

Synchronization and Caching Solution for Cost-Effective E-Learning in Resource and Bandwidth Constrained Environments

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Abstract
Electronic learning (e-learning) content delivery and accessibility have received significant research attention over years in order to ensure reliability, availability and cost-effectiveness through Information and Communication Technologies (ICTs).The evolvement of mobile computing devices especially smartphones bring prospects in overcoming the inherent limitations of the Internet when accessing web contents. Among the potential opportunity revealed includes the ability to work offline. Therefore, this study aims to analyze the existing online and offline e-learning systems in order to explore the uniqueness, technical problems and opportunities in this field. In the same vein, this study proposed synchronization and caching approach for cost-effective e-learning content delivery. The proposed approach synchronizes contents from the original server to local database in mobile computing devices in order to deliver contents to learners in a reliable, cost-effective and timely manner. Finally, comparing existing web-based learning system and the proposed approach, the analyzed results provide empirical evidence that, the proposed approach is significant for bandwidth usage cost saving and hence cost-effectiveness due to ability of working offline. Therefore, synchronization and caching approach cut down several limitations in existing e-learning systems including: reduction of cost of bandwidth usage; improving system performance by cutting down the servers' workload and internet usage overheads; cutting down costs of purchasing hardware and increasing motivation in learning activities by allowing learners to access learning contents anywhere and anytime.
Keywords: synchronization and caching, e-learning, cost-effectiveness, content delivery, offline.

1.0. Background Information

The advancement in Internet and mobile technologies brings a new paradigm of learning over the Internet. In educational environment perspectives, learning system over the Internet has become popular and significant for supporting flexible and cost-effective learning activities especially for Higher Education Institutions (HEIs). Flexibility and accessibility are important factors that need to be considered when implementing e-learning solutions. According to Olson et al (2011), flexibility refers to the standard measure of e-learning being learning for anyone, without restriction of time and space that is ability to learn anywhere and anytime while accessibility refers to the quality of the connectivity.

Mobile phone technology evolves very rapidly offering new capabilities for supporting higher data transmission, storage, and multimedia (Cortez, 2012; Randell, 2013). Furthermore, the rate of mobile phones adoption and access to Internet is generally growing at a rapid rate bringing opportunities for reliability and availability of learning contents in HEIs. In view of Tanzania as an example; the trends of mobile subscriptions increase rapidly. According to TCRA (2014) the trends of mobile subscriptions increased from 2, 963,737 in 2005 to 27, 986,314 in March 2014 leading to a penetration rate to from 10% in 2005 to 63% in March 2014. Similarly, smartphone adoption has increased from 3% in 2010 to 9% in 2014 and promises even more growth to 21% by 2017 (TCRA, 2014).

Furthermore, the survey results of this study conducted at HEIs in Tanzania, found that in average 85% of students own laptops, 65% own smartphones and 78% own mobile phones, that means majority of students own more than one mobile computing devices that can be used as tools to facilitate access to learning opportunities. Implementing cost-effective mobile learning (m-learning) in HEIs is possible due to the fact that already students are using their mobile phones for other activities like mobile banking, mobile money (For example; M-PESA, TIGO-PESA and AIRTEL MONEY), and social networking (Mtega et al, 2014).Similarly, students are using their mobile phones for learning activities via twitter, YouTube, Skype, Facebook and other social media.

Majority of HEIs in Tanzania have adopted web based e-learning system to support learning activities. In view of Moodle (www.moodle.org), as a free web based Learning Management System (LMS) has been popular in academic environment for supporting learning activities. However, web based e-learning systems are subjected to some challenges for learning environment with resource and bandwidth constrained especially for HEIs in developing countries, Tanzania as an example. These challenges include:

i. Running web based e-learning system requires continuous and persistent Internet connection which leads to high cost of bandwidth usage;
ii. Some HEIs can't afford to provide sufficient bandwidth to satisfy a number of available Internet users around the institution to access learning contents through web based learning system;
iii. Some students may have difficulties in accessing the Internet when they are outside the institutional environment even though they own mobile computing devices and sometime may be costly;
iv. Learners may not access learning contents when they are offline;
v. Due to financial constraints, some institutions can't afford the cost of purchasing hardware and software required for supporting e-learning to satisfy the number of available e-learning users.

Employing the opportunities and capability of mobile computing devices for supporting offline e-learning would provide a cost-effective approach of learning content delivery and accessibility especially in HEIs.

