Transforming the Communications Engineering Laboratory Education through Remotely Accessible Software Radio Platform

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Introduction

Communications engineering education has traditionally been confined to focus on theory. While it is essential that students learn the theory of communications, this alone is not enough to prepare them for their careers in telecommunications industry. This is due to the fact that there are several practical challenges in designing and implementing communication systems that are overlooked when focusing only on theory (El-Hajjar, Nguyen, Maunder, and Ng, 2014). For example, in practical communication systems, synchronization and channel estimation are two important signal processing steps at the receiver side, in order to correctly recover the source information. Although synchronization algorithms are taught in most communication engineering courses, students do not fully understand their importance, until they start to implement a communication system.

To bridge the gap between fundamental theory and industry practice, recently a project supported by the Teaching Excellence Development Fund (TEDF) at Curtin University was carried out to redevelop the laboratory classes of a number of communications engineering units offered in the courses of Bachelor of Engineering and Master of Engineering Science. The aims of this project are twofold:

- Redevelop the laboratory classes of telecommunications units by making use of the Universal Software Radio Peripheral (USRP) from National Instruments (NI). These new laboratory classes provide students with hands-on experience and prepare them for their careers in industry.

- Increase the accessibility of the laboratory classes using innovative virtualisation technology, transforming the laboratory to be remotely 24/7 accessible and thus increasing the flexibility and sustainability of laboratory classes.

The newly developed remote laboratory is being used to teach the laboratory classes of the unit Advanced Communications Engineering at both Curtin Bentley (WA) and Miri (Malaysia) campuses in Semester 2, 2015. The initial feedback from students towards the laboratory classes is positive.

Background

In the courses of Bachelor of Engineering and Master of Engineering Science at Curtin University, there are three units for communications engineering: Communications Engineering Fundamentals, Advanced Communications Engineering, and Mobile Radio Communications. In the past, laboratory classes for these three units were mainly designed separately, without an adequate consideration on the inherent links, particularly in the laboratory experiments between these units. For example, in the unit Advanced Communications Engineering, the laboratory experiments were purely based on hardware. While it is essential that students are exposed to hardware for telecommunications, purely hardware-based laboratory lacks the flexibility required in communications engineering education, as communication engineering is one of the most dynamic areas in engineering, with a new generation of communication system emerging almost every decade (Proakis and Salehi, 2010). Moreover, the system development of a hardware-based communications

laboratory typically takes a significant amount of time and has a high cost. This is of particular concern considering that the same syllabus needs to be delivered in multiple campuses of the host institute, which means that the laboratory equipment needs to be purchased/duplicated at all campuses.

Compared with hardware-based laboratory, software based experiments are easier to design with a much lower cost. However, in a software experiment, the whole communication system, including the channel, is simulated by software. This inevitably leads to the drawback of a software-based communications laboratory, where the communication channel is often over simplified. By doing purely software-based experiments, students are not fully exposed to the challenges in designing a real communication system.

After a careful consideration of the pros and cons of hardware and software communications laboratories, we decided to adopt the software defined radio (SDR) (Cass, 2006) to redevelop the laboratory classes. An SDR is essentially a communications platform that uses software to reconfigure radio frequency (RF) hardware. In SDR, communications algorithms are implemented by software. However, the algorithms are tested in real communication environment, as signals are transmitted through real wireless channel environment in the SDR platform. Therefore, SDR has become a popular platform used by researchers as a wireless prototyping platform and by universities as a teaching aid (Welch and Shearman, 2012).

To transform the communications engineering laboratory experience, the laboratory classes have been redeveloped based on the USRP devices from NI. USRP is a flexible and affordable SDR platform that turns a standard personal computer (PC) into a powerful wireless prototyping system. With USRP, students can explore a communication system with live signals to develop a better understanding of theory and implementation.

Communications units are offered in both Curtin Bentley (WA) and Miri (Malaysia) campuses, and will also be offered in Sri Lanka Institute of Information Technology (SLIIT) in 2016. However, as telecommunication is a highly technical area, there is very limited number of staff members in Curtin oversea campuses with expertise in setting up laboratory classes. To increase the accessibility and make full utilisation of the USRP equipment, we have transformed the laboratory to be 24/7 accessible by students from Bentley, Miri, and SLIIT in a more personalised flexible learning environment.

