A Study of Network Optimization Models for High-Performance Networks

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Abstract:- An important feature of a bandwidth optimization system is the adequate provision of internet services with high data rates and wide coverage. Low bandwidth causes poor internet speed, network downtime, constant network traffic congestion and network unavailability during peak and off-peak periods, to mention a few. Existing research on bandwidth optimization focused on bandwidth allocation in creating different channels and traffic isolation to Guarantee good Quality of Service (QoS). Despite several optimization techniques and bandwidth allocation algorithms of existing researchers, there is still reduced connectivity by which internet users are grossly affected in spite of increased energy cost of network devices and other infrastructure. One of the serious issues of optimization techniques is that of the problem of mixed-integer linear programming. Therefore, this article gives a brief overview of a list of bandwidth optimization models deployed through previous researchers, stating the optimal algorithms that work with each of the models while formulating a new bandwidth optimization model that solves the problem of mixed-integer linear programming technique that was the approach adopted from existing works necessary for wireless networks.

***Keywords*:-** *Bandwidth, Traffic Congestion, Bandwidth Optimization, Bandwidth Allocation.*

I. INTRODUCTION

The term "big data" was coined to describe the enormous amounts data applications of information science and technology on a large scale have generated over time. Big data is carried by High-Performing Networks (HPNs), which have had the ability to connect to support numerous separate processes. [70]. Industries increased their focus on high-performance equipment clarifications for performance issues in various network tiers as bandwidth issues on the operations network continued to develop **[18].** When describing a high-performance network, operator networks are called "high performance." [4]**,** ***[10]***], [11], [7] & [6]. Studies have shown that it was not surprising that there is great interest in high-performance networks [16]. In actuality, bandwidth optimization technologies improve the effectiveness of the current network. Through the use of bandwidth optimization, data packets can be relayed. The number of internet-enabled end customers who use high-performance service is always increasing, increasing the demands on HPN. Several investments have been made by large organizations to provide a secure, accessible and efficient internet connection to their users. Based on existing literatures, the current state of problems has been observed so far and outlined viz: Poor internet speed, Network downtime, Constant traffic congestion, energy consumption of internet connectivity on the rise thereby increasing overhead cost of management, network unavailability (peak and off-peak periods). In lieu of this, there is a dire need for optimization of the network because failure to optimize network has led to business being affected, connectivity being marred, increased cost and network unavailability issues to mention a few. However, none of the existing literatures has solved bandwidth optimization technical problems. Some of the bandwidth optimization models comprised Internet traffic data model, [14][*25]*, client server model, **[1]**, fluid flow model, **[8**] [**22**] and user-centric model, as considered by this article. This article evaluates and analyzes existing bandwidth optimization models, optimal algorithms that worked with each model, as well as a new bandwidth optimization model that solves the problem of previous optimization techniques. In achieving this, four sections are presented. Section 1 discusses the introduction, giving an overview of a list of bandwidth optimization models deployed by existing research. Existing bandwidth optimization models that were compatible with each of the models were covered in the section 2. Section 3 develops an optimal bandwidth optimization model that solves the mixed-integer linear programming problem. Section 4 explains the proposed optimization model. Section 5 describes the modified mathematical formula for the optimization model. The conclusion is showcased in section 6.

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II. II EXISTING BANDWIDTH OPTIMIZATION MODELS

Most researchers attest to the fact that having a clear understanding of what high-performance networks are and are not made the best choice for business. The internet is one of the most crucial factors for bandwidth. A network that only consists of lower-cost providers, like many small networks, is not high-performance. Currently, a "high-performance" network is included in the insurance coverage of about 16% of larger companies. This is anticipated to rise in the near future as these networks develop and grow. High-performance networks in computer science simply refer to network equipment, infrastructure, and internet services combined with facilities that are more capable of performing high-speed communications. By initializing every Internet Protocol (IP) address without a hitch, optimization also makes room for having high-quality packet travel simultaneously from sender to receiver and vice versa, such as audio or video files [13].

Since the 20th century, people's network life has become more colorful due to the rapid advancement of computer technology, the popularity of high-performance computers, and the Internet traffic data model, which has also undergone revolutionary changes due to cloud computing and big data technology [14]. The development of Internet application technology also confronts significant difficulties due to the influence of such a large number of network users and voluminous and complex traffic data [9]. As information system performance and cluster architecture improve, issues with network bandwidth and the processing efficiency of traffic are created. How to make the system run with the highest efficiency and shortest completion time has become an issue that affects the overall function of the Internet. The lack of network bandwidth in the computer data processing center is the main factor leading to this problem [12],[23]. Therefore, in the big data communication environment, it is crucial to figure out how to address the issue of how the massive data in the network communication channel takes up too much bandwidth, leading to the traditional communication network channel bandwidth being unable to meet the needs of data communication, poor communication quality, low speed, and so on [15].

