AC 2012-5258: INTERNET ACCESS TECHNOLOGY AND THE LEARNING EXPERIENCE

Dr. Alexander A. Kist, University of Southern Queensland

Alexander A. Kist received a Ph.D. degree in communication and electronic engineering from RMIT University, Melbourne, Australia, in 2004. His research focused on performance modelling and evaluation of SIP Protocol-based 3G Signalling IP networks and the development of methodologies to enable QoS Signalling in multi-service IP networks. He received his bachelor's degree, diplom-ingenieur (FH), in telecommunications engineering from the University of Applied Science, Offenburg, Germany, in 2000. The thesis on the problem of synthesising of partially link-disjoint paths in a network was completed at the Centre for Advanced Technology in Telecommunications (CATT), RMIT University, Melbourne, Australia. From 2004 to 2006, he was a Postdoctoral Research Fellow with the Australian Telecommunications Cooperative Research Centre (ATcrc) and RMIT University, Melbourne, Australia. From 2005, he was the ATcrc networking program Project Leader. Since May 2006, he is a lecturer and since Jan. 2011, a Senior Lecturer in telecommunications at the University of Southern Queensland, Toowoomba, Australia. His research interests include green IT, teletraffic engineering, performance modelling, QoS provisioning, and engineering education. He is a member of the Telecommunication Society of Australia, Engineers Australia, the Australasian Association for Engineering Education (AaeE), and the USQ Teaching Academy. He is also a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE). He has won several learning and teaching awards, including a University Program Award in 2010 and the University Teaching Award in 2011.

Internet Access Technology and the Learning Experience

Abstract: Internet-based technologies are now commonplace in support of learning, whether the students are remote from campus or not. Many factors impact on student experience of these systems, such as the design of the learning experience, the attributes and experience of the learners, but also technical performance. Access speed, geographic location and network traffic all affect how students interact with the technology and hence the learning experience. Internet access options in Australia differ considerably between metro and rural/remote areas; effectively marking a "digital divide". The National Broadband Network (NBN) will provide "superfast broadband" access to all premises in Australia. This study investigates whether the NBN will overcome or entrench the digital divide in the context of online learning tools. This paper discusses how learning experience relates to technical performance parameters and contrasts this information with key parameters of the NBN. The study suggests that a digital divide will remain for locations that have to rely on satellite Internet access, even once the NBN has been deployed.

Introduction

In step with the developments in technology and society, educators have embraced computer and Internet-based learning and teaching tools. This includes administrative tools such as Course Management Systems (CMS), e.g. Moodle, as well as tools with a strong learning and teaching focus, such as peer assessment tools. Such learning tools are used by both, distance as well as face-to-face education. Modern distance education relies heavily on Information and Communication Technology (ICT) to provide students with an equitable learning experience, comparable to their on-campus peers. Such online tools chiefly rely on the Internet and telecommunications infrastructure to deliver these services. Therefore, availability and performance of these learning tools depend on Internet access. The quality of Internet access in turn depends on technology, bandwidth, geographical location as well as network condition and traffic load.

With the wide adoption of the Internet as an essential part of corporate and popular culture, the term "digital divide" is used to describe inequality of Internet access technology along geographical and social lines[1]. Even though the United States and Australia are well developed industrial societies; barriers along social as well as geographical boundaries still exist. This study focuses on the digital divide between metro and rural/remote areas. Using the Australian National Broadband Network (NBN) as an example, the impact on the digital divide in terms of learning systems is evaluated. The Australian government has made a commitment to build the National Broadband Network, a major infrastructure project that will provide "superfast broadband"[2] access to all premises in Australia. Public discussion in regards to the NBN and it advantages have largely focused on the optical fibre component; however, this part of the network will (only) reach 93% of Australia's population. The remaining premises will be serviced by fixed wireless and satellite-based access, effectively implementing a three tier system. Nominally, minimum consumer bandwidth and cost will be the same across all options. However, this equality exists only at an administrative level; technologically there are major differences between the access options. These technological differences are not specific to Australia and exist in other geographically large countries such as the United States as well.

