A Novel Frame Relay Dimensioning Strategy for Cost Efficient Internet Access in Urban Networks

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Abstract: - Frame relay is a technology which is implemented by major fixed network telecommunications carriers worldwide and it has become one of the most extensively-used WAN protocols. Its cheapness, compared to leased lines, and extreme simplicity of configuring user equipment are the main reasons for its popularity. With Frame Relay, users can get the most of their internet by running various internet-based applications. It's the best choice for companies with high networking requirements. Frame relay is a fast packet switching technology which has been designed around the very reliable optical fiber transmission networks. The network switches being modeled use the Open Shortest Path First (OSPF) link algorithm to route both new traffic and traffic seeking alternate routes due to unanticipated network failure. In the model, traffic seeking an alternate route due to failure is distributed over routes with similar routing priorities in a manner duplicating the OSPF algorithm method of even distribution rather than a fill down approach. As frame relay networks are a commercial venture, cost and interswitch bandwidth must be minimized whilst reliability and redundancy must be maximized. To achieve these two goals, the frame relay operator must have extensive knowledge of both network performance and the traffic profile. One way of attaining this knowledge is to use a source model. The source model is implemented based on actual live traffic parameters. It can be used for analysis and simulation of the frame relay network. It is not the intent of this research to replicate existing frame relay networks, but rather to develop an accurate and robust model to be used by network dimensioning engineers in carrying out their duties. The developed model worked well since the simulated data matched the actual real data. With minor changes to account for network statistic presentation, the resultant model can equally be applied to non-frame relay data networks.

Key-Words: - Bursty traffic, congestion management, dimensioning, frame relay, internet, wide area network

1 Introduction

With the advent of MPLS, VPN, and dedicated broadband services such as cable modem and DSL, the end mistakenly appears to loom for the frame relay (FR) protocol. While this may be true for most urban and metropolitan internet users, for a number of Internet clients, especially in suburban and remote rural areas that remain lacking DSL & cable modem services, use of FR may allow for the connection of various remote sites using one single technology.

Frame Relay [1] is proposed to fit in the *national Internet strategy*. Telecommunication operators can start offering clients access to the network over Frame Relay according to the scenario where clients in remote cities lacking adequate bandwidth can be serviced by getting into the Frame cloud and connecting into one of the Internet's routers. Thus a retail chain, for instance, may use Frame Relay for connecting rural stores into their corporate WAN. It is possible to connect the clients' router to Frame Relay and access Internet Services over this circuit. At the same time, if the customer has other Frame Relay ports available in different locations, the same port may be used to connect to Wide Area offices the client has. This integrated approach can be attractive for both parties; from one Frame port, Internet can connect multiple customers. At the same time, the client can connect to multiple remote locations using the one port. Although there is a greater chance of connection then when dedicated lines are used, the economical advantage will in most cases compensate for this.

The requirements for data networking are constantly changing and several factors that have risen at the same time have required a new approach to data networking solutions. These factors include a requirement for better performance, the growth of bursty traffic applications in 3G and proposed 4G networks, availability of noise free transmission lines, the increased intelligence of endpoint devices.

As the need for network bandwidth is growing, the demands on network are also becoming more strenuous. Applications vary between extremely delay sensitive to relatively non-delay sensitive, ad the network should be able to handle both types. High throughput, low transit delay, and high speed interconnections are mandatory components of modern data networks [2 – 5], but a demand for cost effectiveness is also paramount.

FR is a fast packet switching technology that is ideally suited to offering efficient bandwidth on demand solutions. It is one of the 1st implementations for high speed data networks with a relatively high quality transmission infrastructure. As FR becomes more prevalent, a solution for data networks methods of optimizing cost effectiveness and improving network reliability are being sought.

The aim of this research is to develop an accurate and robust model of an existing frame relay network that could be used to: (1) collate actual trunk utilisation; (2) assess impact of varying trunk bandwidths; (3) introduce trunk failure; (4) simulate alternate routing mechanisms for trunk failure.

