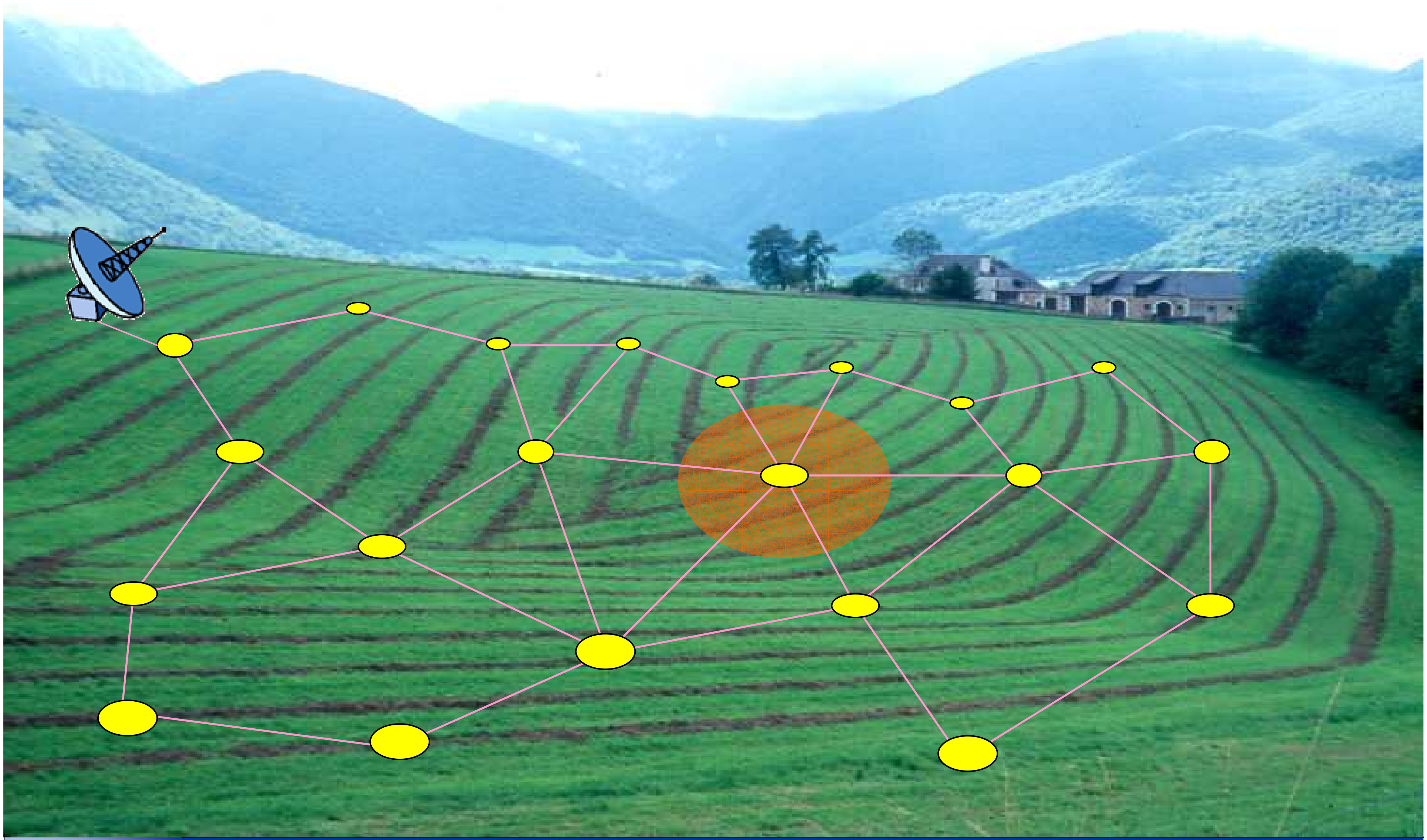
Actuators

- for driving wheels or legs to move the node
- for sensor orientation
- grippers
- small manipulators

Examples of nodes



Mobility allows reconfiguration



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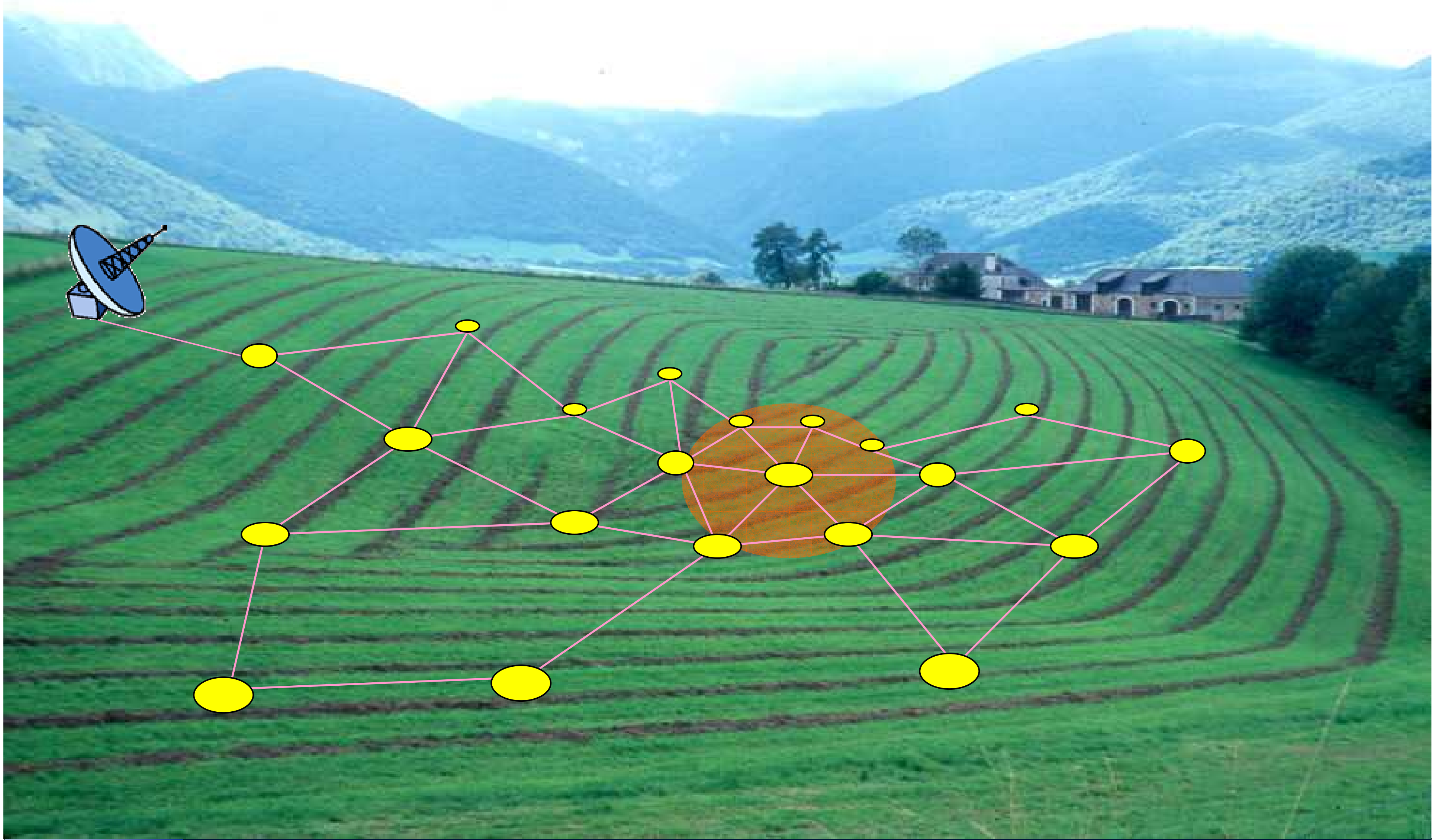


