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Comparative Study of IP Backbone Network Modeled Optimally and through Bandwidth Overprovision

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ABSTRACT: *Due to high traffic variability and significant contribution to CAPEX and OPEX, and expected high reliability, it is no longer practical to construct IP backbone networks by connecting many standalone components without careful planning and design as it is commonly done with the bandwidth overprovision approach. Innovation is required to support growth and proliferation of services and devices while enabling greater efficiencies that drive consolidation and reduction in costs. In this paper, a comparative study on the optimally designed and bandwidth overprovision models of IP backbone network is carried out. Both models were developed by a combination of proper traffic model selection and analysis, and the use of computer modelling and simulating tools in the framework of a doctoral thesis. Riverbed Modeler was first used to optimally design the IP backbone network topology for Benue State in Nigeria. Then, the topology of the IP backbone network was developed based on the generic bandwidth overprovision model and converted into a simulation model also in the Riverbed modeler environment. Then the generalities of the two models were used to perform comparative analyses of the optimally designed model against the bandwidth overprovision model. The results of the study verified that the bandwidth overprovision model is predisposed to inefficient utilization of bandwidth and network resources. This leads to the conclusion that IP backbone networks need to be designed optimally instead of the bandwidth overprovision approach.*

Keywords – *Optimally Designed Model, Bandwidth Overprovision Model, IP Backbone Network, Riverbed Modeler, Topological Characteristics, Performance Characteristics*

I. INTRODUCTION

The IP backbone network is the most important architectural element for building large enterprise networks. It is the root of the network tree that has the rest of the network growing from it and it is responsible for transporting large amount of data very fast and reliably [1], [3]. The purpose of the IP backbone network is to connect regional distribution networks and, in some instances, provide connectivity to peer networks [1]-[3]. The backbone network is made up of routers and switches and the transmission links that interconnect them. There are many important issues regarding the optimal design of IP backbone networks cutting across reliability, cost-effectiveness, scalability and manageability. For these objectives to be realized, there is the need for considerable thought and planning to be put into the design and implementation of the IP backbone network. The following are among the prominent contending issues for designing an IP backbone network optimally.

1.1. Estimation of Network Traffic

Traffic modelling is the most contentious and key element in the design and simulating of communication networks [4], [5]. A clear understanding of the nature of traffic in the target system and subsequent selection of an appropriate random traffic model are critical to the success of design of the system [4]. Effective performance evaluation requires that special care be taken in modelling telecommunications traffic and the corresponding demands for network resources [4].

1.2. The Topology

There are two main types of IP backbone network topologies. These are hierarchical and flat backbone models [3]. The choice between these two types of networks must be carefully made as it dictates the type of routing protocol and creation of the overall network architecture. Another subset of network topology includes full-mesh and partial-mesh topologies. The choice between these two topologies should also be made carefully in order to avert significant capital and operational expenses [3].

1.3. The Wide Area Network (WAN) Technology

The type of WAN technology used has important implications on both cost and quality of service.

1.4. Routers

The routers used in the network should be versatile and support multiple routing protocols. The routers should also support the required WAN technology and WAN links and must be scalable [6].

1.5. Data Network Requirements Analysis

This is relatively a new art [7]. State-of-the art software tools have been developed for laboratory (computer) based network modelling and simulation. Given the complexity that modern data networks have attained, a design is not complete until it has been verified in the laboratory [6].

Bandwidth over-provisioning is one of the most commonly used approaches for the design of IP backbone networks [8]. Bandwidth over-provisioning is commonly used to protect network performance against traffic variations. It typically involves dimensioning links so that their bandwidth exceeds the expected traffic load by large margins, to ensure that the link can absorb both expected and unexpected traffic fluctuations [5], [8]. A major reason for use of the bandwidth overprovision method is the apparent difficulty involved in the estimation of the traffic matrix [5], [8]. This, more than anything else, has raised serious doubts about this traditional approach as a veritable choice for the optimum design of IP backbone networks as traffic is fundamental to the design of any telecommunications network. It thus becomes necessary to conduct a comparative study on the optimally designed and bandwidth overprovision models of the IP backbone network developed for Benue State in Nigeria. Both models were developed by a combination of proper traffic model selection and analysis, and the use of computer modelling and simulating tools in the framework of a doctoral thesis [9]. This study assumes the methodologies for data collection, traffic analysis and estimation of the traffic parameters as reported in [10]. Also assumed is the use of Riverbed (OPTNET) Modeler for the development, simulation and performance analysis of the optimally designed model as reported in [11] and [12] respectively. The bandwidth overprovision topology of the IP backbone network was developed based on the generic bandwidth overprovision model and converted into a simulation model also in the Riverbed modeler environment. Then the generalities of the two models were used to perform comparative analyses of the optimally designed model against the bandwidth overprovision model. The results of the study verified that the bandwidth overprovision model is predisposed to inefficient utilization of bandwidth and network resources.

The rest of the paper is organized as follows: Section 2 discusses the reasons for bandwidth overprovision. This is followed by a discussion in section 3 on the development of the optimally designed IP backbone network model. In section 4, the development of the bandwidth overprovision IP backbone network model is presented. The models' comparison by topological characteristics is presented in section 5; while section 6 deals with the models' comparison by performance characteristics. Lastly in section 7 is the conclusion.

