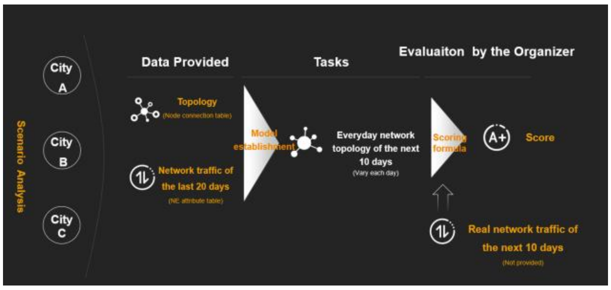
AI-Based Network Topology Optimization

1. Task Analysis

1.1 Task analysis

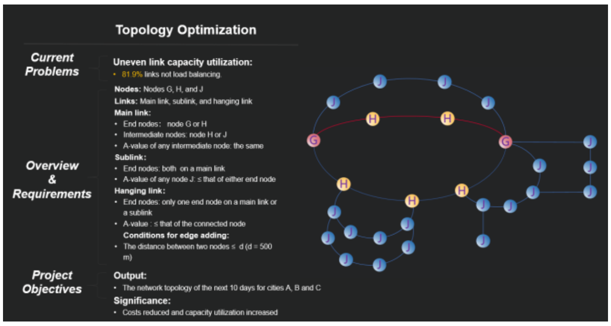


Based on the nodes connections and NE attributes including the last 20 days' traffic of the three cities' networks, we need to provide everyday network topology of the next 10 days. The organizer of the contest will use the formula to evaluate the solution according to the real traffic of the next 10 days, and produce a score accordingly.

In the 4G era, Internet technologies maintained a growing momentum, bringing in numerous unprecedented breakthroughs and diversified network services closely related to people's life. Today increasing traffic brought by the 5G era raises higher requirements for link capacity utilization, making operators expand their network capacity. In addition, the existing network topology planning does not fully consider the increasing network traffic and uneven link capacity utilization.

Against such a backdrop, we optimized the existing network topology through AI technologies. By making forecast on traffic and restructuring nodes on the links with unbalanced load, we completed the entire network topology optimization in a more precise manner. This effectively improves the link capacity utilization, and thus greatly reduces the investments.

2. Network Topology Define:



Based on the network topology and network attribute table provided, we found that 81.9% of network topology links of the cities A, B, and C failed to achieve load balancing.

In our topology, ‘there are three types of nodes and links respectively’, namely, nodes G, H, J, and main ‘links, sublinks, hanging links.

Main link:

- End nodes： node G or H
- Intermediate nodes: node H or J
- A-value of any intermediate node: the same

Sublink：

- End nodes: both on a main link
- A-value of any node J: ⩽ that of either end node

Hanging link：

- End nodes: only one end node on a main link or a sublink
- A-value : ⩽ that of the connected node

Conditions for edge adding:

- The distance between two nodes ≤ d (d = 500 m)
- Number of nodes per link ≤ 30
- Start and tail nodes of any main link should be G or H

3. Our solution

3.1 Solution

Our solution consists of two parts. The first part is traffic forecast. In this part, we built an LSTM neural model with TensorFlow.

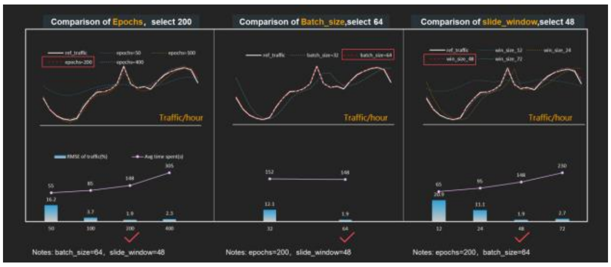
1) **Data processing:** Set the value of missing traffic to 0 and Sort out traffic by network element
2) **Training for traffic forecast:** Use the TensorFlow to build an LSTM neural model. Input data to the model for training, and achieve the traffic of the next 10 days.
3) **Data post-processing:** Sort out the forecast traffic of the next 10 days by day

The second part is topology optimization. We used NetworkX and the DFS algorithm, and optimized the network topology through a brand-new method.

1) **Network building:** Use NetworkX to build network topology and set up the neighbor node library.
2) **Topology recovery：** Use the "DFS algorithm" to search for main links, sort out cross-connected links, find out sublinks and hanging links via the Node-Removing Method, and build a link set.
3) **Topology recovery:** Handle links with heavy and low loads via link combination and partial link optimization
4) **Iteration for optimum topology:** Implement successive iteration for 24 hours and select the optimum topology from the total 25 topology.
5) **Topology restructuring:** Topology restructuring is proposed 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.

