A Flexible Distributed Scheduling Scheme for Dynamic Expeditionary Strike Group (ESG) Mission Environments

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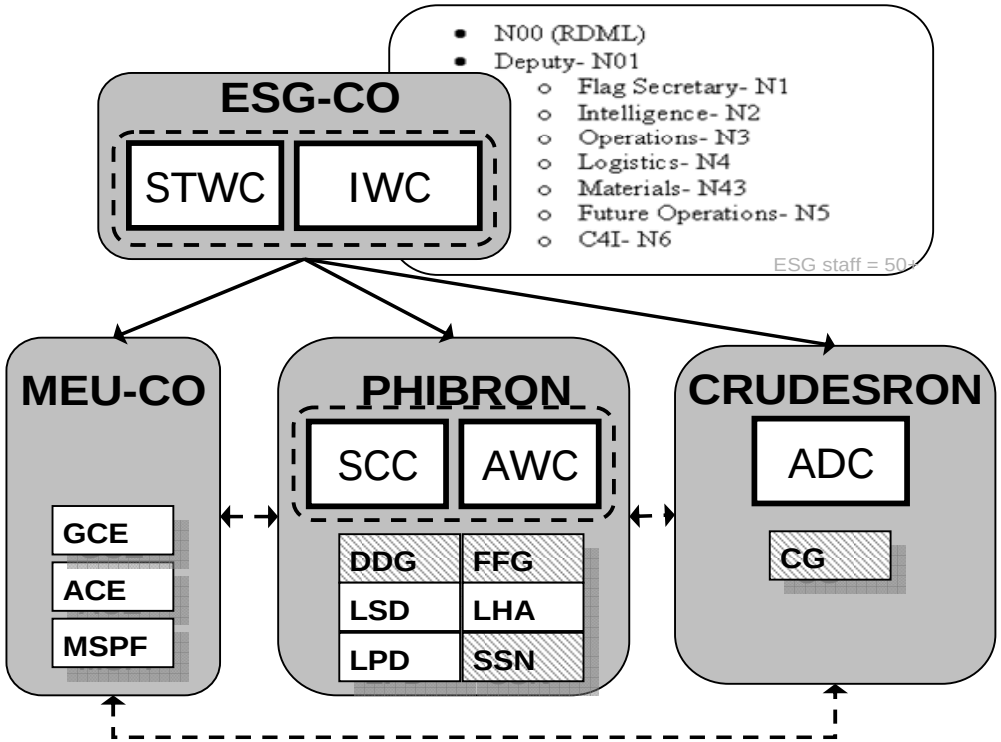
Outline

- A Flexible Distributed Scheduling Scheme for Dynamic ESG Environments
  - ESG Planning Challenges
  - Multi-objective Model for Distributed Scheduling
  - Multi-Objective Optimization and Evolutionary Algorithms (MOEA)
  - Five-step Process for Flexible Distributed Schedule
  - Summary

Expeditionary Strike Group (ESG)



- ESG-CO:
  Expeditionary Strike Group Commander
- MEU-CO:
  Marine Expeditionary Unit Commander
- PHIBRON:
  Amphibious Squadron Commander
- CRUDESRON: AGEGIS Cruiser Commander

- ADC: Air Defense Commander
- AWC: Amphibious Warfare Commander
- IWC: Information Warfare Commander
- SCC: Sea Combat Commander
- STWC: Strike Warfare Commander

- ACE: Air Combatl Element
- GCE: Ground Combatl Element
- MSPF: Maritime Special Purpose Force
- DDG: Destroyer Ship
- FFG: Frigate Ship
- LSD: Dock Landing Ship
- LHA: Amphibious Assault Ship
- LPD: Amphibious Transport Dock Ship
- SSN: Submarine
- CG: Cruiser Ship