As engineering education relies heavily on online learning and teaching tools, this raises the question whether these differences impact on the learning experience for students undertaking distance education. Quality of learning experience is a complex issue, for the purpose of this study, however, technical and educational literature is used to support the notion of a technical threshold for acceptable performance. Details are discussed below. This paper addresses the research question 'Does geographic location within Australia have an impact on the learning experience of distance education students from a technical perspective; and, if so, does the National Broadband Network solve these issues? To be able to answer these questions, this study firstly introduces a theoretical framework that links quality of learning experience and technical performance parameters; secondly, it discusses the relationship of Internet access and geographic location. Both aspects are linked to allow conclusions about expected performance. The findings are supported by trial measurements.

Theoretical Framework

The framework for this study involves two aspects: the relationship between Quality of Service (QoS), Quality of Experince (QoE) and Learning Experience discussed in this section; and technical service aspects of the Internet, discussed in the next section.

In the context of telecommunication, the term of QoE is widely used to "refer to the overall acceptability of an application or service, as perceived subjectively by the end user"[3]. Soldani & Cuny[4] link QoE to "how satisfied he or she is with a service in terms of, for example, usability, accessibility, retainability and integrity of the service." Kilkki[5] defines it "as the basic character or nature of direct personal participation or observation". Kist[6] proposes a definition based on Brooks and Hestnes[7] that links experience and tasks, i.e. "QoE is a measure of user performance based on objective and subjective psychological measures using a service or product to achieve a particular task or objective." QoE of students in a learning environment undertaking a learning task is not the same than ``using a service or a product"; relevant dimensions affecting the experience might be different. To address this issue, a study is on the way[8] in an attempt to answer the research question of "What dimensions of quality of experience (QoE) of online learning can be affected by QoS, and how?" Related literature and initial results suggest that there are a number of factors that impact on the quality of the learning experience.

Wu et al.[9] take a human-centric view of interactive multimedia environments and develop a theoretical framework that builds on psychology, cognitive sciences and sociology as well as information technology in an attempt to "map the QoS-QoE relationship" by "capturing the human-centric quality modalities." (p. 481). The authors define quality of experience as "a multi-dimensional construct of perceptions and behaviours of a user, which represents his/her emotional, cognitive, and behavioural responses, both subjective and objective, while using a system" (p. 483). This model does not specifically focus on learning environments. The extensive literature on online learning suggests that many other factors such pedagogy and learning tool design have a significant impact on learning in online environments.[10] Sambrook's[11] study, for example, shows that user-friendliness, presentation, structure of tasks and navigation within tasks can effect the quality of online learning tools. Basic strategies such as a clear set of instructional goals, the perceived relevance of tasks in relation to these goals and the resultant motivation and cognitive processes of learners, are fundamental to how learners

behave and perform in any learning environment.[12, 13] Some factors, such as system performance, are limited to interactive online environments. Moebs'[14] focussed on the effect of 'flow' on QoE for learners, in an attempt to address this. Although flow is expected to be highly relevant to the effect of system performance (QoS) on QoE, the study does not account for the relative effect of all the factors that are expected to impact on QoE for learning. For the purpose of this paper, it is enough to assume that a QoS threshold exists beyond which technical performance becomes the dominant (negative) factor in the learning experience. This observation is also supported by technical studies into Quality of Experience[15, 16] that suggest that there is a logarithmic relationship between technical performance parameters and quality of experience.

Network access quality is a necessary but not a sufficient condition to provide access to online learning tools in the context of distance education. For the discussion in this paper, the absolute value is not important, but that a threshold exists that marks a minimal quality level. Gilbert et al.[17] support this assumption. The authors suggest that network related technical performance of learning systems is not relevant as long as the service is satisfactory and traditional learning design factors are dominant. However, as soon as there are disruptions, they become a concern. Another aspect is that learning tools might not be perceived as such[18] and this impacts on performance expectations. It is also important to note that the nature of these relationships is service (learning tool) and task specific.

Internet Access and the National Broadband Network

The Australian National Broadband Network aims to deliver "super-fast broadband" to 100% of Australian homes. The Government owned NBN Co has been tasked to "…deliver Australia's first national wholesale-only, open access broadband network to all Australians, regardless of where they live"[2]. The project aims to connect 93% of premises using Fibre to the Home (FTTH) technology and the remaining 7% of premises using terrestrial fixed wireless or satellite wireless technology. Providing a national broadband network and particularly FTTH will have a major impact on education, health, business, government service delivery and many other areas.[19]

