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Predicting Internet Bandwidth in Educational Institutions using Langrage'S Interpolation

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Abstract
This paper addresses the solution to the problem of Internet Bandwidth optimization and prediction in the institution of higher learning in Nigeria. The operation of the link-load balancer which provides an efficient cost-effective and easy-to-use solution to maximize utilization and availability of internet access is extensively discussed. This enables enterprises to lease for two or three ISP links connecting the internal network to the internet. The paper also proposes the application of the Langrage's method of interpolation for the predictability of internet bandwidth in the institutions. The analysis provides a unique graphical solution of effective actual bandwidth (Mbps) and the corresponding acceptable number of internet Users ('000) in the institutions. The prediction allows us to view the actual internet bandwidth and the acceptable number of internet Users as the population of users' increases.
Keywords: Internet Bandwidth, Optimization, Link-Load Balancer, Prediction, Maximized Utilization, Availability of Internet access.

1. Introduction

Internet Bandwidth has become less available due to its high cost of subscription and economic reasons. The acquisition of adequate internet bandwidth has a lot of benefits. An institution or organization without an adequate amount of bandwidth can see unexpected drains due to unsanction (peer-to-peer file sharing) and sanctioned (on-line video meetings) network usage. Several institutions experienced an unpleasant experience due to improper bandwidth management for over three months in the last three years. The internet access became slow because of poor and inadequate bandwidth. Hence, to control access to limited network resources, in such situation bandwidth management or network provisioning is a critical issue. Whichever IP version we are using does not determines how much control we have over our bandwidth. It has been established that IPV6 will provide many more native bandwidth controls but IPV4 requires the installation of extra software or network devices to manage IP traffic.

There are a number of ways to control bandwidth but they sometimes have drawbacks. One way is to set priorities based on origin and address, but this often does not solve the problem as systems handle multiple kinds of data and network bandwidth managers which work best when they look inside a packet to figure out what protocol is being used (Kurose, 2000). Gating is another method which works by holding packets based on a priority scheme. This is accomplished at the device level where most of the devices involved act as routers or bridges between internal and external traffic, with best placement inside the firewall and inside the router.

The other option is to purchase a product to help control network traffic. Among the many products in this area are: Allot NetEnforcer, Packeteer Packshaper, Checkpoint Floodgate–1, Solaris Bandwidth Manager among others. Good products of this type analyze the network traffic; it tells what is going on within the network and allows us to create policies for the management of traffic – a quality of service (QoS) approach. However, it is a good idea to pick a product that is not only able to identify traffic in terms of type, but can apply a policy approach that controls traffic by applications, user and group as well as offering many of the properties of a sniffer to identify which logical connections are the most heavily used. Many of these utilities provide traffic compression to enhance network throughput in addition to centralized management and control. This work is arranged as follows: Section 2 reviews the effective Internet Bandwidth prediction and other numerical applications by experts in Information and Computer Technology. Section 3 addresses one of the best ways of achieving Internet Bandwidth optimization. In section 4 and 5, the Langrage's Interpolation was used to predict the Effective Internet Bandwidth and the Acceptable Number of internet users. Finally, Section 6 analyses the conclusion of the calculations and results obtained.

2. Literature Reviews

In order to provide quality of service (QoS) guarantees while achieving an acceptable level of internet bandwidth utilization, integrated networks often employ the concept of effective bandwidth in call admission control (CAC) and service scheduling (Elwalid, 1993) and (Guerin, 1991). Significant research has been done on the notion of effective internet bandwidth prediction over wire line networks (Elwalid, 1993), (Guerin, 1991), (Choudhury, 1996), (Gibbens, 1991) and (Kelly, 1991).

Guerin et al proposed an approximate expression for the effective bandwidth of both individual and multiplexed connections, arguing that this approximation is necessary for real-time internet network traffic control (Guerin, 1991).

Elwalid and Mitra studied the effective bandwidth for general Markovian traffic sources (Elwalid, 1993). Elwalid et al proposed an approximation for the packet-loss rate (PLR) at a statistical multiplexer using a hybrid Chernoff-dominant eigenvalue (CDE) approach (Elwalid, 1995). The research on effective internet bandwidth has generally been addressed in the context of high-speed (wired) asynchronous transfer mode (ATM) networks. Recently, Mohammadi et al extended the concept of effective bandwidth predictability to wireless ATM networks (Mohammadi, 1997).

