Title :

TN-NTN Convergence for Ubiquitous Connectivity in Future Networks

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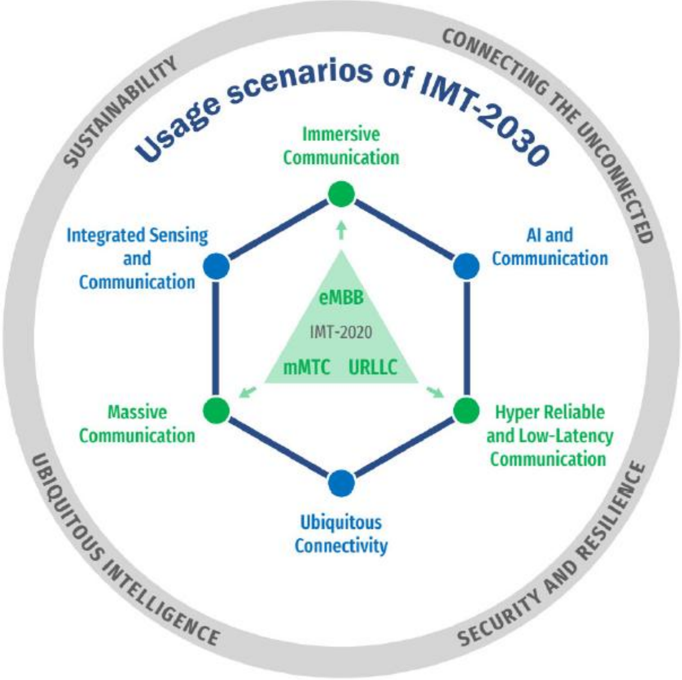
TN-NTN Convergence for Ubiquitous Connectivity in Future Networks

Background :

- Providing **ubiquitous connectivity** to connect the unconnected is one of the overarching goals of future communications systems, in accordance with IMT-2030 vision.
- **Integration of non-terrestrial network (NTN) with terrestrial network (TN)**, whereby coverage area of ground base stations is augmented by satellite and aerial platforms, is considered as one important technology to achieve global coverage.
- However, the **heterogeneity** of various access platforms in integrated TN-NTN systems, coupled with the **dynamics due to mobility of aerial platforms and sensitivity to weather conditions**, introduces significant challenges in design and optimization of the system to serve the users with their diverse quality-or-service (QoS) requirements.