The long-distance cable capacity around the world is much less in capacity than the amount of data transferred. Bandwidth limitation is a source of bottlenecks and delays over the network. As a consequence, QoS degradation due to delay and latency is a serious issue. Really thanks to content delivery networks (CDN) and peer-to-peer technologies (P2P), the end-to-end or the client-server model has been optimized to avoid passing the whole network. Network and application-level solutions are introduced to solve the problem of the delay of un-cached data.

The client-server architecture was utilized when the Internet first started. In such a model, the bandwidth was consumed very fast. Local caching on the client side was introduced as a partial solution [1]. Afterward, proxy caches were used at the proxy level and showed success [2]. Later, cooperative caches have been introduced such as Internet caching protocol and Cache Array routing [3]. Mutual synergy was introduced as a solution as well [4]. CDN technology is evolved to be one of the major border-side solutions to the problem of bandwidth consumption. All the previous solutions are application-level solutions. The idea behind all these solutions is to transfer data once and retrieve it several times. Such a technique requires that the data is static and retrieved. Application-level solutions are employed for real-time data, such as video streaming, compression, and scalable video coding. Some other network-based solutions such as integrated services (interval), differentiated services (DiffServ), and resource reservation protocol (rsvp) used either bandwidth reservation or priority classes' creation for the data [5],[6].

Table 1 Scenarios

Scenario	Mean Arrival Rate (Mbps)			
	Type 1	**Type 2**	**Type 3**	**Type 4**
1.	0.8	1.6	2.4	3.2
2.	3.2	2.4	1.6	0.8
3.	1.6	1.6	1.6	1.6

We use the fluid simulation in [8] that approximates the packet-level simulation. Lee et al. [13] proposed a bandwidth optimization algorithm in GPS servers with multiple service classes, in which we can minimize the total bandwidth while different QoS requirements for each class queue in a multiple queue system are satisfied. Since it is difficult to analytically evaluate the performance for Internet traffic with self-similar and long-range dependent characteristics, the performance was evaluated mainly using simulation. In particular, fluid simulation was performed instead of packet-level simulation to reduce the complexity. The bandwidth optimization algorithm was based on an exterior penalty function method, using the relation between the allocated bandwidth vector and the performance obtained from fluid simulation. However, the bandwidth optimization using an exterior penalty function required a long time to converge because it used many simulations to obtain the direction vector and step size. In a fluid flow model, The input rate of class i in a fluid flow model is constant in a unit time interval length, δ [22]**.** We take into account an environment with four classes of queues, where each input traffic has a length of 213 steps with resolution $\delta = 0.1$s. Table I shows the mean arrival rates of the four different traffic classes in five different cases. The standard deviation of traffic amounts during a unit time interval with length $\delta = 0.1$s is set to the mean amount during the same unit time, and the Hurst parameter is set to 0.85. ($i = 1, \dots, n$), In order to satisfy the Quality of Service (QoS) needs for applications and to advance the transition to user-centric network architectures, bandwidth allocation and management are crucial [2]. Given that bandwidth is a limited resource, artificial intelligence techniques are progressively replacing traditional methods of bandwidth allocation. The development of wireless technology has resulted in the emergence of applications, protocols, and scenarios that have benefited human endeavors [20]. To

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serve a variety of applications, services, and transmissions, scalable and dependable communication networks are required. Sensor networks, machine-to-machine communications, the Internet of Things, millimeter-wave techniques, multiple input multiple output technology, and many more recent advancements have helped to increase the effectiveness of communication and data transmission through wireless networks [3]. The user-centric paradigm based on Quality of Experience (QoE), which is decided by QoS given by the network, is becoming more prevalent in mixed networking situations [5].

III. OPTIMAL ALGORITHMS OF OPTIMIZATION MODELS

An algorithm for scheduling networks is called weighted fair queueing (WFQ). According to [17], the researchers used high bandwidth utilization while continuously submitting data to the users. In this publication, the researchers discussed a number of algorithmic techniques that could reduce the routing network's execution time, energy consumption, and time delays. Peer-to-peer networks were provided with good network services, a flexible network between users, and an absence of traffic regulations. To transfer data, it expanded its bandwidth from source to destination. Additionally, it reduced the amount of unavailable bandwidth. The researchers employed techniques to maximize the bandwidth and transmission speed while transmitting the data in an equal amount of time. Since the bandwidth was consumed in real-time, the article was unable to handle the problem of tracking the network by applying this optimization technique.

