Complex Tasks Allocation for Multi Robot Teams under Communication Constraints

Hung CAO, Simon LACROIX, Félix INGRAND, Rachid ALAMI

Robotics and InteractionS, LAAS-CNRS

CAR 2010, Douai

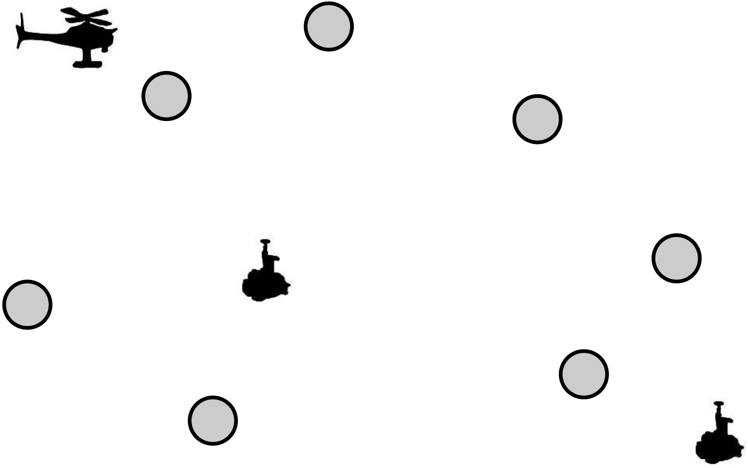
Outline

1. Introduction
2. Problem Formulation
3. Approach Overview
4. System description
5. Conclusions

Outline

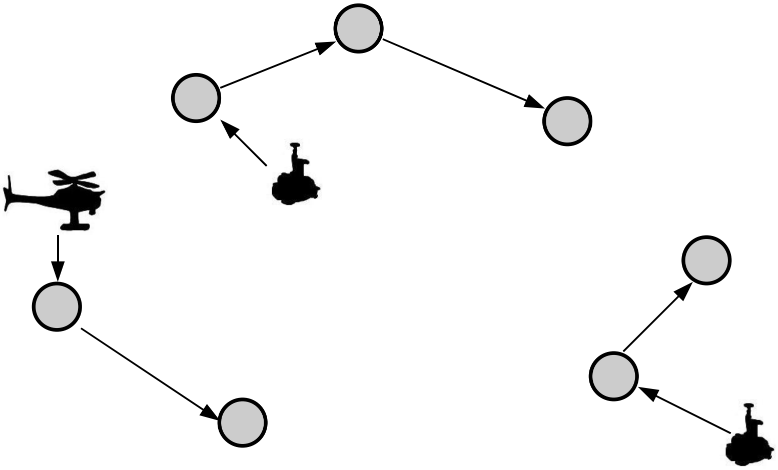
1. Introduction
2. Problem Formulation
3. Approach Overview
4. System description
   - Plan Formalism
   - Mission Manager
   - Individual Planner and Specific Refiners
   - Plan Manager
   - Task Allocator
5. Conclusions

Task Allocation (MRTA)



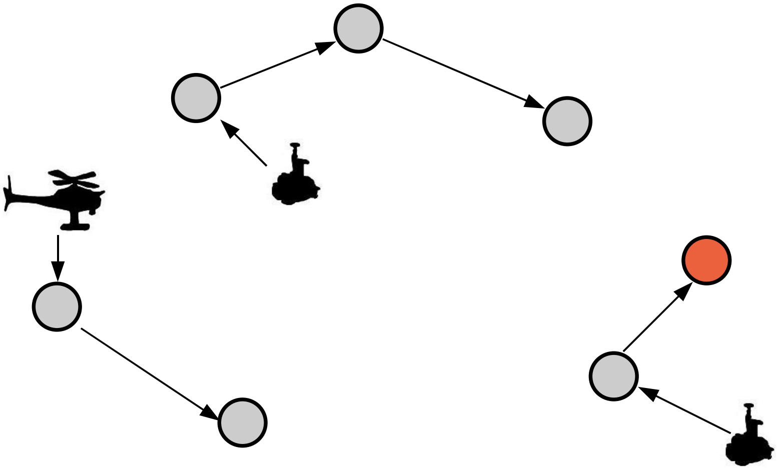
Robots seek to maximal own profit by bidding for tasks. Individual profit helps the common good.