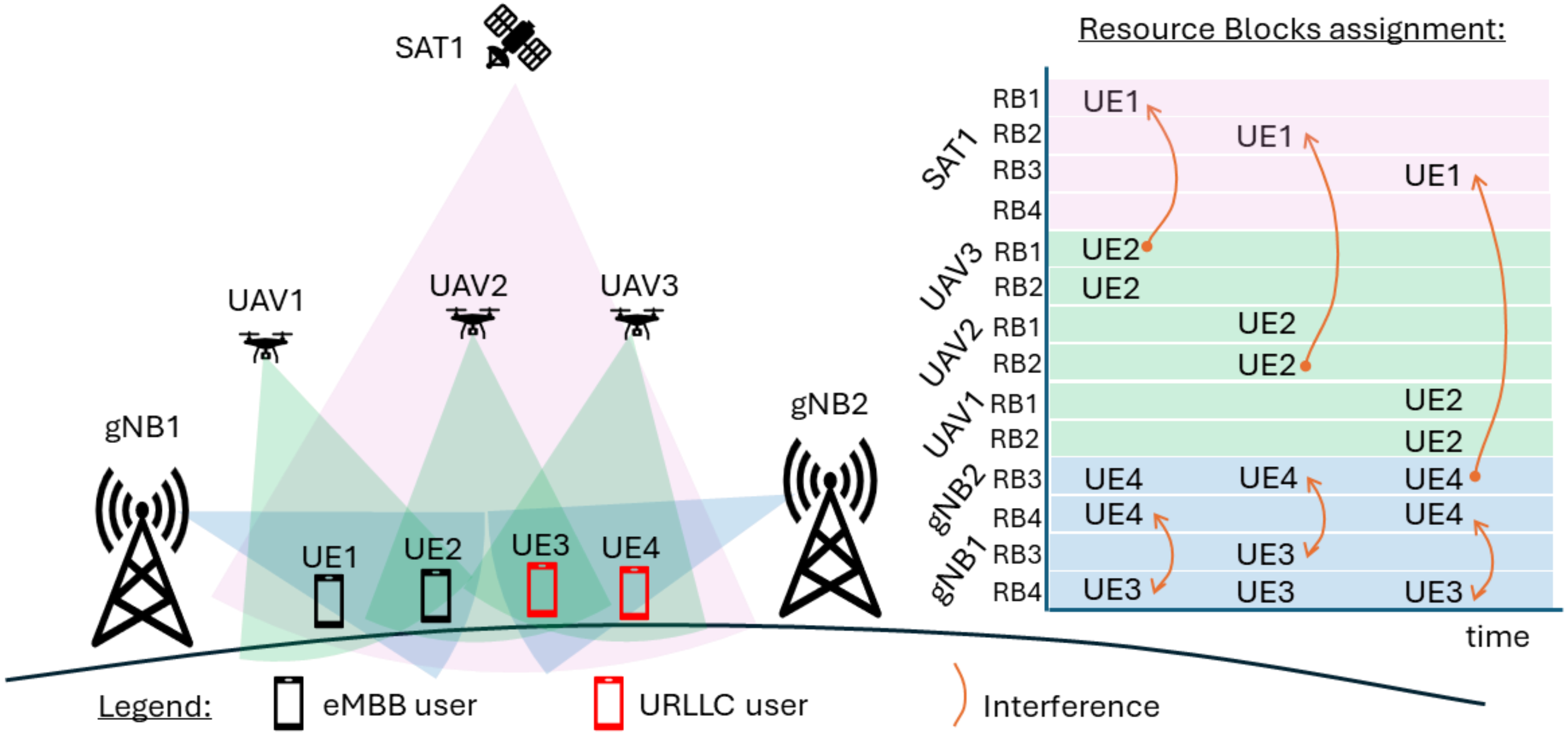


Targets:

To proposes effective methods to tackle the problem of **user association** and **resource allocation**, which includes aerial access point placements, in integrated TN-NTN systems.

Proposed Method:

We first model the three-layered integrated TN-NTN system as follows:



- In the **ground segment**, a set of gNodeB (gNB) base stations are installed in densely populated area to serve the users.
- The **air segment**, which can either be carried by unmanned aerial vehicles (UAV) or high-altitude platforms (HAPS) provides agility to deliver extra capacity to serve ad-hoc demand due to certain major events where large groups of people causes significant surge in traffic load.
- Finally, the **space segment** comprises of satellite access points, which can either be at low earth orbit (LEO), medium earth orbit (MEO), geostationary orbit (GEO), or combination there-off, provides coverage in remote areas unreachable by either ground or air segment.

Proposed Method:

We then formulate the joint user association, resource allocation, and aerial access point placement as:

$$\max \sum_{i\in I} \sum_{p_{j\in P}} \sum_{l\in L} \sum_{n\in N} a_{i,p_j}[n] b_{i,p_j,l}[n] c_{i,p_j}[n] R_{i,p_j,l}[n]$$

Subject to:

C1: $a_{i,p_j}[n] \le c_{i,p_j}[n] \quad \forall p_j \in P, \forall \mathrm{i} \in I$

C2: $\sum_{p_j\in P} a_{i,p_j}[n] b_{i,p_j,l}[n] c_{i,p_j}[n] \le 1 \quad \forall \mathrm{i} \in I$

C3: $\sum_{i\in I} a_{i,p_j}[n] b_{i,p_j,l}[n] c_{i,p_j}[n] \le 1 \quad \forall p_j \in \mathrm{P} \quad \forall l \in L$

