DNA GROUP

http://www.cs.uct.ac.za/Research/DNA/

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Research for 2007 and beyond

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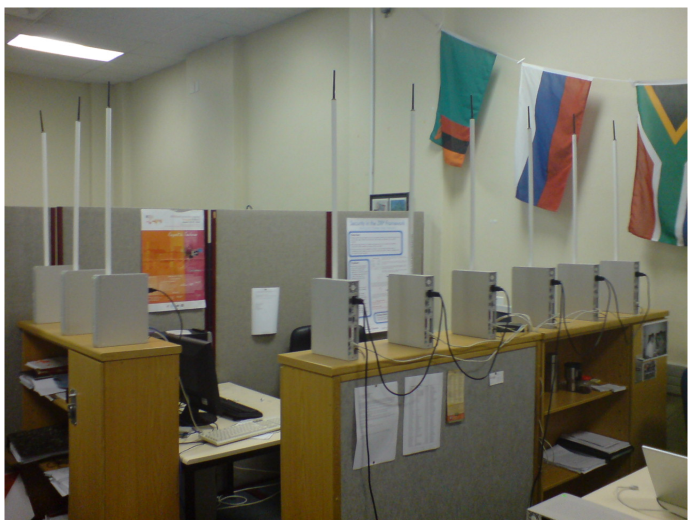

Of all software projects, 15 percent fail right away, and 51 percent are"challenged" – exceeding budget, time frame or not meeting the requirements. On average, only 54 percent of the originally defined features are actually implemented.

The Standish Group, December 2003.

Where is the wisdom now that we have knowledge?
Where is the knowledge now that we have the information?

Songs from the "The Rock", TS Elliot, 1934.

Data Network
Architectures Group

1 Vision

The DNA Group - comprises a number of staff and students in the Department of Computer Science at the University of Cape Town.

Pursuing - international research excellence and local industry relevance, while facilitating the professional growth of its members.

Through - conducting research and teaching in the field of telecommunication networks with a view to the practical application of its results.

Sustained - by a dedicated and persistent effort to always improve in the quest for excellence.

2 DNA Group Specialization

The DNA Group *specializes* in the

- modelling of ...
- building of ...
- security of ...

telecommunication systems and their workloads.

3 PLANNED RESEARCH

This section details the research projects which we would like to undertake in 2008 and beyond. All are related to the DNA Group specializations listed above. Students who have completed their undergraduate years or Honours year in the first-class are invited to approach anyone mentioned here about further study. It is also important to know that these projects are not exclusive of any project of a student may want to propose himself within the field of expertise of the DNA Group . Do you have a brilliant idea? We will listen.

3.1 Wireless mesh networks

Wireless mesh networks (WMNs)[HM06, ea05] consist of mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of WMNs[1]. They provide network access for both mesh and conventional clients. The integration of WMNs with other networks such as the Internet, cellular, IEEE 802.11, IEEE 802.15, IEEE 802.16, sensor networks, etc., can be accomplished through the gateway and bridging functions in the mesh routers.

Mesh clients can be either stationary or mobile, and can form a client mesh network among themselves and with mesh routers. WMNs are anticipated to resolve the limitations and to significantly improve the performance of ad hoc networks, wireless local area networks (WLANs), wireless personal area networks (WPANs), and wireless metropolitan area networks (WMANs).

[1]Source: I Akyildis, et al. Wireless mesh networks: a survey, Computer Networks 47 (2005) 445–487

They are undergoing rapid progress and inspiring numerous deployments. WMNs will deliver wireless services for a large variety of applications in personal, local, campus, and metropolitan areas. Despite recent advances in wireless mesh networking, many research challenges remain in all protocol layers.

As mentioned before, this field of endeavour is open to any study on recent advances and open research issues in WMNs, such as system architectures and applications, protocol design, security and Quality of Service issues. WMN projects currently active in the DNA Group are mentioned in Section 4.

3.1.1 IEEE 802.11 Hardware Testbed

Currently, the DNA Group is assembling a 10 node indoor 802.11 mesh network, which will be used to compliment research with experimental study. In order to mimic a multi-hop environment in such a small space, the wireless signal strength needs to be reduced substantially. Thus, each node is coupled with a 30 dB attenuator. All the nodes are connected through a 100 Mbps back-haul network for control and measurement purposes. Andrew Symington is responsible for the planning and development of this test bed (see Section 4.4). The test bed will be available to future projects, such as those which involve routing[JM96, YG06] and security protocols.

