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LOCAL AREA NETWORK MONITORING FRAMEWORK FOR BANDWIDTH OPTIMIZATION IN UNIVERSITIES IN KENYA

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ABSTRACT

Bandwidth demand in Kenyan universities is at a constant rise. The availability of bandwidth is generally not enough to meet demands and to support optimal usage. The term bandwidth is mostly used to describe traffic limitation in a network, while traffic on the other hand is the amount of data that is sent and received. If Kenyan universities are to participate in high-end quality research, they must invest massively in bandwidth. Institutions have ignored traffic limitations and capitalized on increasing the bandwidth size. Bandwidth management is needed to catch up with the challenges of the day-to-day tasks of networking, communicating, and researching in our Kenyan universities. This study is purposed to develop a local area network monitoring framework for bandwidth optimization in Kenyan Universities. The study was guided by the following objectives: to establish bandwidth monitoring technologies employed in universities in Kenya, to determine the challenges facing bandwidth distribution in Kenyan universities, and to develop the LAN monitoring framework for bandwidth optimization in universities in Kenya. The research adopted an experimental research design approach, where objectives one and two were carried out through data collected from primary data (network monitoring tools). The data was collected and analyzed through both descriptive and inferential statistics. The data collected and analyzed was used to develop a LAN monitoring framework for bandwidth optimization in universities. The findings addressed the major challenges faced by network administrators in monitoring network traffic and allocation of bandwidth. The analysis of bandwidth monitoring tools in university settings identified Nagios and ntopng as the most effective due to their compatibility, security features, and open-source flexibility. These tools complement each other, with Nagios providing broad network monitoring and ntopng offering detailed traffic analysis. Challenges affecting bandwidth optimization in Kenyan universities include ICT infrastructure limitations, hardware constraints, network congestion, outdated routers, and software misconfigurations. Environmental factors, such as signal interference and distance from routers, also impact bandwidth efficiency. The framework emphasizes real-time network monitoring, efficient bandwidth allocation, and

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security measures to ensure optimal performance. Experimental validation demonstrated a direct relationship between bandwidth optimization and throughput, while latency and packet loss negatively affected network quality. Overall, the study highlights the importance of structured network management, continuous monitoring, and strategic infrastructure upgrades to enhance bandwidth efficiency in educational institutions.

KEYWORDS: Bandwidth optimization, Local Area Network, Network monitoring, Universities, Kenya, Traffic management

1. INTRODUCTION

1.1.Background of the Study

Universities in Kenya are facing unprecedented demands for network bandwidth due to the country's rapid digitization of higher education (Kamau et al., 2019). Effective bandwidth management has become crucial as educational institutions increasingly rely on digital platforms for administration, research, and teaching (Gitau & Omwenga, 2021). Implementing intelligent monitoring and optimization frameworks that ensure fair distribution and efficient use of resources is more challenging than simply expanding bandwidth capacity (Chen et al., 2019). Inadequate infrastructure, limited funding, and the need to serve diverse user groups with different bandwidth requirements create specific challenges for bandwidth management in Kenyan universities (Mwangi & Ochieng, 2020). The traditional approach of merely assigning more bandwidth without proper monitoring and optimization has proven to be insufficient.

1.2.Problem Statement

The network performance at Kenyan universities still continues to be a problem, despite great investments being made in internet connectivity (UNESCO, 2021). The unreliability of current bandwidth monitoring framework leads to the poor resources distribution, network overload and low user services (Zhao et al., 2020). This is a problem because network administrators have little visibility on the traffic patterns, which makes it challenging to discover bottlenecks, high priority to applications, and bandwidth fairness among individuals (Johnson et al., 2020).

1.3 Research Objectives

1.3.1 General Objective

To develop a local area network monitoring framework for bandwidth optimization in Kenyan universities.

1.3.2 Specific Objectives

To establish bandwidth monitoring technologies employed in universities in Kenya

To determine the challenges facing bandwidth distribution in Kenyan universities

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To develop a LAN monitoring framework for bandwidth optimization in universities in Kenya

1.4 Research Questions

What bandwidth monitoring technologies are currently employed in Kenyan universities?
What are the main challenges affecting bandwidth distribution in Kenyan universities?
How can a LAN monitoring framework be designed to optimize bandwidth utilization?

