A Course in Network Architecture: Teaching how Technology Aligns with Business

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ABSTRACT

As enterprise, service provider, and national networks expand in scale and scope, there is a growing need in the industry for people with skills in **network architecture**. This role is not merely about glueing technology pieces together; instead, it aims to align technology decisions with business goals, operating within an overarching framework that includes cost, time, and skills constraints and compromises, and plans the design and evolution of the system over time. We believe there is a need to provide University students, once they understand technology fundamentals, with exposure to the architecture process. Our experience with developing and offering such a course at UNSW last year indicates that students are better able to appreciate **why** and **how** technology can be applied to business, not just the **what** of the technology.

1. INTRODUCTION AND MOTIVATION

The role of an architect is well understood in the construction industry – a building architect develops the high-level "concept design" that is then implemented by the building engineer. There are entire University programs devoted to architecture of the built environment. The world of Information Technology (IT) has started realising the importance of system architecture: frameworks and standards for software architecture (e.g. IEEE 1471) have been developed over the past decade, and are routinely included in software engineering courses at Universities. By comparison, no University curriculum today includes any significant coverage of network architecture and its relation to the business. In this paper we present our rationale and experience in trying to fill this gap.

1.1 Network Architecture: What and Why?

Architecture is defined in ISO/IEC 42010:2007 as *the fundamental organisation of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution.* Informally, architecture takes a broad view of the system, evaluating its business context, relating it to the value chain, and understanding the constraints, risks, and trade-offs. It then develops a blueprint of the system, that can then be implemented by engineering. Thus architecture is larger in scope than engineering, and in fact guides it so that its value for the business is maximised.

We believe that network architecture is more important today than ever for at least two reasons:

1. **Technology innovation, integration, and complexity:** Not only are packets moving faster than ever before in the network, but also new services (e.g. voice, video, power, monitoring) are being innovated every day. This creates new logical dependencies (e.g. for supporting QoS, security, mobility, etc.) amongst components in the network. Without a systematic architecture to govern these inter-relationships, their ad-hoc evolution makes the system complex and change-locked, since a change in one component can cause unpredictable behaviour in other components.

2. **Business agility:** Business models are changing, and organisations that are able to leverage technology effectively surpass competitors that cannot. As examples, Amazon thrives while Borders filed for bankruptcy [1], BlockBuster lost revenue to NetFlix and went bankrupt [2], and Skype is growing international call volume twice as fast as traditional telcos [3]. As technology gets more complex, integrating it into the business model requires some abstraction so business and technology speak a common language – this abstraction is provided by the architecture process.

1.2 Why a University Course?

It could be argued that network architecture is best learnt in the industry, where the engineer gets practical experience dealing with operational networks. However, we think there are several reasons why Universities should include network architecture in their curriculum:

- Students spend a lot of time learning the various technologies (switching, addressing, routing, QoS, security, mobility, etc.), but they do not really learn to put these together (our case studies later in this paper will provide examples to substantiate this). A course emphasising integration of network techology with the business drivers helps them appreciate the **why** and **how**, not just the **what**.

- There is growing realisation that network (and indeed IT) architecture needs to become less adhoc and more structured, and frameworks such as SONA (Service Oriented Network Architecture) and TOGAF (The Open Group Architecture Framework) are emerging to integrate IT with business architectures. Emergence of a structured method (though still in its infancy in terms of adoption by industry) makes it more feasible to teach network architecture within a University course.

- As data and information are becoming increasingly digitised, employers seek graduates who can demonstrate higher skills of "knowledge" (linked with decision-making) that cannot be automated. Students also value learning the importance of business drivers, its impact on technology choices, and the level of abstraction at which to communicate with managers at various levels.

- There is growing need in the industry for graduates who have skills in architecture: service providers in emerging economies are grappling with massive growth in subscriber numbers, retailers are realising the huge opportunities in on-line and mobile marketing, and countries such as Australia are embarking on construction of a national broadband network. Each of these sectors is facing a shortage of people who can deal with complexity, and this course is the first step towards providing a formal qualification in architecture that employers can use to recognize these skills.

