

# MINDFul.jl: A Framework for Intent-driven Multi-Domain Network coordination

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## ABSTRACT

Network coordination across multiple domains is a complex task requiring seamless communication between network entities. Network operators target to minimize costs while ensuring the requirements of the user requests. Such efforts are highly challenging in decentralized environments with diverse network operators, where only partial knowledge of the complete network is available. Intent-driven multi-domain coordination offers various benefits, some inherent to Intent-Based Networking (IBN) and others stemming from the standardization of the Northbound Interface (NBI). As standardization is still missing, there has not been a substantial initiative to develop tools that leverage this paradigm. MINDFul.jl is a Julia library that fills this gap and provides the means to accelerate research in this area, both at the architectural and the algorithmic level. It provides a stateful, modular representation of common metro/core IP-optical network equipment as well as the common intent operations. Finally, it facilitates event-based simulations with a hackable interface and offers visualization support.

## Keywords

Julia, Intent-based Networking, multi-domain, IP-optical

## 1. Background

As Software-Defined Networking (SDN) [7] becomes more popular, and many networks shift to centralized control due to easier management and higher efficiency, multi-domain (MD) networking often must remain decentralized due to its very nature. This will cause most of the networks to operate using a centralized SDN controller internally but still need to coordinate in a decentralized fashion with the neighboring domains, as shown in Figure 1. The Intent-Based Networking (IBN) [8] paradigm is built on top of SDN. IBN provides an abstraction layer where high-level objectives (i.e., intents) can be defined and automatically handled by the system.

An intent-driven approach [6, 2] has been proposed, which can substitute traditional MD decentralized protocols like the Border Gateway Protocol (BGP) since they offer higher flexibility of interactions and support for much wider network capabilities. Several design and algorithmic decisions need to be made to develop an IBN framework, like the definition of an intent state machine and the algorithms that enable the state transitions. Commonly, an intent has at least the following four states, although naming conventions might differ:

- uncompiled* for unprocessed intents inside the system
- compiled* for processed intents with a well-defined implementation

## DeCentralized

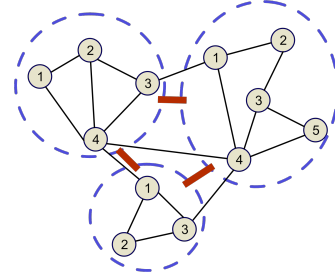


Fig. 1. Domains coordinate in a decentralized fashion, while each domain has centralized control internally.

- installed* for active intents whose implementation has been realized in the appropriate network devices
- failed* for active intents that malfunction after some failure during operation.

Several algorithms need to be provisioned, among which the most crucial deal with:

- intent compilation* for deriving an intent implementation and transitioning an intent to the compiled state
- intent monitoring* to reassure that the installed intents satisfy all the requirements and trigger some fallbacks in case of failure
- intent conflict resolution* for handling situations when several intents require the same resources.

Experimentation with varying architectures has proven difficult due to the lack of a simulation framework. This work proposes a software tool to facilitate research and advancements in IP-optical IBN.

## 2. MINDFul.jl

MINDFul.jl is an open-source Julia library that provides a playground for MD IBN. Although a minimal MD IBN framework is already implemented, users can extend the functionalities provided. The library uses intent Directed Acyclic Graphs (DAGs) [5] to represent relationships between different intents across several domains [4]. This powerful scheme connects higher-level intents, which have a logical objective, with low-level intents, which are responsible for resource allocation, using a DAG. This hierarchical intent structure enables seamless interoperability between domains using *intent delegation*, where an intent node is passed on to a different domain. Representing intent compilation using DAGs is non-restricting, and any Routing, Modulation and Spectrum Assignment (RMSA) algorithm can be implemented. The focus of the

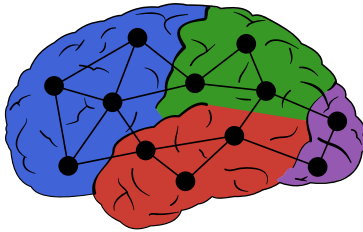


Fig. 2. MINDFul.jl logo

software is *Connectivity Intents*, i.e., intents related to IP-optical connectivity requests.