An improved information application system is proposed by optimizing the fine integration method of fuzzy fractional ordinary differential equations and combining them with software-defined networking (SDN) to address the issues that the network bandwidth of previous information application systems cannot guarantee the quality of big data transmission, resulting in low transmission efficiency and slow data processing, etc. First, the Pade approximation fractional-order fuzzy differential equation fine integration method is derived. The optimization formula for the adaptive selection of the weighted parameter N and the enlarged item number q is then developed using the error analysis theory. An enhanced information application system is created when SDN is used, and the improved algorithm and system are found using performance tests and example simulations. The outcomes demonstrate that the upgraded method has higher numerical accuracy and computing efficiency than the improved algorithm. Additionally, compared to the previous system, the enhanced port data merge rate and task completion efficiency are much higher. It demonstrates that the information application system suggested in this study can more effectively address the issues of poor communication speed and insufficient bandwidth in traditional systems, and it offers a fresh viewpoint for large data bandwidth optimization [14].

This research suggests a brand-new algorithm to make the most of available bandwidth for all text-based applications. The algorithm is used for offline SMS in mobile phones as well as real-time online text chatting. In the core network, text is handled transparently without any changes. The suggested approach employs the 'A-M' paradigm for compression. Depending on the context of the transferred data, using such an algorithm can save anywhere between 25% and 90% of the bandwidth. Other applications such as email, web browsing, etc… will also gain from applying such an algorithm. Real-time text chatting and mobile SMS apps were both demonstrated in this article. The technique relies on a pre-defined dictionary installed on the client side or in a cloud close to each client, with a maximum size of 16 K bytes [1].

We take into account a bandwidth optimization issue in Generalized Processor Sharing servers with numerous class queues in order to reduce the overall bandwidth while still satisfying the QoS criteria for each class queue. In our earlier paper [13], we used a simulation-based optimization technique to achieve an optimum bandwidth vector because it is challenging to quantitatively determine the performance, such as the delay distribution, with self-similar input traffic in a GPS server. However, the previous optimization algorithm requires rather a long simulation time to solve the problem by using exterior penalty function methods. Without using complicated computations, we suggest a new bandwidth optimization approach based on bandwidth ratio adjustment. The time needed to determine the best bandwidth allocation for GPS servers is significantly shorter in numerical findings [8] [22].

In order to meet the Quality of Service (QoS) needs for applications and support the transition to user-centric network architectures, bandwidth allocation and management are crucial. Given that bandwidth is a limited resource, artificial intelligence techniques are progressively replacing traditional methods of bandwidth allocation. The Whale Optimization Algorithm (WOA) was examined in this study to provide the best possible bandwidth allocation in wireless networks. WOA is a new swarm intelligence technique that imitates humpback whales' foraging behavior. This study allocated the bandwidth to real-time users (RTUs) and nonreal-time users while reserving bandwidth for future users. The simulations were implemented in MATLAB and the results were discussed in terms of connection probability with a focus on available bandwidth and the numbers of RTUs on the network. The findings showed that the suggested WOA technique effectively optimized the bandwidth allotted to customers and demonstrated bandwidth management of the limited quantity of bandwidth [2].

The speed at which data flows starts to slow down as the volume of traffic gets close to the network's carrying capacity. By default, new packets will be dropped if a queue buffer on an interface reaches capacity. Switches and routers can use Quality of Service (QoS) to queue and service higher-priority traffic before lower-priority traffic and to remove lower-priority traffic in favour of higher-priority

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traffic during times of congestion [24]. The employment of various queuing techniques to manage which packets are forwarded (bandwidth allocation) and which packets are dropped (Buffer space) was discussed in [21].

IV. DATA FLOW-INTENSIVE MODEL

The model was implemented on a network operating centre and lastly, the prototype developed was evaluated using the OMNET++ simulation tool [Researcher's model, 2022]. Existing works of literature regarding bandwidth monitoring and optimization systems were reviewed using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method. The PRISMA approach was chosen because it was more suited to comparing bandwidth monitoring and optimization models and is most broadly applicable across various study fields. The four stages of PRISMA are identification, screening, eligibility, and inclusion.

