DEVELOPMENT OF TRANSMISSION NETWORK PLANNING TOOL

SOH Zhao Sheng, CHUA Chee Wee

ABSTRACT

A transmission network forms the main infrastructure and provides inter-connectivity of systems and communications across various locations. As the transmission network consists of hundreds of nodes and fibre cable segments, it poses a challenge to track and manage future network resources demands manually. This is especially critical as timely upgrade is required to ensure it can support future growth. A team of DSTA engineers developed the Network Capacity Planning Tool to analyse nodes and bandwidth utilisation so as to actively plan for the future. This article describes the background for the development of the tool, the methodologies and the way forward.

Keywords: transmission, network, infrastructure, bandwidth, tool

INTRODUCTION

A transmission network forms the main backbone connectivity infrastructure across various locations and provides inter-connectivity of systems and communications. It consists of hundreds of nodes that are typically connected in a hybrid or meshed topology, providing resiliency and redundancy. Systems that require the transmission of data, such as data application and communication across various geographical locations, would use these underlying transmission networks.

KEY CHALLENGES

The key challenges faced are the complexity of correlating massive existing data and the manual end-to-end routing assignment of future network resource demands for the transmission network. These information are critical for the forward growth planning in upgrading of transmission network.

A typical transmission network consists of nodes linked up in a certain topology to meet its purpose and ensure network resiliency. Different topologies can be deployed, such as point-to-point, ring, meshed and hybrid topologies. A node, which is usually in a form of an equipment chassis, has many slots to house various types of cards, such as controller cards, network cards and power module cards. Each network card has a fixed number of ports that provides both ingress and egress for data flow. Figure 1 shows a typical node with cards inserted in three out of the four slots, while Figure 2 shows the physical link between two nodes in a point-to-point topology.

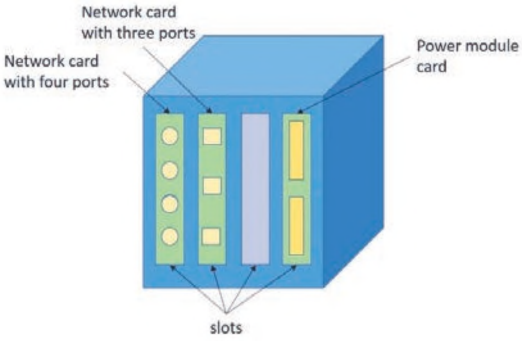


Figure 1. Four-slot equipment chassis with three different cards

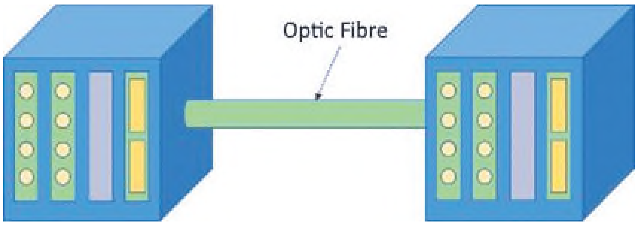


Figure 2. Nodes connected in Point-to-Point topology using optic fibre

In order to manage and monitor all the nodes in the transmission network, a Network Management System (NMS) is used. The NMS enables the user to configure nodes, create links between nodes, and monitor the status as well as utilisation of each node. However, it does not allow the user to plan and analyse potential network growth to meet future bandwidth demands. To carry out forward planning, a suite of data is required. These data include types of nodes, existing slot utilisation, existing port utilisation on each card within the nodes, existing bandwidth capacity and utilisation of links between nodes. However, they can only be obtained by checking on individual nodes and links, which makes the entire process tedious and time-consuming. After obtaining the data, the transmission engineer will need to sort them into tables and do a manual correlation across multiple tables. This process usually takes days to complete.

Once sense-making of the data is done, there is a need to reserve future bandwidth demand on the network for various systems. Bandwidth reservation is done by manually plotting out each circuit end-to-end on the network, with the shortest transmission route in mind. Other than the route, the transmission engineer also has to consider the bandwidth utilisation of each link the network circuit will transverse through, and the availability of ports at both start and end nodes. The plotting of a network circuit is illustrated in Figure 4.