New issues by mobility

- **Energy-aware policies at different levels**
- Self-localization
- Reachability and dynamic routing
- Message scheduling
- Dynamic formation (nodes may join and leave)
- Topology management

Energy requirements

Autonomous robots are operated by batteries, hence they must apply **energy-aware strategies** to prolong their **lifetime** as much as possible.

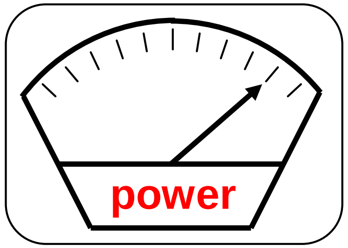
Energy can be saved at different levels:

- Hardware: using low power components
- Devices: disabling specific functions and devices
- Kernel: voltage scheduling
- Application: changing operating modes
- Communic.: selecting transmission ranges and instants
- Mobility: maintaining energy-aware configurations

Energy vs. performance

Real-Time constraints

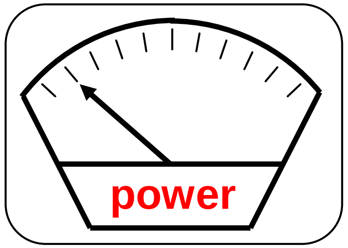
High speed



High power

Long Lifetime

Low energy



Low power

Power consumption

- In CMOS circuits, the power consumption increases with the supply voltage:

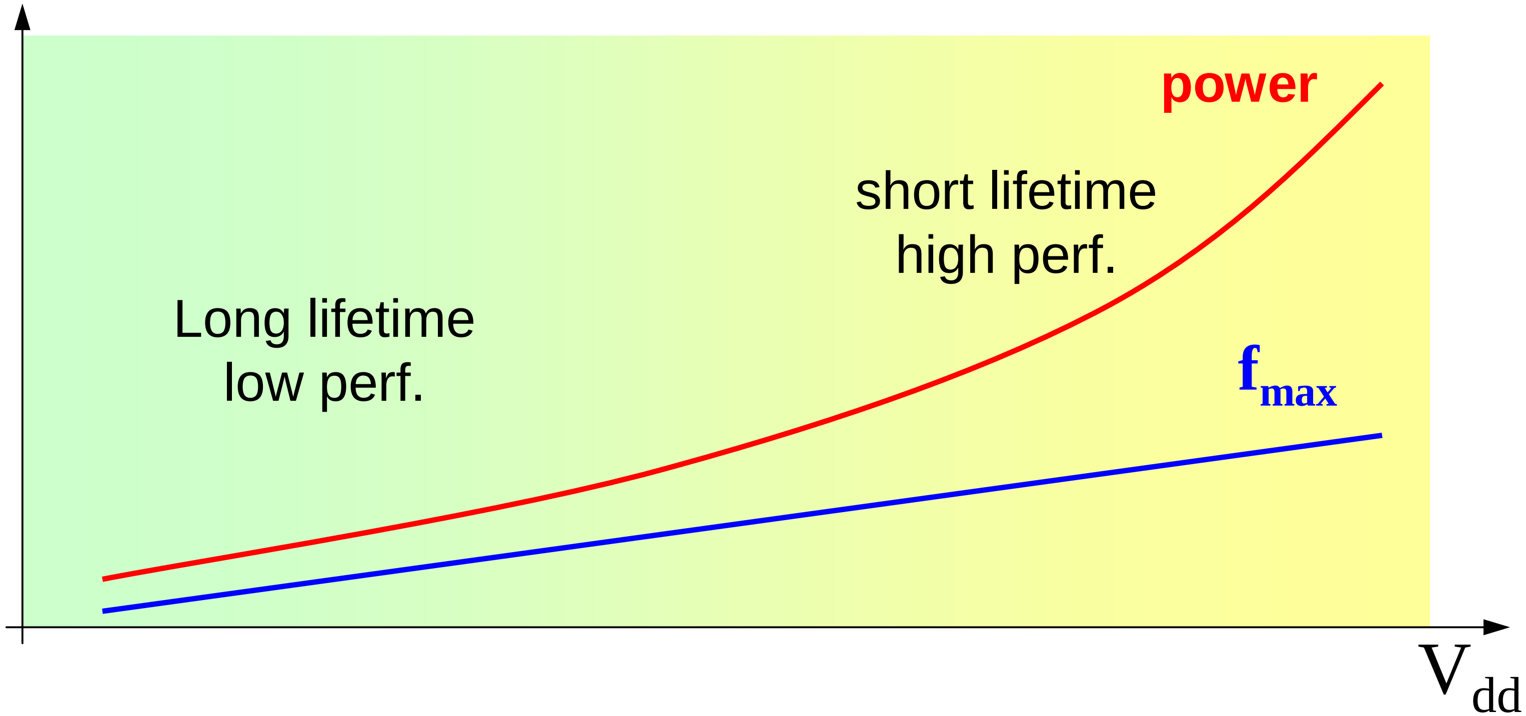
$$P \propto C_{load} \cdot f_c \cdot V_{dd}^2$$

