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Simulation andPerformance Analysis of IP Backbone Network forNext Generation Networks

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Abstract: For communication networks, developing a simulation model requires modeling random user demands for network resources; characterizing network resources needed for processing these demands; and estimating system performance based on the result of the simulation. The application of this theory in connection with the design of new systems can help in comparing different solutions and thus eliminate bad solutions at an early stage without having to build up prototypes.In this paper, a simulation model is developed specifically for performance analysis of the softswitchIP backbone network topology designed for Benue State, Nigeriawithin the frameworkof a doctoral thesis.For the purpose of the performance analysis, the modelled traffic at each of the 23 network nodeswasused to create an aggregate traffic table for the 6 core transmission links. By scaling the traffic each time by 20%, ten simulations were performed for each core transmission link using Riverbed Modeler and the results collated for average bandwidth utilization, packet queuing delay and packet loss ratio as the key performance indicators. The performances of the core transmission links were then verified by the plots of the traffic intensities versus thecollected values of the performance metrics. The results of the performance analysis clearly showed that the design of the Benue State IP backbone network satisfied the primary goals of high reliability, scalability and cost-effectiveness.The study demonstrates the effective way the Riverbed Modeler could be used for active performance analysis of IP backbone network designs for Next Generation Networks.

Keywords: Next Generation Networks,Performance Analysis, Probabilistic Traffic Model,Riverbed Modeler,Simulation Model

I. INTRODUCTION

Even the most carefully designed and operated IP network is subject to any number of performance problems ranging from overloaded links and mis-configured routers to server failures.Simulation is a key technology for the investigation of communication networks [1]. Not only is it useful for preliminary study of protocols and network applications, it can reveal unexpected system dynamics.Unlike analytical models, which often require many assumptions and are too restrictive for most real-world systems, simulation modelling places few restrictions on the classes of systems under study [1]. The generation of user demands and their satisfaction are encapsulated in simulation events, which are ordered by their time of occurrence [1]. The success of a simulation study hinges on identifying appropriate performance metrics and then devising a strategy for exploring the ensuing performance response surface [1]. For communication networks, developing a simulation model requires modeling random user demands for network resources; characterizing network resources needed for processing those demands; and estimating system performance based on output data generated by the simulation [1].

There are two basic approaches to the task of network performance evaluation; one is to collect management information from the active elements of the network using a management protocol, and from this information make some inferences about network performance [2]. This can be termed a passive approach to performance measurement in that the approach attempts to measure the performance of the network without disturbing its operation. The second approach is to use an active approach and inject test traffic into the network and measure its performance in some fashion, and relate the performance of the test traffic to the performance of the network in carrying the normal payload [2].

This paper describes the simulation and performance analysis carried out for the IP backbone Network topology designed for Benue State, Nigeria within the framework of a doctoral thesis [3] using the active approach. In this aspect, the modelled traffic at each of the 23 network nodeswas used to create an aggregate traffic table for the 6 core transmission links. By scaling the traffic each time by 20%, ten simulations were performed for each core transmission link with Riverbed Modeler and the results collated for average bandwidth utilization, packet queuing delay and packet loss ratio as the key performance indicators. The actual performances of the core transmission links were verified by the plots of the traffic intensities versus the values of the performance metrics.

The rest of the paper is organized as follows: Section 2 describes the development of the simulation model. This is followed by a discussion in section 3 of the simulation results and performance analysis. In section 4, the summary of the results are presented.Lastly in section 5 is the conclusion.

II. DEVELOPMENT OF SIMULATION MODEL

To develop the simulation model used for the performance analysis of the IP backbone network, it was necessary to make use of the same values of the modelled traffic parameters estimated in the previous work [4] and the topology designed within the frame work of the doctoral thesis [3]. The Juniper Networks' universal T640 IP router was configured for both the core nodes and edge nodes constituting the IP Layer of the backbone network. The duplex transmission links model and capacities selected and configured in the Modeler in accordance with specified standards [7] is PPP SONET as follows: Gboko – Makurdi = OC-92 (10Gbps); KatsinaAla – Gboko = OC-48 (2.5 Gbps); Otukpo – Makurdi = OC-92 (10Gbps); Oju – Otukpo = OC-48 (2.5 Gbps); Okpoga – Otukpo = OC-48 (2.5 Gbps); and Vandeikya – Gboko = OC-48 (2.5 Gbps). It represents the optical layer of the IP backbone network.Fig. 1 shows the IP backbone network as configured and simulated in Riverbed Modeler environment.

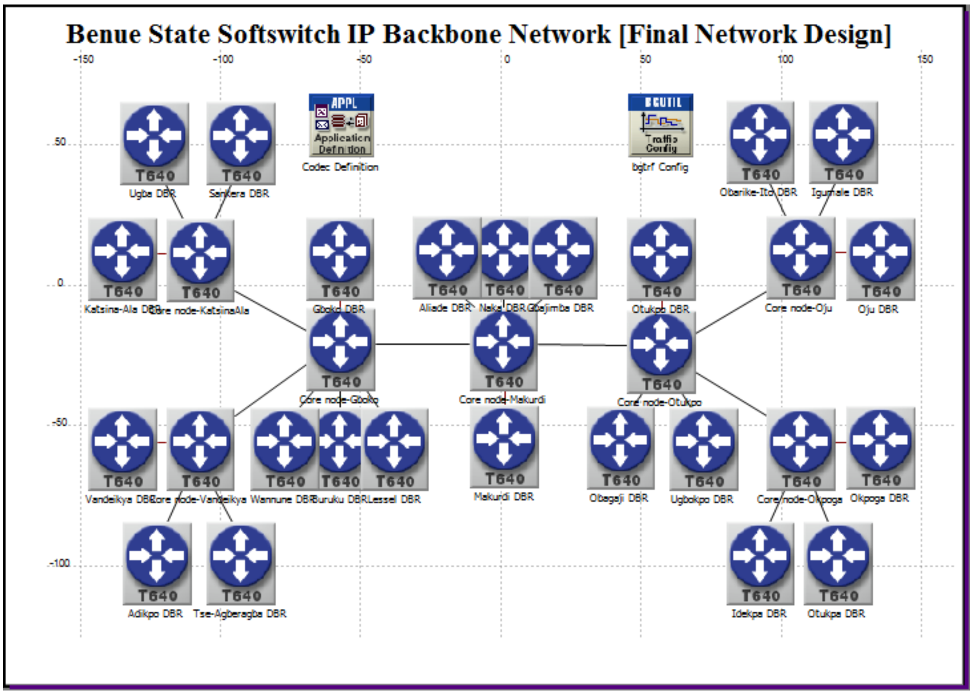


Figure 1: topology of the final design for Benue State softswitch IP backbone network