3. Internet Bandwidth Optimization

Today, internet connectivity and reliability is the heart of every business operation. The campus environment is even of paramount importance than any other establishment. Establishments rely on it to run mission-critical business applications that drive productivity and profits. Campuses rely on it to promote academic knowledge and intellectualism. Actually, internet access is no longer a luxury, but a critical component of the overall network infrastructure that must be highly reliable and always available (Kurose, 2000).

Link- load balancing provides an efficient cost-effective and easy-to-use solution to maximize utilization and availability of internet access while minimizing cost. To improve reliability of internet access, many enterprises lease two or three ISP links connecting the internal network to the internet. One of the links acts as a backup while the primary link is being utilized. This solution improves reliability by providing backup capacity for use during ISP link failure. This mode of internet connectivity is popularly known as multi-homing. However, it does not maximize utilization of all available capacity. Additionally, fail over to the backup link after primary link failure is disruptive to the traffic and affects application performance if it is not automated. This is illustrated in Fig. 1 below.

One alternative to keeping backup links idle is the use of Border Gateway Protocol (BGP) which supports the ability to utilize multiple ISP links simultaneously with multi-homing. But BGP is complex to manage and requires special expertise and active co-operation of the ISPs. In spite of the complexity and the challenges, BGP does not provide an efficient solution. There is no mechanism is BGP to optimize utilization on all the links and to effectively balance the load between in-bound traffic flows. Also, lack of client connection knowledge and slow convergence cause application-level disruptions during link failure for establishment like the University campuses that want to avoid the challenges of BGP routing without the wastefulness of idle backup ISP link, link load balancing offers a powerful solution with quick return on investment. Link-load balancers balance in-bound and out-bound traffic efficiently among all available ISP links using intelligent traffic management. Links are selected using load-balancing methods based on critical performance metrics- such as bandwidth limit, link weight, bandwidth cost and ISP pricing model- which have a direct positive impact on the business.

Institutions no longer have to rely on low-risk, high-cost ISP services to provide reliability. They can aggregate bandwidth of multiple links from different ISPs which do not only reduce cost but also improves overall reliability and availability of access.

Because all the links are utilized simultaneously, failure risk associated with any one link is completely eliminated. Losing a link merely results in reduced bandwidth and not in the loss of access availability and performance. Applications are fully transparent to link failures and restoration, and continue operating, though with changed bandwidth capacity (Kurose, 2000).

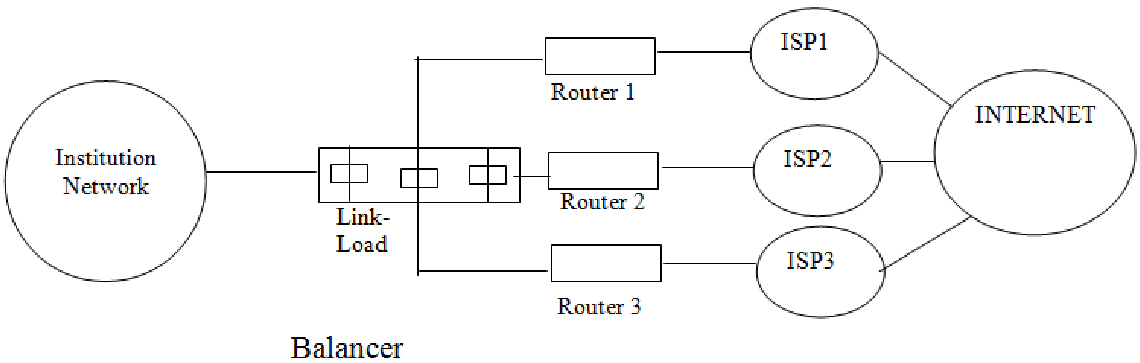

Fig. 1 An institution using a Link-load Balancer

Link load balancers use intelligent checks to monitor the health and performance of ISP links and dynamically switch traffic to healthier and better performing links. Some application products use the physical state of "next –hop" link to determine the health of ISP links. More advanced link-load balancers feature sophisticated health checks beyond the next hop link and use end-to-end proximity measures and service response time to determine the best link to service any given application transaction. In bandwidth optimization, network and application security is a critical enterprise need. Therefore, link-load balancers are ideally positioned at the intersection of the internal and external network to provide security. Using source Network Address Translation (NAT) forces return traffic to use the same ISP link as forward traffic for session persistence and consistent performance. Source NAT provides security by allowing internal network addresses to be private and completely invisible to external users. Additionally, some link load balancers use their layer 4-7 network and application intelligence to thwart Denial of service attacks by blocking traffic from malicious clients without adversely impacting performance for legitimate clients.

