APPENDIX I
BIRTH-DEATH PROCESS

The problem is to find the number of VCCs occupying a system as a function of time, subject to various initial conditions. To approach the problem with some chance of deriving simple formulas, some simplifying assumptions must be made.

Assume VCCs arrive for each origin-destination pair according to a Poisson process with parameter λ whose units are the number of VCCs per second, and that the probability of a new VCC arriving in the interval $[t, t+\Delta t)$ is independent of t. If Δt is small then we could expect that the probability of a new VCC arriving in $[t, t+\Delta t)$ is $\lambda \Delta t$.

Assume connection holding times are independent and exponentially distributed with mean h and units of second. Assume also that the probability that a VCC in progress will terminate in the interval $[t, t+\Delta t)$ is also independent of t. For small Δt, the probability that a VCC in progress will terminate is $\dfrac{\Delta t}{h}$.

Suppose there are N_0 VCCs in the VPC at time $t = 0$. Let $p_t(n)$ be the probability that there will be n VCCs in the VPC at time $t > 0$. We can derive a set of equations for the evolution of these probabilities with time.

Probability of n calls at $t + \Delta t$ = Probability of n calls at t * Probability that no VCCs terminate in $[t, t+\Delta t)$ and that no new VCCs arrive

\+ Probability of $n+1$ VCCs at t * Probability that one VCC terminate in $[t, t+\Delta t)$ and that no new VCCs arrive

\+ Probability of $n-1$ VCCs at t * Probability that no VCCs terminate in $[t, t+\Delta t)$ and that one new VCC arrives

\+ Probability of compound events which are second or higher order in Δt

Let X show a new VCC arrival.

Let X_m show m new VCCs arriving in the interval $[t, t+\Delta t)$.

Let Y show a VCC termination.

Let Y_n show n VCCs terminate in the interval $[t, t+\Delta t)$.

This can be expressed as

$$\begin{aligned}P_{t+\Delta t}(n) = {} & P_t(n)P_{t+\Delta t}(X_0 \mid n)P_{t+\Delta t}(Y_0 \mid n)\\ & + P_t(n+1)P_{t+\Delta t}(X_0 \mid n+1)P_{t+\Delta t}(Y_0 \mid n+1)\\ & + P_t(n-1)P_{t+\Delta t}(X_0 \mid n-1)P_{t+\Delta t}(Y_0 \mid n-1)\\ & + O(\Delta t^2)\end{aligned}$$

Since $P\,(X_m|n) = \binom{n}{m} P(X)^m (1-P(X))^{n-m}$, $P(X) = \lambda\Delta t$, $P(Y) = \dfrac{\Delta t}{h}$

This reduces to

$$\begin{aligned}P_{t+\Delta t}(n) = {} & P_t(n)(1-\frac{\Delta t}{h})^n(1-\lambda\Delta t) + P_t(n+1)(n+1)\frac{\Delta t}{h}(1-\frac{\Delta t}{h})^n(1-\lambda\Delta t)\\ & + P_t(n-1)(1-\frac{\Delta t}{h})^{n-1}\lambda\Delta t + O(\Delta t^2)\end{aligned}$$

reducing to first order terms in Δt

$$P_{t+\Delta t}(n) = P_t(n)(1-(\frac{n}{h}+\lambda)\Delta t) + P_t(n+1)(n+1)\frac{\Delta t}{h} + P_t(n-1)\lambda t + O(\Delta t^2)$$

$$\frac{P_{t+\Delta t}(n) - P_t(n)}{\Delta t} = -(\frac{n}{h}+\lambda)P_t(n) + \frac{(n+1)}{h}P_t(n+1) + \lambda P_t(n-1)\lambda + O(\Delta t^2)$$

and for small Δt, we can find the derivative of $P_t(n)$

$$\frac{dP_t(n)}{dt} = -(\frac{n}{h}+\lambda) + \frac{(n+1)P_t(n+1)}{h} + \lambda P_t(n-1) \qquad \text{(AI.1)}$$

The Mean Value of the Number of VCCs

In principle it should be possible to calculate all the $P_t(n)$ but for our purposes it may be sufficient to calculate the mean of the number of VCCs in the system.

