Coordination in sensor, actuator and robot networks

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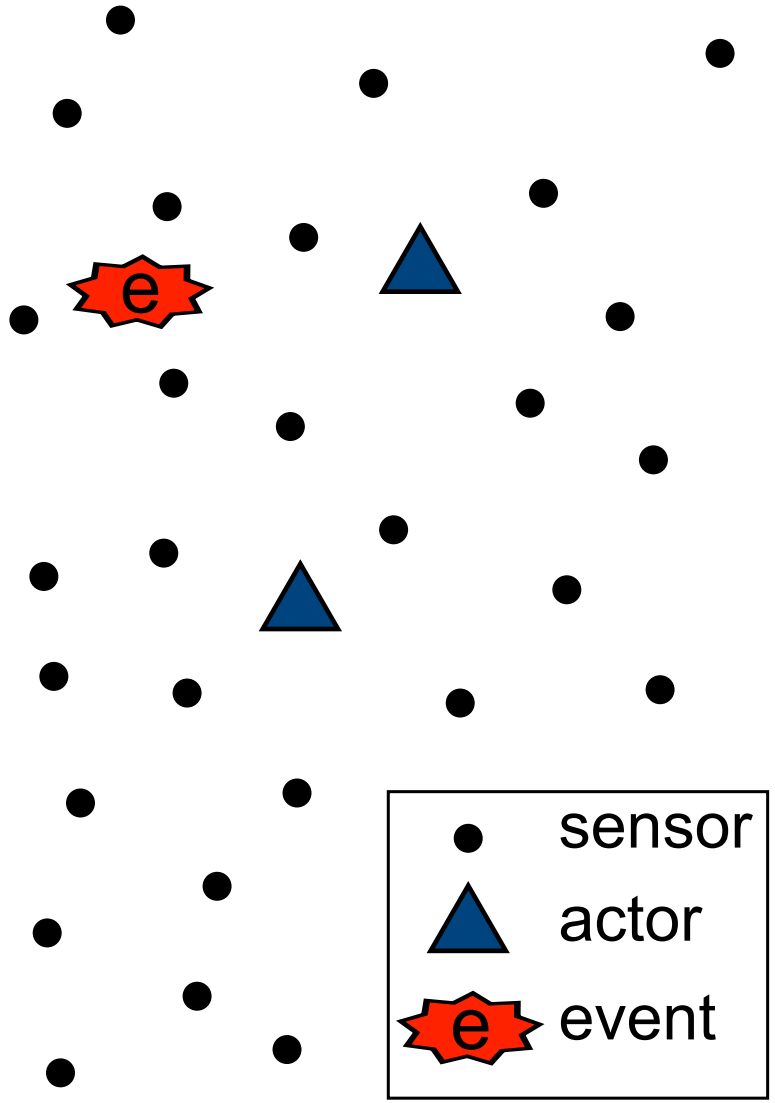
Overview

1. Introduction: Model and Problem
2. Sensor-Sensor Coordination
3. Sensor-Actor Coordination
   - DEPR
4. Actor-Actor Coordination
   - Auction Aggregation Protocols

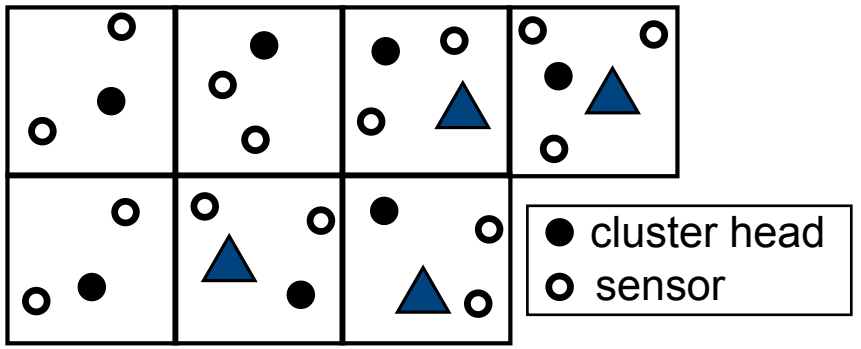
Overview

Model

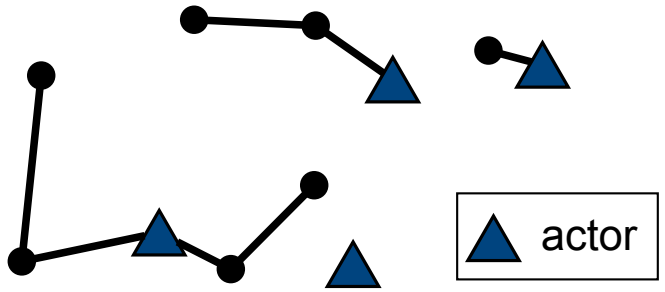
- sensor: low-cost, low-power, detect physical condition/event and transmit to actors
- actor/robot: resource-rich, collect sensor data and act accordingly
- event: physical phenomenon, requires action by actuators



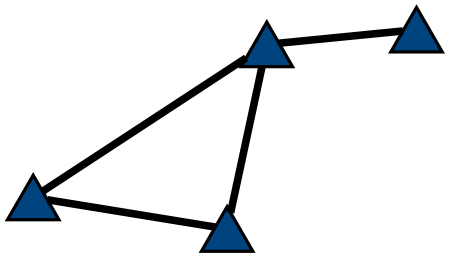
Level 1:
sensor-sensor



Level 2:
sensor-actor



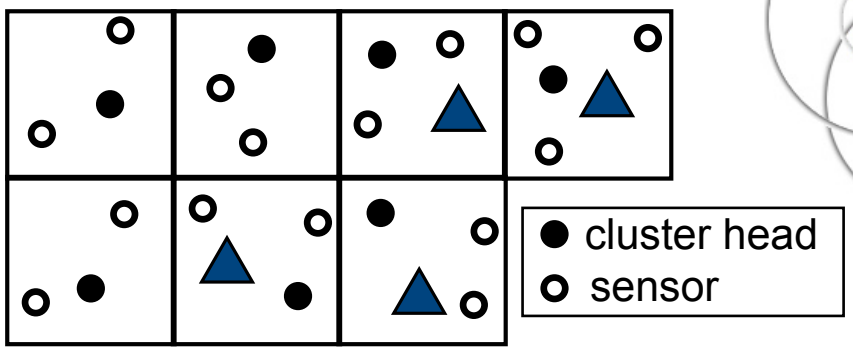
Level3:
actor-actor



Overview

Sensor-Sensor Coordination

- sensor-sensor coordination problem:
  sense in efficient way
  $\Rightarrow$ min. energy consumption, max. lifetime and coverage
- techniques: area coverage, sleeping in turns, clustering, grid-partitioning
- as seen in lecture!



