ACSIJ Advances in Computer Science: an International Journal, Vol. 3, Issue 1, No.7 , January 2014
ISSN : 2322-5157
www.ACSIJ.org

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Optimization Based Blended Learning Framework for Constrained Bandwidth Environment

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Abstract

Adoption of multimedia based e-learning approach in higher education institutions is becoming a key and effective component for curriculum delivery. Additionally, multimedia teaching and learning approach is a powerful tool to increase the perceived level of user satisfaction, leading to enhance the blended learning process. However, transmission of multimedia content over the Internet in Constrained Bandwidth Environment (CBE) is a challenge. This paper developed a framework that addressed the most critical issue not addressed by the existing blended learning frameworks after careful literature scanning. The framework was tested and validated through experimental scientific research process. This paper summarizes the main findings of the PhD Thesis defended by the author some time back.

Keywords: *Blended Learning, Framework, Multimedia learning, Optimization, Constrained Bandwidth Environment.*

1. Introduction

In the current knowledge driven society, the developments in Information Technology have brought about many positive changes in every field including education. Driven by the growing demand of higher education together with increasingly available new innovative information technologies to increase access to learning opportunities, the organizations in Lease Developed Countries (LDCs) are considering cost effective and efficient means for course delivery [34]. The aim of large scale moves to use technology to deliver educational content, by organizations in emerging environments is to prepare them for the information and communication technology revolution. Research shows that demand for higher education is expanding [1] exponentially worldwide, and about 150 million people are estimated to seek for tertiary education by the year 2025.

On the other hand, a larger percentage of eligible candidates do not get access to higher education in LDCs. According to Millennium Development Goal [2], the university enrollment in Sub-Sahara Africa is the lowest as compared to other parts of the world.

To be part of the global village, it is necessary for Sub-Saharan countries to make transition from natural resources based economies to knowledge based economies, in an effort to make departure from the existing situation. Researchers argue that e-learning can be used to deliver cost effective, flexible, and quality higher education more effectively with improved access by learners [3] and has the capacity to provide education for all in LDCs [4]. However, universities in LDCs are integrating Information Communication Technologies (ICT) in their systems at a very slow pace. UNESCO Institute for Statistics report [5] states that “in Sub-Saharan Africa, it is estimated that only 1 in 250 people have access to the Internet as against the global average of 1 in 15” [6].

The implementation of e-learning is an ideal choice for the universities. And the introduction of the concept of blended learning model is a natural start to achieve the goal for the universities in developing countries, which is pursued by many organizations in the developed world.

Research indicates that blended learning approach is the most effective teaching and learning model [7], [8].

Although the concept of blended learning can prove as a ground breaking and innovative approach in the context of developing countries [9], it is not a panacea. There are some obstacles such as Constrained Bandwidth Environment (CBE) which can be a key challenge to its adoption in the sub-region [10]. Constrained Bandwidth Environment refers to insufficient bandwidth as compared to user needs, coupled with other constraints such as high cost, misuse and mismanagement due to ineffective or non-existent Bandwidth Management Policies (BMP), viruses and spam etc.

A large number of organizations in the world are increasingly adopting blended learning solutions in their systems and several frameworks have been designed by various authors such as [10], [11], [12], [13], [14]. A critical review of the issues addressed by the existing blended learning frameworks suggests that many aspects of constrained bandwidth environment are taken for granted that need to be addressed explicitly.

2. Aim of the Research

The main objective of this research was to develop a framework for adoption of blended learning process in Constrained Bandwidth Environment, a peculiar state associated with most of the developing countries. Specifically, the study intended:
(a) To conduct a critical investigation of the literature on current approaches aimed to identify gaps and challenges for implementing blended learning process, within Constrained Bandwidth Environment.
(b)To identify multimedia (learning content) compatible with the challenges of Constrained Bandwidth Environment.
(c) Exploring factors of e-readiness leading to the development of an e-readiness model for organizations seeking to implement blended learning process and their challenges in the context of Constrained Bandwidth Environment.
(d) To design a framework for implementing blended learning process in Constrained Bandwidth Environment.
(e) To test and validate the designed framework.