We believe that by exposing University students to the process relating the big picture to the details, they appreciate better the drivers and impact of work in this field. Under-graduate students benefit by increasing their employability and decision-making capability, while post-graduate students can better select and assess the impact of their research.

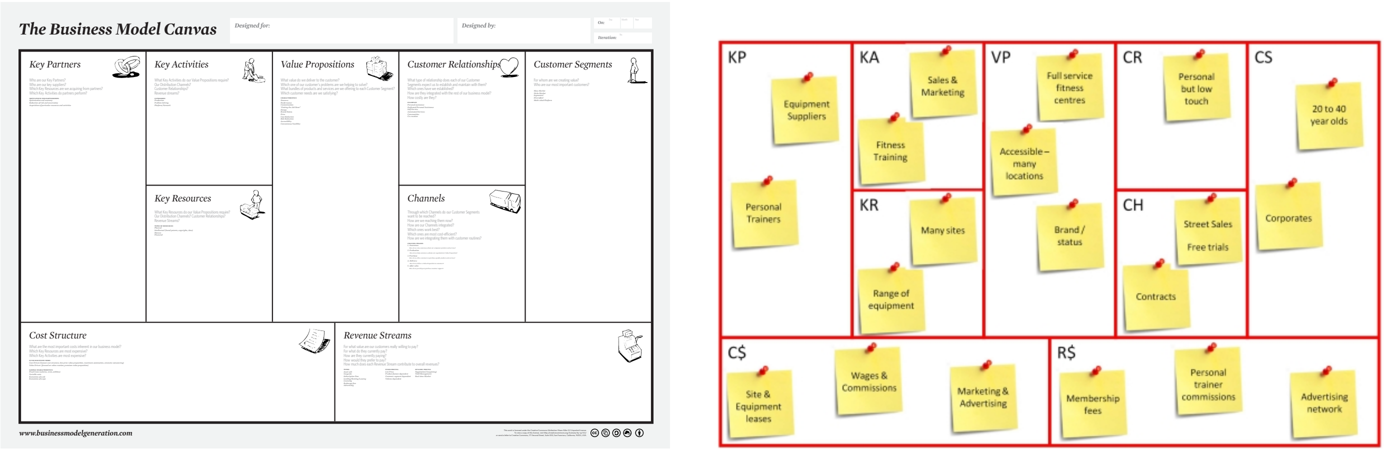
2. COURSE LOGISTICS

Audience: The course targets post-graduate (coursework or research) students, as well as final-year undergraduate students. The course assumes knowledge of the fundamentals of data networks, and familiarity with technologies at various layers of the protocol stack. These include the basics of wired, optical, and wireless transmission at the physical layer, Ethernet framing, switching, VLANs, and Wireless MAC at the data link layer, IP addressing and routing (IGP and BGP) at the network layer, and TCP congestion control at the transport layer. Students are also expected to have some familiarity with network capabilities such as multicast (layer-2 broadcast, IP multicast forwarding), mobility (layer-2 versus layer-3 hand-offs), security (firewalls, ACLs, authentication, certificates), network management (in/out-band, redundancy, FCAPS, SNMP), and QoS (real-time, delay, jitter, sheduling).

Aims: The course aims to develop an understanding of the process of architecting network systems, at scales ranging from national (e.g. service provider), to enterprise (e.g. campus) and embedded (e.g. in-vehicle) networks. The objective is to bridge the gap between business needs and technology solutions, by learning how to: (a) identify and represent high-level goals and requirements, (b) identify and select technology capabilities and services, and (c) develop broad architectures that show how these services can be composed to meet the requirements within given constraints, identifying the key trade-offs in the process. Case-studies include two carrier networks: the Australian National Broadband Network (NBN) and a service provider network, and two enterprise networks: a University campus network and a retail store network. The course uses guest lecturers from Cisco Systems, and involves a group project with practical architecture development.