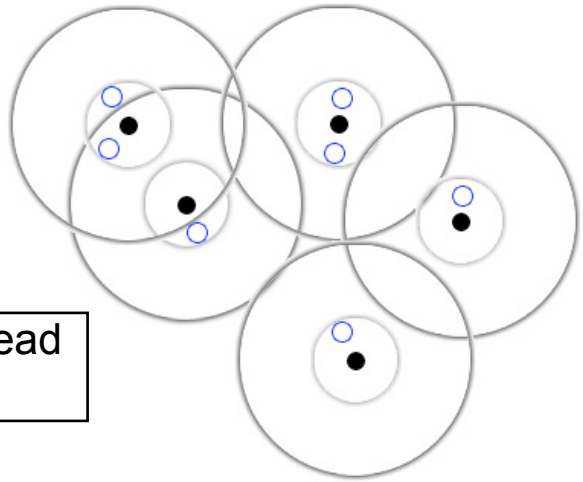


figure: I.Stojmenovic

Overview

Sensor-Actor Coordination

- **sensor-actor coordination problem**:
  establish efficient data paths from sensors to actors
  $\Rightarrow$ min. energy consumption, min. delay

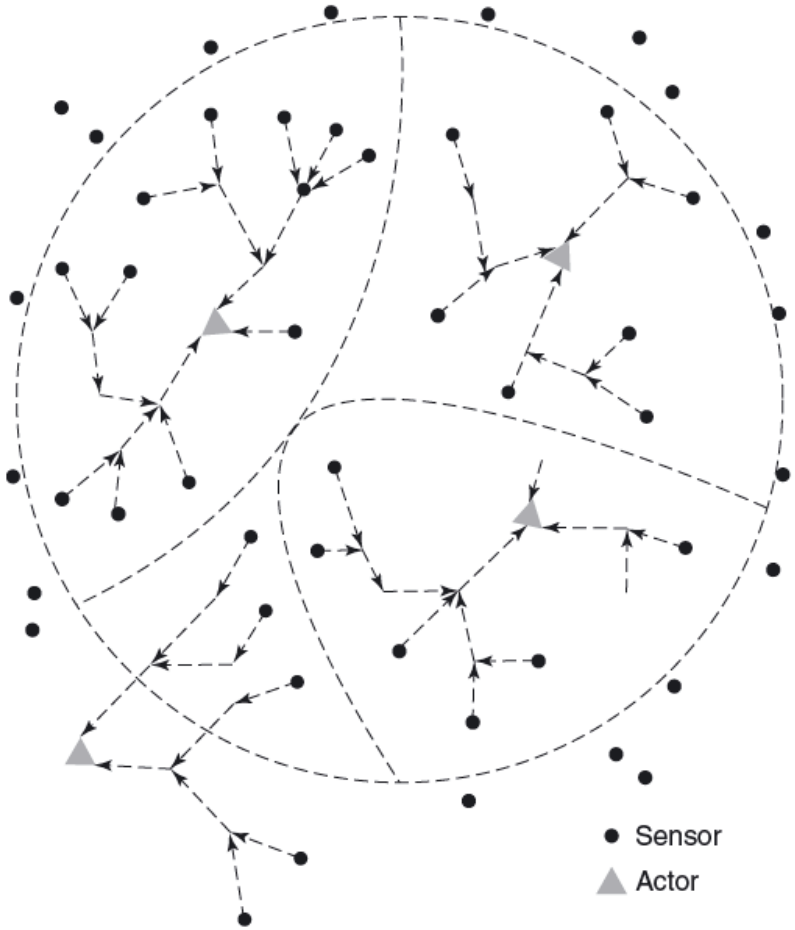


figure taken from [1]

Reliability

Definition

Sensor data packets received by an actor within a given latency bound are **reliable**.
The event **reliability** *is the ratio of reliable data packets over all packets in the decision interval.*
The event **reliablility threshold** *is the minimum event reliability required.*

Sensor-Actor Coordination Problem as ILP Problem

- **integer linear programming**: optimal solution for minimum energy da-trees such that reliability constraint is met

$\mathbf{P}^{Com}_{Min}$: **Event-Driven Partitioning with Multiple Actors**

$$
\begin{aligned}
&Given: && e_{ij},\ c_{ij},\ p_{ij},\ v,\ \tilde{d},\ B,\ r_{th} \\
&Find: && x^k_{ij},\ f^{k,s}_{ij},\ l^{k,s},\ b^{k,s},\ r \\
&Minimize: && C^{TOT} = \sum_{k\in\mathcal{S}^A} \sum_{(i,j)\in\mathcal{S}^E} x^k_{ij} \cdot c_{ij} + \gamma \cdot Q \qquad (1) \\
&Subject\ to: && \\
& && \sum_{j\in\mathcal{S}^V} (f^{k,s}_{sj} - f^{k,s}_{js}) = l^{k,s}, \forall s \in \mathcal{S}^S, \forall k \in \mathcal{S}^A, \qquad (2)
\end{aligned}
$$

⋮ you do not need to know this!

- complete topology information needed, communication overhead, NP complete
  ⇒ use distributed algorithm instead

DEPR: Distributed Event-driven Partitioning and Routing

- approximate solution
- local information
- greedy next-hop selection
- feedback from actors
- sensors probabilistically increase or decrease transmission power based on feedback
- synchronized network

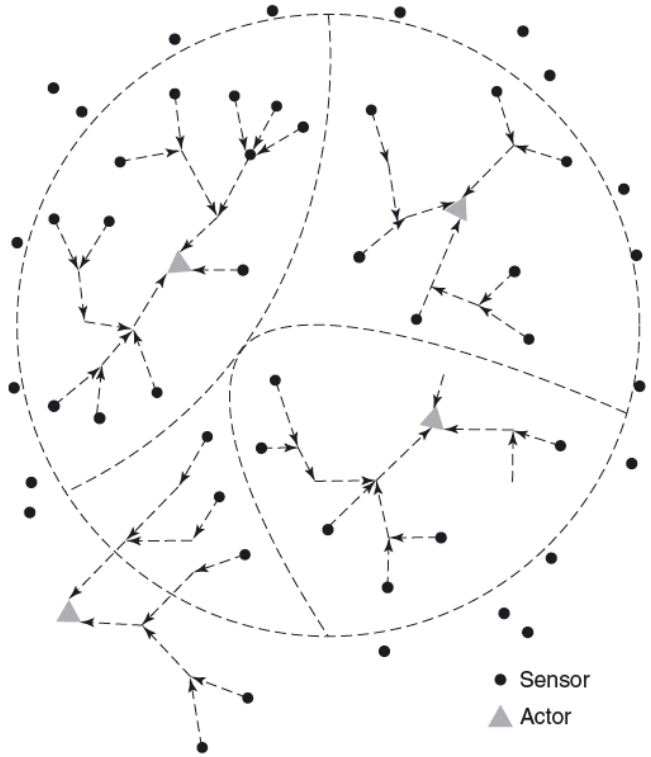
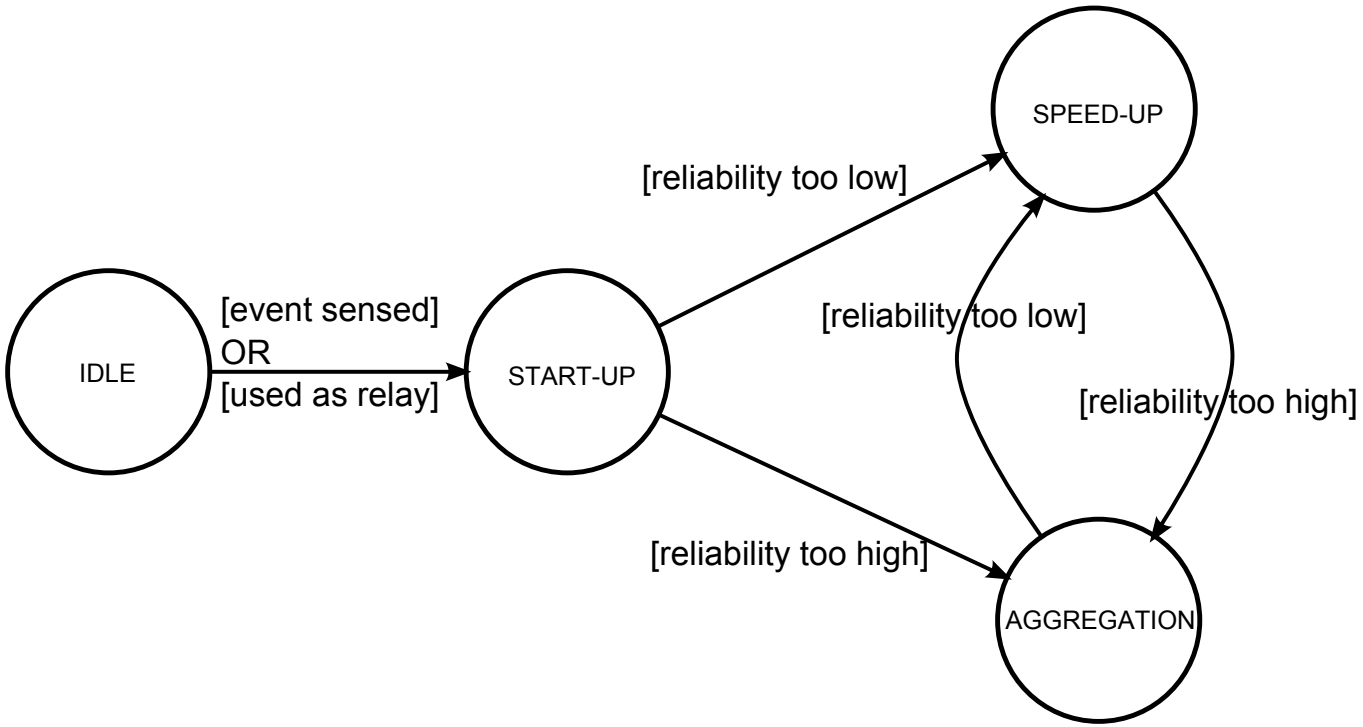


