Smart Classrooms for Distance Education and their Adoption to Multiple Classroom Architecture

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Abstract—This paper provides an overview of the technologies used in smart classrooms for distance education by classifying smart classrooms into four categories and discussing the type of technologies used in their implementation. It gives an example of a successful implementation of distance education technology being used to link university campuses in Japan and the US, and describes its underlying architecture and implementation technologies. It examines the methodologies being used to make distance learning an exciting experience and as effective as the traditional classroom type education. Furthermore, the paper shows how a similar architecture can be extended to a model where a single local class can simultaneously cater to the needs of multiple remote classrooms and presents a workable solution to some of the technical challenges that exist in multipoint, multiple classroom architecture. Finally, it shows how some of the inherent challenges of the system are being managed and identifies physical and practical limitations of a multiple classroom architecture for a successful remote lecturing environment.

Index Terms—Internet, remote lecturing, remote lecturing system, smart classrooms, multiple classroom architecture

I. INTRODUCTION

Digital information has become a social infrastructure and with the expansion of the Internet, network infrastructure has become an indispensable part of social life and industrial activities for mankind. Every day, new Internet applications and more efficient ways of doing existing tasks are being discovered. Although most Internet applications are concentrated on a more efficient or cheaper way of performing existing tasks, the applications in education are mostly concerned with the sharing of scarce resources, available in one location, with many other locations. An interesting example of successful use of the Internet in education is an information security education program that Carnegie Mellon University provides in Japan via a remote lecturing system.

Since its experience with the Great Hanshin-Awaji Earthquake in 1995, Hyogo Prefecture has played a leading role in providing safety and security measures in Japanese society. In 2005, when the Personal Information Protection Law was passed in Japan, Hyogo Prefecture went beyond the measures for physical security and took the initiative in addressing the much-needed cyber security and information and privacy protection. Sensing a significant shortage of experts in information security and an urgent need to train competent leaders, it joined hands with Carnegie Mellon University, a world leader in the area of information security, and by relying on the state-of-the-art remote lecturing technology, brought top-quality security education to Japan in an amazingly short period of time [1].

II. MOTIVATION

As can be understood from the above discussion, by proper use of smart classrooms it is possible to share intellectual resources, available in one location, with many other locations. Such sharing opens new dimensions for education and can be in the direction of either distributing top-quality education, cultivated through years of rigorous research and teaching endeavor at one location, to many other locations or in the way of bringing general education to the doorsteps of those who are unable to physically attend to regular schools because of their personal, family or work related responsibilities.

In view of this, the authors believe that smart classrooms and application of the Internet to education are going to revolutionize our way of schooling in a similar manner that technologies like telephone, radio or televisions dramatically transformed our ways of communication. An object of this paper is therefore to deepen and formalize our knowledge of smart classrooms and distance education through their classification, examination of technologies used in their implementation, and most importantly by thorough examination of a successful implementation with which the author is quite familiar with. Another objective of the paper is to show
how some of the challenges that existed in the present system were addressed.

Furthermore, the paper also tries to address the new challenges which may arise when making a single local class to simultaneously cater to the needs of multiple remote classrooms. Due to the inherent complexity of this mechanism, however, the authors present a workable solution to some of the essential technical challenges of the model from a practical utilization aspect rather than taking the impossible mission of trying to address all of the underlying theoretical challenges.

The rest of this paper is organized as follows. Section III presents a brief survey of smart classrooms, their classification based on geographic positioning of students and the teacher, their implementation technologies, and thorough examination of the successful implementation of Carnegie Mellon system; including its effective teaching techniques. Section IV examines multiple classroom architecture in some details, including circumstances that require such an environment, its inherent challenges and presentation of a workable solution to some of the essential technical challenges in a practical manner. Section V describes the author’s experience of how the inherent challenges of Carnegie Mellon’s system are being managed and section VI gives the concluding remarks.

III. SMART CLASSROOMS

Smart classrooms integrate voice-recognition, computer-vision, and other technologies, collectively referred to as intelligent agents, to provide a tele-education experience similar to a traditional classroom experience.

A. Brief Survey

"Smart Classroom" was inspired by research on "Smart Space" at NIST [2]. Smart Spaces are work environments with embedded computers, information appliances, and multi-modal sensors that allow people to perform tasks efficiently by offering unprecedented levels of access to information and assistance from computers [3].