- Moreover, the supply voltage also affects the circuit delay (hence the max clock frequency):

$$f \propto \frac{V_{dd}}{(V_{dd} - V_t)^2}$$

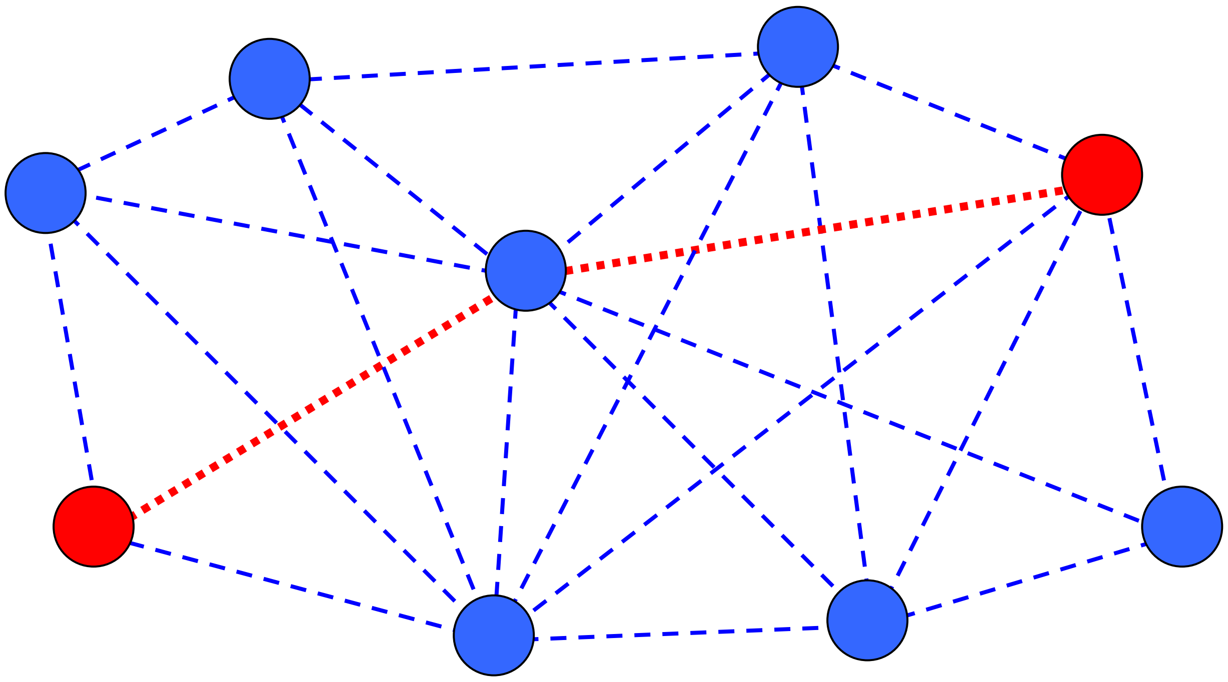
Dynamic Voltage Scaling (DVS)

Energy can be controlled by the speed and the voltage at which the processor operates:



Transmission power control

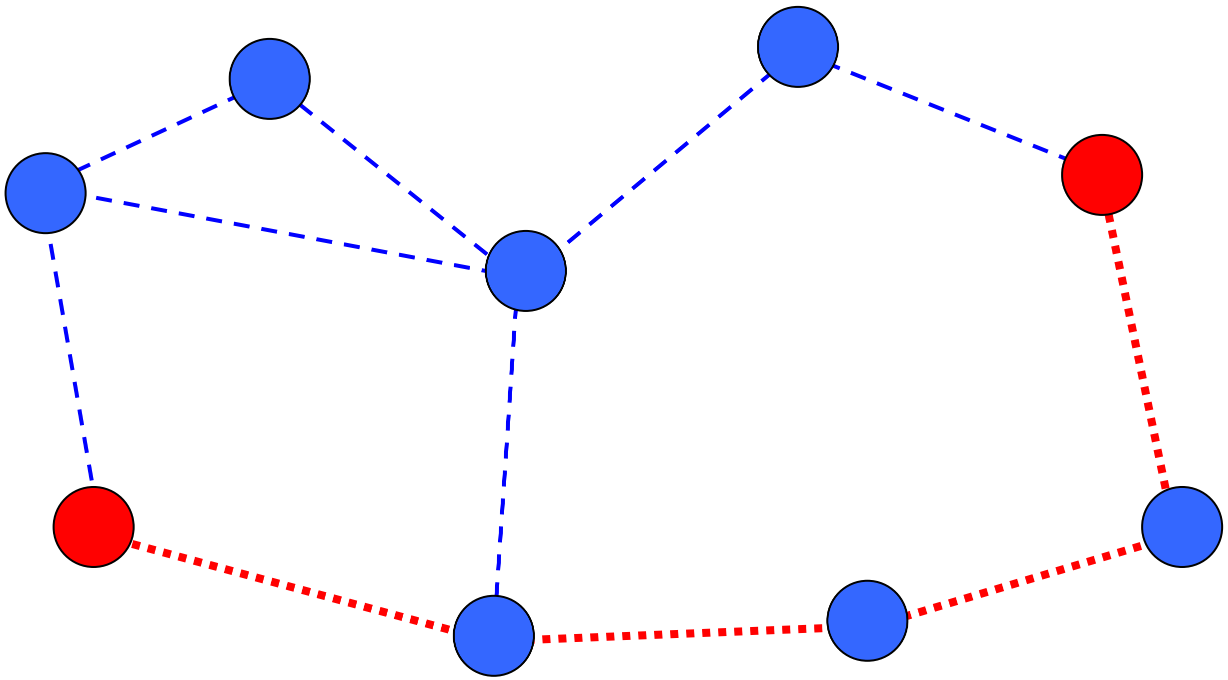
Using longer transmission ranges allows to reach far nodes in fewer hops



