An Integrated Planning Tool for Next Generation Network Modelling

Richard J. Harris *Senior Member, IEEE*, and Donald G. Bailey *Senior Member, IEEE*.

***Abstract*—As technologies change it is important to have a range of generic and tailored tools to support the planning of Next Generation Networks. This paper describes a new network planning tool that integrates measurement, modelling and simulation capabilities in order to provide network planners with the tools required to migrate from existing technologies to Next Generation Networks based on IP and MPLS modes of working. Novel features include generation of traffic demands from service descriptions and routing based on service requirements with queueing and flow models for determining bottlenecks and analysis of failure scenarios.**

***Index Terms*—Network Reliability, Network Planning, Network modelling tools**

I. Introduction

NETWORK planning is an important task for modern communication networks, irrespective of their size. In the past few decades the pace of development has been increasing and network planners have contended with a need to introduce an ever-increasing number of new technologies and integrate them with existing technologies. The major shift from circuit switching to packet-based switching together with the use of dominant internet (IP-based) technologies and protocols has led to major changes in the way networks are designed and managed.

Accordingly, network planners seek new tools that will enable them to address the challenges that these new technologies bring. The motivation for our work was to design a network planning tool that could effectively integrate analytical modelling, simulation and measurement processing, which are the three key tools used by a network planner. This is an ambitious concept that few other planning tools have attempted. Many commercial and open source systems tend to specialize on one particular aspect such as modelling, simulation or measurement processing [4, 5, 6 and 7]. Thus, a planner is often faced with the need to export data from one tool to another in order to consider different scenarios or design factors. This can lead to significant difficulties since the various tools are typically incompatible with each other and much time is spent converting outputs from one tool into inputs for the next tool. This can sometimes lead to planners using simplified models within spreadsheets in order to obtain a workable design whilst sacrificing some accuracy. Scalability of these tools, difficulties in assimilating data presented in a GUI environment and the corresponding complexity of algorithms make the design of a completely integrated tool a very challenging exercise as it can potentially lead to a large, complex and unwieldy tool that is difficult to use. Our tool has been designed to enable time savings through integration of the analytical modelling, simulation and measurement processing functions in one place.

In this work, we shall describe our proposed planning tool and demonstrate that it has many useful features that would enable a modern network planner to capture and process data and then model their network using analytical tools and finally check their design using simulation. The software, known as the ***NGNResiliency*** tool, consists of a GUI built around a standard Windows platform with interfaces to measurement, modelling and simulation systems. It is designed to complement the typical planning and installation cycle depicted in Figure 1. Within its framework, it contains a wide variety of built-in analytical tools as well as some integrated simulation capabilities to support this cycle. In addition to employing standard features found in many other planning tools, we have introduced some new and unique capabilities that provide enhanced planning options – especially in the areas of service modelling and network resiliency. These two areas are a strong focus for the current tool.

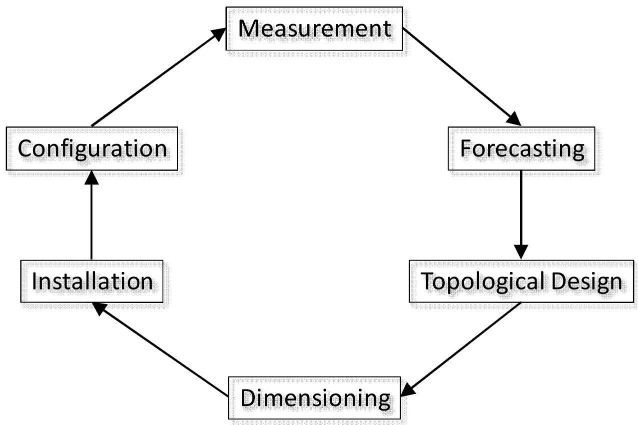

Figure 1: Planning and Installation Cycle

The tool is built around an XML schema that describes the network building blocks and the parameters associated with these blocks. It is capable of exporting the network data in a

Financial support from the Foundation for Research, Science and Technology (FRST) New Zealand, and Telecom New Zealand and Harmonic Ltd is gratefully acknowledged. Richard Harris and Donald Bailey are with Massey University; e-mails: {R.Harris, D.G.Bailey}@ massey.ac.nz.