The difficulty of this task is further compounded by frequent bandwidth change requests to conduct analyses, in support of daily bandwidth reservation by various users. With hundreds of circuit reservations to manage, coupled with frequent changes from users and in the network topology, complex manual computations are error-prone and unsustainable. When errors are introduced, downstream computational analysis and recommendations would be impacted. This could lead to wrong upgrading recommendations that could ultimately delay system implementation or lead to the spending of unnecessary funds to upgrade portions of the network where there are sufficient resources.

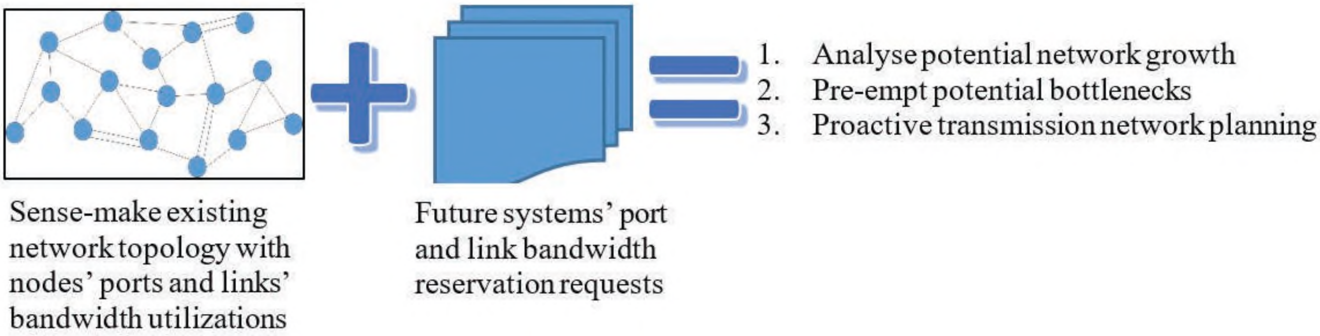


Figure 3. Key challenges that a transmission engineer faces

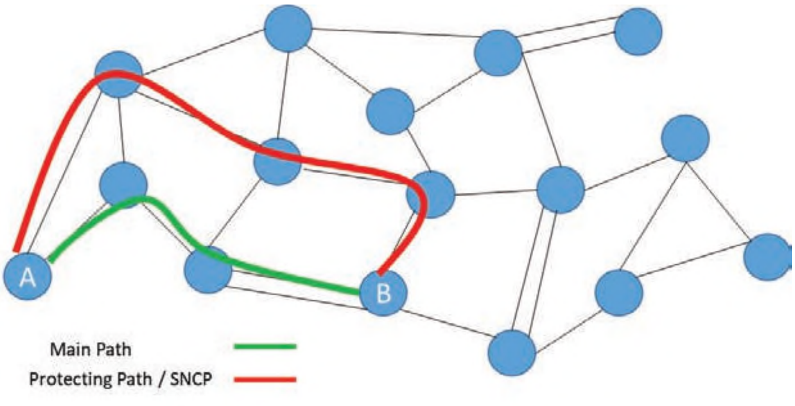


Figure 4. Simplified network with system bandwidth reservations between node A and node B

SOLUTION AND CAPABILITIES

To address these challenges, engineers from different domain expertise collaborated to develop Network Capacity Planning (NETCAP). NETCAP is able to import data from an NMS, in the form of physical ports and link bandwidth of the network, to sense-make existing resource utilisations. In addition to sense-make existing utilisations, it allows users to plan future system resource demands proactively. Thus, engineers are able to analyse potential network resource growth and pre-empt any potential resource demands that exceeds or reach capacities.

The key objective was to enable proactive capacity management through sense-making of existing physical ports and bandwidth utilisations, auto-route generation for future demands, and identification of chokepoints through a visual dashboard display which greatly improves engineers' productivity and analysis. Figure 5 summarises the capabilities of NETCAP.

NETCAP has allowed the team to analyse multiple data, including the utilisation of physical ports and slots of individual nodes, and bandwidth utilisation of each individual physical link across the network. The current NMS can only analyse current link and port utilisations; it is unable to provide a dashboard summary of various physical ports and bandwidth utilisations.

