Paper

The Goals and Benefits of Network Modelling in a Commercial Environment

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Abstract—Modelling is a technique that can be used in the development and sizing of networks. It involves building a mathematical representation of a physical system and is often computer based, allowing system behaviour to be investigated based on the variation of key parameters. This paper will describe some applicable tools for network modelling and consider a range of applications. Whilst modelling and simulation tools are used extensively to design and size ICT solutions, each tool tends to be targeted at a specific range of applications and a specific user community. It is shown that different tools expect different levels of expertise from their user communities. The benefits of using such tools are described, as are some of their limitations. Modelling and simulation provide a cheaper and faster approach to trying new ideas than building prototypes or test networks. They provide a valuable guide to designing networks and can predict operational outcomes.

Keywords—emulation, modelling, performance, service quality, simulation.

1. Introduction

This paper will look at modelling as a technique for use in the development and sizing of networks. It will examine what the basic objectives and goals of modelling are, how the approach delivers benefits and identify the broad principles behind modelling. This will be illustrated using specific applications.

An investigation of the broad applications of modelling in communications systems is given and a description of applicable tools for network modelling provided. A range of applications for these tools will then be considered. This will be followed by some general observations and conclusions about the use of these techniques.

Mathematical modelling has a long history; one example of a mathematical representation of a physical system is the use of the techniques developed the Marāgha School to evaluate geocentric models of the Solar System and their later use by Copernicus to develop the heliocentric model [1]. It is applied in a number of circumstances such as modelling: complex systems based around differential equations [2], financial systems [3] and weather systems [4]. The role of computer model can be summed up as depending on: “thousands and thousands of repetitive calculations based on explicit and deterministic rules. Just what a computer is good at” [4].

Within the networking field, network simulation can be performed either by mathematically evaluating the interaction between the network entities or capturing and playing back data gathered from a production network. This allows the behaviour of the network to be monitored as network parameters are varied in a controlled manner [5].

2. Applications of Modelling

This section of the paper will consider three examples of where modelling has been successfully applied to problems associated with ICT propositions, these are:

- Workforce Management applications for contact centre implementations,
- modelling for investment decisions in network service propositions,
- support of Service Level Agreement (SLA) management in Information and Communications Technology (ICT) proposals.

2.1. Workforce Management

Workforce Management packages are specialist simulation tools used to forecast future workload and plan staffing schedules. More general process modelling tools such as SIMPROCESS [6], used to model business process reengineering projects, have also been used to model the principal activities of a contact centre. Using raw data (call volumes, service times, routing data, schedules and financial data) collected from live systems to build the models, they were able to characterise each customer contact by what the customer wants. What if scenarios were modelled for example; to identify the impact of variation of staffing levels on call abandonment rate. It was found that quite small variations in input conditions can have a significant effect. The benefits of the approach are that it gives: a deeper systems understanding, a view of the impact of variations in inputs and it allows bottlenecks to be identified making process improvement possible.

Workforce Management uses data captured from a contact centre’s Management Information applications, to model overall performance and hence ensure that sufficient agents

are provided to handle the projected customer calling patterns. The goal is to provide best quality of service, using optimal staffing at the lowest cost. Historical data is obtained from the ACD System (Automatic Call Distribution) and real time information from sources such as CTI (Computer Telephony Integration) and diallers [7], [8].
Workforce management packages are usually used by large organisations, but less so by smaller organisations [9]. It is argued that [10] the demand for computer simulation analysis is driven by increasing traffic complexity and the move to skills based routing; the change in operations due to mergers and acquisition activity, business volatility, outsourcing and multiple channels and cheaper, faster desk based computing, combined with specialised contact centre applications.
The key driver for investing in this type of capability is that personnel account for 60 to 70% of a contact centre's costs and effective management of this resource is consequently a priority [11].

2.2. Modelling Investment Decisions

Models have been developed to forecast the profitability of network services, based on the underlying infrastructure and the subscriber population and by linking this to network performance and customer satisfaction [12]. Service quality is expected to be driven by network QoS, network availability and customer care, all of which can be modelled and used to identify the gap between perceived performance and the customer's expectations. Service profitability was found to be dependent on: price, the customer's subjective view of performance, the number of customers willing to re-purchase the service and the new customers the service provider can attract.
Customer satisfaction is a major driver of a customer's intention to repurchase which is a Baynesian decision process. It is subjective, whereas quality is an objectively measurable attribute specified as the sum of service quality and perceived quality. Customer satisfaction is modelled through the interaction of perceived utility and expectation and is a perception function. The profitability of a service is given by revenue generating potential after costs and service penalties have been subtracted.
It is observed that that network upgrades are normally carried out based on past experience and rule of thumb and that there is a gap between network planners and business analysts, who have a very coarse understanding of how improved network performance leads to future revenue generation [12]. The model relates infrastructure to profit as a function of performance, customer behaviour and market dynamics. Rather than maximising service quality, it is more important to ensure that the service quality meets customer expectations.