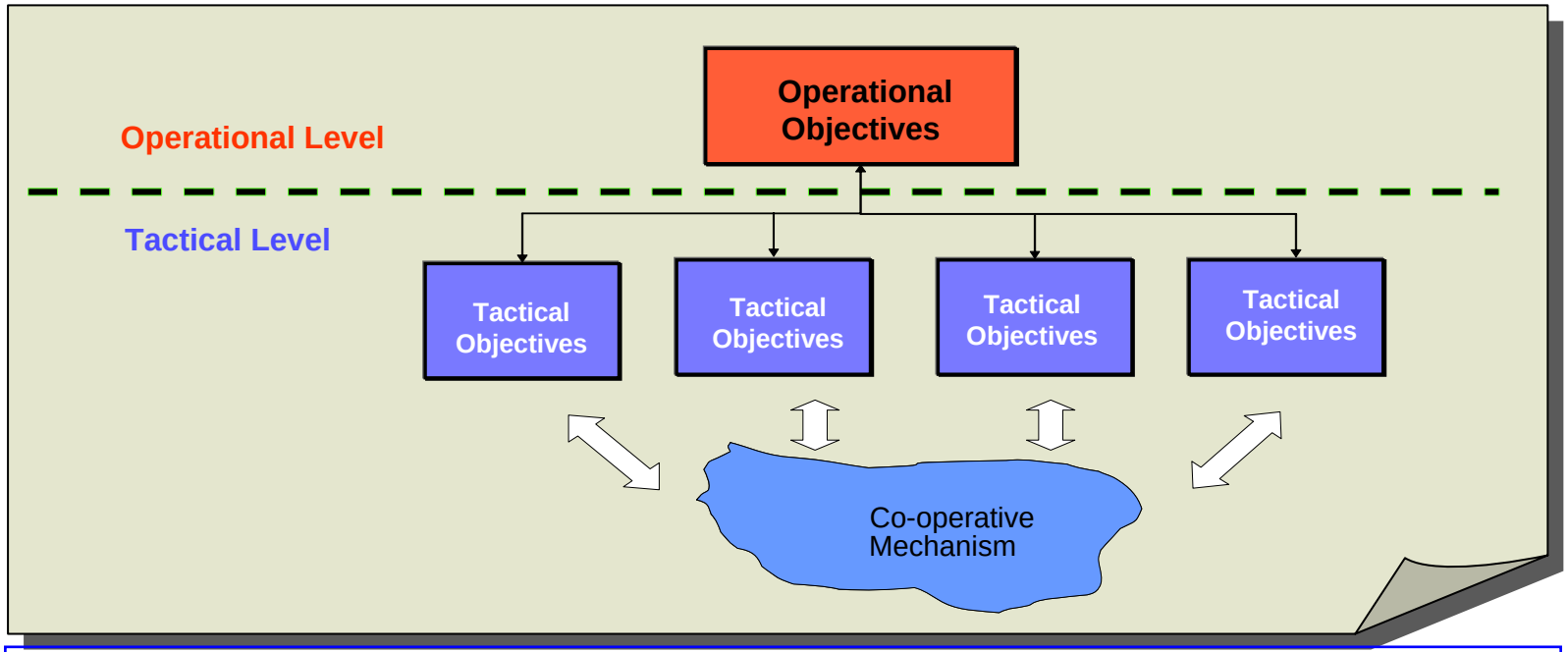
❑ An Expeditionary Strike Group (ESG) is a new US Navy task force that integrates navy warships and marines so that

- Assemble a specific package of assets to combat a specific threat
- leverage the synergistic effects of a unit that trained together for a broad set of missions
- build an organization that could either be as small task force or a larger joint task force

ESG Planning Challenges

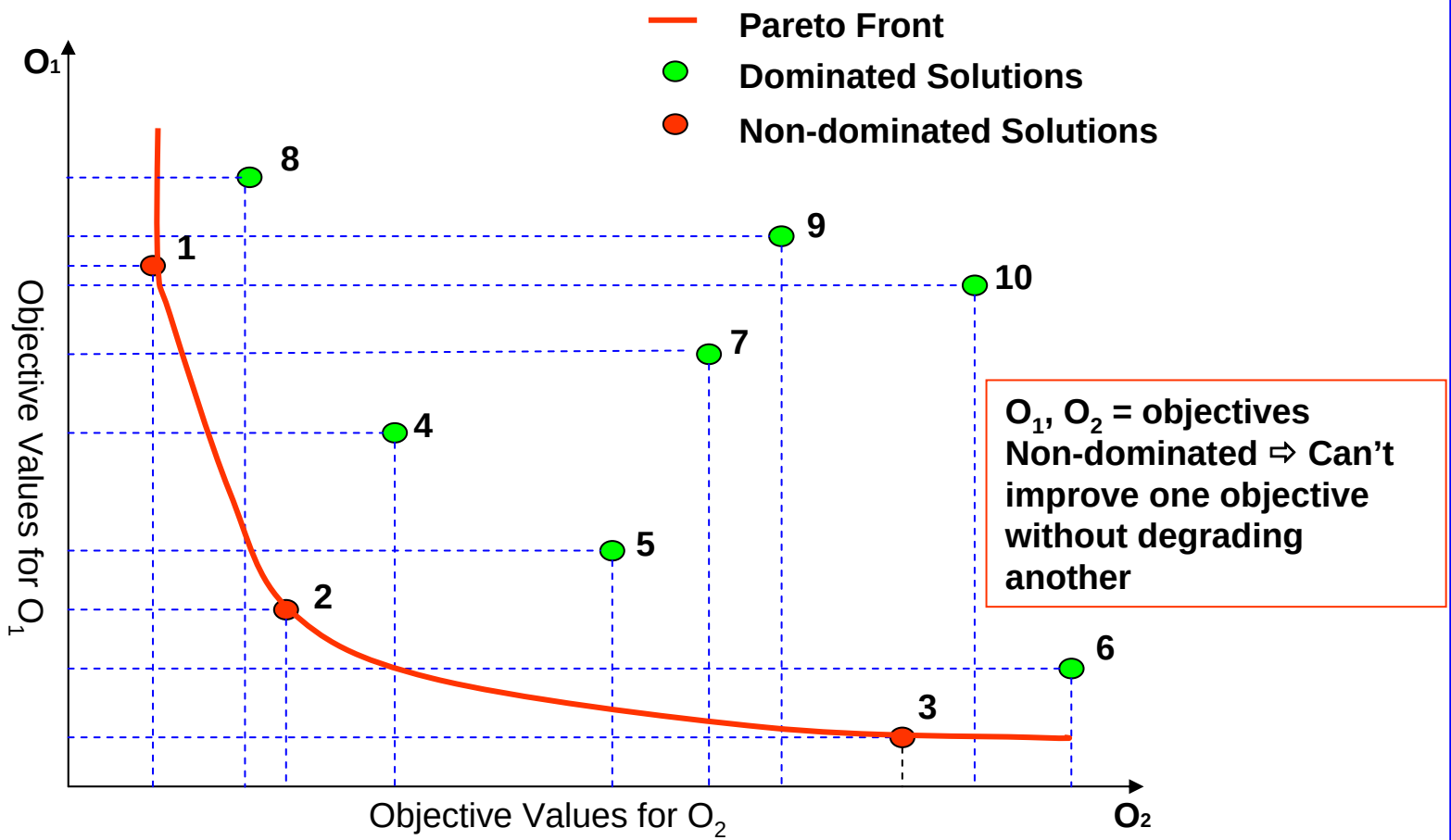
- **Scarcity of Resources**: ESG units are provided with limited resources to accomplish their objectives. The capabilities of resources may degrade after each operation (e.g., require maintenance) and some assets may breakdown due to incidents
- **Concurrent Operations**: conducting multiple concurrent operations that span the entire spectrum of missions is an integral part of an ESG. A complicating factor is that ESG units are being tasked with many unanticipated operations that are not planned for or scheduled a priori
- **Dispersed Operations**: ESG's assets are likely to be dispersed geographically to some location outside the immediate battle-space. At the same time, ESG is required to detach assets to support other commanders, and to assume control of additional assets from coalition partners
- **Conflicts between Local Priorities and Global Mission Objectives**: requires a new planning/scheduling scheme able to resolve priority conflicts among high-level and low-level ESG units