Task Allocation (MRTA)



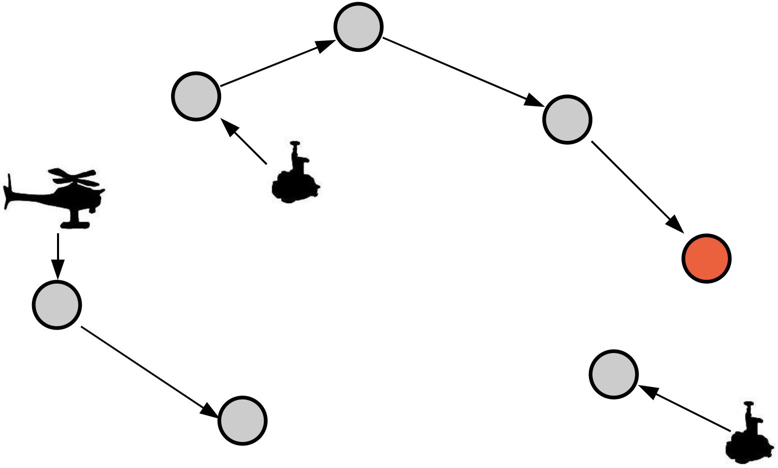
Robots seek to maximal own profit by bidding for tasks. Individual profit helps the common good.

Task Allocation (MRTA)



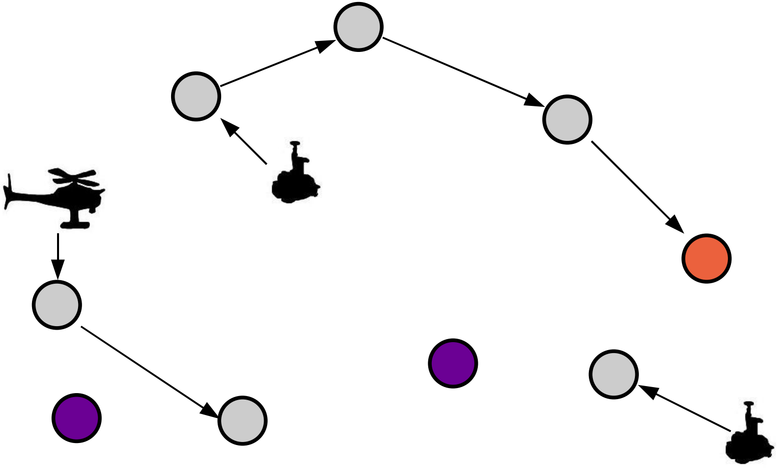
Dynamic re-planning : plan evolution.

Task Allocation (MRTA)



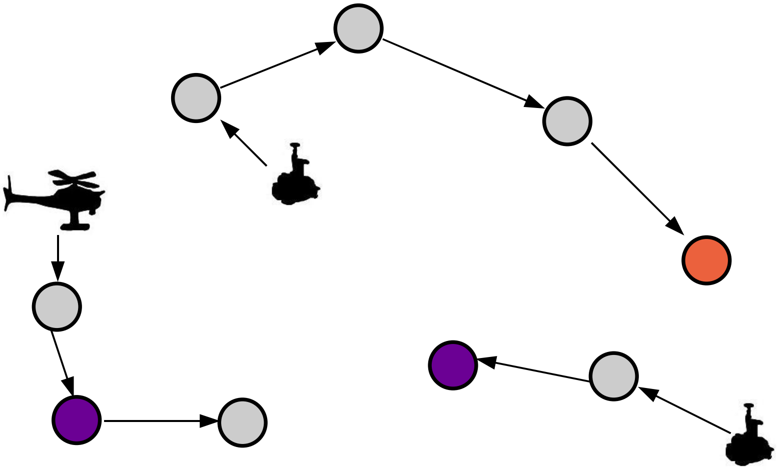
Dynamic re-planning : plan evolution.