figure taken from [1]

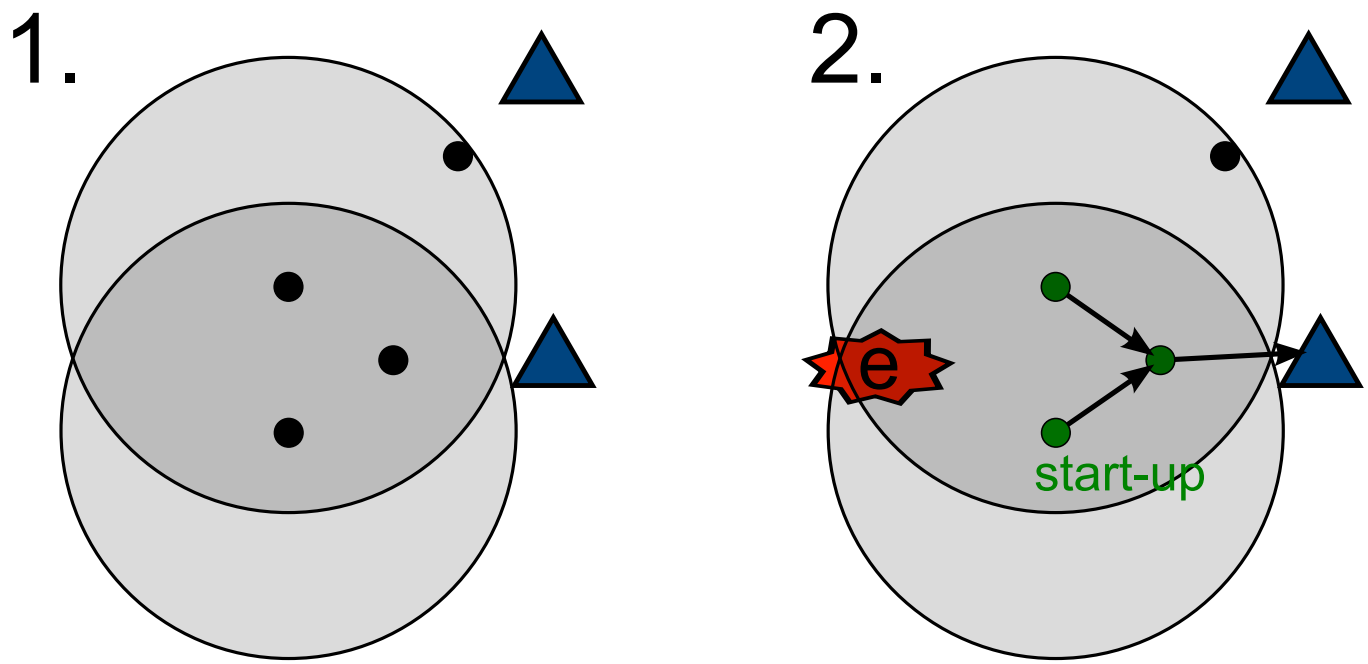
State transitions of sensors in DEPR



- actors calculate collective(!) reliability from all sensors in their tree: reliability $= \frac{\text{reliable packets}}{\text{all packets}}$
- sensors probabilistically increase or decrease transmission power based on feedback from actors

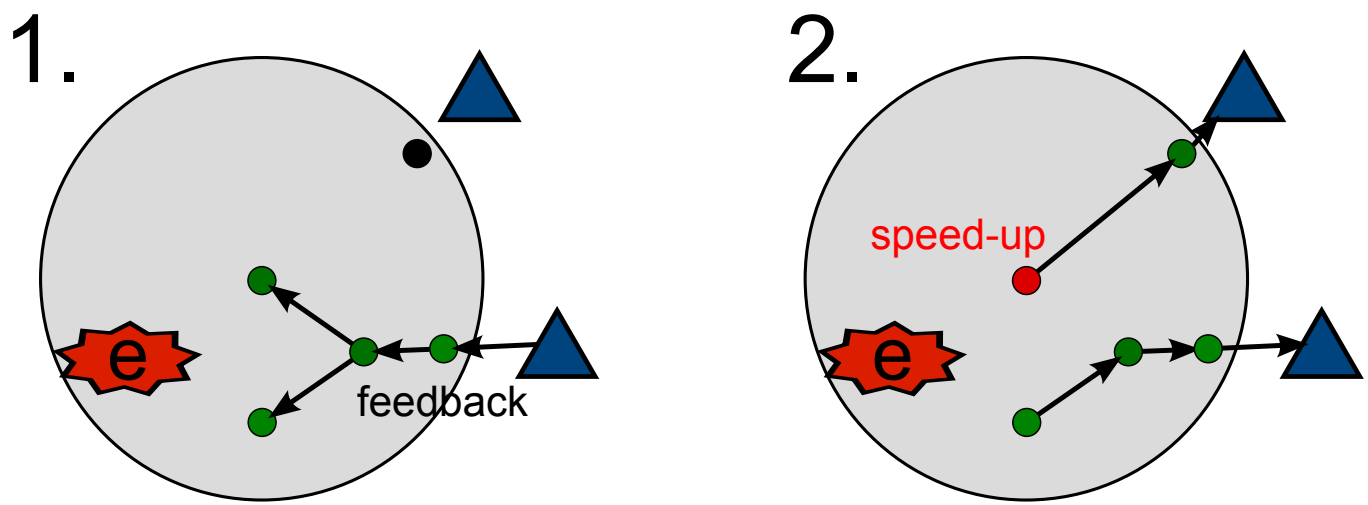
Start-Up State

- entered when sensing event or chosen as next hop by other sensor
- sensor i selects minimum cost next hop by *two hop rule*:
  $cost_j = constant + energy(i, j) + energy(j, \text{actor closest to } j)$