This paper describes a model that has been developed to carry out analysis and simulation of a frame relay network as an aid to optimizing cost effectiveness and improving network reliability by appropriately dimensioning the interswitch trunks. Analysis of current traffic profiles is used to determine effective bandwidth utilization. Simulation of outages can provide insight into network response to unanticipated failures and overloads. Results of both these cases are used in appropriately dimensioning a frame relay network to maximize economic returns and minimize lost data due to unanticipated network failures and overloads.

This paper is organized as follows. Section 2 gives an overview of FR, how it works, uses, and general implementation. In addition, the OSPF routing algorithm used in some frame relay switches is briefly presented. Section 3 discusses the physical implementation of the commercial frame relay network that is being modeled. Section 4 covers the model, how it is implemented, assumptions made and effectiveness. Section 5 covers simulation scenarios. Section 6 summarizes the findings, and discusses improvements and ideas for further study.

2 FR Overview and Implementation

We first present a functional summary of Frame Relay (FR). FR is the first implementation of a bandwidth-on-demand technology to address high speed data requirements. Without the additional overhead required to ensure data integrity, FR is able to operate at speeds of up to 45 Mbps. FR has very limited error checking capabilities in the sense that when errors occur, the data is discarded. The intelligent end systems have the responsibility for data integrity over a frame relay network. FR must be installed over a reliable network for the user to perceive any benefit. FR is not suitable for delay sensitive applications such as video or voice.

Next, we present a summary of the basic principles of the open shortest path first routing algorithm (OSPF) which is used on many frame relay switches. A separate copy of the OSPF algorithm runs in each area with area border routers running multiple copies of the algorithm. The HELLO protocol is sent and received by the systems routers and is used to establish neighbors and form adjacencies. Topological databases are synchronized between pairs of adjacent routers. Adjacencies control the distribution of routing protocol packets. Routers periodically advertise their state using link state advertisements (LSA), which contain information including the router adjacencies and are also issued when a router changes its state. LSAs are flooded throughout an area so that all routers in the area have the same topological database, which is a collection of the LSAs received from other routers in the area. From this database, the routers calculate their shortest path tree, yielding the routing protocol.

3 Actual Network Configuration

We now study the actual network configuration, FR usage, and congestion management.

3.1 Overview

The physical network being modelled consists of six cascade frame relay switches on a national plane (an Australian model is considered). A single switch is located at each of the following six sites: Sydney, Melbourne, Brisbane, Canberra, Adelaide, and Perth. The network is a double star configuration with Sydney and Melbourne as the two hubs, as indicated in Fig. 1. There are generally a number of interswitch trunks between any two switches. The trunks are of varying bandwidth and have historically been dimensioned based on predicted traffic per PVC (permanent virtual connection).

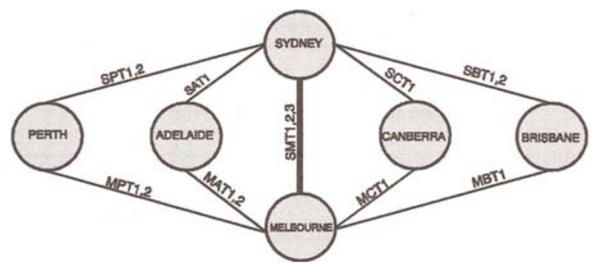

Fig. 1 Actual network configuration

3.2 Usage

The predominant usage by subscribers to the network is for national LAN-to-LAN connectivity. The secondary usage of the frame relay network is for non-LAN data applications. This secondary usage is generally motivated by a requirement by users for a common networking infrastructure and/or the associated cost benefit of frame relay over leased lines. User interconnect can be done by one of several methods: direct ISDN access to the switch utilising cascade ISDN proprietary cards; or access via a frame relay assembler/disassembler, FRAD, which may be a stand alone device or integrated into a router, as illustrated in Fig. 2.

3.3 Congestion Management

First, we present an overview of the general configuration: data link connection identifiers have local significance only; Forward and Backward Explicit Congestion Notification (F/BECN) is operational, but many of the users' routers do not recognize the F/BECN bits; up to 5% of trunk bandwidth is used for inband network management; OSPF does not require any additional configuration in the cascade switches; the network consists of the backbone only, it does not have any areas or stub areas; different route metrics for type of service (TOS) is not being used; statistics are gathered at each switch, and in the case of trunk parameters, approximately 40 different statistical measurements are taken; a number of users are trialing voice-over-frame products, the CIR (committed information rate) of these PVCs has been made larger than would be normal for a data circuit in an attempt to avoid having discard eligible frames, and the voice frames are still vulnerable to delay caused by preceding

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long frames; common interswitch trunks follow physically diverse routes.