... but consumes more power

Transmission power control

Using shorter transmission ranges consumes less power



... but requires more hops

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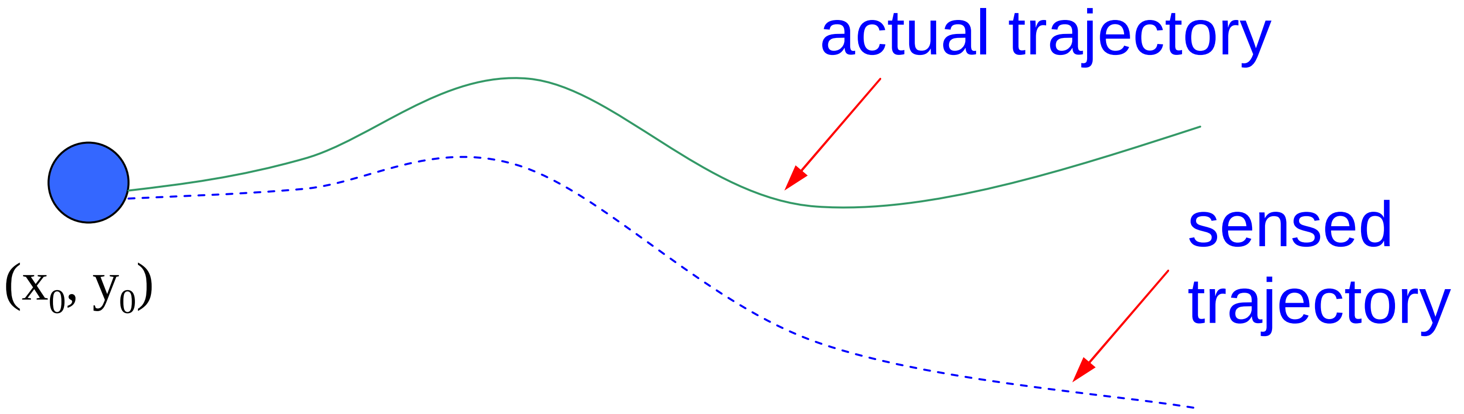
Self localization

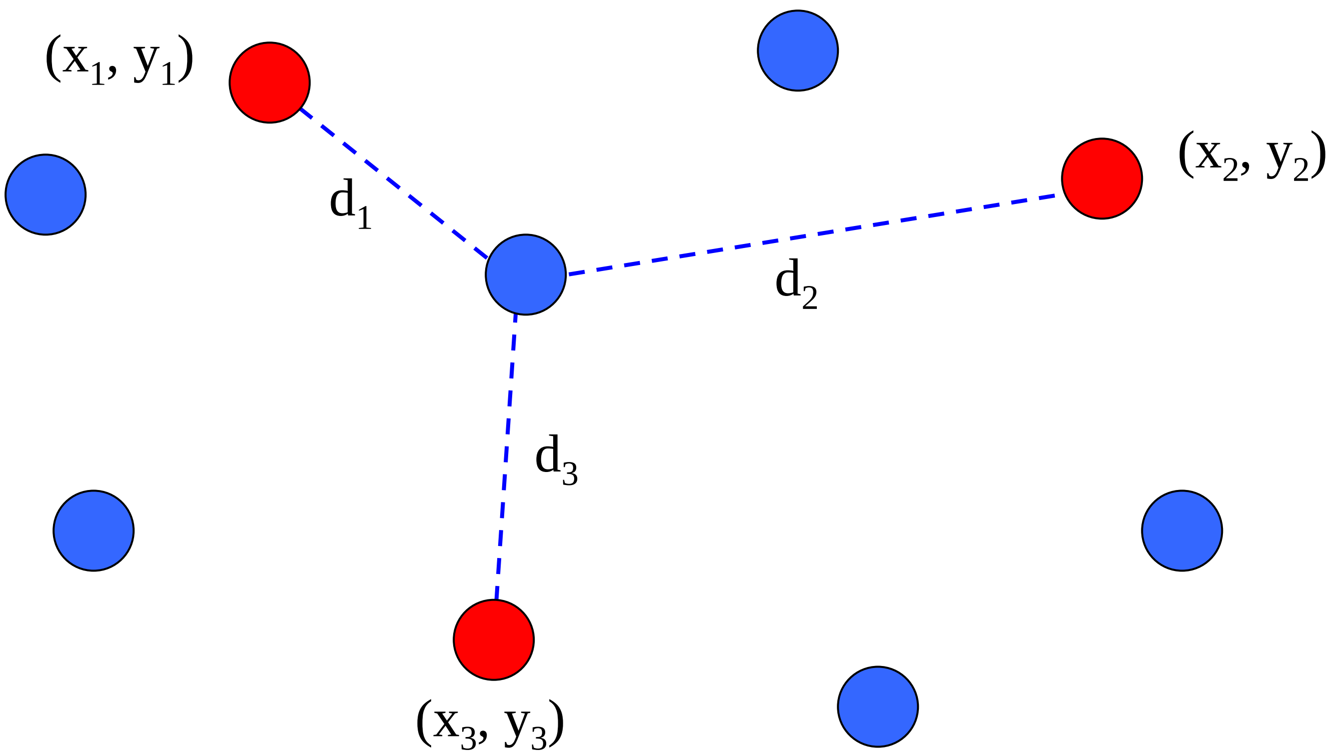
When nodes move they need to keep track of their position. Odometers (i.e.) are not precise and prone to drift:



Triangulation can be used when the position of other nodes is known.

