Spectrum Collaboration Challenge (SC2) Collaboration Protocol: Phase 1 Review

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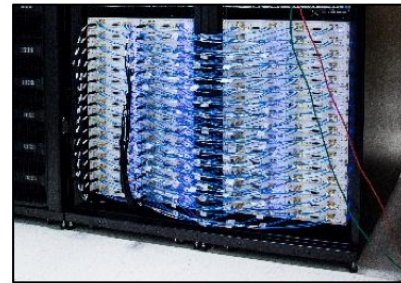*andrew.adams@jhuapl.edu*

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DARPA Spectrum Collaboration Challenge – Challenges

Collaborate Without Co-Design

Create radio networks that work with others without knowing how they "think"

Engineer Emergent Effects

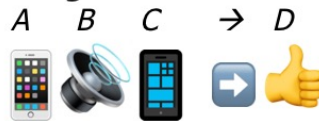*Discover and solve issues that only arise in large-scale realistic settings*

Communicate Without Constraints

too specific

too general

A B C → D

frame 15, slot 7

Create a protocol that supports evolving new forms of collaboration

Evolve The Ecosystem

UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM
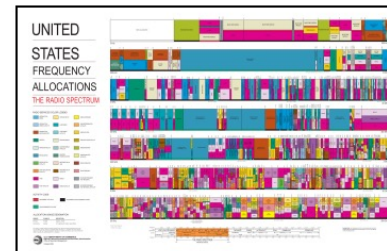
Change radio design, applications, and spectrum management to enable and leverage collaboration.

Thumbs-up image source: http://sr.photos3.fotosearch.com/bthumb/CSP/CSP880/k8803233.jpg
Pencil image source: http://www.pngall.com/wp-content/uploads/2016/03/Pencil-PNG.png

DISTRIBUTION A. Approved for public release: distribution unlimited.

Motivation

- **Review phase 1 collaboration protocol**
  - ➤ **How does collaboration protocol (CP) compare to those used in other domains?**
  - ➤ **What fundamental problems may arise?**
  - ➤ **Which approaches have proven broadly useful which may also be applied here?**

- **Consider improvements for phase 2 (January 2018)**
  - ➤ **What improvements help program execution?**
  - ➤ **What improvements support long term adoption?**

Review Topics

- **Multi-Agent System Overview**
  - ➢ **System Model**
  - ➢ **Collaboration Aspects**
  - ➢ **Ontology Benefits**
- **Phase 1 CP Review**
  - ➢ **Primary functions**
  - ➢ **Potential Pitfalls**
- **Example Collaboration Architectures**
  - ➢ **FIPA – ACL**
  - ➢ **Action – MAP**
- **Conclusions**

