AI-Based
Network Topology Optimization

ITU AI/ML in 5G Challenge

Weeny Wit

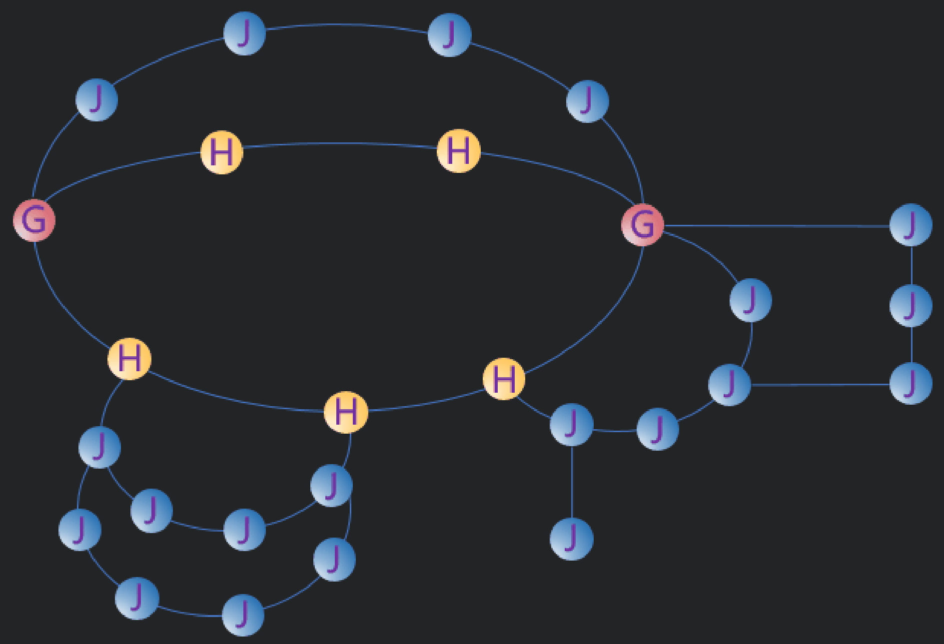
December 2020

Problem Description (1): Background

The existing network topology planning does not fully consider the increasing network traffic and uneven link capacity utilization, resulting in difficult topology optimization and increasing investments in network construction.

Network structure needs to be optimized in a dynamic manner based on the traffic change predicted through AI technologies, to ensure link load balancing when network traffic increases.

This improves network resource utilization, and thus reduce the investments in network capacity expansion.



Rules: 1) Number of nodes per link ≤ 30 2) Edges available for addition ≤ 500 meters 3) Start and tail nodes of any main link should be G or H

Problem Description (2): Task Analysis

Task Analysis

City A

City B

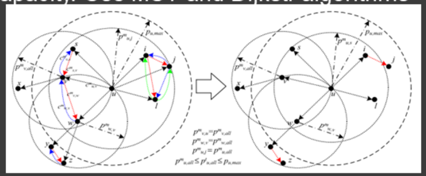
City C

Data Provided	Tasks	Evaluation by the Organizer
Topology (Node connection table)	Modeling	Scoring formula
Network traffic of the last 20 days (NE attribute table)	**Everyday network topology for the next 10 days** (Vary each day)	**Score**
		Real network traffic of the next 10 days (Not provided)

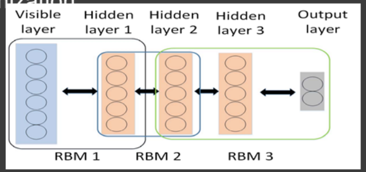
References and ITU AI Standards

References

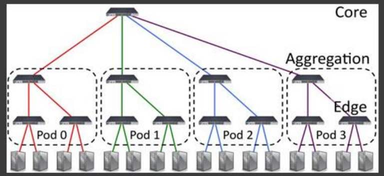
【1】 **Scenario:** Wireless multi-hop networks
Solution: Enable topology control in terms of transmission power and network capacity. Use MST and Dijkstr algorithms



【2】 **Scenario:** Wireless networks
Solution: Implement Energy Capacity Based Localized Topology Control (ECTC), an DBN-based algorithm, for capacity optimization

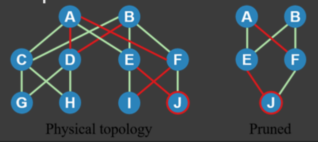


【3】 **Scenario:** Data center networks
Solution: Adjust the set of active network elements (links and switches) to satisfy changing data center traffic.

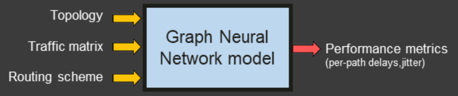


【4】 **Scenario:** Social networks
Solution: Apply the DeepWalk algorithm for network representation learning.

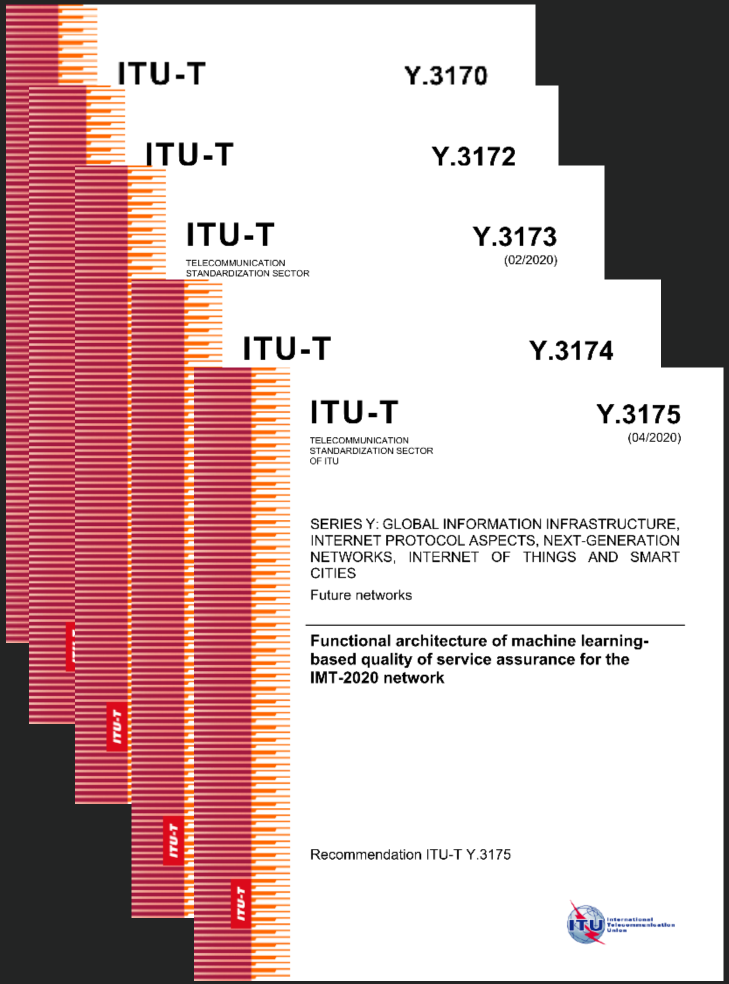
【5】 **Scenario:** Data center networks
Solution: To minimize corruption losses, select corrupting links that can be safely disabled intelligently , while ensuring that each top-of-rack switch has a minimum number of paths to reach other switches.