Structure: The course runs over one session of 13-weeks, with 3 hours of contact time each week. The first week gives an introduction to the course, emphasising the importance of network architecture. The remaining lectures are divided into two parts: (a) The first part outlines the architecture process, citing enterprise architecture frameworks such as TOGAF and DoDAF. It then describes the business architecture, including the context diagram, business model canvas, and the value chain. The objective of this part is to identify the business visions, goals, and requirements so they can be mapped to technology requirements. (b) The second part develops the technology architecture. It starts by determining the capabilities required, and then translates these into service/components and their interconnections. Case studies of carrier and enterprise networks are used as working examples to reinforce the concepts, and guest lectures from industry provide perspectives on real deployments. The course includes a large project that requires students (in groups of 4) to develop an architecture for a system of their choice.

Texts: Unfortunately no text exactly fit our aims. We used [4] as the primary book, though we found the material in it to be more at the conceptual level with few examples the students could relate the principles to. We also used [5] as a reference book, which we found to cover more of the technology, though less of the business side. We used contemporary news articles to highlight the various case-studies in this course.



(a) General Model [9] (b) Applied to a Fitness Club Chain [10]

Figure 1: The Business Model Canvas (a) in general and (b) applied to a fitness club chain

3. COURSE CONTENT

3.1 Architecture: The Process

This course is about a systematic top-down process of architecting a network system. There are several reasons why this is important for any organisation:

- **Strategy:** The system has to align with the business goals, so time, money and effort wasted on non-essential aspects can be minimised. For example, network aspects such as availability, scalability, affordability, security, and manageability will differ in importance across organisations: a bank may value security highly while affordability may be paramount for a University.
- **Complexity:** If a system is allowed to grow in an ad-hoc manner without an architectural blueprint, patchwork accumulated over time makes the system complex and decisions can no longer be optimised. For example, when security or redundancy is added to a network as an after-thought, unexpected consequences arise.
- **Abstraction:** As system complexity grows, architecture is able to hide unnecessary details for management to make high-level decisions without getting bogged down by details. For example, it can aid a decision-maker in choosing between investing in more bandwidth or deploying QoS mechanisms, without knowing protocol details.
- **Repeatability:** For the business to be agile, knowledge has to be reused for a new deployment. Much like software engineers develop classes that can be reused, network architects can develop blueprints or building blocks that can be adapted to new deployments.
- **Defensibility:** Following an architecture process creates documentation that provides firms (especially in government) with an audit-trail, so the decisions are defensible (in terms of technical, budgetary, schedule, and resource requirements) and can meet any regulatory requirements.
- **Risk management:** The architecture process helps identify risks and fall-back options, so organisations can be better positioned to deal with uncertainties (e.g. non-standardised technology).
- **Evolution:** A documented architecture is easier to transfer to new personnel, and hence more robust to organisational changes and outsourcing.

Over the past few years several architectural frameworks have emerged, such as TOGAF [6] and DoDAF [7], that more broadly define a process for enterprise architecture. We refer the reader to [8] for a succint presentation on how such frameworks can be applied towards network architecture.

3.2 Business: Vision, Goals, Requirements

One of the key objectives of the course is to give the students an understanding of business context. In the past, many information technology departments have been accused of implementing technology for technology's sake (for example many video projects pre 1997). While the technology may be successful, the adoption is not, unless it is mapped into some business relevant context. This is the **why** and **how** of the technology applied to business, rather than the **what** of the technology. For example, high definition video communication may be a great technology, but if you are a small florist shop, you may not have a business application for it. There are two aspects to this. The first is to understand how existing technology assets can be utilised in an optimal way. The second is to identify new opportunities to effect business through application of technology.

To understand business context, a couple of widely available tools are used. At the highest level, we take a look at a business context diagram which shows the entity and the external relationships it has. We also look at the overall business vision and the goals the business is trying to achieve. For example, a university may aspire to be “the finest educational institution in the southern hemisphere”. In order to achieve this vision, it would need to have a certain number x of active PhD scholarships, a certain amount y of research funding, and an overall satisfaction score z with undergraduate students. In order to see how a business creates and captures value, we also consider the Business Model Canvas: a general model [9] is shown in Fig. 1(a), while a specific instance [10] for a chain of fitness clubs is shown in Fig. 1(b). This provides a good framework for a discussion on the potential of technology to impact costs, revenues, customers, suppliers and partners. It also clearly identifies the value proposition of the business, which provides clarity in terms of what the business is trying to achieve. For example if a business has a value proposition of *lowest possible prices* it is unlikely to be also looking to provide an *unrivalled customer experience*. This will limit the technology choices that are applicable.