MINDFul.jl is built with modularity in mind. Intent state machines and algorithms can be alternated. The appropriate interfaces are provided to facilitate simulations and evaluate different designs and algorithms under diverse scenarios. The library offers a state representation of a common IP-optical network and an Application Programming Interface (API) to access or modify it. The user can use these interfaces to conduct (event-based) simulations. A company package, MINDFulMakie.jl, can be used for out-of-the-box visualizations like drawing an intent DAG or visualizing a compiled connectivity intent in the network topology. Finally, MINFulCompanion.jl has been planned to contain a catalog of related algorithms and utilities.

The architecture provided by MINDFul.jl is influenced by [9]. The authors of this publication present a techno-economical overview of the equipment used in multilayer metro/core networks. More specifically, we hold on to the pure IP-optical architecture signified by two layers: the electrical layer composed of IP routers and virtual links and the optical layer formed by Optical Cross-Connects (OXC) and physical fiber links. Given the current technological advancements in coherent pluggable transceivers, like the OpenZR+ Multi-Source Agreement (MSA) [1], we seek to also incorporate new trends into the represented architecture of the package. A more detailed description of the modeling and architecture considered can be found in [3].

### 3. Conclusion

MINDFul.jl is a Julia open-source library that facilitates research on MD intent-driven IP-optical networks. It provides a way to develop experimental intent system architectures and customized algorithms, as well as evaluate them using simulations and visualizations. It fills a noticeable gap in the current openly-available tools. The modular architecture, together with Julia's attributes, like speed and dynamicity, can significantly help advance the adaptation of IBN in modern MD networks.

### 4. References

- [1] White paper: OpenZR+ 400G Digital Coherent Optics for Multi-Haul. Technical report, OpenZR+ Multi-Source Agreement, September 2020. Accessed on 28.03.2022.
- [2] Filippou Christou. Decentralized intent-driven coordination of multi-domain ip-optical networks. In *2022 18th International Conference on Network and Service Management (CNSM)*, pages 359–363, 2022. doi:10.23919/CNSM55787.2022.9964606.
- [3] Filippou Christou, Tobias Enderle, and Arthur Witt. Towards a hybrid architecture by introducing coherent pluggable

transceivers in ip-optical core networks with optical cross-connects. In *Photonic Networks; 23th ITG-Symposium*, pages 1–8, 2022.

- [4] Filippou Christou and Andreas Kirstädter. Using intent directed acyclic graphs in multi-domain ip-optical networks. In *(accepted) 33rd International Telecommunication Networks and Applications Conference (ITNAC)*, 2023.
- [5] Filippou Christou and Andreas Kirstädter. Grooming connectivity intents in ip-optical networks using directed acyclic graphs. In *Photonic Networks; 24th ITG-Symposium*, pages 1–4, 2023.
- [6] Luis M. Contreras and Paolo Lucente. Interconnection Intents. Internet-Draft draft-contreras-nmrg-interconnection-intents-03, Internet Engineering Task Force, October 2022. Work in Progress.
- [7] Diego Kreutz, Fernando M. V. Ramos, Paulo Esteves Veríssimo, Christian Esteve Rothenberg, Siamak Azodolmolky, and Steve Uhlig. Software-defined networking: A comprehensive survey. *Proceedings of the IEEE*, 103(1):14–76, 2015. doi:10.1109/JPROC.2014.2371999.
- [8] Aris Leivadeas and Matthias Falkner. A survey on intent-based networking. *IEEE Communications Surveys & Tutorials*, 25(1):625–655, 2023. doi:10.1109/COMST.2022.3215919.
- [9] Franz Rambach, Beate Konrad, Lars Dembeck, Ulrich Gebhard, Matthias Gunkel, Marco Quagliotti, Laura Serra, and Victor Lopez. A multilayer cost model for metro/core networks. *Journal of Optical Communications and Networking*, 5(3):210–225, 2013. doi:10.1364/JOCN.5.000210.