# Using Academic Research Methodologies to Improve the Quality of Teaching:

## A Case Study

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## ABSTRACT

A contract for the European Space Agency (ESA) was carried out by the University of Aberdeen, Scotland, to study the performance of the protocols (particularly TCP/IP) used within the ESA funded CODE satellite communication system (Fairhurst, Ord *et al.* 1993; Fairhurst, McEwan, *et al.* 1993; Fairhurst, *et al.* 1994). As part of that study, data was collected from the routers connected to the VSAT terminal equipment using the Simple Network Management Protocol (SNMP). The analysis of data gathered from that experiment, and the later comparison of some of the methodologies used, formed part of a M.Sc. Engineering by research thesis published by the author of this paper (2000).

The present paper does not particularly concern itself with the results of the above research. Rather, it is intended to illustrate that the experimental methodologies, devised for a leading academic research project undertaken at postgraduate level, can at times be later used to improve the quality of teaching and research at degree level and below. This is contrary to the common but ill-conceived notion that such academic research is overly esoteric and thus somehow unrelated and of no benefit to the more down-to-earth realities of general teaching.

Within this paper some of the practical details of the methodology used in the CODE experiment will be described. This will include the hardware internetwork configurations used during both the “live” satellite data communication link (an expensive resource) and a similar configuration using a “Satellite Link Simulator (SLS)” during the majority time when the live link was unavailable.

Following the model of the above research, the School of Computing at Christchurch Polytechnic Institute of Technology (CPIT) has recently begun work on the creation of an in-house data communications research and teaching laboratory. Although this is in its early stages of formation this presentation will show that parts of its design are derived directly from the above CODE experiments. In addition, some software simulations used in the CODE experiments

will be briefly described along with our plans for using similar software simulations in student research project work.

# 1. INTRODUCTION

A VSAT system named CODE (Co-Operative Data Experiment) was developed to stimulate work in 20/30 GHz (Ka-band) technology. It utilised the 20/30 GHz payload of the Olympus communications satellite. Olympus was owned and operated by the European Space Agency (ESA). It was launched from French Guyana by an Ariane launch vehicle on 12th July 1989 and was expected to be operational until at least 1997 (Hughes 1991). Unfortunately it was destroyed in a meteor shower in late 1993 but not before a great deal of useful data was collected from it.

The Electronic Research Group (ERG), of the University of Aberdeen, Scotland was one major contributor to the CODE project. ERG evaluated the performance of the TCP/IP protocols over the satellite link and attempted to optimise their performance by various means.

Although the original CODE experiment ended dramatically these many years ago, the data collected remained and remains a useful research resource. The commercialisation of the Internet that has taken place, and continues to take place, has caused a resurgence in interest in TCP/IP and with that interest has come increased funding from both private and public sources. The net result is that TCP/IP related research is in a very active state. One particular area of interest is Telephony, including both voice and video over IP (The OpenH232 Project; Rosenburg, et al.; Ott, Perkins, et al). Research data and the results from TCP/IP research experiments, long ago completed and shelved, have become current again as commercial interests pour money into their search for improved commercial solutions.

This paper briefly explains some of the technical problems that are encountered in using a satellite data communications link with TCP/IP traffic. It briefly describes some of the research experiments undertaken by ERG which were related to these problems. The purpose of these descriptions is not to show how the above problems can be solved but rather to show the breadth of research technique and subject knowledge inherent in such complex research. It is proposed that the nature of such research often lends itself to useful duplication at undergraduate level. To illustrate how such duplication can be usefully employed, the developments of a new research and teaching facility at CPIT is described. The design of this facility grew in part out of the various network topologies and techniques that were used during the ERG research. A major intention is to duplicate the original research as part of our teaching of the research process and data communications, to our degree students.

# 2. TECHNICAL ISSUES

## 2.1 Satellites and TCP

The use of satellites has long been seen as a possible means of low cost global communication. Unfortunately, with satellite links come two major problems; the link introduces a fixed communication delay of around half a second for the hop up and down through the satellite and the satellite link is much noisier than a typical terrestrial link. As a transport protocol, TCP does not traditionally handle delays, nor large bit error rates, very well (Fairhurst, McEwan et al. 1993; Zhang *et al.* 1997; Zhang *et al.* 1998). Its design assumes that messages that have not arrived in a short time have been lost due to traffic congestion. This causes TCP to retransmit its messages in very small chunks (reduced window size). This doesn't deal with the satellite delay problem at all but instead it tends to exacerbate it. In addition, rain fades, clouds and other atmospheric conditions, can soon increase the satellite channel bit error rate. This causing more and more retransmissions, at smaller and smaller window sizes, until TCP grinds to a halt hopelessly trying to deal with the falsely perceived traffic congestion. Even in relatively good conditions therefore, TCP messages are often delayed by far more than the fixed half second satellite delay. What makes it worse, is that the resultant delays are variable. Telephony, for example, can stand a short fixed delay (though such delay does introduce the common echo effect commonly heard on long distant satellite telephone calls) but voice traffic cannot suffer varying delays at all. The sound soon becomes unintelligible (Pracht and Hardman 2000).