Several previous studies proposed solutions for supporting both online and offline delivery of learning content, however, there are still considerable gaps to be addressed in order to improve efficiency of e-learning systems as well as content availability. The proposed solutions include; Trifonova et al (2004, 2006) proposed Mobile ELDIT to support both online and offline content delivery. The proposed system can work offline by utilizing a caching proxy. However, the main shortcoming is a single point of failure due to the fact that all data came through the proxy server, if this server was compromised all users connected to such server are subjected to the risk of running out of service and information / data theft. Royyana et al (2010) proposed offline web application and quiz synchronization for e-learning activities to support offline web application for Moodle task/assignment. One technical problem is the implementation of quiz point where the students with Wi-Fi capability phones can download the quizzes and store in their mobile memory. The Quiz engine performance depends upon the number of questions in the quiz as a result the time to display the first question is proportional to the number of questions in the quiz likewise memory requirement is directly proportional to the number of questions in the quiz. But also the proposed system requires continuous Internet connection during downloading. Jordi et al (2012) proposed Moodbile; the android application that supports both online and offline accessibility by storing offline contents in memory cache. However, synchronization functionality was not implemented. The proposed systems require continuous and reliable Internet connection during downloading of contents to memory cache as a result they favor learning environment with sufficient resources and reliable Internet connectivity.

Studies indicate that there is an exponential growth in bandwidth and decline in cost: specifically, the global bandwidth is expected to grow by 32% per year from 2010 to 2015 while the cost of bandwidth is expected to decline at 18% per year (Scott, 2012; Telegeograhy, 2012). It is also indicated that the new subsea cable construction and upgrading to existing systems have resulted in bandwidth price reduction worldwide. Although bandwidth prices have dropped globally, significant geographical differences in bandwidth usage cost remain. Lujara (2008) proposed Compact Disk Read Only Memory (CD-ROM) for offline delivery, however, tremendous growth of the amount of information and increased number of e-learning users do not match with the capacity of CD-ROM for supporting offline learning.

In order to overcome such problems, this study proposes synchronization and caching approach for cost-effective learning content delivery and accessibility. By utilizing the capability of mobile computing devices owned by users, a learner can synchronize contents from a remote server to mobile devices within a short time when the Internet is available and working offline afterwards. With this approach only minimal amount of time is needed for a user to be connected to the Internet, most of the time, the user works offline hence the approach has the potential for reducing the cost of bandwidth usage, improving system performance by cutting down the servers' workload and Internet usage overheads; cutting down costs of purchasing hardware and increase motivation in learning activities by allowing learners to access learning contents anywhere and anytime.

The rest of this chapter is organized as follows: Section 2.0 presents the proposed system architecture; section 3.0 presents bandwidth conservation model for numerical studies; section 4.0 discusses the results; and section 5.0 concludes the paper while giving future works.

2.0 System architecture

This section presents the proposed system architecture. The proposed system comprises of three layers; data storage layer, business logic/ data access layer and presentation layer.

- *The presentation layer*: This layer is the front-end component responsible for providing portable presentation of contents and logistics to allow the user to interact with the server. Physically, it resides in a client machine and is responsible for transforming the output of the data access layer into usable and readable format by user. It provides the mobile devices with a user interface to interact with the back-end of the system and persistent storage for temporary storage of synchronized contents for offline use.

- *The business logic/data access layer*: This is an intermediate layer between presentation layer and data storage layer. Physically, it is located on the server that hosts the web services. It is responsible for handling application business logic and business process validation including sending clients' data requests to the data storage layer and returns the output to the requesting user.
- *Data storage layer*: This layer is made by the database management system (DBMS) component namely MySQL which offers mechanisms for data storage and retrieval. It is responsible for permanent storage of learning contents, for example, the database keeps tracks of learning contents A, B, C, D, E, F, G, H….of which a user can synchronize and store the subset of these learning contents locally in their mobile device for offline use.

When a user makes a request; the Application Programming Interface (APIs) accepts the request by GET or POST methods; then it interacts with PHP classes in data access layer to get data from database or store data into database; and finally returns the output to the requesting user/device in a usable and readable format.