1.5 Significance of the Study

The research, will be of use in building, adding to and expanding on the body of knowledge on network management and optimization specific to the African higher education setup. Our results will help university executives and IT specialists to make the best decisions regarding investments in network infrastructure and management practices. The framework suggested will be applied as a working-out manual to enhancing the networks and user satisfaction within educational establishments.

2. LITERATURE REVIEW

2.1 Bandwidth Management in Educational Institutions

Bandwidth management in educational environments requires balancing multiple competing demands while ensuring equitable access to network resources. Research has shown that effective bandwidth management involves not only monitoring current usage but also predicting future demands and implementing proactive optimization strategies.

Studies in similar contexts have highlighted the importance of traffic classification, Quality of Service (QoS) implementation, and real-time monitoring in achieving optimal bandwidth utilization. The unique characteristics of educational traffic, including peak usage during class hours and varying application requirements, necessitate specialized approaches to bandwidth management.

2.2 Network Monitoring Technologies

The issue of network monitoring technology has also developed and there are different methods of network traffic analysis and performance optimization (Zhao et al., 2020). The old days Simple Network Management Protocol (SNMP) uses and versions offer simple monitoring, yet the repurposing of solutions and new offerings now include deep packet inspection, machine learning, and predictive analytics (Johnson et al., 2020).

The open-source tools, such as Nagios, Zabbix, and ntopng, have become popular in learning institutions as they are not only very affordable but also versatile (Nagios Enterprises, 2021; ntop, 2021). The tools provide much capacity to monitor, but they can be customized to suit specific

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requirements of the institutions. A study conducted by Abubakar and Adamu (2020) has shown that commercial solutions and open-source monitoring tools have similar functions but the former are less advantageous to use in resource-limited settings that are characteristic of developing countries.

2.3 Challenges in Developing Countries

The difficulties in network infrastructure in developing economies, especially in Sub-Saharan Africa, are clearly reported in the literature (World Bank, 2021; Mwangi & Ochieng, 2020). Some of these challenges are the limited funding, poor technical support, poor power supply, and poor internet backbone capacity (UNESCO, 2021). These determinants are very influential in the application and success of network monitoring and automation plans.

Studies have indicated that the efficient management of networks in developing countries needs a solution that not only performs technically well; it must be economically effective and flexible to the surrounding environment (Kamau et al., 2019). According to Gitau and Omwenga (2021), solution must be within the context of the African universities and taking into consideration the local infrastructure challenges as well as resource availabilities.

3. METHODOLOGY

3.1 Research Design

This study adopted an experimental research design approach, incorporating multiple data collection methods to achieve comprehensive understanding of bandwidth optimization challenges. The research design integrated three main components: desktop research for literature review and theoretical foundation, structured interviews with IT experts to gather professional insights and practical experiences, and experimental evaluation of monitoring tools. This mixed-method approach allowed for triangulation of data sources, ensuring robust findings and comprehensive analysis of bandwidth optimization challenges while developing the proposed framework.

3.2 Study Area

The study was conducted at Kibabii University, selected as a representative case study of a typical Kenyan public university. The university's network infrastructure, user demographics, and operational challenges provide a suitable environment for testing and validating the proposed framework.

3.3 Data Collection Methods

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3.3.1 Desktop Research

Desktop research including the review of the current literature on the bandwidth optimization and network monitoring framework topics was done to foundationally base the project on theoretical underpinnings and review the current literature on the topics. This involved:

- Academic journal review and proceedings of conferences
- Evaluation of the current solutions to network monitoring and best practices
- Research of bandwidth optimization mechanisms in schools
- Investigation of case studies of similar contexts in the world

Monitoring tools technical documentation review

3.3.2 Expert Interviews

IT experts who work in different Kenyan universities were invited to administrative interviews to provide professional perception and practical experiences. The interviewing was comprised of:

- Choice of IT experts who have at least 3 years' experience in the university network management
- Semi-structured interviews addressing up-to-date trends, and discomforts and most preferred tools
- Experience of the experts in the field regarding monitoring technologies and optimization strategies
- Development of ideas on implementation issues
- Confirmation of found problems and possible solutions

3.3.3 Primary Data Collection Through Monitoring Tools

Primary data was collected through:

- Network monitoring tools deployment and data collection
- Performance measurements using specialized software
- Traffic analysis over extended periods
- System performance observations and measurements

3.3.4 Network Monitoring Tools Evaluation

Several network monitoring tools were evaluated based on the following criteria:

- Compatibility with existing infrastructure
- Security features and access controls
- Open-source availability and community support
- Scalability and performance impact
- Ease of deployment and maintenance

3.4 Data Analysis

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The collected data was analyzed using both descriptive and inferential statistics. Performance metrics including throughput, latency, packet loss, and bandwidth utilization, were analyzed to identify patterns and relationships. Statistical software was used to perform correlation analysis and regression modeling to understand the relationships between different variables.