2.3. Modelling Service Characteristics

Most broadband implementations have no scope for re-routing in the network for consumer broadband access lines and therefore physical intervention is often required to fix faults [13]. Such faults are often fixed by moving the customer from one port to another, however some DSLAMs (DSL Access Multiplexers) are located at unmanned sites due to equipment and operational costs. These require a visit to fix, creating an issue of man power availability, which may be offset by optimising operative travelling time.
An algorithm has been developed to identify optimum travelling time, thereby reducing operational costs [13]. This ranks the relationship between decision alternatives and setting performance thresholds for several operational parameters. Resolution priority may be given to some high priority clients. Inputs into the algorithm are: the customer category (related to the value of the aggregate business from that customer), prospective penalties, service criticality, type of service and any existing service complaints. Prospective penalties are seen to increase with increasing Quality of Service requirement, bit rate, service type (i.e., VoIP is more sensitive than IPTV which is more sensitive than the Internet). In addition the algorithm makes use of key cost drivers: material cost (which includes operative travelling time), human cost, penalty payments, lost revenue and bad publicity.
The results of the algorithm may be viewed by a number of service restoration options: faults that have exceeded the critical threshold, locations where there are clusters of faults, locations where specific services are clustered, locations with more affected services, locations with more unavailable services affected by a customer complaint.
The possibility of routing around link failures and commencing re-configuration before a fault occurs, thus preventing packet loss, has been considered [14]. An approach based around machine learning from historical activity and correlation with real time events is used. Network failures have a clustering property which is used in the analysis, as was confirmed by looking at a tier one ISP for 8 weeks. It is possible to associate the failure of other links with that of a single link failure, using historical data to formulate the rules for prediction. However this identifies the symptoms and not root causes of failure.
Frequent failures and therefore clusters that fail within a short time of one another can be identified. It is possible to monitor alarms and use a decision engine to trigger the network reconfiguration process, which initiates changes to routing metrics which force the network to re-converge away from the projected failure. The level of confidence and therefore applicability of rules changes with time and consequently it is possible to disable a rule when the associated level of confidence drops below a threshold value. The approach can be validated using NS 2 modelling.

3. Tools For Network Modelling

Network modelling tools can operate at a number of levels, one example of a tool for modelling networks at the physical level, to aid the sales process is British Telecom's (BT)

SPEED tool, which is designed to both improve the speed at which customer data network quotes can be delivered and to reduce the level of expertise required to provide them [15]. It incorporates best practice design principles and makes use of a catalogue of the up to date product and service offerings with their current tariff and discount structures. One of its major differentiators is the sophistication of the business logic, its associated data and the expertise that is modelled internally.

The tool captures requirements in the form of site location information, which is plotted onto a GUI (Graphic User Interface) derived map, allowing traffic flows, CPE (Customer Premise Equipment), link aggregations, PoP (Point of Presence) locations, backup arrangements, service requirements and contract details to be incorporated into the model's driving parameters. The appropriate routers are identified down to sub component level and appropriate pricing generated. Not only does the package deliver pricing and design material, it also generates appropriate bid governance documentation.

SPEED has been a key component of BT's arsenal of sales tools and has been seen as a considerable success in shortening the sales process, reducing the need for specialist staff and standardising solutions. Although typically used for networks of a few hundred sites, it can handle networks containing several thousand nodes.

A number of authors have looked at the accuracy of sophisticated modelling tools, when compared with actual model operation [16]–[20]. Simulations may be defined as any action that mimics reality [16] and computer based models execute a set of rules to mimic a system. The major independent variable which drives most models is time and this is underpinned with other variables known as dependent variables that are functions of time. It is the nature of these variables as discrete or continuous, which define the two major forms of model.

The dependent variables, associated with a continuous model, are known as state variables which are expressed in the form of differential equations that ideally can be solved by analytical means, but often have to be evaluated using simulation techniques. Discrete event simulation models are based on a system containing objects or entities, with the state of the system being defined by in terms of the numeric values associated with those entities. The simulation is then often formulated in terms of an overall process, comprising a number of activities, which are triggered by specific events. Typical modelling entities of such simulation tools are shown in Fig. 1.