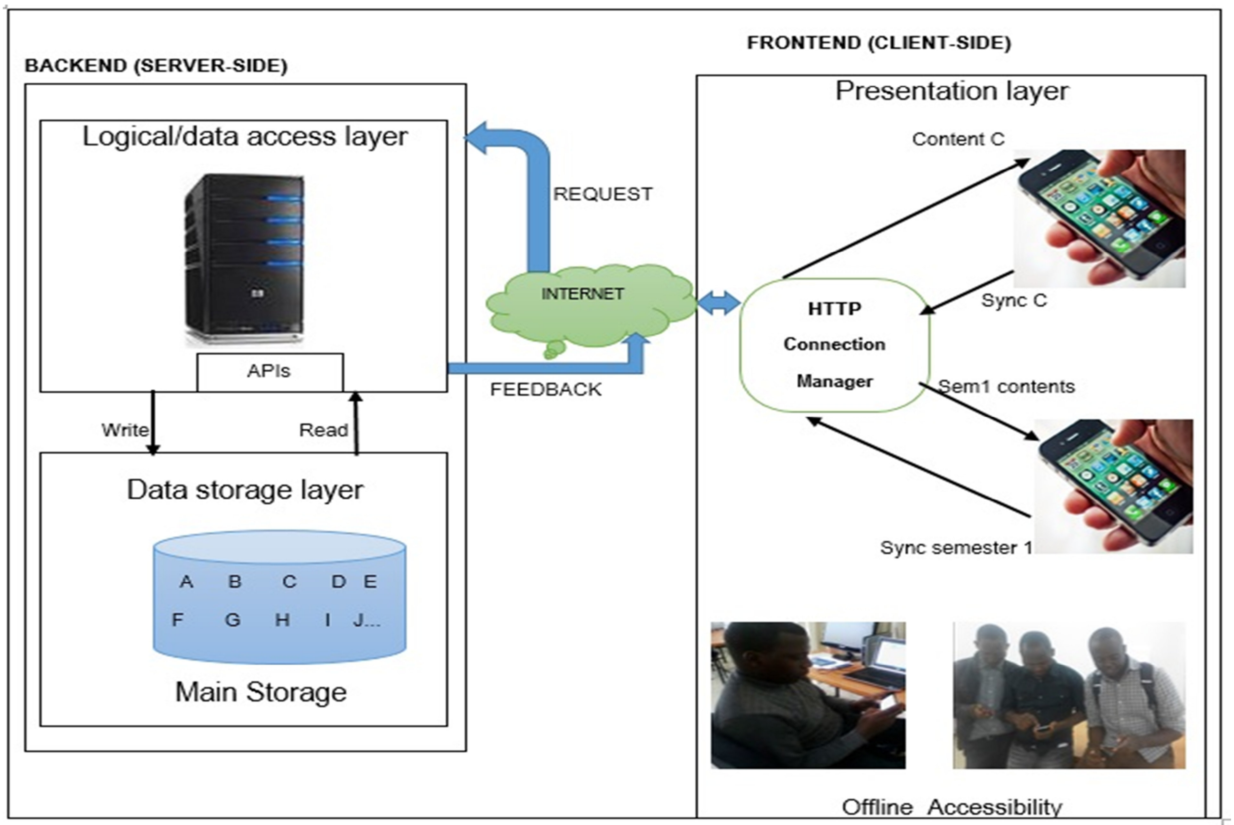


Figure 1: Proposed system architecture

2.1 Activity sequence

This section describes the synchronization and caching activity sequence of the proposed system. The activity sequence shows the sequence of activities in a process and logical decisions that are made (Kendall. K and Kendall. J, 2011). The list of activities gives an overview of how the system achieves the synchronization and caching process. The process consists of activities and logical decision building blocks described below;

- **Activities building blocks***:* The activities building block includes:
  - ✓ *Display sync options activity:* filtered in semester basis, yearly basis, sync all and sync only specific contents. Sync options implemented to help user synchronizing only required contents to avoid filling a cache with unnecessary contents. This is due to fact that the storage capacity of the mobile devices is limited.
  - ✓ *Read selected content activity*: reads contents from the remote server when the Internet is available;
  - ✓ *Cache selected content activity*: synchronizes contents and caches the synced contents locally in a mobile device;
  - ✓ *Enquiry learning content activity* and
  - ✓ *Return learning content activity*: Display the contents from the local database if the contents were cached

locally in a device otherwise retrieve from the remote server.

- **Logical decision building blocks**: test the logical conditions. There are three logical decision building blocks which include:
  - ✓ The logical decision to check the availability of the Internet that guarantees connection to the remote server,
  - ✓ The logical decision to test the sync criteria and
  - ✓ The logical decision to check if the accessed contents were cached and available in the local database (cache).Figure 2 represents the sync and caching activity sequence