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form that is compatible with that schema for use in off-line reporting tools or further data manipulation processes. Data input can be achieved in a variety of different modes including spreadsheet files, text files and WireShark™ [4] pcap files. Data tables within the tool are compatible with Microsoft Excel™ and data in an appropriate format can be pasted into or retrieved from these tables.

Key contributions made by this planning tool include the ability to specify network traffic and routing associated with services using an overlay approach, the integration of modelling, simulation and measurement activities within a single integrated console environment, generic modelling using a mixture of analytic queueing and flow models, and links to recent legacy technology modelling tools to aid in the transition between older technologies and technologies associated with current NGN networks.

The rest of this paper is organised as follows: In Section II, we describe the basic building blocks that form the basis of our planning tool. Section III shows how we have extended these basic concepts to enable more detailed modelling of Next Generation Networks. In Section IV we summarise some of the major functions of the planning tool and show that it comprehensively integrates modelling, simulation and measurement capabilities that support the network planning function. In Section V we describe a sample network and illustrate some of the concepts that have been developed in earlier sections. Finally, in Section VI, we summarise the key conclusions arising from our use of the tool and suggest future directions for development and implementation.

II. Basic Building Blocks

In this Section we briefly outline the basic building blocks of the tool that we have developed. These elements are present in almost all network planning tools with graphical user capabilities and hence we shall focus merely on the way that they are implemented in our tool. Figure 2 shows a typical network diagram that illustrates many of the standard building blocks used in the tool. The figure presents a screenshot of the tool showing the menus and toolbars together with the simple demonstration network.

A. Nodes

Nodes represent the routers and switches in the network. They may represent both real and abstract entities, including virtual routers contained within a single chassis. Frequently used node symbols are provided on our toolbar, but a larger palette of symbols is contained in an associated library.

B. Links

Links are used to connect the nodes. They are represented by lines containing arrow-heads to indicate whether they are uni-directional or bidirectional. A special feature of the links is the ability to show administrative colouring which is used for constrained shortest path routing in IP networks. An example is shown in the figure where link endpoints are shown with coloured arrowheads. Multiple coloured arrowheads are permitted where they are appropriate.

C. Traffic Streams

Traffic streams represent the traffic demand between two points in the network. They are represented in the model using a dashed line with an arrow showing traffic direction, and are typically given a colour to represent the traffic class. Traffic streams can represent traffic in 8 classes that can be grouped into Gold, Silver, Bronze and Best Effort categories respectively. Once again these are illustrated in Figure 2.

D. OD Pairs

As traffic streams may be present in large numbers on the network canvas, they can be aggregated into an Origin-Destination pair that is represented by a single directed line which depicts all traffic stream demands travelling between a designated pair of nodes.

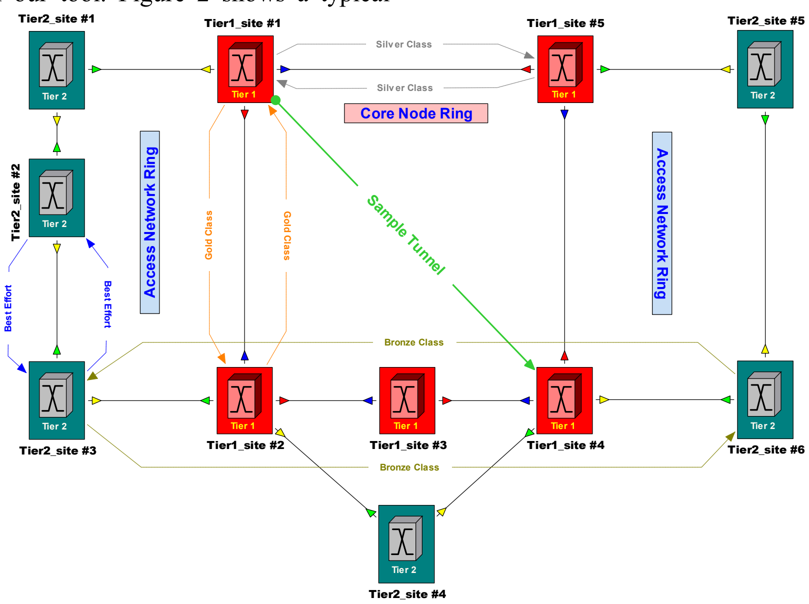

Figure 2: Sample network showing nodes, links, traffic streams and tunnel objects

E. *Paths / Chains*

Chains represent an ordered sequence of links that connect a pair of nodes. We associate one or more chains with a traffic stream, each representing a path taken by the associated traffic.

