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Multi-Agent Consensus-based Bundle Allocation for Multi-Mode Composite Tasks

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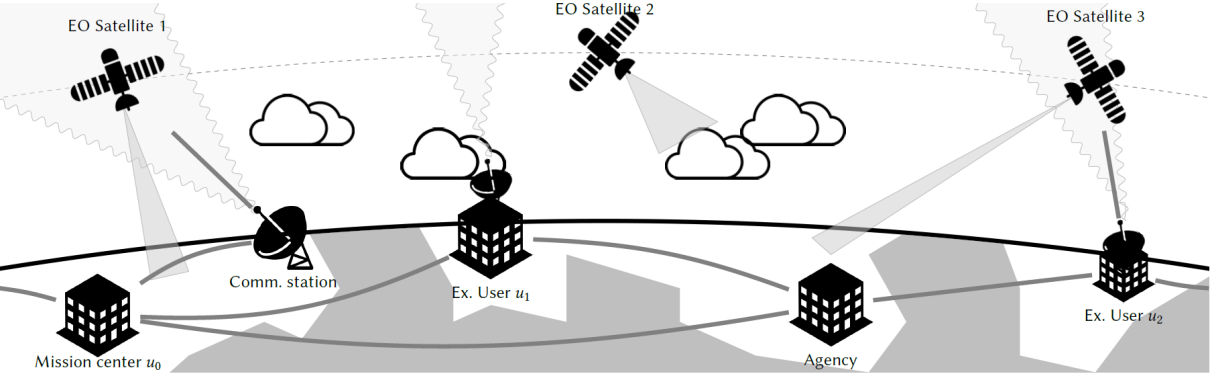
ONERA, DTIS-SYD, Université de Toulouse

How to coordinate schedules in private slots?



- Multiple slot owners having **private plans**
- External **complex tasks** requiring **access to some private slots**
- Complex tasks may be fulfilled in different manners (**modes**)

The Problem: MACTA

Multi-agent multi-mode composite task allocation problem

- a set of agents $\mathcal{A}$
- a set of disjunctive resources $\mathcal{R}$
- a set of requests/composite tasks $\mathring{\mathcal{T}}$
  - composed of multiple atomic tasks (with respective reward)
  - can be fulfilled in different manners (**modes**) with different rewards

Objective: finding the allocation of atomic tasks to agents which **maximizes the sum of scheduled request rewards**, whilst meeting **schedule consistency** constraints

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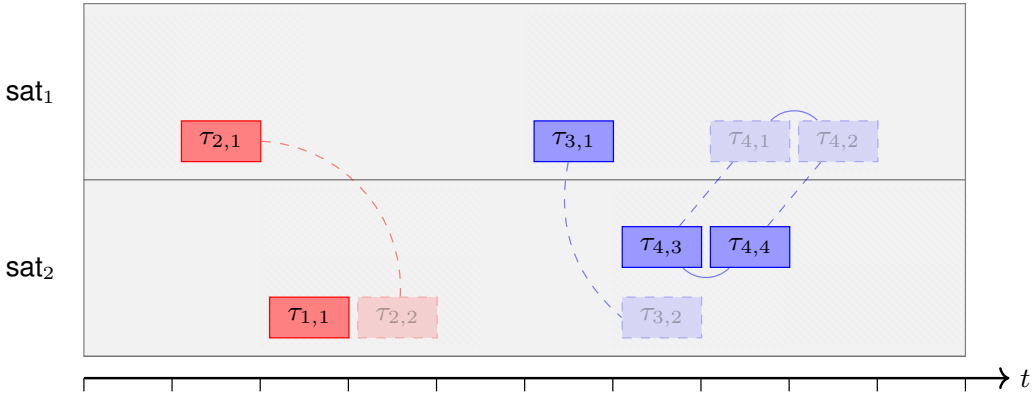
Objective: finding the allocation of atomic tasks to agents which **maximizes the sum of scheduled request rewards**, whilst meeting **schedule consistency** constraints