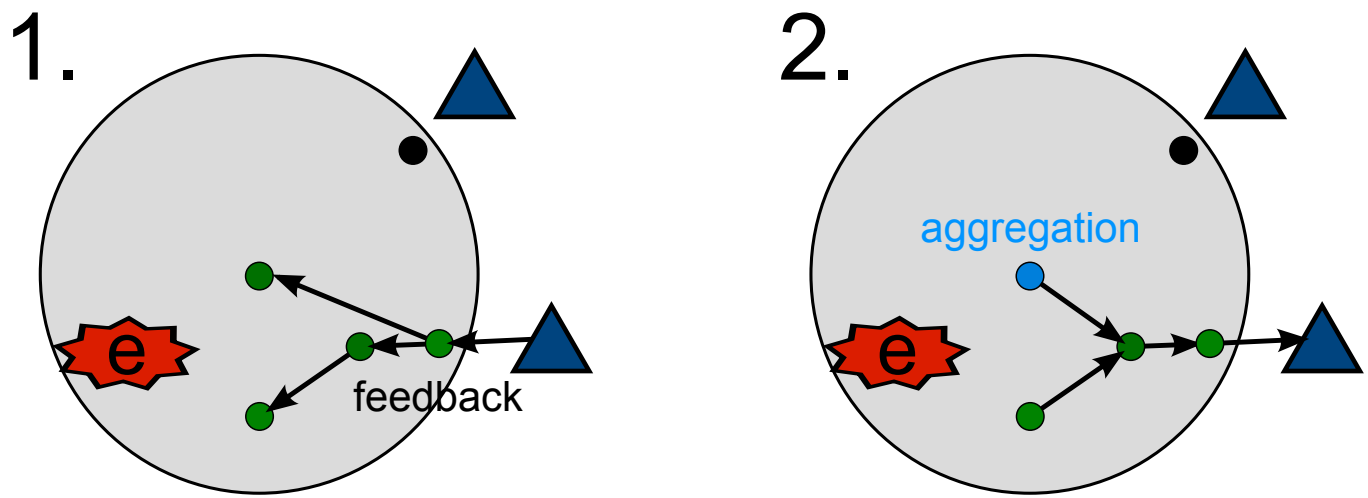
Speed-Up State

- entered when reliability below threshold $\Rightarrow$ reduce delay
- greedy routing: next hop is node within range and closest to any actor



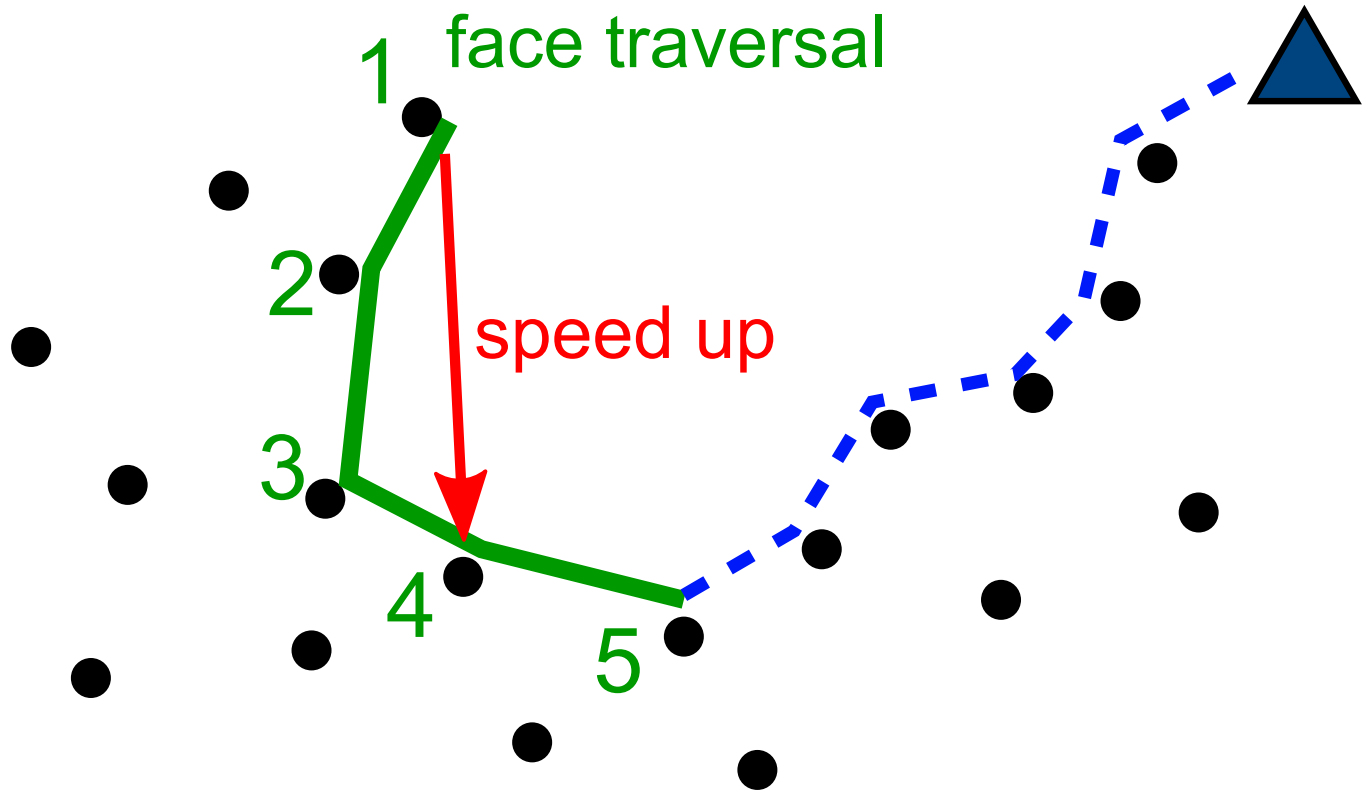
Aggregation State

- entered when reliability above threshold $\Rightarrow$ reduce transmission power
- next hop is closest node that is part of da-tree + rules
- rules:
  - if part of same tree, must be closer to actor
  - if in different tree, I must be leaf and next hop closer to its actor than I am to this actor



Handling Voids

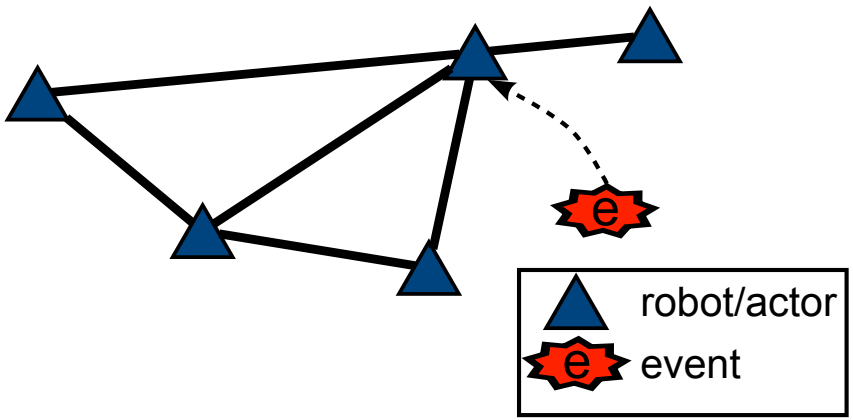
- sensor enters recovery mode when no neighbor is closer to their closest actor than I am to my closest actor
  $\Rightarrow$ use face traversal
- in speed-up state, choose highest hop number on recovery path as next hop