【6】 **Scenario:** Software-defined networks
Solution: Establish a RoutNet-GNN-based model to estimate delays and jitter in different network topology and routing schemes.



ITU AI Standards

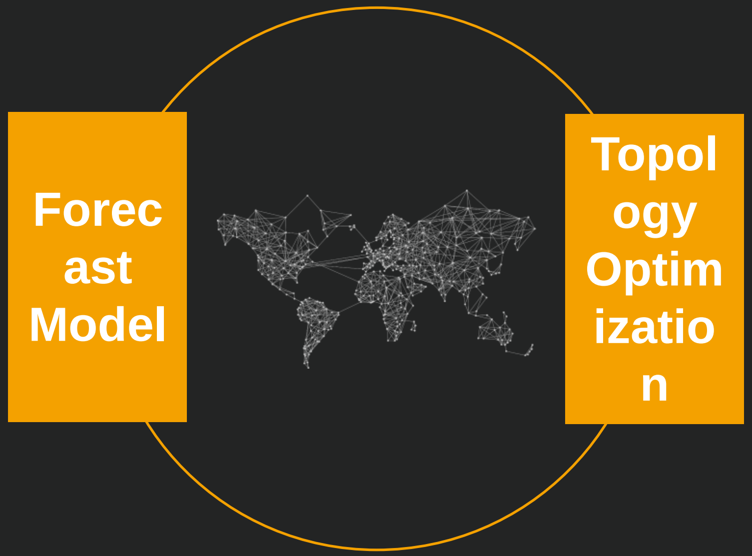


Our Solution

Data processing
Set the value of missing traffic to 0 and sort out traffic by network element

Training for traffic forecast
Use the TensorFlow to build an LSTM neural model.
Input data to the model for training, and achieve the traffic of the next 10 days.

Data post-processing
Sort out the forecast traffic of the next 10 days by day



Topology building
Use NetworkX to build network topology and set up the neighbor node library.

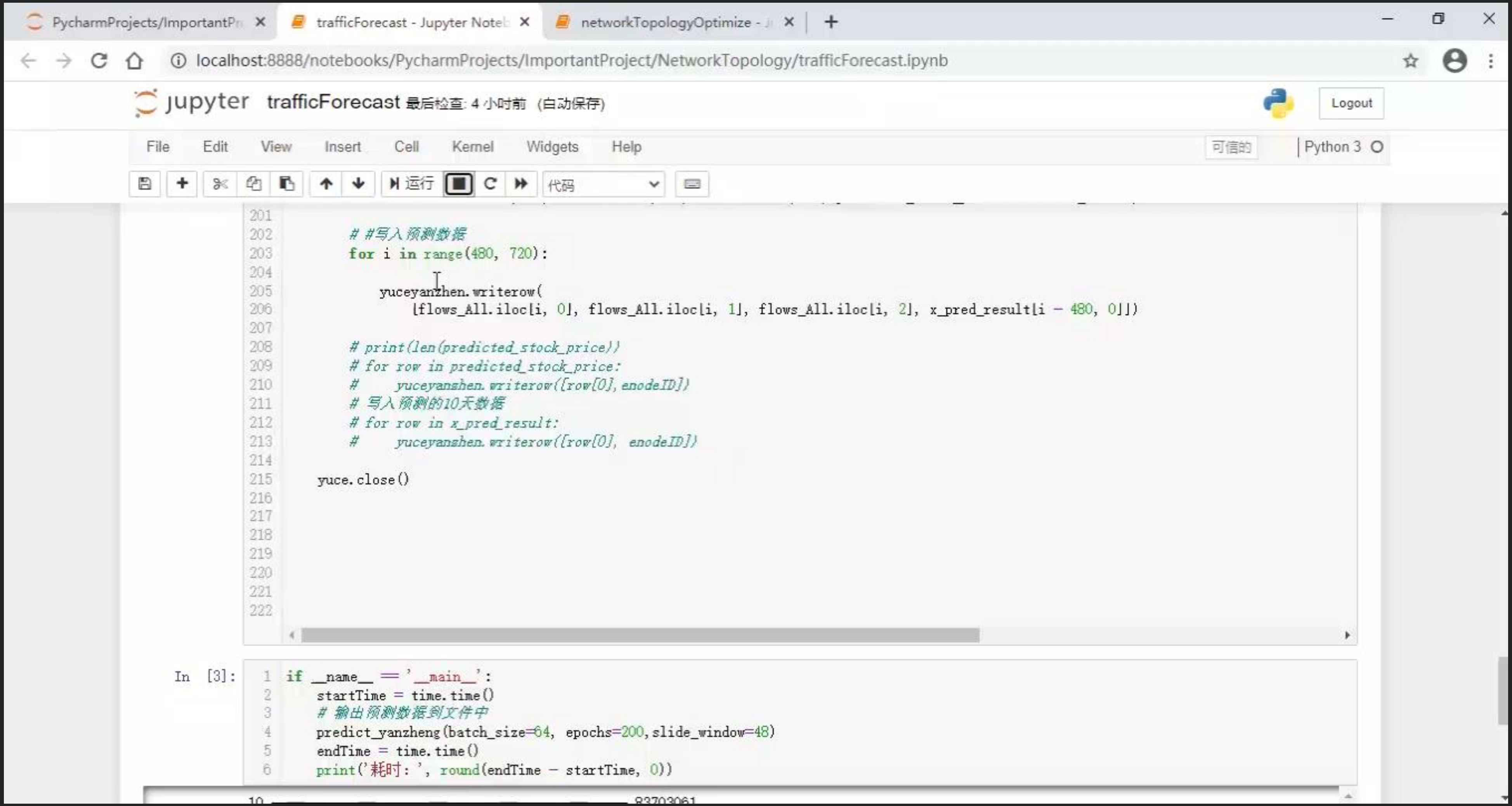
Topology recovery
Use the “DFS algorithm” to discover main links, sort out cross-connected links, find out sublinks and hanging links via the Node-Removing Method, and build a link set.