Task Allocation (MRTA)



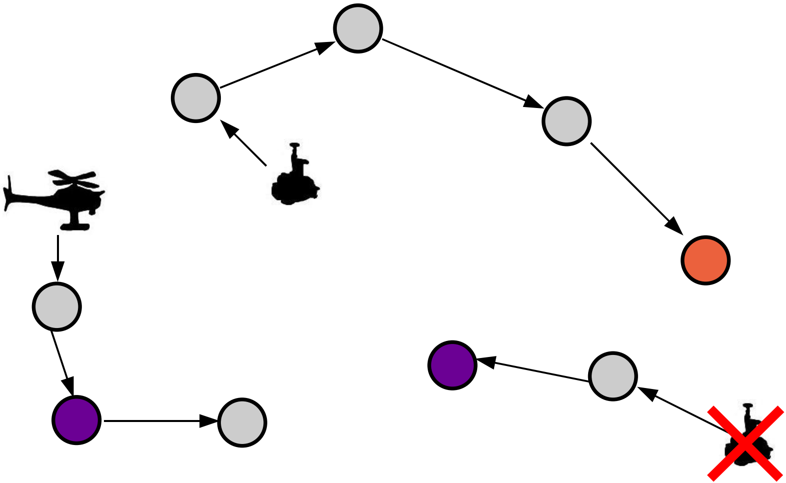
Dynamic re-planning : new tasks arrival.

Task Allocation (MRTA)



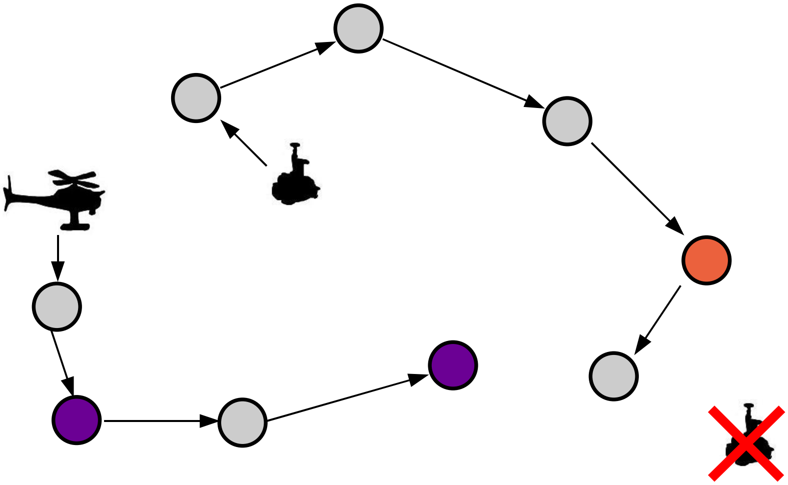
Dynamic re-planning : new tasks arrival.

Task Allocation (MRTA)



Dynamic re-planning : robot's failure.

Task Allocation (MRTA)



Dynamic re-planning : robot's failure.

Outline

1 Introduction

2 Problem Formulation

3 Approach Overview

4 System description
- Plan Formalism
- Mission Manager
- Individual Planner and Specific Refiners
- Plan Manager
- Task Allocator

5 Conclusions

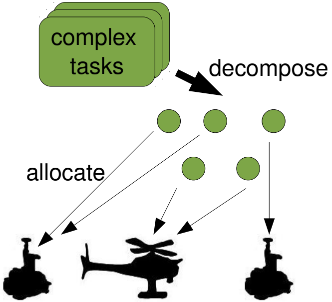
Extensions of our system

1. Complex task structure instead of simple tasks.

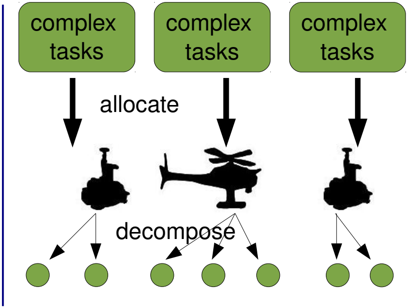
Extensions of our system

2. Communication constraints management over the teams or sub-teams :
   - Opportunistic : dynamic cluster formation [W. Burgard].
   - Explicit Coordination :
     - As inviolable constraints : DisCSP [Doniec], MANET-based task allocation [Mosteo and Montano].
     - As utility (embedded in cost function) in task allocation process : [Atay], [Rooker].