Do not disclose private plan
Some requests may require access to multiple private slots

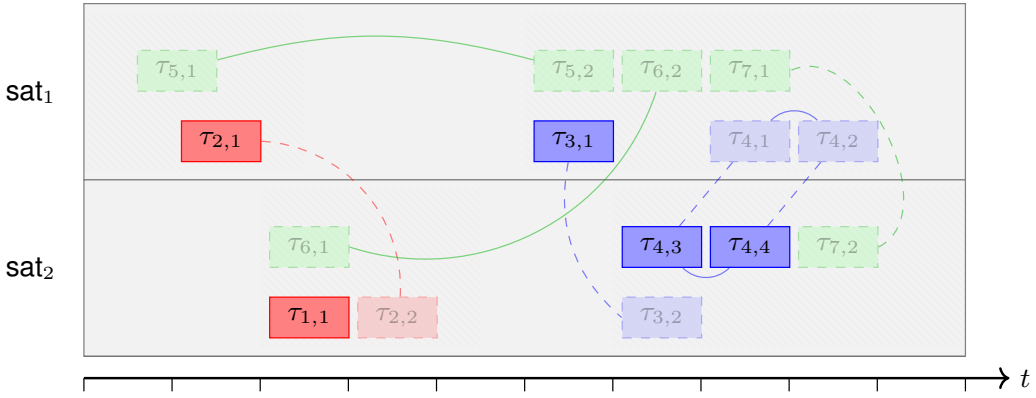
MACTA Example

Private plans



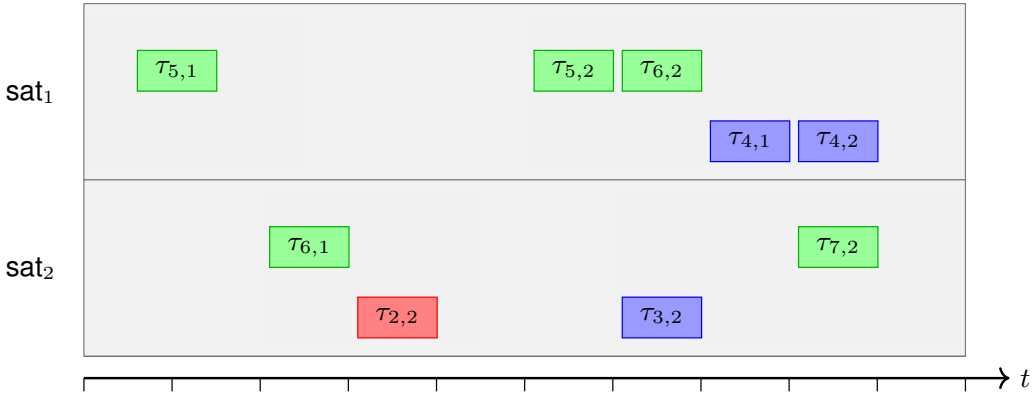
MACTA Example

New requests incoming



MACTA Example

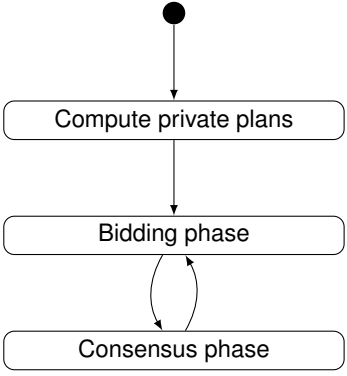
Coordinated optimal solution



The Algorithm: MM-CBGA

Principle

- **M**ulti-**M**ode **C**onsensus-**B**ased **G**rouping **A**lgorithm
- Several agents required for some **multi-agent tasks**
- Extends CGBA to **multi-mode** [HUNT et al., 2014]
  - **Bids on modes** instead of tasks
  - Not dedicated to path-following agents
  - **Multiple private slots** per agents
- Follow a bidding-consensus cycle



