TERMINAL POINTS, BANDWIDTH AVAILABILITY AND BANDWIDTH UTILIZATION IN A VIRTUAL PRIVATE NETWORK (VPN)

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ABSTRACT

Efficiency, Reliability and Cost are the foremost three major criteria usually considered in a telecommunication network. In order to make better use of available network resources, there is a need for planning the bandwidth allocation to communication demands. In this study, a bandwidth allocation problem with three major constraints were simulated and solved for 50, 100, 150, 200 and 250 nodes. The study discovered that increasing bandwidth is not absolutely the only way to take care of the load on networks as the bandwidth availability may not be commensurate with bandwidth utilization.

Key Words: Bandwidth, Reliability, Efficiency, Cost, Bandwidth Availability, Bandwidth Utilization

INTRODUCTION

Communication networks are expected to offer a wide range of services to an increasingly large number of users, with a diverse range of quality of service. This calls for efficient control and management of these networks. The key resource to manage in networks is bandwidth. Therefore, in order to make better use of available network resources, there is a need for planning the bandwidth allocation to communication demands, in order to set up routing tables (or any other route selection criterion) more purposefully. This can be achieved by the use of global information, including not only the available link capacities but also the expected traffic profile. This traffic profile may be given, as when setting up virtual private networks in an ATM backbone of a provider, or estimated by objective traffic measurements [1, 2]. The goal of a VPN is to provide the organization with the same secure capabilities but at a much lower cost. Without proactive management, network capacity fills with inappropriate traffic and viruses, and the connection becomes ineffective. [2, 3, 4]

Several studies make use of Genetic Algorithm (GA) based techniques to solve network problems. The motivation behind GA's in nonlinear optimization problems is that the problem can be expressed such that natural evolution, as reported, can provide an attractive paradigm for implementing general nonlinear searches [5, 6, 7].

METHODOLOGY

A dynamic mathematical model was developed and a Genetic Algorithm method was adopted for the optimization solution.

Terms	Notation
Minimum Required Bandwidth at node n_i.	b_{mi}
Available Bandwidth at node n_i	b_i
Throughput Request at node n_i.	t_{ri}
Allocated Throughput at node n_i.	t_{ai}
Total Available Bandwidth for all the nodes at a given time.	BW
time (evaluation period)	t

$$\max \sum_{i=1}^{k} t_{ai} \qquad (1)$$

s.t.
$$\sum_{i=1}^{k} b_i \leq BW \qquad (2)$$

$$t_{ai} \geq t_{ri} \quad \forall i = 1,2,3,\text{-------},k \qquad (3)$$

$$b_i \geq b_{mi} \quad \forall i = 1,2,3, \text{-------},k \qquad (4)$$

The GA algorithm was implemented with Java programming language. The model was simulated for ten thousand (10,000) generations. Fifty (50), one hundred (100), one hundred and fifty (150), two hundred (200), and two hundred and fifty (250) terminal points/nodes were studied. Each of the nodes were simulated differently under varying bandwidths values of 64Kbps, 128Kbps, 256Kbps, 512Kbps, 1Mbps, 2Mbps, 4Mbps, and 8Mbps for a period of twenty four (24) hours.

RESULTS

The bandwidth utilization tables and curves are as in tables 1 – 5 and figures 1 – 5 respectively.