Normally, in the design of telecommunication networks, the quality of service is determined by use of the network's key performance metrics. This is usually achieved by making sure that the benchmarks set for these performance metrics are not exceeded with the offered traffic intensity. At the same time, since it is not economically viable to design for 100% network capacity, it is usually necessary to select the amount of traffic that will result in the cost-effective provision of bandwidth. For this reason, a traffic table was createdfor development of the simulation model by varyingthe values of the modelled traffic intensity estimated for 100% of the population starting from 20%.In this way, 10 set of values of the traffic were produced for each network node as presented in Table 1**.**

Table I: Traffic Table for Simulation of Benue State IP Backbone Network

S/No.	*Network Nodes*	*Traffic Intensity in Erlangs*									
1	Igumale	211	423	635	847	1059	1271	1483	1695	1907	2119
2	Obagaji	154	307	460	613	766	919	1072	1225	1378	1531
3	Ugbokpo	144	289	434	579	724	869	1014	1159	1304	1449
4	Buruku	304	610	916	1222	1528	1834	2140	2446	2752	3058
5	Gboko	1504	3007	4510	6013	7516	9019	10522	12025	13528	15031
6	Gbajimba	259	516	773	1030	1287	1544	1801	2058	2315	2572
7	Aliade	264	527	790	1053	1316	1579	1842	2105	2368	2631

8	Naka	151	300	449	598	747	896	1045	1194	1343	1492
9	Katsina-Ala	546	1091	1636	2181	2726	3271	3816	4361	4906	5451
10	Tse-Agberagba	181	364	547	730	913	1096	1279	1462	1645	1828
11	Adikpo	219	439	659	879	1099	1319	1539	1759	1979	2199
12	Ugba	275	548	821	1094	1367	1640	1913	2186	2459	2732
13	Makurdi	1546	3093	4640	6187	7734	9281	10828	12375	13922	15469
14	Obarike-Ito	119	240	361	482	603	724	845	966	1087	1208
15	Otukpa	171	341	511	681	851	1021	1191	1361	1531	1701
16	Idekpa	58	117	176	235	294	353	412	471	530	589
17	Oju	579	1157	1735	2313	2891	3469	4047	4625	5203	5781
18	Okpoga	188	375	562	749	936	1123	1310	1497	1684	1871
19	Otukpo	1176	2354	3532	4710	5888	7066	8244	9422	10600	11778
20	Wannune	61	123	185	247	309	371	433	495	537	619
21	Sankera	271	541	812	1083	1354	1625	1896	2167	2438	2709
22	Lessel	109	219	329	439	549	659	769	879	989	1099
23	Vandeikya	209	416	623	830	1037	1244	1451	1658	1865	2072

Using the customized ideal traffic flows designed for the Benue State IP Network topology as reported in the PhD thesis [3], aggregate trafficswere estimated on the core transmission links as presented in Tables 2 – 7.

Table II: Aggregate Traffic for Gboko-Makurdi Core Transmission Link

Edge Nodes	***Traffic Intensity in Erlangs***									
Buruku	304	610	916	1222	1528	1834	2140	2446	2752	3058
Gboko	1504	3007	4510	6013	7516	9019	10522	12025	13528	15031
Katsina-Ala	546	1091	1636	2181	2726	3271	3816	4361	4906	5451
Tse-Agberagba	181	364	547	730	913	1096	1279	1462	1645	1828
Adikpo	219	439	659	879	1099	1319	1539	1759	1979	2199
Ugba	275	548	821	1094	1367	1640	1913	2186	2459	2732
Wannune	61	123	185	247	309	371	433	495	537	619
Sankera	271	541	812	1083	1354	1625	1896	2167	2438	2709
Lessel	109	219	329	439	549	659	769	879	989	1099
Vandeikya	209	416	623	830	1037	1244	1451	1658	1865	2072
Total	**3,679**	**7358**	**11038**	**14718**	**18398**	**22078**	**25758**	**29438**	**33098**	**36798**

Table III: AggregateTraffic for KatsinaAla-Gboko Core Transmission Link

Edge Nodes	***Traffic Intensity in Erlangs***									
Katsina-Ala	546	1091	1636	2181	2726	3271	3816	4361	4906	5451
Ugba	275	548	821	1094	1367	1640	1913	2186	2459	2732
Sankera	271	541	812	1083	1354	1625	1896	2167	2438	2709
Total	**1092**	**2180**	**3269**	**4358**	**5447**	**6536**	**7625**	**8714**	**9803**	**10892**

Table IV: Aggregate Traffic for Otukpo-Makurdi Core Transmission Link

Edge Nodes	***Traffic Intensities in Erlangs***									
Igumale	211	423	635	847	1059	1271	1483	1695	1907	2119
Obagaji	154	307	460	613	766	919	1072	1225	1378	1531
Ugbokpo	144	289	434	579	724	869	1014	1159	1304	1449
Obarike-Ito	119	240	361	482	603	724	845	966	1087	1208
Otukpa	171	341	511	681	851	1021	1191	1361	1531	1701
Idekpa	58	117	176	235	294	353	412	471	530	589
Oju	579	1157	1735	2313	2891	3469	4047	4625	5203	5781
Okpoga	188	375	562	749	936	1123	1310	1497	1684	1871
Otukpo	1176	2354	3532	4710	5888	7066	8244	9422	10600	11778
Total	**2800**	**5603**	**8406**	**11209**	**14012**	**16815**	**19618**	**22421**	**25224**	**28027**