II. REASONS FOR BANDWIDTH OVERPROVISION

The main challenges that service providers face are to reduce costs, and to enable new value-added services that were previously not possible [5], [13]. The traffic explosion in the backbone network comes in unpredictable volumes, characteristics, and patterns [13]. Yet the network operator must design for low congestion over the multiple years that the network is in operation. Harder still, the network must be designed to work well under a variety of link and router failures. Furthermore, obtaining a traffic matrix is a very difficult task; it is impractical to measure it directly, and the best techniques from link load measurements give errors of 20% or more [5]. For these reasons, most networks today are enormously overprovisioned, with typical utilizations around 10% [5].

In [14], the authors noted that many organizations engaged in overprovision of bandwidth for IP backbone network design either have little or no data about their current or future traffic matrices. They stated clearly that, many engineers who manage IP networks expand their networks by simply observing link loads. When a link load exceeds some threshold, they add more capacity. Given no knowledge or high uncertainty of the true, stochastic traffic matrix, this may be a reasonable approach. However, network failures and their subsequent restorations are the phenomena that cause the greatest challenges with such a simple approach [14]. Because of the extensive rerouting that can occur after a network failure, there is no simple or intuitive parameter to determine the utilization threshold for each link [14].

The foregoing illustrates that network engineers and services providers resort to the use of overprovision of bandwidth in the design of IP backbone networks largely due to the difficulty involved in the estimation of the traffic matrix for the differentiated IP based next generation network services. Thus the overprovision of bandwidth is done arbitrary aimed at pre-empting the congestion caused by unpredictable traffic variations and combating the inevitable network failures and services disruptions.

III. DEVELOPMENT OF THE OPTIMALLY DESIGNED IP BACKBONE NETWORK MODEL

The development of the optimally designed IP backbone network model used for this study assumes the procedures for data collection, traffic analysis and estimation of the traffic parameters, and topology design as reported in [10]. Also assumed is the use of Riverbed (OPTNET) Modeler for the development, simulation and performance analysis of the optimally designed model as reported in [11] and [12] respectively. Figure 1 shows the topology of the optimally designed IP backbone network as configured and simulated in Riverbed Modeler environment [3].

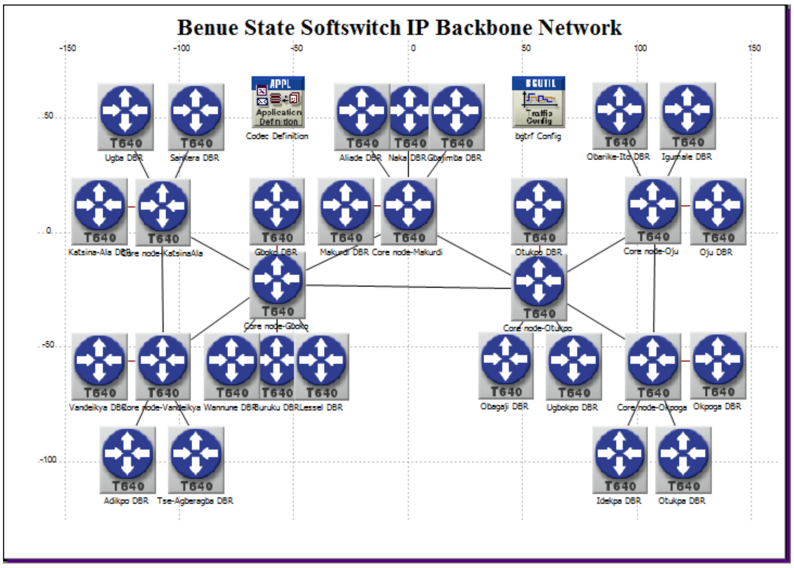


Figure 1. Topology of the optimally designed IP backbone network as configured and simulated in Riverbed Modeler

IV. DEVELOPMENT OF THE BANDWIDTH OVERPROVISION IP BACKBONE NETWORK MODEL

The topology for the bandwidth overprovision model was configured and converted into a simulation model in Riverbed Modeler environment using the same technicalities as for the optimally designed model [11]. The topology is based on the generic bandwidth overprovision network model which is shown in Figure 2 [5], [8**]**. The consistency in the use of the same technicalities is to preserve the QoS and cost optimization objectives already achieved for the design of the optimally designed model. For example, the same VoIP traffic flow matrix, router models, transmission link models and capacities, routing protocols, utility models, etc., were used for the overprovision case study as well. The major extra dimension is the complexity of the full-mesh network topology with the resultant increase in the number of the core transmission links.