Topology optimization
Deal with links with heavy and low loads via link combination and partial link optimization

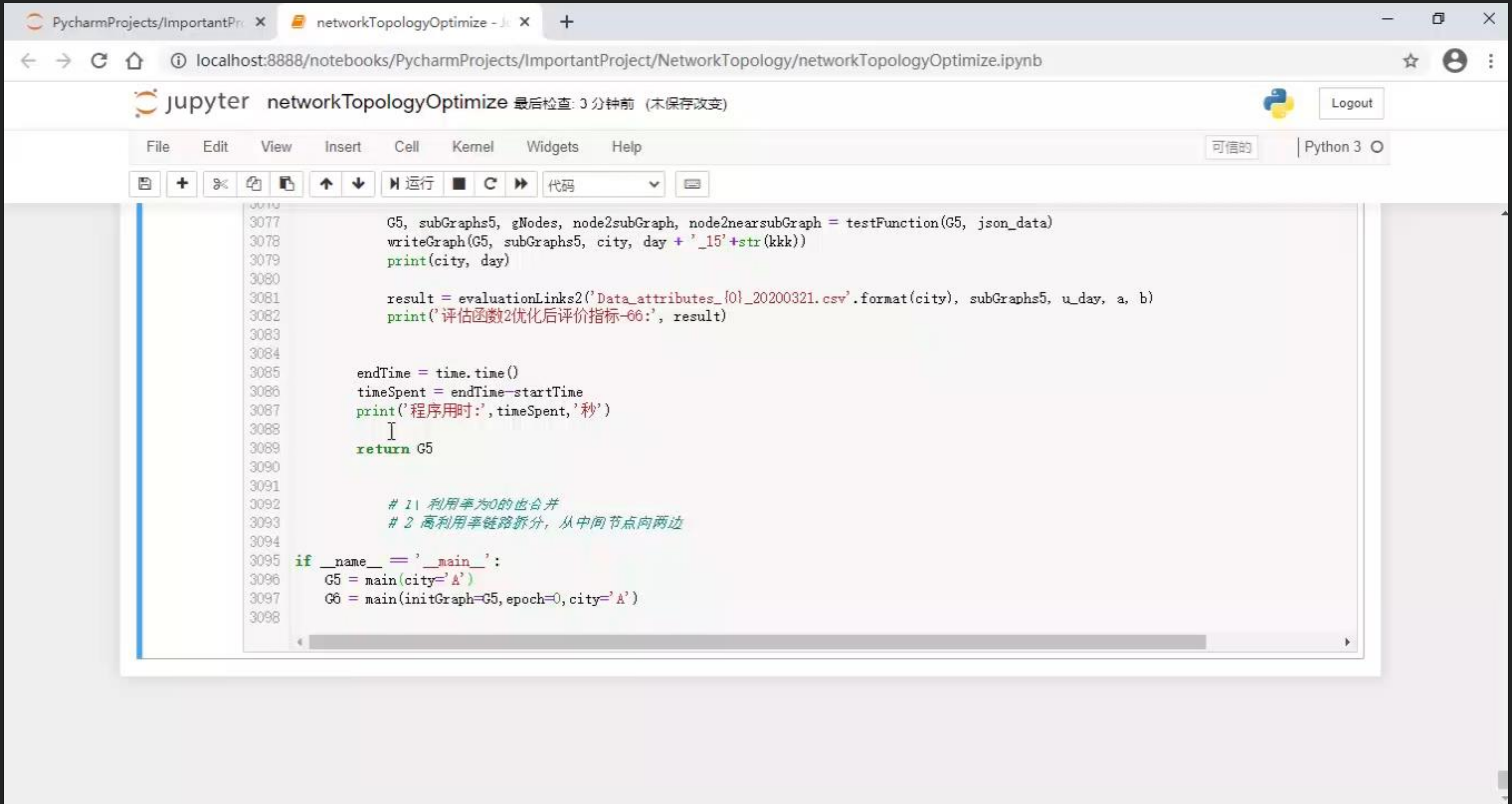
Iteration for optimum topology
Implement successive iteration for 24 hours and select the optimum topology from the total 25 topology.

Topology restructuring
Topology restructuring is to optimize the links with heavy or low loads for a long period of time. The newly added edges are included in the source topology of the next iteration.