Table V: Aggregate Traffic for Oju-Otukpo Core Transmission Link

Edge Nodes	***Traffic Intensities in Erlangs***									
Igumale	211	423	635	847	1059	1271	1483	1695	1907	2119

Obarike-Ito	119	240	361	482	603	724	845	966	1087	1208
Oju	579	1157	1735	2313	2891	3469	4047	4625	5203	5781
Total	**909**	**1820**	**2731**	**3642**	**4553**	**5464**	**6375**	**7286**	**8197**	**9108**

Table VI: Aggregate Traffic for Okpoga-Otukpo Core Transmission Link

Edge Nodes	***Traffic Intensities in Erlangs***									
Otukpa	171	341	511	681	851	1021	1191	1361	1531	1701
Idekpa	58	117	176	235	294	353	412	471	530	589
Okpoga	188	375	562	749	936	1123	1310	1497	1684	1871
Total	**417**	**833**	**1249**	**1665**	**2081**	**2497**	**2913**	**3329**	**3745**	**4161**

Table VII: Aggregate Traffic for Vandeikya-Gboko Core Transmission Link

Edge Nodes	***Traffic Intensities in Erlangs***									
Tse-Agberagba	181	364	547	730	913	1096	1279	1462	1645	1828
Adikpo	219	439	659	879	1099	1319	1539	1759	1979	2199
Vandeikya	209	416	623	830	1037	1244	1451	1658	1865	2072
Total	**609**	**1219**	**1829**	**2439**	**3049**	**3659**	**4269**	**4879**	**5489**	**6099**

Table 8 represents the summary of the aggregate traffic.It is used for simulation of the Benue State IP Backbone network for the purpose of the performance analysis. The simulation was conducted by starting with the values from the first column and proceeding to the last column while the traffics were scaled each time by 20% to obtain the values in the next columns.

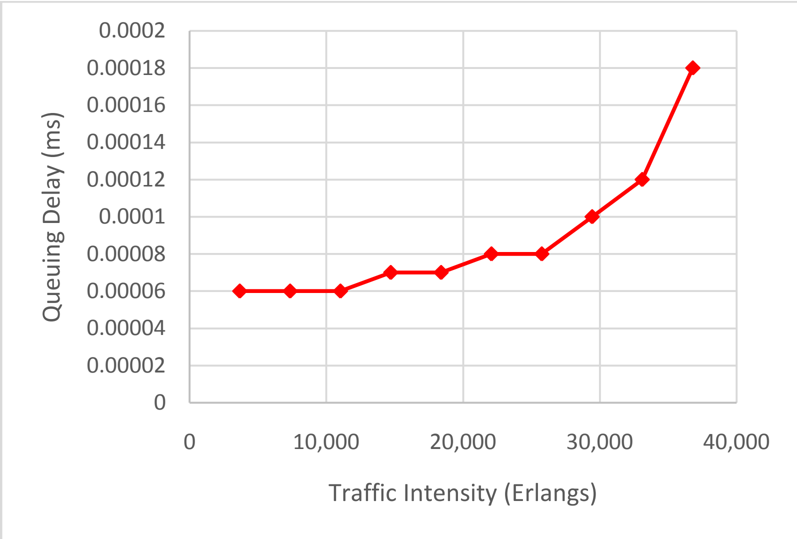
Table VIII: Summary of Aggregate Traffic for the Core Transmission Links

Core Transmission Links	***Capa city***	***Traffic Intensities in Erlangs***									
Gboko – Makurdi	10 Gbps	3,679	7358	11038	14718	18398	22078	25758	29438	33098	36798
KatsinaAla – Gboko	2.5 Gbps	1092	2180	3269	4358	5447	6536	7625	8714	9803	10892
Otukpo – Makurdi	10 Gbps	2800	5603	8406	11209	14012	16815	19618	22421	25224	28027
Oju – Otukpo	10 Gbps	909	1820	2731	3642	4553	5464	6375	7286	8197	9108
Okpoga – Otukpo	2.5 Gbps	417	833	1249	1665	2081	2497	2913	3329	3745	4161
Vandeikya – Gboko	2.5 Gbps	609	1219	1829	2439	3049	3659	4269	4879	5489	6099

III. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

The simulation of the Benue State IP backbone topology of Fig. 1 in the Riverbed Modeler produced simulation graphs for bandwidth utilization, packet queuing delay and packet loss ratio respectively for each of the 6 core transmission links for each value of traffic and the average values of the performance indicators were recorded. The performance metrics benchmarks are: packet queuing delay = 150ms; Average Bandwidth Utilization = 100; Packet Loss Ratio = 0 (Modeler specification) [6], [8]. Queuing delay represents instantaneous measurements of packet waiting times in the transmitter channel's queue [8]. Measurements are taken from the time a packet enters the transmitter channel queue to the time the last bit of the packet is transmitted [8]. Bandwidth utilization represents the percentage of the consumption to date of an available channel bandwidth where a value of 100 would indicate full usage [8]. Packet Loss Ratio is a Boolean value where 0 represents the acceptance of a packet and 1 the rejection of a packet [8]. The parameters are used for the evaluation of the core transmission links which are the resources mostly affecting network reliability [8], [9]-[13], [14]-[16]. The analysis was carried out for the transmission links at the core of the network by checking their status against the stated metrics and benchmarks. One striking feature of the simulation results was the packet loss ratio, which was observed to be 0 for all transmission links for all values of traffic intensity. Consequently, the average values of packet queuing delay and average bandwidth utilizationwere the performance metrics recorded from the simulation graphs forperformance evaluation of the six core transmission links.The performance metrics were collated and plotted against the values of traffic intensities as shown in Figs. 2 – 7.