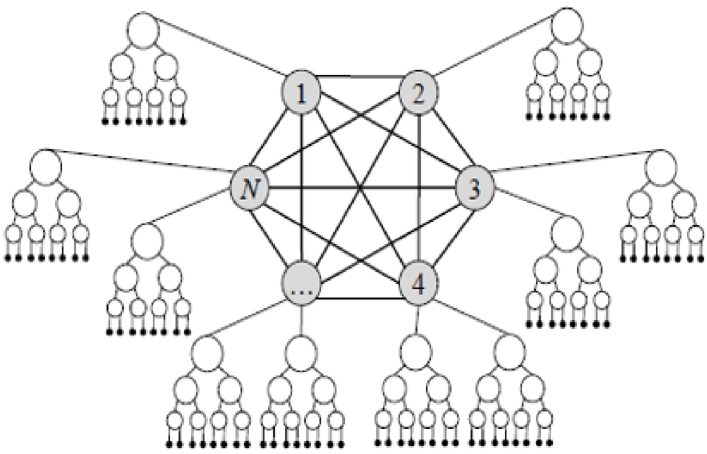


Figure 2. Generic bandwidth overprovision network model

It is worthwhile to note that the use of the Riverbed Modeler facilitates overprovisioned network analysis as it enables the instant evaluation of the model in sharp contrast to the usual practice of performing the fine-tuning only after the backbone network is operational. In this way, it is possible to discern the differences in the links utilization and packet queuing delays between the optimally designed model and the bandwidth overprovision model in the event of simulation. Thus it would be possible to draw inferences about how the cost-effectiveness and performance of the optimally designed model compares with the commonly used bandwidth overprovision model. Figure 3 shows the IP backbone network bandwidth overprovision model as developed and configured in Riverbed (OPNET) modeler environment. Figure 4 shows the bandwidth overprovision model configured with the customized traffic flow matrix in Riverbed Modeler.