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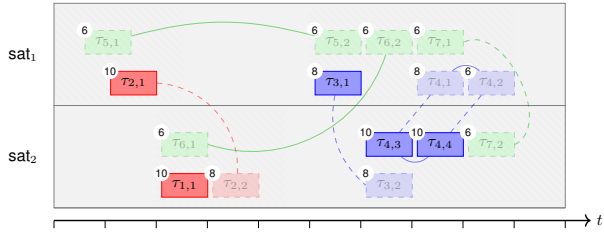
Example



$\beta_{u_1} = \{\}$ $\beta_{u_2} = \{\}$

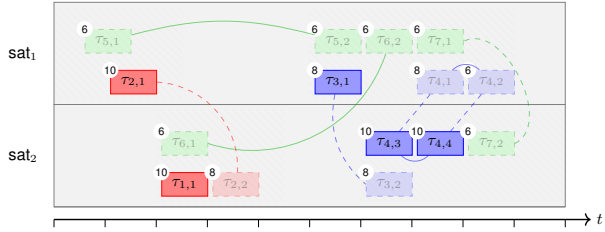
The Algorithm: MM-CBGA

Example

Agent u_1 bids on modes

- $m_{5,1} = \{\tau_{5,1}, \tau_{5,2}\}$:
  - without : $\omega = 10 + 10 = 20$
  - with : $\omega^{m_{5,1}} = 10 + 8 + 6 = 24$

  $\rightarrow$ bid $b_{u_1}[\mathring{\tau}_5][m_{5,1}][u_1] = 4 > 0$ but incomplete



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- $b_{u_1}[\mathring{\tau}_5][m_{5,1}][u_1] = 4$

The Algorithm: MM-CBGA

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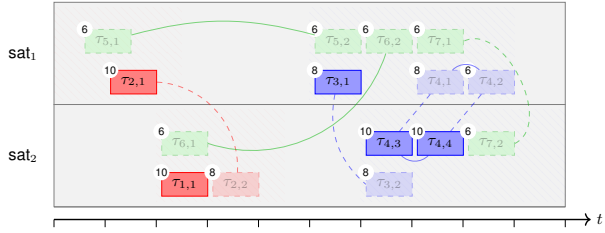
- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
  - without : $\omega = 20$
  - with : $\omega^{m_{6,1}} = 10 + 0 + 6 = 16$

  $\rightarrow$ bid $b_{u_1}[\mathring{\tau}_6][m_{6,1}][u_1] = -4 \leq 0$



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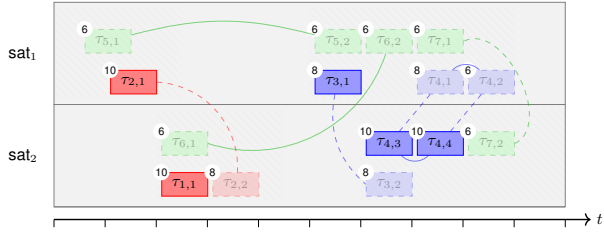
Example



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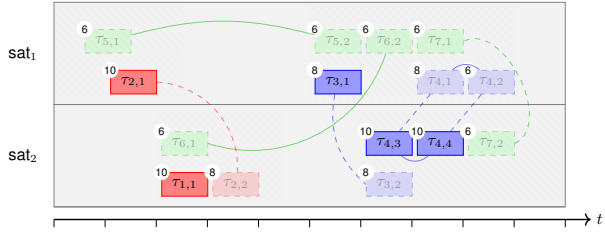
Example

Agent u_2 bids on modes

- $m_{5,1} = \{\tau_{5,1}, \tau_{5,2}\}$:
  - without : $\omega = 8 + 10 + 10 = 28$
  - with : $\omega^{m_{5,1}} = 8 + 8 + 6 + 6 = 28$