## 2.2 Areas of Research

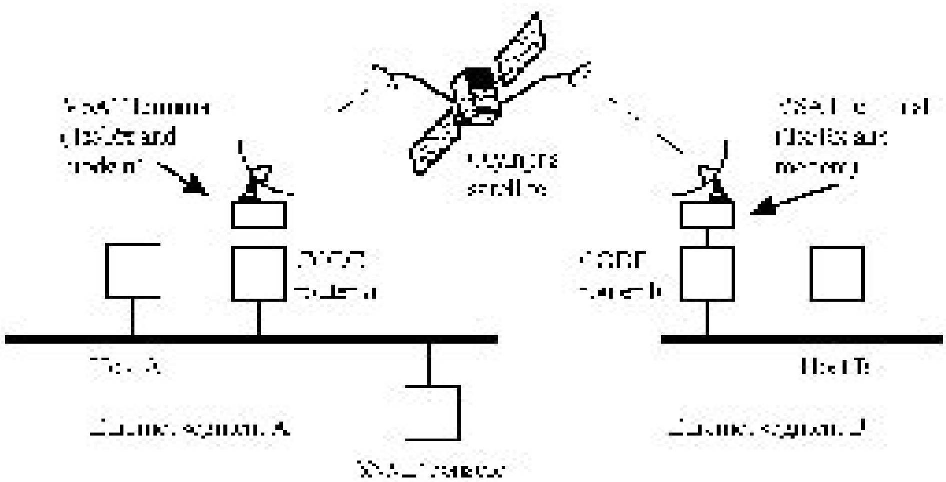
Research continues into optimising TCP for use with satellite links. Various buffering strategies can be used to compensate for the variable delays. The Forward Error Correction (FEC) algorithms used on the satellite link data can be improved. FEC decoders can be designed that adaptively reduce the otherwise crippling bit error rates whilst optimising the link throughput (Fairhurst, Pang and Wan 1998). Modifications to the timeout and window size algorithms in TCP itself can be used to compensate for the fixed satellite delay and packet loss due to link noise. Wide Area Diversity (WAD) systems, such as described in Spracklen, et al. (1995), work on the principle that if, for example, one ground station has worsening signal to noise conditions, owing to cloud or rain fade, then the IP traffic can be quickly sent (terrestrially) via another unaffected ground station. These and similar approaches often rely on measurements of the quality of the communication link (i.e. a channel state estimate).

Some of these attempted solutions were investigated by the University of Aberdeen (Fairhurst, Ord et al 1993; Fairhurst, McEwan, et al 1993; Fairhurst, et al 1994). Out of the data collected during these experiments came an innovative methodology for passively estimating the state of a satellite link (McEwan 2000). The relatively wide nature of the research problem resulted in a particularly broad range of experimental techniques being used. Involving as it did a complex international data communication system, the research also required a very broad but detailed study and understanding of general data communications. It is perhaps because of this breadth and complexity that procedures and results from this research have provided an excellent vehicle for enhancing the quality and effectiveness of data communications teaching at CPIT. However it is the belief of this author that many completed research projects have the potential of being usefully duplicated at undergraduate level.

# 3. THE UNIVERSITY OF ABERDEEN RESEARCH EXPERIMENTS

## 3.1 The Logical Hardware Configurations

During the CODE experiments two types of basic configuration were used: a live VSAT-to-VSAT link via the satellite and a Satellite Link Simulator (SLS) between the sending and receiving routers. The live link has the obvious advantage of being an actual satellite data communication involving real atmospheric conditions, the actual delays and actual Forward Error Correction hardware (including a Viterbi (1971) decoder). Live links are however financially expensive to use and link conditions cannot generally be controlled! The SLS configurations therefore have the advantage of controllability (including the precise setting of a fixed delay and the controlled introduction of bursts of bit errors into the received data stream). Unfortunately the SLS used could only generate error bursts in a periodic manner and those burst were of fixed size (though that size could be altered between experiments). The actual Viterbi decoder on the other hand is known to produce error bursts whose size is roughly Geometric in distribution as is the “waiting time” or guardspace between these bursts.