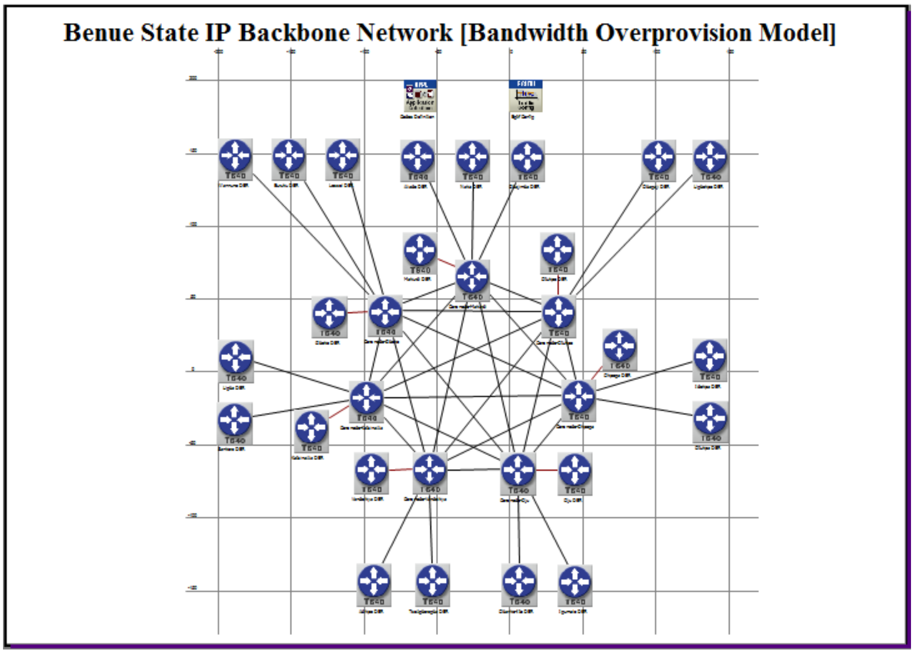


Figure 3. Bandwidth overprovision IP backbone network simulation model

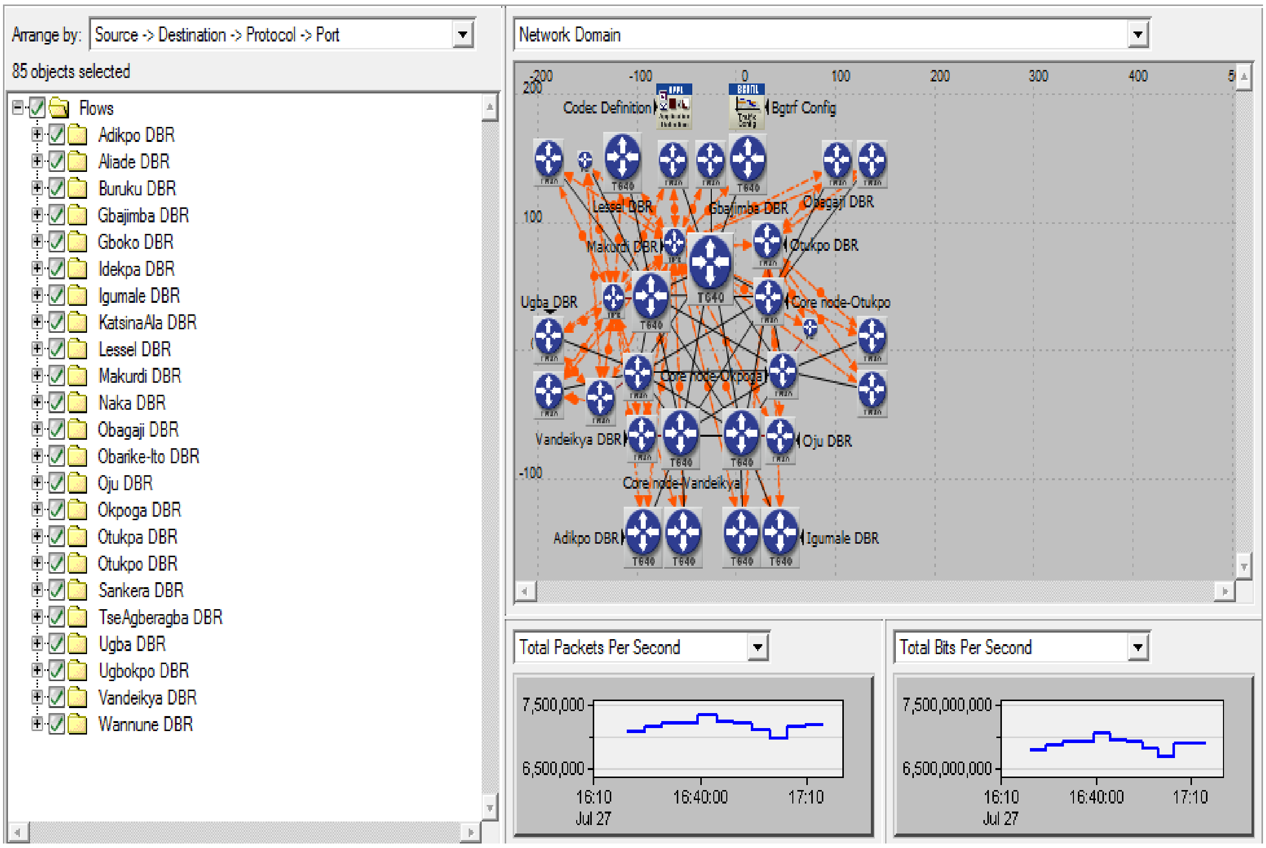


Figure 4. Bandwidth overprovision model configured with the customized VoIP traffic flow matrix

V. THE MODELS' COMPARISON BY TOPOLOGICAL CHARACTERISTICS

Table 1 shows the comparison between the optimally designed model and the bandwidth overprovision model by their topological characteristics. It can be seen that there are glaring cost implications regarding the bandwidth overprovision model. This gives a clear insight into the enormous excess amount of money that is usually incurred on the adoption of the bandwidth overprovision model. In fact the reference to the practice of bandwidth overprovision as "throwing bandwidth at the problem" is as true as "throwing money at the problem". On the other hand, the analysis has shown that the optimally designed model is the best option for designing the IP backbone network in the most cost-effective way.

Table 1. The models' comparison by topological characteristics

Description	*Optimally Designed Model*	*Bandwidth Overprovision Model*	*Remark*
Topology	Partial mesh	Full mesh	A full mesh is associated with high capital and operational costs which are linked to the large number of transmission links and associated terminal equipment. In developing countries, this could prove prohibitive due to the additional problem of negotiating numerous difficult and costly wayleaves, and support costs.
Number of Core Transmission Links	9	21	It can be seen that the installation costs would be more than double.

VI. THE MODELS' COMPARISON BY PERFORMANCE CHARACTERISTICS

Tables 2 to 5 show the comparison between the optimally designed model and the bandwidth overprovision model by their performance characteristics. The performance parameters used are the packet queuing delay and bandwidth utilization. The parameters were collated from the results of simulation of the two models as described in [3] and [4]. The significance of this comparison lies in differences between the number of utilized and unutilized core transmission links, queuing delays and bandwidth utilizations as revealed by the simulation results. The differences between the packet queuing delays and bandwidth utilizations are represented by the percentage decrease in delay and percentage underutilization respectively.

Table 2 represents the models' comparisons in respect of the number of utilized and unutilized core transmission links. It can be seen that the differences between these two elements have significant cost implications.

Table 2. The Models' Comparison by the Number of Utilized and Unutilized Core Transmission Links

Description	*Optimally Designed Model*	*Bandwidth Overprovision Model*	*Remark*
Number of core transmission links utilized	6	10	The extra number of 4 core transmission links explains the increased operational costs associated with the bandwidth overprovision model. This has serious cost implications in terms the extra transmitting/receiving equipment, generating plants, air conditioners, etc. This extra dimension also increases the processing load of the routers thereby increasing the chances of router failures escalating the maintenance costs.
Number of core transmission links not utilized	3	11	The cost of procurement and installation of 11core transmission links and associated terminal equipment is in excess and wasteful as it is non-revenue earning. The overprovisioned network is only evaluated after it is operational. That is why it is referred to as "throwing of bandwidth at the problem".

Table 3 represents the observations recorded for the Makurdi-Gboko and Makurdi-Otukpo core transmission links respectively having similar traffic characteristics. With the decrease in delay reaching up to 100% and bandwidth underutilization as high as 66%, it is clear that the links are grossly underutilized with the adoption of the bandwidth overprovision model.