Fig. 2 (a) and (b) shows the variation of queuing delay and bandwidth utilization respectively with the traffic intensity for the Gboko-Makurdi core transmission link. In Fig. 2 (a), it can be seen that the queuing delay increases with traffic intensity, which implies that the network is performing normally. The values of the queuing delay fall within acceptable limits for an efficient performance of the network for all values of traffic intensity. It is noteworthy that the queuing delay is low and fairly constant up to a traffic load just above 25000 Erlangs and then begins to climb more rapidly for further increases in traffic intensity.



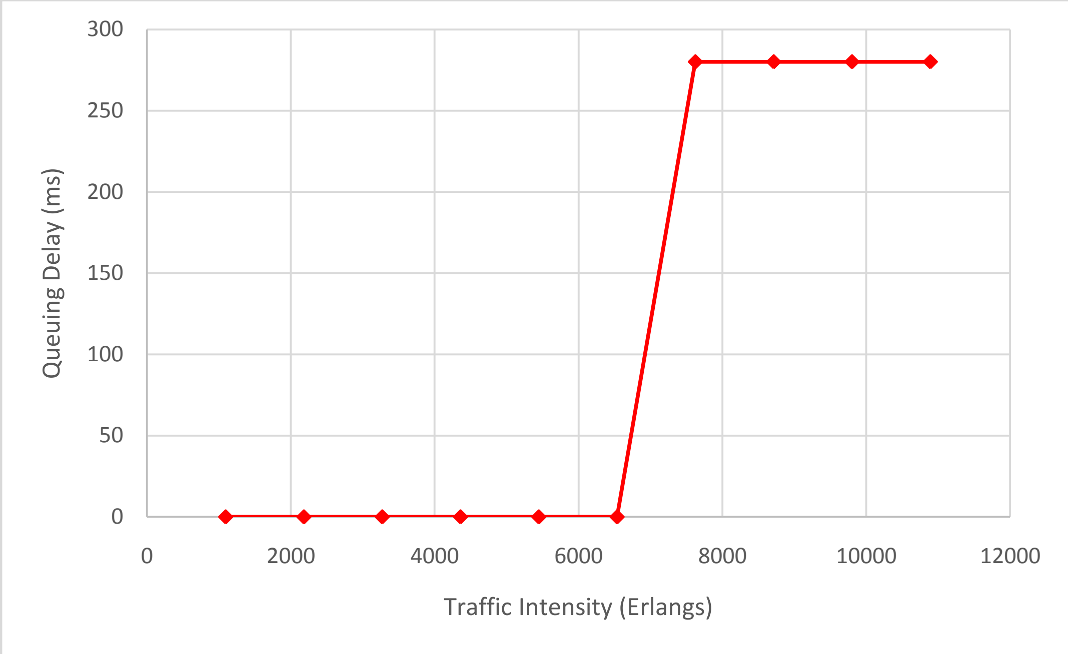
(a) queuing delay versus traffic intensity

(b) Bandwidth utilization versus traffic intensity

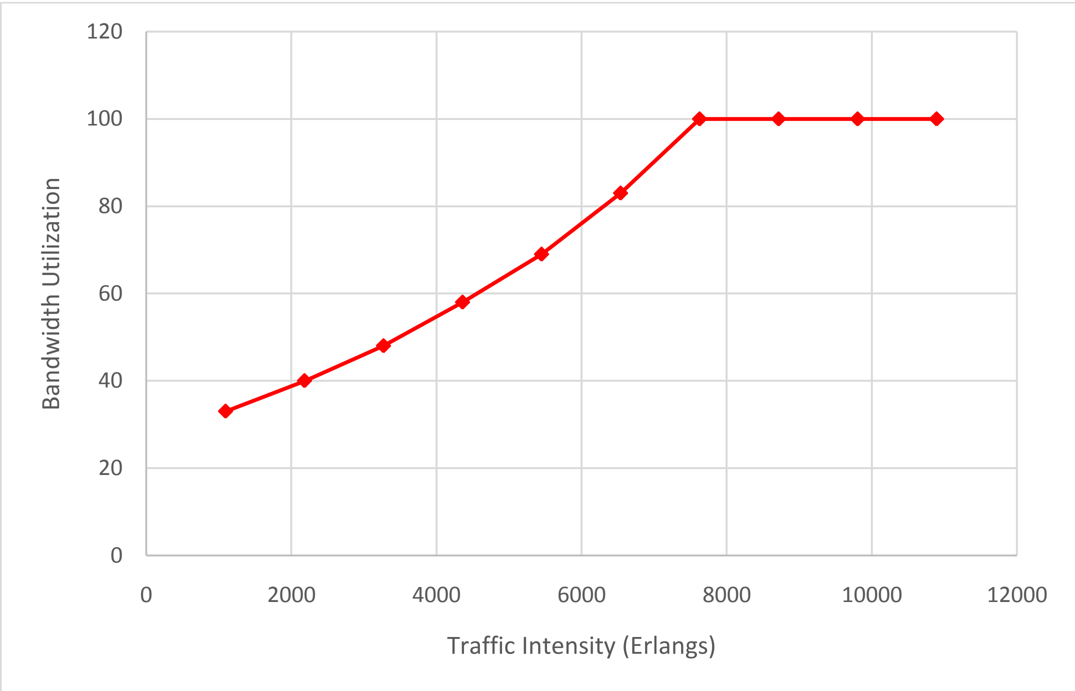
Figure 2: performance analysis for Gboko – Makurdi core transmission link

Fig. 2 (b) shows how bandwidth utilization varies with increases in traffic intensity. It can be seen that bandwidth utilization also increases with traffic intensity, which is also natural for the performance of the network. It can be seen that for the whole period of simulation for all values of traffic, the bandwidth utilization lies below the benchmark with the highest value being 65%. A relatively steeper rise in bandwidth utilization can be noticed above values of traffic exceeding 25,000 Erlangs.