NETCAP enabled the seamless importing of raw data from an NMS and analytical computation to sense-make usage across multiple attributes from physical ports to physical links bandwidth utilisations, factoring across current and upcoming system demands. Its underlying engines are able to compute optimal primary and secondary routes, in cases that require the need for secondary network route analysis. Various "what-if" scenarios in terms of operations impact to different systems can be further drawn out when certain nodes become unavailable. This enabled a holistic analysis of the robustness and relative criticality of the nodes.

The tool includes a geospatial node and physical link planning which users could use to plan network layouts. In addition, node bayface layouts can be developed in NETCAP, allowing visual display of node slots to decide if there are sufficient slots for data traffic card expansion. Furthermore, visual analytics are developed to enhance decision making for users. Immediate displays of visual highlights of nodes or physical links that exceed the threshold allow users to zoom into the area for further analysis and decision making.

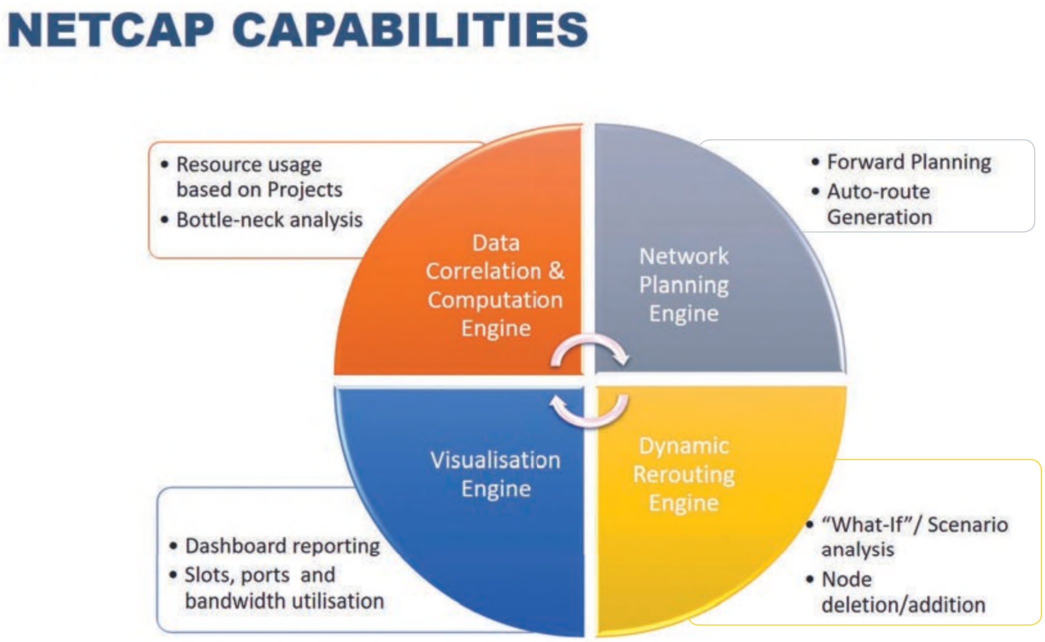


Figure 5. NETCAP engines and their capabilities

ARCHITECTURE AND METHODOLOGY

NETCAP incorporates four engines to generate the results that provide analysis and insights. Together with the four engines, the interface manager controls the various function calls and parameter requests between the various engines and database manager. The database manager provides an interface to store and retrieve information on the external NETCAP database. Figure 6 shows the architecture of NETCAP, and the interactions of the various modules and external agents with it. The following sections briefly describe the methodology implemented within each engine.