As institutions and Enterprises deploy link-load balancers to remove performance bottlenecks and weak "links" from their Internet access infrastructure, it is important to ensure that link load balancers do not become single points of failure. Products that support high-availability (HA) configuration deliver a fully fault- tolerant solution that is highly appropriate for an enterprise's mission-critical needs. In the HA mode, two link-load balancers operate as Active and standby, with session synchronization and transparent sub-second failover. When one device fails, there is no impact to existing connections, because the other device becomes operational with full knowledge of all existing connections and continues servicing application traffic (Kurose, 2000).

4. **Internet Bandwidth Prediction**

The data tables below shows the number of Internet Users of some institutions of higher learning in Nigeria up to the year 2012.

A. University of Lagos

Table 1: Total Number of Internet Users

UNIVERSITY OF LAGOS, YABA.	TYPE OF INTERNET USER	NUMBER OF INTERNET USERS
Unilag MBA Executive Complex, Yaba.	Academic staff Non-Academic Student	40 30 930
LUTH, Unilag , Idi-Araba, Surulere.	Academic Staff Non-Academic	1,400 3,600
Unilag Campus , Akoka, Yaba.	Academic Staff Non- Academic Student	2,450 4,950 7,600
Total Number of Internet users		21,000

The data table above was obtained when the operational ISP internet bandwidth is 80Mbps. From the measured numeric records of the institution, it shows that the campus has the following data analysis in table 2 below.

Table 2: Actual Bandwidth versus Acceptable Number of Internet Users

Year	Acceptable Number of Internet users	Actual Bandwidth
2009	9,000	60Mbps
2010	14,000	70Mbps
2011	19,000	80Mbps

B. Yaba College of Technology

Table 3: Total Number of Internet Users

YABA COLLEGE OF TECHNOLOGY, YABA.	TYPE OF INTERNET USER	NUMBER OF INTERNET USERS
Yabatech Campus, Yaba.	Academic staff Non-Academic Student	1.400 1,600 3,000
Total Number of Internet users		6,000

The data table above was obtained when the operational ISP internet bandwidth is 35Mbps. From the measured numeric records of the institution, it shows that the campus has the following data analysis in table 4 below.

Table 4: Actual Bandwidth versus Acceptable Number of Internet Users

Year	Acceptable Number of Internet users	Actual Bandwidth
2010	3,500	25Mbps
2011	4,500	30Mbps
2012	5,500	35Mbps

5. Results and Calculations

A. Internet Bandwidth Prediction for University of Lagos, Yaba

In three years, we have three measured data points from the SNMP and Solaris Bandwidth Manager Program installed on the Internet Server which can be interpolated so as to predict the effective actual Bandwidth for the Internet access in the entire campus community. Let x_i represents the Acceptable number of Internet users ('000) and F(xi) represents the Actual Bandwidth (Mbps).

The data table is shown in Table 5 below:

Table 5: Actual Bandwidth with Acceptable Number of Internet Users

X_i('000)	F(xi) (Mbps)
9.00	60
14.00	70
19.00	80

Using Lagrange's interpolation Polynomial in (Stroud, 2003) on the three data points available, we have $P_n(x) = L_o(x_o)f(x_o) + L_1(x_1)f(x_1) + L_2(x_2)f(x_2)$

Where,

$$L_o(x_o) = \frac{(x - x_i)(x - x_2)}{(x_O - x_i)(x_O - x_2)}$$

$$L_1(x_1) = \frac{(x - x_i)(x - x_2)}{(x_1 - x_O)(x_1 - x_2)}$$, and $$L_2(x_2) = \frac{(x - x_i)(x - x_1)}{(x_2 - x_O)(x_2 - x_1)}$$