Table 1: Daily Bandwidth Utilization for 50 Nodes

Period	@ 64Kbps	@128Kbps	@256Kbps	@512Kbps	@1Mbps	@2Mbps	@4Mbps	@8Mbps
12 midnight	0.983276	0.994263	0.999985	0.999756	0.999985	0.784922	0.380473	0.190487
1a.m	0.99884	0.994263	0.999985	0.999756	0.999985	0.805693	0.395408	0.200751
2a.m	0.99884	0.999298	0.999985	0.999756	0.999985	0.822029	0.405922	0.207489
3a.m	0.99884	0.999298	0.999985	0.999756	0.999985	0.829897	0.410142	0.211594
4a.m	0.99884	0.999298	0.999985	0.999756	0.999985	0.831614	0.412102	0.211601
5a.m	0.99884	0.999298	0.999985	0.999756	0.999985	0.831614	0.412431	0.212073
6a.m	0.99884	0.999298	0.999985	0.999756	0.999985	0.834846	0.41379	0.213897
7a.m	0.99884	0.999298	0.999985	0.999756	0.999985	0.84403	0.415778	0.216415
8a.m	0.99884	0.999298	0.999985	0.99987	0.999985	0.848207	0.416536	0.216501
9a.m	0.99884	0.999298	0.999985	0.99987	0.999985	0.853672	0.418024	0.21683
10a.m	0.99884	0.999298	0.999985	0.99987	0.999985	0.862913	0.423918	0.21683
11a.m	0.999756	0.999298	0.999985	0.99987	0.999985	0.864573	0.424318	0.217609
12noon	0.999756	0.999756	0.999985	0.99987	0.999985	0.866718	0.424461	0.21806
1p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.86709	0.425706	0.21821
2p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.868235	0.427423	0.218225
3p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.868635	0.427423	0.218575
4p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.869408	0.428367	0.220048
5p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.869408	0.428452	0.220084
6p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.871496	0.428495	0.220184
7p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.871496	0.429039	0.220206
8p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.871496	0.42964	0.220807
9p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.871496	0.429668	0.220985
10p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.871496	0.429683	0.221
11p.m	0.999756	0.999756	0.999985	0.99987	0.999985	0.874157	0.432401	0.221343

Table 2: Daily Bandwidth Utilization for 100 Nodes

Period	@ 64Kbps	@128Kbps	@256Kbps	@512Kbps	@1Mbps	@2Mbps	@4Mbps	@8Mbps
12 midnight	0.98053	0.998383	0.996094	0.998955	0.999355	0.999985	0.777469	0.400851
1a.m	0.98053	0.998383	0.996094	0.998955	0.999355	0.999985	0.791616	0.404263
2a.m	0.993347	0.999756	0.996094	0.99987	0.999813	0.999985	0.808511	0.406952
3a.m	0.993347	0.999756	0.999069	0.99987	0.99987	0.999985	0.815034	0.408947
4a.m	0.994263	0.999756	0.999069	0.99987	0.999928	0.999985	0.817051	0.410156
5a.m	0.994263	0.999756	0.999069	0.999985	0.999928	0.999985	0.8214	0.413668
6a.m	0.994263	0.999756	0.999069	0.999985	0.999985	0.999985	0.822487	0.414555
7a.m	0.994263	0.999756	0.999069	0.999985	0.999985	0.999985	0.828166	0.414591
8a.m	0.994263	0.999756	0.999069	0.999985	0.999985	0.999985	0.828881	0.418267
9a.m	0.994263	0.999756	0.999069	0.999985	0.999985	0.999985	0.829782	0.41954
10a.m	0.994263	0.999756	0.999756	0.999985	0.999985	0.999985	0.834618	0.419598
11a.m	0.994263	0.999756	0.999756	0.999985	0.999985	0.999985	0.83612	0.420105
12noon	0.994263	0.999756	0.999756	0.999985	0.999985	0.999985	0.837007	0.420156
1p.m	0.994263	0.999756	0.999756	0.999985	0.999985	0.999985	0.837994	0.422258
2p.m	0.994263	0.999756	0.999756	0.999985	0.999985	0.999985	0.841298	0.426385
3p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.841498	0.428674
4p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.84167	0.429132
5p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.842428	0.429139
6p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.849295	0.429518
7p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.850539	0.429518
8p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.850682	0.429518
9p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.850682	0.429633
10p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.859022	0.429797
11p.m	0.997925	0.999756	0.999756	0.999985	0.999985	0.999985	0.859022	0.429797