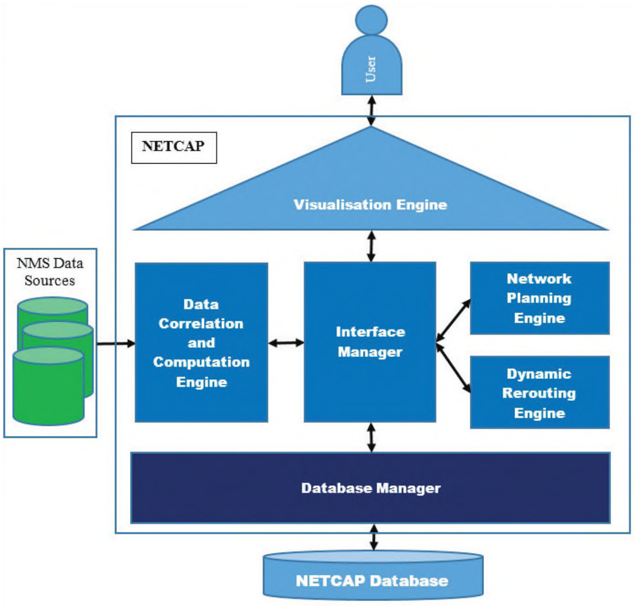


Figure 6. NETCAP architecture and interaction diagram

Data Correlation and Computation Engine

The raw data files that are extracted from the NMS are disparate and unstructured, and hence are unable to be used for any direct computations. The Data Correlation engine does the process of cleaning, filtering, processing, collating, correlating and transforming the multiple raw data sources that are extracted from the NMS. For example, the data from the NMS are represented as logical ports, while the network engineers require only physical ports for analysis and utilisation. Transformation of logical port data to physical ports is thus required. After processing, the data is translated into structured relational data and stored in NETCAP's database. The Data Correlation and Computation Engine was developed to correlate multitudes of raw data together and compute the required utilisations for analysis. This eliminates the human errors that frequently occur during the manual processing of raw data.

The computation engines would take correlated data and compute the existing resource utilisations in the form of physical ports, as well as physical link bandwidth utilisations and present the network utilisation statistics. Figure 7 shows a typical example of how raw data of physical links is correlated to compute the existing bandwidth utilisations. Various users across the various system phases can also make use of NETCAP to enquire on port and link bandwidth availability, and request for budgetary quotations to upgrade the necessary nodes and physical links if existing resources are insufficient. The computation engine would take in these port and bandwidth requests to perform utilisation analysis to assess supportability. This relieves network engineers of handling such requests so that their focus can be better placed at strategic planning and management of network resources holistically.

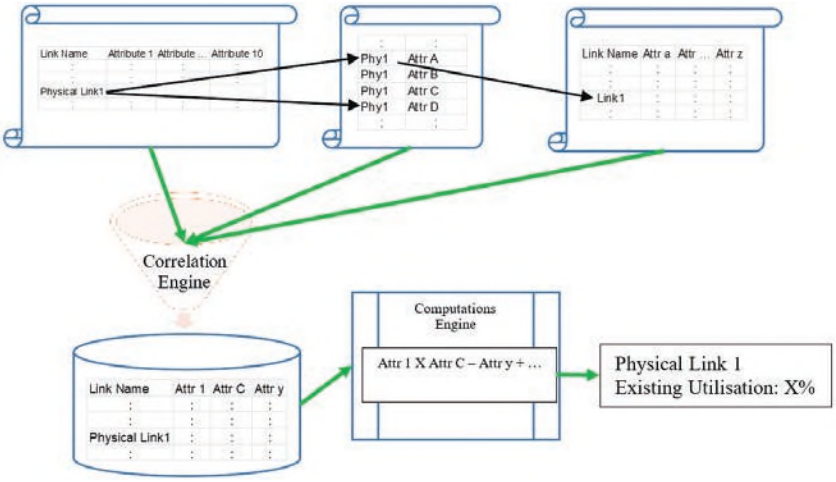


Figure 7. Correlation of raw physical link data for computations of links' bandwidth utilisations

Network Planning Engine

With hundreds of inter-connecting nodes (N) and physical links (L), the transmission network poses great challenges for the proactive management and quantification of detailed itemised resource utilisations and bottlenecks. The Network Planning Engine adopts fundamentals of network science and graph theory to analyse the entire transmission network. The average degree of undirected networks is given as:

$$Average\ degree\ (undirected\ network) = \frac{2L}{N}$$

Using the lower data bound of the network, the average degree is computed as 3. This suggests that each node interacts with three other nodes. Comparing this information with other networks, the transmission network has similar complexities with other undirected networks, as shown in Table 1. The measure of the longest distance between two extreme nodes is considered the network diameter. As the diameter of the network increases, network complexity increases as more nodes and interconnectivity are introduced, especially with a high average network degree. The current transmission network diameter exceeds a value of 10, showing that the transmission network is very complex.