One of the other key objectives of this section is to provide an understanding of tradeoffs. Businesses only have finite resources, hence have to make choices around optimal resource usage. A degree of analytical thinking is required, to identify business requirements, constraints, trade-offs that need to be made and decision making criteria. The emphasis is not on getting the *right* answer (as many possibilities will exist), but providing a rational explanation of a plausible outcome. At the end of this process, the students have a clear understanding of the business vision and goal for their case study. They also have a number of business requirements that can be mapped to future technology requirements. This ensures a high level of alignment between the business objectives and the new technology capabilities to be further investigated.

3.3 Technology: Capabilities and Services

Following the top-down process of network architecture, the business requirements developed above are mapped onto technology capabilities, which can subsequently be realised by composing appropriate technology services. A useful classification of services can be seen in Cisco’s SONA framework [11] shown in Fig. 2. Components such as routing, switching, multicast etc. are grouped into *transport services*, while compression and caching are part of *application delivery*. To illustrate with a simple example, suppose a company has the goal of designing a car that is fun to drive. One of the capabilities the car may have is an integrated multimedia system. This capability may in turn be realised by composing *transport service* (switching, routing, QoS) with *application delivery* (compression, caching), *real-time communications* services (codecs), *security services* (encryption, firewall, intrusion), and *management services* (AAA, configuration, fault), as shown in the system view of Fig. 3. The architecture as shown is at a reasonably abstract level, which not only facilitates easier discussion between the technical and business groups within the company, but is also easy to translate into an implementation using best-of-breed products available at the time.

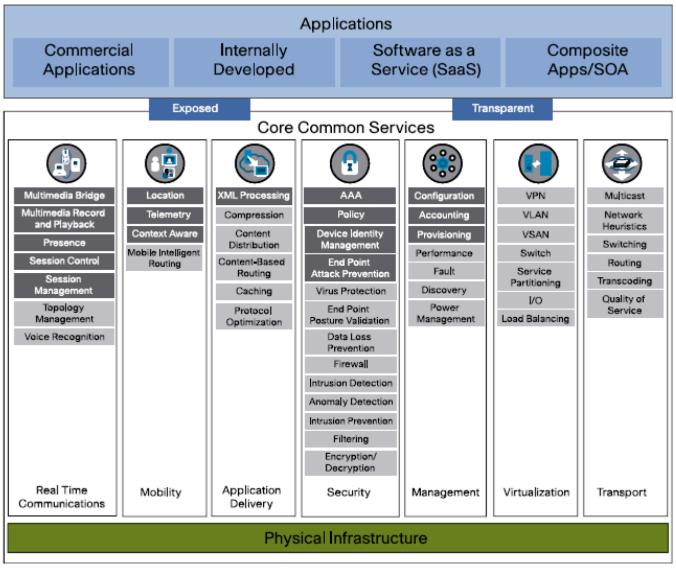


Figure 2: Cisco’s Service-Oriented Network Architecture (SONA) Framework

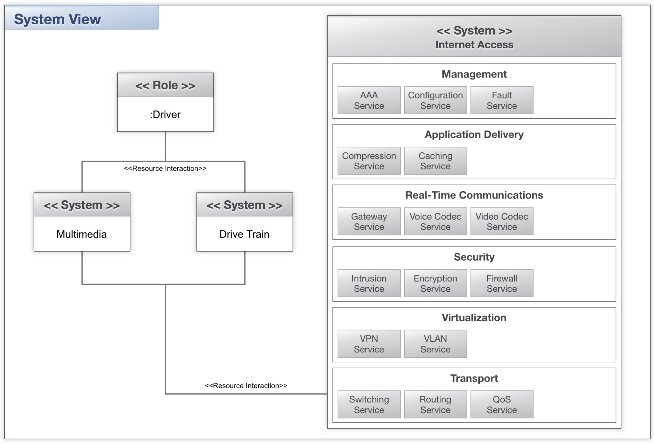


Figure 3: System view of architecture for car with multimedia system

3.4 Case Studies and Projects

To help make the concepts above a bit more concrete, we briefly discuss two case-studies we used as working examples throughout the course to illustrate how business requirements affect key architectural decisions. We also briefly discuss how projects helped students delve deeper into specific network architectures.