  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_5][m_{5,1}][u_2] = 0 \leq 0$



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- $b_{u_1}[\mathring{\tau}_5][m_{5,1}][u_1] = 4$
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- $b_{u_2}[\mathring{\tau}_5][m_{5,1}][u_2] = 0$

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Agent u_2 bids on modes

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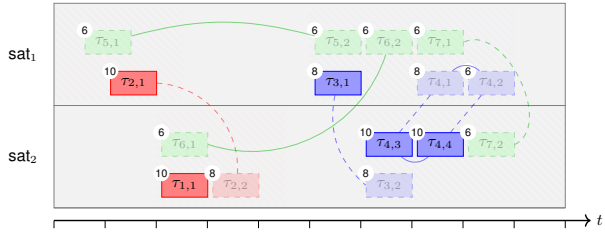
- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
  - without : $\omega = 28$
  - with : $\omega^{m_{6,1}} = 28 + 6 = 34$

  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_6][m_{6,1}][u_2] = 6 > 0$ but incomplete



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- $b_{u_1}[\mathring{\tau}_6][m_{6,1}][u_1] = -4$

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- $b_{u_2}[\mathring{\tau}_5][m_{5,1}][u_2] = 0$
- $b_{u_2}[\mathring{\tau}_6][m_{6,1}][u_2] = 6$

The Algorithm: MM-CBGA

Example

Agent u_2 bids on modes

- $m_{5,1} = \{\tau_{5,1}, \tau_{5,2}\}$:
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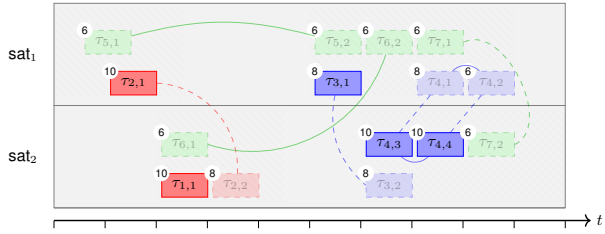
  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_5][m_{5,1}][u_2] = 0 \leq 0$
- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
  - without : $\omega = 28$
  - with : $\omega^{m_{6,1}} = 28 + 6 = 34$

  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_6][m_{6,1}][u_2] = 6 > 0$ but incomplete
- $m_{7,1} = \{\tau_{7,1}\}$:
  - without : $\omega = 28$
  - with : $\omega^{m_{7,1}} = 28 + 6 = 34$

  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_7][m_{7,1}][u_2] = 6 > 0$



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- $b_{u_2}[\mathring{\tau}_5][m_{5,1}][u_2] = 0$
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- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
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  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_7][m_{7,1}][u_2] = 6 > 0$
- $m_{7,2} = \{\tau_{7,2}\}$:
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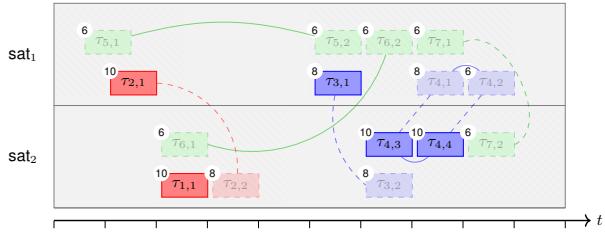
  - with : $\omega^{m_{7,2}} = 28 + 6 = 34$

  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_7][m_{7,2}][u_2] = 6 > 0$



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- $b_{u_1}[\mathring{\tau}_5][m_{5,1}][u_1] = 4$
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- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
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- $m_{7,1} = \{\tau_{7,1}\}$:
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- $m_{7,2} = \{\tau_{7,2}\}$:
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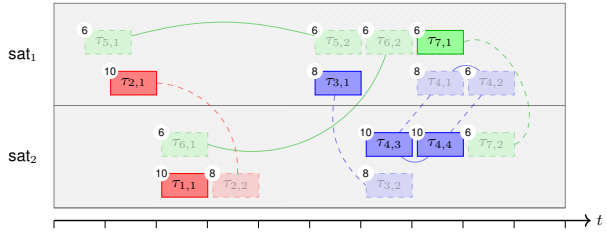
  $\rightarrow$ bid $b_{u_2}[\mathring{\tau}_7][m_{7,2}][u_2] = 6 > 0$