Table 1: Internet Access Options

Coverage areas	Current access types	NBN access types	Technical limitation	Latency (access RTT)
Metro	Dialup, ADSL, wireless broadband, FTTH (limited)	FTTH, FWB, Satellite	"as good as it gets"	< 10ms
Rural, fringe, metro black spots	Dialup, ADSL,	FWB, Satellite	Throughput, to a lesser extend latency	10ms – 50ms
Some rural & remote areas	Satellite	Satellite	Throughput, latency	> 500ms

Geographical location determines which Internet access options are available on a premise. Table 1 outlines the three key coverage areas, current access technology, NBN access technologies, expected Round Trip Times (RTT) and principal performance limitations. This study focuses on the wireless component (the remaining 7%), i.e. Fixed Wireless Broadband (FWB) and satellite access; and its expected impact on the performance of learning and teaching tools. The FTTH segment is not seen as problematic as it provides high bandwidth access at a very low latency.

Fixed Wireless Broadband

FWB access is suitable for fringe areas, metro black spots and sparsely populated areas with suitable propagation characteristics, i.e. not mountainous. It will rely on 4G mobile technology (IMT advanced) with peek data rates of 1Gbit/s. Latency of the access component of the network is low by design, i.e. 10ms under ideal conditions. This has been demonstrated in a field trail [20]. A factor that could introduce additional, unacceptable latencies is extensive wireless backhaul. For most areas this is not an issues as the proposed network topology largely relies on optical fibre backhaul.

Satellite

Areas that are not covered by FTTH or FWB have to rely on satellite access which is available anywhere in Australia. Such areas are not limited to sparsely populated rural and remote areas as highlighted by Kandeepan et al.[21], but also to other areas that are unsuitable for FWB. These include the valleys in the hinterland of the eastern seaboard, for example. The key issue with satellite access is the high latency. Geostationary satellites are in an orbit of 35,786km above the equator which results in minimal RTT of 500 ms based on the propagation delay only. Typical RRT are in the order of 1000ms to 1400ms. The only way to overcome this physical limitation are Medium Earth Orbit (MEO) or Low Earth Orbit (LEO) satellites that can reduce the propagation delay to 125 ms and 10ms, respectively – the former value well above FTTH and FWB.

Methodology

To address the research question, a number of learning tools where chosen and their usability was established to identify general performance thresholds undertaking trials based on network emulation. These thresholds are then translated into network performance parameters and these are compared with the national broadband network specifications.

This study evaluates the performance of two activities that are common encountered in online learning environments. The first activity is the download of a simple Moodle course web page, commonly used for course management; the second option is a more complex task and involves interaction with the Linux operating system remotely. The first is evaluated by measuring objective performance parameters, i.e. completion time; the second test additionally also evaluates the Mean Opinion Score (MOS) of test subjects to provide a better measure of usability. Two network parameters are relevant, access bandwidth ("How fast is the Internet") and latency ("How responsive is the Internet").

Bandwidth – This parameter determines how much data can be transmitted at one time. The target throughput of all NBN options is at least12Mbit/s. Comparing this number to current user applications, the bandwidth will be sufficient – for many premises this will mark an improvement. A lecture recording including audio and video in mp4 format produces files of approximately 1MB per minute. An hour recoding of 60MB takes about 5 minutes on ADSL (1500kbit/s) and less then 40 seconds via NBN's wireless options and less then 5 seconds using NBN's FTTH technology. It is expected that increased capacity will also lead to an increased bandwidth demand in the future which might make bandwidth the limitation.

Latency, the time it takes for information to traverse the transmission path, is the main limiting parameter, in particular, for interactive applications. For telephony, for example, RTT should be less than150ms for acceptable performance; for interactive gaming, RTT of several tens of milliseconds are problematic. Software as a Service (SaaS), such as SharePoint or GoogleApps are also delay sensitive and are likely to be used in an educational setting. The Remote Access Laboratory becomes unusable for RTT exceeding 300ms, for example, as demonstrated in the next section.

Results

The aim of this section is to put the numbers into perspective that were discussed above. Performance thresholds largely depend on the particular service or learning tool that is being used; and for what purpose. Two downloads and an interactive learning activity are discussed.