3.4.1 National Broadband Network

Australia's National Broadband Network (NBN) [12] is a A$40-billion initiative by the Australian government that aims to connect over 90% Australian households with optical fibre at bandwidths of 100Mbps or more over the next 10 years. While the NBN will build and own the fibre, the business model is to wholesale the access to retail providers who will provide Internet service to the household. An important driver is *open access*, whereby retailers can compete with each other on a level playing-field while consumers have wide choice of provider(s). While there are many architecural decisions to tackle, we briefly discuss how the business requirement of open access dictates the fundamental choice of transport technology.

There are multiple choices of how the NBN access network can inter-connect with the carrier (ISP) network. If the access connects at the physical layer (i.e. fibre) to the ISP, all users on that (PON) access segment are locked-in to the same ISP, preventing competition. On the other hand, if the NBN terminates the access with a layer-3 device (router) and routes packets to ISPs, all the complexities of IP addressing (e.g. assigning IP addresses to end-hosts) and routing (to appropriate ISP based on customer flow) would need to be borne by the NBN. Therefore it was deemed that layer-2 connectivity (using VLANs) was architecturally the sweet-spot, since it allows households (and indeed services within a household) to be individually switched to appropriate retail providers of choice at low complexity. This simple example illustrates how technology architecture is driven by business requirements. Moreover, this technology decision has a direct impact on many other aspects (pricing, QoS, multicast, etc.) of the architecture, and these pros and cons should also be considered.

3.4.2 University Campus Network

Since students experience the University microcosm everyday, we picked our University network as a case-study. At the top-level, UNSW's vision is to be a leading research intensive university in the Asia-Pacific region. This translates into a series of goals for the network, such as supporting researchers with a high-capacity network (40Gbps internal and 10Gbps external network links), providing students with easy network access (high-availability wireless with no quotas), and facilitating efficient administration of the University (via high-density data-centers). We invited our IT manager to talk about the major decisions they had to make in architecting the UNSW network, and highlight below a few key issues:

- **Traffic:** UNSW pays its ISP (AARNet) $4 per Gigabyte of download. In 2009 UNSW downloaded 2.5 Petabytes, so its ISP bill was $10 million. Moreover, traffic is rising 30% annually. To contain these costs, the architecture needs to include solutions such as local caching of content, blocking of peer-to-peer content, etc.
- **Wireless:** Wireless usage on-campus has grown exponentially, with over 60,000 unique devices connecting to the University network in Q3 of 2009. Therefore, the University needs to invest in wireless, though not treat it as a replacement for wired.
- **Virtualization:** To support the various groups and activities, the network needs to have logical network partitions for students, staff, labs, servers, printers, etc. Whether these are allocated University-wide or per department has implications for the network management and support arrangement.
- **Security:** UNSW has chosen to have an "open secure" network, whereby things are mostly open (i.e. all inbound and outbound traffic is permitted), but key services (servers, printers, etc) are secured. Key decisions surrounding access control policies relate to whether they are implemented at layer 3 or 4, whether they apply per-IP-group, per-VLAN or per-host, and how they inter-relate with addressing and logging.

The above is just a representative list, there are other major decisions surrounding data-center design, mobility, network management, etc.

3.4.3 Projects

Projects are key to student learning as they immerse them into the architecture process, and teach them thow to present and defend their work in front of key stakeholders. Students were organised into groups of 4, and each group selected a unique topic from a list. Topics ranged from a smart building and smart car to a prison, bank branch, sports stadium, and electricity retailer. The project lasted for 7 weeks, and was roughly in two parts:

1. The **first part** required them to develop the high-level vision and business goals. For this, they had to do on-line searches and where possible interview management personnel and user-groups in that sector. For example, the group architecting a bank branch network met with the local bank manager, and discovered that the key issues facing them were lack of skills in financial advise at the

local branch, and diversity of languages amongst their (student) customers. These could for example be overcome with video services to remote specialists, and so this group focused their architecture to support high-quality video.

