Grooming Connectivity Intents in IP-Optical Networks Using Directed Acyclic Graphs

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Introduction to IBN

Intent-Based Networking (IBN) introduces an extra abstraction layer between the network and the network operator.

IBN does not ask *HOW* but *WHAT*

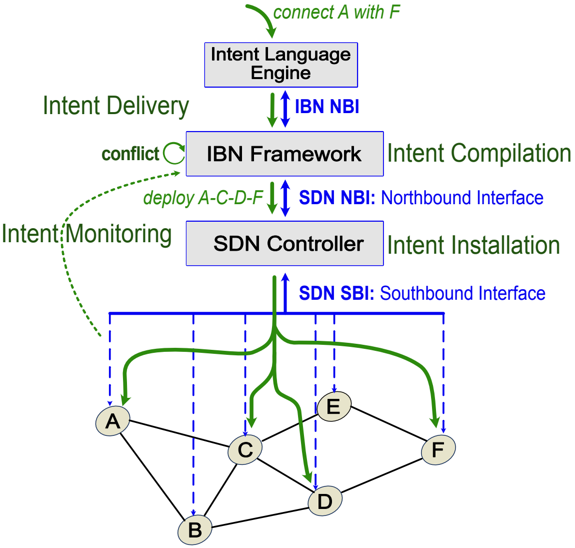
IBN decouples the objective from the implementation.

Why IBN ?

- Reduce expertise requirements
- Reduce human errors
- Easy and fast business plan adaption
- **Machine to machine communication;**
  towards autonomous multi-domain networks
  - higher flexibility
  - compliance with end-to-end QoS requirements
  - accountability
  - confidentiality

This work focuses on providing the suitable intent infastructure to enable these benefits

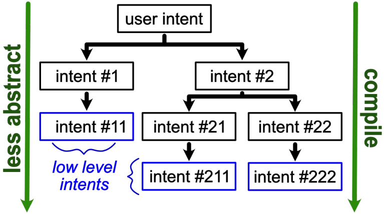
Introduction to IBN - the architecture



Intent Trees

Intent tree is a hierarchical representation of an intent implementation after compilation

- root intent is the original user intent
- child intents are system-generated
- low level intents are device-level intents
- each intent in the tree has a state

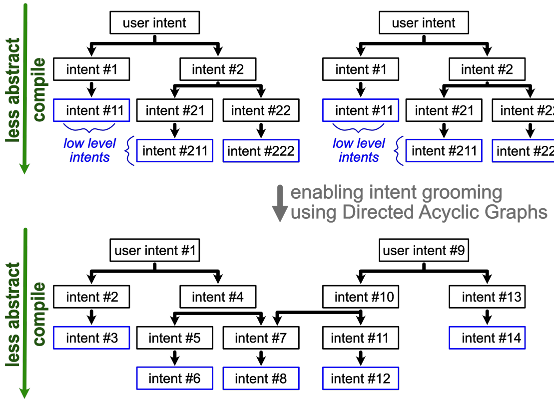


Intent DAGs

In intent tree structures, intent nodes can only have one parent

→ intent trees do not support grooming

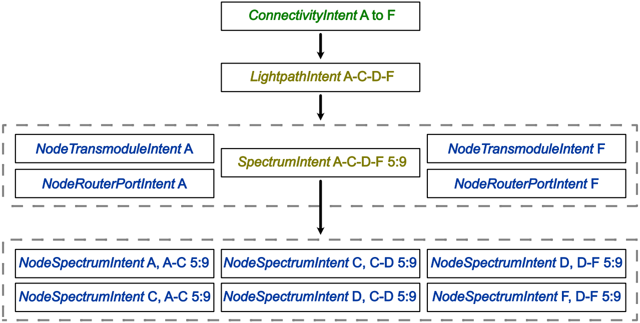
Intent Directed Acyclic Graphs (DAGs)

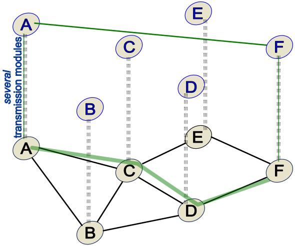


Intent definitions

In order to solve the Routing, Modulation and Spectrum Assignment (RMSA) problem we define the following intents:

- *LightpathIntent*: defines a lightpath
- *SpectrumIntent*: defines a lightpath with spectrum allocation
- *NodeRouterPortIntent*: allocates an IP router port
- *NodeTransmoduleIntent*: allocates a transmission module
- *NodeSpectrumIntent*: allocates spectrum slots in the fiber