We now describe congestion management of frame relay networks. Cascade uses a colour code on frames for rate monitoring and enforcement. Green frames are never discarded by the network expert under extreme circumstances and are defined as the frames received in a given time frame at a rate less than the CIR. Amber frames have the DE (discard eligible) bit set and are defined as frames received in a time frame at a rate in excess of the CIR but under the agreed Excess Burst Size, *Be*. Red frames have the DE bit set and are the first to be discarded. They are defined as frames received in a time frame at a rate greater than *Be*.

Data travelling through the cascade network is queued for transmission and the size of the transmit queues are used to indicate network congestion. The first threshold is set at 16 buffers, *mildly congested* state. When this is exceeded, all red frames are discarded before being queued for transmission, FECN bit is set on frames transmitted on the link and BECN bit set on frames received from the link. The second threshold is 32 buffers, *severely congested* state. When the second threshold is exceeded, FECN and BECN bits are set and all incoming red and amber packets are discarded. If the queue reaches a third threshold of 64 buffers, there is no room in the buffer for any packet and a state of *absolute congestion* is reached. When absolute congestion is reached, all incoming packets are discarded and frames are removed from the transmit queue down to the second threshold of 32 buffers.

4 Model Functions & Implementation

As stated previously, it is not the intent of this work to replicate existing frame relay networks, but rather to develop a robust and accurate source model that can be used for dimensioning interswitch trunks.

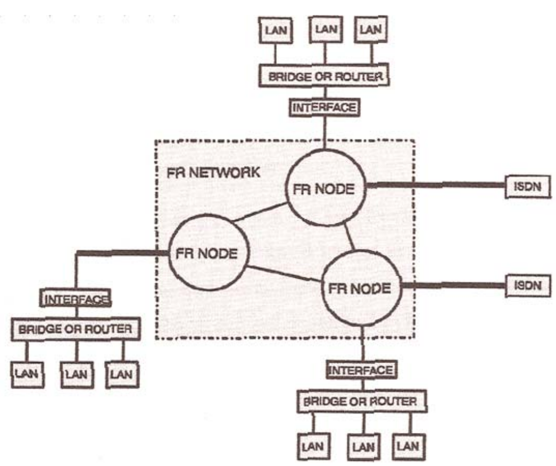

Fig. 2 Typical user interconnect to FR networks

4.1 Preliminaries

Models of telecommunication networks encompass two aspects: (1) the description of the behaviour of the internal components of the network and their interactions; (2) the description of the network input traffic, i.e., the characterization of the behaviour of the users in their access to the telecommunication services provided by the network.

The development of models concerning the latter aspect in often called "source modeling", and it constitutes one of the major topics in teletraffic engineering [6 - 9]. Accurate and robust source models are of paramount importance for the analysis and simulation of telecommunication networks, and hence for the prediction of their performances.

4.2 Model Functions

Each switch records approximately 40 different statistical measurements every 15 minutes on a port-by-port basis. The initial task of the model are involved in interpreting the raw data collected by each frame switch and extracting the parameters required for modeling purposes. Parameters used by the model include day and date fields, interface status, trunk bandwidth, access and egress utilization. The switch records values for average utilization taken over a 15 minute sample period and values for peak utilization taken over the busiest 5 minute period each 15 minutes.

Once the raw data has been transformed to a suitable format, the function of the model is to take user definable inputs for trunk, trunk bandwidth and outage times, and modify the actual trunk utilization values to reflect the simulation parameters.

The process of modifying and updating the trunk statistics for bandwidth variation and outages is iterative and can be carried out until the user has completed the intended simulation scenario. That is, any number of chosen trunks can have multiple bandwidth changes as well as multiple outages, if required in the simulation scenario.

The statistics file for the chosen trunk is overwritten at each iterative step with the modified link statistics. At the completion of the simulation, the model has a copy of actual trunk statistics and a copy of final simulation statistics for each trunk.