One application of modelling tools is the validation of network designs and the validation of network configurations. One tool aimed at providing the ability to simulate network designs in order to optimise capacity and performance, could emulate up to 2000 routers and 1500 subnets and constructed the network model from router configuration files adding traffic analysis and device utilisation modelling to the network configuration and routing functions through additional software. Traffic data could be input from RMON (Remote Network Monitoring) probes, router accounting, MIB (Management Information Base) information and Netflow.

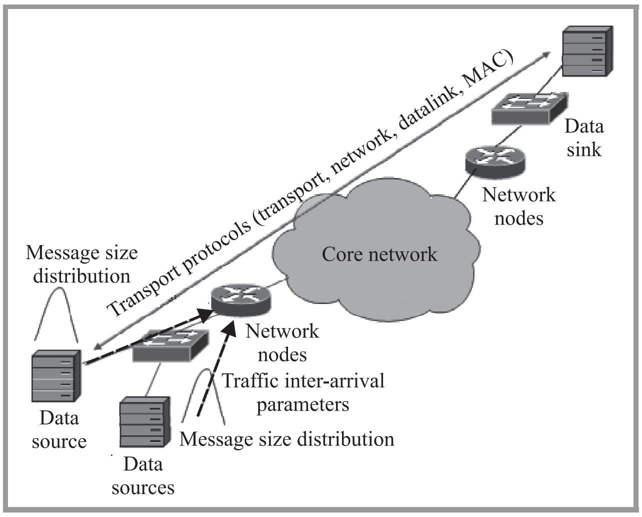

Fig. 1. Typical modelling entities and parameters.

GNS 3 is a graphical network simulator, distributed under a GNU license, which can run under Windows or Linux, can emulate various Cisco devices running a native IOS (Internetwork Operating System) version and is made of three components:

– the Cisco IOS emulator, which will execute a native IOS binary image,

– a user friendly text based layer,

– a graphical environment, which allows model networks to be built.

The capabilities of the tool are limited by the power of the PC that runs the emulator, but sizeable networks can be built of 20 to 30 routers, allowing the tool to be used extensively for training purposes and for preparation for certification exams. Networks can be built that can transmit a thousand packets per second, which is much less powerful than a modern router that could transmit up to a thousand times more. The current version of the tool will accommodate a wide range of routers, but not the whole Cisco range and does not appear to support the very latest models. Once the network has been built and set running, it takes 100% of the PC CPU.

The graphical tool allows the user to select a router or firewall and to configure that device with the desired interface cards. Links between devices can then be created, using the graphical user interface, to allow a network topology to be built. The user interface into the simulator is provided using a TN3270 emulator, with all commands available on the IOS image being used, being available to the user. There are a number of options available to allow the emulation of user traffic and packet capture from the emulated network can be achieved using Wireshark software.

One tool widely used for modelling both networks and protocols is the open source NS 2 package [20]. This is a discrete event simulator that provides functionality for performing: protocol design, traffic studies and protocol comparison. Tools like this overcome the scale limitations and cost of the test laboratory and can provide a more in-depth understanding than traditional analysis can. This package has a simulation core supported by visualisation tools, traffic and topology generators and a trace analysis capability. These are underpinned by a capability to support a wide variety of traffic models, applications, protocols, routing techniques, queuing mechanisms and physical media.
Models are constructed using a series of steps that start with creating the event scheduler, building the network, computing the routes, creating the traffic (inserting errors if required and tracing. Traffic can be created using traces taken from a real network.
Other widely deployed modelling tools are the commercially available COMNET III and OPNET modelling tools. These are discrete event simulators and are widely described in the literature [16]–[21]. Such tools typically provide a graphical user interface for building network models and setting up the model parameters and can model the operation of a network and its protocols and the scheduling of applications on end systems. A model typically tries to incorporate several characteristics of a design problem and when an optimal solution is obtained, the values of the decision variables can be used to evaluate design choices.
Whilst both COMNET III and OPNET offer very sophisticated modelling tools, these are predominantly used by core network designers and researchers, who specialise in network modelling. Those designing customer networks rarely possess traffic projections that are sufficiently accurate to warrant the deployment of these sophisticated modelling tools, indeed many networks are designed based on either the bandwidths deployed on the networks they are expected to replace or on the customer's best estimate of the traffic levels to be carried.