Triangulation

If the position of 3 nodes is known, then a node position can be computed through the distances (d_1, d_2, d_3) from those nodes:



Measuring the distances

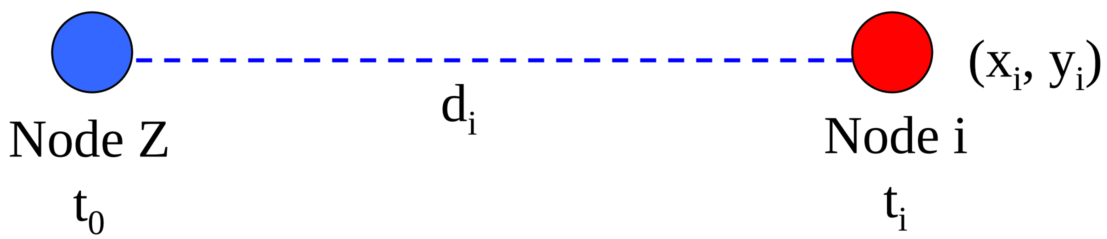
Distances can be measured by acoustic methods:

⇒ At time t_0, node Z emits a sound beacon and a radio signal, simultaneously

⇒ The radio signal allows nodes to keep track of t_0

⇒ Each node i takes the time t_i at which the sound is detected

⇒ The distance d_i is computed as $d_i = (t_i - t_0) V_s$, where V_s is the speed of sound



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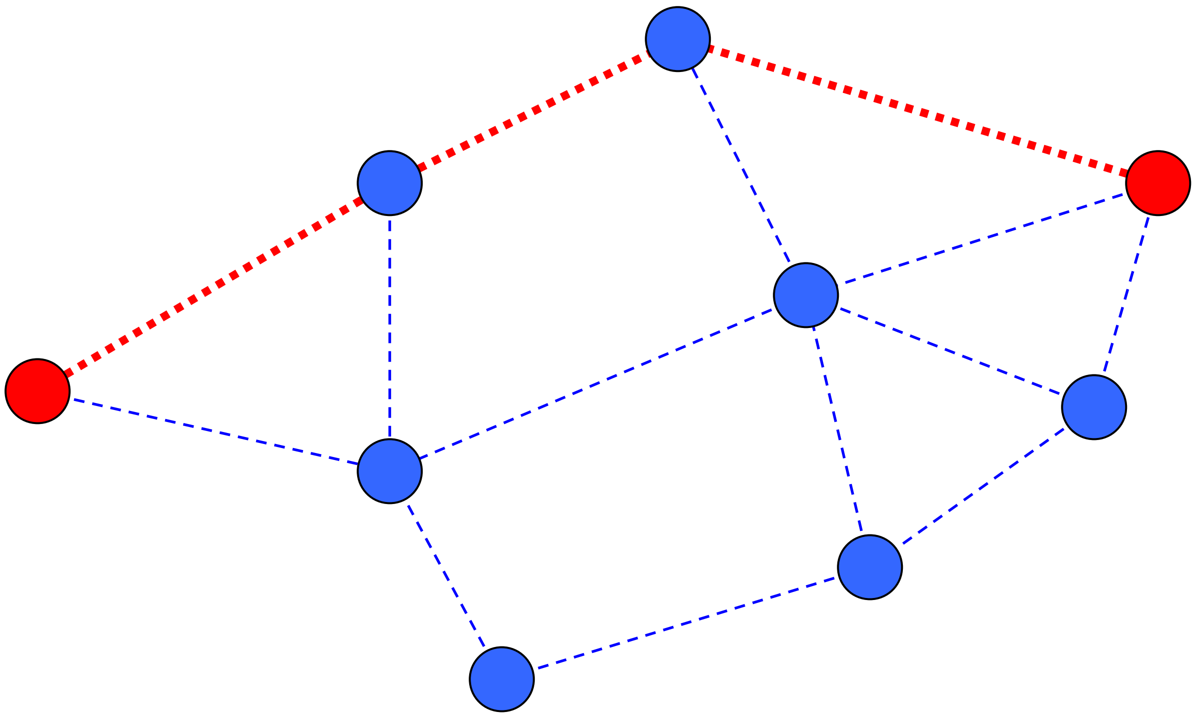
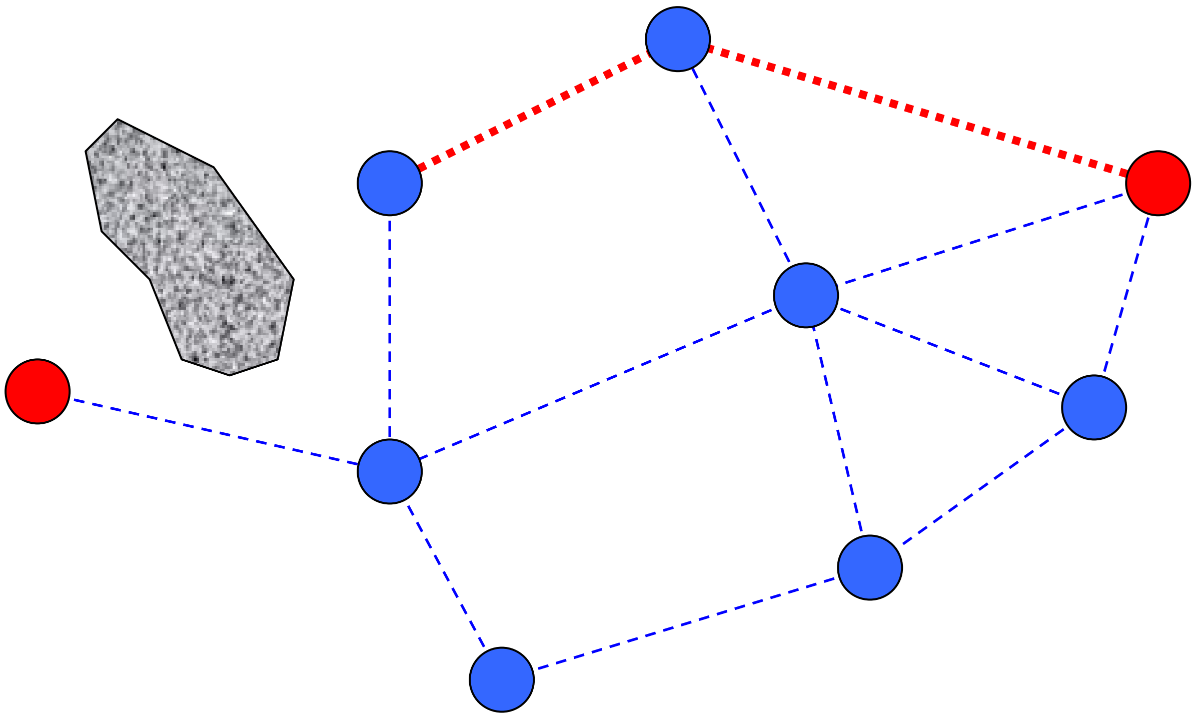
Reachability

