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Peter Stone

Communication in Domains with Unreliable, Single-Channel, Low-Bandwidth Communication

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Motivation

Most multi-agent systems with communicating agents have the luxury of using reliable, multi-step negotiation protocols

Our Focus:

Multi-agent environments with unreliable, high-cost communication

- Robots with aural sensors
- Arbitrarily expandable systems
- RoboCup Soccer Server

Communication Environment

- Many agents, teams
- Single-channel
- Low-bandwidth
- Unreliable
- High cost

Challenges

- **Robustness to active interference**
- **Multiple simultaneous responses**
- **Team coordination**
- Message targeting/distinguishing
- Robustness to lost messages

Soccer Server Communication Model

- All 22 agents (including adversaries) on same channel
- Limited communication range and capacity
- No guarantee of sounds getting through
- Instantaneous communication
- High communication cost

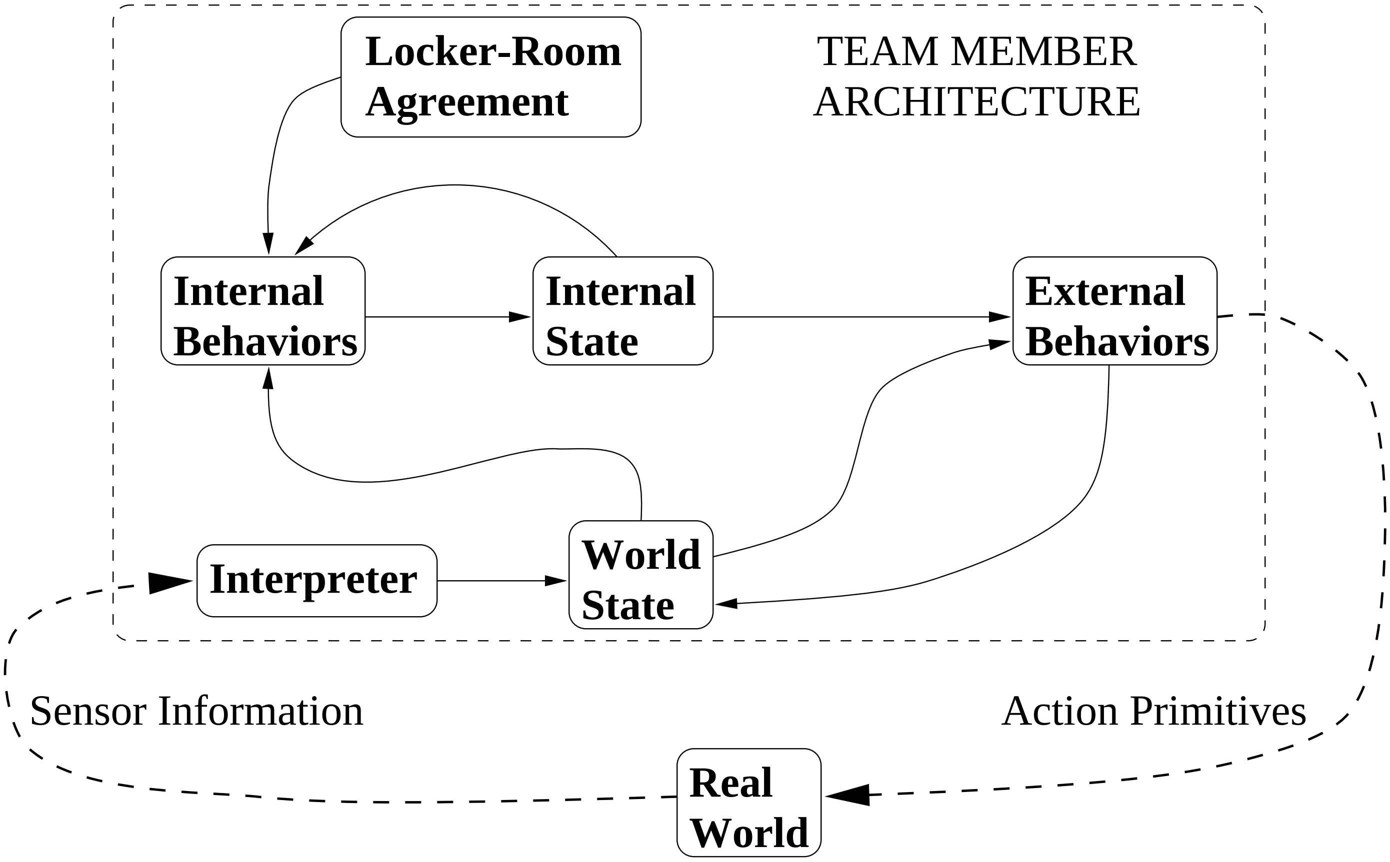
Testing the cost:

Team A: uses 18% of action opportunities to communicate, but ignores messages

Team B: never communicates

Team A loses 3.54 - 1.08 (50 game avg.)