We would like to note that the 24/7 remotely accessible communications laboratory that was developed is not only efficient for teaching laboratory classes of communications units, but also perfect for final year and masters student projects. USRP is a powerful wireless prototyping system, and can be used by students to verify concepts and ideas in their projects at their own pace. We have used USRP for a number of final-year undergraduate and postgraduate student projects. In one of the projects, students implemented an orthogonal frequency-division multiplex (OFDM)-based wireless communication system. In another project, an internship student successfully developed a 2x1 multiple-input single-output (MISO) wireless communication system (Proakis and Salehi, 2010) using 3 USRP devices. In the following, we present the system design of the remotely accessible communications laboratory.

Remote Laboratory System Design

A photo of the remotely accessible communications laboratory is shown in Figure 1. It consists of 12 NI USRP 2920 devices connected to a gigabit switch. The top-right and bottom-right subfigures of Figure 1 show the back and front of the USRP devices, respectively. As two USRP devices form one transmitter-receiver pair, there are altogether six pairs. These six pairs of USRP devices can be remotely accessed at the same time. Students may work individually or as a team on a pair of transmitter and receiver. The USRP devices can be configured to transmit at different frequency bands to avoid interference

among them. This system can be easily scaled to accommodate more USRP devices to cater for classes with a large number of enrolments.

The gigabit switch is connected to the Vsphere server through a control switch. Six Windows virtual machines (VMs) are installed on the Vsphere server such that each VM is connected to a pair of USRP devices. Moreover, one VM and a pair of USRP devices are configured to form a virtual local area network (VLAN), as shown in Figure 1. Thus, students can work remotely on a VM as if they are working on a physical PC with two USRP devices. Once the USRP devices, the switches, and the servers are correctly configured and powered on, there is no requirement of the presence of humans at the physical laboratory to run the laboratory sessions. The architecture of the remotely accessible communications laboratory is shown in Figure 2, where for simplicity, only four USRP devices and two VMs are shown.
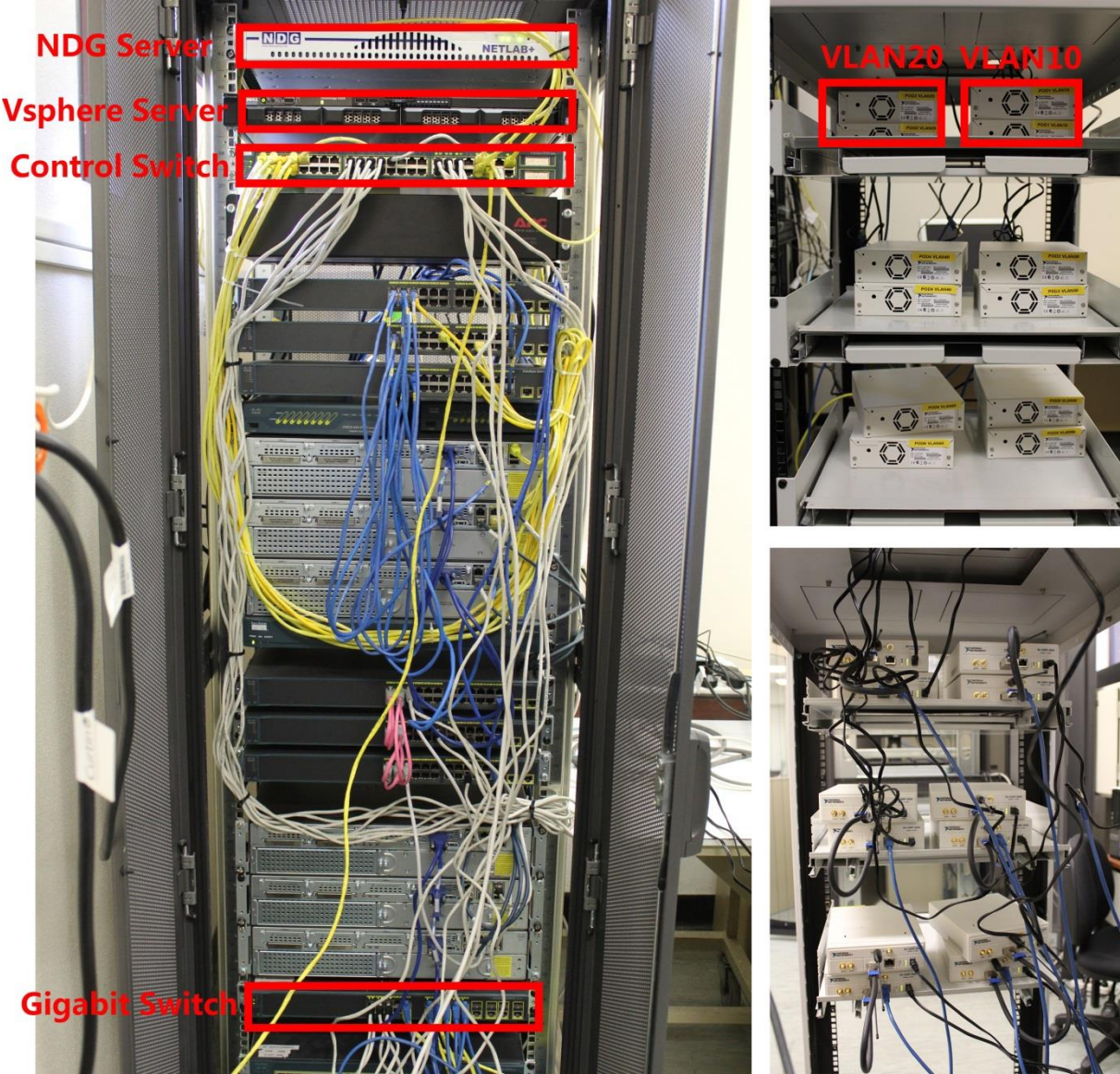