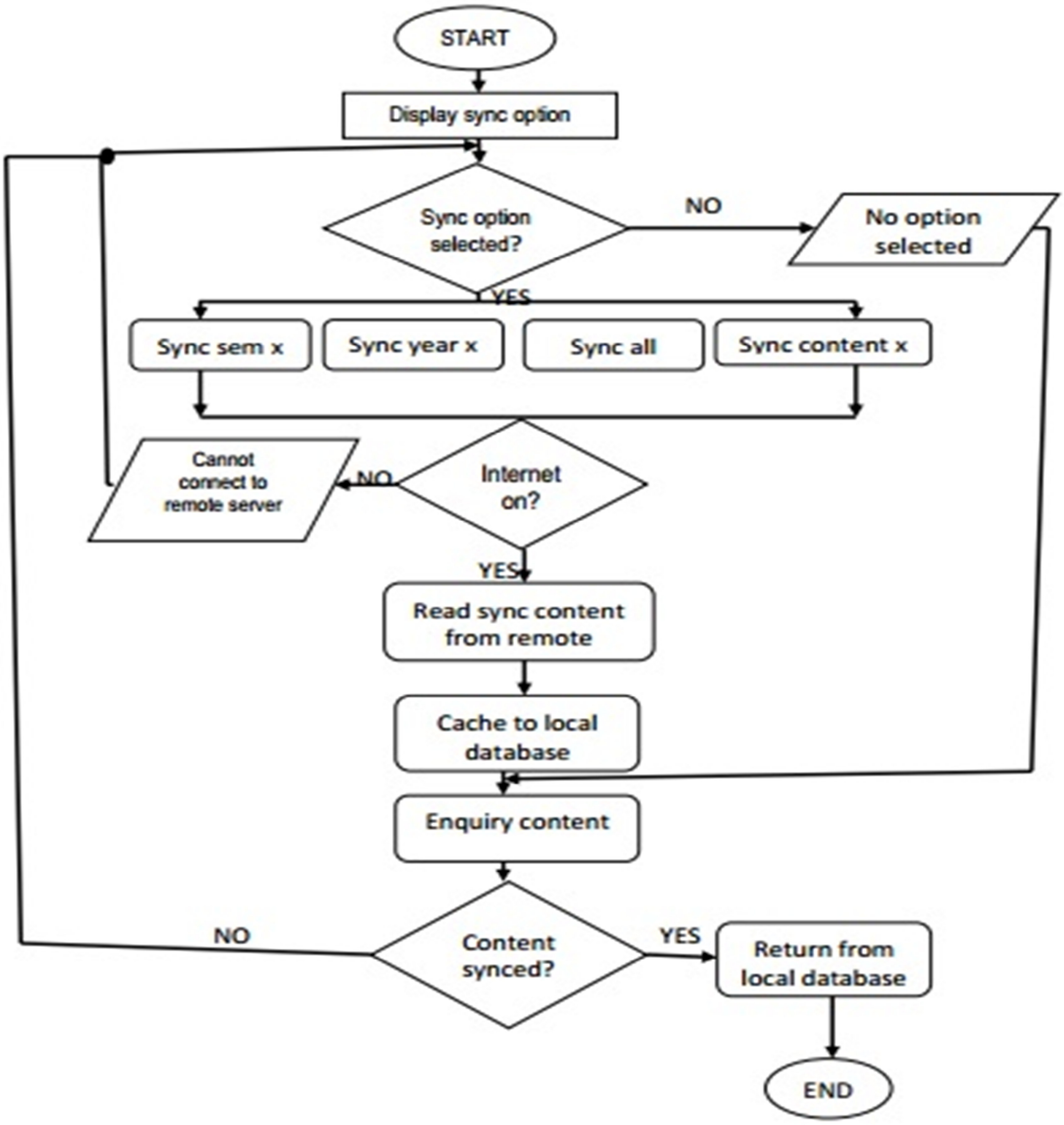


Figure 2: Sync and cache activity sequence

3.0. Bandwidth conservation models for numerical studies

In this section, we introduce the models for bandwidth conservation law and bandwidth allocation for fixed population. The motivation behind bandwidth conservation models is to gain insight on the behaviors/properties corresponding in some ways to a proposed system for content delivery and adopt some of these models in order to predict the cost implications of the proposed system especially in terms of bandwidth requirements. Specifically these models are required in order to:

- *Gain understanding of the proposed system*: Generally, if we have mathematical model which accurately reflects some behaviors of the real-world system, we can also gain improved understanding of the system through analysis of these models. Also models will tell us which factors (For example; cost of bandwidth usage, access speed, servers' workloads and Internet usage overhead) are most important in the system and how different parts relate.

- *Predict or simulate*: Basically, we intended to know what value the proposed system will bring in future with respect to cost of bandwidth, reduction of Internet usage overhead and servers' workloads and efficiency in e-learning content delivery and accessibility. Also the models are needed to judge the cost-effectiveness of the proposed system.

The assumptions made while adopting and using the models include:
- ✓ Fixed population
- ✓ The effect of implicit overhead is negligible for static view of contents

According to Bendadis (2008), the bandwidth conservation law can be expressed as

$$\sum d\,(l) \leq \min\,(Nu * dmax;\ Uu + Us + Ue) \ldots (1)$$

where UX =∑n€Xux indicates the total upload capacity of nodes in set X, d(l) denotes download rate of users, Nu denotes the number of users, dmax denotes maximum allocated bandwidth, Uu denotes the uploading capacity of users, Us denotes the uploading capacity of content providers and Ue denotes the uploading capacity of the servers. Users for this context refer to users that use the application, content providers refer to actors that provide contents to the system and servers refer to external servers dedicated to the service offered by the application.
For the fixed population, it is assumed that Ue, Nl, Pl, NS and PS are known, therefore; for uniform bandwidth allocation another model can be derived from equation (1), that is:

$$Nu * d = \min\left(Nl * dmax, Nl\breve{u}l + Ns\breve{u}s + Ue\right)$$

$$d = \min\left(dmax, \breve{U}l + \beta\breve{u}s + \frac{Ue}{Nl}\right) \ldots\ldots\ldots\ldots\ldots (2)$$

where $\beta = Ns/Nl$. The models (1) and (2) work for peer-to-peer architecture where each workstation acts as both service provider and service consumer. The scenario for client-server architecture would be different but slightly similar in-terms of bandwidth conservation. The bandwidth requirement for client-server architecture is calculated based on the services offered by the system including both static view and dynamic services (Figure 3).

