Challenges and Opportunities in Communication Network for Academic Institutions in Africa

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Abstract—**Many institutions, government departments, businesses and industries now realize the importance of information and communication technology (ICT) to open up the abundant opportunities to compete in the global market. However, many countries in Africa are short of both infrastructure and expertise in communication network to enable ICT. With strong support and collaboration from the government and from industry academia can re-define the paradigm for the education of electrical engineers and computer scientists in ICT. Although many academic institutes in South Africa and some other countries in Africa have in recent years established centers of excellence in communication network through strong support from the industry there are still many challenges to bridge the digital divide. We examine the challenges and issues faced in the network communication program and propose programs to develop strong curricula.**

Index Terms—**broadband communication, convergence, curriculum, digital divide, telecommunication, wireless networks.**

I. Introduction

The ability to communicate through high speed networks is important to the general public, government departments, business, and industry in every country to compete in the global market in this Information Age. Yet many parts of Africa lack the expertise and the infrastructure of high speed networks, thus perpetuating the significant digital divide intra-nationally as well as internationally. In this paper we propose ways in which academic institutions may play important roles in improving the situation. As numerous centers of excellence in communication network in many academic institutions throughout South African have been started with the support from the industry, this paper also suggests what better ways can the academic institutions play a stronger role. We then share our experiences at the University of Cape Town (UCT).

High speed communication networks are important to a developing country (Section II), and opportunities are abundant for developing countries (Section III). Given the current status of network in Africa (Section IV), Academic institutions need to take lead to unleash the potentials in Africa (Section V). As we work towards possible solution and implementation models in our curriculum planning (Section VI) and the detailed communication network curriculum (Section VII), we also make qualitative evaluation of our implementation experiences (Section VIII).

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II. Importance of High Speed Communication Networks

Availability of high speed networks with a large variety of powerful services is important to society. For industry and commerce, it opens up more global business and more job opportunities and is therefore important to the economic growth of the country. It affords government accessibility and the associated possibility of providing e-Government which uses Information and Communication Technologies (ICTs) to improve accessibility and distribution of the services produced for the citizens, for businesses as well as for government employees [1]. To the general public, it offers real access to a wide array of services without the need to travel long distances to reach service points.

Most high-tech jobs are performed with the use of computers connected to a high speed network. Therefore, many such jobs can be performed anywhere in the world without geographical limitations. Indeed, many companies have become global and have hired employees all over the world where the employees have high speed network access.

While ICT enables many opportunities, it in turn is enabled by high speed communication network. High speed communication networks are therefore the enabler of the enablers of the business, education, and job opportunities for every nation.

III. Opportunities for Developing Countries

The world has already been rapidly making high speed networks available everywhere. Communication networks are no longer a luxury but are essential to the economy, industry, and almost all businesses.

Many advanced countries already have high penetration of high-speed networks. High speed digital subscriber line and/or cable modem are already available to not just all corporations but almost all households in North America, Europe, and many parts of Asia.

While the first world has a substantial lead in technology, the higher costs of living of their employees in those countries have lowered the competitiveness of companies. These companies have been moving their bases to the developing countries where they can find labor with a lower cost of living.

These moves create lucrative opportunities for developing countries, especially in Africa, to boost their capacities with respect to skilled human resources and infrastructure.

Many developing countries have been aggressively building up their broadband networking capabilities. Such efforts complemented with their efforts in education to also aggressively increase high-tech expertise have enabled them to join the global high-tech workforce. With the relatively lower cost of living in developing countries, it is a golden opportunity for these countries to compete for jobs and business in the global market.

In many countries in Asia and in Eastern Europe, heavy investments have already been made in high speed network infrastructure as well as in education. These countries include China, India, Japan, Korea, Pakistan, Singapore, and most countries in Eastern Europe. Many were developing countries in the recent past. Yet they are now fast advancing in business, economy, and industry.

IV. Network Status in Africa

In Africa, the availability is uneven and skewed in favor of urban centers compared to rural areas. Some countries are also moving to the next generation broadband access such as fiber to the home or Ethernet for home users. Nevertheless, African efforts are beginning to show exciting results, according to the Internet Usage and World Population Statistics [2].

The African continent does already have the potential to network with the rest of the world. The 28,000 kilometer long South Atlantic Telecommunications Cable (SAT-3) linking Europe, Africa and the Far East was inaugurated on 27 May 2002 [3]. It has a high capacity of 120 Gbps which can support 5.8 million international phone calls or 2304 television channels. Yet sufficient internal infrastructure and expertise are needed to take advantage of such potential over the remaining twenty-two year life of the cable.