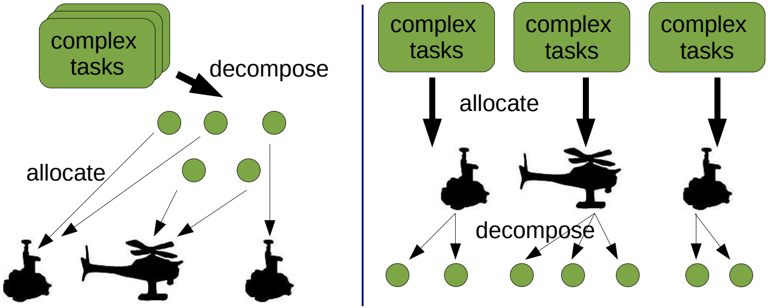
Extension 1 : Complex task and Interleaved Alloc-Dec



Extension 1 : Complex task and Interleaved Alloc-Dec

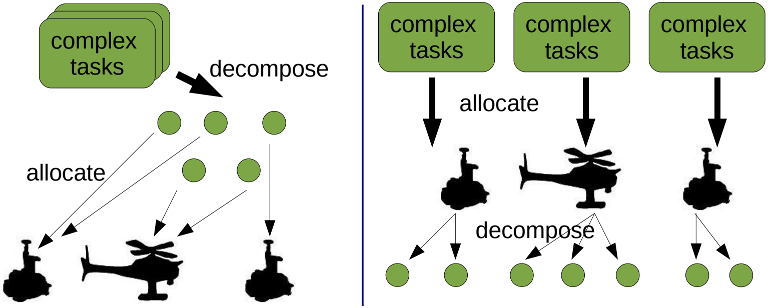


Extension 1 : Complex task and Interleaved Alloc-Dec



- **In-between** approach.

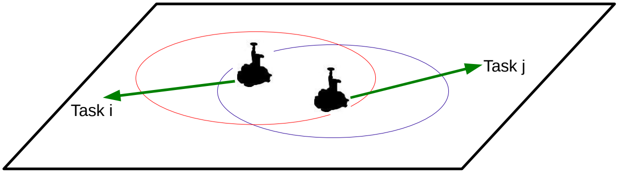
Extension 1 : Complex task and Interleaved Alloc-Dec



- **In-between** approach.
- Expectations :
  - Concurrent task decomposition on allocation yields more efficient solutions.
  - Computationnally tractable.

Extension 2 : Communication constraints

- Spatio-temporal constraints are common in multi-robot teams :
  - The limited-range communication imposes communication constraints over each robot or sub-team of robots.



Task Allocation should handle spatial constraints (like com. range)

Outline

1 Introduction

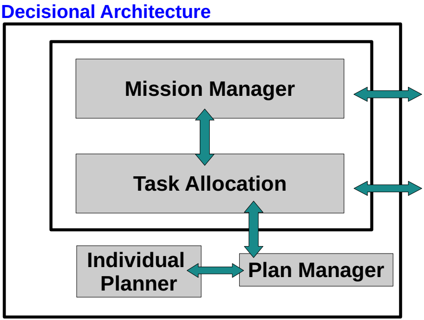
2 Problem Formulation

3 Approach Overview

4 System description
- Plan Formalism
- Mission Manager
- Individual Planner and Specific Refiners
- Plan Manager
- Task Allocator

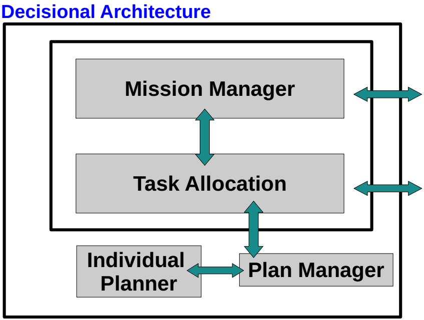
5 Conclusions

Planning Architecture



Market-based Task Allocation centered Architecture.