Fig. 3 (a) and (b) shows the variation of queuing delay and bandwidth utilization respectively with the traffic intensity for theKatsina Ala – Gboko core transmission Link. It can be seen in Fig. 3 (a) that the queuing delay has acceptably low and fairly constant values. However, this lasts only for values of traffic intensity below 7000 Erlangs. Beyond this value, the queuing delay increases rapidly to an abysmal value of 280ms and apparently remains so for further increases in traffic. In Fig. 3 (b), it can be seen that bandwidth utilization is also increasing with traffic intensity, which implies that the network is functioning normally. The rise in bandwidth utilization is quite rapid with every increase in traffic intensity. At a point just above 7000 Erlangs, the bandwidth utilization reaches 100 % and apparently remains at this level for any further increases in traffic intensity. It is important to take note of this region of the graph to avoid overloading of the transmission link.



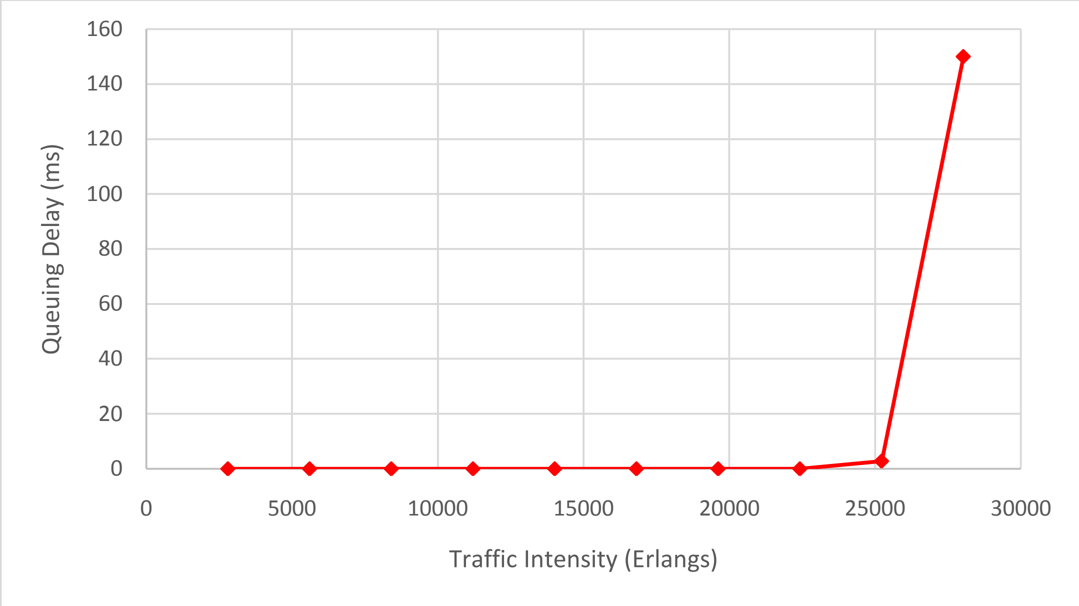
(a) queuing delay versus traffic intensity



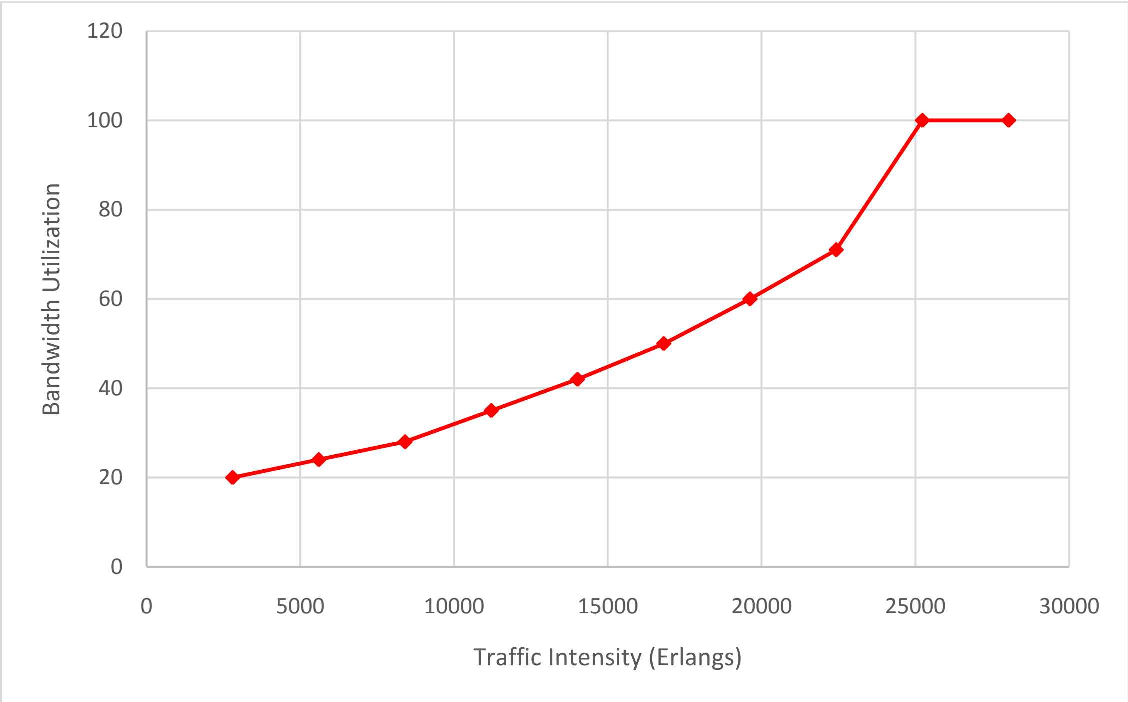
(b) bandwidth utilization versus traffic intensity