Table 3: Daily Bandwidth Utilization for 150 Nodes

Period	@ 64Kbps	@128Kbps	@256Kbps	@512Kbps	@1Mbps	@2Mbps	@4Mbps	@8Mbps
12 midnight	0.941162	0.977325	0.993805	0.997353	0.998554	0.99967	0.999985	0.592067
1a.m	0.941162	0.977325	0.99678	0.999527	0.998554	0.99967	0.999985	0.600257
2a.m	0.967712	0.977325	0.99678	0.999527	0.998554	0.99967	0.999985	0.608869
3a.m	0.967712	0.990601	0.999756	0.99987	0.998554	0.99967	0.999985	0.619426
4a.m	0.967712	0.99472	0.999756	0.99987	0.998554	0.999928	0.999985	0.621536
5a.m	0.967712	0.99472	0.999756	0.99987	0.998554	0.999928	0.999985	0.626686
6a.m	0.967712	0.99472	0.999756	0.99987	0.998554	0.999928	0.999985	0.631907
7a.m	0.992432	0.99884	0.999756	0.99987	0.998955	0.999928	0.999985	0.632436
8a.m	0.992432	0.99884	0.999756	0.99987	0.998955	0.999928	0.999999	0.634131
9a.m	0.992432	0.99884	0.999756	0.99987	0.998955	0.999928	0.999999	0.637622
10a.m	0.992432	0.999756	0.999756	0.99987	0.999298	0.999928	0.999999	0.638859
11a.m	0.992432	0.999756	0.999756	0.99987	0.999298	0.999928	0.999999	0.65006
12noon	0.992432	0.999756	0.999756	0.99987	0.999641	0.999956	0.999999	0.652299
1p.m	0.992432	0.999756	0.999756	0.999985	0.999641	0.999956	0.999999	0.654151
2p.m	0.992432	0.999756	0.999985	0.999985	0.999641	0.999956	0.999999	0.658264
3p.m	0.992432	0.999756	0.999985	0.999985	0.999641	0.999956	0.999999	0.659716
4p.m	0.99884	0.999756	0.999985	0.999985	0.999641	0.999956	0.999999	0.659716
5p.m	0.99884	0.999756	0.999985	0.999985	0.999641	0.999956	0.999999	0.660138
6p.m	0.99884	0.999756	0.999985	0.999985	0.999699	0.999956	0.999999	0.66021
7p.m	0.99884	0.999756	0.999985	0.999985	0.999699	0.999956	0.999999	0.660388
8p.m	0.99884	0.999756	0.999985	0.999985	0.999699	0.999956	0.999999	0.662141
9p.m	0.99884	0.999756	0.999985	0.999985	0.999699	0.999956	0.999999	0.662277
10p.m	0.99884	0.999756	0.999985	0.999985	0.999699	0.999956	0.999999	0.662649
11p.m	0.99884	0.999756	0.999985	0.999985	0.999699	0.999956	0.999999	0.663006