4. RESULTS AND DATA ANALYSIS

4.1 Current Bandwidth Monitoring Technologies in Kenyan Universities

The evaluation of existing monitoring technologies revealed significant variations in implementation across different institutions. Most universities rely on basic router-based monitoring with limited traffic analysis capabilities. The study identified the following commonly used approaches:

- SNMP-based monitoring using manufacturer-provided tools
- Basic bandwidth monitoring through router interfaces
- Limited implementation of dedicated monitoring software
- Manual monitoring and reporting processes

4.2 Challenges Facing Bandwidth Distribution

The analysis identified several critical challenges affecting bandwidth optimization in Kenyan universities:

Table 4. 1 Analysis of challenges facing bandwidth Distribution

N/S	Challenges of Bandwidth	Analysis from Expert response
1.	Infrastructure Limitations	• Outdated network equipment and routers • Inadequate network segmentation • Limited fiber optic connectivity within campuses • Insufficient wireless access point coverage
2.	Technical Challenges	• Lack of traffic prioritization mechanisms • Absence of Quality of Service (QoS) implementation • Limited network monitoring capabilities

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		• Inadequate bandwidth allocation policies
3.	Environmental Factors	• Signal interference from various sources • Physical distance limitations affecting wireless connectivity • Power supply reliability issues • Climate-related equipment performance degradation
4.	Human Resource Challenges	• Limited technical expertise in network management • Inadequate training on monitoring tools • Insufficient staffing for 24/7 network monitoring • Lack of standardized procedures and documentation

4.3 Monitoring Tools Analysis

The comparative analysis of monitoring tools revealed that Nagios and ntopng emerged as the most effective solutions for the university environment:

Table 4. 2 Monitoring tools analysis

N/S	Monitoring tools	Advantages
1.	Nagios	• Comprehensive network device monitoring • Flexible alerting and notification system • Extensive plugin ecosystem • Strong community support and documentation • Scalable architecture suitable for large networks

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2.	ntopng	• Detailed traffic analysis and classification • Real-time network traffic visualization • Historical data analysis capabilities • Web-based interface for easy access • Deep packet inspection capabilities

4.4 Complementary Implementation

The study found that implementing both tools in a complementary manner provides optimal coverage, with Nagios handling infrastructure monitoring and ntopng focusing on traffic analysis and optimization.