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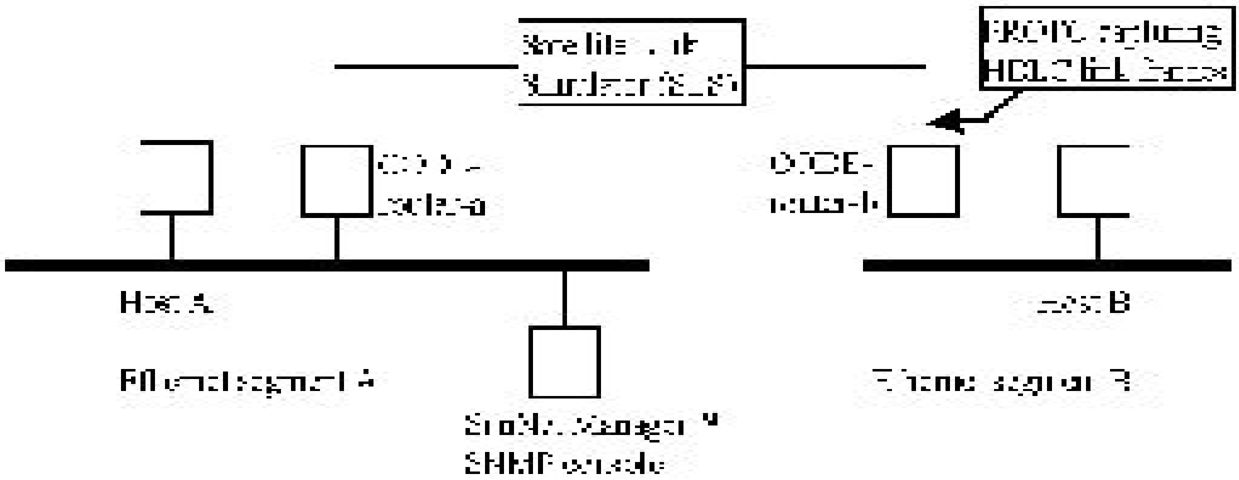

**Figure 2.**

**Hardware configuration used during satellite link simulations.**

network arrangements were those shown in Figure 1.

Figure **1.**

**Hardware configuration used during the "live" experi**ments.

In the configuration shown in Figure 1, Host A received traffic generated by Host B. The SNMP console used SunNet Manager(tm) (Sun Micro Systems Inc. 1992) to gather MIB-II SNMP statistics (Rose and McCloghrie 1991) from the serial satellite link interface of CODE-router-a.

The Satellite Link Simulator (SLS), shown in Figure 2, was used to supplement the data collected from the CODE network. This simulates a satellite link, supplying the required clocks, propagation delay, and noise."

## 3.2 The Physical Hardware Configurations

For practical reasons, it was not possible to place the sending and receiving hosts (A and B above) on separate physical sub-networks, in the manner shown in Figures 1 and 2, without rendering other parts of the ERG research network inoperative! An at that time unique method was therefore devised, using some complex subnet masking, that allowed the hosts and CODE routers to actually be on the same physical subnet yet logically appear to be on the separate subnets required in the experiments (McEwan 2000, pp. 205-255). In practice the scheme was more complex than this suggests - the A and B machines needed to be effectively "invisible" to each other on the shared subnet yet all needed to directly communicate with some other computers on the same subnet. One of these "always visible" machines was the network management station used to collect Simple Network Management Protocol (SNMP) data from the A and B machines. Since the A and B machines were "tricked" into thinking they were on separate subnets, any communication sent from Host A to Host B had to go via the satellite link rather than directly through the common subnet as it otherwise would have. The actual physical network arrangement used was therefore that of Figure 3. However, the subnet masking methodology used made it logically appear to be like that of Figure 1 (or Figure 2).