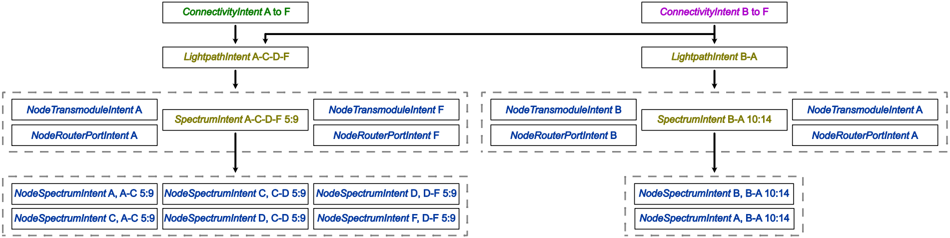


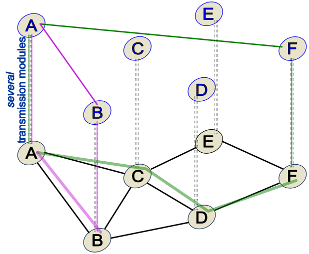


Grooming example

A new connectivity intent is issued.

The new intent will be groomed together with the previous one.





A grooming RMSA algorithm using intent DAGs

The intent DAG is generated from an intent during compilation using an RMSA algorithm

All RMSA algorithm can be translated to an intent-based approach using this design

We adapt a greedy advanced Joint Multi-Layer (JML) heuristic [1]

Original design - JML

1. Build a multilayer graph with vector attributtes in each edge
2. Find candidate paths using a greedy algorithm
3. Choose single path that minimizes cost function

Adapted design - JML

4. Break solution path to predefined intents
5. Attach intents to the intent DAG

Further tuning - LDJM

The adapted algorithm JML remains easy to modify as designed by the original authors

We tuned the cost function to get a Latency-Driven JML (LDJML) variation
(legacy cost function was minimizing costs)

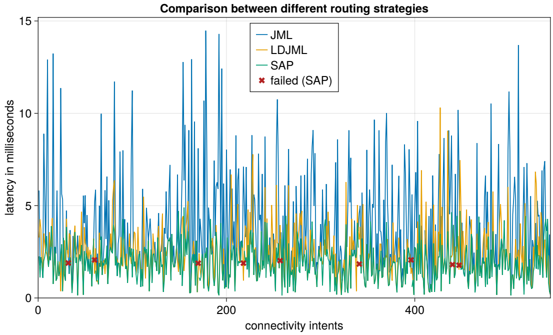
[1] Gkamas, Vasileios, Konstantinos Christodoulopoulos and Emmanouel Varvarigos. “A Joint Multi-Layer Planning Algorithm for IP Over Flexible Optical Networks.” Journal of Lightwave Technology 33 (2015): 2965-2977.

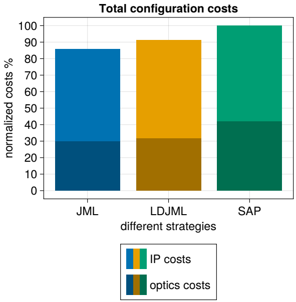
Evaluation

Proof of concept evaluation – reproduce well-known results

We compared 3 algorithms
◊ JML ◊ LDJML ◊ Shortest Available Path (SAP) with intent trees

- JML is the slowest and with the fewest costs
- SAP is the fastest and with the most costs **and blocked traffic**
- LDJML is, as tuned, in the middle without blocked traffic





Summary

Background

Intent trees are a a multi-step intent compilation approach

Hierarchical data structure with gradually decreasing abstraction level

Contribution

Identified major intent tree weakness to perform grooming

Refined architecture by introducing intent DAGs

- support for intent grooming
- modular architecture as any RMSA algorithm can be adapted

Demonstrated the adaptation of an advanced RMSA heuristic to the intent DAG concept

Proof-of-concept evaluation by comparing 3 intent compilation algorithms

Future work

New, exciting benefits are still to be gained for multi-domain operation

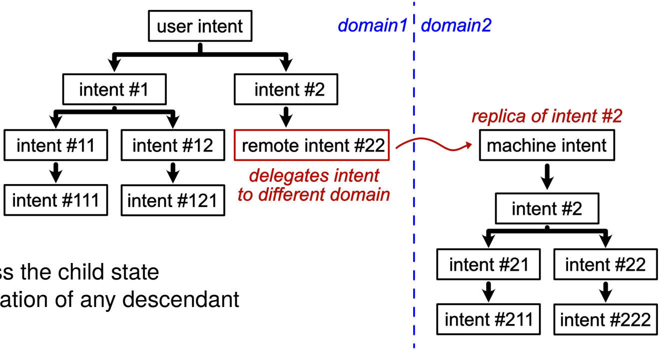
Future work will focus on the design and operation of multi-domain intent DAGs