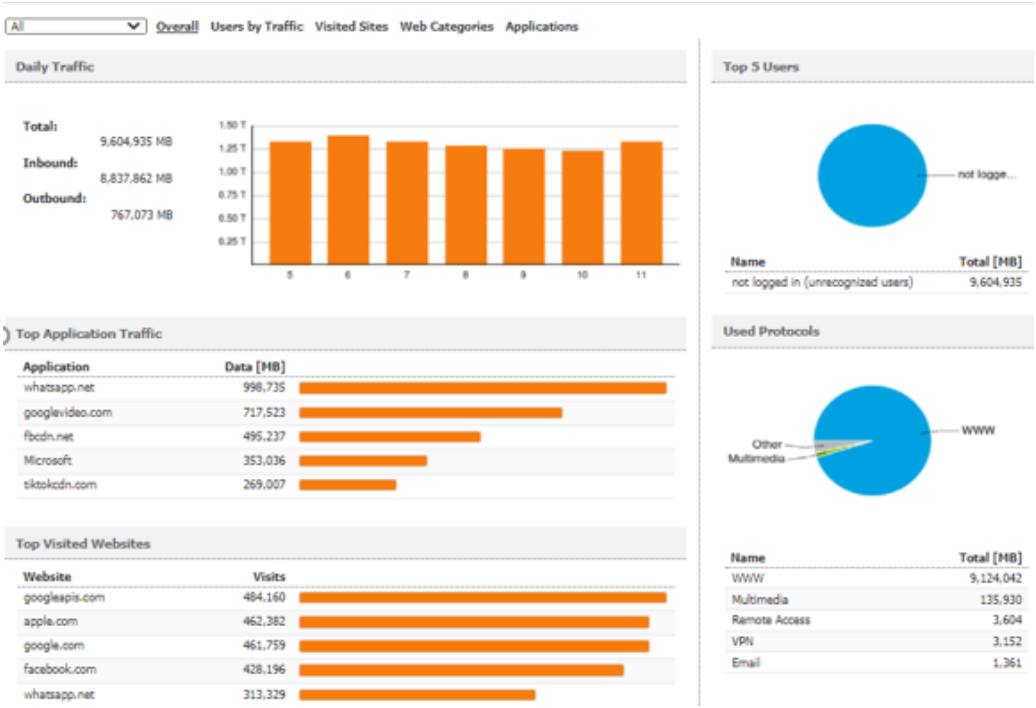

Figure 4.1: Traffic Flow at the Static Firewall Gateway

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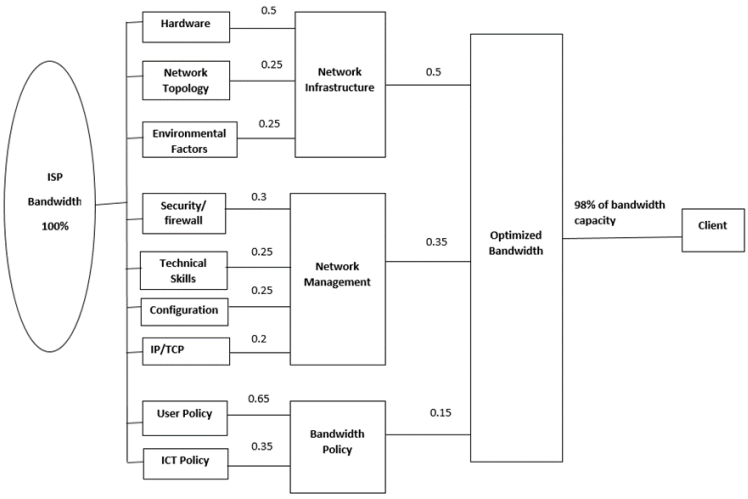
5. Framework Development

Based on the analysis of monitoring tools and identified challenges, a comprehensive LAN monitoring framework was developed. The framework incorporates best practices from the literature review and addresses specific challenges identified in the Kenyan university context.

5.1 Framework Overview: LAN Monitoring Framework for Bandwidth Optimization (LMFBO)

The development of the LAN Monitoring Framework for Bandwidth Optimization (LMFBO) is guided by the analysis of findings from the first two objectives, addressing critical variables that impact bandwidth optimization in Kenyan universities. The framework tackles problems related to bandwidth optimization through systematic management and improvement of ICT structures, network management challenges, application of bandwidth policies, and addressing users' requirements.



The LMFBO framework is designed to systematically analyze and strengthen institutional network performance, allocate resources efficiently, and provide optimal user experience through comprehensive monitoring and optimization strategies.

5.2 Framework Architecture

The LMFBO framework architecture addresses four key sub-constructs:

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N/S	Sub-constructs	Key features
1.	ICT Infrastructure Management and Improvement	• Hardware optimization and upgrade strategies • Network equipment configuration and maintenance • Infrastructure capacity planning and scalability
2.	Network Management Challenges	• Real-time monitoring and alerting systems • Traffic analysis and pattern recognition • Performance bottleneck identification and resolution
3.	Bandwidth Policy Implementation	• Quality of Service (QoS) policy enforcement • Traffic prioritization and bandwidth allocation • User access control and bandwidth limits
4.	User Requirements Management	• User behavior analysis and profiling • Application-specific bandwidth requirements • Dynamic resource allocation based on demand

5.3 Framework Components

The LMFBO framework consists of four main integrated components:

5.3.1 Monitoring Layer

- Real-time network device monitoring using Nagios
- Traffic analysis and classification using ntopng.
- Performance metrics collection and storage
- Automated alert generation and notification
- Network topology mapping and visualization

5.3.2 Analysis Layer

- Traffic pattern analysis and reporting
- Bandwidth utilization trend analysis
- Performance bottleneck identification
- Predictive analysis for capacity planning
- Correlation analysis of network performance parameters

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5.3.3 Optimization Layer

- Dynamic bandwidth allocation algorithms
- Quality of Service (QoS) policy implementation
- Traffic shaping and prioritization
- Load balancing and redundancy management
- Automated network configuration adjustments

5.3.4 Management Layer

- Web-based dashboard for administrators
- Automated reporting and documentation
- Policy management and configuration
- User access control and security
- Performance analytics and trend visualization

5.4 Experimental Validation

That validation was done to the Predicted Bandwidth Utilization, Actual Bandwidth Utilization, and the resultant framework made the threshold of its validation.