Objective: This project or projects will continue where the current project (see Section 4.4) leaves off and requires a keen interest in hardware as well as the theory of wireless networks and their protocols.

3.2 Software engineering - I

Telecommunication requirements are susceptible to change, not only after releasing the product but also along the iterative software development process. For example in the development of UMTS there are typically 20,000 requirements per core node distributed across many different platforms using varying and complex technologies. Customers change, organisations change, technologies change, standards change and hence requirements change.

Information management should be integrated as a subprocess in the software development life cycle. Traceability is defined as the ability to describe and follow the life of a document, be that the requirements, UML or other design documents, the code or the test cases in both directions, towards its origin or towards its implementation, passing through all the related specifications.

Traceability allows us to assure the continuous concordance between the stake holders requirements and the artifacts produced along the software development process. Although the important role of traceability is widely recognized, the application level and consensus about associated practices are quite variable from one software development team to another.

Objective: Although the current project is well on its way to be successfully completed (see Section 4.2 below), thereby producing a software prototype called LSITrace, the intention in this project is to continue the research and make further improvements to the scheme, such as, for instance, using probabilistic LSI techniques and exploring the uniqueness of software artifacts as opposed to simply textual documents to which LSI is usually applied. The importance of good software engineering, at its current level (see quotation on the title page) cannot be overemphasized.

3.3 Software engineering - II

One should not perceive IP telephony solely as a replacement for the established telephone system. Rather, consider it a basis to unify communications services and assess how business and communications processes can be cooperate.

According to the Gartner Group, by 2010, 40 percent of companies will have completed the convergence of their entire voice and data networks to a single network, and more than 95 percent of large and medium sized companies will have started the process. When examining the business impact, one should not look at IP telephony solely as a replacement for the established telephone system. Rather, consider it a foundation to unify communications services and assess how business and communications processes can be changed or integrated with IP telephony and collaborative applications.

Typically, the biggest delays in business processes involve human latency, when a process cannot continue until key people are found, contacted, and informed, and they take the appropriate action, such as giving approval. Moreover, telephone conferencing and enhance collaboration accelerate decision-making.

SOA, or Service-Oriented Architecture, makes it easier to weave these functions directly into data applications and process flows, rather than requiring human beings to switch to separate communications applications or devices. In this project we will examine how VoIP solutions can be used to allow for voice-enabled business processes.

Objective: The following are the general goals of this project:

- Evaluation of the current state of convergence of SOA and VoIP.
- Evaluation of existing frameworks and application server (BlueNote, Bea, Websphere etc.) that support the SDP (Service Delivery Platform) and allows the incorporation of voice services into business processes.
- Modifing the existing VoIP DNA group implementation (ChattaBox) so that it can run in a SOA enabled environment as a webservice.
- Model a simple business process through BPMN or BPEL, like a subset of the tasks in a call center, to show how VoIP services can be monitored and incorporated into a business process.

This project should be particularly attractive to the B.Bus.Sci. students.

3.4 Secure mobile banking

There are many security shortfalls with current mobile banking solutions. We will investigate improved mobile protocols for GSM and GRPS for improved mobile security.

In the past decade the number of online banking users has increased rapidly. This has led many developers to investigate more convenient methods for customers to perform remote transactions. Mobile banking is a new convenient scheme for customers to perform transactions and is predicted to become more popular as the number of mobile phone users increase.

Currently, South African banks such as Standard Bank, ABSA and FNB provide mobile banking through the following three channels:

1. WAP (Wireless Application Protocol)
2. GPRS (General Packet Radio Service)
3. SMS using the WIG (Wireless Internet Gateway).

In this project, we propose the investigation of security issues involved with mobile banking using the cellular GSM network. The goal of this project is to build applications for portable devices that ensure users can securely send their banking information via the GSM network. The types of mobile banking solutions we have selected for this project are SMS banking and GPRS banking.

Objectives:

1. Investigate the different security protocols on offer by the various solutions and their underlying technologies.
2. Investigate possible attacks on mobile banking solutions, both passive and active.
3. Simulate/implement a subset (if not all) of the solutions.
4. Investigate how security objectives such as confidentiality, integrity etc. can be achieved.