Table 3. Comparison of performance characteristics for Makurdi-Gboko core transmission link

Traffic Intensity (Erlangs)	Makurdi – Gboko Core Transmission Link					
	Packet Queuing Delay (ms)			Bandwidth Utilization (%)		
	Optimally Designed Model	Bandwidth Overprovision Model	% Decrease in Delay	Optimally Designed Model	Bandwidth Overprovision Model	% Under utilization
3679	0.00007	0.00006	14	14	6	57
7358	0.00008	0.00007	13	28	12	57
11038	0.0001	0.00007	30	43	17	61
14718	0.00013	0.00008	39	56	23	60
18398	0.00022	0.00008	64	70	28	60
22078	0.0015	0.00008	95	99	34	66
25758	290	0.00009	100	100	40	60
29438	290	0.00011	100	100	46	54
33098	290	0.00012	100	100	51	49
36798	290	0.00014	100	100	58	42

Table 4 shows the comparison of the performance characteristics for the Otukpo-Oju Core transmission link. The results also represents the Otukpo-Okpoga core transmission link as both links have similar traffic characteristics and exhibited similar performance characteristics. It can be seen how significant the differences between the queuing delay and bandwidth utilization results are. Having a queuing delay reduction of 44% and bandwidth underutilization of 47% occurring at the highest traffic intensity between the optimally designed model and the bandwidth overprovision model is a clear case of avoidable underutilization of scarce resources. It means that the design methodology of bandwidth overprovision negates the efficient utilization of bandwidth that is much desired and the hallmark of IP networks.

Table 4. Comparison of performance characteristics for Otukpo-Oju core transmission link

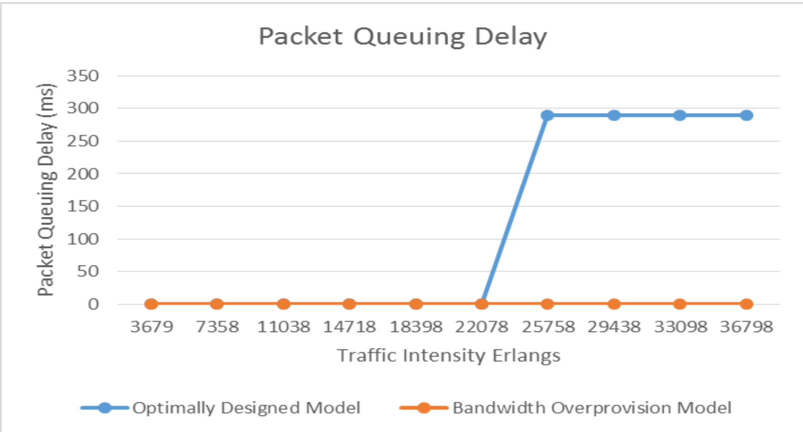
Traffic Intensity (Erlangs)	Otukpo – Oju Core Transmission Link					
	Packet Queuing Delay (ms)			Bandwidth Utilization (%)		
	Optimally Designed Model	Bandwidth Overprovision Model	% Decrease in Delay	Optimally Designed Model	Bandwidth Overprovision Model	% Under utilization
909	0.00006	0.00006	0	7	3	57
1820	0.00007	0.00006	14	14	6	57
2731	0.00007	0.00007	0	22	9	59
3642	0.00008	0.00007	13	28	13	54
4553	0.00009	0.00007	22	36	15	58
5464	0.00009	0.00007	22	43	18	58
6375	0.00012	0.00008	33	50	22	56
7286	0.00012	0.00008	33	54	24	56
8197	0.00014	0.00008	43	58	28	52
9108	0.00016	0.00009	44	60	32	47

Table 5 shows the comparison of the performance characteristics between the optimally designed and the bandwidth overprovision models representing the Gboko-Vandeikya core transmission link. It represents the Gboko-KatsinaAla core transmission link as well since both links have similar traffic patterns and exhibited similar performance characteristics. Here too, it can be seen that bandwidth is wasted with the use of the overprovision model. The differences between the packet queuing delays and bandwidth utilizations are quite clear; the percentage underutilization rises up to the highest value of 53% at 100% of the modelled base traffic (i.e. 3049 Erlangs). The percentage decrease in packet queuing delay is also quite high (50%) even at the highest traffic point. This leads to the conclusion that IP backbone networks need to be optimally designed as exemplified in [3] instead of the bandwidth overprovision approach.

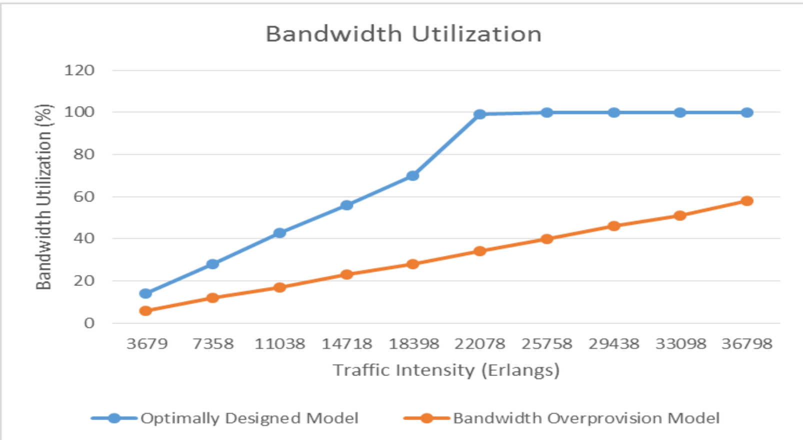
Table 5. Comparison of performance characteristics for Gboko-Vandeikya core transmission link