***Actual Trunk Utilization*:** The model extracts the switch statistics for a chosen day from selected switches and modifies them to a form that depicts actual trunk utilization. These results are used for analysis of the network and also for a basis for user definable simulation scenarios.

***Variation of Trunk Bandwidth*:** The first option in the simulation is for the user to modify the actual bandwidth (BW) of a selected trunk. The purpose of this function is manifold: (1) reduction of bandwidth can be used in analysis to see if the trunk is appropriately dimensioned; (2) reduction of bandwidth can be used to simulate an increase in traffic; (3) variation of bandwidth can be used in conjunction with introduced trunk failure and alternate routing to ensure that alternate route selections are appropriately dimensioned.

An extension to this function is the ability for the user to set a maximum utilization factor for the change in BW that is checked before the modified file is saved. A purpose for this extension is the ability of the simulation to take into account various inband BW requirements for network management, which is 5% in the case of the cascade system.

***Trunk Failure*:** The purpose of this function is for the user to select an outage period for a chosen trunk. The outage period consists of a failure time and a recovery time. Utilization values as well as trunk bandwidth and day/date information for the trunk outage is recorded in an excess traffic file. The actual trunk statistics file is modified to reflect the outage, i.e., interface status is set to 0 (out of service) and the utilization values are also set to 0 (no traffic). The user can also utilize this function to simulate node failure. If all trunks to a certain switch have an introduced failure at the same time, this simulates a switch outage.

***Alternate Routing Mechanisms*:** This function is twofold and a major feature of the model.

The first purpose of the function carries out the redirection of traffic to user definable alternate routes. The alternate routes can be of differing routing priorities and traffic seeking an alternate route will attempt to fill the higher priority routes before moving to a lower priority.

The second purpose of this function is the OSPF feature of even distribution of excess traffic across alternate routes of similar routing priority. This is achieved in a load sharing iterative process that takes into account available bandwidth on alternate trunks, minimum available bandwidth on alternate routes where 2 trunks are involved, and greatly varying quantities of available bandwidth on alternate trunks of similar routing priority.

4.3 Modeling Assumptions

The following assumptions have been made in implementing the model: (1) the source model format adopted has alleviated the need for the model to consider delay; (2) OSPF protocols are not a consideration of the model; (3) OSPF path metrics are modeled as routing priorities; (4) OSPF dynamic routing table and shortest-path-tree are modeled by the user configurable routing table; (5) OSPF dynamic topological database is modeled by the user definable routing table and trunk outage times.

4.4 Model Limitations

The following discussion highlights some of the limitations of the model and associated rationale.

Frequency of Statistics Collection: The cascade frame relay switch records statistics at 15 minutes intervals. Average utilization values are over 15 minute periods and peak utilization values are over the highest 5 minute period in each 15 minutes. This coarse resolution initially appeared to be a major limitation of the model, but after analyzing the statistics of individual trunk utilizations, the effect was not deemed so critical. The traffic profile was bursty, but the trunk utilizations were statistically smoothed by the number of individual users.

Delay Omission: The model has no facility to emulate delay. It takes no account of the ability of the cascade switch's (fast packet) ability to buffer overload data until bandwidth is available. This was not considered a necessary feature as the model is to be used for analysis and dimensioning purposes. As the model is based on live data, the inherent delay feature of the switches is represented in the statistics when used for analysis. For simulation, if the network capacity is so close to overload that delay is required to be implemented, the buffer region for trunk bandwidth has and truly been exceeded.

Physical Network Change: Trunk bandwidth is one of the fields read when the model extracts the trunk statistics the switch raw data files. Actual trunk bandwidth for a particular trunk may vary on a daily, or even 15 minute basis, and the model program will take this into consideration.

The trunk names and corresponding physical port addresses have been hardcoded into the program. If there is any change to a port address or the addition of an interswitch trunk, the program is modified. To accommodate changes in the physical network configuration, 3 header files need to be modified.

The requirement for a change in program code for each physical network change is seen as a weakness of the model. This problem was accepted for several reasons: (1) the live network is generally configured with multiple interswitch trunks between common switches, therefore it was deemed that physical network changes were more likely to involve bandwidth upspeed rather than additional interswitch trunks; (2) the predominant factor was seen as the effort required to implement this feature into the code dynamically. Balancing the perceived benefit of dynamic adaption to physical network change against time constraints and hard code modifications, hardcoding of physical trunk names and addresses was implemented as the best option.