III. Additional Concepts for Real World Modelling

As previously indicated the concepts of nodes, links, traffic streams and chains are well-known and usually would be present in any network modelling system. In this Section, we show extensions to these concepts that will be used to enable modelling of NGN networks using terminology that is appropriate for IP-based networks, in particular.

A. *Tunnels and Label Switched Paths*

Tunnels represent discrete logical managed units of bandwidth (eg VLANs, LSPs) between two points at the network level. Tunnels can be:

- Contiguous – eg an LSP that transits domains, or potentially a VLAN that spans domains.
- Joined together – consecutive in the MPLS sense.
- Nested – as in MPLS over MPLS, or QinQ VLANs.

From the overview of the tunnel concept presented above, it can be seen that it should have some of the properties of a link and some of the properties of a traffic stream as it conceptually falls between these two types of object. This is how the tunnel concept is handled in our tool.

A chain may also be associated with a tunnel and can be classed as 'active' or 'standby' when being used for MPLS based routing. An important extension of the chain concept that we have used in our tool permits chains to include embedded tunnels that can be treated as if they were links.

B. *Domains*

Domains represent regions in a network. They can potentially be treated as a way of aggregating network elements and traffic, or they can be used to represent areas where common rules apply to their operation. For example, the OSPF routing protocol identifies backbone and standard domains where the routing protocol can operate. Links between domains involve gateway devices (routers) which typically channel traffic between the domains. Rules may exist concerning whether a domain can act as a transit stage for traffic or whether it only originates or terminates traffic. Such rules are often associated with the Border Gateway Protocol (BGP4), for example.

C. *Shared Risk Link and Fate Groups*

Shared Risk Link Groups (SRLGs) refer to cases where links in a network share a common conduit (or a common attribute). In the event that one link fails, other links in the group are likely to fail too.

The Multiprotocol Label Switching (MPLS) Traffic Engineering (TE) SRLG feature enhances backup tunnel path selection so that a backup tunnel avoids using links that are in the same SRLG as interfaces which the backup tunnel is protecting. This is of critical importance in the design of resilient networks and is typically handled within the Constrained Shortest Path First (CSPF) algorithms employed by MPLS routers in a modern IP based network.

In our tool, the user can identify the set of links that form an SRLG in various ways. The tool has the capability to render all links in an SRLG operative or inoperative simultaneously, if desired, as part of a network analysis scenario. A sample situation is illustrated in Figure 3.

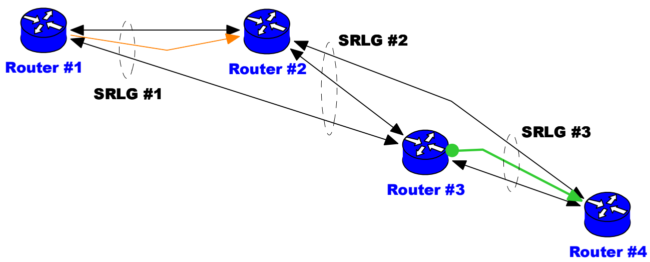

Figure 3: Network model showing SRLGs

The Shared Fate concept as used by Juniper routers represents an extension of SRLGs insofar as it incorporates nodes as well as links that are part of some "shared risk" [2]. Fate sharing involves the creation of a database of information that CSPF uses when computing backup paths to use in case the primary path becomes unstable. The database identifies relationships between elements of the network, such as nodes and links. Ideally, backup paths need to avoid shared/common resources with the primary path as much as possible to ensure that a single point of failure will not simultaneously affect both the primary and backup paths. The fate-sharing database also influences fast-reroute computations on Juniper routers.

D. *LAG groups*

A Link Aggregation Group (LAG) is a bundle of Ethernet links that behave as a single link and yet can be established in a diverse way for service protection purposes. The LAG N protocol sets out to automatically distribute and load balance traffic across working links within a LAG, so that they maximise the use of the group if Ethernet links fail or are restored, providing improved resilience and throughput. There are several variants of this capability including LAG N+N for a worker/standby capability or LAG MC (Multi-Chassis) which provides redundant Layer 2 access connectivity that adds node-level redundancy in addition to the normal LAG link-level redundancy. The tool provides a generic capability to handle such LAG groups.

