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A New State Model for Internetworks Technology

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Abstract

There are a wide range of equally valid approaches to teaching networking. One approach is to teach internetworking technologies (switches, routers). However, an extensive analysis of educational materials in this area has indicated that these devices are typically treated as 'black boxes'. This is contrary to educational theory that supports the need for a conceptual model. Two state models were designed and used as the pedagogical foundation of network curriculum. These models are valid for different levels of technical complexity and work to date strongly suggests they support student learning. Based on these results the models have been further developed.

Keywords: Abstraction, Conceptual Models, Finite State Machine and State Models

Introduction

The ACM/IEEE Computing Curriculum 2001 included Net-Centric Computing in the Computer Science Undergraduate Body of Knowledge (IEEE/ACM, 2001). There are however a wide range of equally valid approaches to teaching network curriculum ranging from quantitative (engineering) to software/algorithmic (computer science) (Kurose, Liebeherr, Ostermann, & Ott-Boisseau, 2002). Both within Australia and internationally there is a demand for a practical 'hands on' approach to networking curriculum. Accordingly some universities have adopted the Cisco Network Academy Program (CNAP) and hence obtain access not only to vendor specific curriculum and certification (Cisco Certified Networking Associate (CCNA) and Cisco Certified Networking Professional (CCNP)) but also low cost equipment (hubs, switches and routers). It should be noted that the CCNP is based upon an educational web site that cost US$25 million to develop and an extensive repertoire of textbooks. Both a typical university curriculum in networking and the vendor specific networking curriculum (CCNA and CCNP) were analyzed. Both curricula teach networking fundamentals however the Cisco curriculum also provides an in-depth 'hands on' approach to switch and router configurations. However in both cases the internetworking devices (switches and routers) are considered as 'black boxes'. This is contrary to Constructivism, the dominant educational theory, in which students construct knowledge rather than merely receive and store knowledge transmitted by the teacher (Ben-Ari, 2001). Von Glasersfeld states, *"… knowledge cannot simply be transferred by means of words. Verbally explaining a problem does not lead to understanding, unless the concepts the listener has associated with the linguistic components of the explanation are compatible with those the explainer has in mind. Hence it is essential that the teacher have an adequate model of the conceptual network within which the student assimilates what he or she is being told. Without such a model as a basis, teaching is likely to remain a hit-or-miss affair.*"(von Glasersfeld, 1989). A conceptual model of a router and a switch is therefore needed. This model must not only be technically correct but also valid for different levels of complexity thereby supporting not only introductory but also more advanced concepts.

State Models

Models are a means of controlling detail and communication. Desirable model characteristics include: diagrammatic, self-documenting, easy of use and hierarchical top down decomposition to control detail. Leveling is the property in which complex systems can be progressively decomposed to provide completeness. According to Cooling there are two main types of diagram: high level and low level (Cooling, 1991). High level diagrams show the overall system structure with its major sub-units. By contrast, low level diagrams are solution oriented and must be able to handle considerable detail. Some systems may be modeled using state diagrams. According to the National Institute of Science and Technology,

> ‘A finite state machine is a model of computation consisting of a set of states, a start state, an input alphabet and a transition function that maps input symbols and current states to the next state. Computation begins in the start state with an input string. It changes to new states depending on the transition function.’ (National Institute of Science and Technology, n. d.)
>
> At any given moment in time the system exists in a certain state. The set of all states is the state space. Significantly the state diagrams should show only relevant details. Two simple state models have been developed – one for a switch and one for a router. However unlike typical state models these new models allow the introduction of progressively advanced conceptual features hence supporting student learning. According to Von Glasersfeld: “Because there is no way of transferring meaning, i.e. concepts and conceptual structures, from one students head to another, teachers, who have the goal of changing something in students heads must have some notion of what goes on in these heads. Hence it would be seem necessary for a teacher to build up a model of the students conceptual world” (von Glasersfeld & Steffe, 1991)

Switch – Simple Model

In the first instance a switch is represented as a simple box with ports/interfaces. Each physical port is represented on the switch model (e.g. Fastethernet 0/1 or Fa0/1). At the simplest level connectivity can be represented by internal connections between the ports within the switch. This simple model does not capture states and hence it is not a state model. At a more complex level switches perform three main tasks: address learning; address forwarding and filtering; loop avoidance. These tasks are associated with state changes within a switch - hence the following state model.