Having evolved from simple multimedia distance education systems over the past decade, the modern smart classrooms augment traditional classrooms with various functional interfaces that enable the teachers to feel a real teaching experience while giving local and remote students a real learning experience just as in a traditional classroom, where teachers and students interact face-to-face. In other words, smart classrooms have become intelligent classrooms for teachers involved in distant education and enable the teachers to use a real classroom type teaching approach to teach distant students.

Its evolution has been due to many research endeavors. Researchers at the Tsinghua University developed a software called “SameView”, which was originally designed to support real time discussions among designers across the Internet [4], became some sort of a reference for creating distance education systems. Shi et al. [5] described the analysis and design of a smart classroom and how the intelligent agents could be seamlessly integrated to bridge the gap between tele-education and traditional classroom activities in terms of the teachers’ experience. Furthermore, his group at the university extended user interface of the “SameView” software into a 3D space for an augmented classroom environment [6]. Recent interests focus on how to make the intelligent agents function as meeting assistants in the smart classrooms [7] thus necessitating them to employ state-of-the-art technologies together with sophisticated software infrastructures [8].

When multiple smart classrooms interact simultaneously to realize distance education among several groups, an inherent challenging issue has been the scalability of its delivery mechanism. The problem has been significantly serious when delivering a lecture to multiple remote classrooms, simultaneously. To address the problem, many smart classroom systems have adopted IPv6 multicast [9] while some have proposed a more practical application level alternatives [5][6], a detailed explanation of which is given in section V.

B. Architectural Considerations

Based on geographical locations of students and the teacher, we identify 4 basic architectures that essentially cover the whole range of smart classrooms (Fig. 1). These architectural demarcations help us understand the general and specific requirements of smart classrooms implementation in terms of technology type, resource utilization, methods of information dissemination, and nature of student-teacher interaction.

1) Single classroom architecture

In single-classroom architecture, a physical classroom is augmented with provisions that enable students to enjoy an enhanced learning experience and teachers to enjoy an enhanced teaching experience than what is provided by a conventional classroom. The provisions include an array of equipment including multimedia playback systems, projectors, large video displays, computers etc. enabling the students to listen to the ongoing lecture without any barriers while having access to supportive information including past lecture material at finger tips. All modern classrooms [10] in most educational facilities today fit into this architecture.

2) Scattered classroom architecture

In this scenario, the students are geographically separated and each student is required to have a personal...
computer. The teacher and the students are connected via the Internet or dedicated networks and a virtual classroom is formed using audio visual and synchronous/asynchronous information access tools that are made available at each participant’s computer [11].

Unlike the single classroom architecture, this setting enables students to study from a remote distance without having a need to be physically present in the classroom. Consequently, it opens a new window for education and allows students to study from their workplaces or houses while enabling them to attend to their personal, family or work related responsibilities [12].

Although this smart classroom model can range in scale from a classroom having a few students to a cyber university, a larger scale accompanies an increasing burden in providing the exact face-to-face learning and teaching experiences to the students and the teacher, respectively.

3) **Point-to-point, two-classroom architecture**

This architecture harmonizes the features of the above two architectures to produce a feasible smart classroom model for realizing high-quality education for two groups of students who are geographically located apart [13]. The architecture essentially connects two geographically separated physical classrooms, with the teacher being located in the local classroom.

In addition to the above mentioned electronics gadgets, the two-classroom architecture also uses sophisticated resources such as media-boards, high-speed dedicated links for high-quality tele-presence etc., which are not affordable by individual participants in a scattered smart classroom scheme. In section E, we present Smart Classrooms in Carnegie Mellon University [14] as an example of a successful realization of the state-of-the-art point-to-point two-classroom architecture.

4) **Multiple classroom architecture**

This architecture is an emerging form of smart classrooms that attempts to scale up the two-classroom model while preserving the quality of deliverance and resource affordability by interconnecting clusters of students to a local classroom through high-speed links. Multiple classroom architecture is a promising solution to realize a high-quality educational facility over the globe and several attempts have been made to implement this scenario [9]. However, because of inherent non-trivial challenges such as bandwidth-effective information transmission, teacher capacity, class interaction, tele-presence etc., its practical deployment, especially over the commercial Internet, has been quite difficult.

In section IV we describe these technical challenges in some details and propose a workable solution together with its implementation approach.

C. **Implementation Technologies**

Smart classrooms integrate an array of technologies to achieve several multi-faceted goals i.e., (a) enable distant teachers to become as effective as those who teach at local classrooms; (b) provide the students with an enhanced local class participation experience; (c) ensure system wide security; and (d) provide accessibility to past contents. In achieving these goals, the adopted technologies should facilitate multiple natural modalities for teaching, learning and class interactions. Furthermore, these must be accompanied by secured, reliable and high speed synchronous/asynchronous contents. The followings can be considered as the most important state-of-the-art technologies which can be used for the implementation of both current and future smart classrooms.