E. *Service Overlays*

The process of specifying the traffic demand in real world networks is both tedious and time consuming. This is because the demands are placed onto the network on a point-to-point basis through traffic streams. Network administrators and planners, however, view the network as providing a set of products and services, and want to investigate the implications of introducing a new product, or the effects of an increased demand for a particular service.

To bridge the gap between the higher level planning tasks and the lower level modelling details, our tool introduces the concept of service overlays. In the context of the tool, a service is defined as a distinct type of traffic stream that will be applied to the network. Services may be grouped into products, for example a VOIP product will consist of two services: the VOIP media, and the signalling.

Each service is made up of a sequence of service components that define how the service maps onto the network model. The service components define the path from a particular source, to the destination of a particular traffic stream that is an instance of the service. The service components are therefore the building blocks from which services and their corresponding traffic streams are created. We have identified three distinct types of service components:

- Service nodes are the nodes through which the traffic streams associated with the service must flow. These may be gateway nodes for the service, for example for authentication or billing, or nodes within the network that are servers for a particular service.
- Service tunnels define the tunnels that the service uses for delivery. Service tunnels can have a set of rules for automatically creating the associated tunnels.
- Service links, like service tunnels, are particular links that must be used as part of the route.

The service definition therefore acts as a template for defining the traffic streams associated with the service. Associated with each service definition is a set of identification and traffic generation rules that define how the service is instantiated onto the network. These define the source and destination nodes, as well traffic demand between them. Four traffic models are used to create the corresponding traffic streams:

- One-to-one: Both the endpoints and demand are explicit, for example if the service is to provide a high speed link between two specified nodes.
- One-to-many: A single source, but with multiple destinations. An example would be a subscriptions service such as IP-TV. The demand for each individual stream would be based on parameters of the destination node.
- Many-to-one: Defines a set of traffic streams from many points with the destination being a service point. If specified as bidirectional, an associated return traffic stream is also generated. Demand for each stream is based on parameters of the source node.
- Many-to-many: A mesh of traffic streams will be generated, connecting a series of sources with a series of destinations. Demand balancing will be used to apportion the demand from each source amongst the different destinations. Examples are VoIP media and peer-to-peer communications.

F. *Service Routing*

While the service definitions are used to generate the traffic streams, the service components are used to determine the route that the traffic takes through the network. Each of the service components is taken in sequence from the source to the destination as illustrated in Figure 4.

Figure 4: Sample service path

Some service components may have a choice of possible components that could be used for the routing. For example, there may be several nodes within the network that provide a particular service. Associated with each service component is a set of rules that selects the particular instance that will be utilized by a particular traffic stream. These may be based on either the location or parameters of the source, destination, or previous service component.

Each service component, including the connection to the next service component, will always provide a simple path (each node or link in segment will occur once at most). However, since the service path may involve backtracking, depending on the locations of the service nodes, the complete path from the origin to the destination may traverse a node or link more than once. The tool was set up this way to enable the true end-to-end characteristics of the traffic stream to be evaluated, in particular the resilience and quality of service.

Once defined, the service overlays enable the associated traffic streams to be both generated and routed in a single step. The traffic generation rules may be changed and the associated traffic regenerated and instantiated onto the network model, enabling very rapid exploration of model parameters at the higher level of services and products.

IV. Using the Planning Tool

The planning tool integrates analytical, simulation and measurement capabilities and these are then used by a network planner to assist in studying and designing a network that meets the desired performance and resiliency standards. In the following subsections we briefly describe the main components and their capabilities.

The tool has been built with a core framework that provides the components described in the previous sections, and a GUI to facilitate editing and viewing of the network and the results of applying various models. The other components of the tool: analytic models, simulation tools, and measurement integration interface with the core through a common application programming interface (API). This enables new models and functions to be quickly developed and integrated with the framework through a plug-in interface.

A. *Analytical Models*

A comprehensive list of analytical models is available in the tool. However, due to space limitations we shall broadly outline the capabilities as they relate to the planning and installation cycle referred to in Figure 1.

1) *Forecasting and traffic generation tools*

A suite of tools enable the planner to generate traffic in different classes using a variant of the well known Kruithoff methodologies and linear regression forecasts of originating and terminating traffic loads. In addition, a traffic generator function has been developed to enable creation of traffic demands based on subscriber PSTN or DSL line data.

capabilities for aggregating traffic from lower levels of the network hierarchy have also been developed to enable analysis across multiple layers. In addition, the aforementioned service overlay tools can also set up traffic streams in the network.