***Traffic Origination and Destination*:** The information provided in the switch raw data files do not include any PVC information. As such, there is no information on originating and terminating switches. The model does not take into account transit traffic due to introduced trunk failure. As seen in Fig. 3, the model does not route traffic as would be expected in a genuine outage.

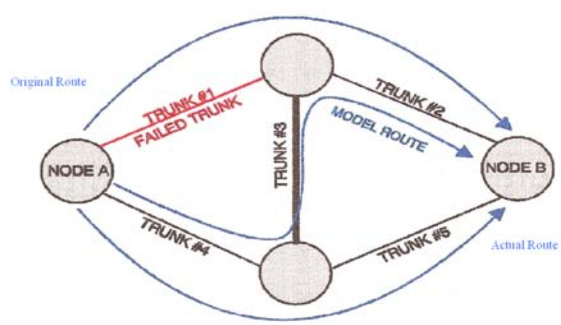

Fig. 3 Modeled versus actual traffic routes

If link#1 fails, traffic that was being transmitted from node A to node B along trunks #1 and #2 (original route) would be modeled as being transmitted along trunks #4, #3, and #2 (modeled route). On the live network the traffic is expected to be transmitted along trunks #4 and #5 (actual route).

Table 1 shows the trunk number and compares the effect of actual and modeled trunk utilizations.

***Congestion Control*:** The model does not directly consider congestion control, FECN, BECN, and DE bits are not passed to the model, and delay is also not a direct consideration of the model. As the model is based on actual switch data, any effect by congestion control measures during the operation of the network is inherent in the data used. As previously stated, if a situation arises where delay is needed, the trunks are too tightly dimensioned.

Table 1 Relative Change in Trunk Utilization

Trunk Number	Model Utilization	Actual Utilization
1	—	—
2	—	↓
3	↑	—
4	↑	↑
5	↓	↑

***Discard and Error Statistics*:** The statistics provided by the Frame Relay switches include data on discarded and erroneous frames. These parameters provide information on how well the network is NOT performing and could be considered as important as trunk utilization and traffic profiles that indicate how well the network IS performing. These parameters were not included in the model due to the fact that on virtually all days when statistics were gathered, the quantity of discards and errors was either zero or less than 0.1%.

4.5 Model Extensions

As with any computer model, there are enhancements that could be added to the model to make it more dynamic to physical network changes, more user friendly, and to create a graphical output and include more statistical switch parameters.

***Physical Network Change*:** The dynamic adaptation of the program to physical network change such as additional interswitch trunks or physical port address change is considered a beneficial enhancement to the model.

***Discard and Error Statistics*:** Including discard and error statistics into the model would be a logical progression. These statistics are readily available within the program and if analyzed correctly, they would provide indication of networking problems.

***Mesh Topology*:** Simulation of the network in a mesh topology or analysis of the network in a mesh topology may be a future requirement. The implementation of this topology is relatively straight forward with the inclusion of additional switch statistics, modification of the routing table to reflect the desired topology and inclusion of additional trunk configuration in the code.

***Graphical Output*:** Graphical output of trunks statistics for analysis, and from results of simulation scenarios was intended to be implemented. Time constraints and the ease and flexibility of massaging and displaying data from database applications such as EXCEL halted this function. It would be a beneficial enhancement to the model, even in a coarse format, so that results can be rapidly displayed.

***Model Adaptability*:** The model is a FR network, but with minor changes to account for statistic presentation, it can be applied to non-FR networks.

4.6 Model Descriptions

The model description encompasses a high level flow chart of the model, the routing flow chart, and a discussion on some routing problems encountered.

***High Level Flowchart*:** The high level flowchart, shown in Fig. 4, shows the iterative process for user definable simulation parameters and the logic for introduced trunk failure and simulated BW variation.