Note that there is a legacy Honours project done by Ming Ki Chong and Kelvin Chikomo in 2006 on this topic.

3.5 Web server performance

Alternatives for enhancing the performance of web servers at different levels and with different approaches are, from highest to lowest level, balancing the Edge Side Includes (ESI) for web caching, load balancing in cluster based web servers (both at level 4-switch, and at level 7-switch), and promoting web traffic over DiffServ Architecture using Token-bucket policies.

Traditionally, the differentiated services architecture (DiffServ) is under consideration to provide different services and QoS in the Internet. The volume of the web traffic is important when we intend to achieve certain QoS for the various kinds of flows. We intend to deploy a DiffServ model where small volumes are managed with high priority and the maximum QoS is achieved. Certain high volume flows should also receive higher priority but not at the expense of low volume flows.

Another way to tackle the problem of enhancing the web server performance is by mean of a scalable content-aware load balancing solution for cluster-based Web information systems that includes service differentiation and quality of service. The architecture is based on a farm of Web servers managed by a content-aware load balancer that differentiates the service required by the workload and implements a control admission under extreme overload. The results show that the burstiness in the workload has to be controlled on the Web servers in order to obtain the best response in terms of performance and overhead.

A third way is to enhance the performance of web server is by caching elements of dynamic web pages. To improve the cache performance in the server site pages should be built from different parts generated independently taking into account the frequency of use of these elements. The web server performance is especially critical when we are using a wireless access network. A solution to be investigated could be the use of this caching approach also at the client side in order to reduce the traffic in the wireless communication network.

Objective: Alternatives for enhancing the performance of web servers at different levels and with different approaches are

1. balancing the Edge Side Includes (ESI) for web caching,
2. load balancing in cluster based web servers (both at level 4-switch, and at level 7-switch), and
3. promoting web traffic over DiffServ Architecture using Token-bucket policies.

This project has been proposed by our collaborators at the Universitat de les Illes Balears, Palma de Mallorca, Spain. A student who undertakes this project should expect to spend time with the *Arquitectura i Comportament de Sistemes Informatics i de Comunicacins, ACSIC Research Group*(see Section 7).

3.6 Modelling the Wireless Internet

IEEE 802.11 or WiFi networks are well-established as wireless local networks for accessing the Internet from locations such as hotels, airports, conference centers and so on (also read Section 3.1). Simultaneously Wireless Mesh networks are coming into operation although many open research questions still remain. In contrast to WiFi networks, mesh networks are peer-to-peer networks where peers communicate with one another as well as connect a community of peers to the Internet. The back haul network which connect to the Internet can be various things.

Recently WiMax networks based upon the IEEE802.16[C.E02, DBE02] series of standards have emerged for this purpose and commercial offerings are already available. WiFi vertically integrated with WiMax has been called the *Wireless Internet*[KP07]. However, as such networks become increasingly complex, performance modeling and evaluation will play a crucial part in their design process to ensure their successful deployment and exploitation in practice. Modelling the Call Admission Control[NH05] algorithms and scheduling for the best Quality of Service are typical issues which come to mind.

Models of systems are essential for their design so as to predict their behaviour once they are built. Models can be prototypes which are usually expensive and not easily scaleable. Simulation models are clearly an option[BCNN], but simulations become complex, are hard to validate and require much processor time when the network becomes large.

Objective: System models always have two parts: The abstraction of the functionality of the system and the workload to which the system is subjected: We call these two parts the *machine-* and the *workload model* respectively. Much attention and research (e.g., [Bia00]) has gone into developing accurate analytic machine models of WMNs, although there still remains much to be done. For example, many models do not take into account channel interference.

In comparison, there is less research so far on developing workload models[DSTG00] largely because it is difficult. Workload models can range from measured traces[CL99], which are not scaleable at all and usually not very representative of reality, to probability density functions fitted to the measured data[LMW94]. The DNA Group has a great deal of experience in the latter. Another challenge involves developing analytic models such a Bernoulli or Markov Modulated Arrival Processes (BMAP/MMAP) to adequate represent the arrival processes applicable to WMNs.