Table 4: Daily Bandwidth Utilization for 200 Nodes

Period	@ 64Kbps	@128Kbps	@256Kbps	@512Kbps	@1Mbps	@2Mbps	@4Mbps	@8Mbps
12 midnight	0.90271	0.996094	0.997467	0.992088	0.997009	0.999784	0.999999	0.792196
1a.m	0.983276	0.996094	0.997467	0.995293	0.999126	0.999784	0.999999	0.828001
2a.m	0.983276	0.996094	0.997467	0.999298	0.999928	0.999813	0.999999	0.832279
3a.m	0.983276	0.996094	0.997467	0.999298	0.999928	0.999813	0.999999	0.83308
4a.m	0.983276	0.996094	0.997467	0.999298	0.999928	0.999813	0.999999	0.839782
5a.m	0.983276	0.996094	0.997467	0.999298	0.999928	0.999813	0.999999	0.841348
6a.m	0.983276	0.996094	0.997467	0.999298	0.999928	0.999813	0.999999	0.846705
7a.m	0.983276	0.996094	0.999298	0.999298	0.999928	0.999813	0.999999	0.846705
8a.m	0.983276	0.996094	0.999527	0.999298	0.999928	0.999813	0.999999	0.850925
9a.m	0.983276	0.996094	0.999527	0.999298	0.999928	0.999813	0.999999	0.851169
10a.m	0.997925	0.996094	0.999527	0.999298	0.999928	0.999813	0.999999	0.851769
11a.m	0.997925	0.996094	0.999527	0.999298	0.999928	0.999813	0.999999	0.851898
12noon	0.997925	0.998383	0.999527	0.999298	0.999928	0.999813	0.999999	0.85335
1p.m	0.997925	0.998383	0.999527	0.999298	0.999928	0.999928	0.999999	0.853379
2p.m	0.997925	0.999298	0.999985	0.999298	0.999928	0.999956	0.999999	0.853894
3p.m	0.997925	0.999298	0.999985	0.999298	0.999928	0.999956	0.999999	0.854974
4p.m	0.997925	0.999298	0.999985	0.999413	0.999928	0.999956	0.999999	0.859838
5p.m	0.997925	0.999298	0.999985	0.999413	0.999928	0.999956	0.999999	0.870073
6p.m	0.997925	0.999298	0.999985	0.999413	0.999928	0.999956	0.999999	0.872583
7p.m	0.997925	0.999298	0.999985	0.99987	0.999928	0.999956	0.999999	0.872626
8p.m	0.997925	0.999298	0.999985	0.99987	0.999928	0.999956	0.999999	0.875316
9p.m	0.997925	0.999298	0.999985	0.99987	0.999928	0.999956	0.999999	0.875316
10p.m	0.997925	0.999298	0.999985	0.99987	0.999928	0.999956	0.999999	0.875316
11p.m	0.997925	0.999298	0.999985	0.99987	0.999928	0.999956	0.999999	0.875316

Table 5: Daily Bandwidth Utilization for 250 Nodes

Period	@ 64Kbps	@128Kbps	@256Kbps	@512Kbps	@1Mbps	@2Mbps	@4Mbps	@8Mbps
12 midnight	0.996094	0.991974	0.986023	0.997696	0.999355	0.999269	0.999556	0.999899
1a.m	0.996094	0.991974	0.996323	0.999985	0.999355	0.999928	0.999641	0.999899
2a.m	0.996094	0.991974	0.999298	0.999985	0.999355	0.999928	0.999756	0.999963
3a.m	0.996094	0.991974	0.999298	0.999985	0.999355	0.999928	0.999928	0.999978
4a.m	0.996094	0.995178	0.999298	0.999985	0.999355	0.999928	0.999985	0.999978
5a.m	0.996094	0.995178	0.999298	0.999985	0.999355	0.999928	0.999985	0.999978
6a.m	0.996094	0.995178	0.999298	0.999985	0.999355	0.999928	0.999985	0.999999
7a.m	0.996094	0.998383	0.999756	0.999985	0.999355	0.999928	0.999985	0.999999
8a.m	0.996094	0.998383	0.999756	0.999985	0.999641	0.999928	0.999985	0.999999
9a.m	0.996094	0.998383	0.999756	0.999985	0.999641	0.999928	0.999985	0.999999
10a.m	0.996094	0.998383	0.999756	0.999985	0.999641	0.999928	0.999985	0.999999
11a.m	0.996094	0.998383	0.999756	0.999985	0.999641	0.999928	0.999985	0.999999
12noon	0.996094	0.998383	0.999756	0.999985	0.999756	0.999928	0.999985	0.999999
1p.m	0.996094	0.998383	0.999756	0.999985	0.999756	0.999956	0.999985	0.999999
2p.m	0.996094	0.998383	0.999756	0.999985	0.999756	0.999956	0.999985	0.999999
3p.m	0.996094	0.998383	0.999756	0.999985	0.999756	0.999956	0.999985	0.999999
4p.m	0.996094	0.998383	0.999756	0.999985	0.999756	0.999956	0.999985	0.999999
5p.m	0.996094	0.99884	0.999756	0.999985	0.999756	0.999956	0.999985	0.999999
6p.m	0.996094	0.99884	0.999985	0.999985	0.999756	0.999956	0.999985	0.999999
7p.m	0.996094	0.99884	0.999985	0.999985	0.999756	0.999956	0.999985	0.999999
8p.m	0.996094	0.99884	0.999985	0.999985	0.999756	0.999956	0.999985	0.999999
9p.m	0.996094	0.99884	0.999985	0.999985	0.999756	0.999956	0.999985	0.999999
10p.m	0.996094	0.99884	0.999985	0.999985	0.999756	0.999956	0.999985	0.999999
11p.m	0.996094	0.99884	0.999985	0.999985	0.999756	0.999956	0.999999	0.999999