Figure 3: performance analysis for KatsinaAla – Gboko core transmission link

Fig. 4 (a) and (b) shows the variation of queuing delay and bandwidth utilization respectively with the traffic intensity for the Otukpo – Makurdi core transmission link. It can be seen in Fig. 4 (a) that the values of queuing delay are satisfactorily low almost coinciding with the traffic intensity axis. This happens only as far as the traffic does not exceed 25000 Erlangs. It can be seen that beyond this value, the link suffers severe degradation as the queuing delay increases exponentially to an unacceptable level of 150ms. The graph of bandwidth utilization which is shown in Fig. 4 (b) further accentuates the performance of the Benue State IP backbone network with respect to the Otukpo – Makurdi core transmission link. The bandwidth utilization increases normally with traffic intensity and can be seen becoming steeper around 22500 Erlangs. Beyond this value it quickly peaks at 100% and apparently stays there for any more increases in traffic intensity.



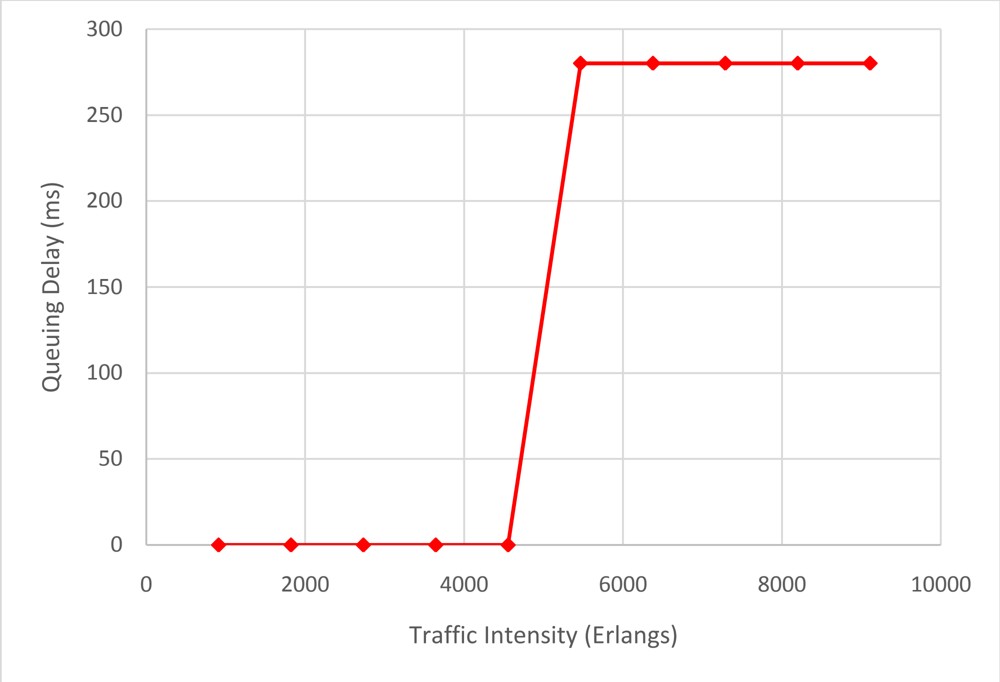
(a) queuing delay versus traffic intensity



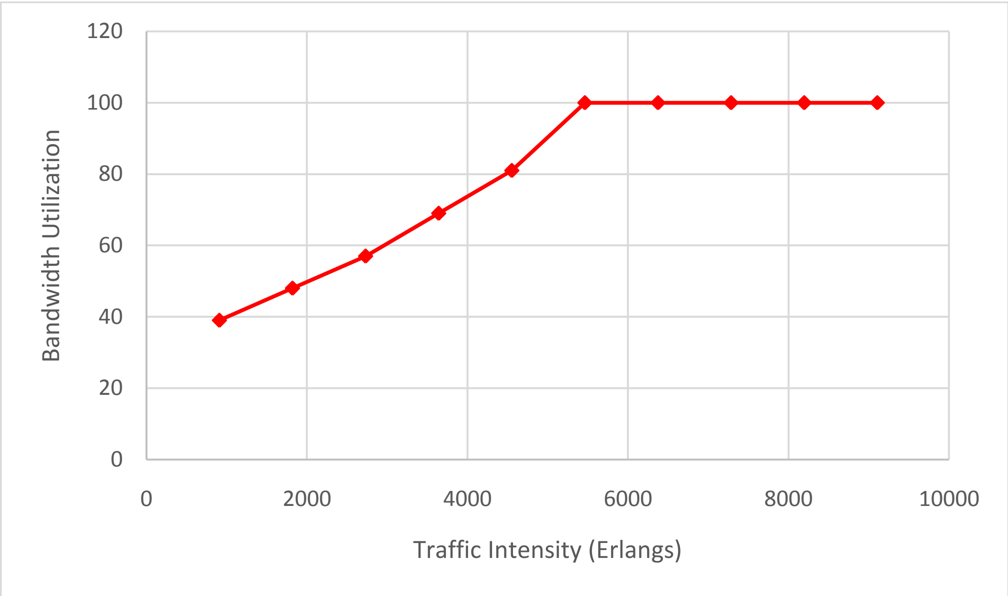
(b) bandwidth utilization versus traffic intensity

Figure 4: performance analysis for Otukpo – Makurdi core transmission link

Fig. 5 (a) and (b) shows the variation of queuing delay and bandwidth utilization respectively with the traffic intensityfor theOju – Otukpo core transmission Link. From Fig. 5 (a), it is obvious that the Oju – Otukpo core transmission link cannot take traffic more than 4,500 Erlangs for it not to perform abnormally. It can be seen that beyond this traffic, the queuing delay changes sharply to the abnormal level of 280 ms and apparently remains at this saturation point thereby congesting the network along this link for all further increases in traffic. The situation along the Oju – Otukpo link is further described by the graph of bandwidth utilization versus traffic intensity presented in Fig. 5 (b). The graph shows clearly that the performance of the link is poor for all values of traffic intensity above 5000 Erlangs as the bandwidth utilization is at its peak at 100% for these values.