4 CURRENT RESEARCH PROJECTS

The projects described here began in January 2007 or the year before. It is a stated objective of the DNA Group to build on past results and each of the current projects allow for further work. Please approach the relevant post-graduate student in the DNA Group or Professor Pieter Kritzinger if you would like to know more.

4.1 Security in wireless mesh networks

This project, by Stephen Asherson, is investigating end-to-end security (authentication, confidentiality, integrity, replay attack protection) of the Optimized Link-State Routing (OLSR) protocol at the application layer. Whilst the IEEE 802.11 MAC layer security is sufficient in establishing a point to point security association, it cannot provide the necessary security that is specific to an application, particularly in a multi-hop environment such as an *ad hoc* network.

As part of the project, a security enhancement has been implemented in C for an OLSR implementation. The enhancement performs the following tasks:

1. Timestamp request/response with other communicating nodes. Necessary to prevent replay attacks. Time synchronization is not assumed.
2. Adds the necessary security data to each control message. This involves asymmetric digital signatures, time stamps, and hash fields to protect mutable fields (which change at each hop - Hop Count and TTL fields) of each message.
3. Provides optional encryption/decryption of OLSR packets.

A comparison is also being done between two different signature schemes: An identity-based signature scheme based on RSA; and a one-time signature scheme known as HORS (Hash to Obtain Random Subset). Providing security mechanisms for each OLSR control message adds additional traffic and processing overhead to the protocol. The security implementation is being tested on a wireless testbed (see Section 3.1.1) in order to determine the overhead it adds.

Objectives: The following are the objectives for the experimental work:

1. What additional traffic overhead is being generated.
2. The processing overhead of each message.
3. The delay associated in establishing routes and the round-trip delay of a message between two nodes.
4. Impact on the stability of the links and routes between nodes.
5. The delivery ratio of OLSR packets between nodes.
6. Data throughput - both the standard OLSR implementation and OLSR with security.

4.2 Traceability in the SDLC document corpus

Software traceability can be of great value in keeping track of the changing requirements, as reflected in the corresponding artifacts and their dependencies throughout the Software Development Lifecycle (SDLC). In general, software traceability can be defined as the ability to trace a requirement, in both a forward and backwards direction through the artifacts which constitute the different stages of a SDLC.

Objectives: The main objectives of this project, done by Hans-Peter Krüger, are as follows:

1. Development of proof-of-concept traceability tool (LSITrace) that would allow the indexing of natural language text documents, UML diagrams as well as source code, perform searches through Latent Semantic Indexing and give the user a graphical representation of the dependencies to similar artifacts.
2. Carry out a case study whereby our LSITrace software will be applied to artifacts of a real world software project.
3. Evaluation of the case study results and draw conclusions on the usefulness of the proposed approach and the tool.

The project suggested in Section 3.2 will capitalise on the results of this project.

4.3 An extensible Wireless Internet software workbench

WiMax networks based upon the IEEE802.16 series of standards are coming into commercial use daily. WiFi vertically integrated with WiMax has been referred to as the Wireless Internet[KP07]. However, as such networks become increasingly complex, performance modeling and evaluation of their Quality of Service (QoS) capabilities will play a crucial part in their design process to ensure their successful deployment and exploitation in practice.

Objectives: This project, being done by Paolo Pileggi, will deliver a software tool, called *Broadband Wireless Access Network Analyser (Bwana)* that brings together simulation and analytical modelling of wireless networks. The analytical technology used is MicroSNAP[Uni90] (for *Stochastic Network Analyser Program*, based on mulit-class queueing network theory[FBP75] previously developed by the DNA Group . The simulation environment is OMNeT++[Var01].

4.4 QoS in IEEE 802.11 networks

Within the Machine Access Control (MAC) sublayer of IEEE 802.11, channel access is coordinated through the Distributed Coordination Function (DCF). However, owing to to its inability to discriminate between traffic classes, DCF provides poor support for time-sensitive applications such as voice and video. Therefore, the IEEE 802.11e task group was commissioned to improve MAC-level coordination. The revised distributed coordination protocol, Enhanced Distributed Channel Access (EDCA), provides four traffic classes and is backwardly-compatible with DCF.