2) Routing tools

Once again there is a wide variety of options that have been incorporated in the tool. Generic path generators and shortest path algorithms are available. These can be enhanced with rules to ensure that paths conform to administrative link colouring – such as required in Constrained Shortest Path First (CSPF) routing in MPLS networks. Routing to conform to MPLS-TE (using RSVP-TE) as well as MPLS-LDP requirements is also available. Users may also determine likely Fast Reroute options if this facility is enabled in their routers. Tools that enable disjoint paths to be created for backup purposes and tools that create paths according to standard routing protocols such as OSPF, RIP, EIGRP and IS-IS have also been included.

3) Performance modelling tools

These tools can be further categorized into queueing-based and flow-based tools. Queueing models based on advanced QNA or more complex MAP-2 implementations are available to estimate queueing delays in the network. Generally these models are best applied to relatively small networks as their complexity and running times may be unacceptable in large network designs. Alternatively, flow based models tend to scale better and these models are also available to assist in modelling performance of the network.

A comprehensive flow model has been incorporated into the tool so that flows in the network can be mapped under both normal and failure conditions. In either case, it is possible to determine whether nodes, links or tunnels are overloaded. In addition, if elements have failed, backup paths are generated, based on the protocols used to create them initially. Hence, if OSPF was used to identify a path based on a particular metric, then a new path is constructed using that metric with the failed component(s) excluded. Likewise, if Fast Reroute (FRR) is specified and it is enabled for some component in an MPLS based LSP, then failures of those components will result in a search for appropriate FRR pathways. At the conclusion of the analysis, a graph can be produced to show the traffic flows on network elements before and after the failure scenario.

4) Design and dimensioning tools

Several dimensioning tools are available to determine capacity for NGN networks. The simplest model is based around a flow model and is able to assign discrete capacities based on typically available link capacity configurations. Planners can specify whether capacity can be a mixture of sizes or units must all be of one size and type. A simple dynamic programming implementation returns the appropriate solution. Rules concerning utilization limits can be enforced with this design. A more complex model from [2] is also available which sets out to optimize the design from a cost viewpoint. This model incorporates a standard QNA queueing method approach but employing MAP-2 traffic models [8].

5) Resilience and reliability tools

A special focus for this planning tool is network and service resilience and thus there are functions for determining node, link and chain reliability based on Mean Time between Failures (MTBF) and Mean Time to Repair (MTTR) data. Manufacturer's data or actual historical data can be used to provide the input to these reliability routines. Additional functions are provided to determine whether networks are bi-connected physically as well as at a service or protocol level.

6) Network configuration tools

After LSPs have been identified in the planning process, network managers are often required to configure the network resources to match the designs emerging from the tool. This process is potentially vulnerable to errors; hence it is proposed that scripts for common manufacturer's routers (such as Cisco and Juniper, etc) be delivered from the tool so that they can be directly entered as instructions to routers. Although this is currently at an elementary level it is hoped that more advanced scripting will be possible in future versions of the tool.

B. Simulation Tools

Simulation is an important requirement for planning of networks as it is used to verify designs and test *what-if* scenarios. The tool includes two built-in simulators that provide performance modelling for PSTN/VoIP and ATM network situations. In addition, the tool has a facility to generate standard tcl files as used by the well-known network simulation tool NS2. These files can be submitted directly to an NS2 simulator and, under certain conditions, NS2 can be initiated by the tool and results retrieved for further analysis.

C. Measurement Processing

The tool has been designed to integrate with measurement repositories so that practical data can be imported into the model for processing and analysis. As there are many different databases with different formats for their data, this is potentially a difficult task. At the time of writing, the tool can import data from WireShark [3] pcap files and process filtered traffic flows to generate a network representation of the measurement data and determine queueing parameters associated with the traffic flows observed in the data file. Standard text based files (.csv or .dat) can also be processed if they are in a suitably defined format. As the tool has been designed around the plug-in concept, specialist plug-ins can be developed to link with other formats and databases such as the output of NetFlow™ monitors or SQL databases.