Figure 1: The remotely accessible communications laboratory with USRP devices, switches, and servers

USRP platform with LabVIEW software

The USRP devices are configured/programmed using the NI LabVIEW software. LabVIEW is a graphical language for programming math and signal processing applications. The graphical programming interface makes it can be easily learned by students. Students can

view and design the whole process of communication systems, measure signals at various places of the system through virtual instruments (VIs). Two USRP devices can be connected through a multiple-input multiple-output (MIMO) extension cable, which provides synchronization between the transmitter and the receiver. This arrangement provides the flexibility needed in the laboratory classes. When students study basic concepts such as modulation and demodulation, two USRP devices can be connected through the MIMO extension cable, such that students can focus on these concepts and do not need to consider synchronization. Later on, after advanced communication system topics are taught to students, the MIMO extension cable will be removed such that synchronization and frequency offset estimation must be carried out at the receiver by students.
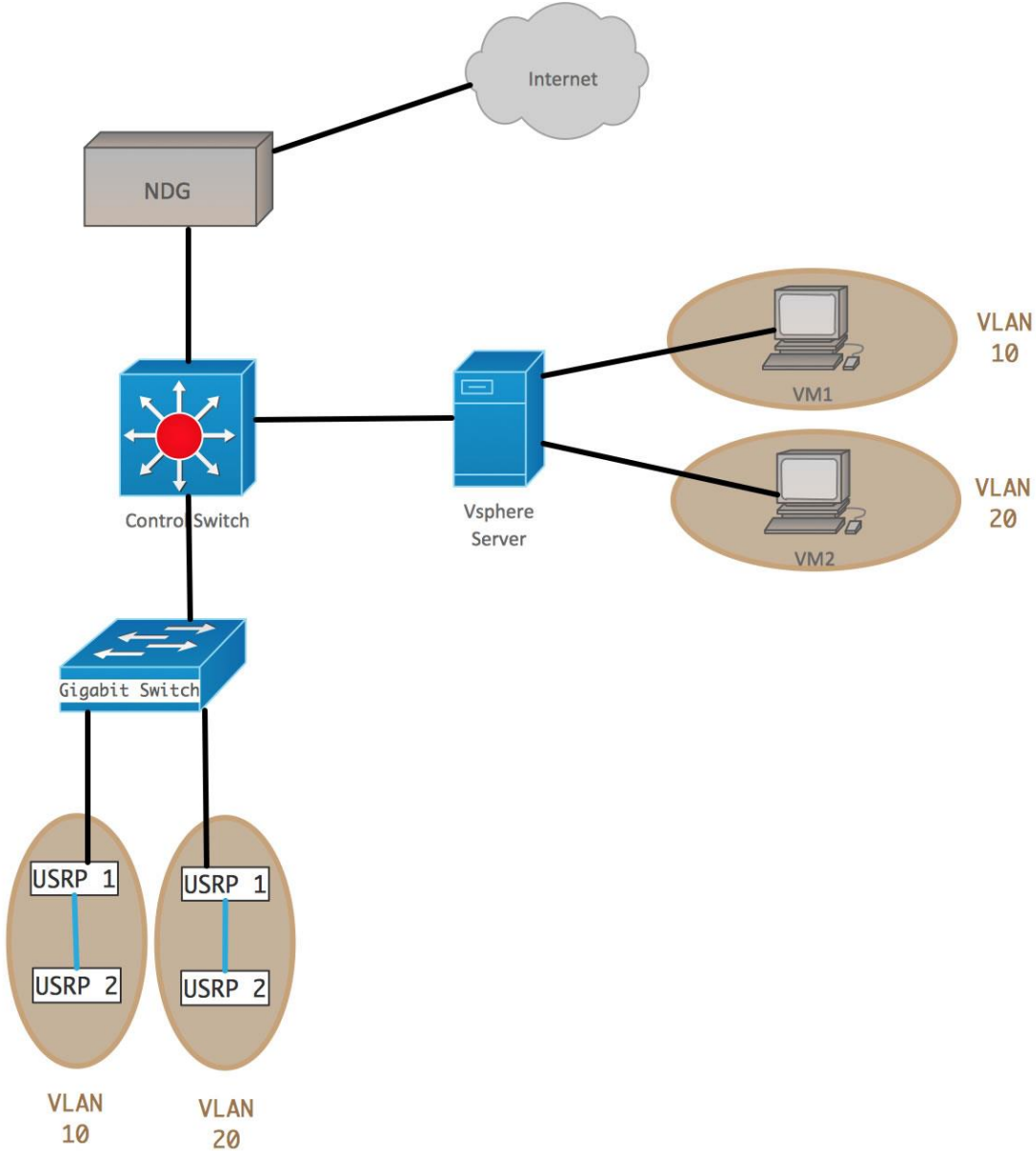

Figure 2: Architecture of the remotely accessible communications laboratory. For simplicity, only four USRP devices and two VMs are shown

Before the start of laboratory experiments of the first communications unit, we run an introductory laboratory session. During the first part of this session, students are introduced to the LabVIEW graphical programing environment (National Instruments, 2015), including the concepts of VI, front panel, block diagram, and programming and data structures. Students are introduced to the NI USRP hardware during the second part of the introductory

laboratory session, including the steps to correctly initialize the USRP devices. As three communications units use the same laboratory, there is no need to repeat the introduction session for the other two units.