4. Highlights

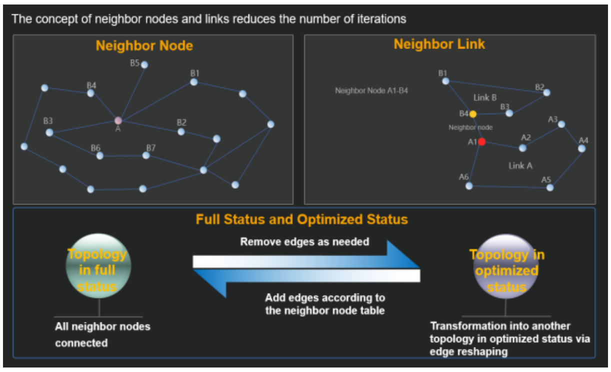
3.1 Highlights (1): Enhanced LSTM Traffic Forecast Model for Traffic Change



We first built an LSTM neural network model with TensorFlow. Then we input 480 samples of per-NE traffic of the last 20 days into the model to check whether our forecast is correct. Among all these samples, 75% were used for training, and the other 25% were used for testing.

To achieve the most accurate result, we finally set the most suitable parameters through evaluating the RMSE of traffic and average time consumed, and achieved the traffic per hour in the next 10 days. With multiprocessing technologies, we multiplied the network efficiency.

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

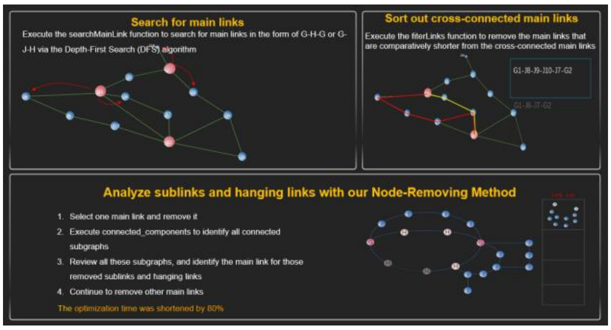


Second, to conveniently adjust node connections of the topology, we also defined neighbor nodes, neighbor links, network topology in full status, and network topology in optimized status.

For neighbor node, we believe that one node on specified links is adjacent not only to the appropriate nodes on the same links, but also to the nodes located within 500 meters. We also formulated a neighbor link table to gather all the links where neighbor nodes are located together.

In our solution, topology in full status indicates all neighbor nodes are connected. Such topology includes both existing connections and all potential neighbor links. We can either transform topology in full status to the one in optimized status by removing appropriate edges, or achieve a topology in full status by adding some edges to the related topology in optimized status in accordance with the neighbor link table.

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



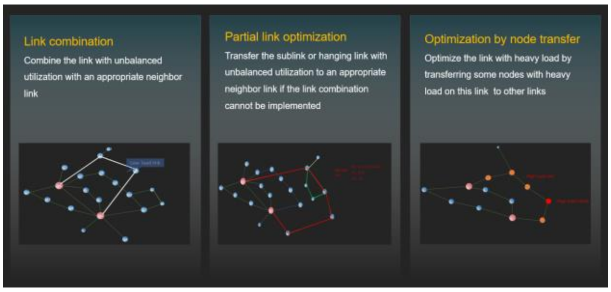
Third, to make original network connections satisfy the requirements of desired network topology, we took the lead in using the DFS algorithm and "Node-Removing Method" together to accelerate topology recovery.

"Node-Removing Method" :

We then searched for sublinks and hanging links of each main link through our unique "Node-Removing Method" . Edges unhooked from the link when we remove two nodes from one main link are identified as sublinks and hanging links of this main link.

1) Select one main link and remove it
2) Execute connected_components method 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.

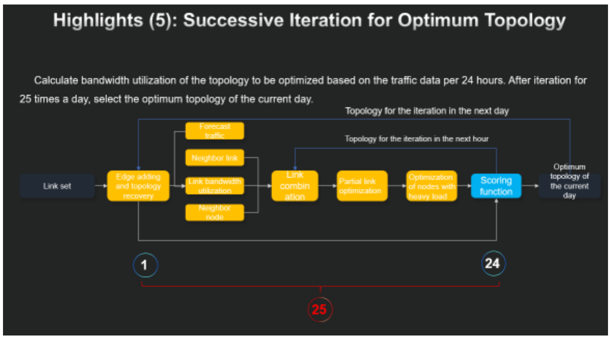
3.4 Highlights (4) : Topology Optimization from Multiple Perspectives



Fourth, we further optimized the recovered network topology by adjusting the links with unbalanced loads through three different ways, including link combination , partial link optimization, optimization by node transfer。

1) **link combination:** We combined a link with unbalanced utilization with an appropriate link by adding or removing related edges.
2) **partial link optimization:** We transferred a sublink or hanging link with unbalanced utilization to an appropriate neighbor link.
3) **optimization by node transfer:** We transferred nodes on links with heavy loads to other links to balance link utilization in a precise manner.