$\rightarrow$ add $m_{7,1}$ to bundle



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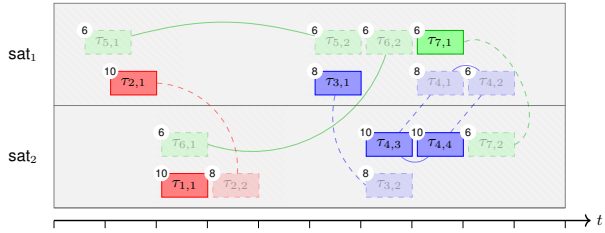
The Algorithm: MM-CBGA

Example

- Agents send their bid (+ extra infos)



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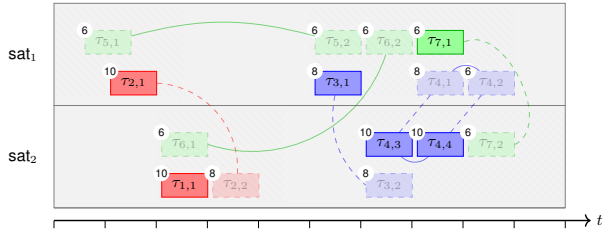
Example

- Consensus phase
  1. Aggregate bids
  2. Check inconsistencies
  3. Destroy bundle up to inconsistent mode



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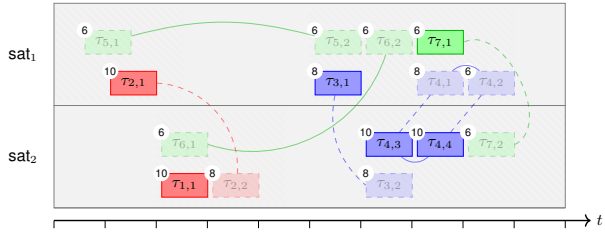
  $\rightarrow$ $\sum b_{u_i}[\mathring{\tau}_5][m_{5,1}][u_i] = 4 > 0$ and complete



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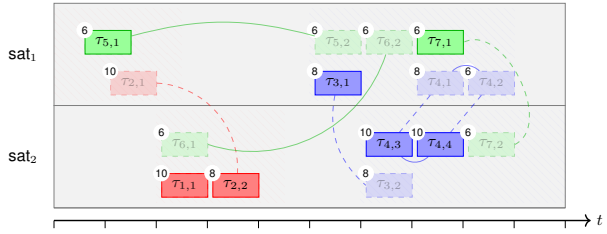
  $\rightarrow$ add $m_{5,1}$ to bundle



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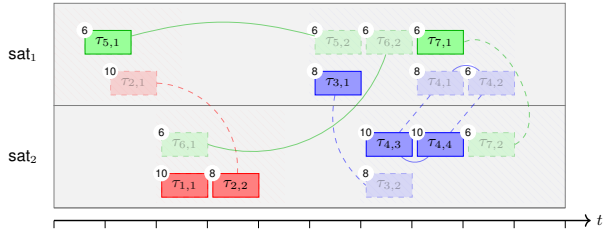
  - without : $\omega = 10 + 10 = 20$
  - with : $\omega^{m_{5,1}} = 10 + 8 + 6 = 24$

  $\rightarrow \sum b_{u_i}[\mathring{\tau}_5][m_{5,1}][u_i] = 4 > 0$ and complete

  $\rightarrow$ add $m_{5,1}$ to bundle
- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
  - without : $\omega = 24$
  - with : $\omega^{m_{6,1}} = 8 + 6 + 6 = 20$