C4: $\sum_{l\in L} \sum_{p_j\in P} a_{i,p_j}[n] b_{i,p_j,l}[n] c_{i,p_j}[n] R_{i,p_j,l}[n] \ge R_{th}^{\beta}$
$\forall \mathrm{i} \in I_{served}, \forall \beta \in \{eMBB, URLLC\}$

C5: $\|\boldsymbol{q}_m[n+1] - \boldsymbol{q}_m[n]\| \le v_{max}\, T/|N| \quad \forall \mathrm{m} \in M$

C6: $\|\boldsymbol{q}_m[n] - \boldsymbol{q}_k[n]\| \le d_{min} \quad \forall \mathrm{m}, \mathrm{k} \in M, \mathrm{m} \ne k$

C7: $\sum_{i\in I} \sum_{l\in L} a_{i,p_j}[n] b_{i,p_j,l}[n] c_{i,p_j}[n] \le |\rho_j| \quad \forall p_j \in \mathrm{P}$

C8: $b_{i,p_j,l}[n] \le a_{i,p_j}[n] \quad \forall p_j \in P, \forall \mathrm{i} \in I, \forall l \in L$

Symbol	Description
$a_{i,p_j}[n]$	user association binary variable Value 1 means at time n, user i is associated with j-th node of platform p
$b_{i,p_j,l}[n]$	Resource block (RB) allocation binary variable 1 means at time n. l-th RB of BS j at platform p is allocated to user i
$c_{i,p_j}[n]$	Coverage binary variable 1 means at time n, user i is within the coverage of j-th BS of platform p
$\gamma_{i,p_j,l}[n]$	SINR of l-th RB on link p_j ->i
$\boldsymbol{q}_m[n]$	$= (x_m[n], y_m[n], H)$ is the position of UAV m at time slot n
ρ_j	Total number of RBs available at BS j

C1: User only associate with platform whose **coverage** area includes the user
C2: 1 user can only associate with **1 platform** at the same time
C3: each **resource block** can only be assigned to 1 user
C4: minimum **data rate** of a specific user should be satisfied
C5: UAV moving **speed** constraint
C6: two UAVs should maintain a **safe distance** from each other
C7: resource constraint to ensure resource blocks assigned do not exceed **available resource** blocks
C8: resource **allocation constraint** to ensure resource block is assigned only if user is associated with platform

Proposed Method:

- Proposed a genetic algorithm called **Multi-Objective Evolutionary Algorithm based on Diverse Adaptive Decomposition (MOEA/DADE)** that introduces the following novel components:
  - Multi-strategy mutation (Polynomial, Gaussian, DE/rand/2, DE/best/2, and DE/current-tobest/1).
  - Distance-based external population maintenance.
  - Sparsity-guided adaptive weight update
- The **decision variable** $\mathbf{x} = [\boldsymbol{\mu},\ \boldsymbol{\omega},\ \mathbf{L}_U]$ includes:
  - Access association variables $\boldsymbol{\mu}$
  - Resource block allocation $\boldsymbol{\omega}$
  - UAV trajectory/locations $\mathbf{L}_U$