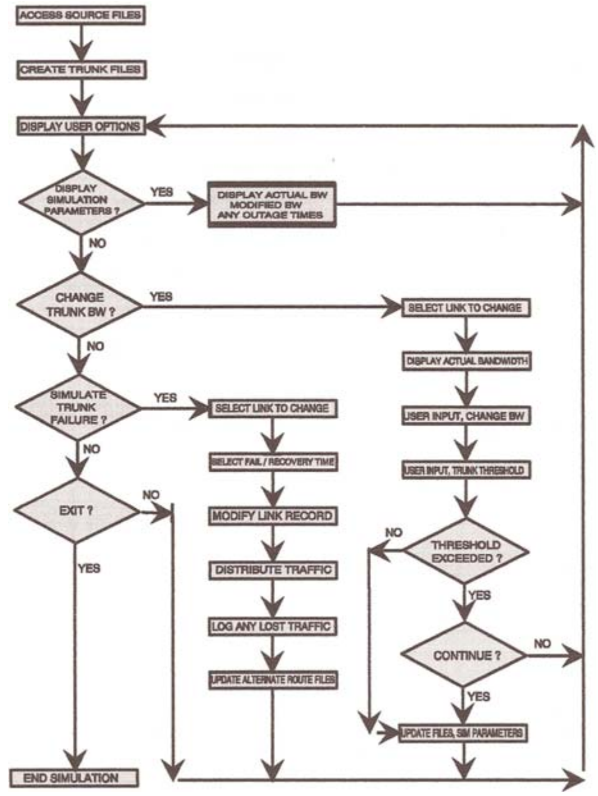

Fig. 4 High level model flowchart

***Routing Implementation*:** Routing for the FR network is held in a routing table which is derived from the topological database. The FR routing table describes each destination that the switch can forward to, as well as an associated cost and the path. Routing has been implemented in the model by a user definable routing table, as depicted in Table 2.

Table 2 Routing Implementation

Trunk Identifier	Trunk	Trunk ID	1ST Route Choice	2ND Route Choice
A	smt1	50-1-005	10B,10C	2Fk,2Gl,2Gm,2Dj, 2Ej,2Hn,2Ho,2In,2Io
B	smt2	50-1-124	10A,10C	2Fk,2Gl,2Gm,2Dj, 2Ej,2Hn,2Ho,2In,2Io
C	smt3	50-1-125	10A,10B	2Fk,2Gl,2Gm,2Dj,2Ej, 2Hn,2Ho,2In,2Io
D	sbt1	50-1-072	10E	2JA,2JB,2JC
E	sbt2	50-1-123	10D	2JA,2JB,2JC
F	sct1	50-1-010	1KA,1KB,1KC	200
G	sat1	50-1-033	1LA,1LB,1LC, 1MA,1MB,1MC	200
H	spt1	50-1-023	10I	2NA,2NB,2NC, 2OA,2OB,2OC
I	spt2	50-1-067	10H	2NA,2NB,2NC, 2OA,2OB,2OC
J	mbt1	50-2-008	1Ea,1Eb,1Ec,1Da, 1Db,1Dc	200
K	mct1	50-2-005	1Fa,1Fb, 1Fc	200
L	mat1	50-2-043	10M	2Ga,2Gb,2Gc
M	mat2	50-2-056	10L	2Ga,2Gb,2Gc
N	mpt1	50-2-088	10O	2Ha,2Hb,2Hc, 2Ia,2Ib,2Ic
O	mpt2	50-2-067	10N	2Ha,2Hb,2Hc, 2Ia,2Ib,2Ic

The decoding of the 1st and 2nd route choices is XAB where routing priority is X and links comprising the alternate route are AB. We note that any route choice where A or B is zero, 0, indicates that no link is available, i.e., X0B indicates that route choice X has only one link comprising the alternate route, and X00 indicates that there are no links comprising the alternate route. The format of Table 2 depicts associated cost as a routing priority, path as AB alternate route and destination as trunk acronym, eg. mat2 is Melbourne-Adelaide-Trunk-2.

Another routing concern is orientation of traffic at various switches. The statistics used in the simulation are gathered from the Sydney and Melbourne switches. The traffic orientation was not a problem until alternate routing was implemented.

As seen in Fig. 5, if trunk#1 fails, Route B via trunk#3 and #2 would be used as the alternate route. This does not present a problem for traffic orientation as outbound utilization on the Sydney switch is added to outbound utilization on the Melbourne switch. If trunk#3 fails, then Route A via trunks#1 and #2 would be used. This does not present a problem for traffic orientation. Outbound traffic from Sydney on trunk#1 needs to be added to inbound traffic at Melbourne on trunk#2.