1) **Sensing**

Sensing technologies include capturing of vital information in the classroom to realize tele-presence, interaction, and quality delivery of lecture contents. Systematically arranged arrays of video cameras and microphones are used to sense the information. The quality of sensing depends on the performance of video and audio devices, camera focusing and zooming, appropriate device positioning and switching, etc. Context-aware sensing in smart classrooms is a promising approach for reaching the goal of attentive teaching and learning. Some important context-aware sensing methods include signal strength tracking for speaker detection, speech recognition for interpreting voice into commands, auto focus and auto zooming for emphasizing important imagery (smart cameraman), gaze tracking for predicting actions, sensor fusion for extracting behavioral details in the classroom [8]. The intelligently sens ed information is then subject to appropriate rendering.

2) **Rendering**

The technologies used to render audio visual information play a key role in smart classrooms. With recent technologies, use of large multiple projection screens has become an alternative to each student having a desktop computer display. The multiple screens are intended for displaying the course contents, teacher’s movements, and a full view of students in each class. Augmenting video contents, such as close-ups of the lecturer, close-ups of students on the floor, etc. are displayed with overlain windows on the screen. This approach, however, is not scalable to cases where there are more remote students on the floor than can fit in the display screen. More sophisticated visualization methods like 3D imaging, which render each image as if the remote students were seated in a large hall, are emerging.

3) **Presentation support**

For quality deliverance, teachers should be facilitated with an environment that allows them to use natural teaching modalities rather than confining them to a computer by requiring the use of a mouse and keyboard. In order to integrate natural teaching modalities with the system, the state-of-the-art technologies provide devices that accommodate pen-based electronic writing, which incorporates most functions of a mouse in a touch screen (Smart Boards), laser-pointer-based interaction tools (Laser2Cursor), speech-capable virtual assistants, which perform through voice actions on presentation slides, biometric-based login etc [13].
4) Transmission

Smart classrooms must be supported by a transmission infrastructure that uses suitable technologies to ensure low latency and maximum bandwidth utilization. In other words, it requires datagram delivery (UDP) to support interactive real-time audio visual experience and a reliable delivery mechanism (TCP) for exchange of lecture materials and control information. Because most smart classroom technologies have simply adopted commercial video conferencing products that use traditional peer-to-peer reliable/non-reliable delivery paradigms, duplicated audio/video streams injected to the network inhibits the expansion of smart classrooms to group deployment. To overcome this problem, considerations are given to adopt bandwidth efficient technologies as well as to use bandwidth guaranteed transmission links as discussed in section IV.

5) Security

Security in smart classrooms concerns the prevention of illegal access to a live class, post access to class recordings and other resources used. Establishment of such security can come in three phases: (a) appropriate authentication and access control at the user interface; (b) use of secure transmission methodologies; and (c) prevention of permanent storage of classroom resources from unprivileged users. Such measures range from ensuring physical security to enhanced data encryption algorithms.

6) Asynchronous support

While the synchronous information flow enables the members to gain the feeling of ‘being there’, the success of any smart classroom architecture also significantly depends on how well it supports the participants feeling ‘beyond being there’. Such services are provided by asynchronous information access, such as web-based on-demand access to previous session recordings and other important resources.

D. Cost-Complexity Levels of the Technologies

The specific impact of each of these technologies for the implementation of the above described 4 architectures would entail a complex task of analyzing a thorough macroscopic behavior of each model together with its varying complexities and cost requirements. Although a whole paper can just be dedicated for a serious consideration of this scenario, in this paper we opt to take a heuristic approach of showing what relative importance these technologies can have for each architecture. The following section also shows the specific technologies that are actually being used in the two-classroom architecture of the Carnegie Mellon system and their associated impacts.

Radar plot in Fig. 2 illustrates normalized values for cost-complexity levels of these technologies in the respective architectures. Here, a normalized value is decided by considering a heuristic fuzzy set of (low, medium, high, very high) and assigning a value (1, 2, 3, or 4), respectively. The heuristic value itself is assigned by considering requirements and limitations of each architecture. For example, requirements for security and rendering would normally increase with increasing number of remote members. This is because both security and rendering technologies play important roles in the distributed model. However, cost constraints of individual clients on scattered classroom architecture can dictate for a less rendering feature than what would be ideally desired.