From the available data points,

$$L_0(x_0) = \frac{(x-14)(x-19)}{(9-14)(9-19)}$$, $$L_1(x_1) = \frac{(x-9)(x-19)}{(14-9)(14-19)}$$ and

$$L_2(x_2) = \frac{(x-14)(x-14)}{(19-9)(19-14)}$$

At this junction, we can now obtain values for the expected number of internet users and the corresponding effective actual Bandwidth. For 20,000 internet users, the corresponding effective Actual Bandwidth will be calculated as follows:

$$P_n(20) = L_o(x_o)f(x_o) + L_1(x_1)f(x_1) + L_2(x_2)f(x_2)$$

$$= \frac{(20-14)(20-19)\ (60)}{(9-14)(9-19)} + \frac{(20-9)(20-19)\ (70)}{(14-9)(14-19)} + \frac{(20-9)(20-14)\ (80)}{(19-9)(19-14)}$$

$$= \frac{(6)(1)\ (60)}{(-5)(-10)} + \frac{(11)(1)\ (70)}{(5)(-5)} + \frac{(11)(6)\ (80)}{(10)(5)}$$

= 7.2 - 30.8 + 105.6

:.P_n (20) = 82 Mbps

For 25,000 Internet users, the corresponding effective actual bandwidth will be evaluated as follows:

$$P(25) = \frac{(25-14)(25-19)\ (60)}{(9-14)(9-19)} + \frac{(25-9)(25-19)\ (70)}{(14-9)(14-19)} + \frac{(25-9)(25-14)\ (80)}{(19-9)(19-14)}$$

$$= \frac{(11)(6)\ (60)}{50} - \frac{(16)(6)\ (70)}{25} + \frac{(16)(11)\ (80)}{50}$$

= (1.32) (60) - (3.84) (70) + 3.52(80)

= 79.2 - 268.8 + 281.6

:.P_n (25) = 92Mbps
Further calculations show that:
$P_n(30)$ = 102Mbps , $P_n(35)$= 112Mbps, $P_n(40)$ =122Mbps,
$P_n(45)$ = 132Mbps, $P_n(50)$ =142Mbps, $P_n(55)$ =152Mbps,
$P_n(60)$ =162Mbps and P_n (65) =172Mbps
The new table is shown below:
Table 6: Interpolated Bandwidth with Number of Internet Users

Xi ('000)	F (xi) (Mbps)
9.00	60
14.00	70
19.00	80
20.00	82
25.00	92
30.00	102
35.00	112
40.00	122
45.00	132
50.00	142
55.00	152
60.00	162
65.00	172

The graph of the interpolated Actual Bandwidth and the corresponding Acceptable number of internet users is shown below:

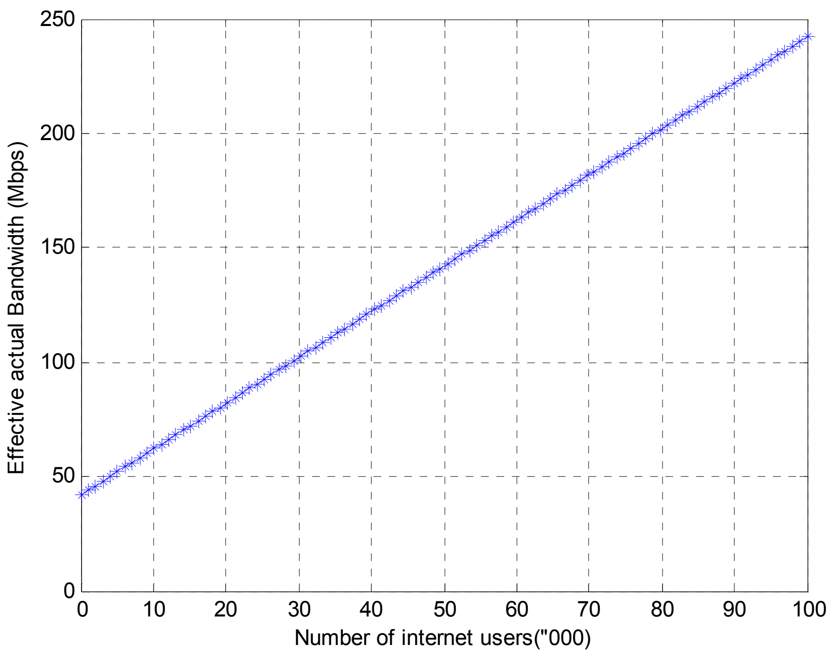

Fig 2: Graph of Effective Actual Bandwidth Vs Acceptable Number of Internet Users in University of Lagos, Akoka, Yaba. LAGOS.