To address the specific objectives, this research sought to develop the framework guided by the following research questions:
1. What are the current approaches and their challenges for implementing blended learning process, within Constrained Bandwidth Environment?
2. What type of multimedia content is compatible with the challenges of Constrained Bandwidth Environment?
3. What are the factors of e-readiness leading to the development of an e readiness model for the organizations seeking to adopt blended learning systems, and their challenges within Constrained Bandwidth Environment?
4. What framework design supports the implementation of blended learning process in Constrained Bandwidth Environment?
5. How well does the proposed framework address the issues of Constrained Bandwidth Environment?

3. Methodology

This study used mixed research methods; qualitative and quantitative that had approaches such as case study, surveys, and experiments, dictated by the nature of the study and research questions that could not be answered by using a single approach [15].

3.1. Research Design Framework

This research followed the generalized research design framework format as suggested by [15]. Fig. 1 presents the research design framework of the study.

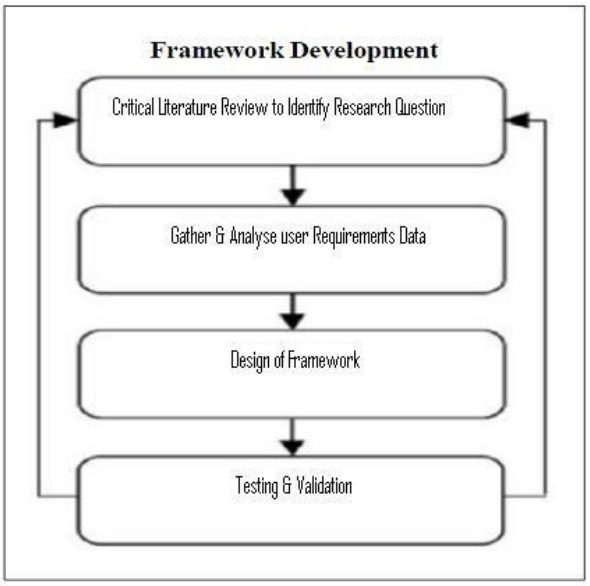

Fig. 1 Research design framework

First phase presented the 'Critical Literature Review' to identify Research Question. Second phase was 'Gathering and Analyzing user Requirement Data' for e-learning which is part of blended learning process. Third phase was 'Design of the Framework'. Design of the

framework was informed by first and second phases that worked as input to the design phase. The designed framework was tested and validated at fourth phase that completed the framework development process. Following sections present the brief description of all the phases.

3.1.1 Identifying approaches for adoption of Blended learning process in CBE

The aim of identifying existing blended learning approaches, strategies, and their challenges was to identify the research question. To achieve the objective, literature survey was conducted by using various 'key words' and 'citations' during research process aimed to provide an answer to Research Question 1. Secondary source of data was acquired through the studying of technical literature; research articles, research reports, books, journals, reports on the general problem area, attending and participating in International conferences, interaction with e-learning experts, and stakeholders [16]. The literature survey also included relevant PhD thesis reports submitted to various universities in the world.

The literature review results revealed that [10], [11], [12], [13], [14] are most popular models for adoption of blended learning. An overview of the identified blended learning frameworks suggest that mainly they address issues related to the following components: Institutional (Administrative & academic affairs etc.); Learners & Lecturers concerns **(**Audience requirement analysis); Pedagogical (Content analysis). Technological Infrastructure (Hardware & software); Learning Content (Teaching and learning material); Management & Evaluation (Logistics, student support services); Ethical (Copyright etc.); Resources (Human & financial resources); Interface Design (user interface); and Interactivity (Interactivity among various learning modes in blended learning environment).

The critical analysis of literature points to the lack of frameworks for adaptation of blended learning process that addresses the important issue of constrained bandwidth environments. The need has therefore remained for framework that support implementation of blended learning process in constrained bandwidth environments [18].

The reviewed literature gave a way forward to gather data on user requirements.

3.1.2 Gathering User Requirements Data

User requirements data was gathered through study investigation that comprised of literature investigation and empirical investigation. Literature investigation aimed to identifying multimedia compatible with challenges of CBE and focused on the most important and dominant multimedia application, namely video format, using a Multi-Level Systematic Approach (MLSA). The research found that MPEG4 (.mp4) is the only video format, in addition to MP3, JPEG, the audio and graphic formats that are compatible with the challenges of developing countries, to answer Research Question 2.