  $\rightarrow \sum b_{u_i}[\mathring{\tau}_6][m_{6,1}][u_i] = 2 > 0$ and complete



$\beta_{u_1} = \{m_{5,1}\}$

- $b_{u_1}[\mathring{\tau}_5][m_{5,1}][u_1] = 4$
- $b_{u_1}[\mathring{\tau}_6][m_{6,1}][u_1] = -4$

$\beta_{u_2} = \{m_{7,1}\}$

- $b_{u_2}[\mathring{\tau}_5][m_{5,1}][u_2] = 0$
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The Algorithm: MM-CBGA

Example

Agent u_1 bids on modes

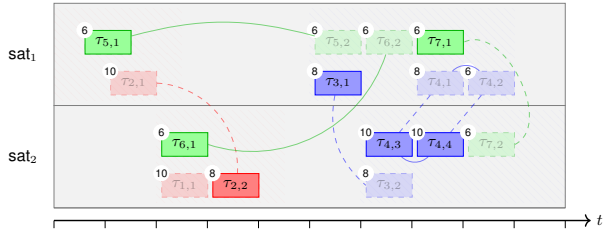
- $m_{5,1} = \{\tau_{5,1}, \tau_{5,2}\}$:
  - without : $\omega = 10 + 10 = 20$
  - with : $\omega^{m_{5,1}} = 10 + 8 + 6 = 24$

  → $\sum b_{u_i}[\mathring{\tau}_5][m_{5,1}][u_i] = 4 > 0$ and complete

  → add $m_{5,1}$ to bundle
- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
  - without : $\omega = 24$
  - with : $\omega^{m_{6,1}} = 8 + 6 + 6 = 20$

  → $\sum b_{u_i}[\mathring{\tau}_6][m_{6,1}][u_i] = 2 > 0$ and complete

  → add $m_{6,1}$ to bundle but discard $\tau_{1,1}$



$\beta_{u_1} = \{m_{5,1}, m_{6,1}\}$

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$\beta_{u_2} = \{m_{7,1}\}$

- $b_{u_2}[\mathring{\tau}_5][m_{5,1}][u_2] = 0$
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- $b_{u_2}[\mathring{\tau}_7][m_{7,2}][u_2] = 6$

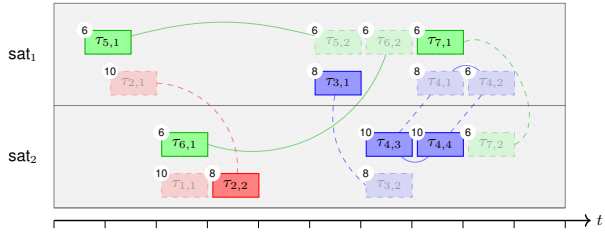
The Algorithm: MM-CBGA

Example

Agent u_2 bids on modes

- $m_{5,1} = \{\tau_{5,1}, \tau_{5,2}\}$:
  - without : $\omega = 8 + 10 + 10 + 6 = 34$
  - with : $\omega^{m_{5,1}} = 10 + 10 + 6 + 6 = 32$

  $\rightarrow$ $\sum b_{u_i}[\mathring{\tau}_5][m_{5,1}][u_i] = 2 > 0$
  and complete



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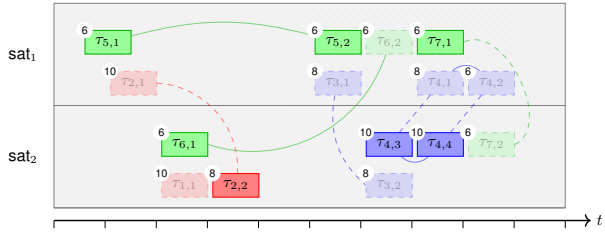
  and complete