$$B = d(s) + d(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

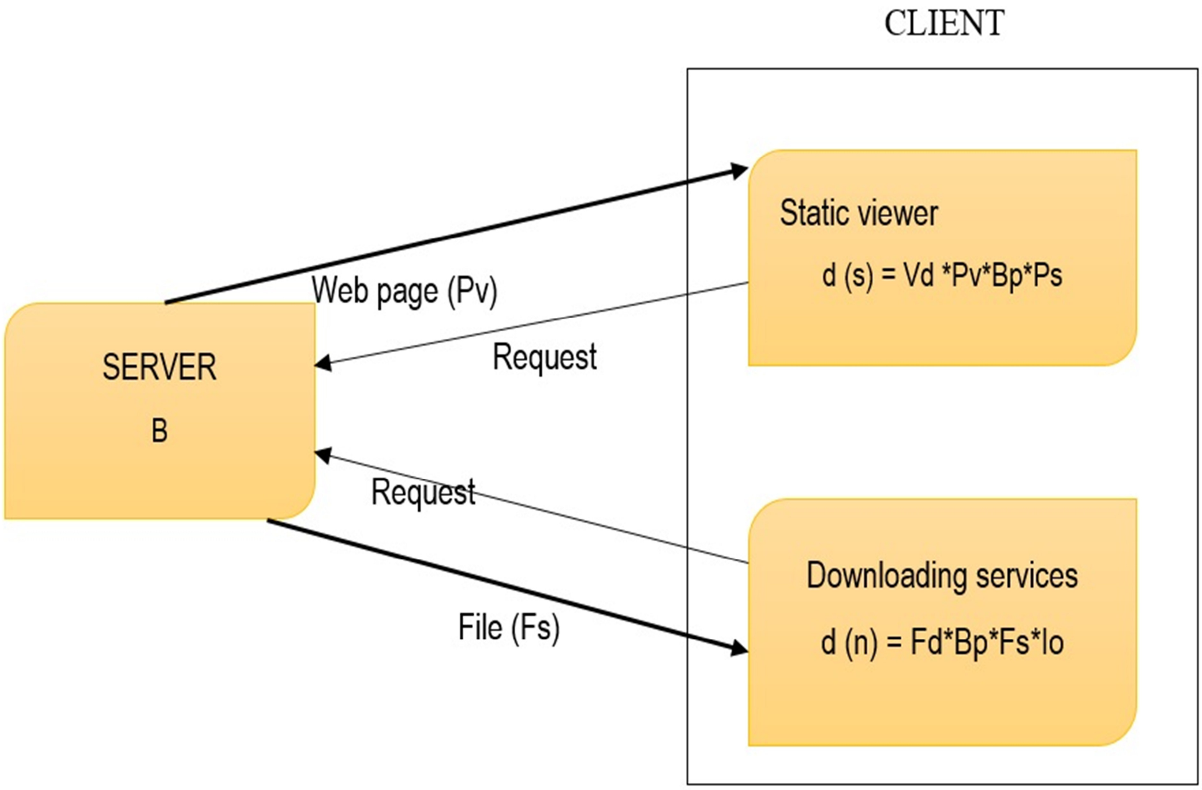


Figure 3: Client-server bandwidth conservation

Where B denotes the maximum allocated bandwidth for a particular application hosted in a server, d (s) denotes bandwidth required for static services and d(n) denotes bandwidth required for downloading services. The bandwidth required for static services d(s) is calculated using equation (4),

$$d(s) = Vd * Pv * Bp * Ps \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where Vd denotes average daily visitors, Pv denotes average page viewed, Bp denotes the billing period and Ps denotes average page size.
The bandwidth required for dynamic services is calculated using equation (5)

$$d(n) = Fd * Bp * Fs * Io \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

Where Fd denotes average file downloaded, Fs denotes average file size and Io is the Internet usage overhead.
We considered a learning environment with 600 learners of which 300 learners use Internet based learning system, thus needs continuous Internet connection and the remaining 300 learners use a proposed synchronization and caching approach. Out of 300 users of synchronized approach, 200 users are working offline after synchronizing their contents locally in their mobile devices and 100 users work online. In the conduct of the study, we considered constant value of parameters {Pv, Ps, Bp, Fd, Fs} which assumed to be {25, 20, 30, 20, 100}. Substituting the values into given equations (3), (4) and (5) forms two linear models:

$$Bc = 58.59375Io + 439.453125 \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

and

$$Bs = 58.59375Io + 146.484375.\ldots\ldots\ldots\ldots\ldots.(7)$$

Linear models (6) and (7) represent continuous Internet connection based approach and synchronization and caching approach respectively. The value of parameter Io varies based on the user access behavior.

4.0 Results and Discussion

This section discusses the results from this study based on the gaps which this study intended to address. This paper presents synchronization and caching approach, a mobile based e-learning content delivery system as an alternative content delivery approach in learning environment with resource and bandwidth constraints. Therefore, the numerical evaluation results are discussed in-terms of contribution of this study. The details are as follows;

4.1 Significant bandwidth usage cost savings

The bandwidth usage cost found to be a limitation for effective use of e-learning systems in HEIs. In order to cut down these limitations, this study proposes a sync and cache approach that employs the opportunities brought by the mobile computing devices for working offline. From model (6) and (7), the parameter values of Io {0.85, 0.7, 0.55, 0.35, 0.25} represent the system operations under overhead conditions, busy all the time situation, normal Internet usage, sometimes shorter, sometimes longer time is required and when sometimes it is idle as presented in fig. 4.