Multi-objective Model for Distributed Scheduling



- **Operational Level Objectives:**
  - Maximize Task Completion Accuracy ("mission success")
  - Minimize the Makes-pan of Mission Execution ("speed of command")
- **Tactical Level Objectives:**
  - Maximize Task Completion Accuracy
  - Allocate Resources to Minimize Task Execution Cost (Time including Coordination)
- **Co-operative Mechanism:**
  - Task announcement
  - Contracting
  - Coordinated Task Execution

Multi-objective Optimization (MO)



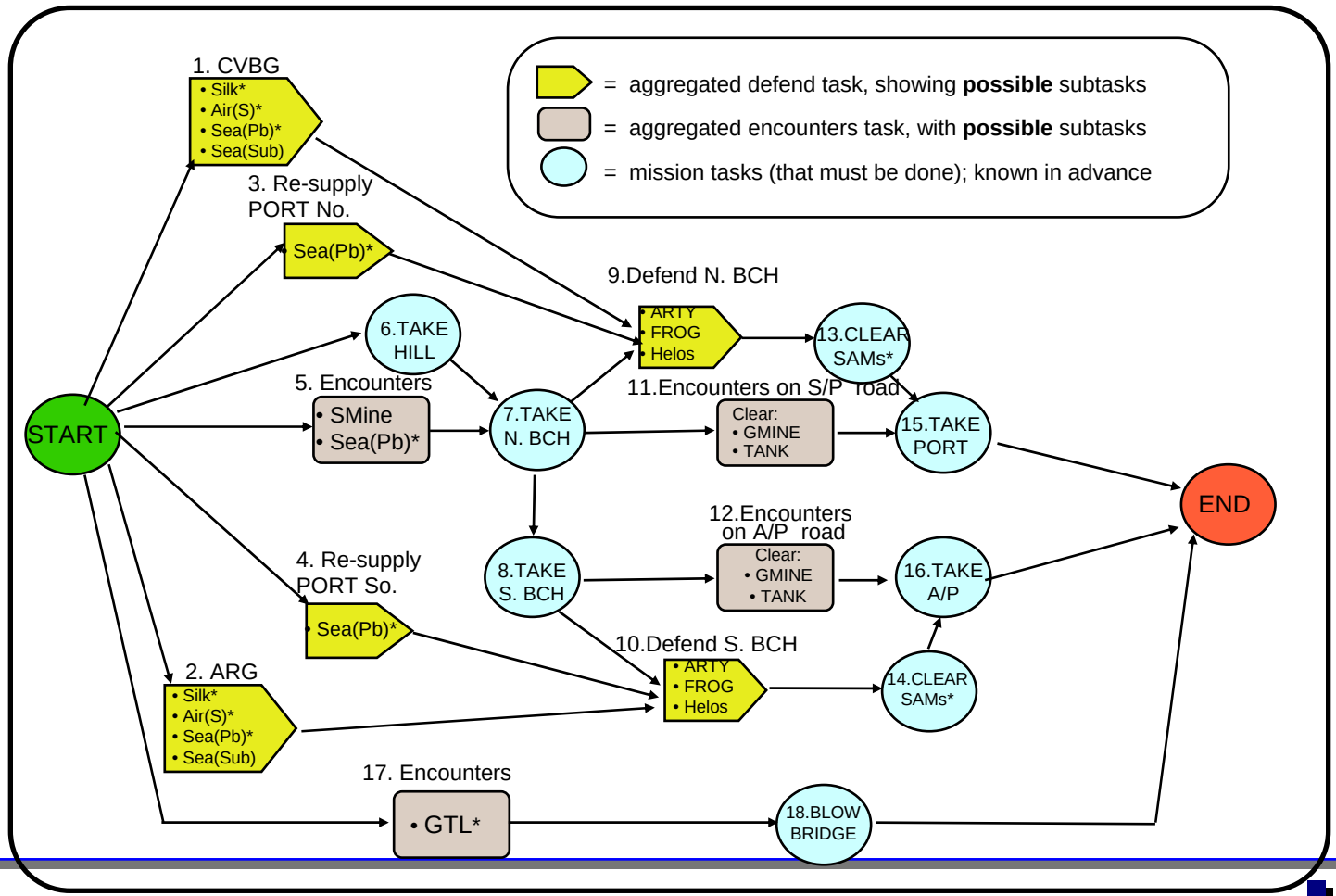
- Real world optimization problems often involve more than one objective, which may be conflicting with each other, thus, no global optimum can be found
- Pareto-based MO focuses on finding a set of promising solutions, namely, Pareto front, from which a solution can be chosen