Switch State Model - Address Learning

The minimum relevant switch states for address learning are: MAC address, MAC address type and port identification. A simple table can be incorporated into the simple switch diagram to capture this information (Figure 1) hence establishing a simple state model. In the initial state (S0) this table is empty. Obviously the connecting PCs must be represented as simple state diagrams with their MAC addresses. PC state information can be derived from the command line ‘*ipconfig*’.

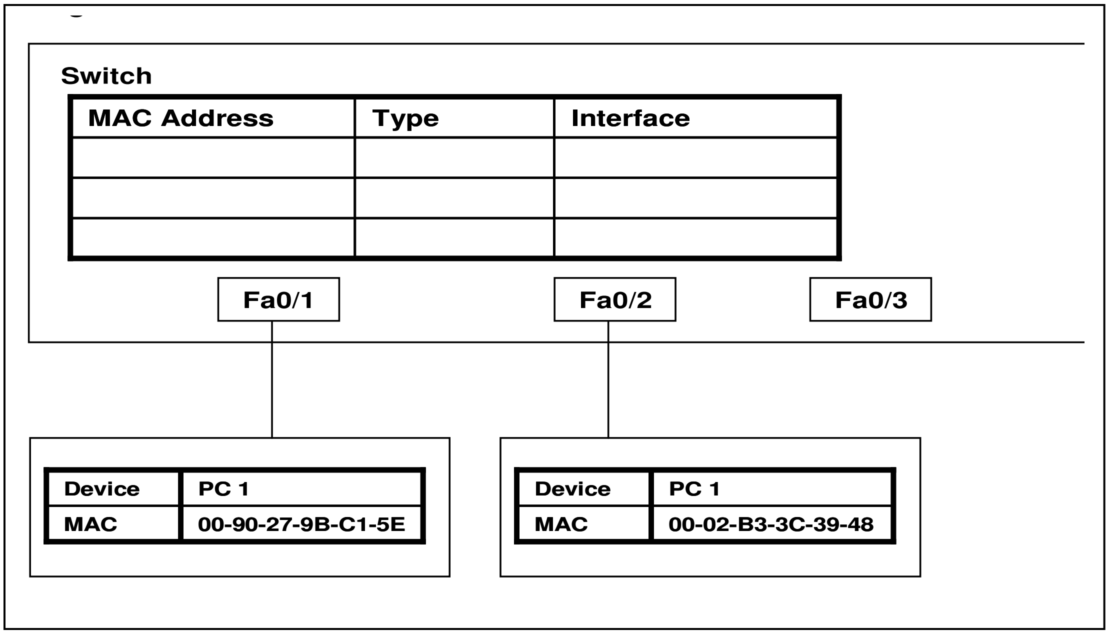

Figure 1: Switch S0 state model

When a PC attempts to send a data frame to another PC the switch learns the MAC address of the transmitting PC and hence enters the next state S1.

Switch State Model - Address forwarding/filtering

The process of address learning continues until the switch learns the MAC addresses of all the connected PCs (Figure 2). This information can be derived from the switch command '*Switch#show mac-address-table*'. In this state the switch can forward and filter data frames.