We have developed three experiments in the unit Advanced Communications Engineering and four experiments in the unit Communications Engineering Fundamentals. The unit Advanced Communications Engineering focuses on analogue and digital passband modulation (Haykin, 2001). Students are required to implement amplitude modulation (AM) and frequency modulation (FM) communication systems using USRP. In the other unit, students need to implement baseband signal operations like modulation, pulse shaping, and matched filtering. These laboratory experiments are both interesting and challenging to students. Figure 3 demonstrates a screenshot of a VM with the LabVIEW front panel showing the quadrature phase shift keying (QPSK) modulated transmission signals with various input parameters.
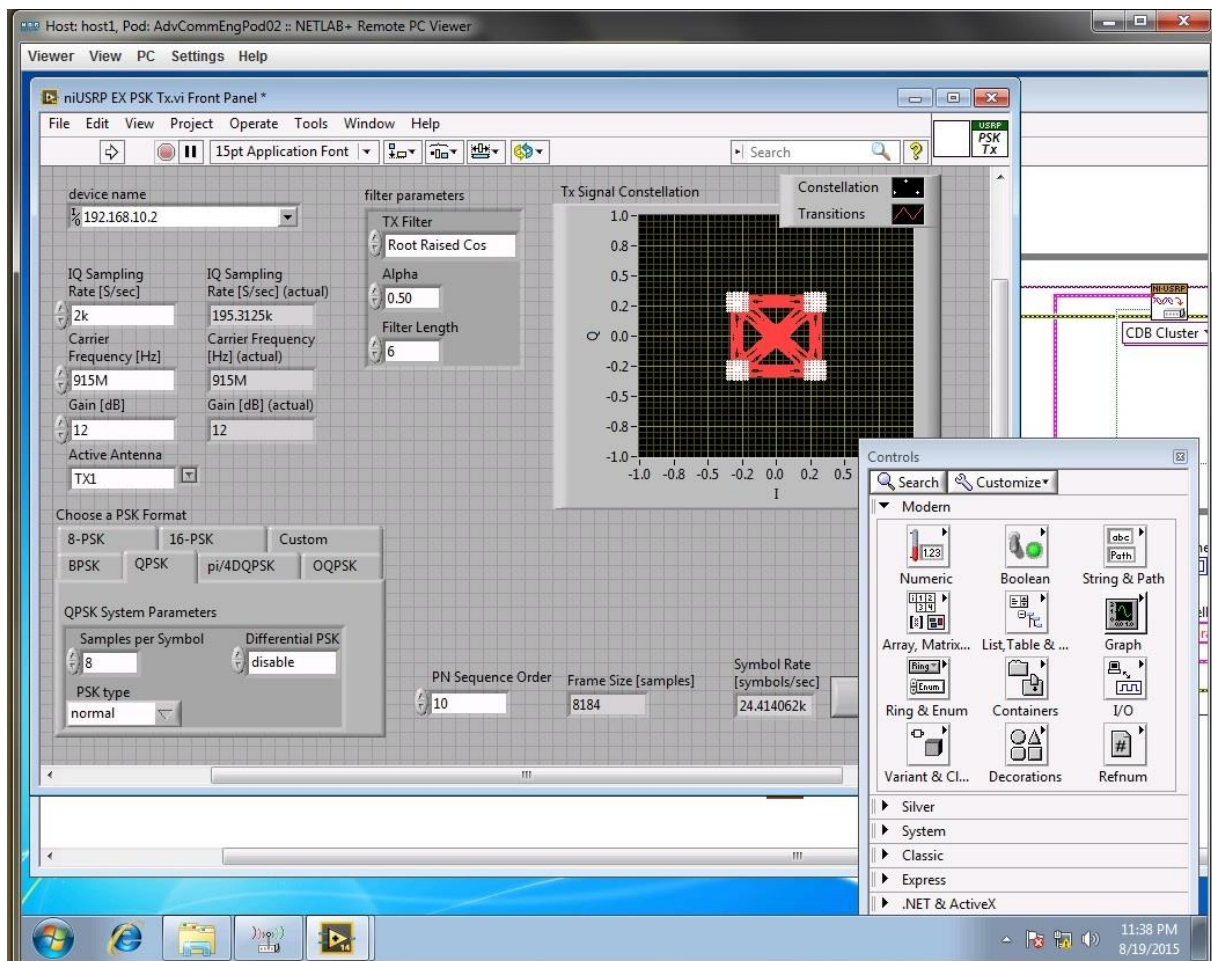

Figure 3: Screenshot of a VM with the LabVIEW front panel showing the QPSK modulation scheme with various input parameters

Remote access through NETLAB+

We chose the NETLAB+ system from the Network Development Group (NDG) as the interface of the remote laboratory. NETALB+ is a laboratory appliance for information technology training and distance learning. It is used in our project to enable remote access. Students can have access to the USRP equipment in an environment that is easy to use and manage. Moreover, under the NETLAB+ environment, students at different locations can form a team and work together remotely. The topology of the NETLAB+ system in the remote laboratory is illustrated in Figure 4.