Overview

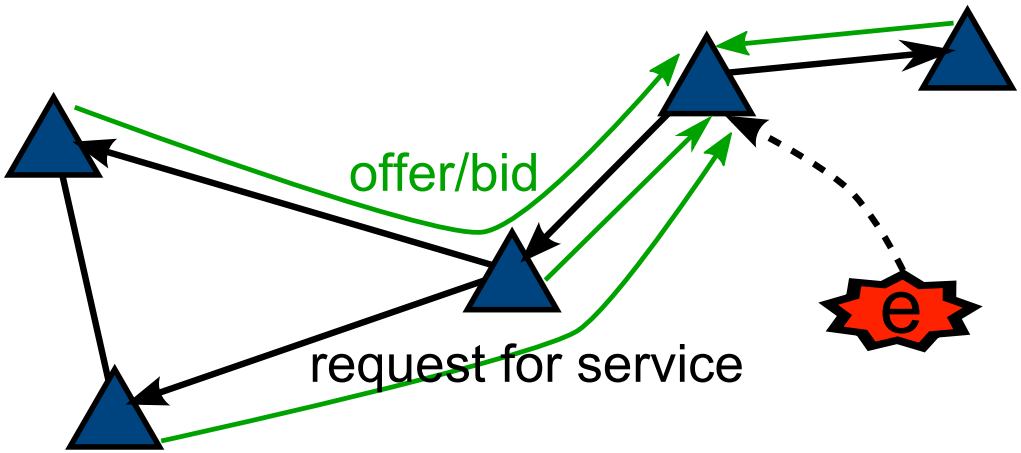
Actor-Actor Coordination

- **actor-actor coordination problem**: allocate acting tasks to actors/robots in "optimal" way
- optimization dimensions:
  - action completion time
  - energy consumption
  - travel distance
- different versions of task allocation problem
  here: event reported to one robot, find best robot to respond



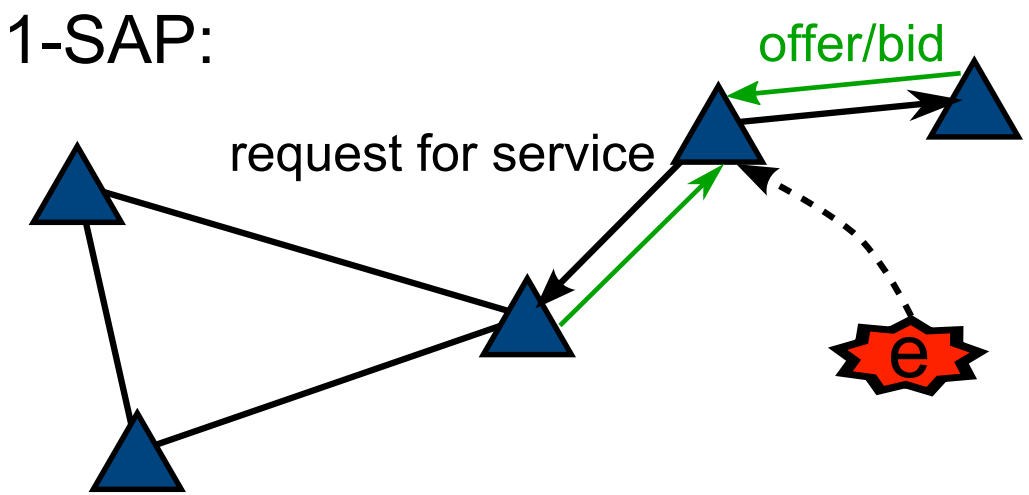
Auction based Solution: SAP

- **Simple Auction Protocol (SAP)**: flood request for service to **all** actors
- retransmit request for service exactly once
- actors reply with offer by seperate routing task
  $\Rightarrow$ many messages, high response time but optimal solution



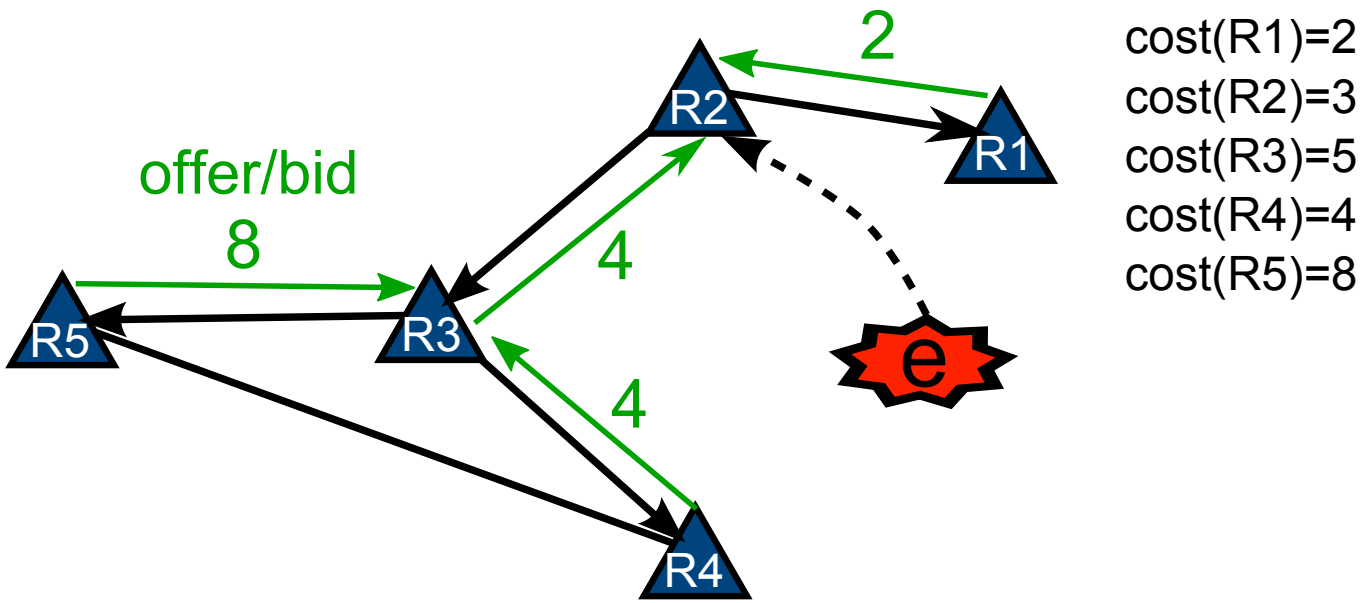
Improvement k-SAP

- **k-SAP**: only flood request for service to k-neighborhood
- actors reply with offer by seperate routing task