Switch#show mac-address-table

Mac address	*Type*	*Interface*
00-90-27-9B-C1-5E	*dynamic*	*fa0/1*
00-02-B3-3C-39-48	*dynamic*	*fa0/2*

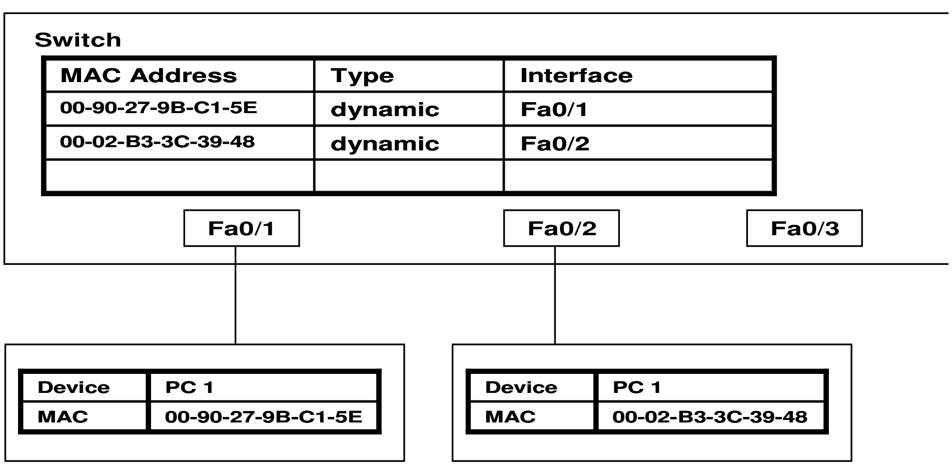

Figure 2: Switch – Sn state model

The state diagrams may be extended to include Virtual LAN (VLAN) state information by including in the switch table a VLAN column (figure 3). Again this state data may be derived from the switch configuration command, ‘***switch#show vlan***’,

Switch#show mac-address-table

VLAN	*Mac address*	*Type*	*Interface*
1	***00-90-27-9B-C1-5E***	***dynamic***	***fa0/1***
1	***00-02-B3-3C-39-48***	***dynamic***	***fa0/2***

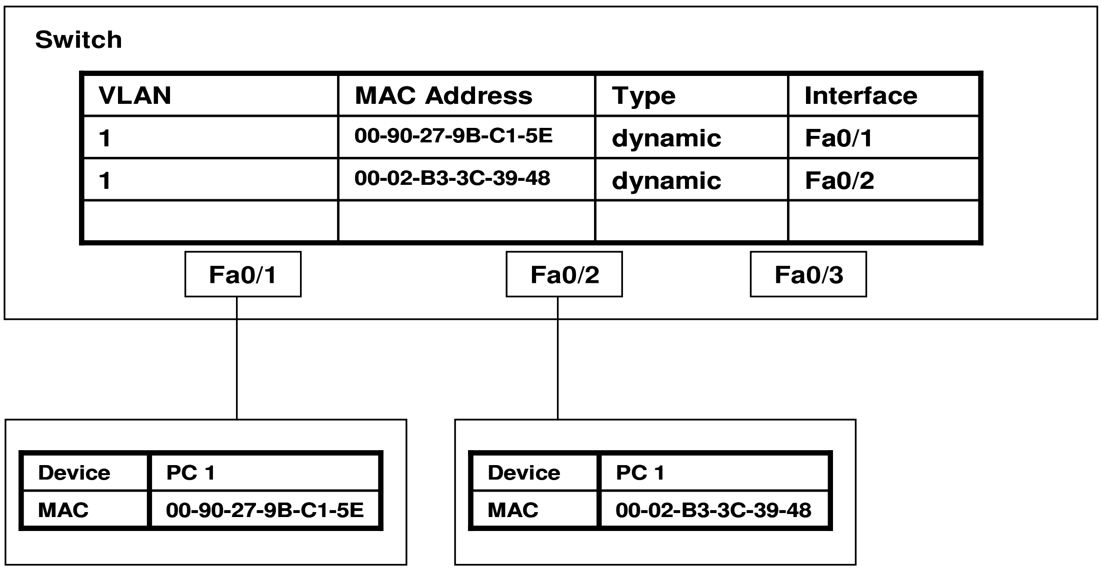

Figure 3: Switch – VLAN state model

Switch State Model - Loop Avoidance

The third function of a switch is loop avoidance i.e. Spanning Tree Protocol (STP). The switch state model may be extended further to capture STP information by including a second switch