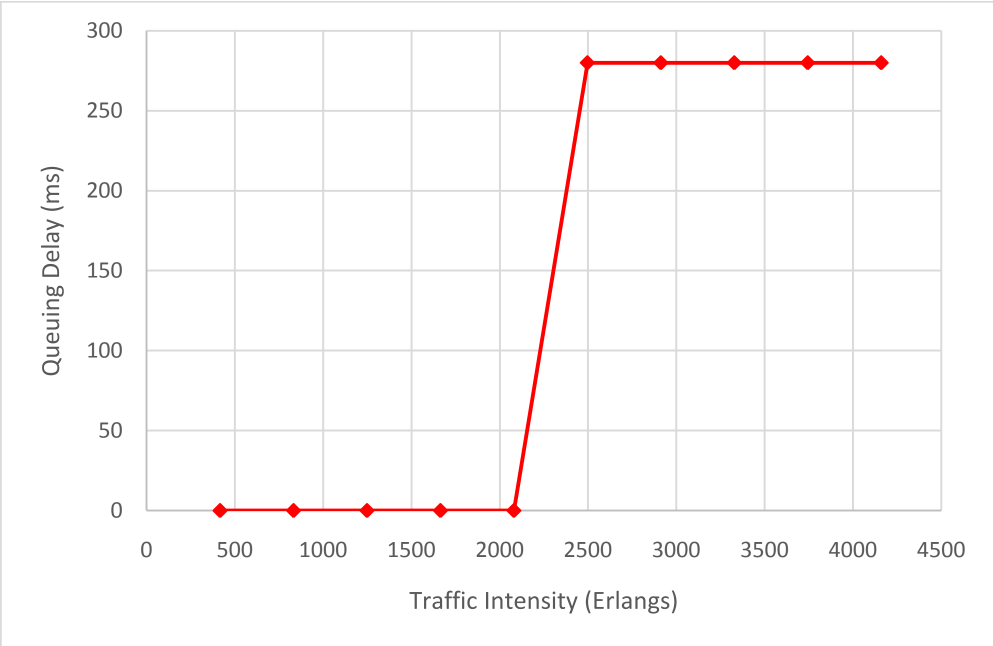
(a) queuing delay versus traffic intensity



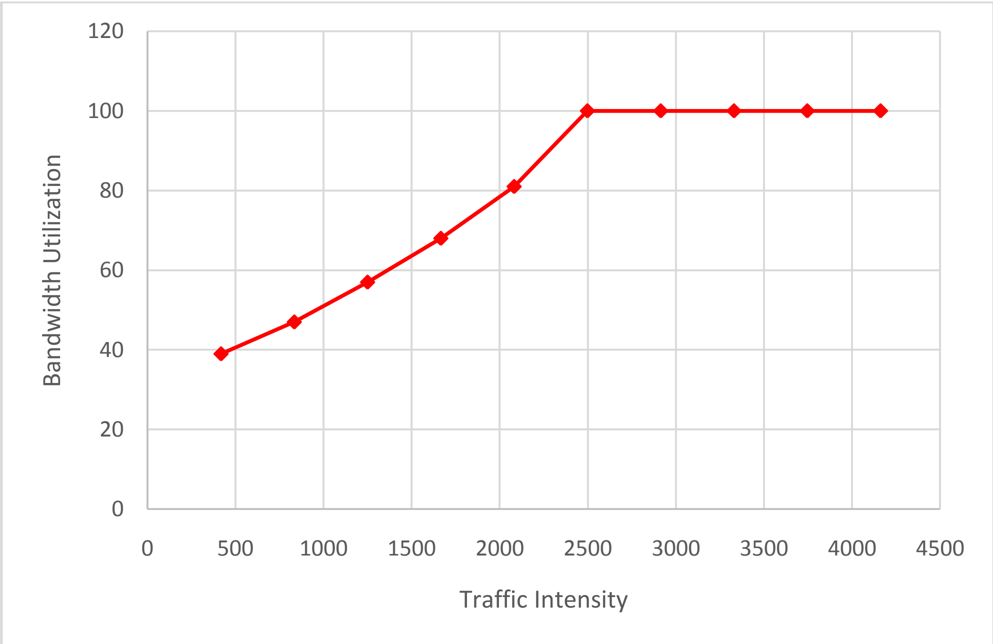
(b) bandwidth utilization versus traffic intensity

Figure 5: performance analysis for Oju – Otukpo core transmission link

Fig. 6 (a) and (b) shows the variation of queuing delay and bandwidth utilization respectively with the traffic intensityfor the Okpoga – Otukpo core transmission Link. It is obvious from Fig. 6 (a) that as far as the Okpoga – Otutkpo transmission link is concerned, the performance of the network will be abnormal for traffics more than 2000 Erlangs. It can be seen that above this figure, the network switches to a state of congestion along this link as the queuing delay changes drastically to an extremely high point at 280 ms and apparently remains at this level for all higher traffics. In terms of bandwidth utilization, it can be seen that the congestion of the link sets in with the traffic equal to 2500 Erlangs and persists for all higher traffics as can be seen in Fig. 6 (b).