With the lack of sufficient infrastructure, only 3.2 Gbps (out of the 120 Gbps potential) was utilized in 2003, with only 1.4 Gbps between Africa and US, and 1.88 Gbps between Africa and Europe. As of the beginning of 2004, Africa (with 14% of the world's population) accounts for only 2.5% of the world's total international Internet usage. The good news however is that between 2000 and 2005, Internet penetration in Africa had grown by 429.8% compared to the world total of 169.5%, by far the fastest growth rate [2].

In South Africa, Internet users currently constitute only 9.9% of the population, which stands at 44.8 million according to the mid-year estimates from Statistics South Africa [4]. Yet this 9.9% penetration represents 20.0% of all users in Africa [2]. The country is still in need of low-cost high-speed networking capability though. The university is in a position to provide catalytic leadership and expertise, and need to strengthen its partnership with and receive strong support from the government and industry.

V. Challenges to Academic Institutions

Many companies today are global and are investing in developing countries, but are not investing as much in Africa [2]. Two major reasons are: 1) lack of network infrastructure and advanced network services, and 2) insufficient local expertise to jumpstart the industry. To ICT-enable the people and to unleash the potentials in Africa, it is necessary to build up the high-speed network capability throughout each country and to produce more people with high-tech knowledge and skills. Such opportunities are unique and must be taken advantage of, else the developing countries will continue to lag further and further behind the Digital Divide.

Universities, industries, and government must all partner together to improve the situation. In particular, academic institutions need to take important roles and need support and collaboration from all possible players.

The curricula of high-tech departments in developing countries must, therefore, seek to identify the problems associated with the emerging knowledge society and stimulate creativity in the quest for appropriate solutions along with the awareness of global investment trends in technology.

Factors contributing to the insufficiency of local expertise include emigration of skilled people soon after completing their studies, which is partly caused by the orientation of the curricula towards solution models predicated on a developed economy for their successful implementation. The newly educated practitioner quickly gets frustrated on the job and looks elsewhere for a more satisfying work environment.

Note that the more general education in engineering and science are experiencing similar problems which are studied elsewhere. However, the scope of this paper is only on the education in communication network, which is an enabling technology for many other industries to become competitive.

In particular, it is important to invest in postgraduate program which are not only effectively but also highly competitive globally in both curriculum and in research. Developing countries cannot afford to continue to lose the best university graduates who seek better postgraduate education elsewhere. Globally competitive postgraduate education must be available within these countries.

We now make the following observations to guide the design of the telecommunications curriculum within the context of the overall electrical engineering curriculum.

In terms of research, partnership with the industry and especially through the Telkom Centers of Excellence, the program has been strong in many institutions including UCT. Plenty of opportunities for research theses in ICT at both master's and doctor's degree levels have resulted. We do see, however, that there are insufficient taught postgraduate courses as there has been a tradition of pure research at this level. One may see that most institutions in Africa are lacking a strong postgraduate curriculum in communication network, as is evident from their respective websites.

The difficulties in coursework may be attributed to the following:

To train students with the best updated knowledge, one needs to include up-to-date materials in the industry as well as the cutting edge of scientific inquiry. Balancing the teaching of principles and their basis in science, with frequent reference to current practice in industry and the accurate forecasting of developmental trends is a continual challenge. The questions as to where South Africa is and where it must go with respect to global competitiveness tempered by cohesive local and national developmental strategies guide our focus at UCT. On that premise, the team then devised a communications curriculum that addresses those questions, while remaining committed to the university's overall transformation objectives.

The fields of communication networks and systems are changing very rapidly in the industry. The state-of-the-art developments in the industry are mostly not yet written into textbooks. Textbooks may lag about 5 years behind and by the time they are written, the materials will no longer be the state-of-the-art. Therefore the amount of work needed to teach the updated materials is much more.

Yet, faculty members are often evaluated more according to research outputs than on teaching outcomes. This practice curtails their motivation to develop such courses.

VI. Curriculum Planning at the University of Cape Town

A few years back, the Department of Electrical Engineering at UCT reviewed its curriculum in line with the Washington Accord, as interpreted by the Engineering Council of South Africa [5], and decided to strengthen the telecommunications option in line with its transformation objectives and in response to the developing ICT market in the country and the region. This effort coincided with the growing collaboration with the Department of Computer Science in the Faculty of Science with respect to communication networks. Thereafter, the staff in the communications field worked in consultation with our industrial partners to expand the curriculum and re-focus it on solving the problems of the continent. The focus was to be on integrating the state-of-the-art practice in industry with leading-edge research and sound engineering principles.