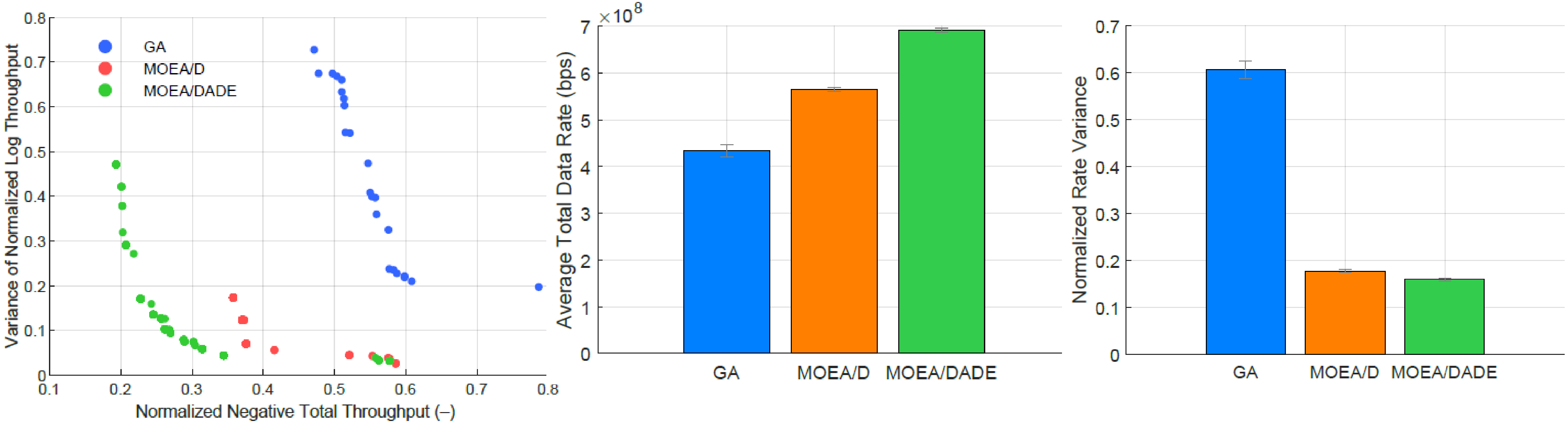
Impact:

Benefits of the proposed algorithm includes:

- Increase the number of users that can be served, satisfying the required quality of service (QoS)
- Optimize the utilization of resources, both in terms of resource blocks as well as the utilization of aerial base stations.
- Maintain the fairness among the users that are served.

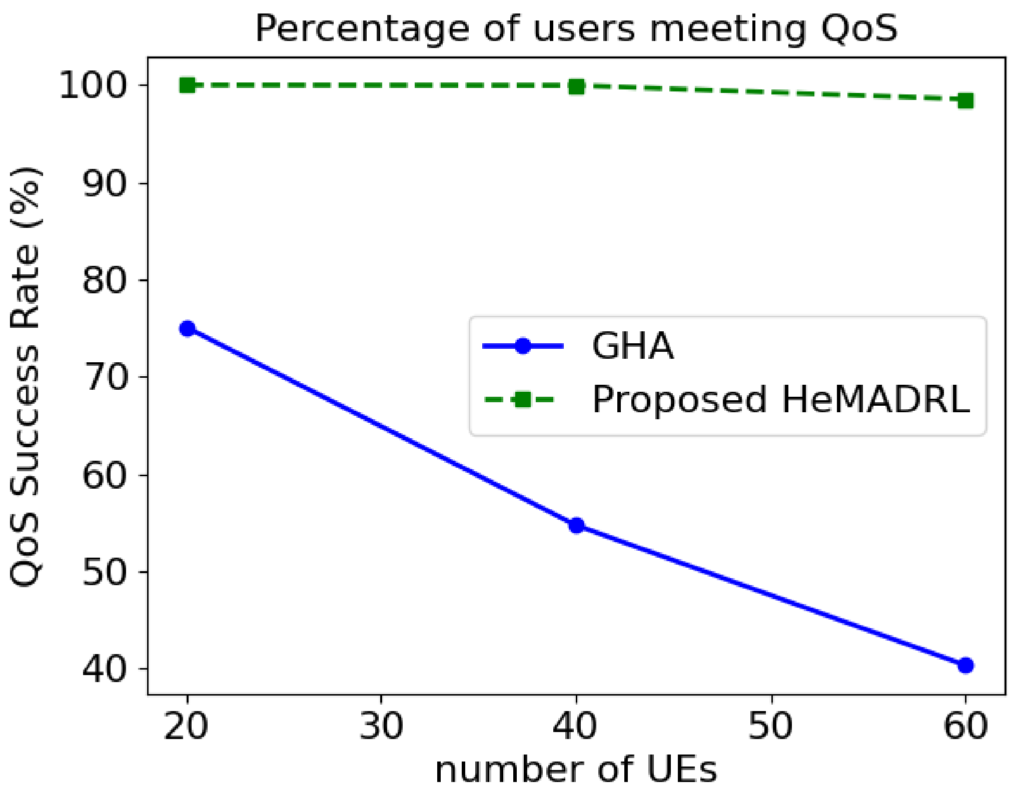
Output/Outcome:

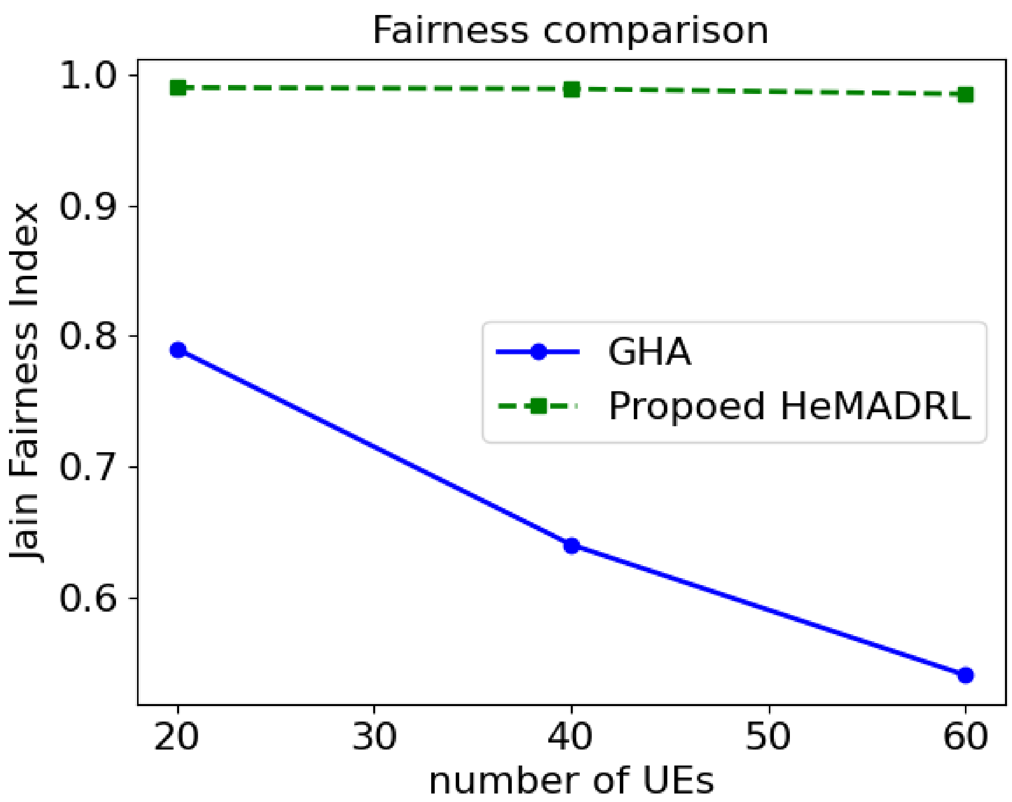
Performance of the proposed MOEA-DADE algorithm:



Output/Outcome:

Performance of the proposed multi-agent





GHA: Greedy Heuristic Algorithm
HeMADRL: Heterogeneous Multi-Agent Deep Reinforcement Learning

Conclusion:

Summary:

- Addressed the user association and resource allocation problem in integrated TN-NTN system.
- Two approaches are proposed, one based on evolutionary algorithm and another based on multi-agent deep reinforcement learning approach.
- The proposed method is able to achieve higher overall throughput, satisfying more users, while maintaining the fairness among users.

Future works:

- Integrated TN/NTN based Resilient Connectivity & Sensing for Smart Maritime Operations
- Intelligent Network for Universal Integrated TN/NTN
- 3GPP NTN Terminal and MIMO in Payload, incorporating multi-band multi-beam ESA
- New Architecture with Cooperative Swarm Nano-Satellite Constellation