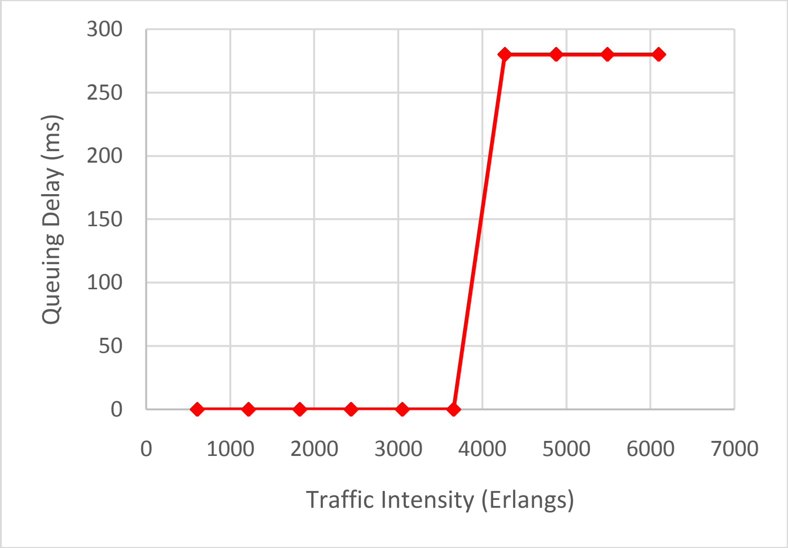
(a) queuing delay versus traffic intensity



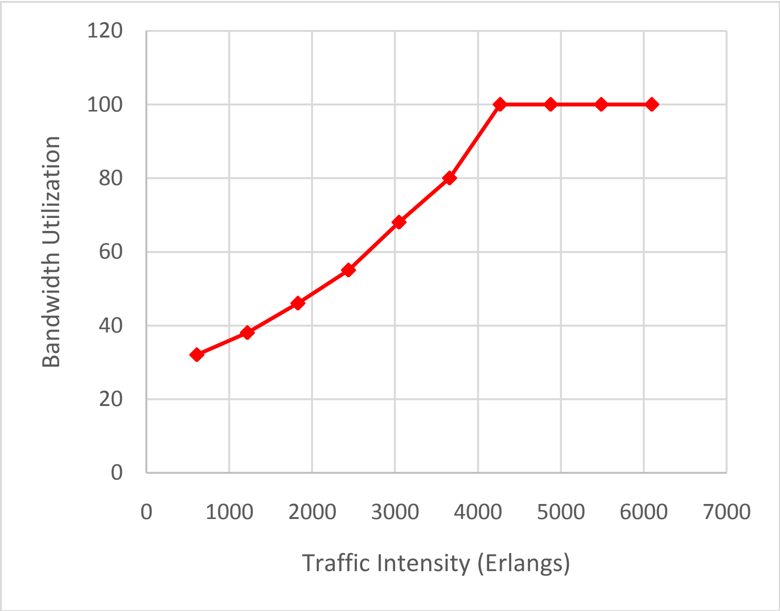
(b) Bandwidth utilization versus traffic intensity

Figure 6: performance analysis for Okpoga – Otukpo core transmission link

Fig. 7 (a) and (b) shows the variation of queuing delay and bandwidth utilization respectively with the traffic intensity for the Vandeikya – Gboko core transmission Link.Considering the graph of queuing delay against traffic intensity presented in Fig. 7 (a), it is clear that at points above the traffic of about 3500 Erlangs, the queuing delay has switched from a near-zero level to an abysmal value of 280 ms which apparently remains unchanged for all higher values of traffic intensity. In terms of bandwidth utilization, Fig.7 (b) confirms that the performance of the network may only be acceptable if the traffic offered to the transmission link is about 3000 Erlangs and less.



(a) queuing delay versus traffic intensity



(b) Bandwidth utilization versus traffic intensity

Figure 7: performance analysis for Vandeikya – Gboko core transmission link

IV. SUMMARY OF RESULTS

The Gboko – Makurdi core transmission link has the best performance. It is the only transmission link that did not show any sign of overloading with all the ten values of the traffic intensities. The next best performing transmission link is Otukpo – Makurdi. The link showed overloading only when it was simulated with the last two traffic intensities respectively. Two transmission links, namely Katsina Ala – Gboko and Vandeikya – Gboko exhibited similar patterns of behaviour. Both links performed normally with six values of the traffic intensities and showed overloading for the remaining four simulations. Another pair of transmission links, namely, Oju – Otukpo and Okpoga – Otukpo also exhibited similar patterns of behaviour. In this case, both links performed normally for five values of the traffic intensities and showed overloading for the last five simulations. However, all the transmission links performed well up to the values corresponding to 100 % of the modelled traffic. The corresponding values of bandwidth utilization at these traffic points are given as: Gboko – Makurdi = 26%; Otukpo – Makurdi = 42%; Katsina Ala – Gboko = 69%; Vandeikya – Gboko = 68%; Oju – Otukpo = 81; and Okpoga – Otukpo = 81. This is a clear indication the design of the Benue State IP backbone network satisfies the primary goals of high reliability, scalability and cost-effectiveness. It is noteworthy that the best performing transmission links, namely Gboko – Makurdi and Oukpo – Makurdi constitute the inner core of the backbone network and naturally require to be designed to be more resilient than the outer core made up of Katsina Ala – Gboko, Vandeikya – Gboko, Oju – Otukpo, and Okpoga – Otukpo and this is accordingly demonstrated by the above-stated results.

V. CONCLUSION

The main problem addressed in this paper is simulation and performance testing of IP backbone network.The results of the analysis showed that all the 6 core transmission links performed well up to the values corresponding to 100 % of the modelled traffic. It is noteworthy that the best performing transmission links, namely Gboko – Makurdi and Oukpo – Makurdi constitute the inner core of the backbone network and naturally require to be designed to be more resilient than the outer core made up of Katsina Ala – Gboko, Vandeikya – Gboko, Oju – Otukpo, and Okpoga – Otukpo and this is accordingly demonstrated by the results of the performance analysis. The measured queuing delay and packet loss ratio also showed appreciable optimal levels for all normal performance conditions. On the whole, the results showed that the design of the Benue State IP backbone network satisfies the primary requirements of high reliability, scalability and cost-effectiveness.The study demonstrates the effective way the Riverbed Modeler could be used for active performance analysis of IP backbone network designs for Next Generation Networks.

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