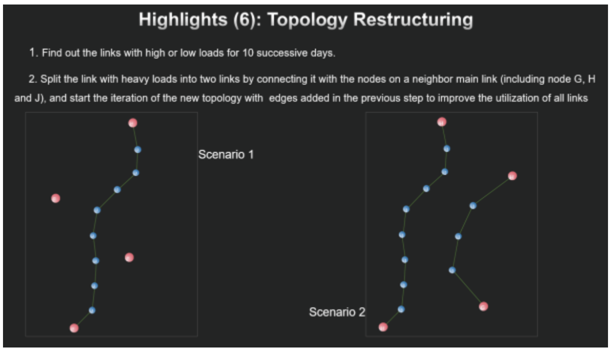
3.5 Highlights (5): Successive Iteration for Optimum Topology



This flow chart describes how we optimize the link load status and keep pursuing optimum topology through successive iteration.

We optimized the current network topology with the forecast link utilization per hour, achieving the source topology for the iteration carried out in the next hour. After running such successive iteration for 24 times, we selected the best network topology of the day from the total 25 topology. In the next day, this selected topology will be taken as the source topology and put into another round of iteration.

3.6 Highlights (6): Topology Restructuring

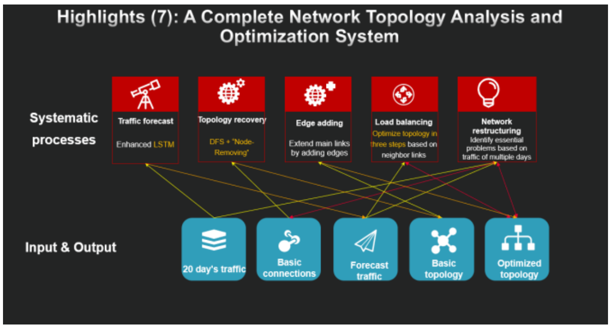


After completing the required task, we also made in-depth study on the optimization of network topology, which is topology restructuring. Specifically speaking,

1) We first find out links with problems, namely the links with low or heavy loads for a long period of time.

2) Second, we 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.

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



Last but not the least, we set up a complete network topology analysis and optimization system.

We got the forecast network traffic through the enhanced LSTM model and recovered the basic network topology via the "Node-Removing Method" and the DFS algorithm.

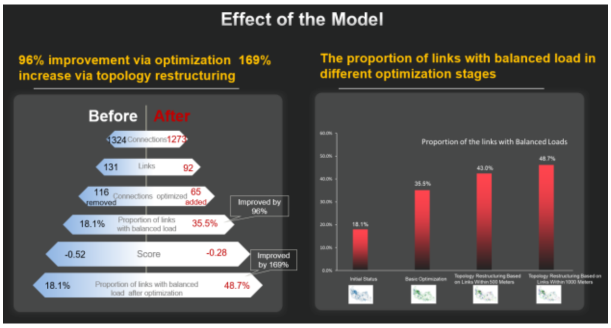
Via edge adding, we extended the length of the main link and achieved an optimized topology.

We applied the forecast network traffic to the optimized topology, made analysis based on the link relations as shown by the neighbor link table, and optimize link capacity utilization in three different ways.

Through topology restructuring, we enhanced the entire network efficiency.

4.Effect

4.1 Effect of the Model (1)



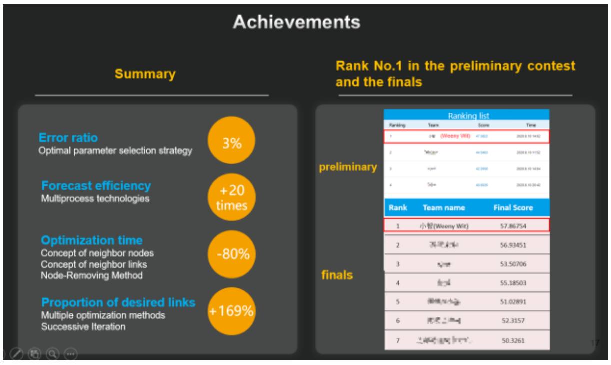
With our solution, the proportion of the links with balanced load increased from 18.1% (based on the original topology give in the task) to 35.5%, witnessing an increase of 86%. With outstanding performance in both the preliminary contest and the finals, we ranked first among all players in China.

After the contest, we made further research on network restructuring, enabling the the proportion of the links with balanced load increased from 18.1% to 48.7%, with an increase of 169%.

Here we can see the proportion of links with balanced loads in different stages of network topology optimization.

1) This shows the proportion of such links in the original network topology before we started the optimization.
2) The proportion increased to 35.5% after our basic network topology optimization through the aforementioned three methods.
3) After restructuring the links within 500 meters, we increased the proportion to 43%.
4) The result indicates that the links with balanced loads increased to 48.7%.

Summary



Through selecting the most appropriate parameters, we controlled the error ratio of traffic forecast with the LSTM model within 3%.

With the distributed and multi-process technologies, we increased the traffic forecast efficiency by 20 times.

By introducing neighbor nodes, neighbor links, and other unique methods, we reduced the average time for topology optimization by 80%.

Through the link optimization and topology restructuring, we increased the proportion of the links with balanced load by 169%.

With outstanding performance, we ranked No.1 in both preliminary contest and the finals in China.