Improvement SAAP

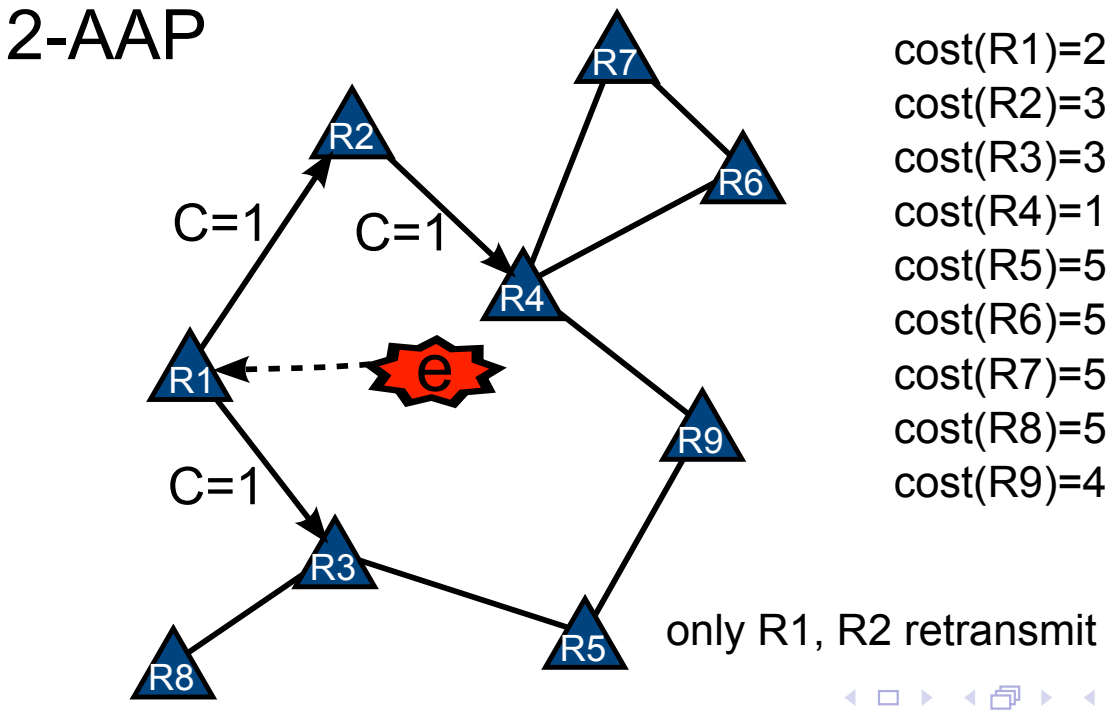
- **SAAP**: Simple Auction Aggregation Protocol
- include ID of parent in retransmission of request for service
  $\Rightarrow$ creates response tree
- use tree to report back: wait for bids of children, reply with best bid in subtree
- if node hears noone listing it as parent, it becomes leaf and starts reporting back



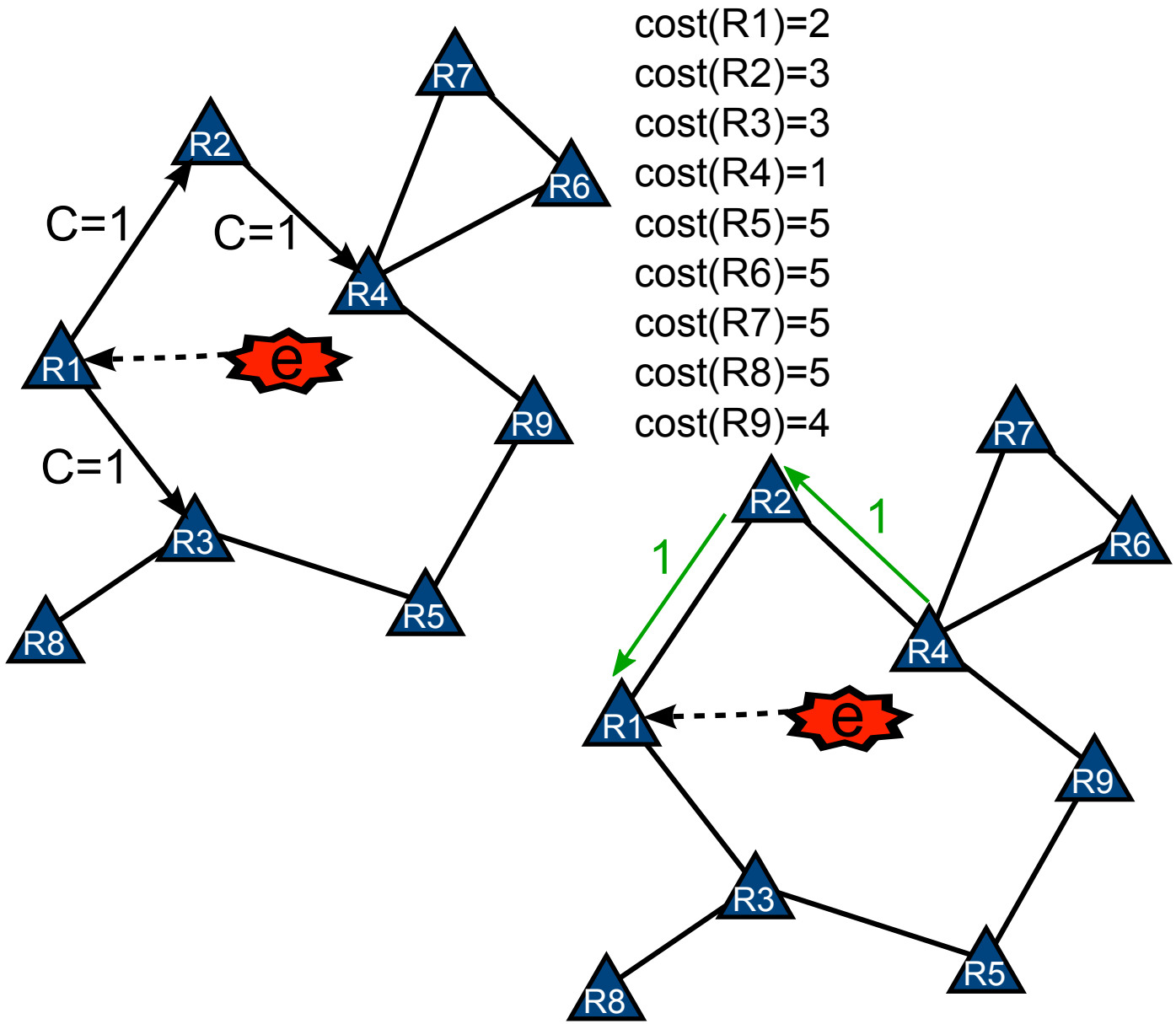
$\Rightarrow$ combine improvements to k-SAAP

Improvement k-AAP

- **k-AAP**: robots already learned cost of all robots in their k-neighborhood
- include best known cost C in retransmission of request for service
- only retransmit when cost $\leq C$ in k-hop neighborhood
- leafs start reporting back
- use tree to report back, reply with best bid in subtree