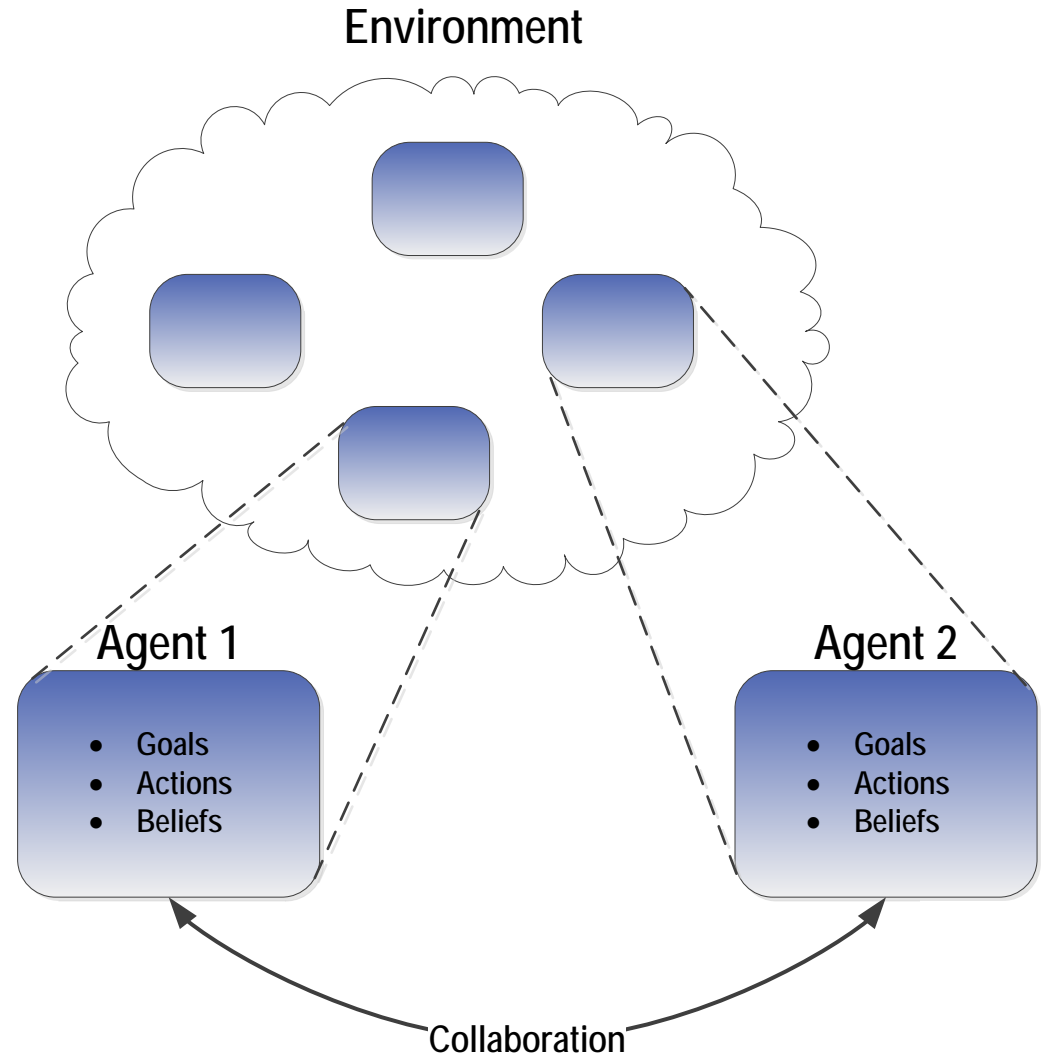**Unclassified**

Multi-Agent System Model

- **Environment defined by**
  - **State space**
  - **Possible actions**
  - **Effect of actions upon states**
  - **Agent observations**

- **Agents defined by**
  - **Individual goals**
  - **Policies for selecting actions**
  - **Individual beliefs**