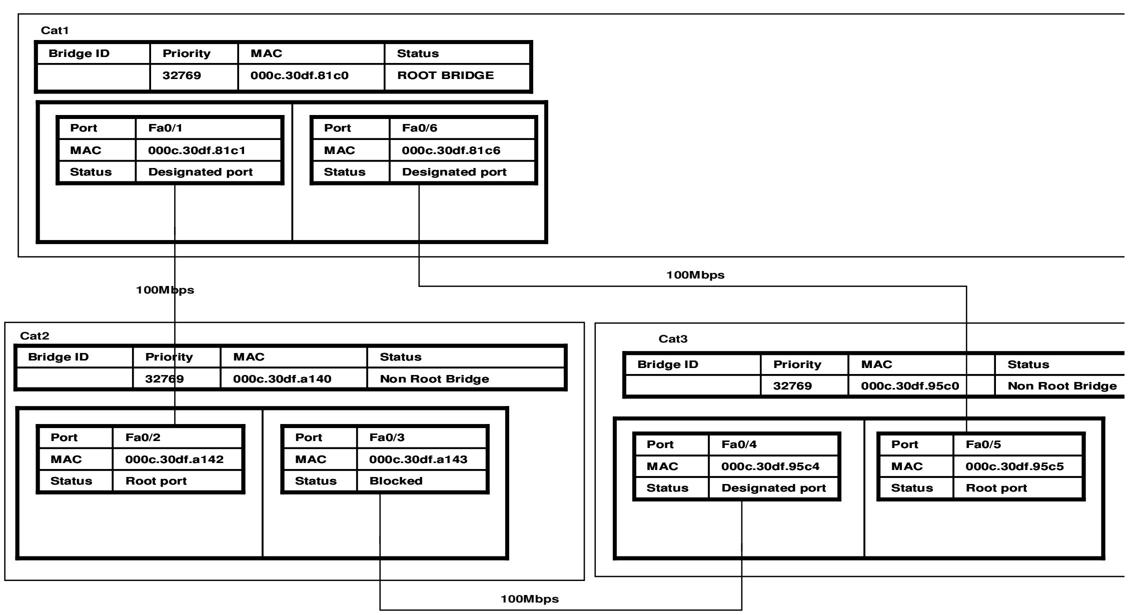

Figure 4: Redundant Switch Links

table incorporating Bridge Identification based on Priority and MAC address (Lewis, 2003). Furthermore port status (Designated, Root, Blocking) may be added to the ports (Figure 4).

Router Model

A PC can be modeled as a simple state device with a logical (IP) to physical (MAC address) Address Resolution Protocol (ARP) table and a Network Interface Card (NIC) table (IP address, Subnet mask and MAC address). The PC command "**IPCONFIG**" output directly maps onto these simple PC state diagrams. A router can then be modeled as a state diagram using the ARP and NIC table (as found in the PC) plus a routing table (figure 5). Hence an incremental learning path is provided. The router commands "**show arp**" and "**show ip route**" can be used to in conjunction with the diagrams to show the state changes as networks are connected together.