Network	Average Degree
Internet	6.34
Power Grid	2.67
Protein Interactions	2.90
Transmission Network	3.00

Table 1. Average degree of some undirected network

The network planning engine generates an optimal network path and computes all the necessary resource utilisations required from the nodes and connecting physical links across the path. This is achieved by computing the shortest path available between these two end nodes by adopting a variant of A* search algorithm with additional meta-heuristics that is relating to the transmission network. The algorithm finds the shortest path by generating and maintaining a tree of paths which originates at the start node, extending those paths one link at a time until it reached its end node. Such an implementation enabled the completion of entire computations and analysis of the entire set of transmission data under a minute. Initial implementations of the engine had seen challenges, such as a shortage of computational memory as well as computations that exceed an hour.

As there are many system bandwidth reservation requests, the network planning engine would aggregate bandwidth requests that have the same end nodes. This allows NETCAP to minimise network path searches and improve performances. Using the network topology shown in Figure 8, network path searches would be conducted once the bandwidth reservations are aggregated. Some of the nodes consist of multiple physical connecting links, such as the connectivity between the nodes B and C in Figure 8. The Network Planning Engine would carry out load balancing by distributing the bandwidth utilisation demand that is routed through these two adjacent nodes amongst the least utilised physical link. The computations of concurrent physical link utilisations would be more balanced without one of the concurrent links overloading in such scenarios. An illustration is shown in Figure 9 where bandwidth reservations may be loaded onto Link_CB_L2 instead of the other physical link between node B and node C, if Link_CB_L2 is found to be underutilised.

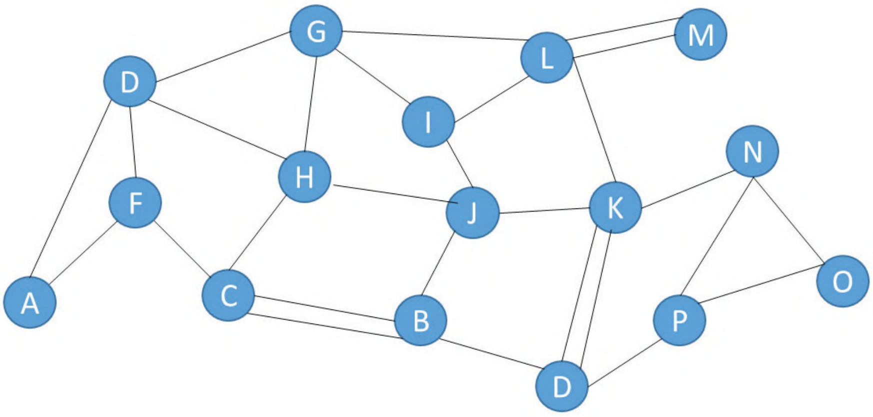
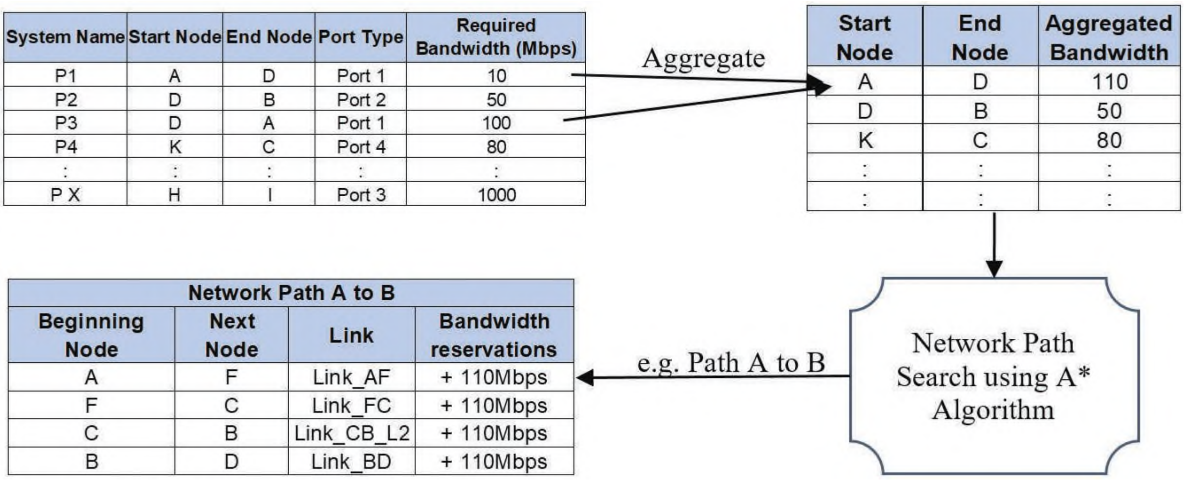