The resulting expanded program (Section VII) was first implemented during 2005 to 2007. Along the way, the design team intends to continue monitoring the uptake rate for the courses, the numbers of those who decide to major in communications and stay in the program till graduation, those of the latter group who proceed to do postgraduate research in ICT-related areas versus those who find employment in other fields, as well as those who desire to emigrate after graduation.

Student feedback questionnaires will be used along with secondary sources of information on the so-called "brain drain" problem with respect to the UCT graduate who majors in communication systems and networks. These questionnaires will be aligned with the City of Cape Town's Digital Divide Assessment [6] as well as various other project reports on African responses to the United Nations Millennium Development Goals [7].

Researchers in communication networks, communication systems, and speech technology in both the Department of Electrical Engineering and the Department of Computer Science are eager to leap forward. The two departments collaborate to develop and provide a more comprehensive curriculum to prepare qualified engineers as the workforce to expand the competitiveness of the industries [8].

Within the general areas of broadband communication, UCT offers both courses and research opportunities leading to masters' degrees in electrical engineering and computer science. Research in the general areas of broadband communication includes several research groups involved in data communication, telecommunication, data network architecture, wireless network, and human languages and speech technology. PhD opportunities abound in these areas. The partnership is swiftly expanding to incorporate the Centre for Higher Education and the Department of African Languages. The whole focus is on appropriate searches for Afro-centric solutions to ICT-related problems. The interdisciplinary approach engenders an ability to take cultural and linguistic factors into consideration when generating ICT solutions in the African context.

VII. Communication Network Curriculum at UCT

The curriculum consists of both postgraduate and undergraduate level courses and thesis research guided by the faculty.

The group first builds a stronger background and emphasis in communication networks beginning at the undergraduate level and provides a broader variety of courses at the postgraduate level.

A. *Background courses*

Background courses leading to communication or network include computer programming, a study of signals and systems in both a Fourier analysis course and a probability and random processes course. In these courses, the group teaches applications not only in communications but also in power and computer engineering. The Fourier analysis course is in the second year whereas the probability and random processes course is in the third year of study. Both are core requirements.

In the probability and random processes course, we challenge students to think critically, carefully, and systematically as they approach various problems in daily life, in communications, and in various other fields. They must take uncertainty and perturbation into account if their solutions are to be robust and realistic

B. Basic Communication and Network courses

Beginning in 2005, we offer the basic courses in communication systems and networks for third year undergraduate students.

The networks course covers all the 5 layers in the simplified OSI network model, following the book by Kurose and Ross, and aims to prepare students with solid foundations in computer and communication networks [9].

The communication course includes both analogue and digital communication [10]. They used to be 2 separate courses in analogue communication and digital communication, respectively. We are condensing the analogue part very much to leave plenty of room in the same course to cover the elements of digital communication.

In recent years different institutions have taken different approaches. It was conventional for UCT and for some other institutions to spend a semester in the third year in analogue communications and then spend another semester in the fourth year in digital communication. It would then leave little room for advanced topics within a four year undergraduate program.

The UCT change is based on attempts to include in the curriculum more advanced communication systems and networks courses which are lacking today, without unduly overloading the undergraduate curriculum. As newer materials are added, a need arises to remove some existing content to make room for them. An additional consideration is that most computer and communication devices used today in daily life are digital. The analogue part may therefore in principle be trimmed down to only making enough preparation to learn digital communication. After all, without much of an existing analogue infrastructure to maintain or upgrade, the graduate engineer will be designing state-of-the-art digital solutions most of the time for the local, regional and global markets.

The digital communication part follows the first few chapters of the book by Sklar [11]. This book takes quite a practical perspective appropriate to engineers in the industry and in a developing country. Using this somewhat advanced book for 3rd year student is the result of our attempt to expose students to practical issues early in their undergraduate study.

Having completed the fundamentals in the third year leaves room for advanced courses in the 4th year of the undergraduate program. These advanced courses are especially suited to those students that are keen to specialize in communications.