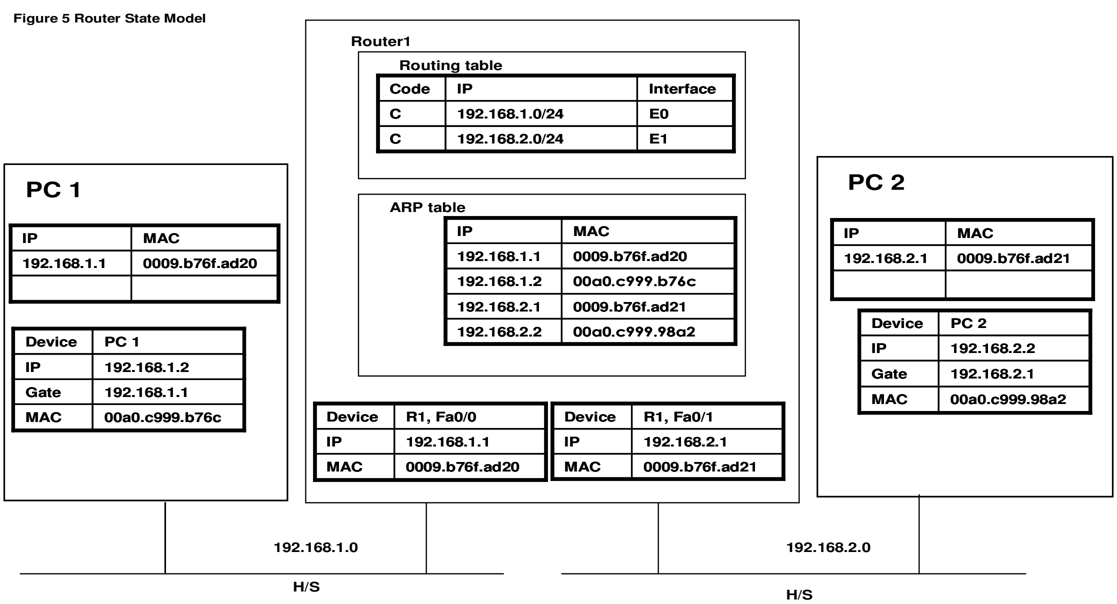

Figure 5: Router State Model

Evaluation

The switch and router models were evaluated in a teaching environment. Two groups were selected as part of the experiment design. The first group was doing an undergraduate course in networking. At the undergraduate level it is possible to study vendor specific awards (CCNA and CCNP) or more generic network units. A standard university unit consists of a 2 hour lecture and 2 hours of workshop time (fully supervised) every week for a 12 week semester. The CNAP mandates student contact time hence the CCNA curriculum represents the equivalent of two standard university units i.e. a total of 96 hours. Students must successfully complete the CCNA prior to enrolling on the CCNP course. The CCNP course consists of the equivalent of four university units each of which has 48 hours of staff contact time per 12 week semester.

This university offers a number of postgraduate awards in Information Technology. There are Master Courses specifically designed for graduates with a non-IT undergraduate qualification i.e. conversion masters. For these students there are two units (106 and 206) as a prerequisite chain. The first unit (106) is an introductory unit to computer and network technology. Half of this unit (24 hours) is allocated to computer technology and the other half (24 hours) is dedicated to network technology. It should be noted that there are no prerequisites to this unit. The second postgraduate unit (206) is dedicated entirely to network technology. Each postgraduate unit is a standard university unit (48 hours of staff contact time per 12 week semester). The vendor based curriculum students were taught in the normal Cisco prescribed manner using online Cisco material, practical lab exercises (hand on) and case studies presented by Cisco curriculum. The units for the postgraduate students were based on the models developed for switches and routers (Figures 1, 2, 3, 4 and 5).

Students on all the above courses (undergraduate vendor based CCNA/CCNP and postgraduate IT) completed a questionnaire which was designed to determine their understanding of router operation. This questionnaire was distributed at the end of the semester. Questions included both simple definitions (e.g. What is a router?) and questions to determine the depth of understanding of router operation. In particular students were provided with router and PC configurations diagram for a given network and asked to explain its operation. In addition to this the postgraduate students participated in an open forum during which all discussions were recorded. Furthermore the questionnaire was also given to a qualified and experienced network expert who was not involved teaching the postgraduate curriculum.