## 3.3 Viterbi Decoder Burst Statistics

The research concentrated on the FEC Viterbi decoder burst statistics. A major effect of the burst errors resulting from Viterbi decoding was that data link layer High level Data Link Control (HDLC) flags could be corrupted (McEwan 2000, pp. 40-60). On some occasions sufficient numbers of consecutive HDLC flags would be corrupted such that they appeared to be data link frames with bad frame check codes. This effect was analysed in detail and used

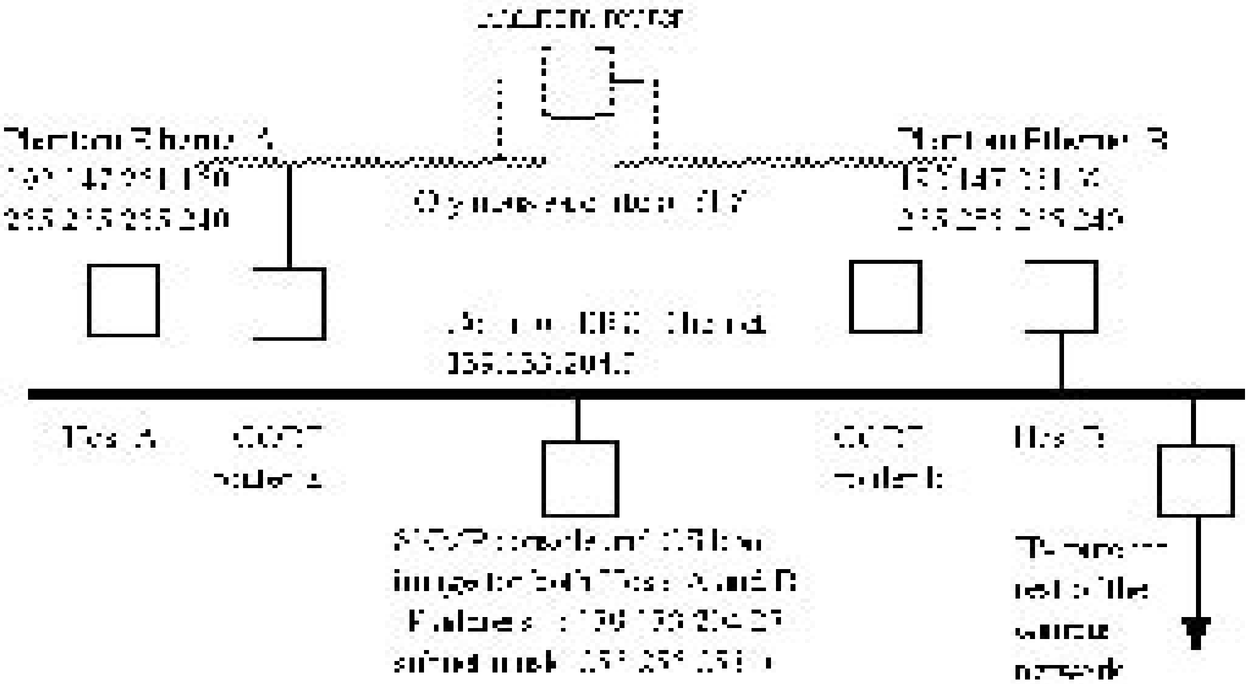

**Figure 3.**

**In practice Hosts A and B were on the same physical subnet.**

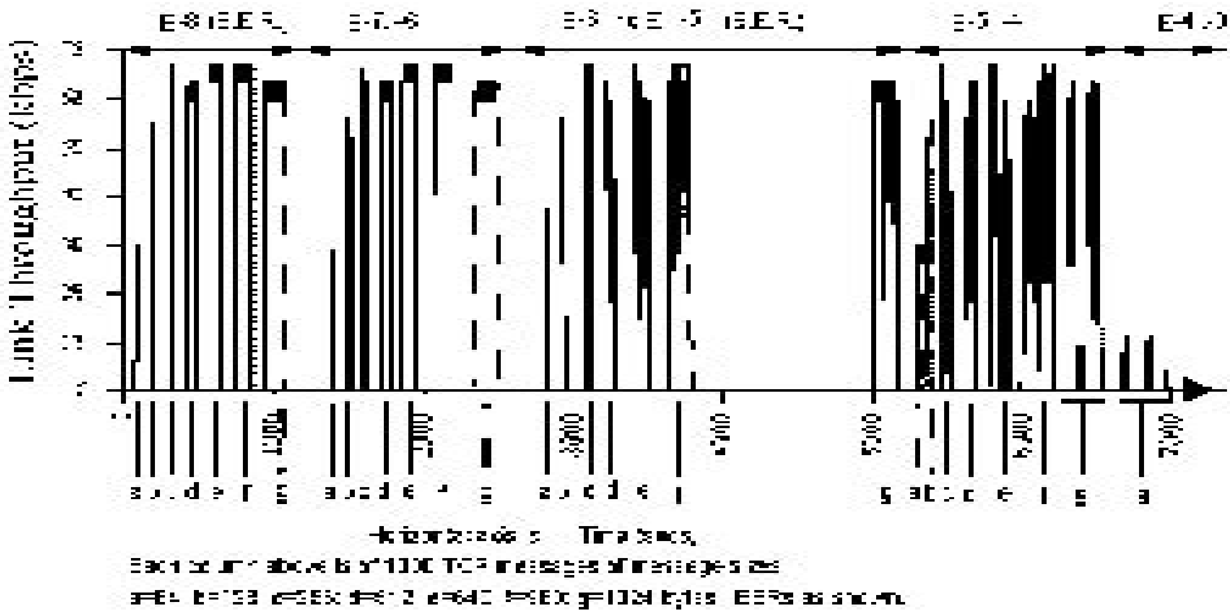


**Figure 4.**

**TCP performance - from receiver router SNMP MIB II statistics.**

algorithmically as part of the methodology devised as a channel state estimate.

## 3.4 SNMP and the Modem Logs

As part of the process of evaluating the performance and quality of the satellite link, various data was collected from a variety of sources. In particular, statistics were collected from, CODE-router-a SNMP MIB-II, the CODE receiver satellite modem logs, and from the direct capture of the HDLC frames using XCAP (Mohd 1993) and PROTO (McEwan 2000, pp. 187-198). The SNMP captures were done using SunNet Manager(tm). Each such experiment involved several hours of data collection. The resulting data sets were very large. A gawk (GNU Free Software Foundation) program was therefore written to automate the task of processing these data sets (McEwan 2000, p. 123). This program filtered out irrelevant data, converted absolute values to delta values and converted UNIX epoch time values into timestamps (in microseconds) normalised to the experiment start times.

Figure 4 shows the link throughput of TCP for various message sizes being sent under gradually worsening signal to noise conditions over a live 64 kbits/s VSAT-to-VSAT link over Olympus. This figure was obtained from some of the processed SNMP data (McEwan 2000, p. 130).

Figure 5 is an example of a graph created from data retrieved from the modem logs (McEwan 2000, p. 286). It shows the fluctuations of the receiver signal to noise ratio during one of the experiments. Positions a and b show where the VSAT antennae were manually realigned with Olympus. Sudden falls in Eb/No were caused by dense cloud interrupting the signal.

## 3.5 The Simulations

Various Monte Carlo type simulations were carried out to test the Geometric Model (GM) of Viterbi burst statistics (Deutsch and Miller 1981). Morris (1995) verified that this model is a good fit for moderate to large burst lengths. More accurate models (Chao and McEliece 1990; Chao and Yao 1996; Best et al. 1995) are available but the GM model had the advantage of simplicity and probably sufficient accuracy for use in the channel state estimation methodology being devised.

The simulations relied heavily on expectation algebra in calculating means, variances and standard errors since the distributions being used are probabalistic. Also, since the frequency distributions of burst sizes and the error free guardspaces are geometric and not normal, heavy use was made of the Central