Figure 8. A typical meshed network



System Name	Start Node	End Node	Port Type	Required Bandwidth (Mbps)
P1	A	D	Port 1	10
P2	D	B	Port 2	50
P3	D	A	Port 1	100
P4	K	C	Port 4	80
:	:	:	:	:
P X	H	I	Port 3	1000

Start Node	End Node	Aggregated Bandwidth
A	D	110
D	B	50
K	C	80
:	:	:
:	:	:

Network Path A to B			
Beginning Node	Next Node	Link	Bandwidth reservations
A	F	Link_AF	+ 110Mbps
F	C	Link_FC	+ 110Mbps
C	B	Link_CB_L2	+ 110Mbps
B	D	Link_BD	+ 110Mbps

Figure 9. Illustration of a typical process to compute bandwidth reservations for each physical link

System engineers may request the need for a secondary network route to provide redundancy and robustness for system implementation. In such cases, secondary route protection with nodes traversal that is totally independent and mutually exclusive of its primary route is generated through applying the algorithm twice. However, during secondary route computations, additional constraints where nodes traverse during the primary path search are not available for selection.

Dynamic Rerouting Engine

Other than processing the raw data from NMS, NETCAP allows the team to conduct scenario planning, such as the addition, modifications, and deletion of the resources which include network cards, nodes and physical links. This feature will enable proactive and dynamic resource planning and management for potential network upgrades.

During exercises, quick analysis on what-if scenarios, such as node failure and physical fibre cut, are commonly simulated. As shown in Figure 10, suppose there is a 10MB system circuit between node C and D. When there is a failure in node B for system circuit C←→D, the dynamic rerouting engine would compute a pair of new primary and secondary network paths. In addition, the rerouting engine would add an additional 10MB bandwidth utilisation for each of the physical link for the new secondary path generated while removing the 10MB utilisation that is on the affected original network path. With this, analysis on the impact of node B on the entire transmission network could be studied. The dynamic rerouting engine allows impact analysis for future transmission network growth to be conducted easily. As shown in Figure 11, the entire process of re-computing the affected network routes and bandwidth utilisation begins from the dynamic rerouting engine. The Dynamic Rerouting would identify the affected network routes.

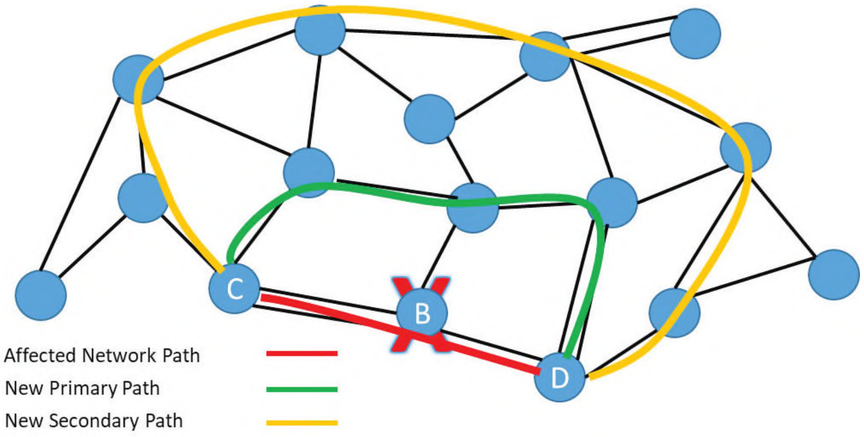


Figure 10. Rerouting of system circuits due to failure of node B

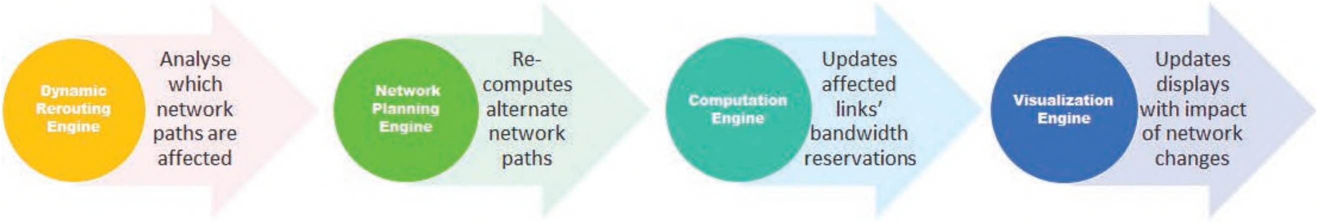


Figure 11. Figure showing the various engines and their processes for scenario planning