Table 1: Vocabulary of terms used by an expert

Experts Terms used
Inter connects networking (LANs, VLANs, etc)
Interfaces (Physical and Logical)
Links Networks
Subnet Portion of an IP address
Path determination
Layer 2 rewrite action
Forward the Packet
Switching

The responses for all student groups and the expert were analyzed. The expert clearly demon-

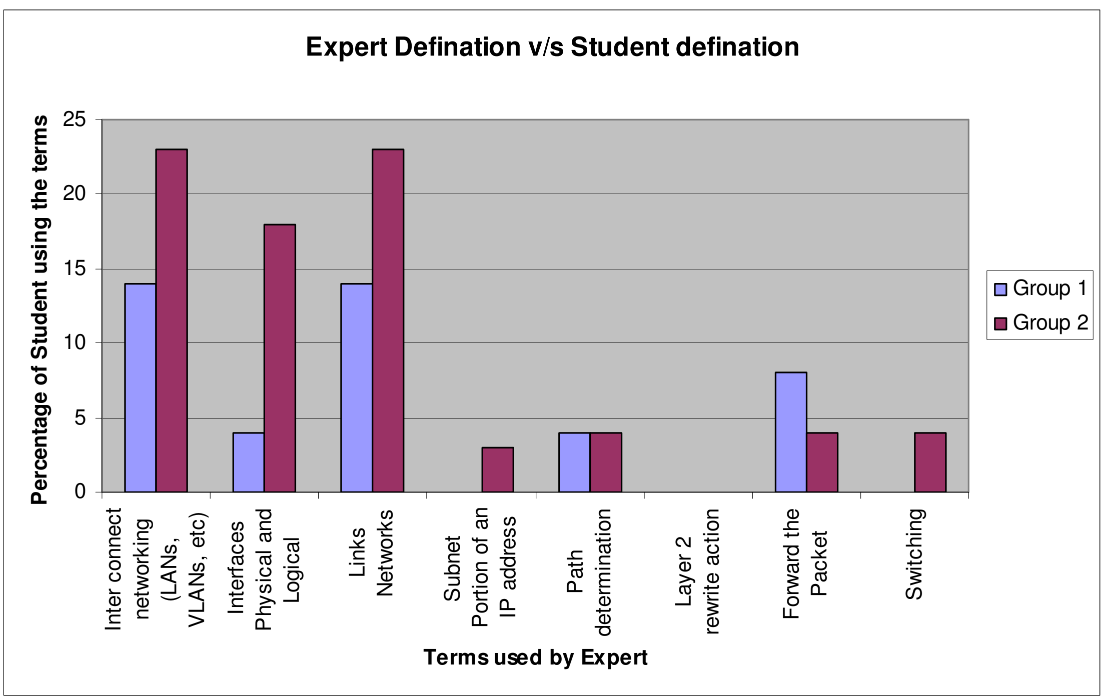

Figure 6: Expert term versus student definitions

strated the use of a wide range of technical vocabulary and a clear understanding of router operation (Table 1).

Group 1 which was doing the Vendor specific course provided standard text book based definitions. However, they demonstrated a lack of depth of understanding of device operation (Figure 6).

Group 2 was studying on the postgraduate university unit 106 and 206 which were taught using these models also provided standard text book based definitions. However they clearly demonstrated a far better understanding of router operation. They had a far more extensive vocabulary of technical terms all of which were in conjunction with expert definition as shown in Figure 6. The students on the unit 206 performed comparably to those on unit 106.

From the analysis of terms used by the expert and the two groups, it is highly significant that the percentage of students using terms that the expert used was in most cases much higher in group 2 then in group 1 who were taught using the model.

Further Work

Given the success of these models as an aid to learning they were further developed. Additional port state information includes: Port Number, priority and cost (Figure 7). Again the state diagram model corresponds to switch command line output. This state model can be used to show all state transitions occurring during STP operation i.e.

S0 Initial state

S1 Root Bridge elected (i.e. Bridge ID status)

S2 One Root port per Non Root Bridge elected

S3 One Designated Port per segment elected

S4 Non-root and non-designated ports blocked i.e. operational

Furthermore, using these diagrams it is possible also to capture port state transitions: Disabled, Blocking, Listening, Learning and Forwarding.