Aligning a strategy with challenges, opportunities, and realities that abound the context is an important preliminary step leading to the successful adoption of an innovation [19]. Also the process of development of such a strategy must involve the concern of relevant stakeholders at the earlier stage on one hand and the stakeholders must be 'e-ready' on the other hand, in order to design a coherent achievable strategy tailored to meet their needs [20]. The key stakeholders identified by this research included: Institutions, lecturers, and students [21].

Basing on this background, this research used a multiple case study approach, an appropriate research method in the situation when the intent of the study is description or theory building as suggested in [22], in order to achieve the underlying objective of the empirical investigation**.** Researchers selected 3 universities in Uganda, in line with [23] guidelines and developed three survey questionnaires; Institutional Readiness Questionnaire (IRQ), Lecturers' Perception Questionnaire (LPQ), and Students' Perception Questionnaire(SPQ) to explore factors contributing to e-readiness in constrained bandwidth environment as shown in Fig.2.

Prior reliability testing of the data collection tools was done using Chronbach's alpha coefficient, in line with suggestions of [24] that gave the average correlation among the various items in the questionnaires. The responses were coded into the Statistical Package for Social Sciences (SPSS) to run the reliability test. The Chronbach's alpha coefficient value for Institutional and Students' questionnaires were found above 0.7 which is acceptable. However, for lecturer's questionnaire, reliability test could not run because most of the questions were open ended aimed to extract information from lecturers rather than seeking their opinion.

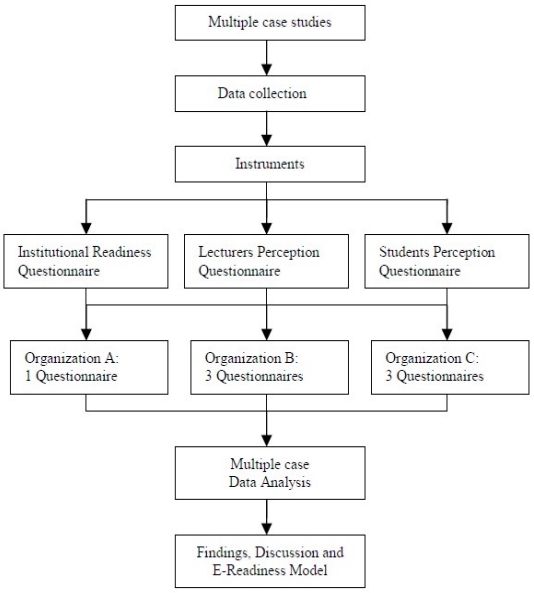

Fig.2 Survey research design

The questionnaires were distributed among identified stakeholders in a sample of three organizations (universities); A, B and C. The study applied convenient sampling technique used widely in Doctoral Thesis reports (e.g., [25]). Furthermore the methodology used is appropriate for this research and has achieved recognition by researchers at International level (e.g., see [26]).

The study concluded with identification of the network (bandwidth) related issues and assessed the level of e-readiness leading to the development of an e-readiness model, influenced by three survey questionnaires; IRQ, LPQ, and SPQ as the answer to Research Question 3.

Lack of sufficient bandwidth, Low speed Internet, High cost of bandwidth, Ineffective or non-existent Bandwidth Management Policies (BMP) leading to mismanagement of available little bandwidth were among the main critical issues identified during the investigation.

Identification of multimedia compatible with challenges of constrained bandwidth environment and an E-readiness Model, was a step towards designing a framework that addressed the critical issues not addressed by existing blended learning frameworks and models.

3.1.3 Design of the Framework

Design of the framework is informed by previous sections 3.1.1 and 3.1.2. Section 3.1.1 affirmed the need of a blended learning framework adaptable in constrained bandwidth environment. E-learning which is an essential part of blended learning occurs, when at least there is learning content (multimedia) and network to deliver the content [27]. Hence multimedia and network (bandwidth) related data constitutes the main part of user requirements data for design of blended framework adaptable in constrained low bandwidth environment.

On that pretext, section 3.1.2 gathered data on user requirements; identified multimedia (learning content) compatible with challenges of constrained bandwidth environment through literature investigation and identified the most critical (bandwidth or network related) challenges, organizations seeking to implement blended learning solutions are facing. The framework that addressed the issue of constrained bandwidth environment not addressed by existing blended learning frameworks is presented in Fig.3. The framework presented used a popular framework by Khan [13] as basis and has two main components; Network Optimization and Multimedia Optimization.