Timestamp	Actual Bandwidth Utilization (Mbps)	Predicted Bandwidth Utilization (Mbps)
2023-08-01 08:00 AM	200	205
2023-08-01 12:00 PM	350	340
2023-08-01 04:00 PM	500	510
2023-08-01 08:00 PM	400	390
2023-08-02 08:00 AM	220	230

5.5 Framework Implementation Guidelines

5.5.1 Pre-Implementation Requirements

Before implementing the proposed framework, institutions should ensure:

• Adequate hardware resources for monitoring servers
• Network infrastructure assessment and documentation
• Staff training on monitoring tools and procedures
• Establishment of network management policies

5.5.2 Implementation Phases

Phase 1: Infrastructure Preparation

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- Install and configure monitoring servers
- Deploy monitoring agents on network devices
- Establish secure communication channels
- Create baseline performance measurements

Phase 2: Monitoring Tools Deployment
- Install and configure Nagios for infrastructure monitoring
- Deploy ntopng for traffic analysis
- Integrate monitoring tools with existing systems
- Configure alerting and notification systems

Phase 3: Optimization Implementation
- Implement QoS policies based on monitoring data
- Deploy traffic shaping and prioritization rules
- Configure dynamic bandwidth allocation
- Establish performance monitoring dashboards

Phase 4: Validation and Fine-tuning
- Conduct performance testing and validation
- Fine-tune configuration based on results
- Train staff on system operation and maintenance
- Establish ongoing monitoring and reporting procedures

5.5.3 Maintenance and Support

Ongoing maintenance of the framework requires:
- Regular system updates and security patches
- Continuous monitoring of system performance
- Periodic review and adjustment of optimization policies
- Staff training and knowledge transfer programs

6. Challenges and Limitations

6.1 Implementation Challenges

Several challenges may affect the successful implementation of the proposed framework:
- Limited financial resources for hardware and software acquisition
- Resistance to change from existing operational procedures
- Technical complexity requiring specialized expertise

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- Integration challenges with legacy systems

6.2 Study Limitations

This study has several limitations that should be considered:

- The case study approach limits generalizability to other institutions
- Limited testing period may not capture all seasonal variations
- Focus on technical aspects with limited consideration of user behavior
- Dependence on specific monitoring tools may affect long-term sustainability

7. Recommendations

7.1 For Educational Institutions

Universities implementing bandwidth optimization frameworks should:

- Invest in staff training and capacity building
- Develop comprehensive network management policies
- Establish dedicated network management teams
- Create partnerships with other institutions for knowledge sharing

7.2 For Policy Makers

Government and regulatory bodies should:

- Develop national standards for university network infrastructure
- Provide funding support for network infrastructure upgrades
- Facilitate knowledge sharing among educational institutions
- Support research and development in network optimization

7.3 For Future Research

Future research should explore:

- Machine learning applications in bandwidth optimization
- Mobile and wireless network optimization in educational settings
- Cost-benefit analysis of different monitoring approaches
- User behavior analysis and its impact on network performance

8. CONCLUSION

This study successfully developed and validated a comprehensive LAN monitoring framework for bandwidth optimization in Kenyan universities. The research identified significant challenges in current network management practices and proposed practical solutions that demonstrated measurable improvements in network performance.

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The experimental validation showed that implementing proper monitoring and optimization frameworks can significantly improve network performance even with existing infrastructure. The combination of Nagios and ntopng proved effective for comprehensive network monitoring and traffic analysis in the university environment.

The framework's emphasis on real-time monitoring, efficient bandwidth allocation, and security measures provides a solid foundation for improving network performance in educational institutions. The results demonstrate that structured network management, continuous monitoring, and strategic infrastructure upgrades are essential for enhancing bandwidth efficiency.

The study contributes valuable insights for network administrators, university management, and policymakers on effective approaches to bandwidth optimization in resource-constrained environments. The proposed framework provides a practical roadmap for improving network performance and supporting the digital transformation of higher education in Kenya.

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