Each student has an account in NETLAB+ created by the laboratory instructor. Students can book laboratory sessions individually or as a team at any time if the USRP devices are available. Students work on Windows VMs to configure the USRP devices. Figure 5 shows the NETLAB+ interface taken during a laboratory session where all six pairs of USRP devices are booked (six student groups).

A distinct advantage of the remote laboratory is that it is platform independent. Students can use any computer (PC and laptop) with any operation system (Linux, Windows, and Mac) from any location to access the USRP devices, for example at an internet café. No software needs to be installed on the students end to access the laboratory and thus licensing is not an issue.
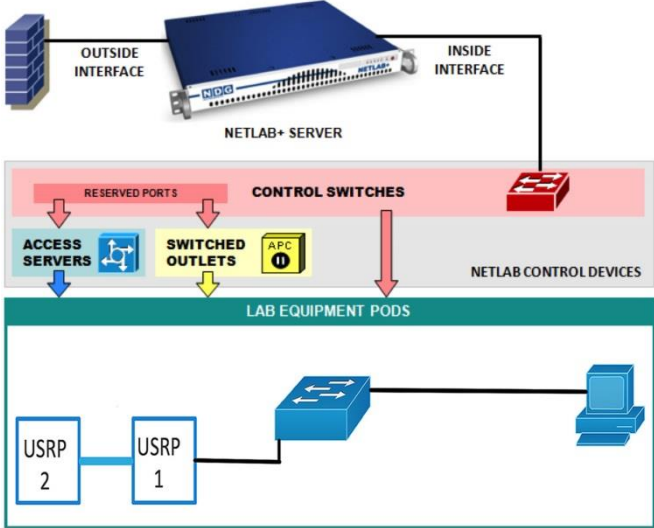

Figure 4: Topology of the NETLAB+ system in the remote laboratory
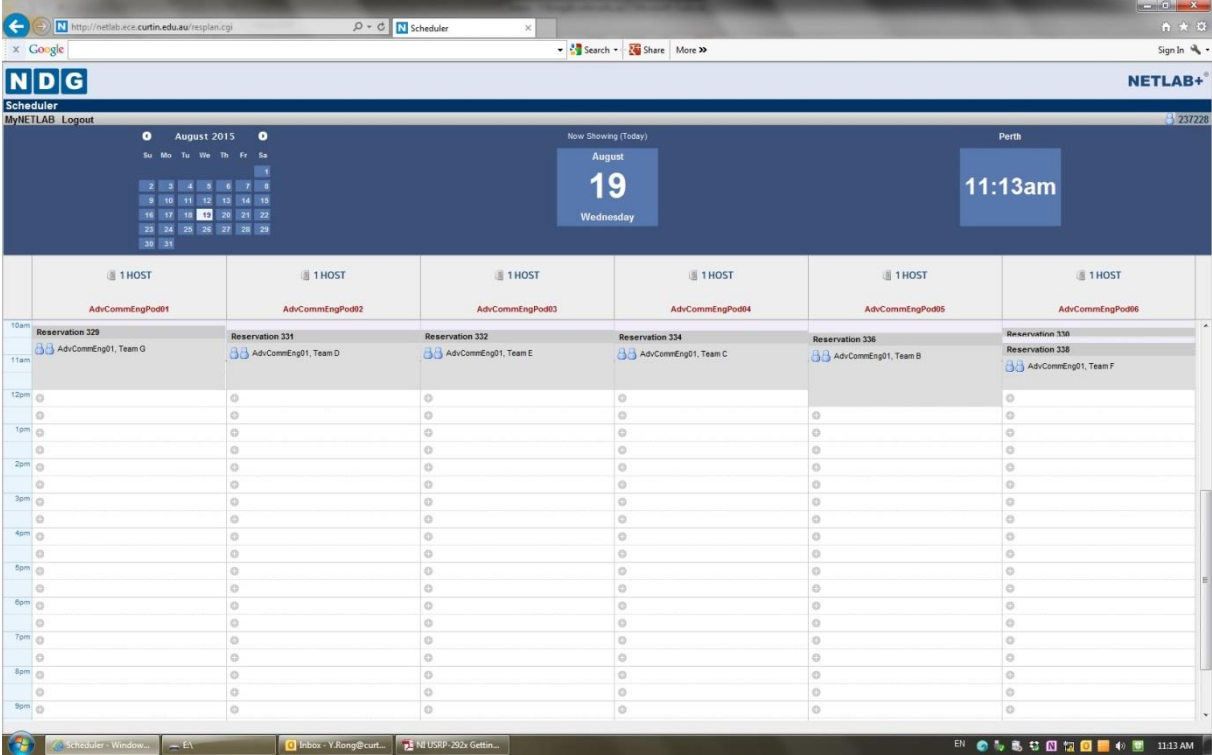