Figure 1 depicts the time it takes to download a course home page from the CMS against the access bandwidth on a reverse logarithmic scale. For the experiments, the key limiting factor is the access link, for practical systems, the server itself or access links to the server could also be bottlenecks. The error bars show 95% confidence intervals. Diamond markers indicate test results that have been obtained using a network emulator. The triangle shows measurements for a sample ADSL connection, and the square marker depict a sample for a 3G network data connection. The NBN target of 12 Mbit/s is marked by the dashed line. This demonstrates that for this particular application, even at minimum ADSL speeds, access bandwidth is not an issue and most access options will see a considerable improvement with NBN access.

Figure 2 depicts an example of another generic service which is lecture recordings. The graph shows the time it took to download the file versus the access bandwidth. The file was a 10 minute lecture recording, 8.4 MB in size. On a technical level, this scenario is different from the first example, as this is a single, large file which is downloaded via one connection. Web pages are built of multiple small files that are downloaded in parallel such as scripts and pictures.

As above, 95% confidence intervals and the NBN target bandwidth of 12 Mbit/s are shown. The results for 3G and Satellite indicate longer download times than expected due to the link capacity. This is due to the nature of the wireless channel, throughput fluctuates with channel interference. There is also an indication that at higher speeds, a server bottle neck is being reached. It is expected with the wide availability of NBN access that server infrastructure will be adapted to provide adequate service. Most users will see considerable performance improvements in this category, once the NBN is deployed.

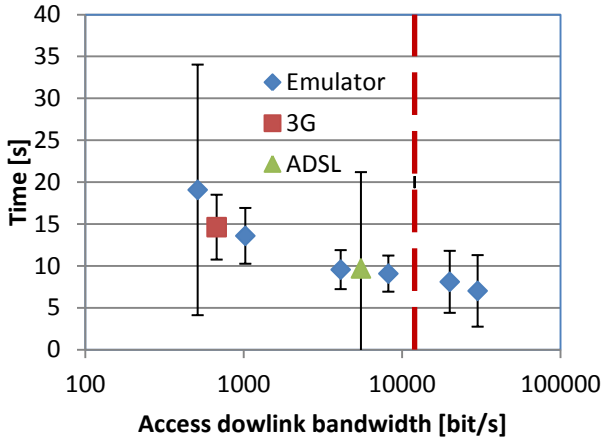

Figure 1: Download time (course web page) versus access bandwidth.

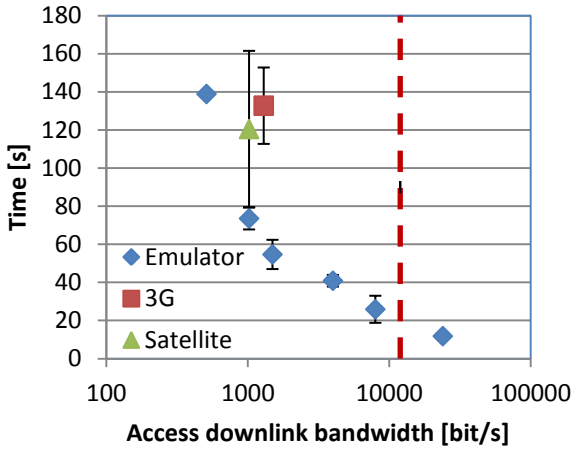

Figure 2: Download time (lecture recording) versus access bandwidth.

The second set of results introduce objective performance measures and subjective user perceived performance for a Remote Access Laboratory activity that involves writing and testing a short script that controls a hardware relay. Details of the experiments are outside the scope of this paper and are discuss in another article.[6] Figure 3 depicts the Mean Opinion Score of test subjects (excellent = 5; good = 4; fair = 3; poor = 2; bad = 1) versus RTT. Figure 4 depicts relative task duration versus RTT, for the same experiment.

Test duration varies considerably between test subjects. To overcome this, relative duration was used: average duration was calculated for each subject and the relative difference between attempts is depicted in Figure 4. For acceptable delays, test duration is determined by the ability of the subject. As the testers were not familiar with the activity, the first run took longer than subsequent runs. In the following attempts performance increased.

All test subjects agree that above 300ms usage became very difficult or impossible. This is reflected in the MOS ratings as well. It is expected that RTT for most services using the FTTH or FWB segment are well below the 100ms mark (dashed line on the left) and therefore provide acceptable performance for this interactive task. As the latency for (geostationary) satellite access exceeds 500ms (dashed line on the right) the activity is not suitable for this access type.