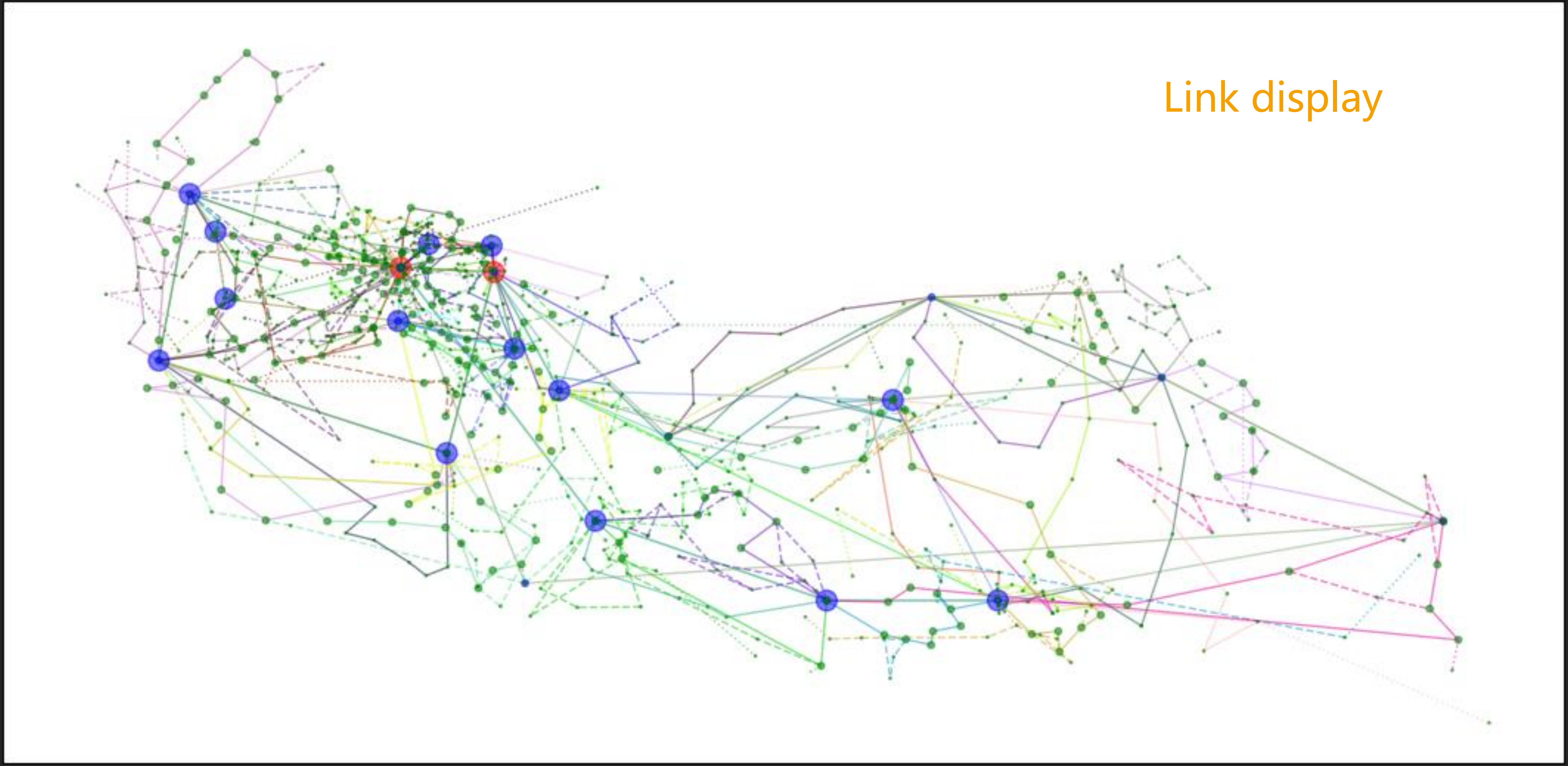
Our Solution



Our Solution



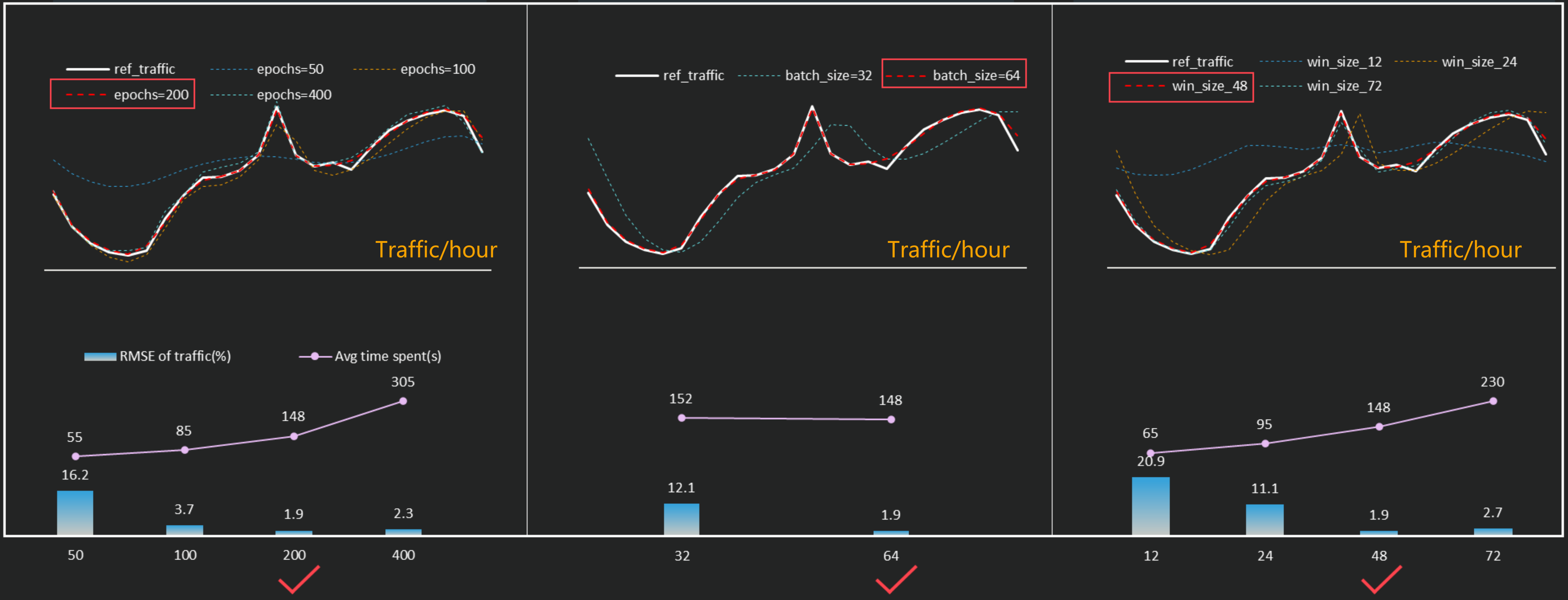
Our Solution



Highlights (1): Enhanced LSTM Traffic Forecast Model for Traffic Change

We built an LSTM neural network model with TensorFlow, input 480 samples of per-NE traffic of the last 20 days into the model, and selected appropriate parameters with integrated consideration of three factors. The ratio of errors in traffic forecast is reduced to 3%. With distributed and multiprocess technologies, the operating efficiency is increased by 20 times.

Comparison of Epochs，select 200 | **Comparison of Batch_size,select 64** | **Comparison of slide_window,select 48**



Notes: batch_size=64，slide_window=48

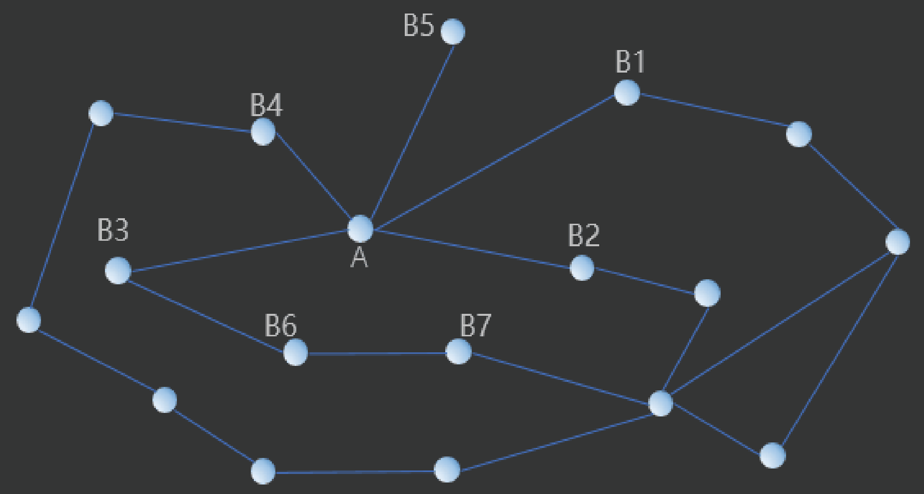
Notes: epochs=200，slide_window=48

Notes: epochs=200，batch_size=64

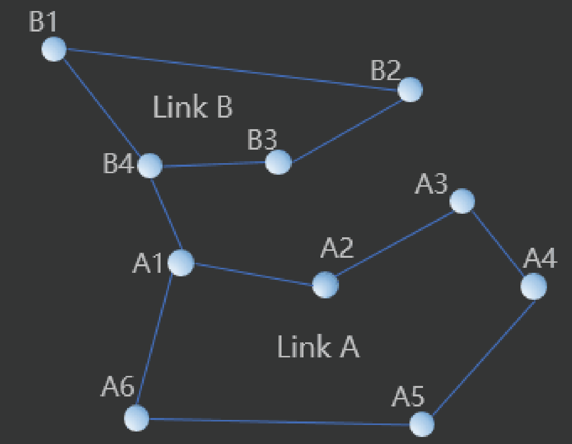
Highlights (2): Topology in Full Status and Topology in Optimized Status