Next, the Network Planning engine would search for alternate network paths before the Computations engine re-computes the physical link bandwidth utilisations for the entire network in the event of node failure or cuts in physical fibre.

Visualisation Engine

The Graphical User Interface incorporates the visualisation engine. With the correct use of the data visualisation dashboard, it significantly improves analysis and productivity. The visualisation engine aims to communicate the result analysis to the user effectively with minimal interpretation effort. The visualisation engine adopts many visuals such as interactive geospatial information, charts, summarised information tables, and digitised node bayfaces.

The Visualisation Engine highlights the top few nodes with respect to physical port utilisation as well as physical link utilisation in the dashboard. In addition, the dashboard which is shown in Figure 12 allows users to modify desired bandwidth and physical port threshold interactively, and drill down to the respective resources on the geospatial map that exceeds the predefined threshold.

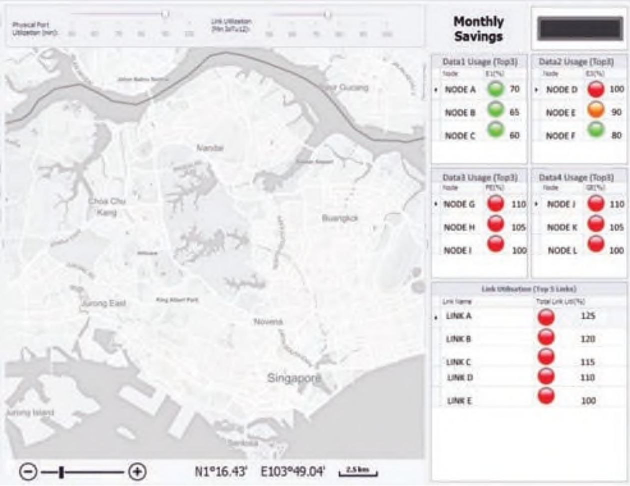
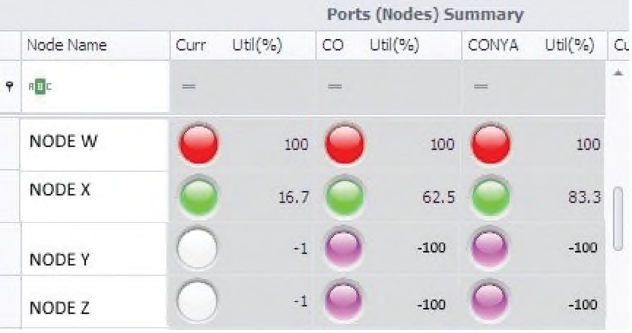


Figure 12. Dashboard layout of NETCAP

Besides displaying computational statistics, the visualisation engine uses summarised information tables to highlight and display nodes with physical ports as well as physical links that exceed the threshold. Figure 13 shows the summarised physical port information table used by the visualisation engine.

Colour coded icons, inspired by traffic lights, are used to visually highlight nodes that have potential issues with certain physical ports, based on system types. Figure 14 shows the determining factors in representing the utilisations through colour coded icons. With a single visualisation, network engineers can easily identify which type of physical port of a particular node is approaching or had exceeded the predefined utilisation threshold.