We are combining a couple of postgraduate courses with fourth-year undergraduate courses. Combining them this way also helps us to better manage our resources. The difference in focus comes in the associated tutorials and laboratory exercises for undergraduates and research seminars for postgraduates. For each course combination, a teaching assistant and course tutors team up with the instructor to create a stimulating and varied learning environment.

C. Advanced Communication and Network Courses

We attempt to combine the analytic strength from academia with the practical experience from industry in the advanced courses. Trying to teach materials that are currently of high interest to industry requires frequent updates in course materials entailing many tasks in the on-going course development process.

We combine the efforts from both departments to offer the following courses:

1) Wireless data networks and systems;
2) Convergent telecommunication and data networks;
3) Digital communications;
4) Network and Internet security;
5) Optical communication networks;
6) Broadband communication networks;
7) Formal methods and analysis of computer networks.

These courses are at the postgraduate level, but some of them are also open to the fourth-year undergraduates. The courses address the issues of technological convergence at appropriate points. In some courses we include plenty of up-to-date materials of high interest to the industry in South Africa and the rest of Africa in terms of global investment trends in technology. The goal is to alert the students to the myriad of opportunities looming all around them all over the continent. We skill the while showing them that they do not need to leave the continent in order to have successful careers.

VIII. Experiences at University of Cape Town

During the 2005-2006 periods, we started to deploy the above new curriculum. It is proving quite popular with both the students and the employers of the first crop of the graduates involved. The draw card is the combination of some scientific rigor and a sense of solid practical currency and relevance of the curriculum. We share our limited initial experiences below:

A. Importance of a strong curriculum to the students

We note that there are indeed strong interests in a strong curriculum. We have received many inquiries from prospective postgraduate students in this curriculum and have increased our postgraduate enrolment.

Some companies have also expressed interests in our new postgraduate courses. They view them as the relevant knowledge and training for the students who will become their prospective employees.

We hope that the attractiveness of a strong program will counteract the brain drain. Our intention is that students do not need to go abroad for proper postgraduate studies if they find a strong program is also available in their homeland.

B. Process for continuous progress

An important new element we put in is a process for students to make continuous progress. We do not believe that most students can benefit from deferring their efforts to only a period of intense study right before the final examination at the end of the semester. We believe instead that most students need to make continuous progress to learn throughout the semester.

In order to facilitate such a process, we found it necessary to make continuous assessments by spreading a number of tests throughout the semester in addition to having a final examination.

It is also helpful that the tests are not on the incremental materials taught since the previous test but rather are on all cumulative materials taught from the beginning of the course up to the material taught by that time. Tutorial problems require the student to integrate new material with skills acquired in prior learning to bring about a holistic developmental experience.

The tests also give students continuous indications on whether or not they understand the course materials. For the students, these test indicators serve to tell students what materials they need to understand better and what materials they need to get help on. For the instructors, these test indicators show how well the students are following the course. Additional tutorial and review sessions are scheduled accordingly to help especially those who would have failed to perform well in the tests.

We find this approach essential for a student who might turn out to be the only expert in her/his field involved in a given project quite early in the field. This situation is quite uncommon in developed countries in that the graduate is almost guaranteed to undergo a period of nine months to a year of training before going it alone on company projects. The Department of Electrical Engineering further makes up for this missing period of on-the-job training by compelling students to register for two periods of industrial experience as a graduation requirement.

C. Learning to think as an engineer

In the probability and random processes course, which includes communication application examples, we took an approach different from what many students expect. The course puts emphasis on how to think as opposed to how to prepare for and tackle examinations. That approach is similar to that used in courses in combinatorial mathematics, whose goal is to sharpen the process of formulating a problem and thinking out a solution process.

Many problems in the homework and in tests cannot be solved by direct application of mathematics. The questions generally do not tell or indicate what equations or formulas to use. They are practical engineering problems as well as interesting daily life problems. Students learn how to think, how to analyze the problems, as well as how to approach and formulate the problems [12]

D. Teaching advanced communication and network courses

We have developed 2 new courses in the first semester of 2005 and one new course in the second semester. The two new first semester courses are the Wireless data networks and systems course and the Convergent telecommunication and data networks, both outlined in the appendix. The new second semester course is broadband communication networks.

It had taken an enormous amount of effort to develop the course materials, and we anticipate it will take a heavy load again to update the course materials each year we teach this course.

While students are learning a lot of new material, many do find difficulty in studying without a textbook. It was not easy for most of them to search for reading materials on their own. We then find it necessary to compile reference materials to help them study. After all, many students are finding the course materials very interesting and many have been motivated by the experience to take thesis research in these fields.