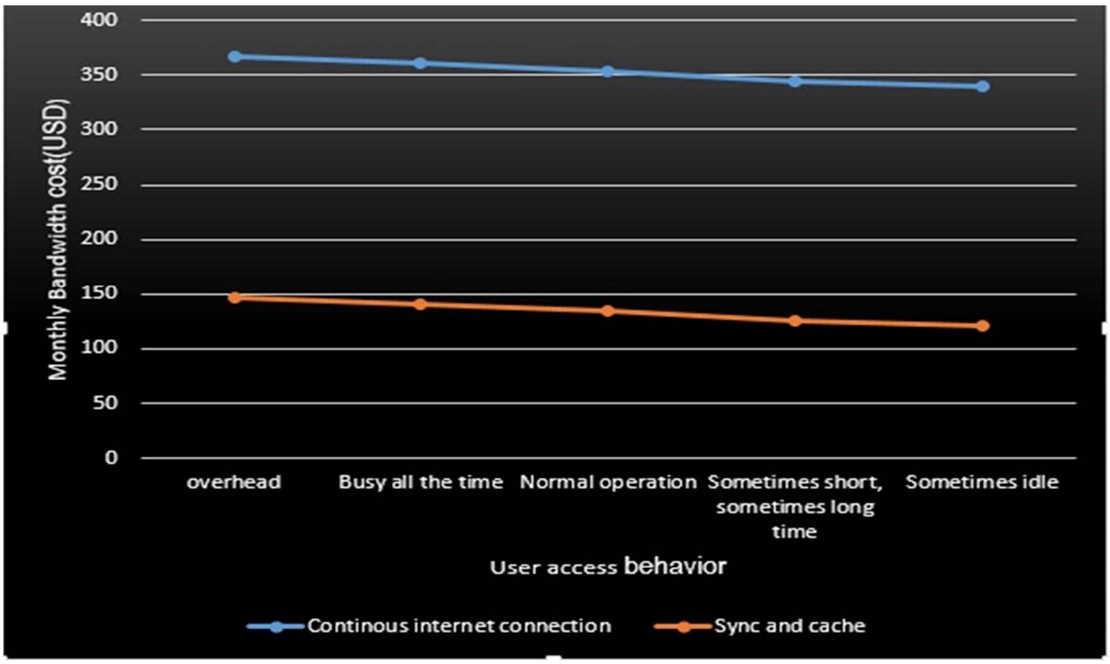


Figure 4: Bandwidth cost implications between continuous Internet connections based approach and the proposed sync and caching approach

The results provide empirical evidence that synchronizing contents locally in mobile devices for offline use is significant for bandwidth usage costs saving.

4.2 Reduction of Internet usage workload

Synchronization and caching approach is potential for cutting down the Internet usage workload as a result speedy Internet access. The local server keeps tracks of most of synchronized contents stored locally in its database. Thus, the next time a user requests such information, the local server returns the cached version of the contents instead of reconnecting to the Internet. Similarly, the proposed approach is potential for reduction of network overload. Network overload is caused by too much legitimate web traffic due to large number of users connecting to the web site in a short interval. The proposed approach guarantees the ability to work offline by synchronizing contents locally in mobile devices as a result reducing network traffic. Likewise, the proposed approach alleviates servers' workload. A web server has defined load limits, since it can handle only a limited number of concurrent client connections. The persistent storage serves as an intermediary server to manage contents offline. Having an intermediate server to retrieve and display contents, there is an enormous reduction of load on the original server. As the persistent storage has all the contents that are requested by the user in its database, therefore; there is no need to connect to the original server every time as a result it improves e-learning system performance. Figure 5 presents the relationship between the access speed and Internet usage overhead. The results provide empirical evidence that as the Internet usage workload increases, the response speed decreases as a result the performance of the system decreases respectively. Reducing Internet usage workload is potential for improving system performance. From the results in Fig. 5, below 50% Internet usage workload, the system operates under normal situation hence offers reasonable access speed while above 50% the system operates under overload situation as a result average access speed is relatively very slow. Therefore, in order to improve e-learning system performance, the Internet usage workload should be reduced.