Evolutionary Algorithms (EA) for MO

- Fitness Assignment
  - Pareto Ranking: an individual's rank corresponds to the number of individuals in current population by which it is dominated
  - Non-dominated Sorting: individuals are classified according to their non-dominance and fitness are shared in one class
- Elitism – *keep elitists in population*
  - Archiving: archive Pareto optimal solutions found so far during search
  - Recombination: include more high ranked individuals than low ranked in next generation
- Niching – *keep diversity of population*
  - Fitness Sharing: reduce the payoff of the fitness of individuals in one area
  - Crowding: only fraction of crowd individuals is selected to produce offspring

Illustrative Example

Mission: Assign a joint group of Navy and Marine Forces to capture a Seaport and take an Airport to allow for the introduction of follow-on forces. Utilize two suitable landing beaches: North Beach with a road leading to the Seaport; and South Beach with another road leading to the Airport. Intelligence sources report existence of hostile forces and potential counter-strikes.

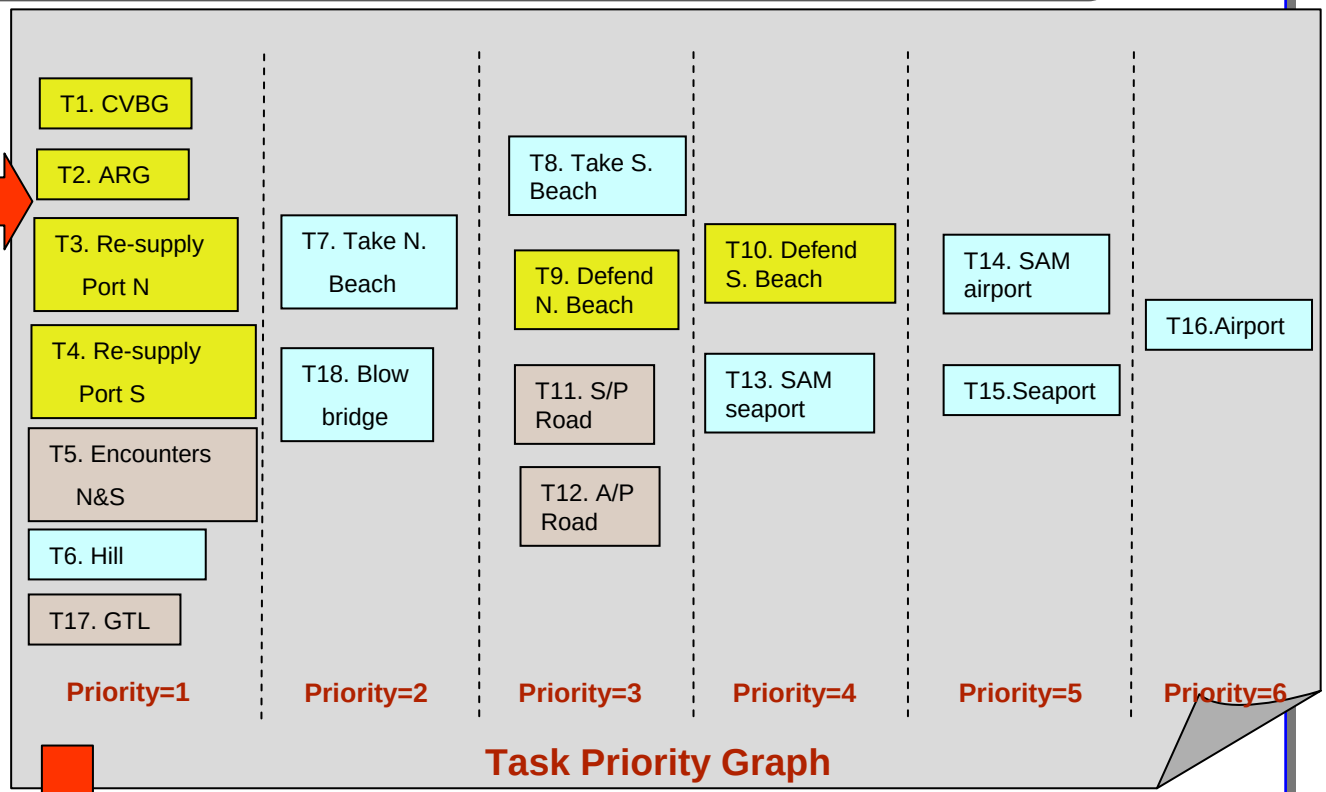


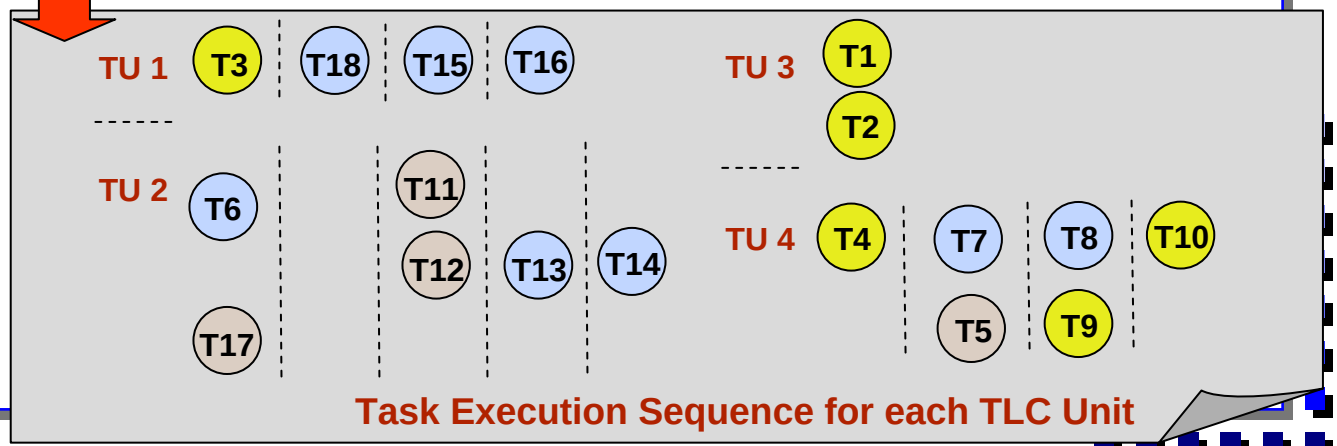
Solution Methodology for Flexible Distributed Scheduling - 1

Task precedence Graph

Step 1: Central Plan Decomposition

The task precedence graph is first decomposed based on task priorities, and then distributed among the tactical units





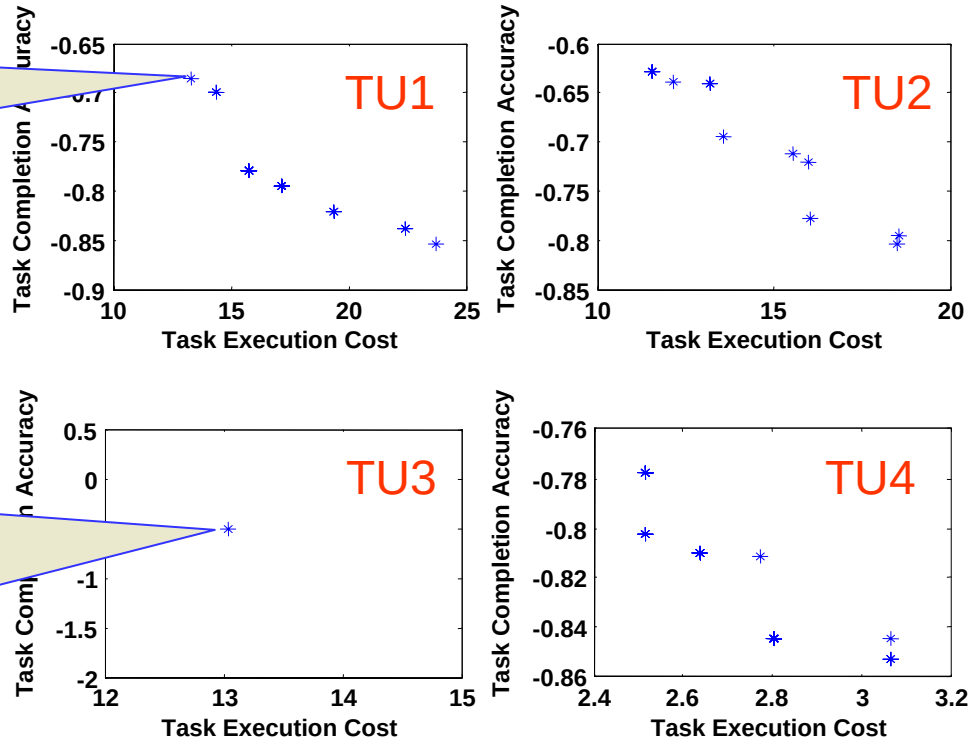
Solution Methodology for Flexible Distributed Scheduling - 2

Step 2: Tactical level Scheduling

- **Objectives:**
  - Maximize task execution accuracy
  - Allocate Resources to Minimize Task Execution Cost (Time including Coordination)

Corresponding to each solution in Pareto fronts, there is a local task-asset schedule

Not every TU can generate multiple local schedules. The more local schedules generated, the higher flexibility of global schedule will obtain