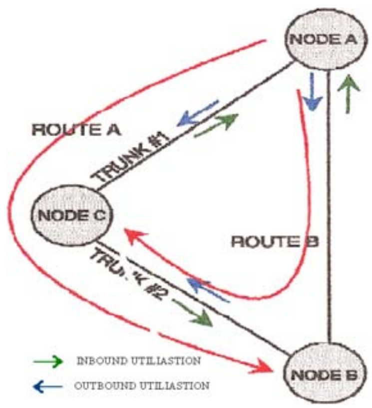

Fig. 5 Traffic orientation

A solution to this problem was to swap the inbound and outbound utilizations on one of the links prior to carrying out alternate routing calculations, and then swap them back. To distinguish in which particular instance of alternate routing this is to occur, the model uses lower case letters in the alternate route choice (refer to Table 2).

The routing flowchart in Fig. 6 shows the implementation of both the routing priority and the "swap" traffic functions to deal with traffic orientation at different switches.

5 Simulation & Performance Analysis

The following graphical results and discussions are based on live switch data from a single day. For each of the analysis and simulation results the model was rerun. The graphs are of Utilization versus Time, with utilization as a percentage on the ordinate axis and time in GMT on the abscissa axis. The abscissa axis has a fixed scale while the ordinate axis has a variable scale based on the maximum value for the utilization of each particular trunk.

5.1 Results

In this section, we depict and analyze both actual and simulated traffic data using our developed model. The model was implemented using C programming. Since the length of the C code was 30 full A4 pages, we are unable to attach it to this paper as a separate Appendix.

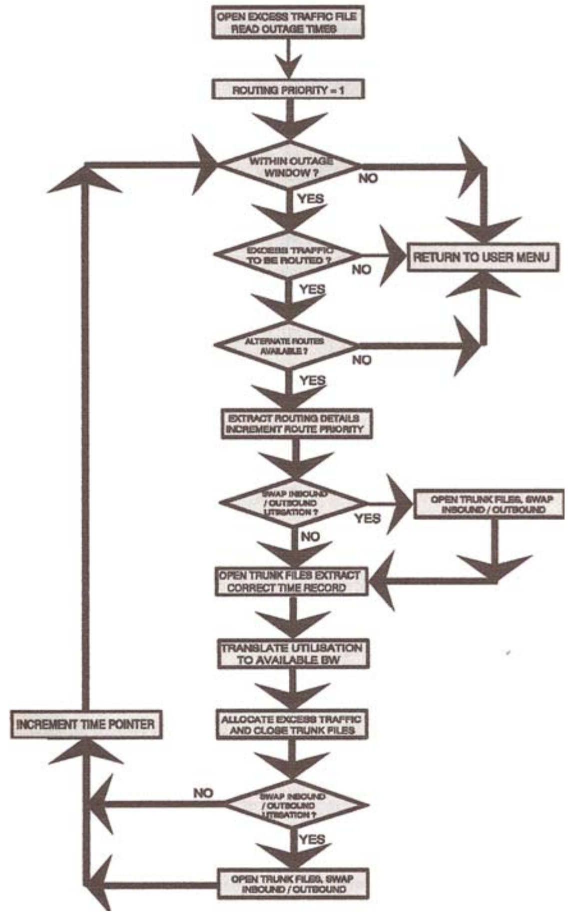

Fig. 6 Routing flowchart

Analysis Results**:** The results shown here are actual traffic data. This data is used for analysis of network performance. Due to publishing space restrictions, we only depict in this paper the actual statistics on SBT1, shown in Fig. 7. We note that actual statistics were also obtained, although not displayed in this paper, for SMT1, SMT2, SMT3, SBT2, SPT1, SPT2, SAT1, SCT1, MBT1, MCT1, MAT1, MAT2, MPT1, and MPT2.