Traffic Intensity (Erlangs)	*Gboko – Vandeikya Core Transmission Link*					
	Packet Queuing Delay (ms)			*Bandwidth Utilization (%)*		
	Optimally Designed Model	*Bandwidth Overprovision Model*	*% Decrease in Delay*	*Optimally Designed Model*	*Bandwidth Overprovision Model*	*% Under utilization*
609	0.00006	0.00006	0	8	4	50
1219	0.00007	0.00007	0	16	8	50
1829	0.00008	0.00007	13	24	12	50
2439	0.00009	0.00007	22	33	16	52
3049	0.0001	0.00007	30	40	19	53
3659	0.00011	0.00008	27	48	23	52
4269	0.00012	0.00008	33	54	28	48
4879	0.00014	0.00009	36	58	32	45
5489	0.00017	0.00009	47	62	35	44
6099	0.0002	0.0001	50	66	39	41

The comparison of the performance characteristics between the optimally designed model and the bandwidth overprovision model is further illustrated graphically in Figures. 5 to 7. Figures (a) represent comparison of the packet queuing delay while Figures (b) represent comparison of the bandwidth utilization. For the same reasons as earlier stated, Figure 5 represents both the Makurdi-Gboko and Makurdi-Otukpo core transmission links; Figure 6, the Otukpo-Oju and Otukpo-Okpoga core transmission links; and Figure 7, the Gboko-Vandeikya and Gboko-KatsinaAla core transmission links. Generally, it can be seen that, the graphs of the packet queuing delay and bandwidth utilization for the optimally designed model are situated above those for the bandwidth overprovision model signifying a more optimal and realistic performance for the former.



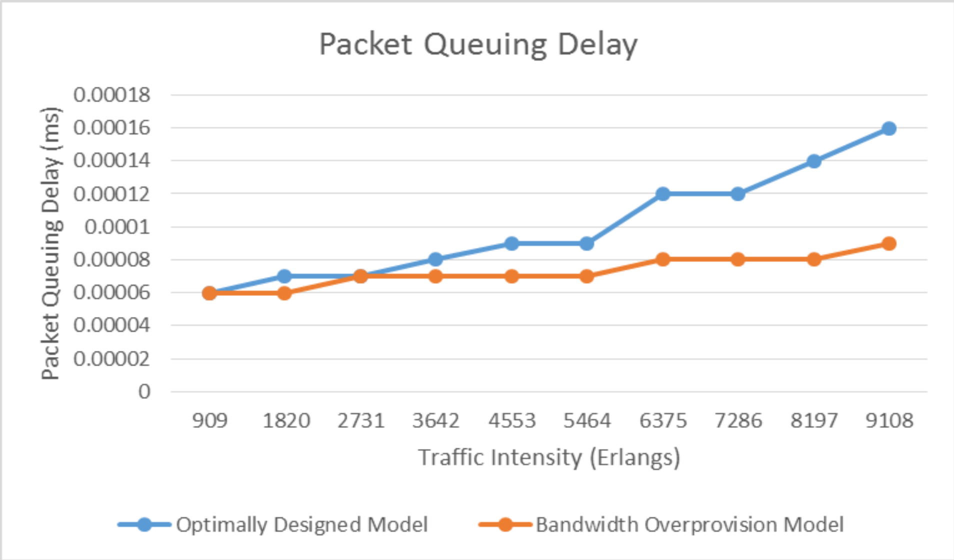
(a)



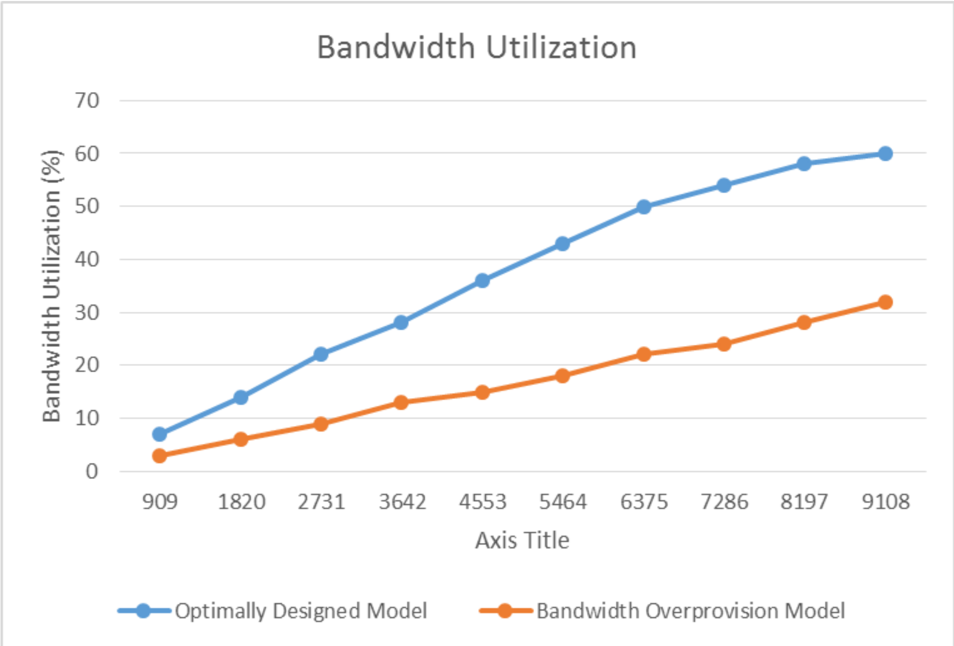
(b)