Ports (Nodes) Summary

Node Name	Curr	Util(%)	CO	Util(%)	CONYA	Util(%)
NODE W	🔴	100	🔴	100	🔴	100
NODE X	🟢	16.7	🟢	62.5	🟢	83.3
NODE Y	⚪	-1	🟣	-100	🟣	-100
NODE Z	⚪	-1	🟣	-100	🟣	-100

Figure 13. Summarised physical port information table from different system phases

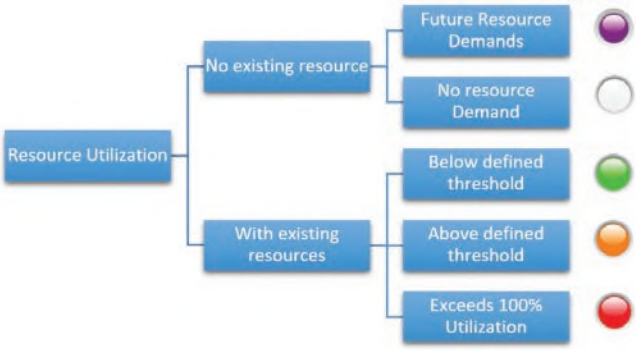


Figure 14. Determining factors for utilisation icons representations

After the team had identified relevant resources that could exceed the desired threshold, additional information such as node slots availability for additional data traffic cards was essential. The visualisation engine displays the bayface layout of each node, similar to the actual node design, and correlates slots that have inter-dependencies. In addition, the visualisation allows comments related to the cards to be inserted for reference.

TOOL VALIDATION

Results of the physical port utilisations were validated using result sets that were manually generated previously. With NETCAP, both primary and secondary routes are generated and displayed within the tool. This allowed the team to validate if the network route generated was correct, as well as the underlying physical links' bandwidth utilisations.

BENEFITS AND PRODUCTIVITY GAIN

With the use of NETCAP, the manual effort required to synchronise the database for bandwidth utilisation had been reduced from three days to one day, improving productivity by 60% and eliminating human errors. Furthermore, the response time for bandwidth utilisation checks based on system bandwidth requirements had been reduced from five working days to less than one day, thereby improving overall productivity by more than 80%.

INSIGHTS

Using NETCAP, users can quickly gain insights into the various physical ports and physical link utilisations based on future system demands. Once utilisations as well as potential bottlenecks are identified, transmission engineers can rely on the node visualisation to determine if there are sufficient slots to insert relevant network cards for upgrades.

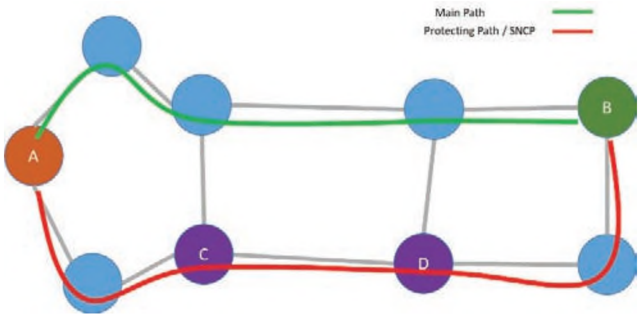


Figure 15. Simple network with two different system demands, A←→B and C←→D

Another insight that the tool showcased is that systems with high bandwidth demands might not necessarily translate into more circuit links bottlenecks. In addition to system bandwidth demands, it is also dependent on routing configuration, secondary route protection requirements and existing topology. Using NETCAP, some systems that have high bandwidth demands have shown to generate lesser bandwidth bottlenecks than systems with lower bandwidth demands. Using a simple example of Figure 15 and Table 2 to illustrate, a system with end nodes at A and B may require higher total network bandwidth demands than another system with end nodes C and D, though the latter requires higher bandwidth. With higher network bandwidth demands, the former system may create more bottlenecks within the transmission network.

End Nodes	System Bandwidth Request	Secondary Route	Links Traversed	Total Network Bandwidth Utilisation
A, B	500 MB	Yes	9	4500 MB
C, D	1000 MB	No	1	1000 MB

Table 2. System bandwidth requests and their impact on the network

CONCLUSION

After the deployment of NETCAP to the transmission team in December 2017, the tool has since replaced manual calculation and is being used for daily analysis. The development and deployment of NETCAP to the transmission team has greatly improved the team's productivity and most importantly, it has enabled holistic proactive transmission network resource planning and management.

With basic functionalities of the tool developed, the team is not resting on its laurels. One of the long-term goals for NETCAP is to develop it from a standalone solution into an Enterprise Solution where users can conduct bandwidth checks and obtain almost real-time results via the network. This step forward would free up the transmission team to conduct more strategic planning for the growth of the transmission network.

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BIOGRAPHY

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