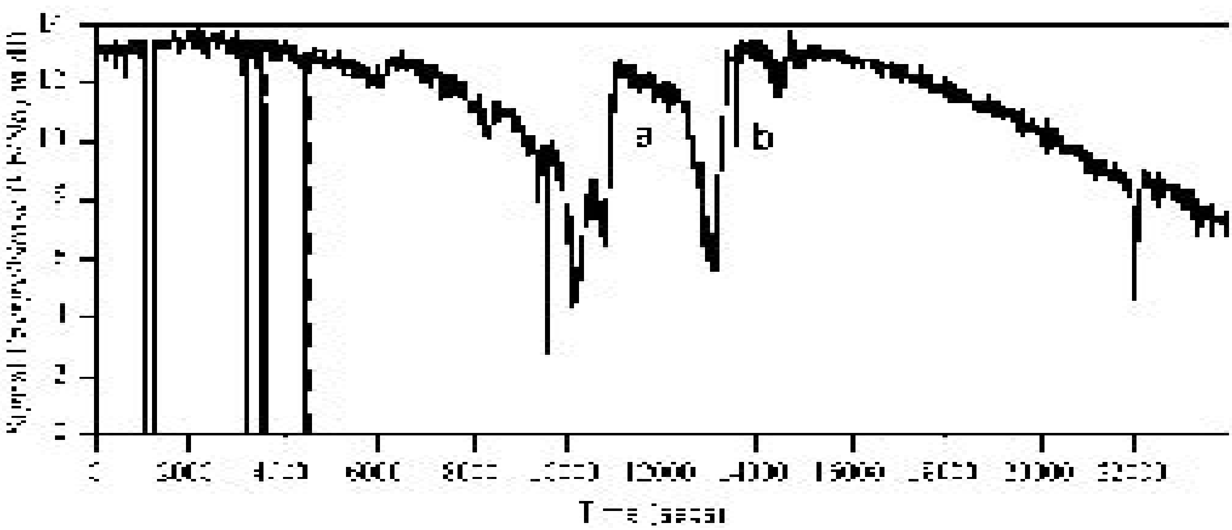


**Figure 5.**

**CODE VSAT receiver signal to noise fluctuations.**

Limit theorem in the calculations of standard errors. The simulations allowed the interactive input of the required number of samples and the number of sampling trials to undertake. Amongst other quantities the simulations then calculated (both ideal values and from the sampling trials):

- A table of probabilities for each possible burst size and guardspace (using the mathematical formula for a geometric probability distribution).
- Mean burst sizes and guardspace lengths.
- Standard errors on the above means.
- The mean number of expected HDLC error frames synthesised out of framing flags for each trial. (This used a complex probability distribution function, which involved the sum of many Geometric distribution parts. The function was determined following some earlier data analysis).
- Standard errors on the above means.

The purpose of calculating these statistics (as in most quantitative research) was to be able to ultimately devise a channel state estimate that could be expressed in terms of an estimate within known limits at a statistically guaranteed level of confidence.

The basis of many Monte Carlo type simulations is the "roulette wheel" and the above simulations are no exception to this. To create the required geometric distribution for the sampling experiments required a "roulette wheel" (implemented as an array in memory) that had very many low values and gradually less and less numbers of high values (the exact proportion being calculated from the geometric distribution function). The index into this "array" roulette wheel (which simulates its spinning and selection process) is then chosen using a normal linear random number. Each successive random number drawn points to a new value in the geometrically distributed array. A "good" random number generator is to be preferred in any Monte Carlo type simulation. The one adopted was that of (Learmouth and Lewis 1973).

### 3.6 Proto

A protocol capturing software/hardware tool (including some packet analysis capability) called "PROTO" was independently designed by the author of this paper during the research experiments at Aberdeen (2000, pp. 187-198). A more sophisticated and expensive tool called XCAP (Mohd 1993) had previously been designed by other researchers at ERG as part of an earlier ESA contract. Unlike XCAP, PROTO uses very simple capturing hardware and instead relies on the speed of assembly language programming for the real time capture of HDLC frames. It has a user interface written in C. PROTO can therefore be thought of as "the poor man's XCAP". However it does include much of the functionality of XCAP (though the existing version of PROTO is a single channel capturing tool whereas XCAP is dual channel). PROTO is illustrated capturing raw satellite link HDLC frames in Figure 2.

A working version of PROTO was demonstrated to the Head of Research of ESA and various heads of research groups from various universities, in late 1993.

## 4. THE SCHOOL OF COMPUTING SPECIALISED NETWORK FACILITIES

A problem with teaching data communications in an educational institution is that there is always an inherent danger of data comms experiments interfering with the normal operation of the campus network. Many institutions have traditionally simply avoided much in the way of practical data comms laboratory work. With the growing importance of internetworking in general this is obviously an unsatisfactory situation. With campus network infrastructures already in place and centralised administration of IT established it often proves difficult (and expensive) to implement new network laboratories that are sufficiently flexible and sufficiently isolated from the normal campus. The campus network managers are rightly wary of change, especially when such change appears to threaten the security and stability of the main campus network. The School of Computing at CPIT (with the cooperation of CPIT's IT division which is in charge of managing the campus network) are in the process of implementing a data comms research facility that deals with many of these traditional problems.