The concept of neighbor nodes and links reduces the number of iterations

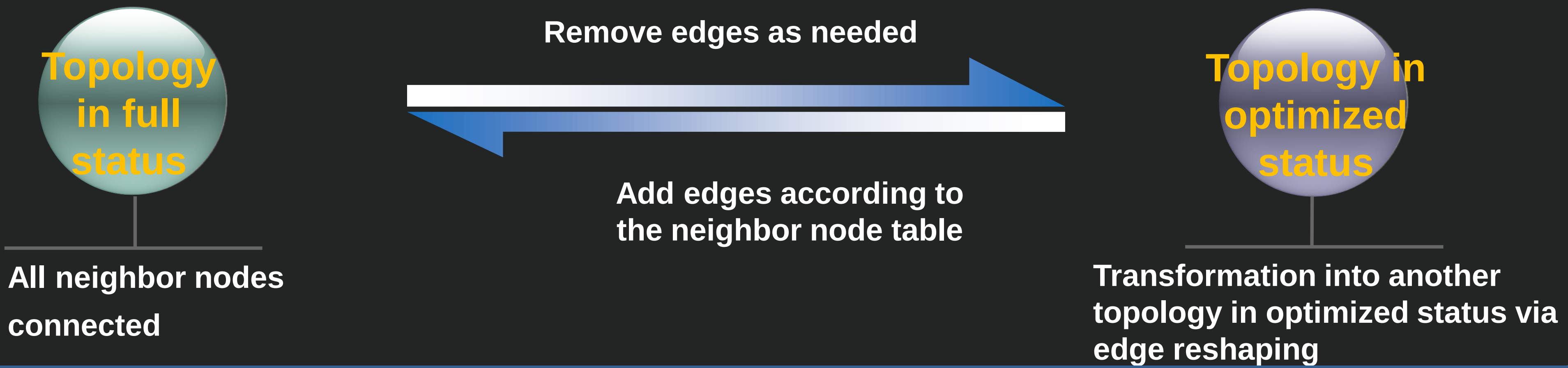
Neighbor Node



Neighbor Link



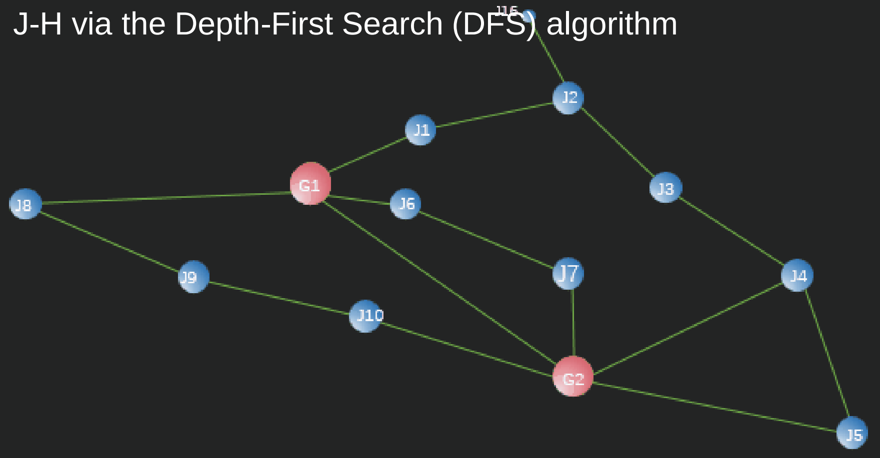
Full Status and Optimized Status



Highlights (3): DFS + Node Removing Method to Accelerate Topology Recovery

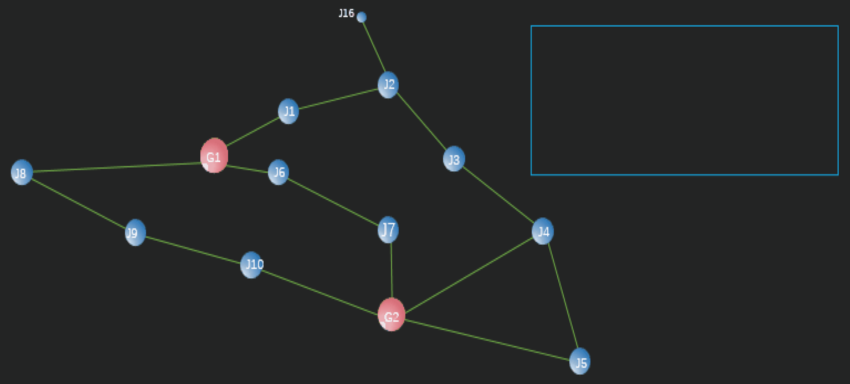
Search for main links

Execute the searchMainLink function to search for main links in the form of G-H-G or G-J-H via the Depth-First Search (DFS) algorithm



Sort out cross-connected main links

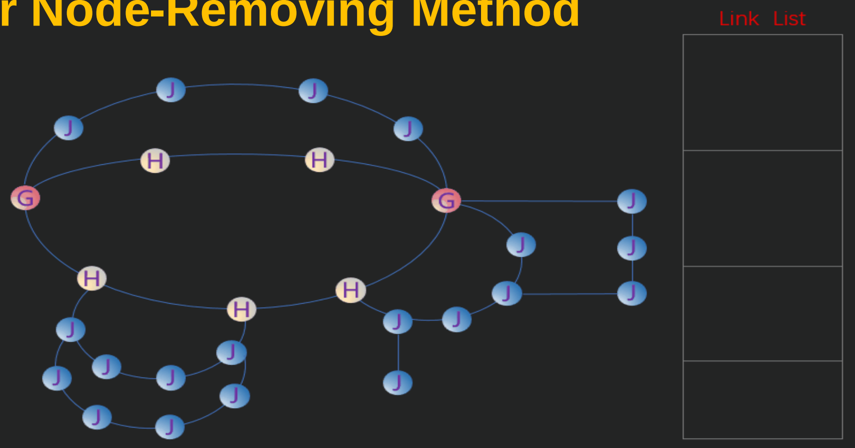
Execute the fiterLinks function to remove the main links that are comparatively shorter from the cross-connected main links



Analyze sublinks and hanging links with our Node-Removing Method

1. Select one main link and remove it
2. Execute connected_components to identify all connected subgraphs
3. Review all these subgraphs, and identify the main link for those removed sublinks and hanging links
4. Continue to remove other main links

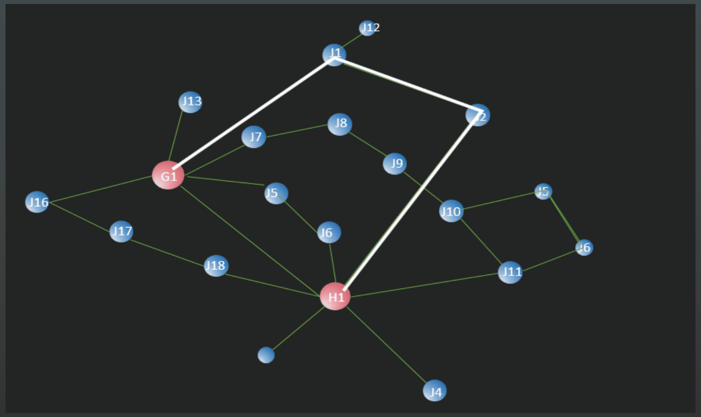
The optimization time was shortened by 80%