Environment

Agent 1
- Goals
- Actions
- Beliefs

Agent 2
- Goals
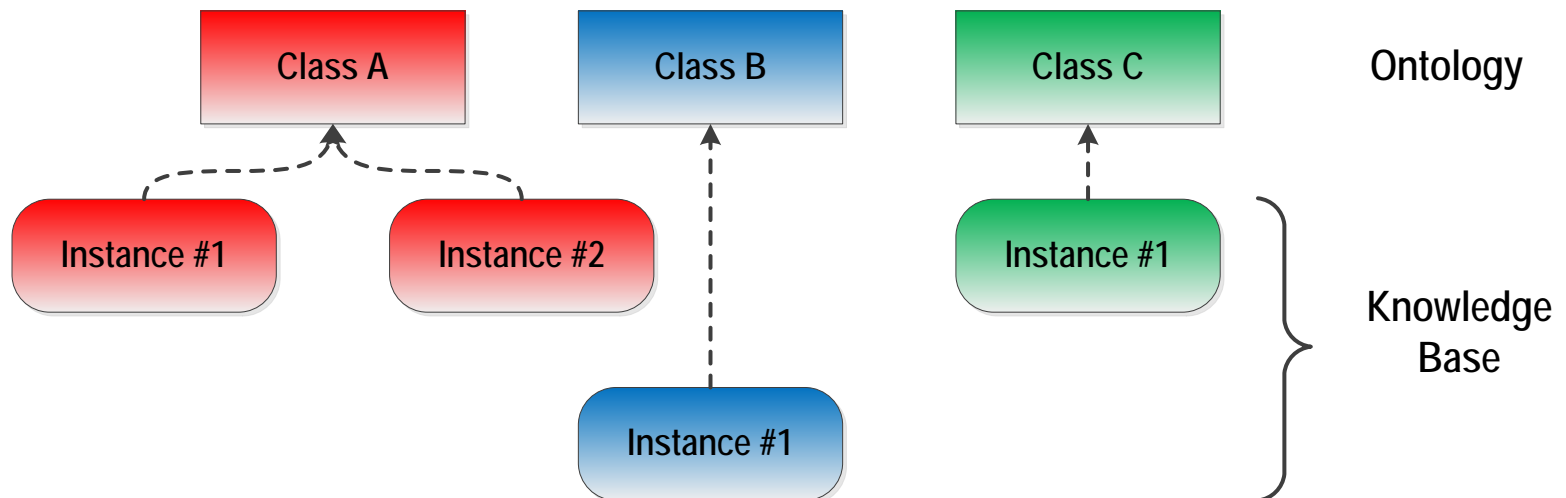- Actions
- Beliefs

Collaboration

Aspects of Collaboration

- **Many existing collaboration architectures incorporate some of the following aspects**
  - ➢ **Communication**
    - – **Specify message types and content**
    - – **Use ontologies to describe domain**
  - ➢ **Subteams**
    - – **Provide means to assemble smaller teams to accomplish goals, and add hierarchical structure**
  - ➢ **Joint Plans**
    - – **Support generation and execution of plans across subteams**
  - ➢ **Joint Goals**
    - – **Support coordination and communication of intentions across subteams**
  - ➢ **Subtasks, Roles**
    - – **Provide means to breakdown goals into smaller tasks and allocate per individual capabilities**
  - ➢ **Negotiation**
    - – **Provide means to resolve conflict and request assistance**

Why use Ontologies?

- **Provides explicit definition of domain**
  - ➢ **Concepts (classes)**
  - ➢ **Properties and attributes of classes (slots)**
  - ➢ **Constraints on slots (facets)**
- **Agents share common understanding of structure of information**
  - ➢ **Enables reuse, analysis, and separation of domain knowledge from operational knowledge**

Class A   Class B   Class C   Ontology

Instance #1   Instance #2   Instance #1

Instance #1
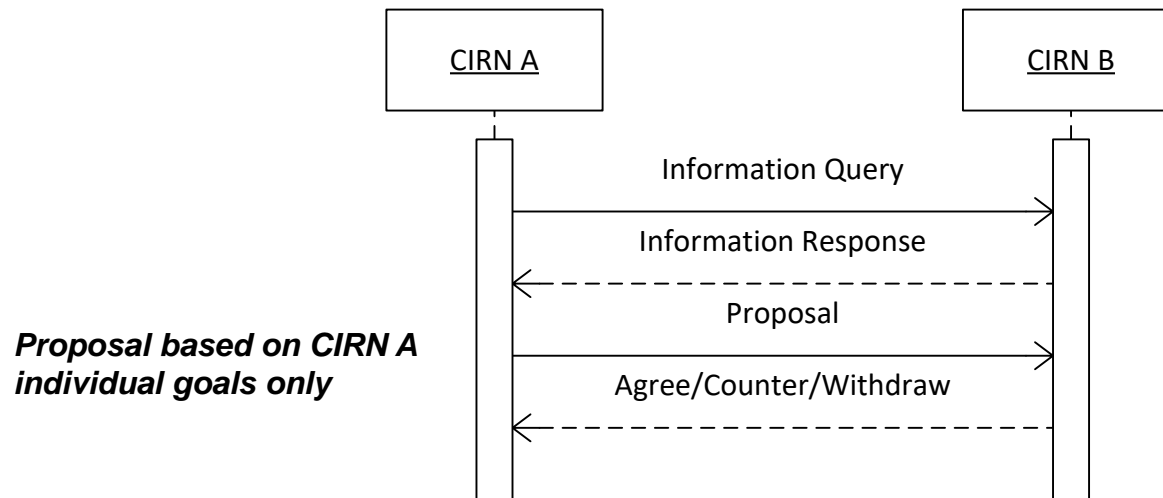
Knowledge Base

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Phase 1 Collaboration Protocol