Team Member Architecture



- Utterances are **external behaviors**
- **Locker-room agreement** specifies interpretation of messages
- **Internal behaviors** update internal state

Our Approach

Message fields:

- Team identifier
- Unique team-member ID
- Encoded time stamp
- Time-stamped team strategy
- Selected internal state
- Target type
- Target
- Message type
- Message data

(CMUnited 4 <Encoded-stamp> <Formation-number> <Formation-set-time> <Position-number> <single player> 3 <"where are you?">)

Sample Message Types

- Request/respond ball location
- Request/respond teammate location
- Inform pass destination
- Inform going to the ball
- Inform taking/leaving position

With unreliable communication, agent behaviors must not depend on timely responses.

Robustness to Active Interference

- Opponents can mimic old messages
- Different problem from encryption – they can interfere without decoding

Locker-room agreement specifies invertible function of specific message fields for encoded time-stamp

Results

- Function: <Uniform-#> * (send-time + C)
- Old messages ignored
- 5-minute game: 73 false messages heard by avg. of 3.6 teammates
- **All properly ignored**

Multiple Simultaneous Responses

Some messages request responses from multiple teammates: "where are you?"

Message Target	Response requested: no	Response requested: yes
Single agent	a1	b1
Whole team	a2	b2
Part of team	a3	b3

- Cases a1-3: simply update internal state.
- Case b1: respond immediately
- Case b2-b3: delay response based on difference of sender and receiver ID numbers.

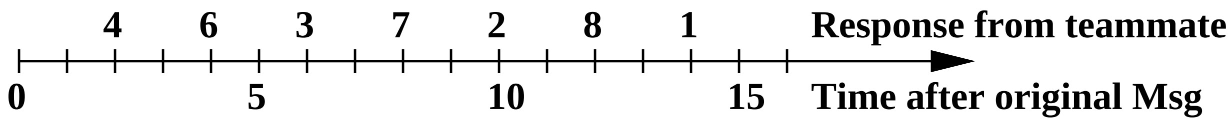
Results

- All 11 agents in hearing range
- **Response requested from all**
- Repeated 50 times

	Number of Responses			Response Time (sec)		
	Min	Max	Avg	Min	Max	Avg
No Delay	1	1	1.0	0.0	0.0	0.0
Delay	6	9	8.1	0.0	2.6	0.9

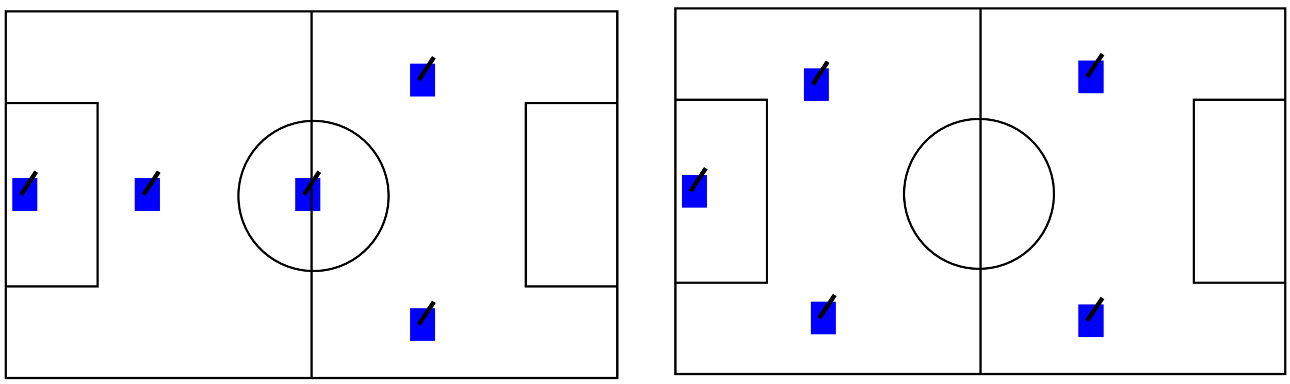
Example: communicate delay = 2 seconds:

Team Member 5 Sends a Message Requesting Multiple Responses



Team Coordination

- Independent agents may not agree on choice of multiple team strategies.
- Time-stamped team strategy field gives precedence to recent decisions.



- Teams use multiple **formations**
- Pre-specified formation switches possible using locker-room agreement
- Or switch based on communication from team captain

Results

- **Team captain** announces formation change
- Those who don't hear, get the information from subsequent communications

Decision-Maker	Entire Team Change Time (sec) Min	Max	Avg	Var	Heard From Decision-Maker
Goaltender	0.0	23.8	3.4	17.8	46.6%
Midfielder	0.0	7.9	1.3	2.8	80.6%

Conclusion

Communication method for domains with. . .

- Low bandwidth
- Single channel
- Unreliable transmission

Provides. . .

- Message targeting/distinguishing
- Robustness to active interference
- Multiple simultaneous responses
- Team coordination

Successfully used by CMUnited simulator teams