E. Smart Classrooms in Carnegie Mellon

At Carnegie Mellon, smart classrooms are designed to support video conferencing (VC) and are being used to distribute education, mostly from its main campus in Pittsburg to its branches and affiliate institutions around the world. They incorporate the point-to-point two-class architectural model and implement most of the abovementioned design criteria. Presently, remote lecturing sessions are provided between campuses in Pittsburg, Kobe, Athens, Adelaide and Doha.

For example, in a situation where a lecture given by a lecturer in one smart classroom (local classroom) is transmitted online to another smart classroom at a remote location (remote classroom), each smart classroom is equipped with the following gadgets:

- 2 x Videoconferencing CODEC
- 2 x projectors
- 2 x Cameras
- 2 x Monitors
- 2 x Large Screens
- Smart Board
- Document Camera
- Lectern
- Multiple Microphones
- Multiple Speakers
- Lighting
- Sound proofing

Usually in both classrooms, lecture slides from a computer or instruction-aiding materials taken by a document camera are projected by a projector onto one of the large screens. In the other large screen of the remote classroom, a video image of the lecturer, transmitted from a lecturer camera installed in the local classroom, is overlapped with a small window showing a video image of the remote classroom itself, which is taken by an audience camera in the remote classroom and is transmitted to the local classroom as well. The monitors in the local classroom are mostly used for the purpose of aiding the lecturer. One of the monitors, placed on the lectern, displays the lecture contents or the transmitted
video image of the remote classroom. The other monitor is tuned to show the video received from the remote classroom. The lectern serves both as a control panel for a videoconferencing system and for lecture delivery.

Secured live remote lectures are carried out using 4Mbps IP (H.320/H.323) videoconferencing via Internet2, and a dedicated 512 Kbps ISDN connection is maintained as a backup system. Lectures are delivered via SMART Board™ (a large-sized touch screen) with PowerPoint® slides which are shared through commercial Internet using Microsoft’s NetMeeting® software. A typical remote lecture scene from CyLab Japan is shown in Fig. 3. Here, the left screen displays the remote students at the US campus and a PowerPoint® slide, which is shown to both the local and remote students, is displayed on the right screen.

In order to make distance learning an exciting experience and at least as valuable as the traditional classroom type education, Carnegie Mellon combines unique teaching techniques [14] with the effective use of a number of other technologies like SMART Board™ for presentation, the Blackboard® system for Internet-based learning and lecture recording, the Lecture on Demand (LOD) system that enables students to have access to all previously taught courses and lectures, and Virtual Training Environment (VTE), which is a Web-based knowledge library for information assurance, computer forensics, incident response and other IT-related topics.

1) SMART Board™

Most distant education systems are still based on desktop computing, and the teacher is required to sit in front of a desktop computer and use a keyboard or mouse to conduct a distant education course. Such restrictions make the teacher feel uncomfortable and reduce the efficiency of the course as teachers have natural tendencies to use handwriting and make annotations on the blackboard. At Carnegie Mellon, on the other hand, SMART Board™ is used. With SMART Board™, the teacher is no longer tied up to a desktop computer and using a cumbersome keyboard and mouse to interact with the distant education system. Making annotations on the courseware displayed on SMART Board™ is just as easy as writing on an ordinary classroom blackboard. The teacher can also point to something displayed on SMART Board™ and say some words to complete the action he/she wanted, erase annotations made previously, scroll a page up, skip to another page, etc. [15].

This gives the teacher a feeling that he/she is not just using some computer program but is teaching in a real sense, especially when the teacher has both local students and remote students at the same time. Another appealing feature is that original courseware plus any annotations the teacher makes on the materials are recorded and can be replayed to the class for review (Fig. 4).

2) Blackboard® System

With the help of Blackboard, Inc. [16], Carnegie Mellon has developed a special version of Blackboard® software that enables the university to create Internet-based learning programs. The software connects teachers, students, parents, and administrators via the Web, enabling Internet-based assignments, Web class sites, and online collaboration with classmates. The software also assists instructors with course administration and includes a content management system for creating and managing digital course contents.

There are separate areas for the syllabus, course information and announcements, textbooks, lectures, assessments, assignments, resources, grades, and course statistics. Built-in tools for communication and collaboration include a discussion board, email, and a chat. Students can take notes in an online notebook, check the class schedule on a calendar, turn in homework assignments using the Digital Drop Box, and do research using the integrated Academic Web Resources. The Blackboard® is also used to administer examination, conduct course evaluation and submit students’ grade, among others [17] (Fig. 5).

3) Lecture on Demand System

Figure 3. A remote lecturing session from CyLab Japan.