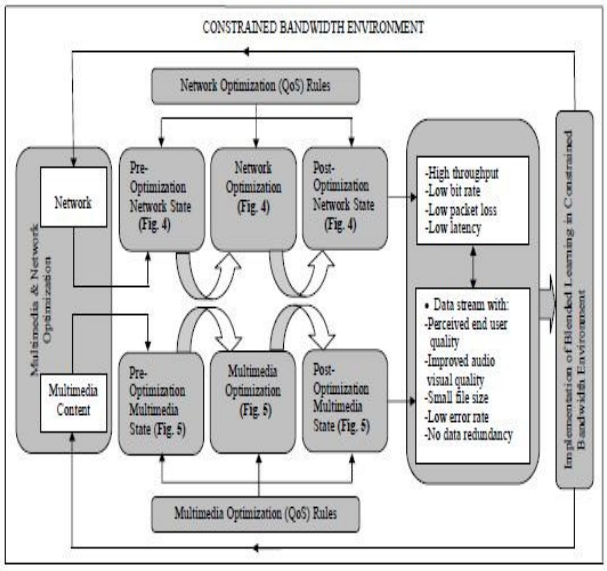

Fig. 3 Optimization Based Blended Learning Framework for (CBE) (OBBLFCBE)

Khan's framework has eight dimensions; Institutional, Pedagogical, Technological, Interface design, Evaluation, Management, Resource support, and Ethical. Although Khan's framework considered many factors leading to the adoption of a successful blended learning strategy in organizations. However, the issue of adopting blended learning process in constrained bandwidth environment has not been addressed. More particularly, the Pedagogical dimension of the framework states that organizations are required to provide sufficient

bandwidth, which is limited in CBE, and carryout learning content analysis without providing details about the type of content compatible with the challenges of constrained bandwidth environment where designing the content is costly.

The underlying thesis defended in this research addressed the above most two critical issues and posits that: in constrained bandwidth environment, optimizing the network and multimedia content supports a framework for the adoption of blended learning process. Moreover, research shows that application and network are symbiotic and performance is enhanced when both network and learning content are optimized together [28]. These two issues were impeding the technology integration process in developing countries.

The framework as shown in the Fig.3 comprises of a sequence of processes. Each process has its input and output. Network optimization and Multimedia optimization are the main components governed by their respective Quality of Service (QoS) rules. Pre-optimization states are inputs to optimization states of network and multimedia processes, whereas post-optimization states act as their outputs.

However, for next process the interaction between the optimized states of network and multimedia, these two outputs act as inputs, and output results of this process provide a high performing multimedia content to be used to implement blended learning process in constrained bandwidth environment and close the loop. The details of the main components of the framework; Network Optimization and Multimedia Optimization along with various related technological concepts are discussed in the following sections.

3.1.3.1 Network Optimization

Fig. 4 as mentioned in Fig. 2 outlines the techniques that can be used to optimize the network system in an organization. Pre-optimization and Post-optimization states of network are also shown in the figure for the purpose of comparison.

Filtering the network traffic that is done using packet filter firewalls is aimed to reduce the congestion. The acceptance or discarding decision of each arriving packet is made by the firewall by comparing the information at its header, with a set of governing rules called Access Control Lists (ACLs) [29].

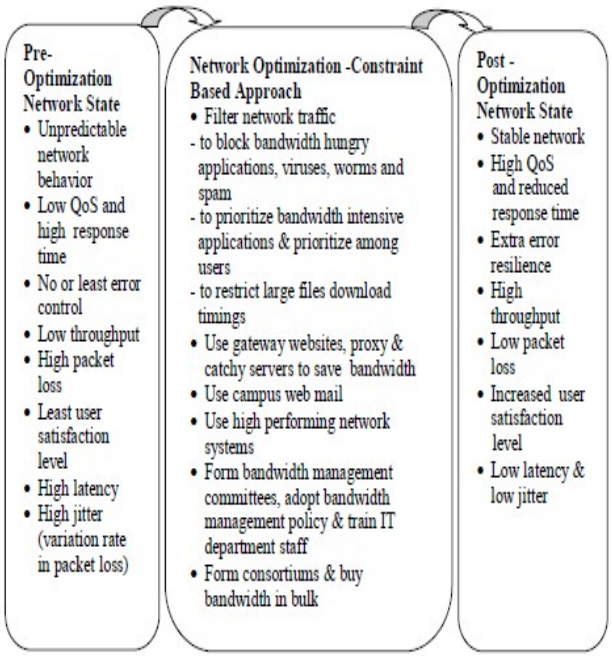

Fig. 4 Network Optimization

Authentication: User Authentication System (UAS) can be used to restrict the access to network resources from unauthorized users by issuing them log in passwords. [30].