Connection can be lost due to many reasons



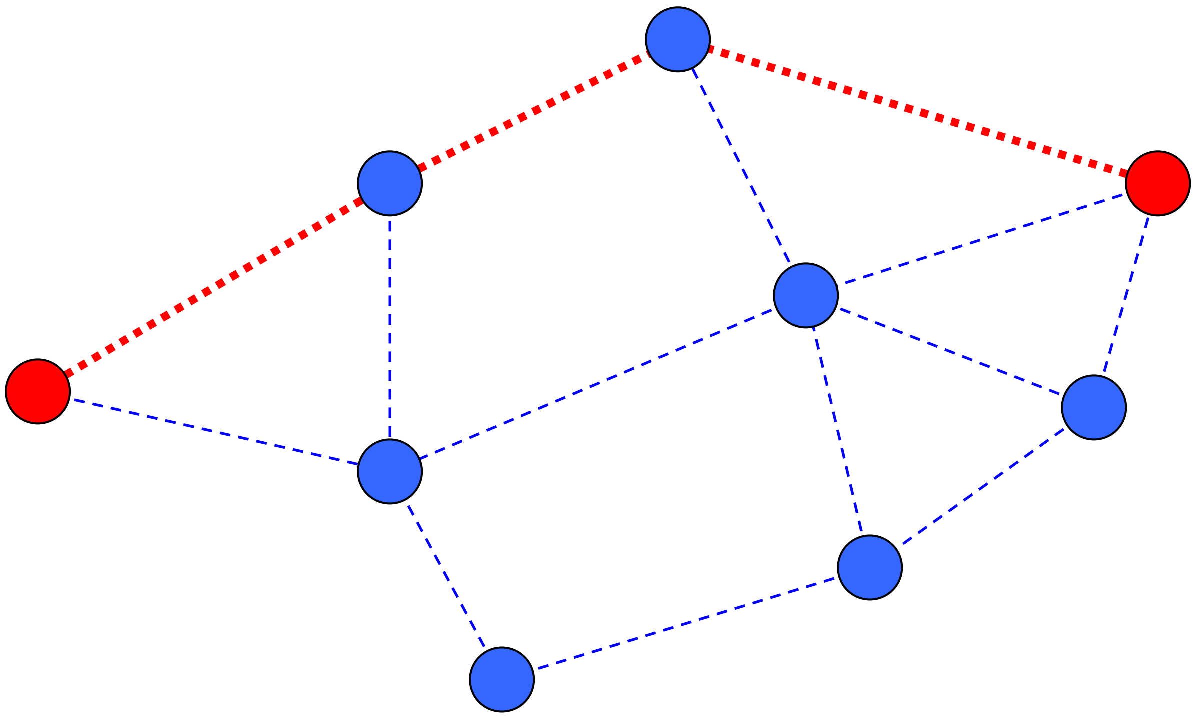
Reachability

Connection can be lost due to **obstacles**:



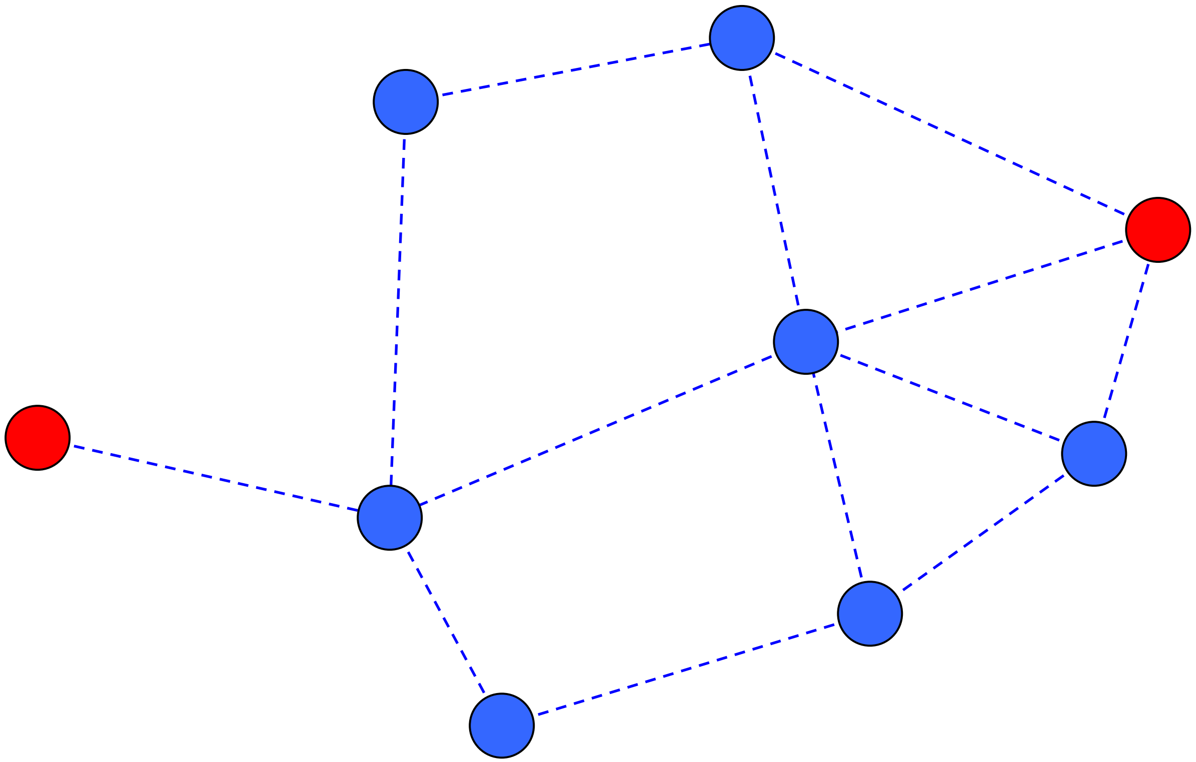
Reachability

… or to **long distance**:



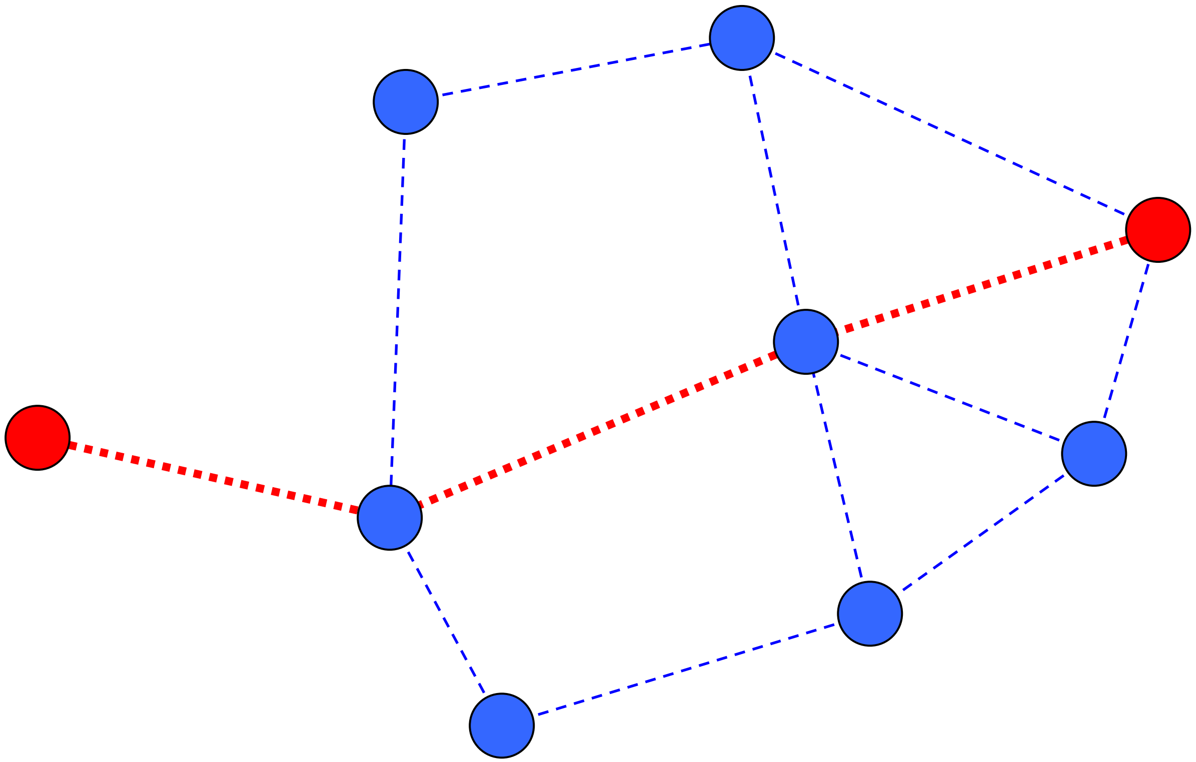
Reachability

… or to **long distance**:



Reachability

⇒ An alternative path has to be found.



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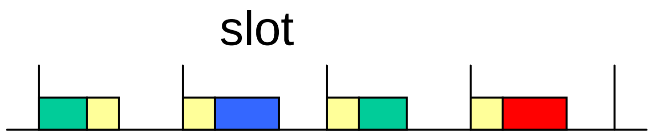
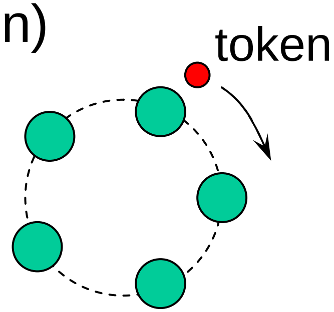
Message scheduling

Predictability in communication requires absence of conflicts in accessing the channel.

Possible solutions:



1. **TDMA:** very predictable, but
   - ⇒ requires precise clock synch.
   - ⇒ unflexible for dynamic changes (static, table-driven)



2. **Token passing:** no synch. required, but
   - ⇒ Unsuitable for stringent RT requirements
   - ⇒ Need to handle token loss
3. **Implicit schedule:** flexible to changes
   - ⇒ Requires consensus at every change
   - ⇒ Not very scalable, requires hierarchical approaches

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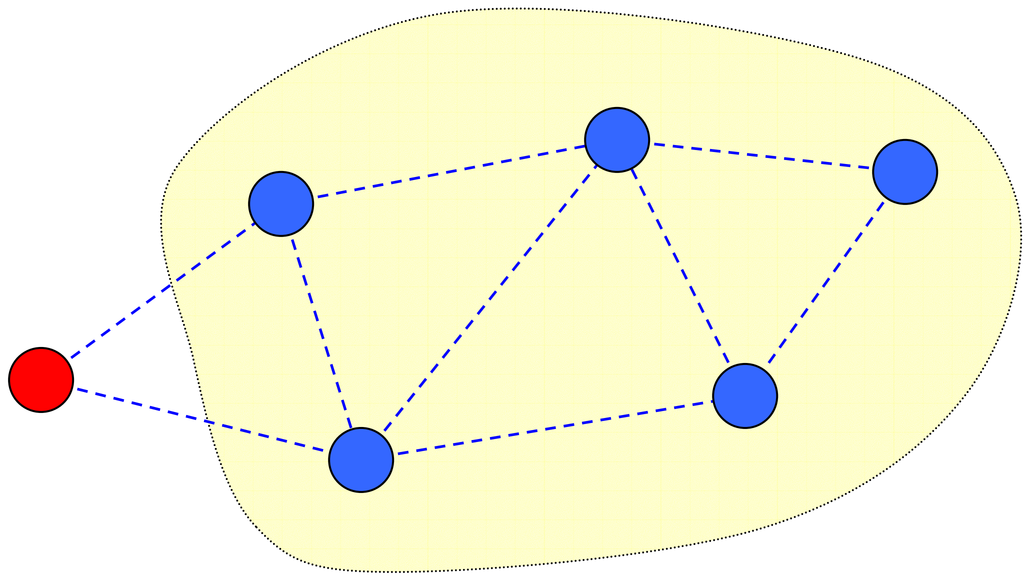
Dynamic scheduling