Whereas these performance thresholds are based on trials with a small sample size, in combination with the framework discussed above and the technical literature on QoE, this is enough to initially address the research questions. More detailed answers require more comprehensive trials and tests. However, these will not change the general trends reported in this study, as they are largely based on the physical limitations of the different access technologies and not the experience of individual users.

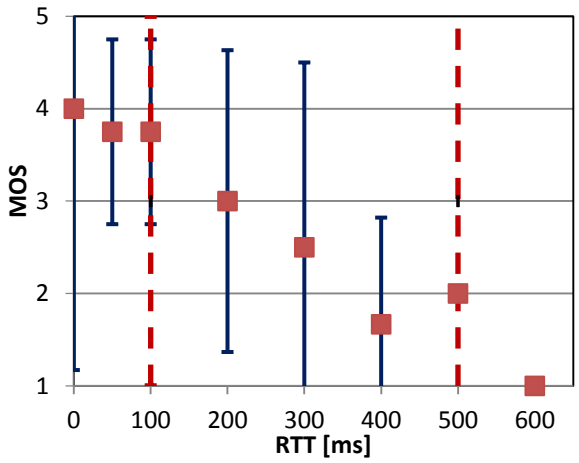

Figure 3: MOS (RAL) versus RTT.

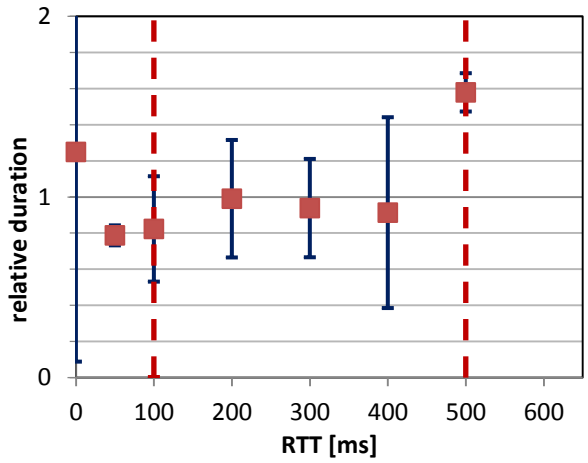

Figure 4: Relative average test duration versus RTT

Findings

The Australian NBN will not fundamentally change the three tier access also found in other countries. Particular technologies to provide fixed wireless or satellite access do not offer the same fundamental quantum leap that the change from copper to optical fibre provides for fixed line access. In fact this has the potential to create an even larger digital divide, as there are no obvious technological limits to the amount of bandwidth that can be offered to the premise via optical access; the bandwidth is unlimited from a current perspective. Rural and fringe areas on the other hand will have to rely on wireless access, mainly because of the high cost of deploying fibre.

It is expected that the deployment of the FTTH component will lead to new bandwidth hungry applications in the learning and teaching space. Concrete examples or practical details of such future applications are not known at this point. However, it will be difficult to offer (interactive) applications with large bandwidth demands via the FWB or the satellite segment of the network.

FWB will provide services that are more then sufficient for current learning and teaching applications. Areas that are outside the FTTH and the FWB footprint will have to rely on satellite access with its limitations. Capacity is not seen as an issue, but latency is a problem. A fleet of LEO satellites is necessary to overcome this issue. Therefore, some areas will remain problematic in terms of latency and reliability. Featherstone[22] provides a detailed discussion of the efforts involved in providing broadband access to a distributed remote community. The article highlights that fibre optic access is necessary to enable interactive services which are even more important in remote locations.

Bandwidth is not an issue with current learning and teaching tools. Emerging L&T applications that build on the high throughput available through FTTH, might not work in the wireless network segment. Once the NBN is deployed, most premises in Australia will have faster and more reliable broadband access. Some interactive learning and teaching systems will not work in areas that depend on satellite access - the digital divide will remain.

Conclusions

Many learning tools rely on Internet connectivity and with rapid technological development; Internet access for many premises is no longer an issue. Initiatives such as the NBN will further improve access and reach premises on the fringe and in black spot areas that currently have no sufficient broadband access. This study concludes that such programs will not overcome but shift the "digital divide". For the performance of current learning tools, the bandwidth provided by the NBN will be adequate; latency for satellite-based internet access, however, is a problem. Learning and teaching systems that are highly interactive and therefore latency intolerant will not work in areas that use satellite internet access in the foreseeable future. Further work is required to investigate details of the impact on specific learning and teaching systems as well as applications.

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