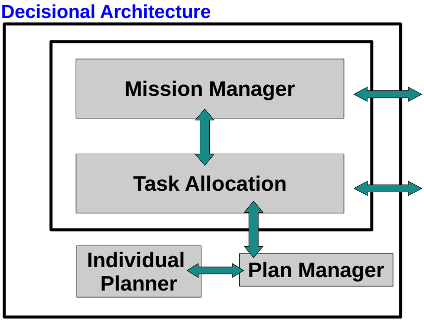
Planning Architecture



The task allocator is relying on :

- Specific refiners.
- Plan Manager.

Planning Architecture



Feed-backs : loop over *decompose* and *allocate*

Outline

1 Introduction

2 Problem Formulation

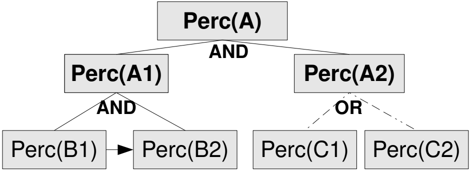
3 Approach Overview

4 System description
- Plan Formalism
- Mission Manager
- Individual Planner and Specific Refiners
- Plan Manager
- Task Allocator

5 Conclusions

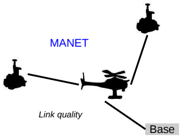
Plan formalism

- Plan formalism : tree-based task structure (TAEMS) :
    - AND/OR branching : express different alternatives.
    - Ordering constraints [Allen99] : express complex missions.
    - Auctions over complex task structures : enhance mission efficiency.



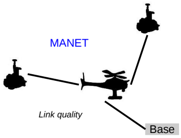
How communication constraints influence Task Allocation

- MANET (Mobile Ad-hoc Network) infrastructure : monitor the communication link quality.



How communication constraints influence Task Allocation

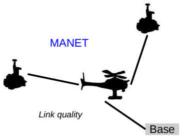
- MANET (Mobile Ad-hoc Network) infrastructure : monitor the communication link quality.
- The communication is handled in 3 ways :



How communication constraints influence Task Allocation

- MANET (Mobile Ad-hoc Network) infrastructure : monitor the communication link quality.
- The communication is handled in 3 ways :

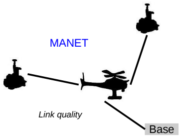
1. as an utility embedded in the bidding value of a robot for a task.



How communication constraints influence Task Allocation

- MANET (Mobile Ad-hoc Network) infrastructure : monitor the communication link quality.
- The communication is handled in 3 ways :

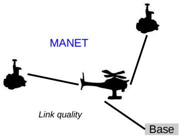
  1. as an utility embedded in the bidding value of a robot for a task.
  2. as hard constraints :



How communication constraints influence Task Allocation

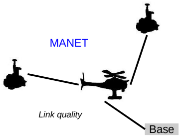
- MANET (Mobile Ad-hoc Network) infrastructure : monitor the communication link quality.
- The communication is handled in 3 ways :

1. as an utility embedded in the bidding value of a robot for a task.
2. as hard constraints :
    1. as fixed constraints of communication with the base station (see *Plan Manager*).



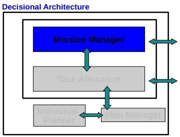
How communication constraints influence Task Allocation

- MANET (Mobile Ad-hoc Network) infrastructure : monitor the communication link quality.
- The communication is handled in 3 ways :
  1. as an utility embedded in the bidding value of a robot for a task.
  2. as hard constraints :
     1. as fixed constraints of communication with the base station (see *Plan Manager*).
     2. as synchronization communication between two robots achieving 2 dependent tasks (see *Task Allocator*).



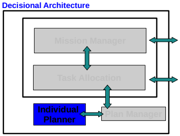
Mission Manager

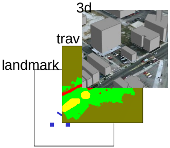
- Mission Manager has complete information about the team mission(s).
- It is enable to decompose the mission (through specific algorithms, centralized/distributed) into independent goals (individual/joint).
  - The mission decomposition process solely involves information about :
    - The missions progress and not individual robot plan.
    - Composition and abilities of the robots in the sub-team in question.