Prioritizing the network traffic: Prioritization technique is applied to enhance the Quality of Service (QoS) for real time applications such as video and audio by processing them before all other data streams, aiming to provide low latency as dictated by policy rules configured on the router interface. In a similar manner, the technique is used to prioritize among various categories of users based upon their associated privileges [30].

Time-Based ACLs: Time based ACLs are used to restrict the users from downloading and uploading huge files, during the busy working hours of the week that consumes a lot of bandwidth. ACLs can be configured on a router in the network system by using simple command (Cisco IOS Software Release 12.0.1.T) by creating the time range on the router, using preferably the Network Time Protocol (NTP) synchronization.

Cache and Proxy: Cache and proxy, the two local memory devices are the best option to save bandwidth [31]. The cache saves the most frequently digital contents needed by the students. On the hand, proxy servers are used to save the recently or more often visited WebPages.

3.1.3.2 Multimedia Optimization

Fig.5 as mentioned in Fig.3 presents the multimedia optimization techniques along with Pre-optimization and Post-optimization states.

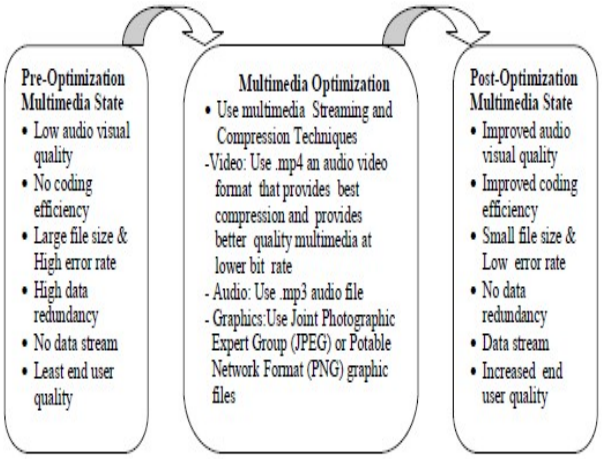

Fig.5 Multimedia Optimization

Multimedia may refer to presentation of information using multiple forms of media (text, graphics, audio, and video). The concept of interactive multimedia in constrained bandwidth is still a challenge [20]. However, compression and streaming techniques stated in Fig.5 can be used to enhance the media quality [32].

Multimedia Streaming: Multimedia streaming techniques enable the user to receive a real time continuous audio video data once the sender start sending the file, without waiting when full contents are ready in local storage. However, the data is compressed before it is transmitted and is again decompressed before viewing by the viewer. In on demand option, the client receives the streaming multimedia contents as per demand.

Multimedia Compression: The compression technique is applied to reduce the huge file size to manageable level for efficient transmission of multimedia content. The compression process significantly reduces the bandwidth requirements as required in the context of LDCs.

Video. Transmission of time sensitive multimedia contents such as video requires much bandwidth is challenge in low bandwidth networks. However, the compression technique applied under Quality of Service (QoS) can significantly reduce the demand for high bandwidth [33]. Section 3.1.2 identified MPEG4 (MP4) as the standard video format compatible with constrained bandwidth environment that provides better quality at low bit rate, is appropriate for use in developing countries.

Audio: Research indicates that MPEG-3 (MP-3) audio format is compatible with the challenges of CBE [34].

Graphics: Joint Photographic Expert Groups (JPEG) and Portable Network Graphics (PNG) graphic files are identified as compatible with CBE [34].

3.1.4 Framework Testing and Validation

3.1.4.1 Framework Testing

An experimental testbed as shown in figure 6 was designed to test and validate the designed framework.