The mean is defined as the expectation of the number of VCCs

$$\overline{n}(t) = \sum_{n=0}^{\infty} nP_t(n) \tag{AI.2}$$

Using A.1 and A.2 together

$$\frac{d\overline{n}}{dt} = \sum_{n=0}^{\infty} n\frac{dP_t(n)}{dt} = -\sum_{n=0}^{\infty} n(\frac{n}{h}+\lambda)P_t(n) + \frac{1}{h}\sum_{n=0}^{\infty} n(n+1)P_t(n+1) + \lambda\sum_{n=0}^{\infty} nP_t(n-1) \tag{AI.3}$$

or, after some manipulation

$$\frac{d\overline{n}}{dt} = -\frac{1}{h}[\sum_{n=0}^{\infty} n^2 P_t(n) - \sum_{n=0}^{\infty}(n+1)^2 P_t(n+1)] - \frac{1}{h}\sum_{n=0}^{\infty}(n+1)P_t(n+1)$$

$$+\lambda[\sum_{n=0}^{\infty}(n-1)P_r(n-1) - \sum_{n=0}^{\infty} nP_t(n)] + \lambda\sum_{n=0}^{\infty} P_t(n-1)$$

Now $P_t(n) = 0$ if $n < 0$, and we shall assume that $P_t(n) \to 0$ as $n \to \infty$ fast enough to ensure convergence of any of the summations in equation (A.3); with these assumptions it is possible to simplify the RHS of (A.3). In fact the terms in square brackets become zero and the two remaining summations are equal to the mean and to 1 respectively. Thus

$$\frac{d\overline{n}}{dt} = -\frac{1}{h}\sum_{n=0}^{\infty}(n+1)P_t(n+1) + \lambda\sum_{n=0}^{\infty} P_t(n-1)$$

$$-\frac{1}{h}\sum_{n=1}^{\infty} nP_t(n) + \lambda\sum_{n=-1}^{\infty} P_t(n)$$

$$-\frac{1}{h}\sum_{n=0}^{\infty} nP_t(n) + \lambda\sum_{n=0}^{\infty} P_t(n)$$

and hence

$$\frac{d\overline{n}}{dt} = -\frac{1}{h}\overline{n} + \lambda \tag{AI.4}$$

This is the main result, and could be derived heuristically in a couple of lines.

Solution for Mean of Number of VCCs

The solution of (A.4) for initial condition $\overline{n}(0) = N_0$ is well known:

$$\overline{n}(t) = \lambda h + (N_0 - \lambda h)e^{\frac{-t}{h}} \tag{AI.5}$$

APPENDIX II

MIRROR SITE AND PROXY SERVER CONCEPT

Mirror sites and proxy servers both have the potential to improve the use of network resources and to reduce latency times in response to requests.

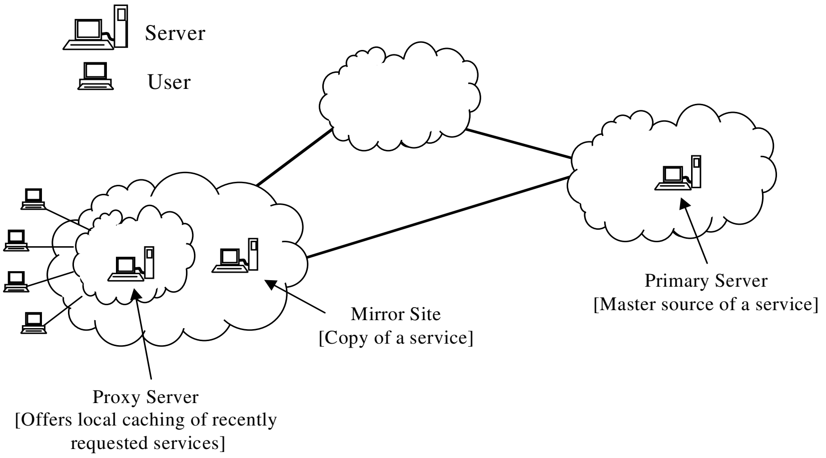

Figure AII.1: The relationship between a Primary Server, Mirror Site and Proxy Server.