### 4.1 The CPIT Data Communications

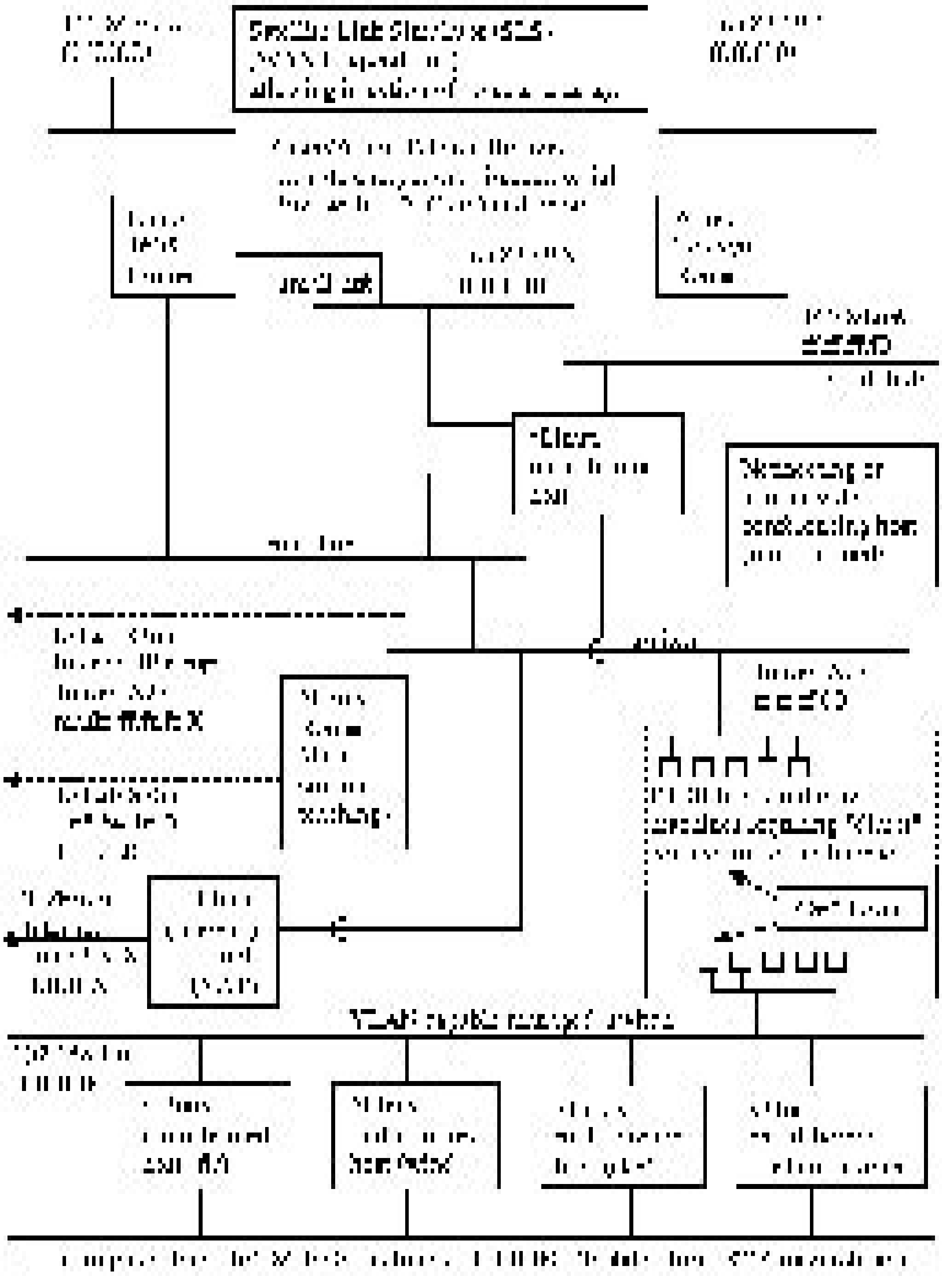

**Figure 6.**

**CPIT School of Computing research network configuration.**

## Research Lab

The research lab implementation shown in Figure 6 is based on the Aberdeen research lab configurations (Figures 1, 2 and 3) but with several interesting additions that safely allow its use without disturbing existing campus network facilities.

One normal teaching lab (lab S265) is configured by IT division in such a way that it can be physically disconnected from the main campus network and connected into the new research lab facility (lab S264). Currently this is done by physically moving a single cable that is wired through to a patch panel in the new research laboratory. A proposed development to this scheme should soon see this facility being provided logically by simple Virtual LAN (VLAN) reconfiguration in software (Passmore and Freeman).

Although lab S265 is normally not connected into the research lab experimental network, functionality has been added to the scheme such that any normal campus computer can connect to the experimental network via telnet. This is done via the hosts named “fir”, “earth” and “wind” in Figure 6. These hosts run the Linux operating system. They are configured as multi-homed hosts, meaning here that they have two network cards; one connected to the main campus network and one onto the research lab network. Note that they are not configured to route traffic between the experimental network and the main campus. Any traffic on the experimental network is thus effectively isolated from the main campus and vice versa.

In reality, Figure 6 shows a slightly simplified representation of what has been implemented. Various proxy and firewall strategies have also been employed in order to strengthen the security and isolation of the facility. In particular the research lab has a direct connection to the Internet (bypassing the normal campus firewall). This connection has been innovatively provided to us by IT division, using a special VLAN configuration that ensures the research labs effective isolation from the main campus network. This direct Internet connection allows students and staff involved in data comms and Internet courses, to undertake research experiments which require unrestricted Internet access.