Figure 5: Screenshot of the NETLAB+ interface taken during a laboratory session where all six pairs of USRP devices are booked

Discussions

Feedback from students has been obtained through discussions before the conclusion of laboratory sessions at both campuses of the host institute. The initial feedback from students towards the laboratory classes is positive. Most students had positive experience with the remote laboratory. They think that the remote laboratory access system is easy to learn and convenient to use, and the NI USRP is helpful in learning the concepts in communications engineering. It is agreed by a majority of students that the remote delivery system was a success and should be further utilized in future. Students from both campuses agree that the remote delivery of laboratory classes made the unit learning more uniform over the two locations. Without the system, we would have lost much useful exposure to experimental facilities in communications engineering.

In summary, the remote laboratory we developed improves the quality of teaching communications units and in general engineering teaching and learning in a number of aspects

- It provides students hands-on experience with the state-of-art USRP platform. This helps students develop a better understanding of theory and implementation and prepares them for their careers in industry.

- Due to reasons such as part-time job commitment and time-table clashing, sometimes we find it is really challenging to find a common laboratory time suitable for everyone. With the remote laboratory we developed, class scheduling is made easier as the laboratory time is flexible and students can learn at their own paces (Jona, Roque, Skolnik, Uttal, and Rapp, 2011).

- The remote laboratory is more secure as students do not physically interact with the USRP equipment. Therefore, damage to equipment through inappropriate use is reduced. The safety of students is improved, and thus, reducing the cost of occupational health and safety (Weddell, Bones, and Wareing, 2014).

- The new laboratory is ideal for demonstration, for example in the university open days, to showcase the interesting principle of wireless communication in mobile phones that students use in their daily life. Thus, this laboratory contributes to motivate students study engineering, and increase the first year retention rate (Cardoso, Vieira, and Gil, 2012).

- This laboratory is also perfect for final year and masters student projects. USRP is a powerful wireless prototyping system, and can be used by students to verify concepts and ideas in their projects.

- The innovative and efficient laboratory teaching method developed in this project can be readily transferred to other areas, particularly other engineering teaching areas such as mechanical and civil engineering.

- The remotely accessible laboratory enables cross campus students collaborations, facilitates shared teaching among staff members, and provides savings of academic resources on equipment and staff employment, making the laboratory teaching highly sustainable. As the communications units are offered in multiple campuses, we receive fewer complaints from oversea campuses on faulty equipment since we introduce the remote laboratory.

Conclusions and Future Work

As reflected in the UES (University Experience Survey, 2015), quality of teaching is very important for student retention and satisfaction. The transformed communications laboratory improves the quality of laboratory class teaching of communications units by providing

students hands-on experience with the state-of-art USRP platform. This helps students develop a better understanding of theory and implementation and prepares them for their careers in industry. The remotely accessible laboratory also enables students learning at a flexible time.

The initial results from this project have been very encouraging. In the future, we will add video camera access to the laboratory, such that remote students can view the physical USRP devices. This is helpful when considering that the LED lights on the USRP devices indicate the work status of the devices. We will make the remote laboratory more robust by upgrading the server hardware and software.

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Acknowledgements

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