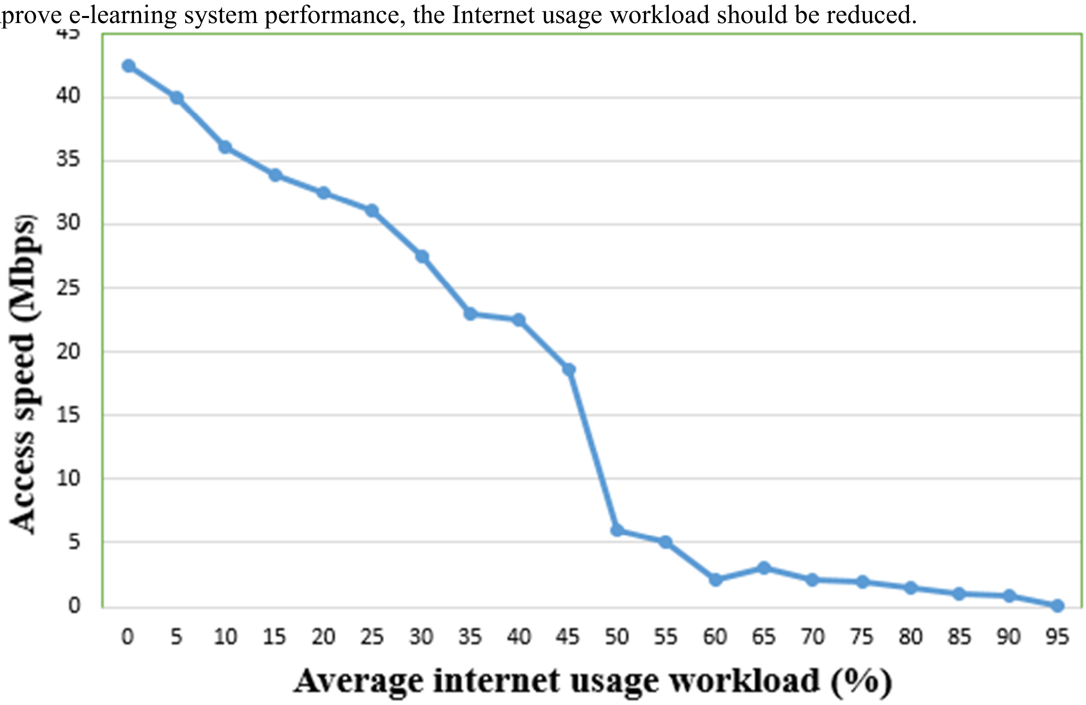


Figure 5: Relationship between access speed and Internet usage workload

4.3 System usability testing

The proposed system was exhaustively tested using black box testing technique, in an attempt to test the system externally and to reduce errors. A pilot usability evaluation was conducted in a mobile side. The System Usability Scale (SUS) questionnaire was used to measure the usability and user satisfaction of the proposed system. Question items included in the SUS survey has a five-scale ranging from strongly disagree (1) to strongly agree (5). Figure 6 summarizes the results of system usability tests