Individual Planner and Specific Refiners

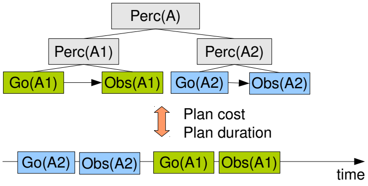
- Models for Specific Refiners allowing spatio-temporal reasoning :
- **Navigation Model** : built from Traversability and Landmark Map.
  - Estimation of navigation cost and time.
- **Perception Model** : built from 3D Map.
  - Estimation of the zone a robot can perceive from every position.
  - Estimation of the best positions to perceive a zone.
- **Communication Model** : built from 3D Map.

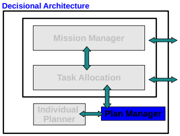




Plan Manager

Scheduling :

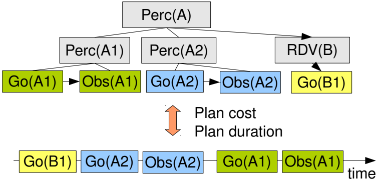


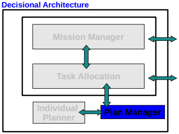


- We proposed a constrained optimization algorithm.

Plan Manager

Operating in the plan (Removing/Adding) :



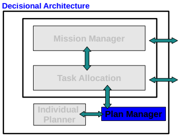


- A fast and sub-optimal incremental algorithm.

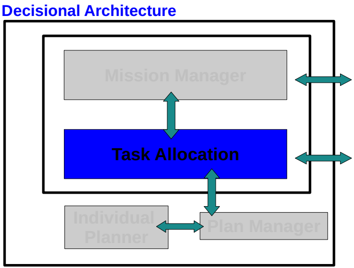
Plan Manager

Monitoring plan consistency :

- **temporal constraints** : task starting and ending deadline.
- **communication constraints** : communication rendez-vous with the base station.

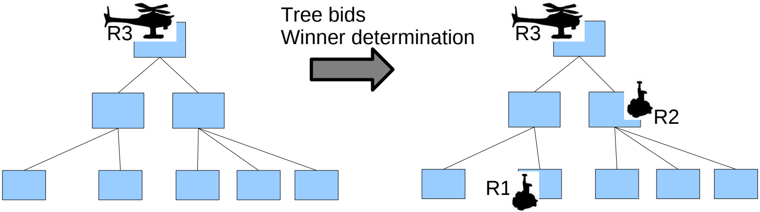


Task Allocator



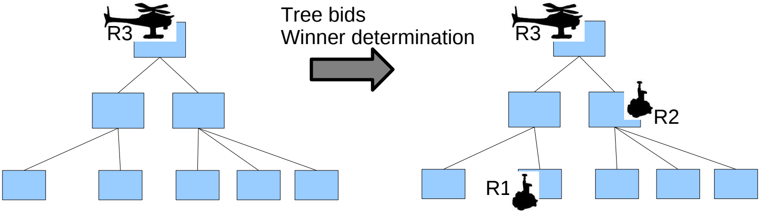
Market-based Task Allocation over complex tasks

- Interleave allocation and decomposition.



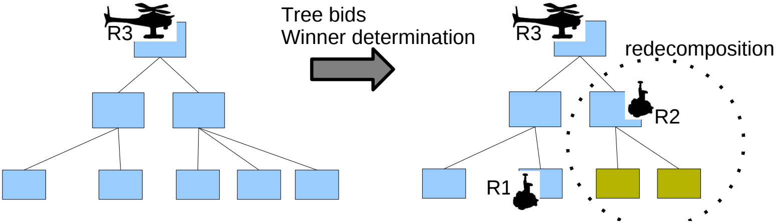
Market-based Task Allocation over complex tasks

- Interleave allocation and decomposition.
- Allocate plan instead of single tasks.