Figure 4. Lecture delivery via SMART Board™.

Figure 5. Blackboard System.
The VC system is equipped with recording functions and all lectures, whether remote or local, are recorded and archived in a database for later retrieval. The system incorporates all of the security features mentioned in section C and only allows the officially enrolled students from within the campus network to logon to the system to retrieve previously recorded lectures. The LOD system has a search function that enables searching for a desired lecture using the semester, recording date, lecture name, lecture number and lecturer name as parameters. Lecture slides, together with all the relevant supplementary materials, can also be easily accessed for each lecture via the LOD system. Fig. 6 shows a typical search result, with the upper window indicating the search parameters and the lower window indicating the search results, together with the associated dates, lecture numbers, classrooms, lecturers, lecture names, lecture materials, etc.

Fig. 7 depicts a replay of a recorded remote lecture from the US campus, in which the upper left window displays a remote lecturer and the lower left window shows information on the lecture itself and contains actual files for all the relevant reading materials used in the lecture. The right window, which is synchronized with the video, shows the PowerPoint® slides that were shared through the NetMeeting® software during the lecture. The handwritten remarks are the annotations made during the lecture.

4) Virtual Training Environment

VTE is produced by the Software Engineering Institute at Carnegie Mellon University. The Library contains a collection of training materials presented in many formats, such as documents, demonstrations, recorded lectures, and hands-on labs. It is a known fact that the best way to ensure mastery and retention of a specific instructional subject is to present the subject to the user in multiple, increasingly-engaging formats [18]. Students read about a topic, hear about it, see it, and then put it into practice. They can repeat any step until they feel comfortable with the material. A graphical presentation of this idea by CERT® is shown in Fig. 8. As can be observed, the subject mastery level continues to increase as one utilizes more of his/her sensory powers.

VTE can be accessed with a Web browser through the Internet. Its lectures can be downloaded in PDF format or viewed online in FlashPaper® format. Students can enhance their learning by replaying recorded lectures, which are synchronized forms of lecture slides, videos and transcripts. Hands-on labs, which are performed on virtual machines, help the students to master and retain the subject matter.

5) Teaching Techniques

Effective teaching is of a concern to all instructors, and there are many paradigms and methodologies related to this subject [19]. Carnegie Mellon system has adapted a discussion type lecturing method in an interactive manner [14]. Preparation for a lecture starts by downloading reading materials from the Blackboard® system and submitting summary of paper reviews via its Digital Drop Box, prior to the lecture. During the lecture, active participation by students is highly encouraged and used in evaluating their performance. In hands-on sessions, students are free to exploit the virtual training environment and repeat the learning process until they achieve the expected level of proficiency. The Blackboard® system, VTE, and LOD system also play vital roles during post studies and preparations for exams.

IV. MULTIPLE CLASSROOM ARCHITECTURE

With the two-classroom architecture, it is quite easy to optimize design parameters to realize i.e., (a) maximum use of the network channel bandwidth; (b) maximum use of end system resources; and (c) straightforward adaptation to the performance of the network channel and...
receiving hosts. For example in Carnegie Mellon, when a remote lecturing session takes place between the Pittsburg and Kobe campuses, a videoconferencing system is operated at its full speed as both campuses are connected via Internet2 and the end systems can handle the speed. On the other hand, for sessions between Pittsburg and Athens, the transmission speed is adjusted to the bottleneck bandwidth as Athens does not have access to Internet2.

In a situation where a lecture from the Pittsburg campus has to be delivered simultaneously to both the Kobe and Athens campuses, it is desirable to keep the communication speed between the Pittsburg and Kobe campuses at the full rate enabled by Internet2 and adjust the delivery to Athens campus at a rate that can be handle comfortably by the linking system. This cannot, however, be achieved without an appropriate multiple classroom architecture. Despite the fact that most smart classroom systems, e.g., [1][9], provide some forms of support or extendable interfaces for multiple virtual classrooms, they come in primitive form, do not capture the real semantics of multiple classroom architecture and also heavily rely on the network infrastructure (IPV6-multicast). Although some recent work e.g., [6], have tried to address these issues, the proposed solutions require extensive modifications to the existing systems. Hence, we are motivated to further investigate this area with the aim of coming up with a more practical solution.

This section explains some of the challenges that are being faced in implementing a multiple classroom architecture and introduces mechanisms that improve the situation to an acceptable practical level.