- **Phase 1 CP primarily supports communications and negotiation through a number of specific messages**
  - **CIRNs share information regarding capabilities and status**
  - **CIRNs may negotiate access to shared spectrum resources**
- **Collaboration efforts determined individually**
  - **No teams, tasks, or roles across CIRNs**
  - **No state machines specified for message processing**

Proposal based on CIRN A individual goals only

CIRN A		CIRN B
	Information Query →	
	← Information Response	
	Proposal →	
	← Agree/Counter/Withdraw	

Potential Phase 1 Pitfalls

- **Protocol ambiguity**
  - ➢ **Given that collaboration policies are determined individually, any implicit assumptions regarding CIRN behavior may not be true**

- **Collaboration hurdles**
  - ➢ **If the collaboration cost (implementation or performance) is greater than its individually perceived benefit, CIRN participation may be limited**

- **Non-Cooperative Behavior**
  - ➢ **If CP does not dictate CIRN behavior, without shared goals individual CIRNs may exhibit selfish or malicious behavior**

- **Limited use outside domain**
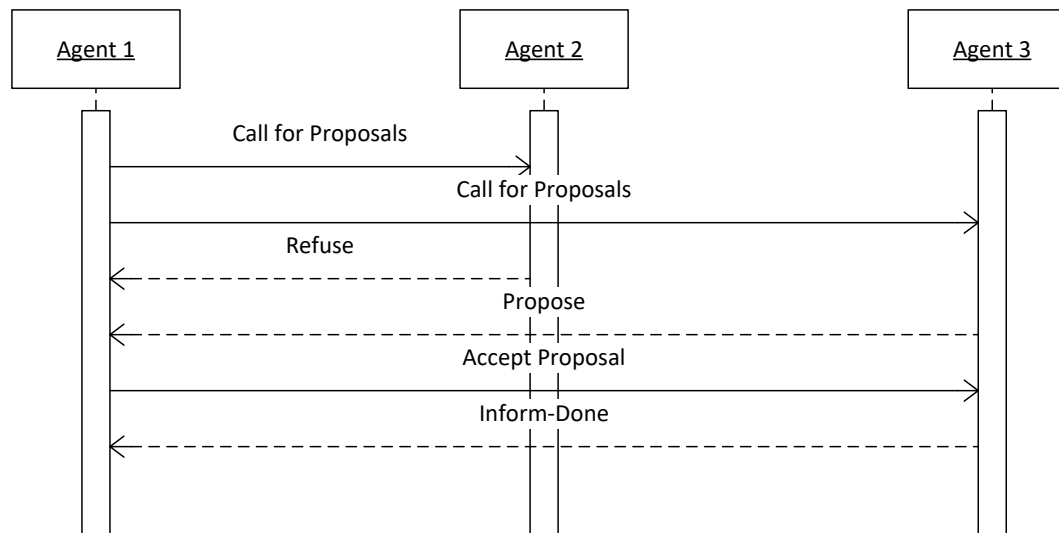 - ➢ **If CP too specific to SC2 domain, reuse in other domains may be limited**