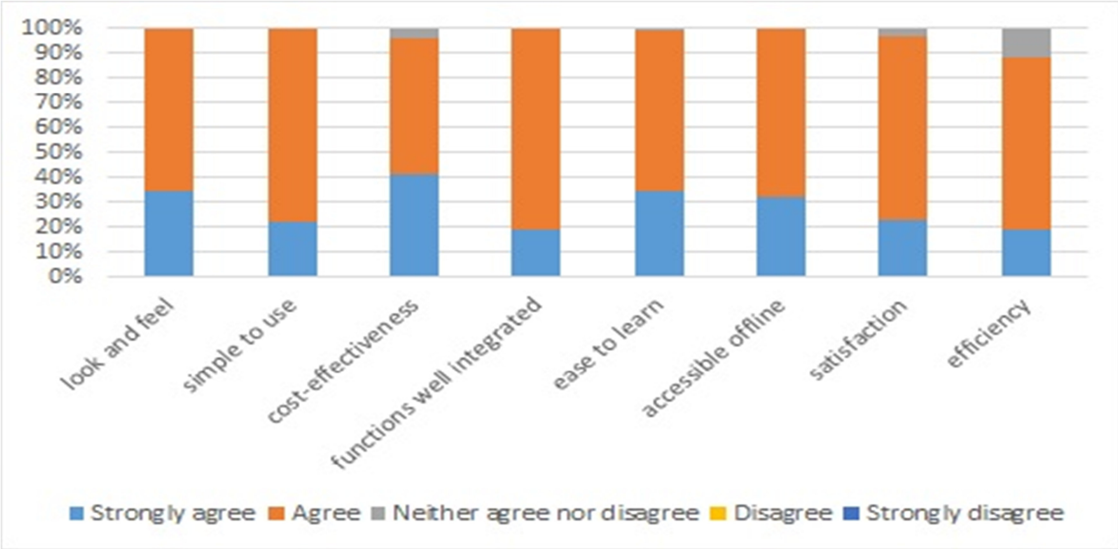


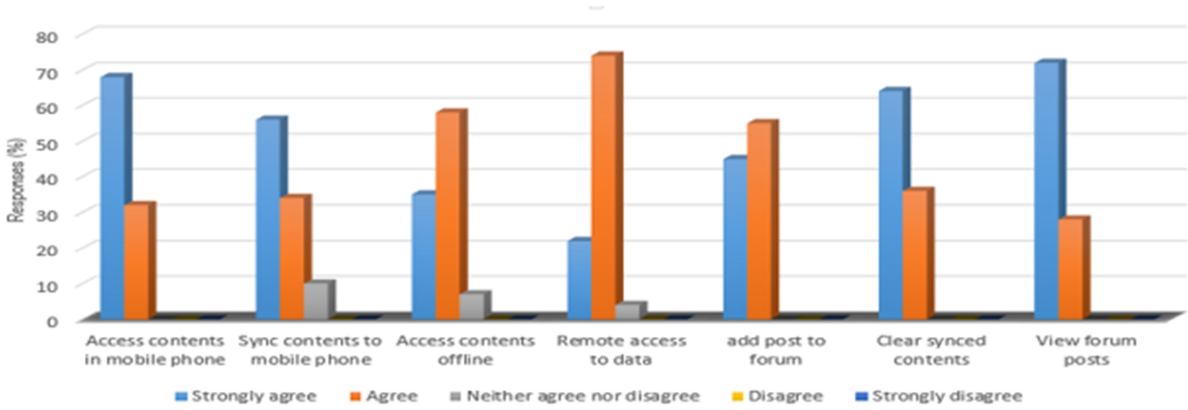
Figure 6: System usability test

The results presented in figure 6 show that in average 27.88% of users strongly agreed, 68.88% of users agreed and 3.24% of users neither agree nor disagree with the system usability. Furthermore, neither disagree nor strongly disagree with usability of the system were reported. The results suggest that the usability of the prototype is good as it was agreed by majority of users. Similarly, the mean rating of users' satisfaction was high (74%). However, the initial response from the users was agreeable; rational usability testing of the system on a large number of users is proposed for future study.

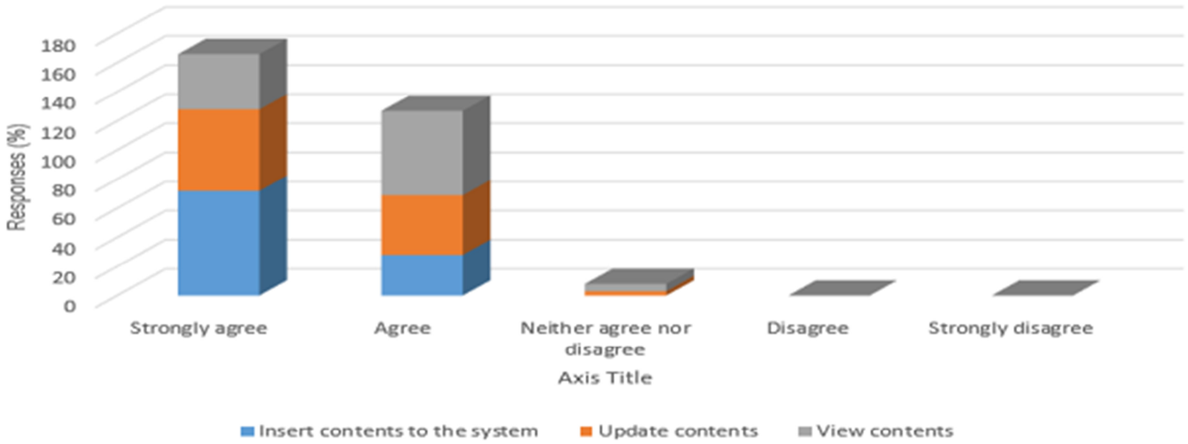
4.4 User acceptance functional requirement testing

This section presents the results from user acceptance functional requirements testing. Testing and validation of the proposed system was conducted in order to evaluate the system against the system design requirements specified. System testing is the process of evaluating a system or system component in order to verify that it satisfies requirements or to identify differences between expected and actual results. System validation is the confirmation by examination and the provision of objective evidence that the particular requirements for a specific intended use are fulfilled.

The results indicate that the system developed satisfy the system design requirements specified as revealed in the results presented in figure 7 (a) and (b). Majority of users' agreements ranged from strongly agree to agree as evidenced by the results presented.



(a) Learner



(b) Instructors

Figure 7: User acceptance functional requirements testing results

5.0 Conclusion and Future work

This paper proposed a synchronization and caching approach for cost-effective e-learning. The proposed solution is mobile based content delivery system that has several contributions in filling the gaps in existing e-learning systems for enhancement of content delivery and accessibility especially in HEIs facing challenges of resources and bandwidth constraints. Similarly, the proposed approach is significant for users in learning domain to be able to work offline. In learning environment, ability to work offline cuts down several limitations facing Internet based learning systems including; first, significant bandwidth usage cost savings due to less dependence on the Internet; secondly, improving learning system performance by cutting down the servers' workload and Internet usage overheads; thirdly, cutting down costs of purchasing and maintaining hardware in the institution due to the fact that the contents will be synchronized and made available in devices owned by the learners, and fourth, increased motivation in learning activities by allowing learners to access learning contents anywhere and anytime.

After the completion of system implementation, the future plan is to do rigorous impact assessment and implementing further enhancement of the system in real working environment, then deploying the system to the intended HEIs. After rigorous impact assessment and further improvement of the system, we also envision adapting the proposed system to secondary and primary schools.

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