4. Applications of these Tools

A survey of the recent literature suggests that much of the work with modelling tools is focussed in the area of radio networks, particularly Mobile Ad Hoc Networks (MANETs). However, the technique is being applied to a number of other significant areas such as:

- the modelling of the impact of Intrusion Detection and Distributed Denial of Service attacks,
- modelling of video transmission across Wireless LAN infrastructures,
- simulating QoS models and traffic congestion scenarios,
- evaluating the packet loss probability in voice over IP networks,
- examining traffic bandwidth constraints in networks which deploy DiffServ Traffic Engineering techniques (DS-TE).

Modelling tools are not only used for design and research purposes, they can also be effective teaching tools, allowing the student to carry out hands-on experiments, without recourse to the costly provision of extensive teaching networks. This allows essential networking concepts to be taught to students.
It is sometimes desirable to model the impact that adding a new application to an existing network has on that network. This requires the network planner to identify the individual transactions that make up the interactions between the user and the new applications and superimpose these on a model of the existing network.
The network model is typically constructed by:

- Using packaged software to build a model of the switches and routers deployed in the target network or a simplified representation of that network.
- Loading appropriate live device configurations onto that model.
- Setting the utilisation of that network based on peak and average link utilisation figures extracted from the live network. This information may be loaded from files prepared using standard SNMP polling packages.

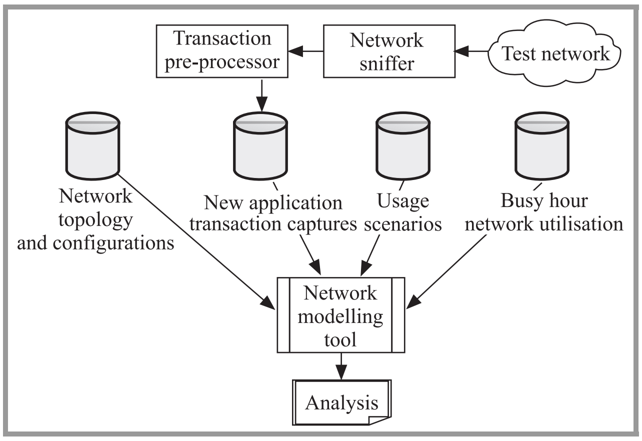

Fig. 2. Transaction profiling.

The transaction profile of the new application is normally captured from a test network using LAN capture software such as Sniffer or Wireshark LAN data capture software on a suitable portable device. Once captured, this information is fed in to another specialist application to provide a set of transaction representations that may be fed into the network modelling tool.
This coupled with estimates of overall transaction volumes, including numbers of simultaneous users, allows the network manager to see the impact of the new application on overall network performance.

BT Algorithmica is a division within BT that is concerned with network modelling and optimisation. This team can develop a set of algorithms to provide an exact fit to any network problem under investigation. They have modelled performance of BT's 21st Century UK network and the global MPLS (Multiprotocol Label Switching) platform.
The tool set is based on three components delivered by OPNET, which form layer zero of the modelling capability, to this Algorithmica adds a layer of sophisticated software libraries, scenarios and a SDK (Systems Developers Kit). The *scenario bank* can be used to generate the network model. The tool is being used in for example: the cell planning of WiMAX networks, 21CN infrastructure modelling and the designs for Next Generation Access.

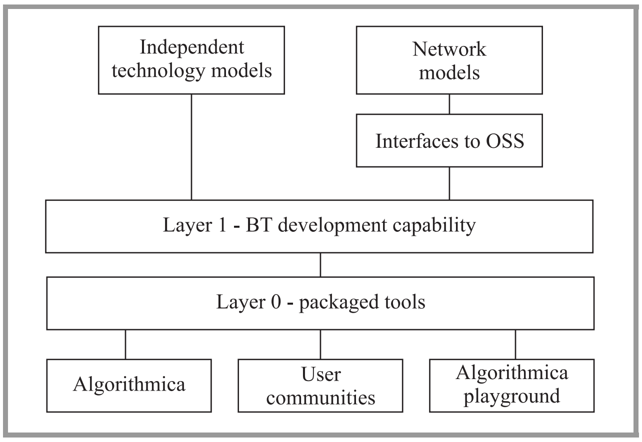

Fig. 3. Overview of the BT Algorithmica Suite.

Network simulations are built using:

– a network model built from existing router configurations,

– traffic based on MIB data collected using an industry standard SNMP MIB poller,

– a transport layer built from the inventory and topology of BT's underlying SDH and wavelength layer core networks in Europe.