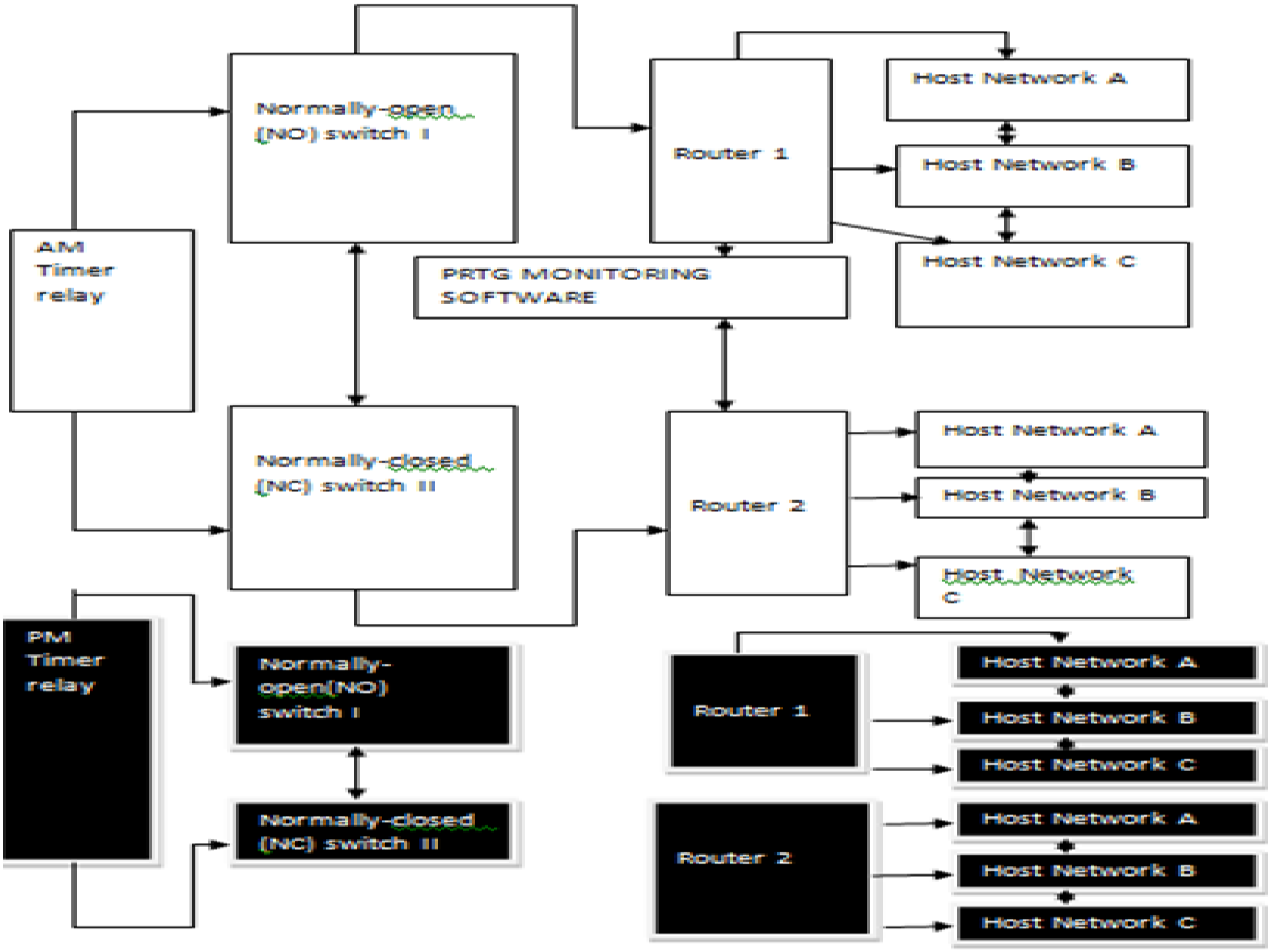

Fig 1 Data Flow Intensive Model

The main purpose of the review was to classify systems that have been adopted in existing bandwidth monitoring and optimization models and the types of problems found. From the existing articles, the bandwidth optimization issues discovered were categorized with various metrics, approaches, and systems employed by researchers. The articles revealed the flaws in the current systems. Firstly, the new mathematical integration equations based on time-series routing is deduced. A two discrete time-series of the input data for the bandwidth optimization based on the Anti-Meridian (AM) and Prime-Meridian (PM) formula is given as:

By existing works**,** The system's energy consumption, E, was dependent on the device's energy consumption, P, which changed with time, t. If T was the duration for a particular period, then energy was provided by:

$$E(T) = \int_0^T P(t)\, dt \qquad (1)$$

As a result of the input data for the that are two discrete time series: Anti-meridian (AM) and Prime-Meridian (PM) in this thesis study, a modified mathematical equation [5] was initially formulated from the existing mathematical model for the integration of (AM)/(PM) Timer relays)

GENERAL MATHEMATICAL analysis of existing Formulae FOR AM/PM TIMER RELAY

$$U(T) = \int_0^T R(t)\, dt \qquad (2)$$

Take note that

$$\int_0^T R(t)\, dt = R(T) - R(0) \quad (3)$$

Where R (T) is any antiderivative of R(t) (that means R'(T) = R(t)). This is the fundamental theorem of network calculus.

Among them

$$U_1(T_1) = \int_0^T R1(t)\, dt \qquad (4)$$

For Anti-Meridian (AM) Time

$$U_2(T_2) = \int_0^T R2(t)\, dt \qquad (5)$$

For Prime-Meridian (PM) Time

- *Decision Variables*
  U(T) = utilized energy, R(T) = Consumed energy

- *Objective Function*
  $U_1 (T_1) + U_2 (T_2) = \int_0^{T_1} R_1(t_1)\, dt + \int_0^{T_2} R_2(t_2)\, dt$

$$U(T) = \int_0^T R(t) dt = 1/2[R(t)(T) + R(t)(0)(T - 0)$$

= ½ [TR(t) + 0

= ½ R(t) T

= TR(t)/2

Where R(t) = Total Traffic Volume (sent and received)/ Total traffic speed (sent and received)

R(t) = Total amount of energy utilized in network devices

As a result of the gaps registered and observed in the formula for existing works as applied in (i) which are as follows,

- Existing formula concentrated on power consumption of network devices while leaving out the energy consumption rate of the wireless devices
- Existing formula also focused on AC power of the network devices only while leaving out the DC source of power especially when there is power outage due to any form of circumstance
- The am/pm timer relay was not eventually integrated because the previous mathematical model only applied am/pm while leaving out the automatic switching of NO-NC switches as a result of the triggering by am/pm timer relay.

A new mathematical equation was in turn developed which is known as **ENERGY-SAVING AND COST REDUCTION BANDWIDTH EQUATION(ESCRBE)**

V. MODIFIED MATHEMATICAL ENERGY-SAVING AND COST REDUCTION BANDWIDTH EQUATION

In Wireless networks, the activities that consume most of the energy are network bandwidth transmission and reception. The energy consumption for transmitting or receiving data depends on the network traffic volume and the network traffic speed from the source to the destination. Under such considerations, the expected energy to transmit a PRTG analyzed monitoring metrics to the network administrator is defined in Equation (6).

$$F_{UX}(M) = \{MF_{amtr} + M\varepsilon_{no}e^2, \; e \le eth \;\; MF_{pmtr} + M\varepsilon_{nc}e^4, \; e > eth \quad (6)$$

Where F_{UX} is the utilized energy for data transmission, M is the monitoring model for the Anti-Meridian (AM)/Prime-Meridian (PM) Timer relay, Famtr is the consumed energy for transmitting or receiving data according to the morning period between 12am till 12 noon, while F_{pmtr} is the consumed energy for transmitting or receiving data according to the prime-time between 12noon till 12 midnight the following day. ε_{no} is the coefficient of energy consumed in the normally-open switch, ε_{nc} is the coefficient of energy consumed in the normally-closed switch, and eth is the number of active normally-open/normally closed cisco wireless routers defined in Equation (7).

$$eth = \frac{\sqrt{\varepsilon_{no}}}{\varepsilon_{nc}} \qquad (7)$$

The expected energy to receive a PRTG analyzed monitoring metrics for the anti-meridian time/prime-meridian time to the network administrator is calculated in Equations (8) & (9)

$$F_{SX}(M) = MF_{amtr} \qquad (8)$$

$$F_{SX}(M) = MF_{pmtr} \qquad (9)$$

Since a normal cisco wireless router n_i only transmit data to the network hosts via the network server, the following equation can calculate its energy consumption:

$$F(n_i) = F_{UX}(M) \quad (10)$$

However, the utilized energy of a network host must include the consumed energy of destination network bandwidth from host networks, AM/PM timer relay, and normally-open/normally-closed switches to the Energy-saving and cost reduction monitoring model. Therefore, the