In 2006, we also begin a course in digital communication with emphasis on fundamental understanding and use in the industry. It also follows the practical approach by Sklar [9], which is quite different from most other books that contain a large amount of mathematics typical in the academia. It is hoped to help students more on basic understanding. Yet for those students interested in research, they may optionally use a different textbook with more mathematical vigor to prepare them towards research.

The rest of the advanced communication and network courses from the list in Section 8.3 complement the above courses to add more breadth to the curriculum.

IX. Conclusions

With largely insufficient network infrastructure and lack of expertise, Africa is much in need in both areas. This need is made even more acute by the increase in investor interest in the expanding mobile and satellite communication systems development on the continent. A university with adequate, appropriate effort and support may take the lead to address these problems by providing a timely curriculum backed by appropriate research. At UCT, we have implemented a new curriculum to combine the strength of the global telecommunications industry with the analytical strength of academia. Preliminary efforts show that much more work needs to be done as the program unfolds. We look forward to exploring opportunities for collaboration and wining additional support from interested parties.

We recommend that other institutions with communication systems and networks programs on the continent re-examine their curricula, if they have not yet done so. This recommendation is prompted by the need to address the rapid wave of convergence and thus bridge the digital divide and provide skilled engineers for Africa. There is a twin need to prepare students for technical positions without the backup of vast corporate experience such as that enjoyed by their counterparts in developed economies. It can be met through exposing students to industrial experience while they are still doing undergraduate studies, as well as combining academic rigor in class with practical insight in tutorials into what is happening in the field all around.

APPENDIX

The contents of the postgraduate courses in communication and network are outlined below.

A. *Wireless data networks and systems course [13]*

This course is newly developed in 2005 and consists of 24 lectures spread over 13 weeks on the following topics:

Wireless network technology: wireless applications, wireless links, mobility in different wireless systems, wireless security. Network architecture, components, protocols, and standards in the GSM and General Packet Radio Service 2.5G Wireless, 3G Wireless including 3GPP and 3GPP2, 3.5G/4G Wireless, Wireless LAN, Wireless MAN, Bluetooth, ad hoc networks, inter-working.

B. *Convergent telecommunication and data networks course [14]*

This course is newly developed in 2005 and consists of 24 lectures spread over 13 weeks on the following topics:

1) Network Convergence: Network trends, evolution, and markets.
2) Internetworking: Hierarchical TDM networks, Internet, LAN/SOHO and access networks, WAN and core networks, and API.
3) Services and applications requirements: QoS, service platform, AAA, VoIP.
4) Next generation networks: Multi-service platform, soft-switch.
5) Data plane technology: Multiplexing, Routing, MPLS, Switching, Timing, RTP.
6) Control plane technology: Signaling, call setup, and connection controls (SS7, H.323, SIP, MGCP).
7) Applications: Telephony, packet voice, streaming.

There is also emphasis on convergence issues and experiences, in comparison and contrast to traditional voice and data communication networks.

C. *Digital Communication course*

This course is newly developed in 2006 and consists of 48 lectures spread over 13 weeks on the following topics:

1) Introduction: digital communication systems, wireless links and media, optical links and media.
2) Propagation: radio wave propagation, antenna gain, channel characteristics, multipath fading and signal modeling, Fresnel zones, link budgeting, instrumentation and measurements, delay spread measurements.
3) Modulation-Demodulation Methods: Advances in baseband and bandpass digital modulation, MODEM architectures and performance, noise and interference, modem performance for coherent and non-coherent systems without coding, multilevel modems, adaptive equalization, synchronization.
4) Error Control Coding: the error control problem, interleaving, block coding, convolutional coding, advanced error control coding, effects of coding on throughput, automatic repeat request; trade-offs between modulation and coding.
5) Spread-Spectrum Systems: elements of spread-spectrum systems, pseudo-noise sequences, direct sequence spread-spectrum system performance, direct sequence and frequency hopping code division multiple access, synchronization, applications, detection and estimation.
6) Diversity Techniques: diversity branch and signal paths, techniques for combining and switching, antenna diversity and space-time coding, performance improvement.
7) Optical Communication Systems: optical fibre fundamentals, modulation schemes, line codes, wavelength division multiplexing.
8) Systems Engineering: concepts, access schemes, performance comparison of advanced modulation techniques, radio link design, spectrum utilization, capacity and throughput, digital wireless personal communications.

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