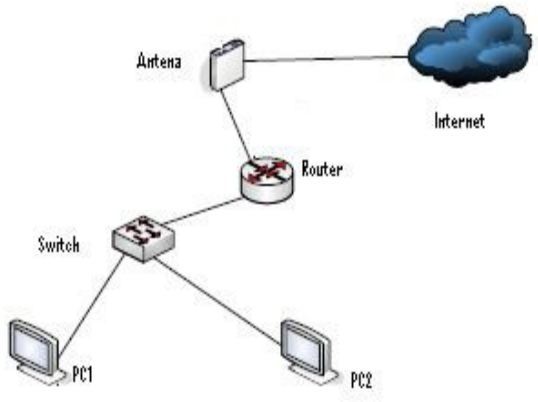

Fig.6 Experimental test bed system architecture

The testbed used following main hardware and software; two computers connected to a Cisco router by means of a Cisco switch, 128 kb broad band Internet connection, various multimedia files (video, audio, graphics, and text), multimedia conversion software, and "Net catcher"- a multimedia performance measuring tool installed on one of the client computers. We acquired one video file from Internet and converted it to various other types for the sake of consistency.

Afterwards, all these files were compressed-converted to .mp4 (commonly used video standard). Similar procedure was adopted for other types of media files. The user-driven metric 'latency' was used to measure the performance of various media (video, audio, graphics, and text) files when they were transmitted over a wireless network connection. The media performance was measured in four phases:

Phase I: Unoptimized Network & Unoptimized Multimedia (UNUM)
Phase II: Unptimized Network & Optimized Multimedia (UNOM)
Phase III: Optimized Network & Unoptimized Multimedia (ONUM)
Phase IV: Optimized Network & Optimized Multimedia (ONOM)

Multimedia Performance for Unoptimized Network: This section presents the screen shots taken by Net Catchlite tool that measured the latency, when unoptimized and optimized multimedia (.flv video) files were transmitted over the unoptimized wireless network. The average latency for unoptimized and optimized .flv file was 559ms and 422ms as shown in Fig.7and Fig.8 respectively.

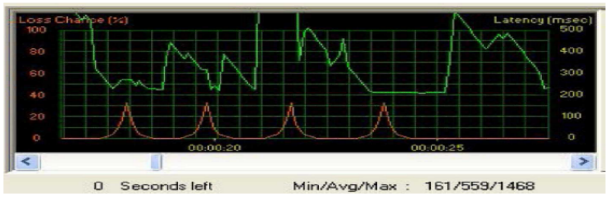

Fig.7 latency results for unoptimized .flv video file

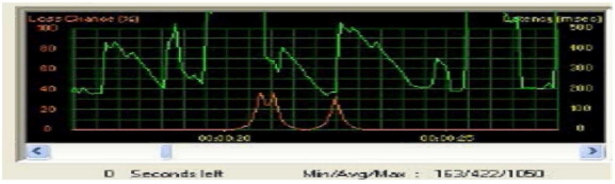

Fig. 8 latency results for optimized .flv video file

Multimedia Performance for Optimized Network: Prior to transmission of multimedia files over the network, this research optimized network by configuring policy map on the router interface by allocating specific amounts of bandwidth to various classes and prioritizing a specific type (e.g., video and audio) over other network traffic, aimed to apply Quality of Service (QoS) to increase the perceived level of user satisfaction [35].

With optimized network state, Net Catchlite tool measured the latency of unoptimized and optimized multimedia (video) files (.flv) when transmitted over the optimized wireless network. The average latency for .flv was 221ms and 212 ms respectively as shown in Fig 9 and 10.

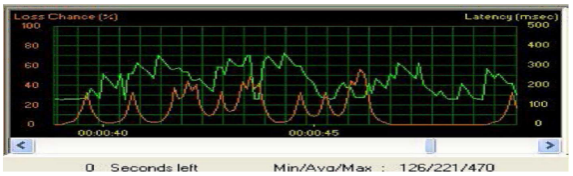

Fig. 9 Latency results for unoptimized flv

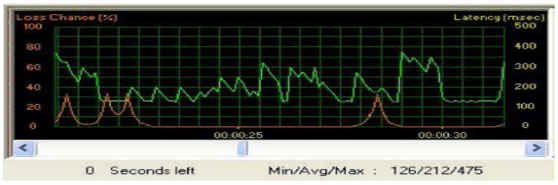

Fig. 10 Latency results for optimized .flv

Analysis of Multimedia performance results: The analysis of .flv video format performance is presented in Table 1 that illustrates the latency comparison for various phases.