In this graphical representation above:
We represent Effective Internet Bandwidth (Mbps) as B and the Number of Acceptable Internet Users ('000) as U. Mathematically; we have the relation governing the two parameters as shown below:

$$B = mU + C_0 ,$$

Where, m = The gradient of the straight line and
C_0= The Starting Internet Bandwidth.
Also, m = ΔB/ΔU = (122 – 82)/(40 – 20) = 40/20 =2. Therefore,

$$B = 2U + C_0$$

From the graph, C_0 = 42 Mbps.
The final relation could be written as

B = 2U + 42 ………………. (1)

The equation (1) above governs the relationship between the Effective Internet Bandwidth (B) and Number of Acceptable Internet Users (U) in the University of Lagos, Yaba, Lagos, Nigeria.

B . Internet Bandwidth Prediction for Yaba College of Technology, Yaba

In three years, we have three measured data points from the SNMP and Solaris Bandwidth Manager Program installed on the Internet Server which can be interpolated so as to predict the effective actual Bandwidth for the Internet access in the entire campus community. Let x_i represents the Acceptable number of Internet users ('000) and F(xi) represents the Actual Bandwidth (Mbps).

Table 7: Actual Bandwidth with Acceptable Number of Internet Users

X_i('000)	F(xi) (Mbps)
3.50	25
4.50	30
5.50	35

Using Lagrange's interpolation Polynomial in [9] on the three data points available, we have $P_n(x) = L_o(x_o)f(x_o) + L_1(x_1)f(x_1) + L_2(x_2)f(x_2)$

Where,

$$L_o(x_o) = \frac{(x - x_i)(x - x_2)}{(x_O - x_i)(x_O - x_2)}$$

$$L_1(x_1) = \frac{(x - x_i)(x - x_2)}{(x_1 - x_O)(x_1 - x_2)} \quad \text{and} \quad L_2(x_2) = \frac{(x - x_i)(x - x_1)}{(x_2 - x_O)(x_2 - x_1)}$$

From the available data points,

$$L_0(x_0) = \frac{(x - 4.5)(x - 5.5)}{(3.5 - 4.5)(3.5 - 5.5)} \quad , \quad L_1(x_1) = \frac{(x - 3.5)(x - 5.5)}{(4.5 - 3.5)(4.5 - 5.5)} \quad \text{and}$$

$$L_2(x_2) = \frac{(x - 3.5)(x - 4.5)}{(5.5 - 3.5)(5.5 - 4.5)}$$

At this junction, we can now obtain values for the expected number of internet users and the corresponding effective actual Bandwidth. For 6,500 and 7,500 internet users, the corresponding effective Actual Bandwidth will be calculated as follows:

$$P_n(6.5) = L_o(x_o)f(x_o) + L_1(x_1)f(x_1) + L_2(x_2)f(x_2)$$

$$= \frac{(6.5-4.5)(6.5-5.5)\ (25)}{(2)} + \frac{(6.5-3.5)(6.5-5.5)\ (30)}{(-1)} + \frac{(6.5-3.5)(6.5-3.5)\ (35)}{(2)}$$

$$= \frac{(2)(1)\ (25)}{(2)} + \frac{(3)(1)\ (30)}{(-1)} + \frac{(3)(2)\ (35)}{(2)}$$

= 25 - 90 + 105

:.P_n (6.5) = 40 Mbps

$$P_n(7.5) = L_o(x_o)f(x_o) + L_1(x_1)f(x_1) + L_2(x_2)f(x_2)$$

$$= \frac{(7.5-4.5)(7.5-5.5)\ (25)}{(2)} + \frac{(7.5-3.5)(7.5-5.5)\ (30)}{(-1)} + \frac{(7.5-3.5)(7.5-3.5)\ (35)}{(2)}$$

$$= \frac{(3)(2)\ (25)}{(2)} + \frac{(4)(2)\ (30)}{(-1)} + \frac{(4)(3)\ (35)}{(2)}$$

= 75 - 240 + 210

:.P_n (7.5) = 45 Mbps

Further calculations show that:

P_n(8.5) = 50Mbps , P_n(9.5)= 55Mbps, P_n(10.5) =60Mbps,
P_n(11.5) = 65Mbps, P_n(12.5) =70Mbps, P_n(13.5) =75Mbps,

$P_n(14.5)$ =80Mbps and $P_n(15.5)$ =85Mbps
The new table is shown below:
Table 8: Interpolated Bandwidth with Number of Internet Users