2. The **second part** required them to develop the technology architecture. They had to express the architecture in terms of the capabilities and services, and specifying their inter-relations to show how they met the requirements. The students found this challenging, especially since they had to present their architecture and rationale to the class within 10 minutes using at most 5 slides.

4. CONCLUSIONS AND FEEDBACK

Businesses increasingly need to leverage technology effectively to improve competitiveness. As networking technologies become more complex, there is a growing need for skills in integrating this knowledge to architect systems that align with the business needs now and into the future. Our course on "Network Systems Architecture" offered at UNSW in 2010 aims to fill this gap. It emphasises a top-down approach that starts with the business goals and develops a holistic technology architecture to satisfy those needs. In the process, it helps students identify key constraints and trade-offs, so they can make decisions that are defensible from a system-wide perspective. Practical case-studies from carrier and enterprise networks (supported by guest lecturers) were used as working examples throughout the course to illustrate the complexities, and group projects gave students experience in developing and defending network architecture over a large range of systems.

The course was run for the first time in the second half of 2010, and offered to post-graduate by coursework students as well as industry professionals. The class size was approximately 54 (of which 6 were from industry), and the feedback was in general positive: over 80% of students said that this course would enhance their career prospects, and that they would recommend it to their friends. Among the most valuable aspects of the course were stated to be the face-to-face interaction with industry professionals, and the real-world nature of the projects. Some of the negative feedback suggested that the course content was not technical enough and lacked proper principles. There was also concern amongst students that this course was more suited to senior industry people, and students did not have the breadth of knowledge in networking to embark on architecture work.

From our (the lecturers Vijay and Adam) perspective, the course was challenging but very enjoyable to run. We will offer it again in the second half of this year, and plan to improve it in several ways:

1. We will make the initial (business) component of the course more rigorous by including well-grounded principles of business modeling.

2. We will commence the project at the very beginning of the course, so students get 6 weeks to develop their business model and another 6 to develop the architecture. We additionally hope to provide more individual guidance to each project by assigning each group a mentor from industry.

3. To engage students more actively in the classroom, we will assign each group to one lecture session for which they have to seed discussion on a set of issues related to that lecture, that will then be scribed by them on the course Wiki.

We hope that the course is even more rewarding when we offer it this year, and we hope that we can develop a set of notes (in the form of a small book) that can be shared with the rest of the teaching community.

5. REFERENCES

[1] Forbes Blogs, "Borders Bankruptcy Boosts Amazon, Apple, Google", `http://blogs.forbes.com/greatspeculations/2011/02/17/borders-bankruptcy-boosts-amazon-apple-google/`.

[2] Wikipedia, "Blockbuster Inc.", `http://en.wikipedia.org/wiki/Blockbuster_Inc`.

[3] GigaOm, "Skype is Killing it on Long Distance", `http://gigaom.com/2011/01/06/skype-is-killing-it-on-long-distance/`.

[4] James D. McCabe, "Network Analysis, Architecture, and Design", 3rd edition, Morgan Kaufman, 2007.

[5] Priscilla Oppenheimer, "Top-Down Network Design", 3rd edition, Cisco Press, 2010.

[6] Architecture Forum, "TOGAF version 9", `http://www.opengroup.org/togaf/`, 2009.

[7] US Department of Defence, "DoD Architecture Framework v2.02", `http://cio-nii.defense.gov/sites/dodaf20`, 2010.

[8] Joshua McCloud, "Enterprise Architecture for Network Designers", 2010.

[9] "The Business Canvas", `http://www.businessmodelgeneration.com/downloads/business_model_canvas_poster.pdf`.

[10] 9 Dimensions, "The Business Model Lifecycle", `http://9dimensions.com.au/blog/tag/business-model-canvas`.

[11] Cisco Systems, "Service-Oriented Network Architecture", `http://www.cisco.com/en/US/netsol/ns629/`.

[12] Australia's National Broadband Network, `http://www.nbnco.com.au/`