Figure 5. Graphical comparison of performance characteristics for Makurdi-Gboko core transmission link: (a) queuing delay, (b) bandwidth utilization

In Figure 5 (a), it can be seen the abrupt change in queuing delay occurring at 22078 Erlangs in the case of the optimally designed model. However, the queuing delay in the case of bandwidth overprovision model still continues at the lowest ebb up to the highest traffic point signifying an excess of bandwidth in the system. Figure 5 (b) accentuates the wide disparity between the bandwidth utilization for the two models. It can be seen that the utilization in the case of the optimally designed model is higher and even reaches overloading at the traffic of 22078 Erlangs. However, in the case of the bandwidth overprovision model, the curve moves on at low rate till the highest traffic point.



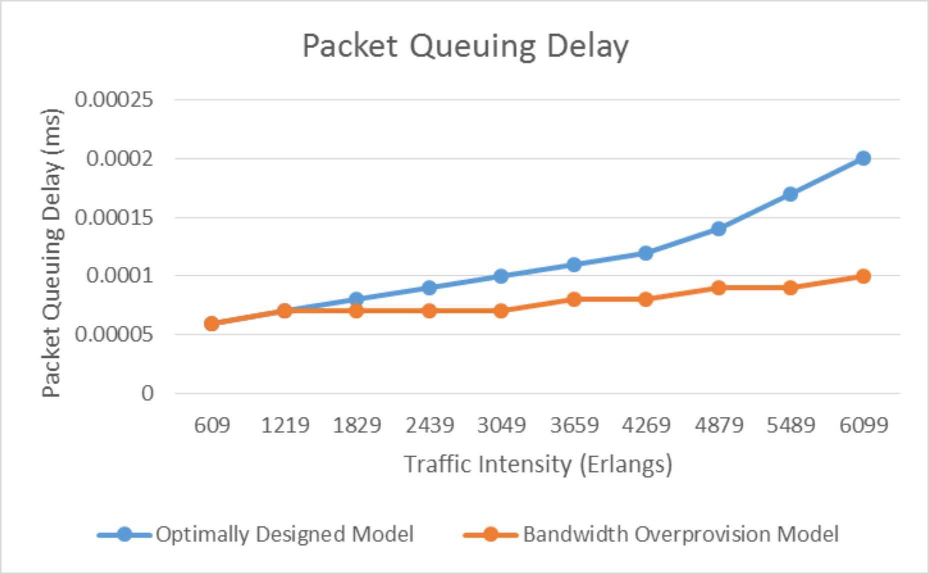
(a)



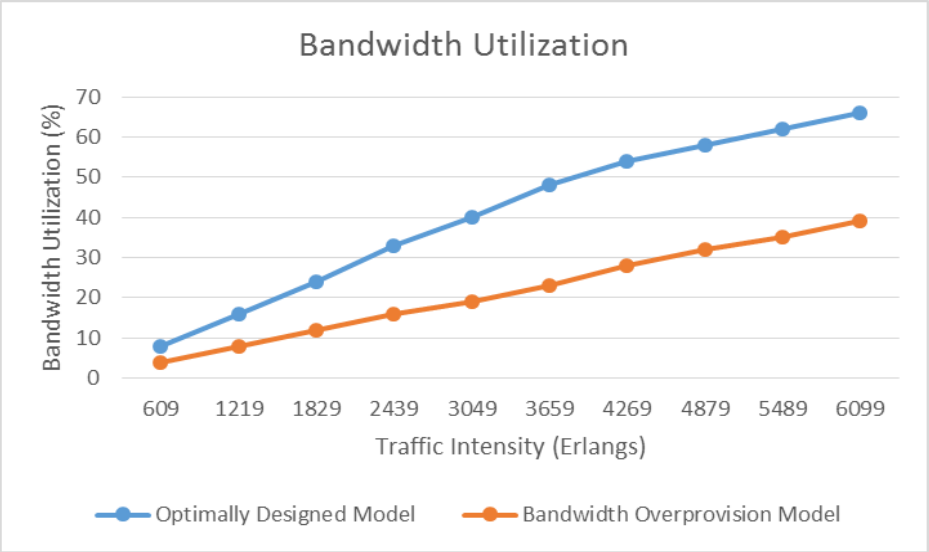
(b)

Figure 6. Graphical comparison of performance characteristics for Otukpo-Oju core transmission link: (a) queuing delay, (b) bandwidth utilization

In Figure 6 (a), the graph of the packet queuing delay in the case of the optimally designed model apart from being above that of the overprovision of bandwidth model, the gap between the two continues to widen till the highest traffic intensity with the graph of the optimally designed model becoming steeper. This is an example of a more optimum and realistic performance for the optimally designed model. Figure 6 (b) also demonstrates a similar trend. The bandwidth utilization curve for the optimally designed model lies above and at a steeper angle than that for the bandwidth overprovision model. This signifies a more efficient use of bandwidth by the optimally designed model.