A. Technical Challenges

1) Lack of scalable transmission technologies

Traditional transmission technology should be extended to support multipoint-to-multipoint delivery in multiple classroom scenarios. One possible approach to addressing the scalability issue is to leverage the IP Multicast technology that does not require data replication, as adopted in [9]. But the current, state-of-the-art IP Multicast is still not fully matured due to several problems, such as lack of ubiquity of IPv6 multicast routers, need for application level support for facilitating reliable multicast, through-firewall access problems, and inadequate network support for member awareness. Although emerging multicast delivery methods relax the IP-multicast dependency up to a certain extent, they are still complex, more generic and cannot easily be integrated with existing systems for the implementation of multiple classroom architecture that we envision for the delivery of quality education around the globe.

2) Lack of efficient grouping mechanisms

For classrooms using different networks and having device heterogeneity, connection to a learning session requires methods for serving the members in a multi-group fashion. In the absence of such a mechanism, the learning experience of the whole group can deteriorate due to the presence of a single member that has inferior capabilities (e.g., network speed, processing power etc.). Although one solution is to not allow such crying-baby members to join a session, another currently adopted solution is to provide such members with differential quality service by forming several different service groups. This grouping can either be static or dynamic. The former is lightweight and very simple to implement but suffers from the problem of ensuring guaranteed quality when there are changes in the member’s specs in the short run. The latter ensures guaranteed quality to some extent, but suffers from the problems of implementation complexity, excessive transmission overhead, and erroneous grouping due to the imprecise state-of-the-art network measuring techniques.

3) Lack of efficient session management

In multiple classroom scenarios, the amount of cross information flow is huge. To integrate any session management to the system, extra tools for rendering the interactive audio visual information and appropriate session control for managing the interaction are required. Ideally, the teacher must be able to communicate with any student and the students must also be able to communicate with the teacher in a manner similar to communication in a face-to-face classroom environment. However, such services are not practically scalable. Simple but static session configurations do not provide flexibility to the system. On the other hand, dynamic session configurations are complex, require context-sensitive technologies (e.g. smart cameraman), and take up a considerable control overhead.

B. A Workable Solution

Our approach in providing a workable solution to facilitate high-quality education around the globe through multiple classrooms involves the following two important aspects:

1) Simplify the transmission and session management complexity.

This can be achieved by capturing the semantics of the multiple class architecture. In our approach, we identify several positive issues and couple them with some practical constraints in order to relax some of the ideal requirements mentioned in section IV-A.

Firstly, the teacher’s limitations in the handling capacity inherently impose an upper limit on the number of students per class and the numbers of remote classes. These can relax some of the abovementioned scalability needs in implementation. Secondly, it is natural for the teacher to have the power to control the class behavior. This makes teacher-centered session control preferable and eliminates the need for complex session controlling methodologies that are not scalable even for small group sizes. Thirdly, consideration of the time difference as a parameter in forming classroom groups enables feasible quasi-static grouping mechanisms to be realized (i.e., classrooms located at countries in a manageable time-zone can be considered as belonging to a group). Lastly, by identifying the internet peak hours in certain countries or areas, it is possible to schedule smart meetings in such a way that network-handicapped clients join in during the
off-peak hours (e.g. in Sri Lanka, network usage statistics shows that the international network channels are lightly loaded before 9 am and after 5 pm [20]).

By considering the general technical limitations and the practical issues related to smart classroom scenario, we propose a distant education model that assigns different clusters of groups to a particular geographical time-zone. Each group in a cluster consists of multiple classrooms, in which one classroom is essentially a local classroom. Each group in a cluster conducts sessions independently and falls into non-overlapping timeslots to use the network bandwidth affectively. Other clusters belonging to different time-zones operate in a similar manner to deliver a certain course content internationally.

2) Make it easily integratable with existing systems.

The methodology we propose can be applied as a complete solution for both developing new systems as well as easily modifying existing two-class room systems to realize their speedy upgrades. We achieve this through the use of application level multicast (ALM) servers in order to efficiently forward multimedia information among the networks. In this approach, because the ALM servers act as proxies in forwarding packets to other destinations, end system protocols are preserved. As such, because our approach does not require modification to the multimedia streaming (e.g. RTP streaming) technologies of current systems, it has the advantage of being easily integrated with existing systems. Furthermore, all standard multimedia streams (most current systems provide compatibility with Windows Media Player, QuickTime and Real-Player) can be transcoded at the ALM servers to cater for diverse channel bandwidths. However, the session controlling invariably needs an application level wrapper to coordinate the end system components, such as video encoders, audio/video switches (e.g. muting), display controls etc.