Highlights (4) : Topology Optimization from Multiple Perspectives

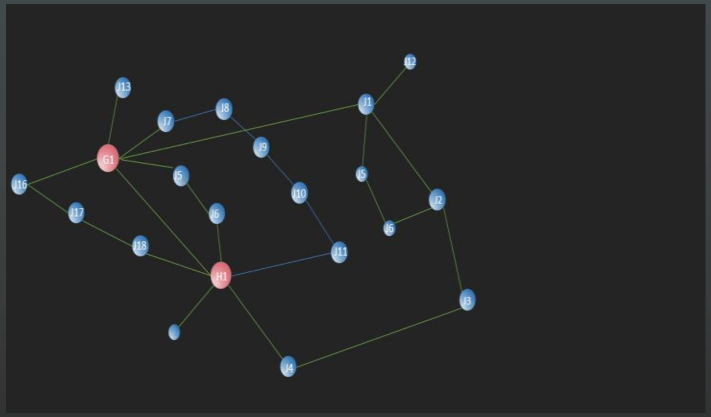
Link combination

Combine the link with unbalanced utilization with an appropriate neighbor link



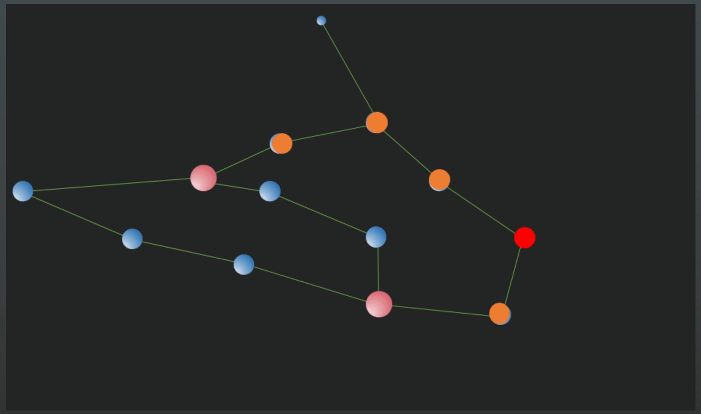
Partial link optimization

Transfer the sublink or hanging link with unbalanced utilization to an appropriate neighbor link if the link combination cannot be implemented



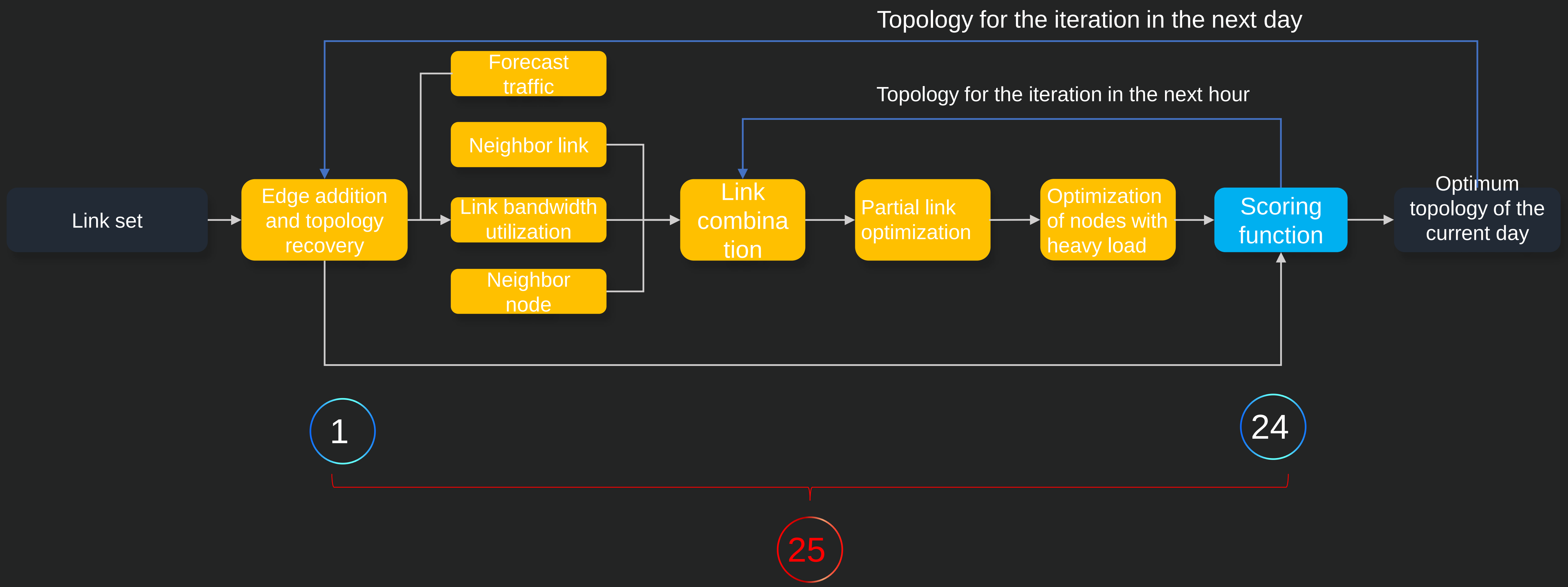
Optimization by node transfer

Optimize the link with heavy load by transferring some nodes with heavy load on this link to other links



Highlights (5): Successive Iteration for Optimum Topology

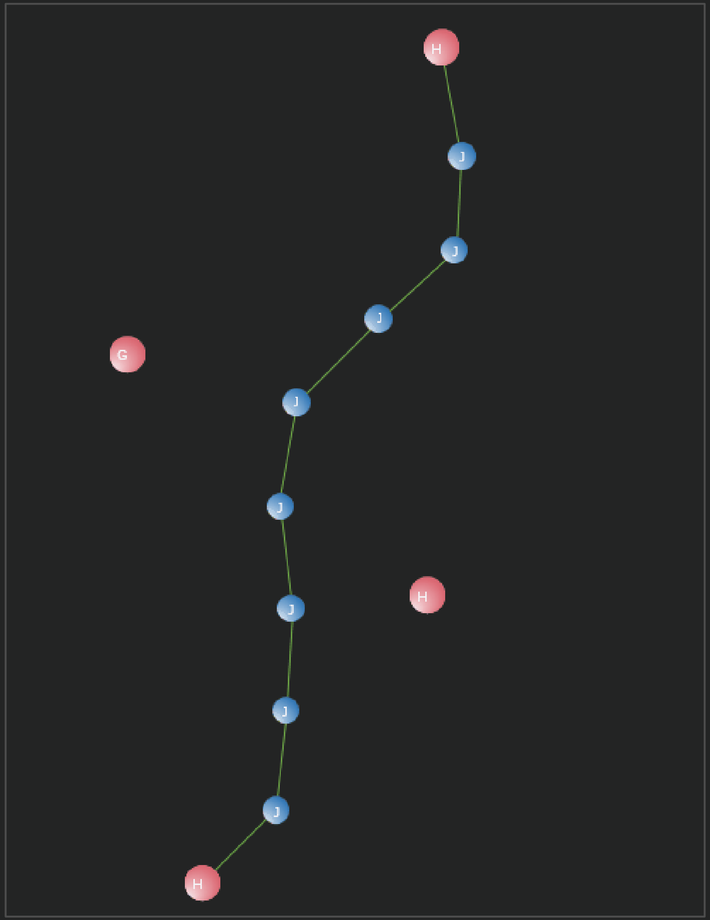
Calculate bandwidth utilization of the topology to be optimized based on the traffic data per 24 hours. After iteration for 25 times a day, select the optimum topology of the current day.