(a)



(b)

Figure 7. Graphical comparison of performance characteristics for Gboko-Vandeikya core transmission link: (a) queuing delay, (b) bandwidth utilization

Figure 7 also similarly demonstrates the higher bandwidth efficiency of the optimally designed model over the bandwidth overprovision model. It can be seen that, the graphs of the packet queuing delay in Fig. 7 (a) and bandwidth utilization (Figure 7 (b)) for the optimally designed model is situated above that of the bandwidth overprovision model with their separations becoming progressively wider as the traffic intensity increases.

IV. CONCLUSION

In this paper, a comparative study is carried out on the optimally designed and bandwidth overprovision models of IP backbone network with both models developed by a combination of proper data collection and traffic analysis, and the use of computer modelling and simulating tools. The results of the comparative analyses of the optimally designed model versus the bandwidth overprovision model showed glaring inefficiencies on the part of the bandwidth overprovision model for all core transmission links. For instance, for the optimally designed model and bandwidth overprovision model respectively, the total number of core transmission links is 9 and 21; the total number of utilized core transmission links is 6 and 10; and the total number of unutilized core transmission links is 3 and 11. In terms of performance characteristics, the results also showed low efficiency on the part of the bandwidth overprovision model. On the whole, the results of the comparative performance and cost-benefit analyses of the optimally designed model versus the bandwidth overprovision model showed that the bandwidth overprovision model is predisposed to inefficient utilization of bandwidth and network resources. Thus, the method of bandwidth overprovision has been verified as not ideal for the design of IP backbone networks.

REFERENCES

[1] Byrav Ramamurthy, K.K. Ramakrshnan, Rakesh K. Sinha, "Cost and reliability considerations in designing the Next-generation IP over WDM backbone networks", Published in Computer Communications and Networks (ICCCN), Proceedings of 20th International Conference, pp 1-6, 2011

[2] Khalid Raza, Mark Turner, "CISCO Network Topology and Design", 2002. ciscopress.com/articles/article.asp?p=25188seqN=5

[3] "Introducing Network Design Concepts", www.scte.org/documents/pdf/CCNA%20Sample.pdf

[4] Victor S. Frost, Benjamin Melamed, "Traffic Modeling for Telecommunications Networks", IEEE Communications Magazine, March, 1994.

[5] Rui Zhang-Shen, "Designing a Predictable Backbone Network Using Valiant Load-Balancing", PhD Dissertation, Department of Electrical Engineering, Stanford University, June, 2007.

[6] Cormac Long, "IP Network Design, Parts 1: Fundamental Principles; Searchnetworking.techtarget.com/tip/IP-network-design, 2000-2015.

[7] Cisco, "Backbone Core Network Design – Cisco network Topology and Design", www.ciscopress.com/articles/article.asp?p=25188seqNum=5, sited 27th Nov., 2015.

[8] Yaqing Huang, Roch Gu´erin, "Does Over-Provisioning Become More or Less Efficient as Networks Grow Larger?", Dept. of Electrical & System Engineering, University of Pennsylvania, Philadelphia, USA, Work supported by NSF grants ANI-9902943 and ITR-0085930.

[9] Tarkaa S. N., Development of Optimal IP Based Backbone Network in a Developing Economy – Benue State, Nigeria, Department of Electronic Engineering, University of Nigeria, Nsukka, Thesis to obtain the Degree of Doctor of Philosophy in Electronic Engineering, 2016.

[10] Nathaniel S. Tarkaa and Cosmas I. Ani, "Modeling and characterization of next generation network: from data collection to estimation of traffic parameters", American Journal of Engineering Research (AJER) Volume-4, Issue-10, pp-167-177, 2015.

[11] Nathaniel S. Tarkaa and Cosmas I. Ani, "Design of cost-effective synthetic IP backbone network topology for a developing economy", American Journal of Engineering Research (AJER) Volume-5, Issue-7, pp-95-105, 2016.

[12] Nathaniel S. Tarkaa and Cosmas I. Ani, "Simulation and performance analysis of IP backbone network for next generation networks", International Journal of Research in Engineering and Science (IJRES), Volume 4, Issue 7, PP-23-33, 2016.

[13] Juniper Networks Inc., "Evolving Backbone Networks with an MPLS Supercore", White Paper, 2015.

[14] Robert D. Doverspike, K.K. Ramakrishan, and Chris Chase, "Chapter 2: Structural Overview of ISP Networks; Guide to Reliable Internet Services and Applications, Computer Communications and Networks", Springer-Verlay London Limited, 2010.