  → add $m_{5,1}$ to bundle, but discard $\tau_{3,1}$



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The Algorithm: MM-CBGA

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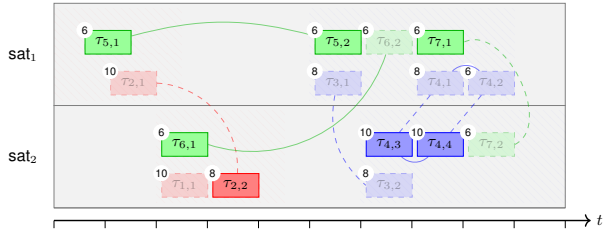
  - without : $\omega = 8 + 10 + 10 + 6 = 34$
  - with : $\omega^{m_{5,1}} = 10 + 10 + 6 + 6 = 32$

  $\rightarrow \sum b_{u_i}[\mathring{\tau}_5][m_{5,1}][u_i] = 2 > 0$
  and complete
  $\rightarrow$ add $m_{5,1}$ to bundle, but discard $\tau_{3,1}$
- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
  - without : $\omega = 32$
  - with : $\omega^{m_{6,1}} = 32 + 6 = 38$

  $\rightarrow \sum b_{u_i}[\mathring{\tau}_6][m_{6,1}][u_i] = 2 > 0$
  and complete



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- $b_{u_2}[\mathring{\tau}_7][m_{7,2}][u_2] = 6$

The Algorithm: MM-CBGA

Example

Agent u_2 bids on modes

- $m_{5,1} = \{\tau_{5,1}, \tau_{5,2}\}$:
  - without : $\omega = 8 + 10 + 10 + 6 = 34$
  - with : $\omega^{m_{5,1}} = 10 + 10 + 6 + 6 = 32$

  $\rightarrow \sum b_{u_i}[\mathring{\tau}_5][m_{5,1}][u_i] = 2 > 0$
  and complete

  $\rightarrow$ add $m_{5,1}$ to bundle, but discard $\tau_{3,1}$
- $m_{6,1} = \{\tau_{6,1}, \tau_{6,2}\}$:
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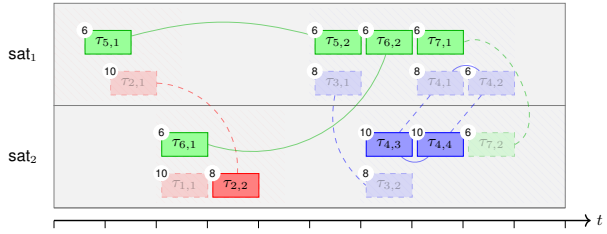
  - with : $\omega^{m_{6,1}} = 32 + 6 = 38$

  $\rightarrow \sum b_{u_i}[\mathring{\tau}_6][m_{6,1}][u_i] = 2 > 0$
  and complete

  $\rightarrow$ add $m_{6,1}$ to bundle



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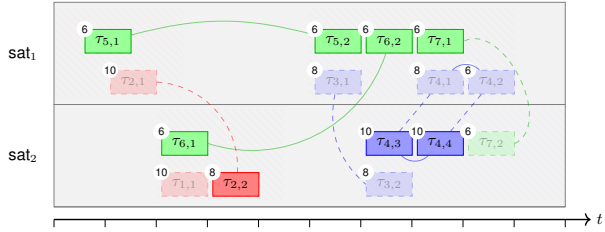
- $b_{u_2}[\mathring{\tau}_7][m_{7,2}][u_2] = 6$

The Algorithm: MM-CBGA

Example

- No more conflicts!
- The system stabilizes (guaranteed!) with reward 58
- But not optimal, since $m_{7,1}$ has been decided early in the process
- By choosing $m_{7,2}$ instead, optimality is reached with reward 60