Where overseas networks have been modelled, this can look at choices such as: whether infrastructure should be self-built or bought in from a third party, what technology and suppliers should be used, tariffing decisions and PoP location.
Increasingly network customers are seeking network performance guarantees and hence modelling of this is a concern for network providers. It has been demonstrated that queuing delays for such traffic systems can be evaluated [22] by assessing a G/M/1 queue with a Pareto based input. The analytical average queuing delay of the self-similar traffic can be compared to the delay from a simulated model, to obtain a useful model for delay prediction [23]. In this case the self-similar model was generated by loading a packet rate and packet size derived from trace data into the OPNET modelling tool to generate traces for comparison with the live data.
The OPNET package provides traffic simulation tools that simplify traffic analysis. These have been used in a number of studies of self-similar traffic, for example to simulate a priority based queuing system for DSCP (Differentiated Services Code Point) based QoS models [24] or to generate traffic traces which mimic live traffic [25]. These studies suggest that in moderate and high utilisation models, provisioning based on traditional methods may be over optimistic and may result in under estimating network resources like buffers and CPU capacity when trying to provide QoS guarantees (i.e., queuing delays, buffer overflow probabilities and packet loss rates) to the corresponding class traffic. They further show that the timescale for observation does not change the behaviour of the traffic pattern, whilst multiplexing makes peaks worse and uncontrolled heavy peaks cause traffic loss and jitter [25].
On some occasions the behaviour of protocols, which have not been implemented in commonly available network devices needs to be tested. One field where this is common is in the simulation of protocols associated with MANETs where protocols can more readily be emulated using a network simulation tool than they can be created with a routing device. In these cases the implementation of routing protocols, in radio networks where the network nodes themselves are capable of moving relative to each other, can be emulated [26].

5. Observations and Conclusions

This paper has looked at modelling as a technique for use in the development and sizing of networks. It has examined the basic objectives and the broad principles of modelling, illustrating how the approach delivers benefits by reference to specific applications.
The tools described cover a number of academic studies and direct commercial applications. It is arguable that the most widely deployed commercial tools are work force management and other contact centre dimensioning software, which looks at how the available work force, expected voice traffic arrival patterns and call patterns affect contact centre performance. These facilities whilst set up initially by network specialists are often run by the business managers responsible for running the contact centre.
Tools such as SPEED are frequently run by large numbers of sales engineers, who have significant network design expertise, but little in the way of formal modelling skills. These tools isolate the designer from the complexities of the core network and instead focus on providing a costed network based on a VPN (Virtual Private Network) core, which is treat essentially as a black box with fixed performance characteristics. Application dimensioning tools tend to be used by a smaller number of specialists, who have more modelling knowledge and are more interested in the characteristics of the client VPN, than they are the core network. Such capabilities are usually used to model the

impact of a new application on the existing network or to track down application performance issues.

Large scale discrete network simulation tools tend to be used widely as a research capability or, by some network providers in a commercial environment, as detailed design tools. Such tools are both powerful and versatile but tend to require support from small teams of design staff with more specialist modelling knowledge.

Whilst network simulation tools provide a powerful means of analysing system performance ahead of design or to compare alternatives, they do have their limitations [27]. Errors in simulations or improper data analysis can produce misleading results. In some cases different packages produce different results; hence it is important that practitioners and researchers document which parameters and which modelling tool are used, in order that others can replicate their results. It is important to validate simulation models against the real world. It has been suggested that 85% of test results in the published literature cannot be repeated by other authors, because key parameters of the model used are not reported.

Further issues pointed out [27] were:

- the statistical significance of the results collected,
- results should only be collected when the model has reached steady state,
- the simulation assumptions should always be clearly documented,
- the appropriate selection of traffic flows,
- where a given factor is varied, a sensitivity analysis should be performed.

In a more commercial context: a number of communications equipment providers produce models for sizing their more complex offerings. These can come with limited explanation of how they determine dimensioning and are quite capable of delivering results, which have unwelcome cost implications, impact on project delivery or are counter intuitive. Further the engineer has limited information on either the track record or accuracy of such models, as a predictor of real behaviour. This can pose a problem to the designer, who may end up having to explain the results delivered by such models, without having the detail needed to provide the justification required by an unhappy customer.

In the final analysis modelling provides a cheaper and faster approach to trying new ideas than building prototypes of test networks. It provides a valuable guide and can predict other outcomes; it does however have its limitations.

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