Needed for:

- Admitting an external node to join the team
- Excluding a node (crash, low battery moving policy, …) and free the unused bandwidth
- Dynamically updating bandwidth requirements (changing rates or messages)
- Changing transmission frequency (due to high noise or interference) without resetting the communication

Dynamic team formation

Joining a team

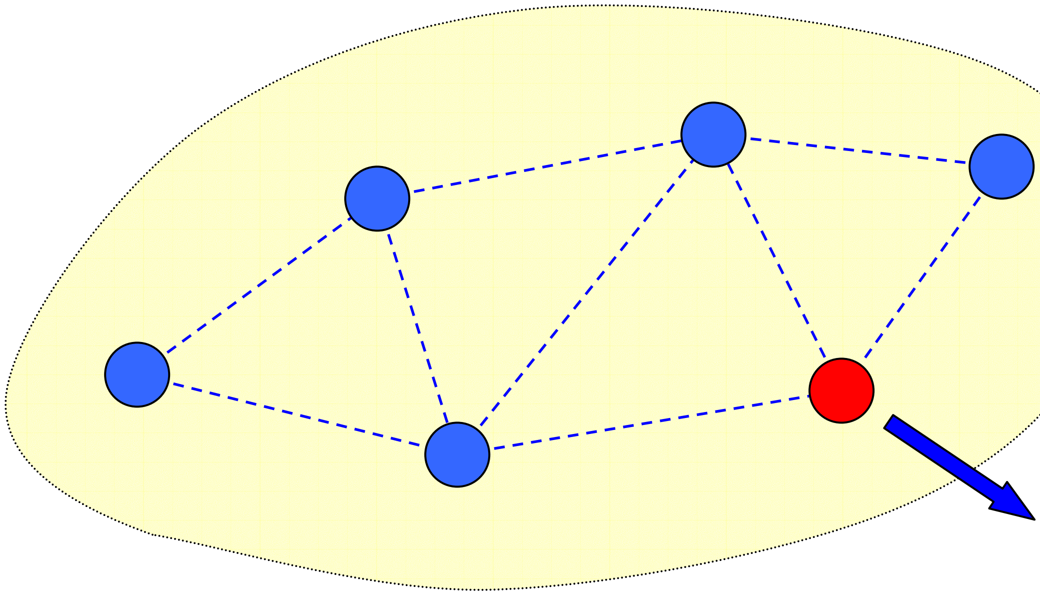


⇒ Everybody must agree to accept the new node

⇒ If a cooperative implicit schedule is used, all nodes must update the schedule simultaneously

Dynamic team formation

Leaving a team

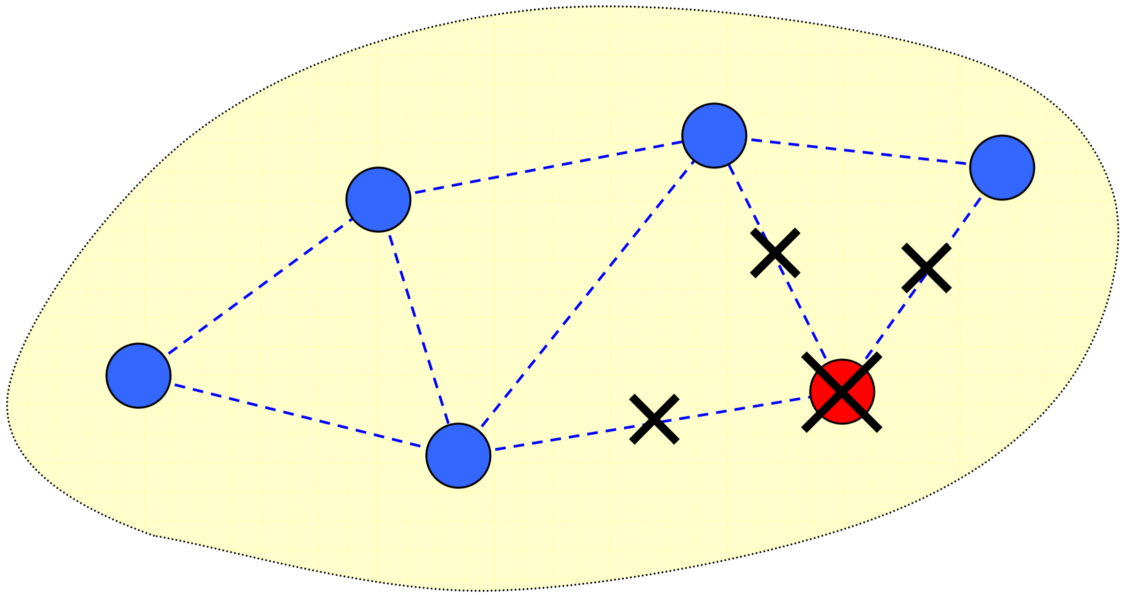


⇒ Everybody must be notified about the leaving node

⇒ If a cooperative implicit schedule is used, all nodes must update the schedule simultaneously

Dynamic team formation

Excluding a node from team



⇒ Node exclusion can be triggered after a node crash

⇒ Everybody must be notified about the node exclusion

Distributed consensus

Very recent and huge research has been started in the field of distributed consensus problems for multi-agents

Sample applications are

- formation control of mobile robots
- swarm-based computing
- task assignement
- air traffic control
- payload transport
- cooperative control of unmanned vehicles
- automated highway systems
- control of communication networks
- design of sensor networks
- flocking of social insects

Distributed consensus

The i-th agent has its own state x_i.

$$\dot{x}_i(t) = u_i(t)$$ where u_i is the local protocol

We want $\forall i, j : \left| x_i(t) - x_j(t) \right| \to 0$ for $t \to \infty$

The analisys is based on

- algebraic graph theory
- matrix theory
- control theory (convergence, stability, etc.)

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Why managing topology?

- strategy for moving the team units
- better estimation of the agreement time
- detecting silent nodes
- reducing tx power for the same connectivity
- better bandwidth usage (simultaneous tx by distant nodes)