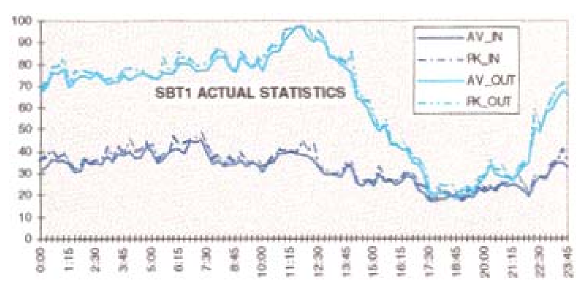

Fig. 7 Real traffic data for SBT1

We observe from Fig. 7 that at time 11:15, the utilization, average, and peak have flattened off at approximately 95%. This would represent an overload of the trunk and the introduction of delay by the live network. We also observe on SBT1 that there is an extended period 00:00-15:00 where the traffic is in excess of 70%. The network should reroute some of the PVCs to SBT2, which averages a much lower utilization value for the same period.

Simulation Results**:** Due to publication space restrictions, not all simulation results are shown in this paper. These include: (1) a simulation scenario of an outage on the Sydney-Perth-Trunk-1 from 12:45-13:15 GMT and on Sydney-Perth-Trunk-2 from 09:00-09:30; (2) a simulation scenario of an outage on the Melbourne-Perth-Trunk-2 from 06:00-06:45 GMT and a decrease in bandwidth on Melbourne-Trunk-1 for the entire day.

A simulation scenario is conducted for an outage on both Sydney-Melbourne-Trunk-1 and Sydney-Melbourne-Trunk-2 from 02:00 to 02:15 GMT. This simulation demonstrated the model's ability to simulate multiple trunk failures, to reroute traffic over multiple alternate routes, and the load sharing process. The routing priority function is exhibited by the 1st route choice SMT3 having no available outbound bandwidth and the 2nd route choice routes, all other links out of Sydney, have an increase in outbound utilization for the outage window. The traffic orientation "swapping" function is also demonstrated by the increase in inbound utilization on all links to Melbourne during the outage window.

A single simulation trace is depicted in Fig. 8. We note that the simulated profile of Fig. 8 matches the actual profile of Fig. 7, which indicates that the developed model works well.

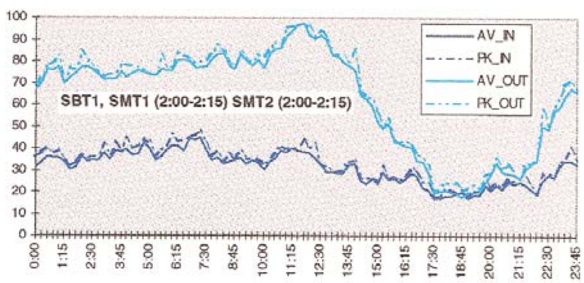

Fig. 8 Snapshot of simulated traffic data

5.2 Performance Analysis

The model only deals with 5 parameters from each 15 minutes period per kink. These parameters are average and peak inbound utilization, average and peak outbound utilization, and bandwidth. With this limited number of changing parameters, the analysis of the model has been carried out using manually. For each iterative step in various simulation scenarios, these 5 values were checked manually. Once a high degree of confidence was gained in the mathematical manipulations of the model, graphical results were used to check model operation

One of the model assumptions was that it would be operated by knowledgeable personnel. This requirement is a necessary skill for interpreting the graphical results and being able to recognize and account for any anomalous results.

6 Conclusions and Future Work

In this paper, we developed a model to be used in the simulation of a commercial Frame Relay network for the purpose of dimensioning the interswitch trunks. A minor portion of this paper presented an overview of FR theory and the OSPF link algorithm. The model was implemented using C language, resulting in an intensive code extending over 30 full A4 pages. The generated graphs depicted original and simulation statistics on a trunk by trunk basis. The simulation & analysis results of Section 5 demonstrated that the model was effective in analysing actual data and predicting the behaviour of the live network under expected network component failure and overload. This was validated by the results of Figs. 7 and 8, which indicated that the simulated data was consistent with the real data.

The results of this research are promising and can find applications in many internet-based applications. As the model is being used on a commercial basis, the enhancements to enable mesh analysis and dynamic adaptation for physical changes need to be studies in future work. With minor changes to account for network statistic presentation, the developed model can equally be applied to non-Frame Relay data networks.

Acknowledgement

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