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APL

Example Protocol: FIPA ACL

- **Foundation for Intelligent Physical Agents (FIPA), Agent Communication Language (ACL)**
  - **Focuses on specifying interaction protocols rather than agent behavior**
    - **Based upon speech-act theory (messages are actions)**
    - ***Similar concept to phase 1 CP***
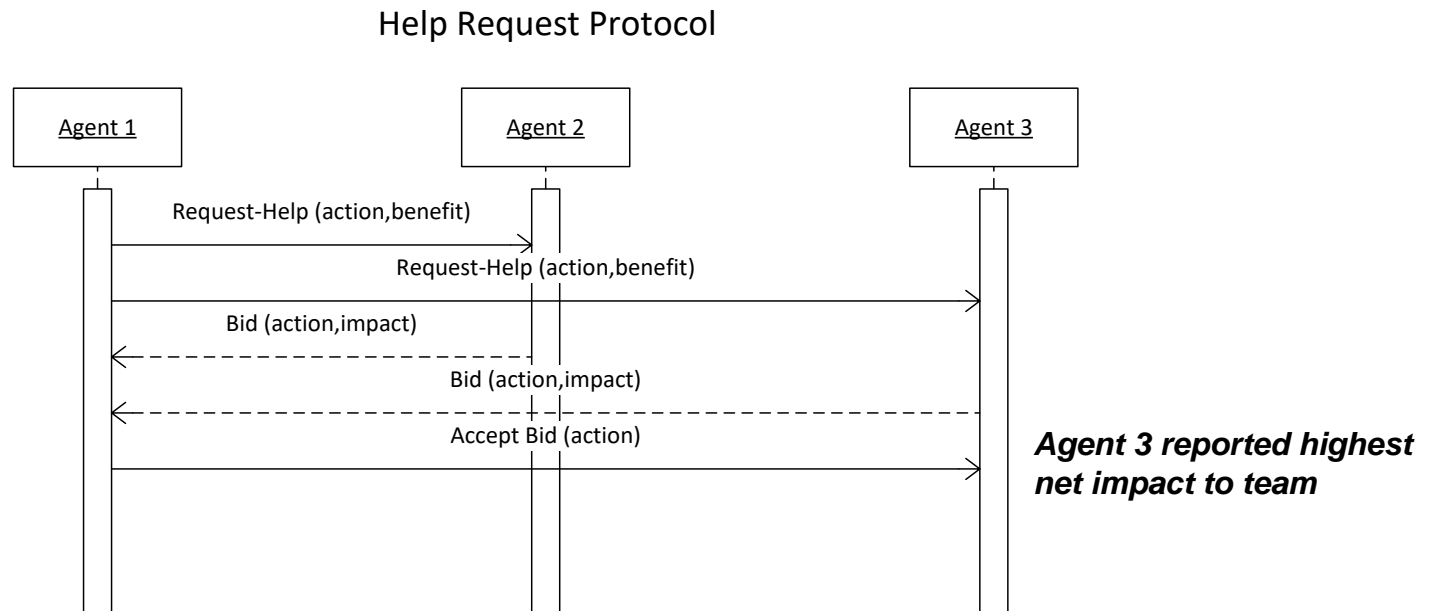 - **Supports use of ontologies**

Contract Net Interaction Protocol

Agent 1		Agent 2		Agent 3

Call for Proposals

Call for Proposals

Refuse

Propose

Accept Proposal

Inform-Done

Example Protocol: Action – MAP

- **Action – Mutual Assistance protocol (MAP)**
  - ➢ **Incorporates "helpful" actions into teamwork architecture**
  - ➢ **Agents request help if task can't be completed individually**
  - ➢ **Other agents bid if *perceived* net impact positive**
    - – *Perceived net impact* $\Delta_i(\pi_i', \pi_i) - \Delta_j(\pi_j, \pi_j'')$
  - ➢ **Bid with highest impact selected**

Help Request Protocol

| Agent 1 | Agent 2 | Agent 3 |

Request-Help (action,benefit)

Request-Help (action,benefit)

Bid (action,impact)

Bid (action,impact)

Accept Bid (action)

Agent 3 reported highest net impact to team

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Conclusions

- **Phase 1 CP focused primarily on communications and negotiation**

- **Phase 2 CP may benefit from the following additions**
  - ➢ **Use of ontologies to support reuse in other domains**
  - ➢ **Reuse of various messages currently defined in FIPA – ACL**
  - ➢ **Trust metrics to express past collaboration experiences**
  - ➢ **Specification of collaboration behavior to mitigate protocol ambiguity and reduce individual cost**
    - – **Would need to determine optimal balance between behavior specification and CIRN autonomy – not a trivial problem**

APL

Questions?

Unclassified

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