Coordination-aware task allocation via a lightweight supervisory layer

An event-driven approach to multi-agent Search and Rescue

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1. The problem

Search and Rescue (SaR) can benefit from autonomous agents.

In SaR missions, we need to:
- Find victims quickly
- Explore as much as possible
- Remain responsive to rescue

With multiple agents, we need to avoid conflicts so we need Supervision:

How can a lightweight supervisory framework dynamically allocate sub-tasks within a robotic team to optimize the trade-off between safety constraints and performance objectives under environmental uncertainty?

2. The Testbed

Tiny 2D grid-based testbed
Properties include:
- Agents and victims
- Propagating fire
- Vulnerability and perception

Map generated procedurally:
- Rooms and tunnels with sizes
- Initial fire
- Vulnerability

Example 50x50 map

3. Supervisory Architecture

The supervisory task-allocation layer will
- Sit above the controllers
- Aim to allocate tasks as efficiently as possible.

The supervisor will:
- Let agents act freely
- Intervene when **event** occurs

Event types:
- Spatial conflict: agents come too close
- Impatience: agent stops discovering new territory
- Victim discovered: high-priority rescue trigger

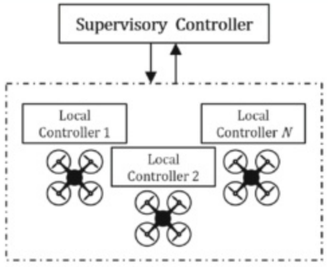


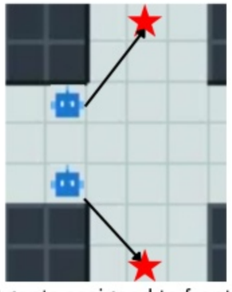
Diagram of Architecture

4. Event Resolution

Task generation

The supervisor will, when event arises:
- Create new task(s)
- Compute bidding costs for agents
- Assign task to lowest cost agent

Frontiers:
- Border between explored and unexplored area



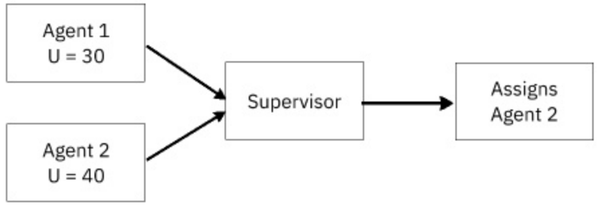
Agents assigned to frontiers

Auction System

- SSI auction, single-task capacity per agent
- Capability multiplier gates rescue-only tasks
- Burgard spatial penalty drives dispersion
- All agents bid when victim discovered

$$U_{i,j} = (B_j \cdot C_{i,j}) - T_{i,j} - P_{i,j}$$

Function used in the auction:
- U = Utility
- B = Base reward (task type)
- C = Capability multiplier
- T = Travel cost
- P = Penalty (Bulgard spatial exclusivity)



5. Results

Supervised compared to 2 baselines across same seeds:
- Unsupervised (fully decentralized)
- Shared (only has shared map)
- Success when all victims are found before timeout

Homogenous fleet:
- Much higher success rate
- Higher exploration velocity
- Less exploration redundancy

Heterogenous fleet:
- Exploration increase persists
- Does not yet translate to more saved victims

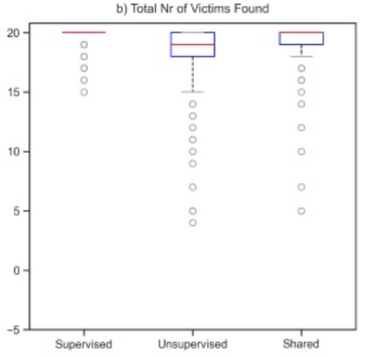
Shared baseline has much higher communication bandwidth
- Intervention duration averages around 11ms
- Supervision reduces inter-agent collisions
- Damage reduced by 25%

Success rates and times across 216 paired simulations:

Architecture	Success Rate	Time to All Found
Supervised	91.7%	177.59 ± 43.93
Unsupervised	50.5%	220.81 ± 53.37
Shared	75.9%	184.02 ± 50.03

Average time steps to reach milestone:

Milestone	50%	70%	80%	85%	90%
Supervised	81	108	126	136	151
Unsupervised	92	137	165	183	201
Shared	80	108	128	139	153



6. Conclusions

What we showed:
- Event-driven supervision outperforms decentralized coordination for exploration
- Active allocation also outperforms shared-map awareness
- Safety does not suffer under these gains
- Exploration and rescuing are not yet balanced properly

What remains open:
- More interesting heterogeneous fleet
- Lossy communication
- Comparison against other supervisory methods