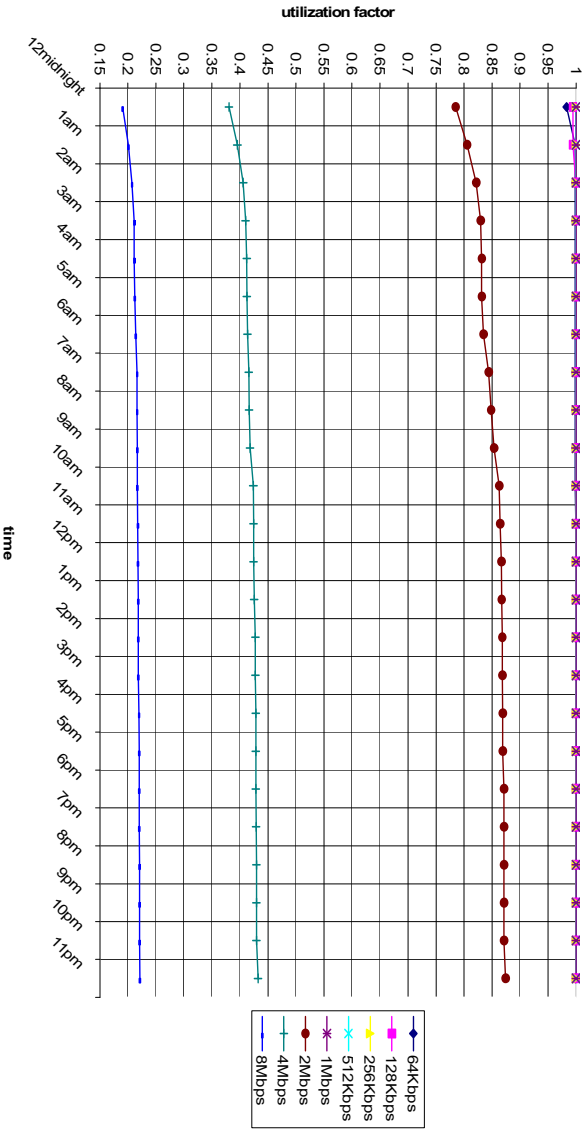

FIGURE 1: DAILY BANDWIDTH UTILIZATION FOR 50 NODES

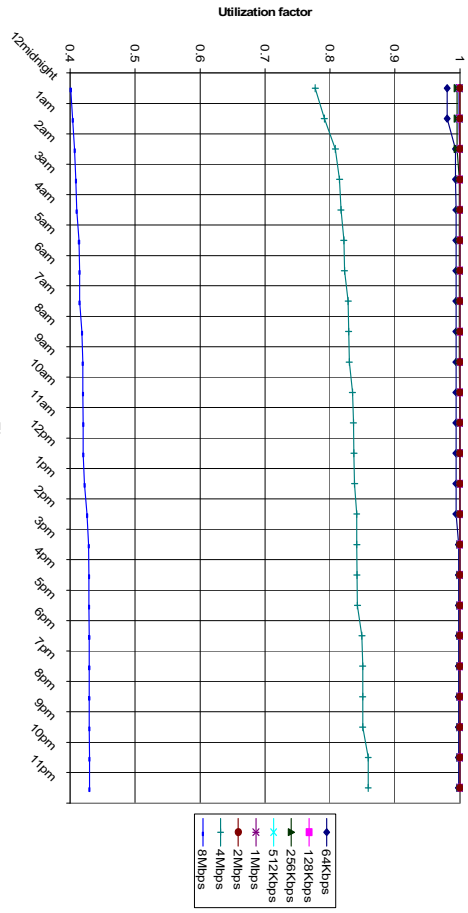

FIGURE 2: DAILY BANDWIDTH UTILIZATION FOR 10

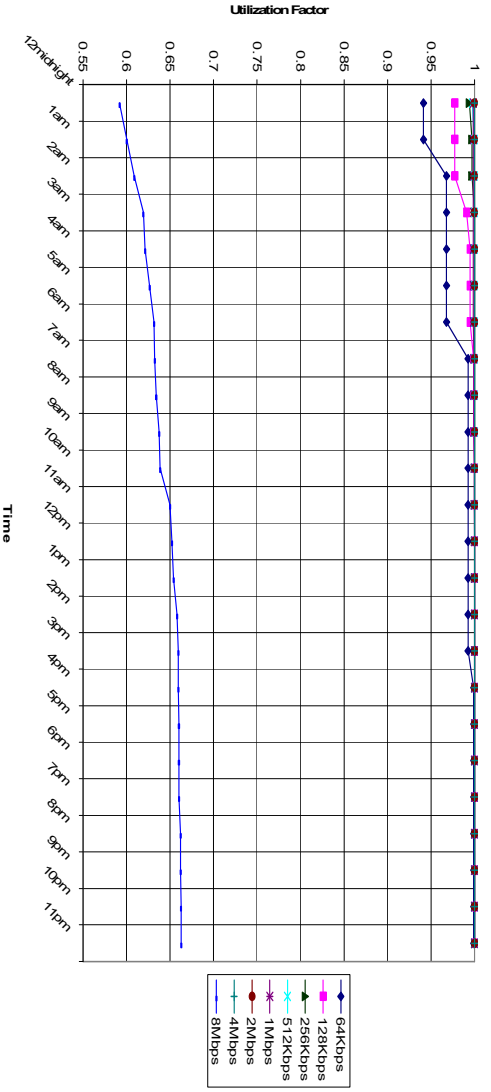

FIGURE 3: DAILY BANDWIDTH UTILIZATION FOR 150 NODES 0 NODES

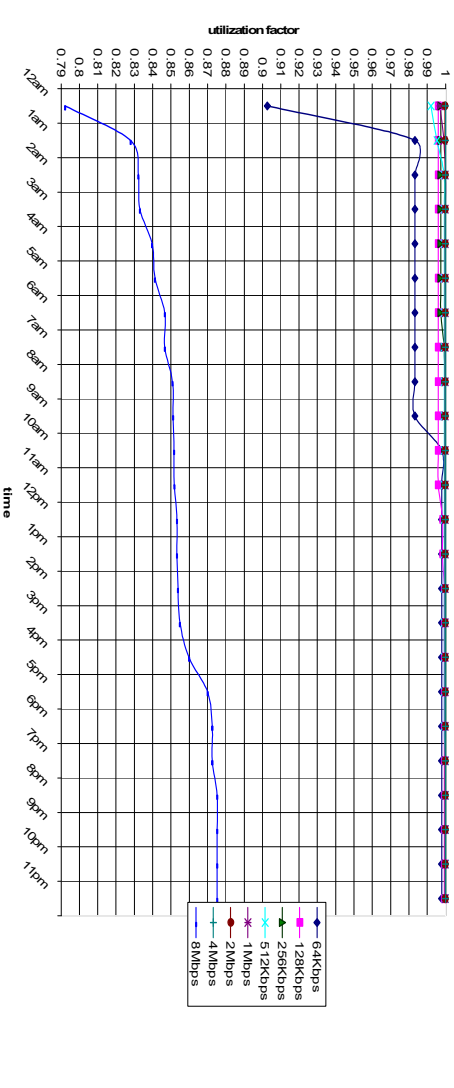

FIGURE 4: DAILY BANDWIDTH UTILIZATION FOR 200 NODES

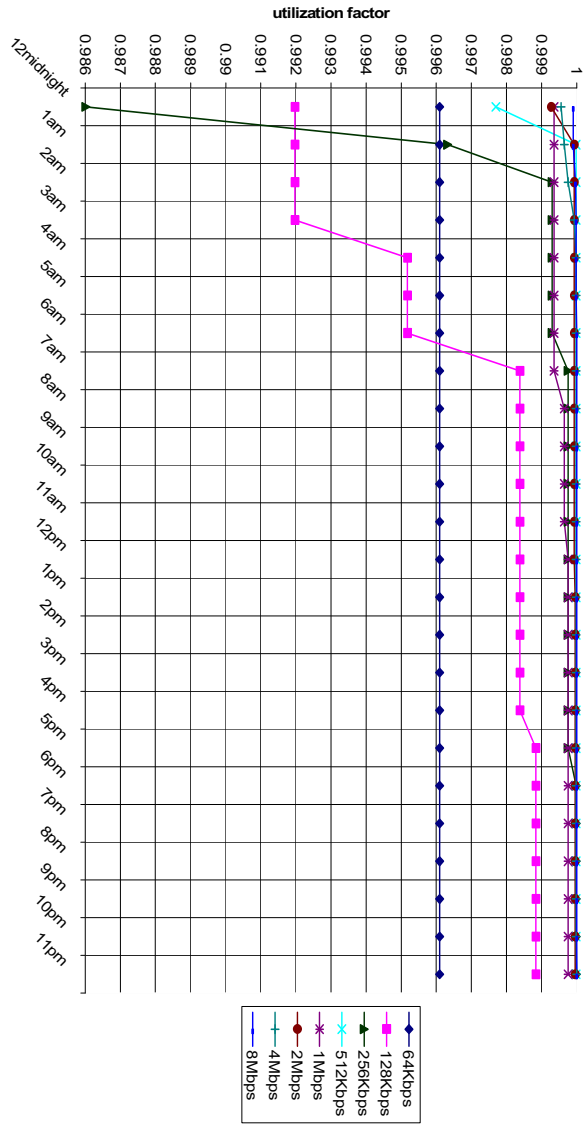

FIGURE 5: DAILY BANDWIDTH UTILIZATION FOR 250 NODES

INFERENCES FROM TABLES AND FIGURES

From the tables and the graphs (tables 1 - 5 and figures 1 – 5), the following inferences could be inferred for various nodes at different bandwidths.

(i) The bandwidth consumption varies randomly with time and the number of nodes. The arrival pattern portrays the peak periods to be varying among the nodes.

(ii) With 50 nodes the daily bandwidth consumption curve is fairly or approximately linear. With 150, 200 and 250 nodes it gets to a point where there is a considerable increase in the bandwidth consumption and the curve becomes non-linear. The implication is that bandwidth is wasted whenever there is no proportional increment in available nodes.

(iii) There is always a critical point in bandwidth availability at which further increase in available bandwidth (BW) did not improve the utilization factor for the nodes. In actual fact the utilization factor starts decreasing. If the cost of purchase of bandwidth is to be minimized and available bandwidth optimized, VPN must not be operated above the point.

(iv) Each node acts adaptively and optimally to the dynamics of the external environment so that the available bandwidths are shared optimally for each node despite the fact that each node behaves as a selfish node.

(v) The utilization factor can be as high as 99.99% (250 nodes @ 4096/8192kbps).

CONCLUSION

Simulation results show that if the cost of purchase of bandwidth is to be minimized and the available bandwidth optimized, the number of nodes and utility must be commensurate with the quantity of bandwidth purchased by operators of Virtual Private Network. The utilization factors were as high as ninety nine point ninety nine percent (99.99%).

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