Table 1 Latency results analysis for .flv

Phases	Optimized Network	Optimized Multimedia	Average Latency (milliseconds)	Percentage of Latency Reduction
I- (UNUM)	X	X	559	N/A
II (UNOM)	X	✓	422	24.51 %
III-(ONUM)	✓	X	221	60.46 %
IV (ONOM)	✓	✓	212	62.07 %

The percentage of latency reduction is also calculated. We notice that at every phase, latency factor continue to reduce as compared to initial phase when both network and multimedia files were not optimized. The results further indicate that at phase IV when both network and multimedia were optimized, latency factor reduced significantly, from 559 ms to 212, suggesting a reduction of 62.07%.

In a similar manner, 6 other video files (.mov, .mkv, .mpg, .mpg2, .avi, .mp4); 3 Audio files (WAV, M4A, MP3); 3 Graphic file files (bmp, tiff, JPEG); and 2 Text (PPT) files were transmitted over Internet one by one and results calculated in 4 phases. Study results indicated that performance of multimedia was improved significantly, when network and application were both optimized that verified the main theoretical concept of the framework.

3.1.4.2 Framework Validation

To ensure the soundness and accuracy of the designed framework, Verification and Validation (V&V) was done based on: Correspondence between model and statement of the problem which is in line with results presented in above section; Model Behavior was tested and proved that it does what it is expected to do; and Conservation of Flow was confirmed from consistent results in section 3.1.4 when several media files from each category were transmitted over the network that shows the stability of the model. The validation process was further enhanced by sending prototype results to users and IT staff working in various universities in Uganda. The designed framework was highly evaluated by users and IT professionals as shown in Table 2 (1- lowest score, 4- highest score) as answer to Research Question 5.

Table 2: Framework evaluation results by stakeholders

Item	Individual Scores										Mean	Standard Deviation
Realistic& Reasonable	4	3	4	3	3	3	3	3	4	4	3.363	0.504
User Level of Satisfaction	3	4	3	3	1	3	3	3	2	3	2.818	0.704
Representation & Solution of Critical issues	4	4	3	2	3	4	4	4	3	3	3.363	0.674
Quality of the Model	4	4	3	3	2	4	3	3	2	2	3	0.774
Usage as stakeholders' aid tool	3	4	4	3	3	4	3	4	3	3	3.363	0.504
Practical value of model for HEI in LDCs	4	3	3	3	3	4	4	4	3	3	3.363	0.504
Scientific value of model	4	4	3	3	2	3	3	2	3	2	3	0.632
Intention of using model	2	4	4	2	3	4	3	3	4	3	3.181	0.75
Contribution to enhance blended learning process in LDCs	3	4	3	4	2	3	4	3	4	3	3.272	0.646

4. Conclusions

The fundamental contribution of this research was providing Optimization Based Blended Learning Framework for Constrained Bandwidth Environment, with multimedia optimization and network optimization as its two main components. The research achieved this main objective. The framework emphasizes that performance of multimedia (learning content) can be improved when network and application are both optimized, in return that would increase the perceived level of user satisfaction, enhancing the blended learning process for organizations seeking to implement blended learning solutions in developing countries. Increasing the perceived level of user satisfaction in developing economies is a big mile stone indeed [17].

The novelty of this research is that it linked practical with theoretical foundation and relevant literature, aimed to make both scientific and practical contribution, and laid the foundation stone for further research in the area to make subsequent developments[17].

The output of this study has several far reaching implications for community of stakeholders that include; higher education institutions, students, researchers, and information system providers.

This research addresses the question of high practical value, is rooted into realistic and idealistic grounds that leads to increased usefulness of knowledge created to guide researchers. The study focused on evaluating the performance of learning content which is an integral part of blended learning process.

This research can make significant improvements on the landscape of African higher education system. At the same time, this study has given a way forward to Institutions of Higher learning to protect their valuable institutional resource (bandwidth) through prioritizing time-sensitive applications to minimize delays. The findings of the study can be used by information system developers, e-learning solution providers, and instructional designers to increase the perceived level of user–satisfaction when delivering multimedia content to the users in LDCs.

The future research may include:
(i)How to improve the performance of multimedia content, to increase further the level of user satisfaction by reducing latency factor more than shown in the current study?
(ii)How the findings of this research can be replicated in different context?
(iii)The research utilized mixed methods approach that enabled the researcher to study depth and breadth of the problem, provided the ability to triangulate the findings of the research methods used and hence giving a way forward for the utilization of the methodology by other researchers in future studies.
(iv)Researchers can use Multi Level Systematic Approach (MLSA) introduced in this study for in-depth analysis of research problems.

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