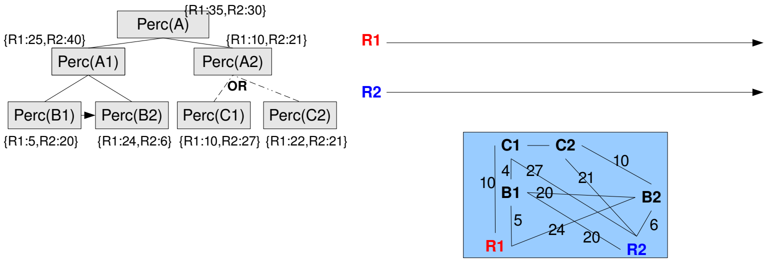


Market-based Task Allocation over complex tasks

- Interleave allocation and decomposition.
- Allocate plan instead of single tasks.
- Allow bidder to propose its own decomposition for a abstract task and the associated cost.



Task Allocator



Bidding rule and Bid valuation : Each robot computes the cost of each task $c_{val}(N)$ node in the tree with scheduling capability from *Plan Manager*. Re-decomposition cost : $c_{dec}(N)$. *Bid price* : take the minimum :

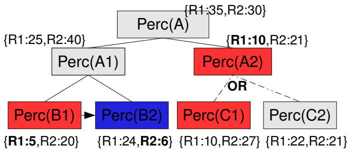
$$bid(N) = min\{c_{val}(N), c_{dec}(N)\}$$

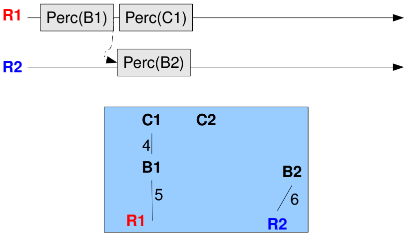
Task Allocator

Our winner determination algorithm is a two steps algorithm :

- **Input** : Reserve prices, set of bids.
- **Goal** : Choose a set of cost-minimizing bids subject to
  1. Optimal tree with dynamic programming algorithm (bottom-top walk).
  2. Communication inconsistencies resolution. Resolution requests are sent to related robots. A new winner determination process is done with new bids.

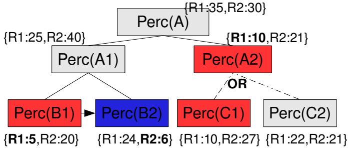
Task Allocator

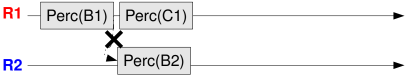




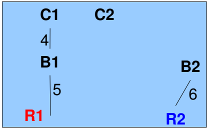
WDA Phase 1 : Clearing the tree to get the optimal tree. Bold costs are the winners.

Task Allocator



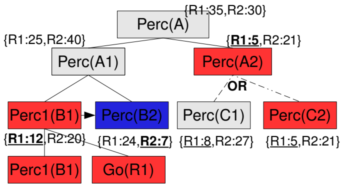


Com. impossible between (R1,B1) and (R2,B2)

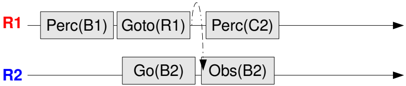


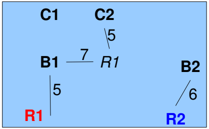
WDA Phase 2 : Detect communication constraint violation, ask resolution request to *R1* and *R2*.

Task Allocator



Global plan cost : 17 + 6 = 23





WDA Phase 2 : *R1* proposes a new tree with communication task. New costs are underlined.

Outline

1. Introduction
2. Problem Formulation
3. Approach Overview
4. System description
   - Plan Formalism
   - Mission Manager
   - Individual Planner and Specific Refiners
   - Plan Manager
   - Task Allocator
5. Conclusions

Conclusions

- Work in progress :
  - Done : Specific refiners, Communication infrastructure.
  - In progress : Plan Manager and Task Allocator.

Conclusions

- System's Expectations :
  - Able to reason about *hard* communication and temporal constraints with *Plan Manager*.
  - Yields better solution quality than systems with allocation over simple tasks.

Conclusions

- Questions.