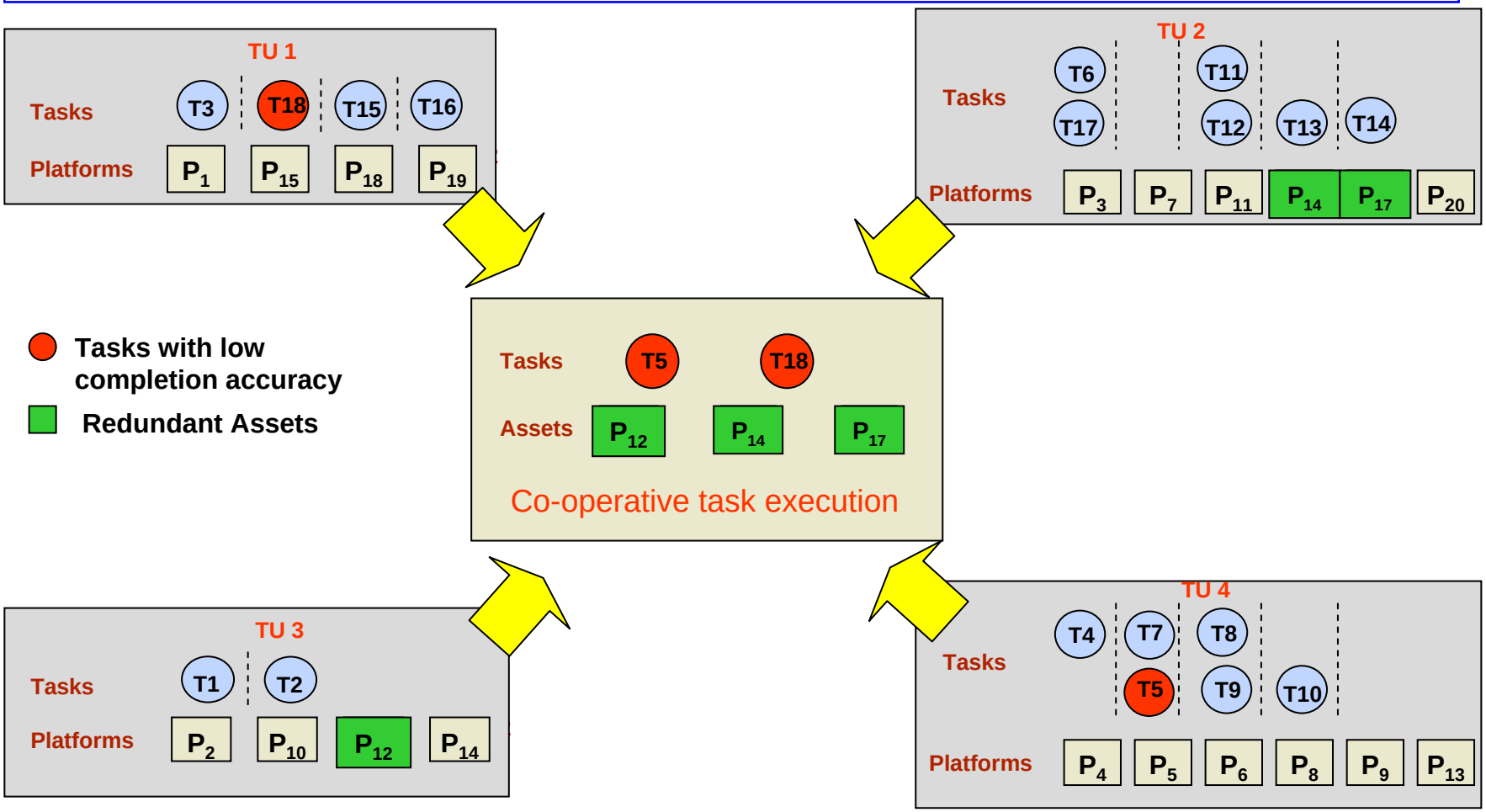


Pareto Fronts found for TU_1-TU_4

Solution Methodology for Flexible Distributed Scheduling - 3

Step 3: Co-operative Resource Re-deployment (single optimization problem)

- **Objectives:**
  - Re-deploy resources to coordinate on tasks with low accuracy
  - Maximize the mean task completion accuracy



Solution Methodology for Flexible Distributed Scheduling - 4

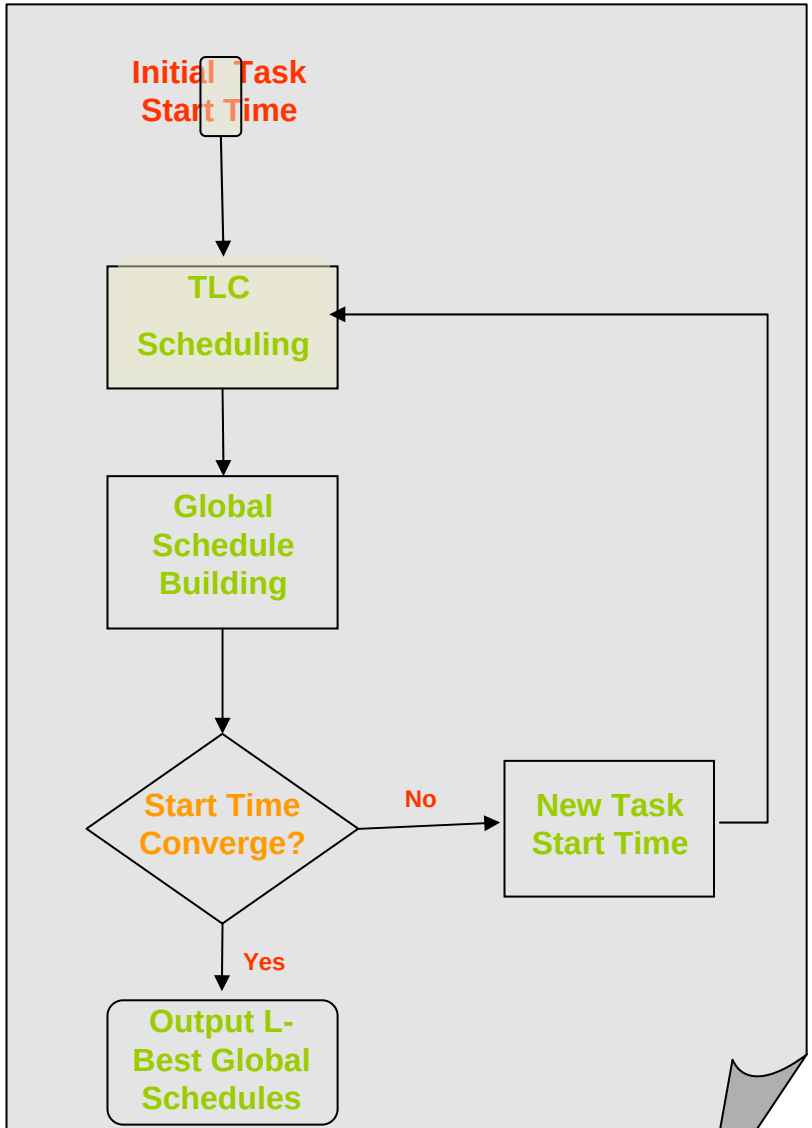
Step 4: Operational Level Global Schedule Building