Xi ('000)	F (xi) (Mbps)
3.50	25
4.50	30
5.50	35
6.50	40
7.50	45
8.50	50
9.50	55
10.50	60
11.50	65
12.50	70
13.50	75
14.50	80
15.50	85
16.50	90

The graph of the interpolated Actual Bandwidth and the corresponding Acceptable number of internet users is shown below:

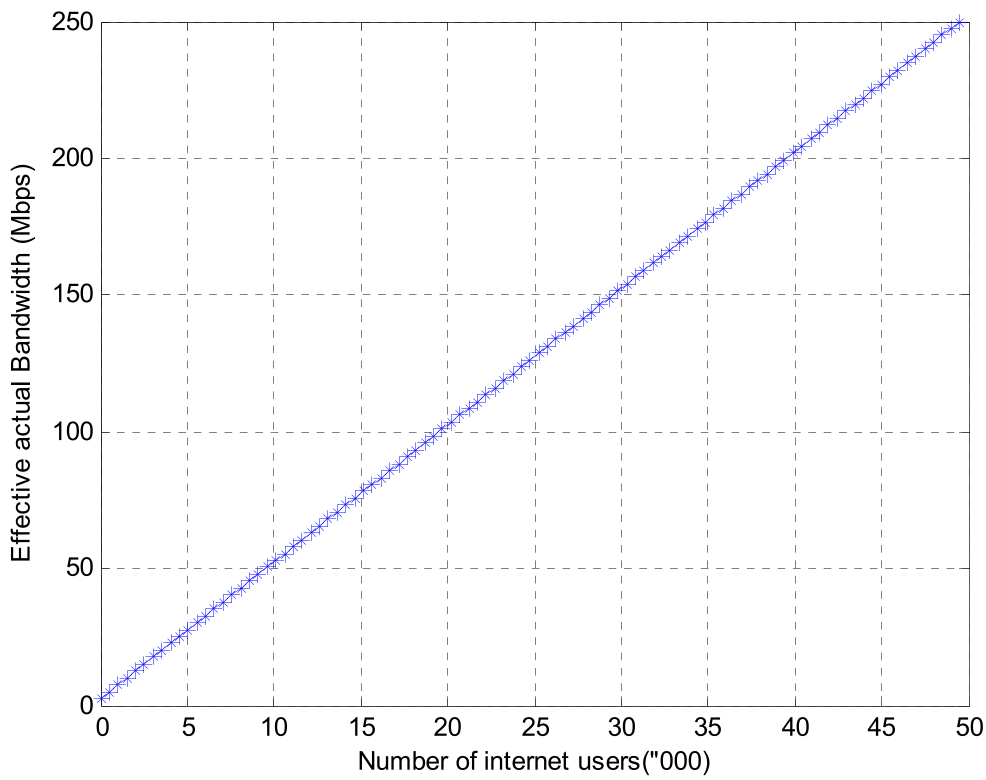

Fig 3: Graph of Effective Actual Bandwidth Vs Acceptable Number of Internet Users in Yaba College of Technology, Yaba. LAGOS.

In this graphical representation above:
We represent Effective Internet Bandwidth (Mbps) as **B** and the Number of Acceptable Internet Users ('000) as **U**. Mathematically; we have the relation governing the two parameters as shown below:

$$B = mU + C_1 ,$$

Where, m = The gradient of the straight line and
C_1= The Starting Internet Bandwidth.
Also, $m = \Delta B/\Delta U = (55 - 25)/(9.50 - 3.50) = 30/6 = 5$. Therefore,

$$B = 5U + C_1$$

From the graph, $C_1 = 7.5$ Mbps.

The final relation could be written as

$$B = 5U + 7.5 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The equation (2) above governs the relationship between the Effective Internet Bandwidth (B) and Number of Acceptable Internet Users (U) in the Yaba College of Technology, Yaba, Lagos. Nigeria.

5. Conclusion

In this paper, the method of Internet Bandwidth optimization known as Link-Load Balancing proved to be an effective way of maximization of utilization and availability of internet access. The Langrage's method of interpolation stands out to be one of the best means of predicting Internet Bandwidth and the acceptable number of Internet Users in a campus-based environment (Cherry, 2004). The graphical representation allows us to view and evaluate the effective actual internet bandwidth and the corresponding acceptable number of Internet Users as the population of user's increases.

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