The research, undertaken by Andrew Symington, presents a method of quantifying the performance of DCF using three standard metrics : normalized throughput, latency and jitter. This is achieved by using existing analytic models and Multiclass Queuing Network (MQN)[Gel91] theory. Finally, the results will be validated by conducting experiments in a simulated environment and on a hardware test bed (see Section 3.1.1).

Objectives: The following objectives are in mind for this project:

1. Identify the factors that are influential in determining the performance of DCF.

2. Use a number k of network topologies to stress-test the performance of DCF in a multi-hop environment.

3. Use a number ω of workloads to stress-test the performance of DCF in a multi-hop environment.

4. For each topology $i, i = 1, \ldots, k$

   (a) Derive an appropriate multiclass queuing network for experiment i. For each service centre use the analytic models of Bianchi[Bia00] and Chatzimisios *et al* to calculate the expected throughput, response time and jitter as a function of the number of stations contending for channel access.

   (b) For each workload $j, j = 1, \ldots, \omega$

      i. Calculate the performance of DCF in topology i under workload j using the system model constructed in 4a above.

      ii. Calculate the performance of DCF in topology i under workload j using an appropriate hardware test bed.

      iii. Calculate the performance of DCF in topology i under workload j using an appropriate simulation.

5. Draw conclusions from the range of experiments and assess the suitability of the system model as a means by which to evaluate the system-wide performance of DCF in multi-hop ad hoc IEEE 802.11 networks.

5 Current membership of the DNA Group

Professor Pieter Kritzinger, a permanent staff member of the Computer Science Department, founded the DNA Group in 1986. Pieter usually spends June – October in Europe, involved with our various international partners. He teaches the Third year Networks course and an Honours course on Stochastic Models of Computer Systems.

Dr Andrew Hutchison, now of T-systems in South Africa, was a full-time Senior Lecturer in the Computer Science Department at UCT until 2000 and since 2004 holds an Adjunct Professorship in the Department. Andrew spends what time he can with the DNA Group and teaches an Honours course in Computer Security.

There are currently one PhD student (Alapan Arnab), 4 MSc students (Stephen Asherson, Hans-Peter Krüger, Andrew Symington, Sameshan Perumal) and an Honours student, Paolo Pileggi in the Group.

During the past 5 years alone, 1 PhD student and 10 MSc students graduated from the Group. Half of these Masters graduates received their degree with distinction (see Section 9).

The DNA Group is furthermore proud of its international focus. Current international collaborators in the DNA Group are

– Dr Falko Bause of Lehrstuhl IV, Universität Dortmund, Germany. The group he belongs to specialises in *Modelling and Simulation, Computer Networks and Distributed Systems, Computing Systems and Performance Evaluation*, http://ls4-www.cs.uni-dortmund.de/. Dr. Falko Bause has lectured Honours courses in the Department of Computer Science at UCT on several occasions and is a co-author of a monograph on Stochastic Petrinets with Professor Kritzinger.

– Professor S Budkowski, Director of Research of Institute National des Télécommunication, France, http://www.int-evry.fr/recherche/en/. Professor Budkowski has paid numerous visits to the DNA Group and many students in the Group have, over the period of more than a decade, paid extended research visits to Institute National des Télécommunication.

– Dr William Knottenbelt of the Department of Computing at Imperial College, University of London. Dr Knottenbelt (http://www.doc.ic.ac.uk/ wjk/), an alumnus of the DNA Group is a member of the Analysis, Engineering, Simulation and Optimization of Performance (AESOP) research group at that university.

– Professor Markus Siegle of the Universität der Bundeswehr München where his research involves the design of computer- and communication-systems, http://www.unibw.de-/inf4/personen-/prof/ms.

– More recent are our collaborators in the *Arquitectura i Comportament de Sistemes Informatics i de Comunicacións (ACSIC)* Research Group at the Universitat de les Illes Balears in Palma, Majorca under the supervision of Professor Ramon Puigjaner, who is no stranger to South Africa.

6 Funding and International Collaborators

The DNA Group is a grantholder in the NRF Information and Communication Technology Focus area and participates in the Technology and Human Resources for Industry (THRIP) program. THRIP provides funding which, in principle, equals that of our industry partners. Our industry partners are Telkom SA and Nokia-Siemens Communications (South Africa). Our annual budget for all uses is on the average about ZAR1/2-million.