## 4.2 The Degree Student Research Facility

A third lab (S263) contains a suite of computers on their own re-configurable subnetwork that connects directly to the research lab via a router. The main purpose of S263 is to allow degree students to set up their own research experiments that connect through to the fixed network configuration (including the simulated satellite link) in lab S264. (The computers in S263 are also used for general computer hardware experiments such as in the teaching of PC assembly and upgrade).

The research labs of S263 and S264 are currently physically protected by magnetic locks and keys. The keys are distributed to eligible students via the CPIT main library booking/administration system.

## 4.3 General Teaching Uses For the Specialised Labs

The specialised labs of S263, S264 and S265 are used for most of our specialised teaching needs in computer architecture, operating systems (OS) and data communications (including the Internet). In particular they are used in the teaching delivery of all layers of the OSI data communications stack, from the particular viewpoint of the TCP/IP protocol suite. Internetworking services (e.g. configuration of DHCP, DNS, Web servers, proxy and filtering firewalls and other network security mechanisms etc.) are currently being covered using OS platforms LINUX and Windows 2000 (all versions).

## 4.4 The Proposed Research Lab Experiments

### 4.4.1 Research into New Hardware Designs

To complete the physical infrastructure required the following research activities are in process:

1. Research is being undertaken into the real-time capturing capabilities of Linux. It is intended that this should lead to the redesign of PROTO such that it runs on this platform with a GUI front-end. In addition later research will investigate the integration of PROTO functionality into web browser technology (using XML as the native data format). It is intended to offer any successful prototype of the new PROTO as educational freeware.
2. On completion of the new PROTO, work will begin on the design of a Satellite Link Simulator. The intention here will be to design a cheaper yet in many ways more sophisticated unit than that used at Aberdeen. In particular it is intended that the future design will include the functionality of being controlled by a software Viterbi decoder to give more realistic link noise distributions. It will include a presettable link delay. It is also intended to allow the injection of captured live data stream noise data into the link by means of an SLS interface.

#### 4.4.2 Student Research Experiments

As discussed in this paper. The future plan is to introduce those degree students taking the final year data communications subjects to the research processes originally undertaken by the ERG research group in Aberdeen. These include:

1. Using subnet masking techniques in physical network configurations in order to match the logical network requirements.
2. FEC Viterbi decoder simulations in software (and possibly in provided hardware, since the required circuitry is simple).
3. A statistical analysis of Viterbi decoder burst errors (for different equivalent receiver signal to noise ratios).
4. Injecting models of Viterbi bursts (e.g. from the GM model) into the satellite link simulation. The purpose of this is to study their effect on the creation of data link layer error frames (by flag synthesis and corruption of good HDLC frames).
5. Monte Carlo Simulations to test all the models used and to check out any channel state estimation methodologies discovered.
6. Real-time protocol data capture and analysis using PROTO (or similar) and an SNMP network management workstation.
7. Processing the large SNMP data sets using languages such as Awk, Perl or Python.

## 5. CONCLUSION

This paper has attempted to show the breadth yet depth of educational experience than can be extracted from a major academic research project. It has, by example, shown how the work of that project has usefully being influential in the design of facilities and for some proposed future teaching programmes at CPIT.

It might have appeared that leading-edge academic research is overly esoteric to have any directly useful input to the teaching of undergraduate courses. However, a major function of an undergraduate degree course should be to prepare the student for possible postgraduate research. Research activities involved in such preparation in no way need to be original in order to be instructive. Research is as much about methodology as it is about results and a major advantage of duplicating previously published research at undergraduate level is that it is tried and tested. Instructive results and the satisfaction brought with them can be guaranteed. Re-inventing the wheel is not only useful - it is safe. The prior knowledge of research methodology and/or results, though not essential, is very useful in helping us devise performance criteria and instruments of assessment. Furthermore, it is a recurring truth that the research of yesterday becomes the mainstream of today.

The research process is in any case generally less about new ideas than about developing old ideas. In re-inventing the wheel we can look forward to many pleasant surprises, since innovation tends to occur naturally. With its quality comes a measurement for merit. The suggestion made has therefore been that we should re-use research in our teaching (much as we re-use objects in programming). Indeed research is all about inheriting the lessons from previous research; adapting them, adding to them, and improving upon them. By treating such research as somehow separate from our teaching we neither prepare the student for their postgraduate futures nor provide a reliable path for them to display innovation and merit.

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