D. Utilities

A wide range of utilities is provided to enhance the functionality of the tool. These include capabilities to reduce screen clutter so that the planner can focus on key aspects of their design - this is achieved through the application of display filters. A set of alarm symbols on nodes can be used to highlight problems encountered by the algorithms such as capacity over-runs, queue overloads etc. An extensive range of reports are available in both text and html formats that summarise the results of algorithms and other utility functions.

V. SAMPLE NETWORK

A. Practical Network Design

The tool described in this paper has been used in various forms to undertake studies of practical networks and determine whether they meet certain design objectives, are capable of handling traffic loads that may result from regulatory decisions as well as general growth scenarios. For space and confidentiality reasons it is not possible to describe or display these studies in detail, however we can outline a sample network arrangement that shows some of the capabilities of the tool.

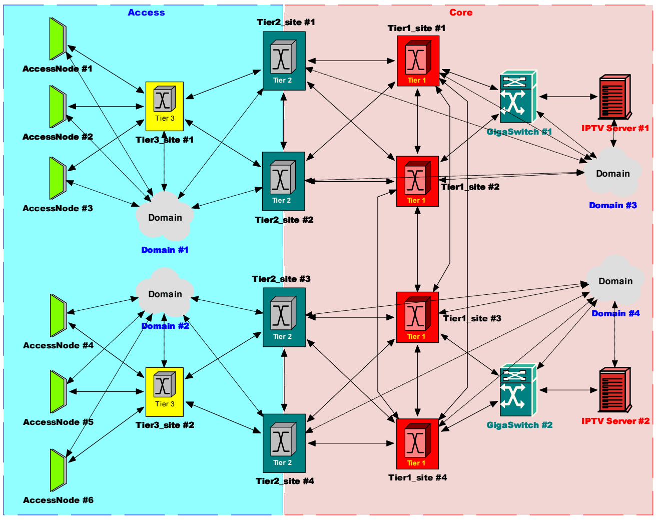

Figure 5: Sample network showing a simplified study of the connections to an IPTV server

Figure 5 shows a scenario where a new product – IPTV – is to be introduced into the network. We specify the services and service components that make up this new service. These will include components that will ultimately decide the service routing which links an access node with an appropriate IPTV server. These services or service components would typically include the following: Service link(s) describing the rules for connecting the access nodes to Tier 3 sites; Service tunnel(s) from Tier 3 sites to the gateway Tier 2 sites; Service tunnels from the Tier 2 site gateways to the Tier 1 nodes, and Connections from the Tier 1 sites to the desired IPTV server.

The figure shows the two servers in Domains 3 and 4 respectively. In conjunction with the service routing process, the tool can be used to compare the traffic flows in the network for the cases where one or two IPTV servers are implemented to deliver the product.

Queueing models enable the jitter and other QoE performance metrics to be estimated. By using additional service overlays to model cross-traffic, the network is able to be modelled under a range of load and traffic mixes enabling potential problems to be identified prior to deployment.

Several advantages are gained from using the tool described in this paper. First, specifying the traffic at the service level enables the traffic streams to be generated and instantiated automatically. Other tools require the traffic streams to be instantiated individually. While this is not particularly onerous in the trivial example shown in Figure 5, for practical networks, it can be both time consuming and error prone. Second, the way that the service is implemented can also be specified at the service level, enabling variations to be explored relatively quickly simply by making minor changes to the service overlay specification. Third, the analytic tools enable the network hotspots to be quickly identified under a range of failure conditions, and solutions explored. Fourth, once deployed, the true traffic measured on the network may be directly compared with the predictions, enabling more accurate forecasting.

VI. CONCLUSIONS

Planning of NGN networks is a complex process. A planning tool has been described that addresses this task through an integrated framework that allows a planner to apply analysis and simulation methods to investigate appropriate network configurations. Traffic measurement data can also be used to establish parameters or to provide comparative data for comprehensive studies. The tool provides methods for laying out products in the network and generating the associated traffic loads. An extensive range of modelling tools allow planners to assess network and service reliability as these are very significant elements in modern communications.

It is anticipated that further models will be incorporated into the tool in the future to allow detailed optimisation of the network and services that are to be implemented. Internal optimisation routines that handle linear constraints and nonlinear objective functions are a first step towards achieving this goal. Where more extensive computations are required, the tool has been designed to enable flexible generation of file formats that external tools such as NS2 and CPLEX require for their analysis.

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