AII.1 Mirror Site Concept

A mirror site is a Web site that contains a copy of service available from a primary server. Usually, the mirror site has exactly the same service as the primary server. The difference is only in the location of the sites. The value of the mirror site concept is in reducing congestion by distributing traffic to other network resources [KON97]. The mirror site concept also has the potential to reduce the time required to access services. This is an important factor in the quality of service provided by the WWW [BOL96].

The mirror site concept is usually explained in terms of connecting users in one geographical area to the local mirror site but the problem of optimising the use of the set of mirror sites and primary server is more complex. It is not guaranteed that the mirror site in the same geographical area as the user will provide the optimal use of resources.

A particular mirror site can become overloaded if there is heavy demand from the local user community.

The common implementation works like this when a user makes a request to the primary server: the primary server usually provides a list of its mirror sites, but users cannot tell which mirror site can be accessed with the least congestion.

Those who deploy WWW servers have a growing interest in understanding the geographic dispersion of access patterns. The work in [LAM96] draws on a large body techniques for visualization of network data in the geographic domain. The work is rooted in information visualization [FAI88] and statistical graphics [CLE88] with emphasis on interactive exploration. Other examples include Becker *et al*'s [BEC95] techniques for displaying communication traffic, and Cox's [COX92] animation of NSFNet traffic. Both show network connections by drawing links between nodes and show inbound traffic by assigning traffic volume to a range of colors.

Mirror sites have the potential to improve network efficiency, but we cannot gain the maximum benefit without some form of traffic control to distribute load properly among the sites.

AII.2 Proxy Server Concept

The proxy server offers local caching of recently requested services for a group of users. Measurements have shown that the caching proxy can significantly reduce network load [ABR95].

The concept of a proxy cache is that user requests for service go to a local server instead of directly to the primary server. The local server fetches a copy of the service, saves it on disk and forwards it to the user. Subsequent requests from other users of the proxy cache are provided with the saved copy.

A proxy server requires proper dimensioning to meet its load requirements. In [BOL96], the authors discuss a design to avoid server overload. Server performance can be optimised by carefully dimensioning the server (so that it has enough resources such as CPU power and disk space to handle expected requests) and the network (so that it has enough resources such as bandwidth and buffers to transport requests and replies), and by using mechanisms such as caching to minimise the resource requirements of user requests.

Issues in caching management include matters such as data replacement with limited disk capacity [ROB90] [SEL88], keeping the data in cache up-to-date [WOR94], etc.

Real time service which request some level of minimum acceptable resources cannot be cached. The trend of web applications is toward real-time services such as Internet chat, Internet phone, real audio, real video, etc.

APPENDIX III

NOTE ON SIMULATION PROGRAM

All of the computed results and simulations in the research are prepared on MATLAB for Windows Version 4.2c.1. MATLAB is a product of the MathWorks, Inc. We use the module LP supplied with the MATLAB optimisation toolbox to solve the Linear Programming model. The simulation programs are grouped into 4 major parts as follow:

- Fixed Virtual Path Management (FVPM) (chapter 4)
- Dynamic Virtual Path Management (FVPM) (chapter 4)
- State Dependent Virtual Path Management (SDVPM) (chapter 5)
- Performance evaluation in the Internet (chapter 7)

The code can be made available by contacting the author or Laboratory for Telecommunication Research, School of Biomedical Science and Electrical Engineering, Swinburne University of Technology.

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