- **Objectives:**
  - optimize operational level objectives (mission success and speed of command)
  - assemble local schedules into a global schedule
  - resolve conflicts among local schedules and ensure the feasibility of global schedule
- **Global Schedule Building Process:**
  - *Right-shifting*

    local TU schedules are reassembled according to the task graph. The start times of tasks that have precedence constraints will be shifted to a time when all its preceding tasks have been accomplished
  - *How to achieve the stability of schedule?*

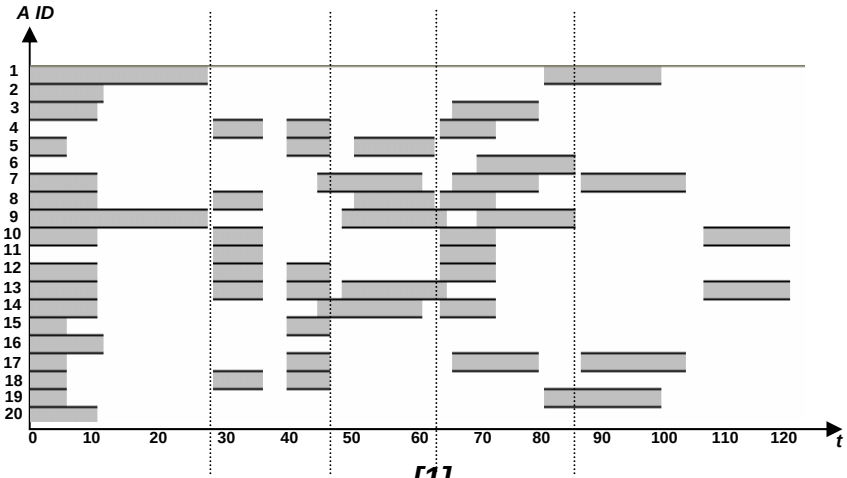
    Iteratively right-shift using new start times at each iteration till the schedule converges.
- **Outputs:**

  L-neighboring schedules



Global Schedule Building Process

L-Neighboring Schedules



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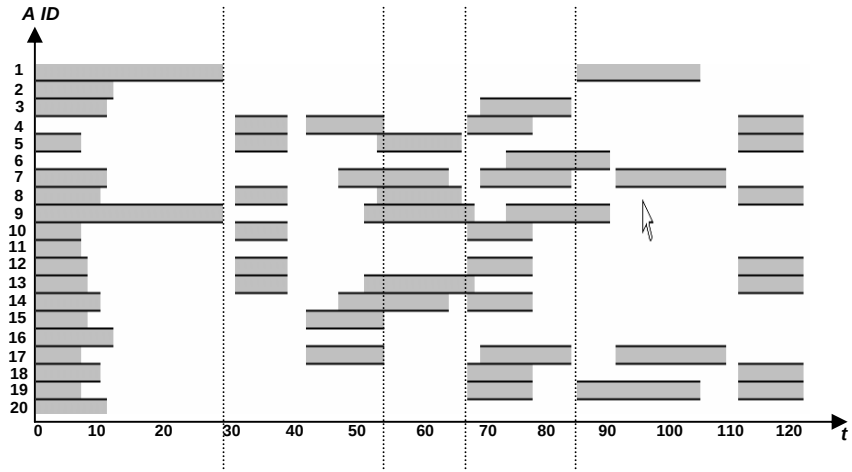

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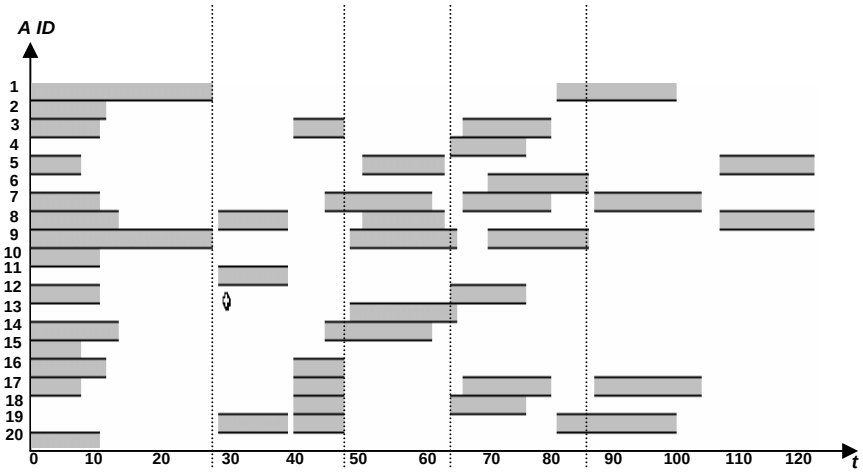

