system failures. This issue has traditionally been a challenge for AI and learning-based methods, although recent works propose different methods to increase environment diversity (**???**) and consequently the agents' robustness.

5.2 Limitations due to interactions

When the DE, OP, and RTE act together, additional limitations might emerge. These are mainly related with forecasting quality and the OP-RTE interaction.

- **Long-horizon forecasting**. The DE is faced with challenging prediction windows when a delay exists between the current and the target times. Uncertainty in these situations might be too large using traditional methods. Newer models that use attention mechanisms that learn complex patterns in data like (**?**) or (**?**) could be explored.
- **Multiuser prediction**. To forecast future user distributions and demands, the DE can do it on a per-user basis or rely on multivariate output models (**??**). The latter is not sufficiently-explored and can be the basis of frameworks to leverage low amounts of data (e.g., new users, non-stationary patterns) (**?**).
- **Search space complexity.** As a consequence of the OP-RTE interaction, once the OP sets a long-term resource allocation, the RTE will amend some parts of it as real-time operations take place. While maybe no more than tens of beams will be part of this process during a RTE cycle, the related search space will be notably more complex, as the RTE will be required to simultaneously make decisions on multiple variable types (e.g., beam center, bandwidth, power) instead of following a sequential process.

5.3 Areas of future work

We finally address unexplored research directions that are related to more advanced problems in the context of autonomous constellations.

- **Transfer learning for satellite architectures**. All models and algorithms so far have been designed in the context of specific satellite architectures. This assumption limits the application of one model to multiple satellite architectures. In the future, it is expected that satellites will have flexibility in their own configurations (**?**), to better address operators' needs. Being able to successfully transfer the models to these new configurations will be essential to maintain service quality.
- **New prediction models**. Historical data of current user bases might be rich enough to forecast using simple neural architectures. However, it is possible that this is not always the case, especially if new users choose on-demand services more frequently. In those cases, more complex neural architectures including Graph Neural Networks to leverage spatiotemporal data (**?**), attention mechanisms to improve performance (**?**), or transfer learning frameworks capable of few-shot-learning (**?**) might be better suited.
- **Orbits as resources.** In this paper, like most studies on satellite communications, we assume all satellites are located on the same orbit. This might not always be the case, especially for megaconstellations. In that sense, we could consider allocating orbital resources as the fifth subproblem from a constellation perspective. It is likely that AI and learning-based methods can also be applied in that context.
- **Multiagent systems.** Finally, we want to highlight the possibility that the resource control is decentralized as opposed to a centralized DE, OP, and RTE. These scenarios align with the literature on multiagent systems (**??**), and satellite constellations are a specific use case that is starting to be explored (**??**).

6 Conclusion

In this work, we propose an AI-based framework to tackle the system-level challenges in the Dynamic Resource Management problem for satellite communications. This framework incorporates three necessary components (Demand Estimator, Offline Planner, and Real-Time Engine) to address the sequence of subproblems (beam placement and shaping, gateway routing, frequency assignment, and power allocation) that lead to the complete resource allocation. We identify potential component interactions that are often overlooked by current approaches and discuss why AI and learning-based methods are well suited to handle them. In this context, we examine the benefits of applying AI to solve the complete resource allocation problem, highlighting prevailing performance limitations that AI could overcome, as well as unexplored areas of future work.

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