Highlights (6): Topology Restructuring

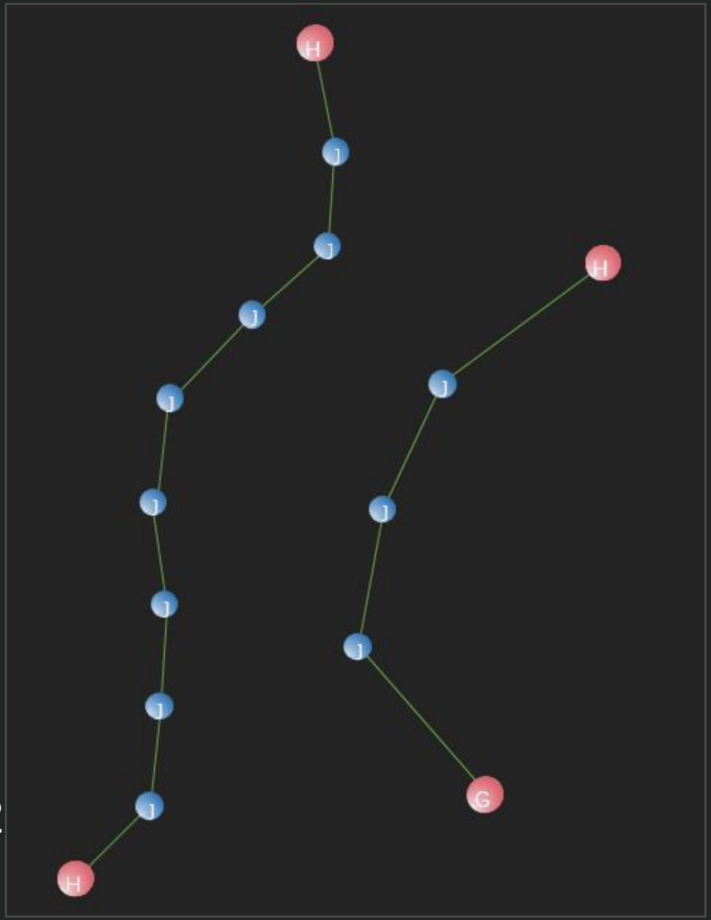
1. Find out the links with high or low loads for 10 successive days.

2. Split the link with heavy loads into two links by connecting it with the nodes on a neighbor main link (including node G, H and J), and start the iteration of the new topology with edges added in the previous step to improve the utilization of all links