Since it was founded, 4 students in the DNA Group who obtained their MSc degrees with the Group, went overseas to study for their doctorates. These are Andrew Hutchison who completed his PhD in 1996 at the University of Zurich, Stephen Donaldson (see the DNA Group alumni list in the end) at the University of Oxford in 1999, William Knottenbelt at Imperial College in 2000 and Justin Templemore-Finlayson at Institute National des Télécommunication in 2003.

During 2003, Johannes Appenzeller of the Swiss Federal Institute of Technology in Lausanne (EPFL) visited the DNA Group for 6 months to complete the project work for his Diplom awarded by EPFL. Several students from Germany such as Kia Lampka (Universität Erlangen-Nürnberg , who subsequently obtained a PhD from Universität der Bundeswehr München) and Olaf Klüge (subsequently completed his PhD at Universität Erlangen-Nürnberg and now works for Fokus in Berlin) and several others have spent time with the group.

Our international relationships are further enhanced by membership of IFIP WG7.3 [2](Computer System Modelling), WG6.1 (Architecture and Protocols for Computer Networks) and WG6.3 (Protocol Performance) as well as that Professor Kritzinger is the South African representative on the IFIP Technical Committee 6 (Telecommunication Systems). We are furthermore also active in WG11.1 (Information Security Management) and WG11.2 (Small Systems Security).

6.1 Critical Success Factors: Non-Technical

It would be ideal if one could lay future plans based on purely scientific and technical considerations. The South African and increasingly, world reality is however different.

[2]IFIP is the International Federation of Information Processing, the "United Nations" of the information technology world, while WG stands for "Working Group"

6.1.1 The South African reality

The DNA Group (like with almost everything else in South Africa) has the unenviable task of producing useful results for a *developing world* (read "local industry") in order to fund itself and retain local credibility. Simultaneously, it needs to compete with increasingly tough standards of the *developed world* in terms of publications and research judged by international peer review. One thus has to strike a balance between these two somewhat, but not totally, conflicting demands.

6.2 Critical Factors: Technical

Within the context described above, there are certain ingredients of a successful research project for degree purposes.

6.2.1 Clearly Defined Deliverable(s)

In any project it is important to know what the end product is in order to recognize it when one sees it. Every project must therefore have a tangible deliverable in the time span available (about 1200 man hours – for the *tangible part,* not the full requirement – for Masters). In the DNA Group the deliverable has almost always been a software system (for instance, SPEARII for GNY logic analysis of security protocols by Elton Saul[3], prospeX developed by Nico de Wet for UML based performance analysis of systems or SusanX by Ksenia Ryndina for improved use case requirements specification), but we have had a student receive his Masters degree with distinction without writing a line of code (Petri net Reduction and Synthesis by Stephen Donaldson). Another variation is the proposal of a solution method or technique and the development of a system to evaluate the proposal such as, most recently, the work of Ian Davies on Binary Decision Diagrams.

6.2.2 Scope for Original Work

The requirements for a Masters degree at UCT do not extend to *original* work. That it must be the candidate's *own* work is understood. The scope for truly original work does, however, determine the quality of the degree in the end. A good piece of *own*-work will almost certainly not lead to a distinction. One should thus be on the lookout for the scope of original work in any proposed project.

7 Financial Support

The DNA Group has in the past done its best to ensure that its students have the financial support they need (as opposed to what they would like). Our sources of funding have been mention before. Students should *not* make a decision to join the DNA Group only because we provide (usually) sufficient funding, but those who do decide to join us are invited to apply for support by providing us with a budget of expected income and expenditure for the year.

One of the conditions of accepting an award is that you must obtain permission from your supervisor in the DNA Group *before taking on any other duties*, including tutoring or a Teaching

[3]Elton works for Microsoft in the USA, Nico is a partner in a local software company, Red Button and Ksenia is working on a doctoral degree at the IBM Zurich Research Laboratory

Assistantship in the department. Another is that you will be expected to work as a research assistant, on the average, 3 hours per week for staff members in the DNA Group .

We recently received a grant under the Key International Science Capacity (KISC) initiative of the NRF. This programme allows for the international exchange of research students and staff[4]. Basically students who join the Group to work towards a Masters degree are eligible for a research exchange program with international universities in France, Spain, the United States, Britain or Germany. Successful students will receive

– An economy return airfare from Cape Town.