C. Implementational Approach

This section explains how the ALM and leader-speaker session control can be integrated to implement our proposed model.

1) ALM with quasi-static grouping.

Application level multicast (ALM) is a solution for distribution of synchronous/asynchronous contents among “a group”. We propose an ALM topology with quasi-static grouping mainly deriving from an ALM methodology used in [20] for supporting international telemedicine. Fig. 9 is an example of this approach where 3 countries belonging to a single time-zone have statically been configured to form 2 groups based on their bandwidth and member counts. The 2 groups are then assigned different time slots to enable full network bandwidth capability for a single group and in most cases, depending on the resource restrictions, one local classroom may be required to participate in both groups.

In general:

- ALM servers are placed at strategic static locations in each country belonging to a particular geographic time-zone group. In practice, the maximum number of classes is limited to 5 in consideration of delivering quality education.
  - When the number of classes is large enough to fit into more than one group, the static grouping is implemented with the average available bandwidth as a second grouping parameter.
  - All the ALM servers establish lightweight signaling with a central server and form a multicast tree in accordance to an algorithm similar to the narada protocol [21].
  - Each ALM server is associated with a database; in which information that has already been passed through is cached extensively to support a faster asynchronous access. (Proprietary contents can be protected by either employing encryptions or simply labeling them as non-cacheable.)
  - In synchronous transmission, information is disseminated from the source to the nearest multicast server, in accordance with network topology cached in the associated database, and delivered to the group through the overlay tree.
  - In asynchronous transmission, information is usually disseminated from the original source through the multicast overlay, unless it has already been cached in the database.
  - ALM servers or end clients connected with lower bandwidth links are treated with reduced transmission load using known application level rate controlling methods [22].

2) Leader- speaker session controlling model

Let a smart classroom implementation have N classrooms with Mx students in the x classroom, with the teacher in the 0th classroom. To reduce the network burden, caused by the requirement of transmitting all the information at high quality, this session controlling methodology passes the control to the participants to transmit and render information in different flavors. (E.g. in high-quality or reduced quality, render information on full screen or in a overlay form.) In this leader-speaker model, the teacher is labeled as the session leader who controls the session. The teacher selects the target audience, speaker, according to various signals he/she receives from the participants. All members besides the leader and speaker are listeners. In this scenario the speaker can be a whole classroom x, or a particular
student $M_i$, in the $x$-th classroom. To facilitate this type of session control, the smart classrooms are equipped with multiple display screens (4 screens) for rendering presentation notes, leader’s video, speaker’s video, and listeners’ video with associated audio rendering. When 4 screens are not provided, this can be realized using 3 screens as in [5] with overlapping videos of presentation slides and the leader on one screen. The features of the session controlling algorithm are shown in Fig. 10.

- A smart classroom session is initiated according to asynchronous notification messages issued by the leader (i.e., signaling when and who is allowed to join).
- Initially, presentation slides, leader’s video and local class video are delivered at high quality on a full screen with all the listeners on a different screen.
- When another class or a particular student requests for focus through some interaction, the leader transfers the speaker’s rights to the participant under current focus. That is, by using system support and the information received from listeners’ audio/video the teacher identifies the next speaker.
- When a different class is to be started, it is simply a matter of labeling another leader, who then changes the local classroom and starts a new session.

![Leader-speaker session controlling model.](image)

Figure 10. Leader-speaker session controlling model.

V. EXISTING AND FUTURE CHALLENGES

Although ALM and leader-speaker session control addresses multiple classroom requirements of existing two classroom architectures, there are other potential issues that need to be addressed in order for smart classrooms to become more effective in a distance education environment. In this section, we briefly explain some of the challenges that have been faced in the two-classroom architecture of Carnegie Mellon system in regard to system downtime, optimal adjustments, and quality delivery together with practical approaches that are being taken for their efficient management.

A. System Downtime

After having gotten used to the 4Mbps IP (H.320/H.323) videoconferencing via Internet2, which almost provides a real-time teaching and interactive environment, a problem arises when it is switched to ISDN connection during network downtime. The speed drops by at least 10 times and it feels like watching an old, slow-motion movie. Nonetheless, when considering cost performance issues, it makes more sense to provide a low speed backup system, especially when the frequency of system down time is low.

During the past two years, network downtime has only been experienced once, and due to an alternative backup delivery system, there has been no total system disruption. It is therefore considered a good design criterion to have a backup delivery system in order to ensure system continuity.