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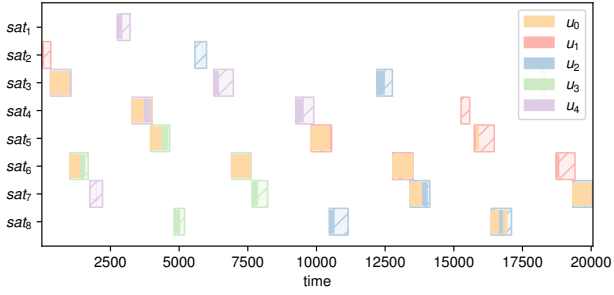
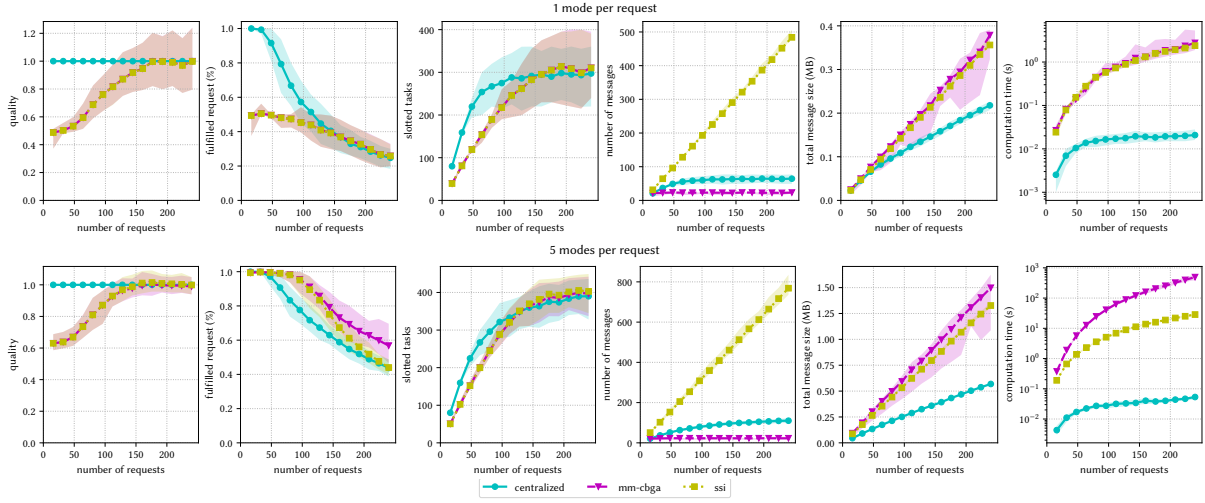
The Experiments: EOSCSP

Problem Settings

- Randomly generated Earth observation scheduling problems (EOSCSP) available on Zenodo (`https://doi.org/10.5281/zenodo.7550677`)
- 8 satellites, 4 orbit slots owners coordinate with MACTA to accept new requests
- 16 to 240 requests for randomly chosen POIs (10 amongst 27 European cities)
- Two configurations: 1 mode per request and 5 modes per request



The Experiments: EOSCSP (cont.)



Conclusion

Summary

- New allocation problem (MACTA)
- A novel algorithm (MM-CBGA) to solve MACTA in a decentralized fashion
  - Performances equivalent to SSI
  - Same quality than the centralized solver on larger and harder instances
  - Requires less steps to converge but more time than SSI on larger instances
  - Requires less, but larger messages
- Instances available on Zenodo

Perspectives

- Better heuristics and upper bounds to consider requests and modes (e.g. modes included in others)
- Evaluate and compare performances of other coordination mechanisms on MACTA (e.g. DCOP)
- Online dynamic order books, with unpredictable events due to weather conditions than can discard some tasks due to cloud coverage

Acknowledgements

This work has been performed with the support of the French government in the context of the “Programme d’Invertissements d’Avenir”, namely by the BPI PSPC project “LiChIE”

We are hiring!

Post-doc researcher
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AI, MAS and Optimization
for
Managing Multi-Constellation Systems