Example: 2-AAP



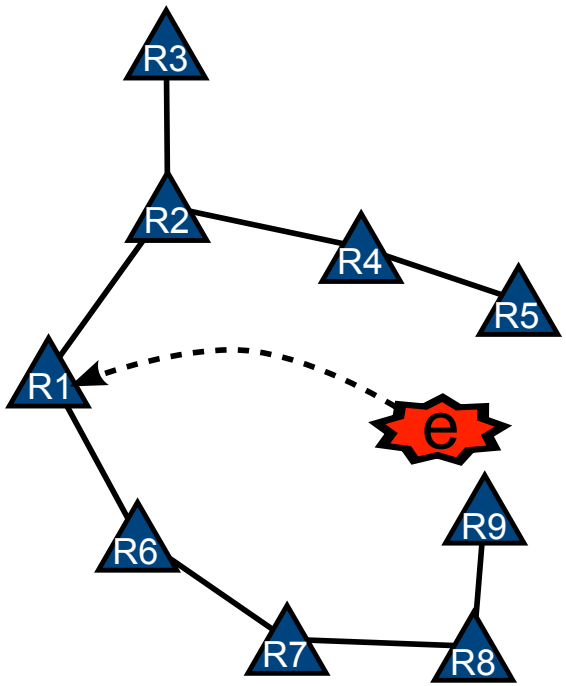
Summary

- Purpose: learn techniques and algorithms used in coordination of sensor-actor/robot networks
- Sensor-Actor Coordination: DEPR-Protocol: creation of data reporting trees from sensors to actors
- Actor-Actor Coordination: Auction-based protocols for task assignment with reduced message overhead

Questions

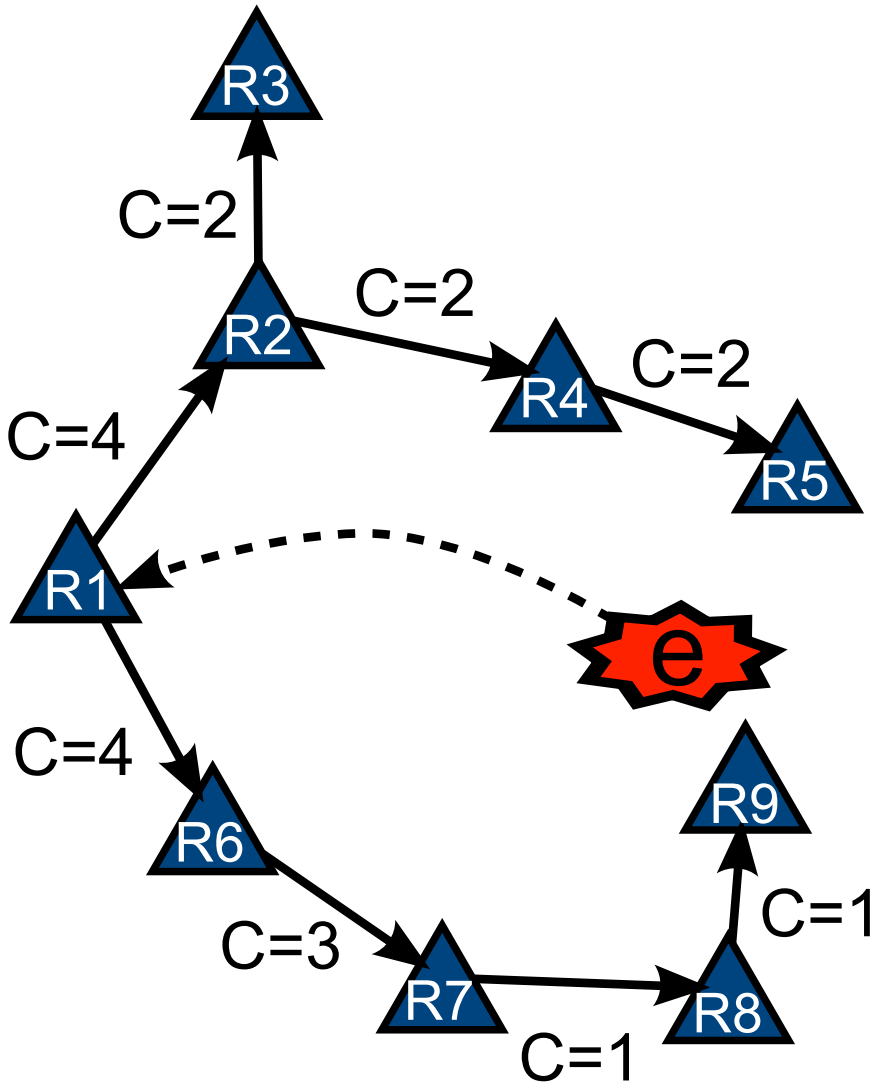
Question 1

k-AAP is an auction based protocol in robot-robot coordination to find the best robot to respond to an event reported to a collector robot. Every robot knows the acting cost of all the robots in its k-neighborhood. Starting from the collector robot, a request for service is broadcasted. This message includes the value C of the best cost that the robot that transmitted this message is aware of. Every robot retransmits the message only if there is a robot with cost <= the received C in its k-neighborhood and updates C accordingly.
Which robots will retransmit the request for service when an event is reported to collector robot R1 and 2-AAP is used? What is the value of C in each message?



cost(R1)=5
cost(R2)=6
cost(R3)=8
cost(R4)=4
cost(R5)=2
cost(R6)=4
cost(R7)=4
cost(R8)=3
cost(R9)=1

Answer 1



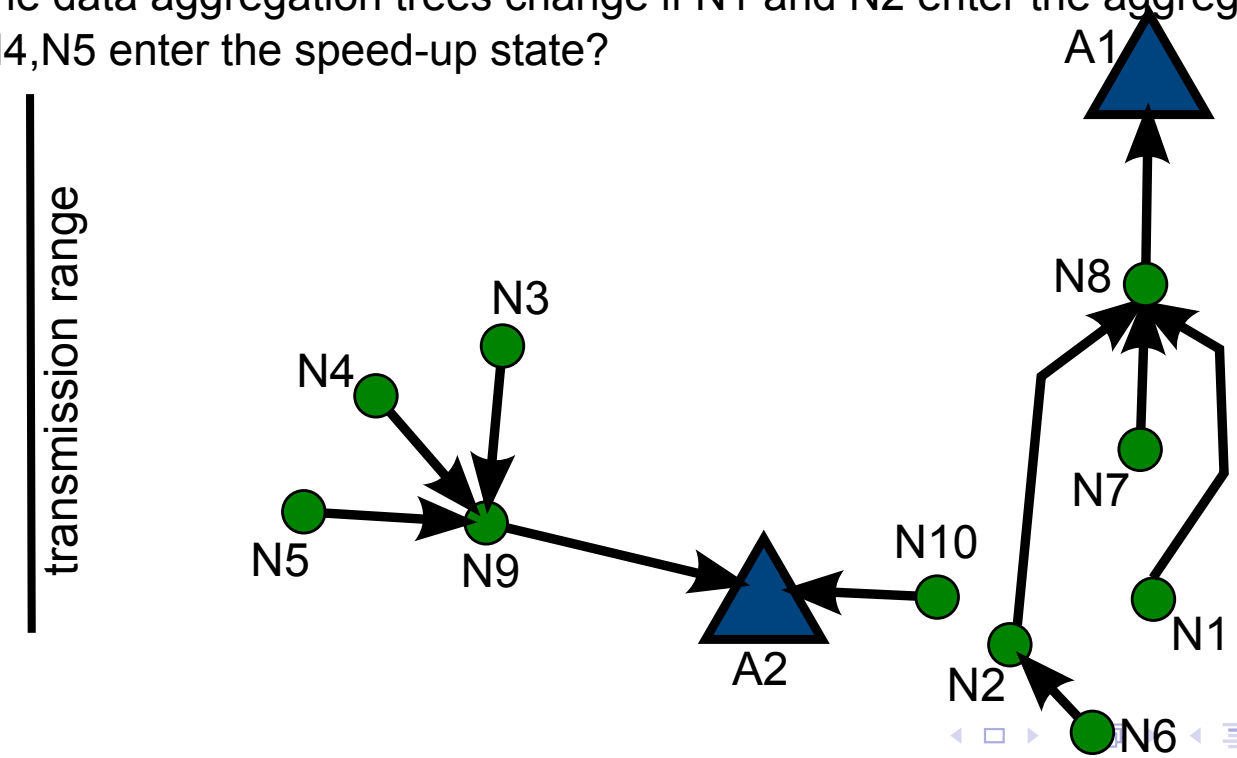
R1 retransmits, C=4
R2 retansmits, C=2
R4 retransmits, C=2
R6 retransmits, C=3
R7 retransmits, C=1
R8 retransmits, C=1
R3,R5,R9 don't retransmit