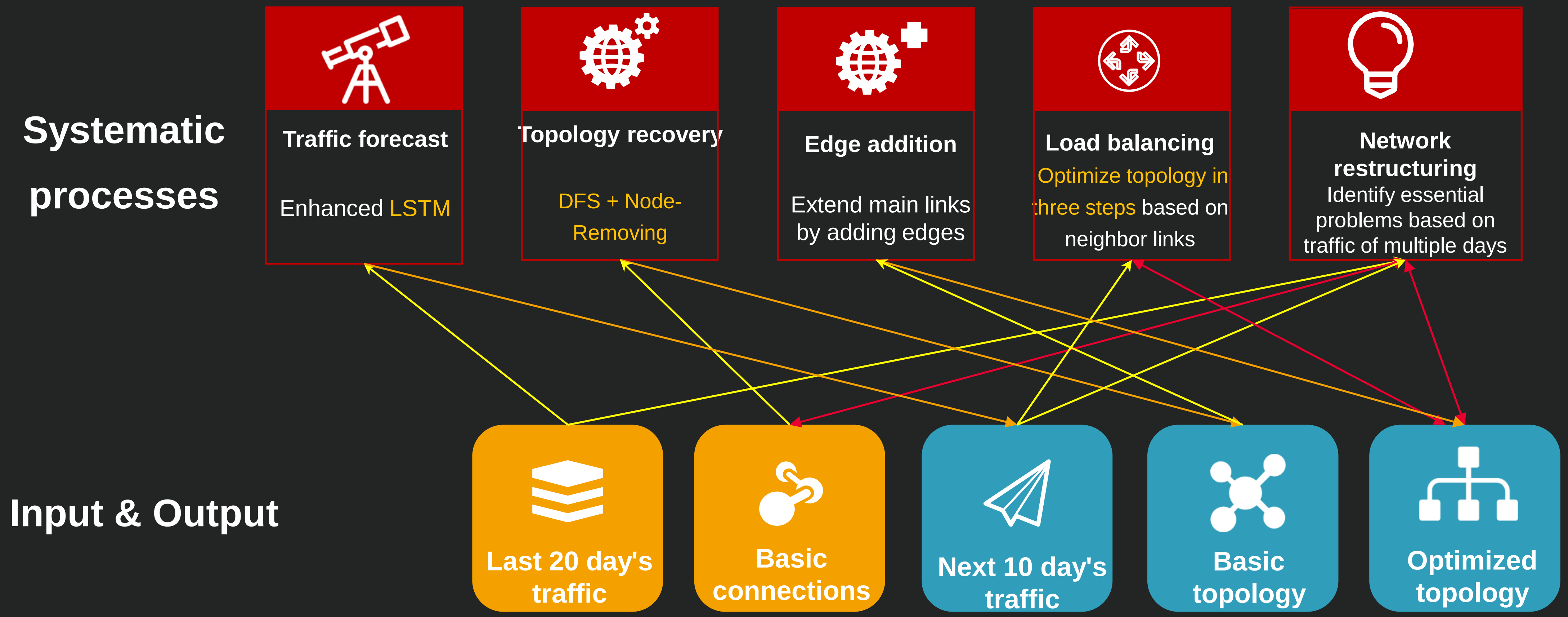


Scenario 1

Scenario 2

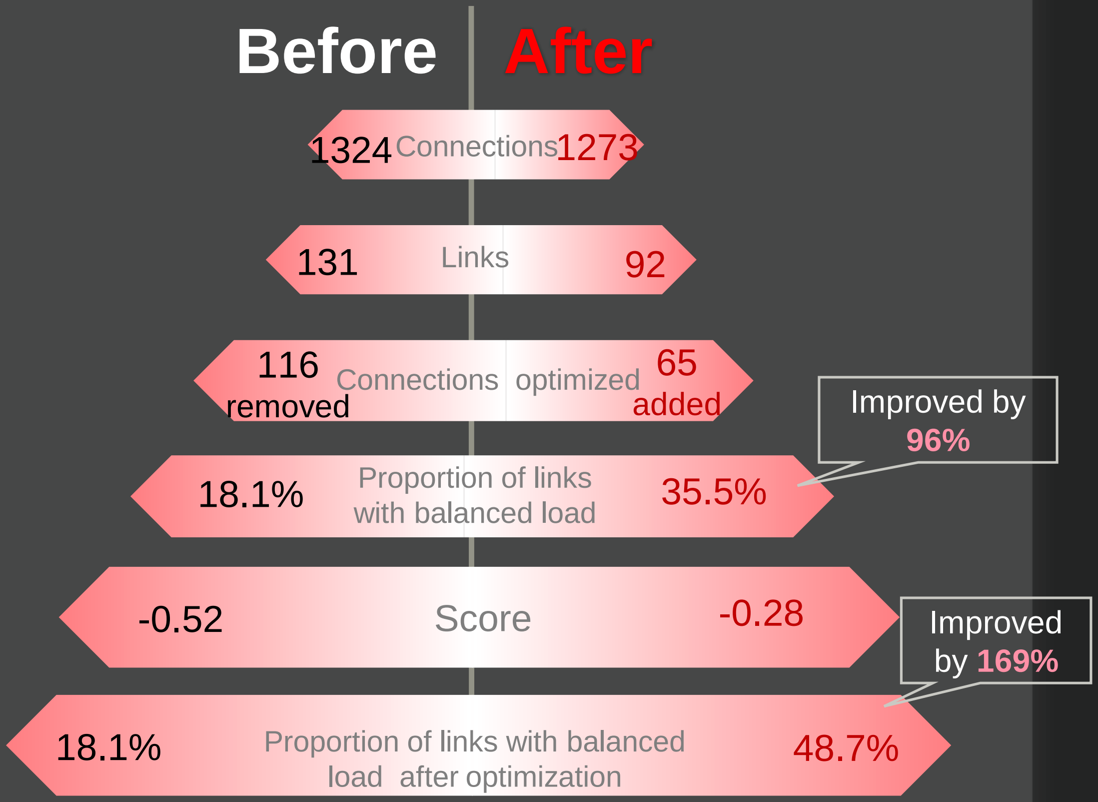


Highlights (7): A Complete Network Topology Analysis and Optimization System

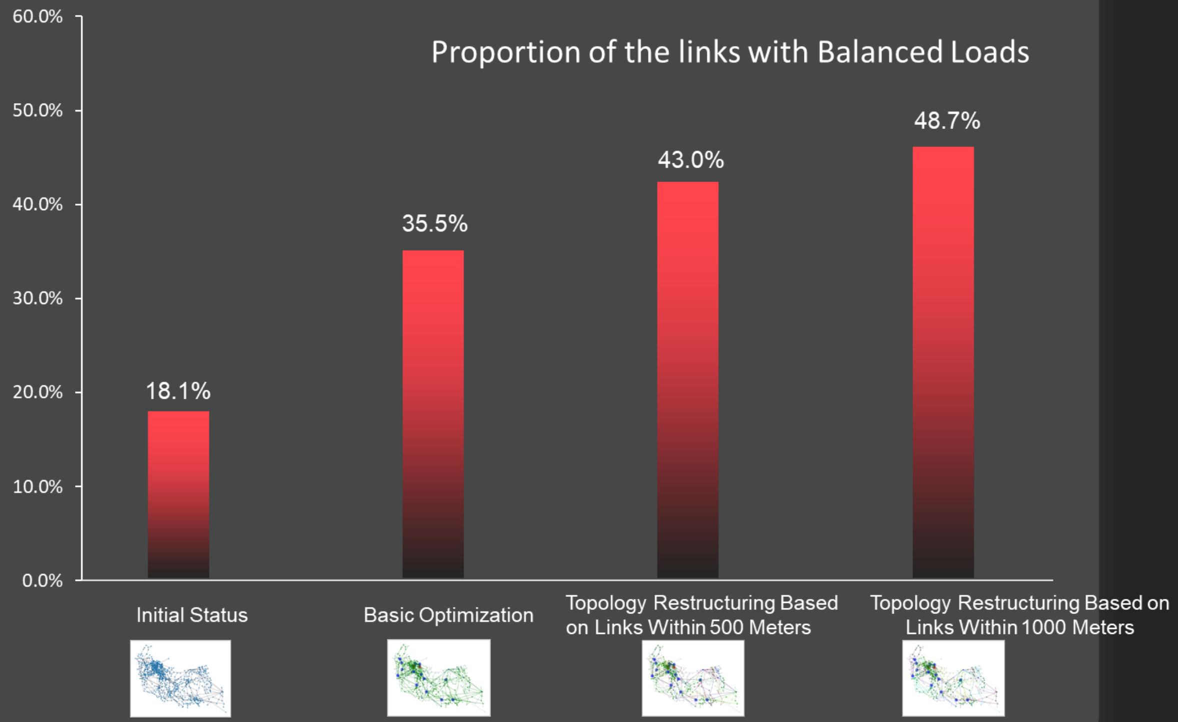


Effect of the Model

96% improvement via optimization
169% increase via topology restructuring



The proportion of links with balanced load in different optimization stages



Achievements

Summary

Error ratio — 3%
Optimal parameter selection strategy

Forecast efficiency — +20 times
Multiprocess technologies

Optimization time — -80%
Concept of neighbor
Node-Removing Method

Proportion of desired links — +169%
Multiple optimization methods
Successive Iteration

Rank No.1 in the preliminary contest and the finals

preliminary

Ranking list

Ranking	Team	Score	Time
1	小智 (Weeny Wit)	47.3822	2020.8.10 14:02
2	[illegible]	44.5493	2020.8.10 11:52
3	[illegible]	42.2958	2020.8.10 14:04
4	[illegible]	40.6929	2020.8.10 20:42

finals

Rank	Team name	Final Score
1	小智(Weeny Wit)	57.86754
2	[illegible]	56.93451
3	[illegible]	53.50706
4	[illegible]	55.18503
5	[illegible]	51.02891
6	[illegible]	52.3157
7	[illegible]	50.3261

Feedback

Comments by the Judges

- Network topology optimization, one of the most challenging tasks requiring professional knowledge
- Propose innovative approach to increase the proportion of load balancing link and predict traffic accurately
- The complete topology analysis and optimization system and the unique algorithm help to increase the proportion of the links with balanced load by 169%
- Rank No.1 with the highest scores in both algorithm and final evaluation
- Good generalization and practicality

First Prize in ITU AI/ML in 5G Challenge (China)

References

【1】Flexible Adjustments Between Energy and Capacity for Topology Control in Heterogeneous Wireless Multi-hop Networks

【2】A DBN-Based Independent Set Learning Algorithm for Capacity Optimization in Wireless Networks

【3】ElasticTree Saving Energy in Data Center Networks

【4】DeepWalk: Online Learning of Social Representations

【5】Understanding and Mitigating Packet Corruption in Data Center Networks

【6】Unveiling the potential of Graph Neural Networks for network modeling and optimization in SDN

Thank you