– Subsidy to pay for reasonable accommodation at the destination.

– A daily living allowance.

8 Acknowledgement

Current students, Alapan Arnab, Stephen Asherson, H-P Krüger, Paolo Pileggi and Andrew Symington have all contributed to this document in various ways. Not to mention the DNA Group alumni without whom the group would not have existed. The project described in Section 3.5 is a proposal from Professor Ramon Puigjaner and his group.

9 MSc graduates and Alumni of the DNA Group

The following persons have worked as slaves in the DNA Group during the past decade or more.

1. J van Dijk, MSc (1988). Thesis title: *"An Estelle Compiler"*
2. P Stutz, MSc (1989). Thesis title: *"Office Automation and CoSNet"*
3. A C M Hutchison, MSc (1991). Thesis title: *"Modelling Dynamic Routing in Wide Area Networks"*
4. H Donnelly, MSc (1992). Thesis title: *"XSNAP: A Multiclass Queueing Network Solver"*
5. S Donaldson, MSc (1993) . Thesis title: *"Complexity of Petri Net Reduction Transformations"*
6. G W Wheeler, PhD (1995). Thesis title: *"Protocol Engineering from Estelle Specifications'*
7. R Ulrich, PhD (1995) (University of Erlangen-Nürnberg). Thesis title: *"Reservoir-Based Resource Management for Slotted High Speed Networks"*
8. W Knottenbelt, MSc (1996). Thesis title: *"Generalized Markovian Analysis of Timed Transition Systems" Graduated with distinction*
9. H Kabutz , PhD (1997). Thesis title: *"Analytical Performance Evaluation of Concurrent Communicating Systems using SDL and Stochastic Petri Nets"*.
10. M Mestern, MSc (1998). Thesis title: *"Distributed Analysis of Markov Chains"*

[4]More details can be found at http://www.cs.uct.ac.za/Research/DNA/

11. J Templemore-Finlayson, MSc(1998). Thesis title: *" A graphical representation for the Formal Description Technique Estelle"*

12. P Wall, MSc (1998). Thesis title: *" Bisimulation as a Verification and Validation Technique for Message Sequence Charts"*

13. S Buffler, MSc (1999). Thesis title: *" ROLAND: A Tool for the Realistic Optimisation of Local Access Network Design"*

14. M Nelte MSc, (2000) Thesis title: *"Biological Security Techniques"*

15. I Davies, MSc (2001) Thesis title: *"Symbolic Techniques for the Performance Analysis of GSPN"*

16. E Saul, MSc (2001) Thesis title: *"Logic-Based Security Protocol Analysis "Graduated with distinction.*

17. Y Yavwa, MSc (2001) Thesis title: *"Investigating cost effective communication alternatives for geographically hostile regions"*

18. M Welz, PhD (2003) Thesis title: *"Modulating Application Behavior for Closely Coupled Intrusion Detection*

19. J Appenzeller, (2003) Diplom thesis title:*"Real-time System Development with UML: A Case Study*

20. M Chibesakunda, MSc (2004) Thesis title: *"A Methodology For Analyzing Power Consumption In Wireless Communication Systems"*

21. L Walters, MSc (2004) Thesis title: *"A Web Browsing Traffic Model for Simulation*

22. F Lifson, MSc (2004). Thesis title: *"Specification And Verification Of Systems Using Model Checking And Markov Reward Models"*.

23. O Ryndina, MSc (2005) Thesis title: *"Improving Requirements Engineering: An Enhanced Use Case Modelling and Analysis Method". Graduated with distinction.*

24. N de Wet, MSc (2005) Thesis title: *"Model Driven Communication Protocol Engineering and Simulation Based Performance Analysis Using UML 2.0". Graduated with distinction.*

25. J Landman, MSc (2005) Thesis title: *"Analytical Models of IP Traffic on UMTS Mobile Networks". Graduated with distinction.*

26. P Sikalinda, MSc (2005) Thesis title: *"An Enterprise Storage Workload Analyzer"*

27. B Tobler, MSc (2006) Thesis title: *"Generation, Analysis and Verification of Security Protocol Implementations". Graduated with distinction.*

28. R van Rooyen MSc (2007) *"Composite Web Services Security Considerations". Graduated with distinction.*

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