Question 2

DEPR is a distributed protocol in sensor-actor coordination which is used to find data aggregation trees from sensors to actors. According to feedback from the actors about observed reliability/delay, sensors transition into a speed-up or an aggregation state. In the speed-up state the next hop is chosen as the node within transmission range which is closest to any actor. In the aggregation state a node i chooses its next hop j as the node that is closest to itself for which the following conditions are met:

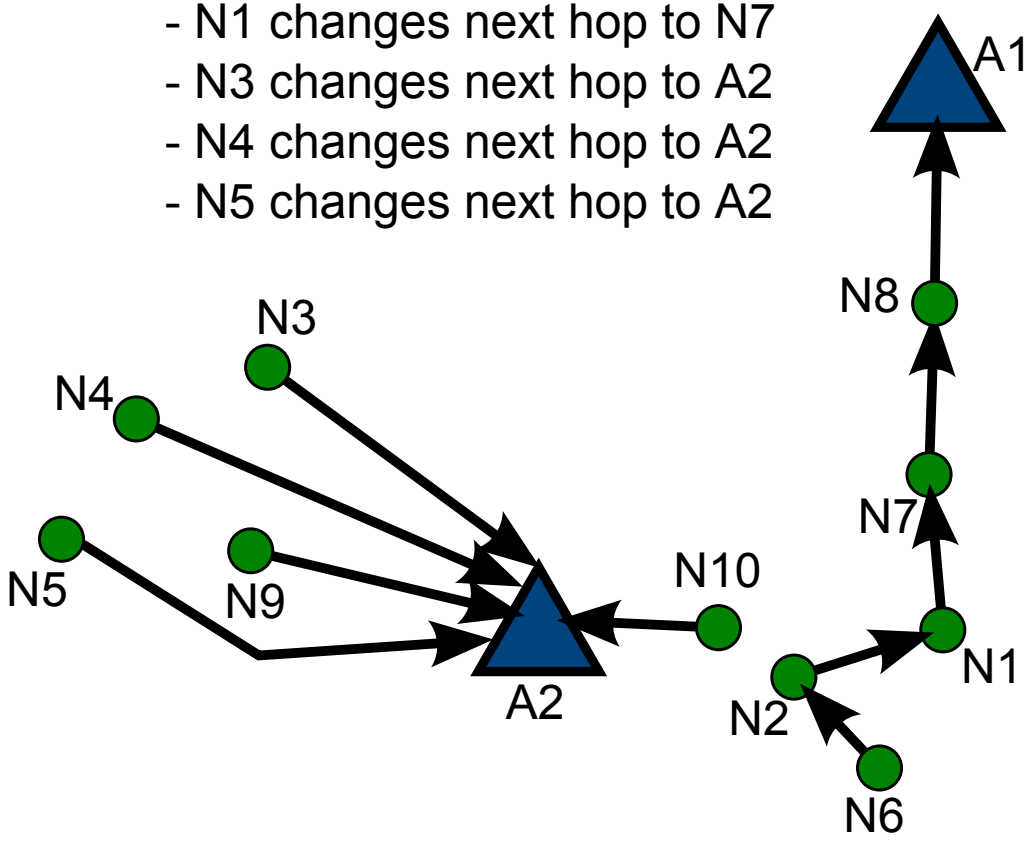
- if i and j are in the same tree, j must be closer to the actor
- if i and j are in a different tree, i must be leaf and j closer to its actor than i is to the actor of j

How do the data aggregation trees change if N1 and N2 enter the aggregation state and N3,N4,N5 enter the speed-up state?



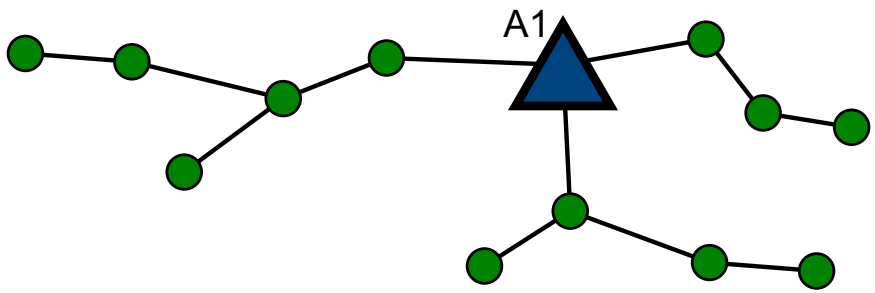
Answer 2

- N2 changes next hop to N1
- N1 changes next hop to N7
- N3 changes next hop to A2
- N4 changes next hop to A2
- N5 changes next hop to A2



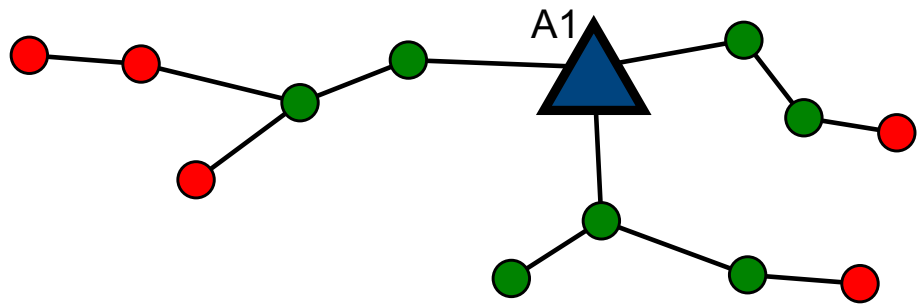
Question 3

DEPR is a distributed protocol in sensor-actor coordination which is used to find data aggregation trees from sensors to actors. Actors broadcast collective feedback about observed delay of sensor data packets to all sensors in their tree. Data packets received by an actor within a given latency bound are called reliable. The reliability is the ratio of reliable data packets over all packets received by an actor in an interval. Assume that every sensor shown below generates one packet of sensor data per interval. Each sensor forwards the packets towards the actor as soon as they are generated or received. One hop takes 1 unit of time. The intervals are long enough so that every packet reaches the actor before another interval starts. Packets with latency <=2 are considered reliable. What is the value of the reliability observed by actor A1? The minimum reliability required by the application is 2/3. To which state will some nodes probably transition to after receiving feedback from the actor?



Answer 3

reliability observed by A1: 7/12
7/12 < 8/12=2/3 so reliability is too low and some nodes will probably transition to the speed-up state



Thank you!

References

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