Backup slides

MD IBN and intent delegation

Extend from single domain to multi domain

- expand intent tree to span several domains
- *remote intent* delegates an intent replica to the neighbor domain
- state update properties still hold due to parent-child relationship



→ Confidentiality

Parent can only access the child state
and no internal information of any descendant

→ Accountability

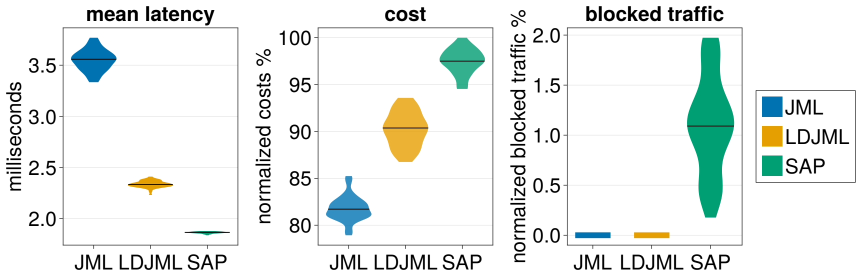
In case of a network fault, the state of the corresponding intent is updated
Clear whom to hold responsible

Multiple seeded simulations

40 simulations.

The demand matrix is generated using different seeds and a truncated normal distribution for every node pair

The aggregated traffic is ca. 62 Tbps



Tables used

TABLE I
PROPERTIES OF THE LINE CARDS.

Line cards L		
n_l (ports)	r_l port rate (Gbps)	c_l (cost units)
10	100	26.72
2	400	29.36
1	1000	31.99

Values based on [1,2,3,4] and GNPy

(1) P. Papanikolaou, K. Christodoulopoulos, and E. Varvarigos, "Multilayer flex-grid network planning," in 2015 International Conference on Optical Network Design and Modeling (ONDM), 2015, pp. 151–156

(2) A. Eira and J. Pedro, "On the Comparative Efficiency of Next- Generation Coherent Interfaces for Survivable Network Design," in 17th International Conference on the Design of Reliable Communication Networks (DRCN), 2021.

(3) "White paper: OpenZR+ 400G Digital Coherent Optics for Multi-Haul," OpenZR+ Multi-Source Agreement, Tech. Rep., September 2020, Accessed on 28.03.2022. [Online]. Available: https://openzrplus.org/site/assets/files/1074/openzrplus whitepaper - sept 29 2020 final.pdf

(4) F. Rambach, B. Konrad, L. Dembeck, U. Gebhard, M. Gunkel, M. Quagliotti, L. Serra, and V. Lopez, "A multilayer cost model for metro/core networks," Journal of Optical Communications and Networking,2013

TABLE II
PROPERTIES OF THE OPTICAL TRANSMISSION MODULES

(a) Pluggable modules

CPT		
r_t (Gbps)	d_t (km)	b_t ($\times$ 12.5 GHz)
400	480	6
300	1600	6
200	2880	6
100	5840	4

(b) Transponder modules (conservative)

CET *conservative*		
r_t (Gbps)	d_t (km)	b_t ($\times$ 12.5 GHz)
800	160	8
700	200	8
600	240	6
500	480	6
400	880	6
300	2080	6
200	6120	6
100	9260	4

(c) Transponder modules (advanced)

CET *advanced*		
r_t (Gbps)	d_t (km)	b_t ($\times$ 12.5 GHz)
800	400	10
700	700	10
600	1200	8
500	2800	8
400	4400	8
300	5080	8

Costs used

Costs used	
Device	cost units
CET	20
CPT	8
linecard	see line cards table
line card chassis	4.7
fiber end-to-end	100
fiber per km	0.5/km

General costs based on [1]

CDC ROADM costs is a function of node-degree and add/drop signals [1]

Transponder/Pluggables cost is 40% based on [2]

(1) F. Rambach, B. Konrad, L. Dembeck, U. Gebhard, M. Gunkel, M. Quagliotti, L. Serra, and V. Lopez, "A multilayer cost model for metro/core networks," Journal of Optical Communications and Networking,2013

(2) P. Wright, R. Davey, and A. Lord, "Cost Model Comparison of ZR/ZR+ Modules Against Traditional WDM Transponders for 400G IP/WDM Core Networks," in 2020 European Conference on Optical Communications (ECOC), 2020.