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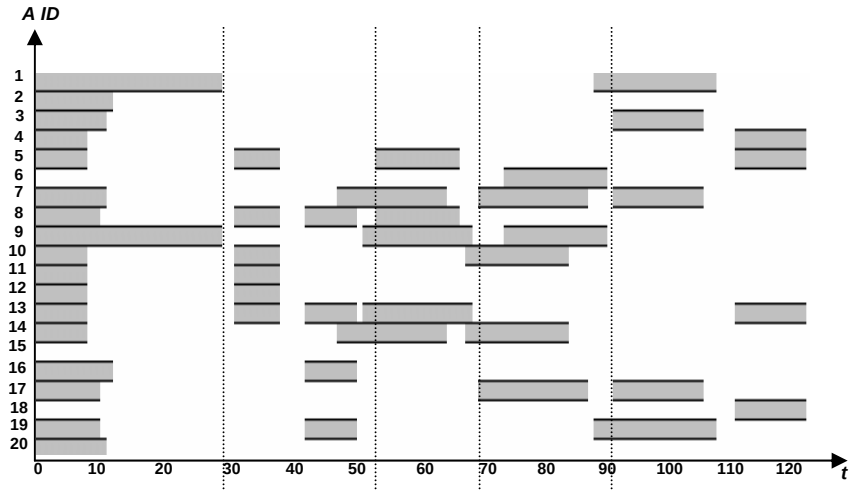

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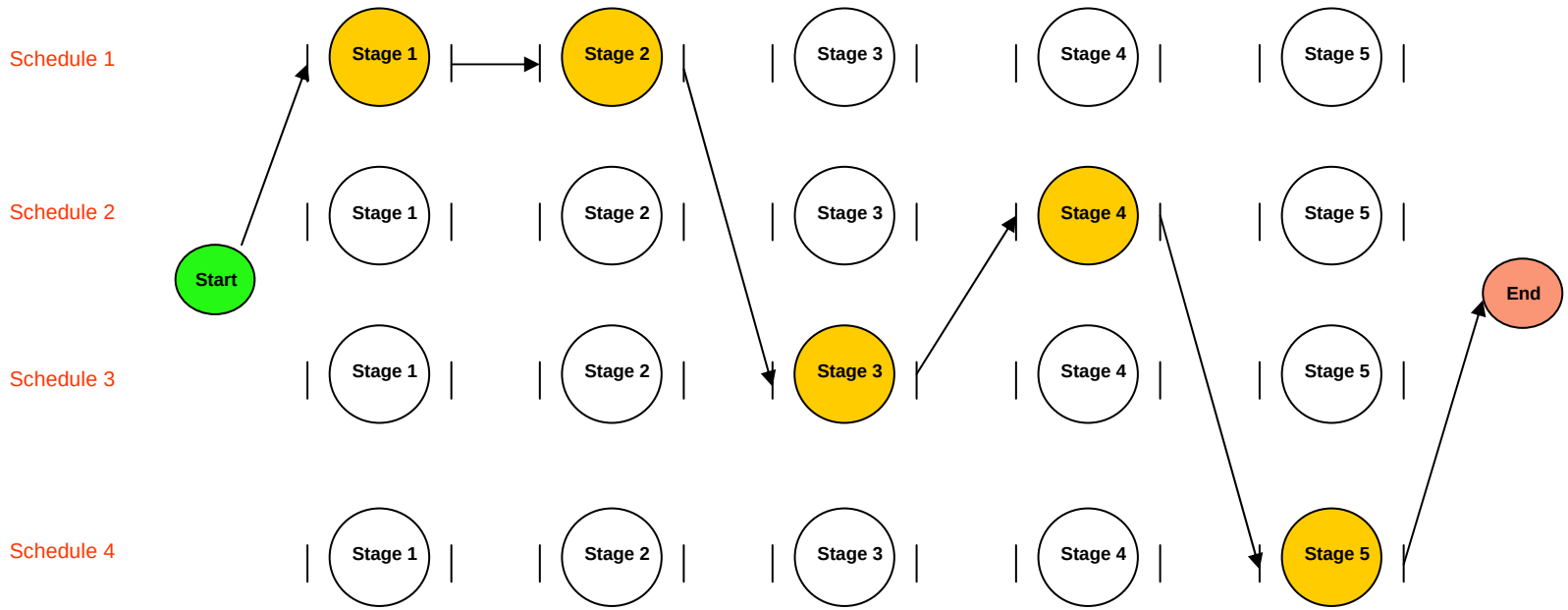
Solution Methodology for Flexible Distributed Scheduling - 5

Step 5: Adaptive Scheduling

- **Objectives:**
  - adapt to mission changes (new tasks, asset breakdowns, unit unavailability,…)
- **The global schedule can interact with the environment in the following way**
  1. **divide L-Neighboring schedules into several stages**
  2. **monitor mission execution and check feasibility of the current schedule**
  3. **Once infeasibility is detected, search among alternative neighboring schedules at the same stage until a feasible schedule is found**
  4. **instructs lower level tactical units to adapt to schedule changes**



Summary

- A flexible distributed scheduling scheme for dynamic ESG environments
- Multi-Objective Evolutionary Algorithm (MOEA) is employed to generate L-Neighboring schedules
- Final schedule is obtained by assembling different stages of L-Neighboring schedules in order to adapt to mission changes
- Insights into flexible scheduling
  1. Flexibility is limited by resource availability
  2. Higher the variety of generated schedules, higher the flexibility

Questions?