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energy consumption of a network host DI_j is calculated as Equation (11).

$$\mathbf{F(DI_j)=F_{SX}(M)O_j+(O_j+1)\,MF_{WR}+F_{UX}(M)} \quad \mathbf{(11)}$$

where O_j is the number of Network Hosts in Server J, And F_{WR} Is the Total Energy Linkage For For One-Hour Interval Of Am/Pm Timer Relay. Under The Above Considerations, The Residual Energy Of A Network Host Ni Can Be Estimated By Equation (12).

$$F_s^t(N_i)=\{F_s^{t+1}(N_i)+Fux(M,e),\; F_s^{t+1}(Ni)>0,\, F_s^{t+1}(N_i)\geq 0 \quad (12)$$

While The Energy Loss Of A Network Between The Source (Isp) To Destination (Clients/Consumers) DIj Is Described In Equation (13).

$$F^t_s(Dij)=\{F_s^{t-1}(DIj)-F(DIj),\; F_s^{t-1}(DIj)>0,\, F_s^{t-1}(DIj)\leq 0 \quad (13)$$

During the initialization stage, the prtg monitoring software is activated to monitor initial network hosts and gives the analysis based on the date/time, network traffic volume, network traffic speed, network downtime and network coverage metrics based on the consumed energy. Once the prtg has monitored the network hosts, the am/pm timer relays will be triggered by the monitoring sensors of the prtg via the network administrator. Furthermore, the normally-open/normally closed switches are then triggered by the am/pm timer relays to switch-on active cisco wireless (border gateway) routers and switch off passive cisco wireless (border gateway) routers till whenever the network bandwidth of the host network is about to clog up, then this process is vice-versa. This process is called the **Energy-saving and cost reduction control model**. (ESCRCM).

The process of selecting network hosts to build an optimal network bandwidth algorithm by the by the prtg is described in the testing and evaluation stage.

Other components used were Anti-Meridian/Prime-Meridian (AM/PM) Timer relay which triggered the Normally-open (NO), Normally-Closed (NC) switch. The NO-NC switch switched active routers on and made other routers passive.

The bandwidth optimization model is presented on mixed-integer programming which was used to solve the mathematical equation involving the integration of the am/pm timer relay that triggers the no/nc switches both on peak and off-peak modes (12 midnight till 12 noon and also from 12 noon till 12 midnight the following day) from PRTG data collected for this study.

The various algorithms developed for the bandwidth optimization technique vary in accuracy when applied to other optimization models from the bandwidth usage [26]. Therefore, three (3) optimization algorithms namely: FUE-sub-channel matching algorithm (FSMA), Joint sub-channel and power allocations algorithm (JSPA) and integrated structure cabling system (ISCS) algorithms were applied in comparison with the new bandwidth optimization model was presented with a new mathematical equation that solves the integral problem of merging the am/pm timer relay.

VI. CONCLUSION

The EEBMOM was developed using bandwidth optimization techniques. These techniques had five methods which were hardware compression, deduplication, object caching, traffic shaping, and rectifying the forward error. Data collection for this research based on bandwidth monitoring using the Paessler Router Traffic Grapher (PRTG) network monitoring software was done at a network operating centre in South-Western Nigeria. The data collected comprised 8,673 records of bandwidth monitored metrics such as Date/Time of bandwidth monitoring, network Traffic volume (of end-to-end connectivity), network traffic speed (from source to destination and vice-versa), network downtime, and coverage. The model was formulated using bandwidth optimization (BO) techniques while the data collected were coupled with three algorithms: FUE-sub-channel matching algorithm (FSMA), Joint sub-channel and power allocations algorithm (JSPA), and integrated structure cabling system (ISCS) algorithm. The performance of the algorithms was evaluated based on four BO metrics: network bandwidth dropping, network bandwidth blocking, bandwidth utilization and bandwidth consumption. The optimal algorithm was used to formulate the optimization model using the PRTG monitoring tool. A new mathematical equation was formulated from the model for the integration of Anti-Meridian (AM)/ Prime-Meridian (PM) Timer relays and the Normally-Open (NO)/Normally-closed (NC) switches for energy-efficiency to design the EEBMOM. The EEBMOM was implemented by solving an optimization problem using the mixed-integer programming optimization technique. The EEBMOM was tested and evaluated using the OMNET++ simulation software. (OSS).

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