B. Sound Level Adjustments

Adjustment of sound levels for microphones and speakers can become a challenging issue. To simulate a natural sound level, initially ceiling microphones were used, which were equidistantly located from students and lecturers. Although this configuration made sound level adjustment quite easy, it resulted in a feedback problem, i.e., ceiling microphones of the receiving side partially fed back the sound to the sender side, generating a howling effect. The problem was solved by switching to table top microphones operable in half duplex mode. These have a push button switch that can be pressed for activation. These microphones stay off when not in use and thus do not create a feedback problem. But because some people speak too close to the microphones while others talk from far away, optimal sound level adjustment is made a challenging task. Though currently system administrators at both sides try to manually adjust microphones and speakers’ gain on the fly, during its future upgrade, technology may allow us to switch to auto gain microphones and speakers that can deliver a regulated desired output level range regardless of large signal variations at the input.

As can be observed, providing a solution to one problem, may lead to another unexpected problem. Thus, it is quite essential to consider experiences of others when creating new smart classrooms for distance education. Furthermore, when upgrading an existing system, it is equally important to involve the users too. For example, a software solution for auto-gain microphone adjustment has been available in iChat AV software since 2004 [23], or when University of Tasmania (UTAS) upgraded their video conferencing system between their three campuses in 2005, they not only switched to Auto-directional/auto-gain microphones [24], but also tried to involve valuable advices of their users.

C. Auto Tracking Feature of the Camera

Auto tracking cameras are used in the VC rooms, and normally, an image from a lecturer camera is transmitted to the remote site. In the Pittsburg campus, from where most of lectures are delivered, transmission of a student camera is triggered via students’ push button microphones. Once a student pushes a microphone button, the camera automatically zooms-in to that location and the student camera image is transmitted until the student releases the button.

Initially, the lecture camera tracked a moving lecturer and was always centered at the lecturer in the scene.
Tracking of a lecturer who continuously moves around, however, has become a challenging issue and continuous tracking has also annoyed remote side viewers. Students almost feel dizzy when they view a zoomed-in, back-and-forth moving image of a lecturer in a relatively small screen. The situation was improved by selecting a wider camera angle for fast-paced lecturers, and tracking was limited to cases when a lecturer fell outside the camera’s current view.

CyLab Japan which has a smaller VC room and student population, does not make use of auto tracking features. Instead, predefined, fixed student camera positions (front-left, front-right, back-left, back-right, full view) and lecturer camera positions (left, center, right, full view) are set manually via easy to use touch panels from the lectern. To ensure timely tracking, a portable remote controller is also available for this purpose and allows a co-instructor, teaching assistant, or system administrator to help in the process.

It is worth noting that some of the fancy features of the instruments may not always be useful. Furthermore, rather than trying to push for the fantasy world of fully automated systems, some practical approaches and a few manual adjustments here and there may save a great deal of effort.

D. Auto Gain Feature of the Camera

A built-in auto gain feature of the camera becomes very handy when keeping track of a moving lecturer or a zoomed-in audience. However, the feature cannot set an optimal value when the color of the tracked object is in sharp contrast with the background, e.g., when trying to focus on a lecturer who is wearing black clothes and standing against a white wall. Furthermore, continuous usage of the camera results in an increased dark current accumulation that reduces the effective resolution.

Such problems can be overcome by performing background correction - during zoom-in and camera tracking operation, and dark signal correction at a regular interval - during prolonged use. Presently, because such functions are not part of the standard built-in features of the camera, these procedures have to be performed manually.

VI. CONCLUSION

With current commercial IT products, it is quite easy to link distant locations together and distribute top-quality education, developed through rigorous years of research and teaching endeavors, from one location to many other locations. However, the effectiveness of remote lecturing largely depends on the ability to fine-tune the products, like parameter optimization and overriding of auto settings, and most importantly, on the ability to enhance these with suitable homegrown technologies designed for a dedicated purpose.

At Carnegie Mellon, state-of-the-art remote lecturing systems are combined with indigenous homegrown technologies like VTE, lectures are delivered in an interactive manner, and learning is reinforced by stimulating multiple sensory powers. With the support of Hyogo Prefecture, Carnegie Mellon was able to establish CyLab Japan and bring the much needed information security education into the country in an amazingly short period of time. This enables Japanese students to acquire world-class security education and obtain US degrees without leaving Japan.

In order to extend a similar type of architecture to a multiple classroom architecture, this paper proposed a model that can overcome many of the technical challenges that exist in this scenario. It also showed how the model can be implemented by the use of ALM and leader-speaker session control technologies with incorporation of some practical assumptions.

REFERENCES


[18] https://www.vte.cert.org/


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