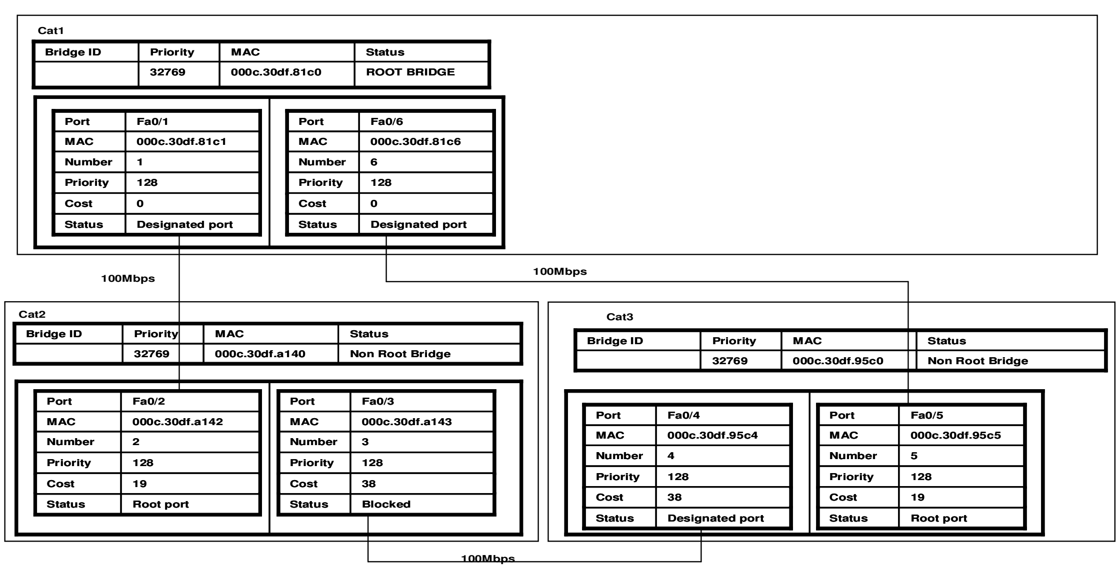

Figure 7: Redundant Switch Links

Conclusion

Postgraduate students, whose learning was based upon the state models, demonstrated a comprehension of devices comparable to a qualified and experienced expert in this field. Furthermore these students performed significantly better than other students. Postgraduate students are arguably more mature and are likely to have better study skills than undergraduate students. However one group of postgraduate students had completed only 24 hours of instruction in contrast to CCNP students who had successfully completed the CCNA (96 hours of instruction) and an additional semester of CCNP material (at least 96 hours of instruction). Furthermore the CNAP mandates continuous on-line assessment of CCNA and CCNP students. Further work is currently being undertaken extend the scope of this work but the results to date clearly indicate the diagrams have a significant impact on student learning. Based on this success the state models were further developed. Work to date suggests these models can be used to capture all relevant state information.

References

Ben-Ari, M. (2001). Constructivism in computer science education. *Journal of Computers in Mathematics and Science Teaching, 20* (1), 45-73.

Cooling, J. E. (1991). *Software design for real-time systems*. Padstow, Cornwall: Chapman and Hall.

IEEE/ACM. (2001). *CC-2001 Task Force, Computing Curriculum (Final Draft).* Retrieved from http://www.computer.org/education/cc2001/final

Kurose, J., Liebeherr, J., Ostermann, S., & Ott-Boisseau, T. (2002). *ACM SIGCOMM Workshop on Computer Networking: Curriculum Designs and Education Challenges.* Retrieved from http://www-net.cs.umass.edu/sigcomm/education/education_workshop_report_final.pdf

Lewis, W. (2003). *CCNP Cisco networking academy program: Multilayer switching guide*. Indianapolis IN: Cisco Press.

National Institute of Science and Technology. (n. d.). Retrieved from http://www.nist.gov/dads/HTML/finiteStateMachine.html

von Glasersfeld, E. (1989). Cognition, construction of knowledge, and teaching. *Synthese, 80*, 121-140.

von Glasersfeld, E., & Steffe, L. P. (1991). Conceptual models in educational research and practice. *Journal of Educational Thought, 25* (2), 91 - 103.

Biographies

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