TELE9757
Quantum Communications

Course Outline – Semester 1, 2019

Never Stand Still | Faculty of Engineering | School of Electrical Engineering and Telecommunications

Course Staff

Course Convener: A/Prof Robert Malaney, Room 747 E10, r.malaney@unsw.edu.au

Consultations: You are encouraged to ask questions on the course material, after the lecture class times in the first instance, rather than via email. Lecturer consultation times will be advised during lectures. ALL email enquiries should be made from your student email address with TELE9757 in the subject line, otherwise they will not be considered. Technical questions by email are encouraged but will not be answered by email. Rather they will be answered and/or discussed at the next class.

Keeping Informed: Announcements may also be made during classes, via email (to your student email address) and/or via online learning, class website, and teaching platforms – in this course, we will use Moodle to post marks https://moodle.telt.unsw.edu.au/login/index.php. Please check the class web site prior to sending a general administrative email as this website is updated weekly and important administrative matters will be posted there (https://subjects.ee.unsw.edu.au/tele9757).

Course Summary

Contact Hours

The course consists of 3 hours of lectures.

Lectures	Day	Time	Location
	Tuesday	6pm - 9pm	Webster Theatre B (K-G15-290)

Context and Aims

The main aim of this course is to develop amongst students from different backgrounds a solid understanding of the key concepts and principles that underpin the emerging and exciting new world of quantum communications. The course is particularly aimed at Graduate Engineers and Physicists wishing to understand Quantum Communications. Quantum Communications and Quantum Networks are anticipated to be the core networking technologies of the 21st century. In fact these communication systems have already appeared in the commercial world in many variations. The course introduces the key concepts important for understanding, testing, analyzing and improving the performance of quantum communication networks. It will have particular focus on actual quantum networks currently being deployed and the use of such networks for secure information transfer. Designed from an engineering perspective the course will first introduce the basic quantum physics that underlies quantum communication principles. It will then introduce and explore the key concepts that drive quantum communications.

Indicative Lecture Schedule

Period	Summary of Lecture Program
Week 1	**Introductory Lecture** - Who wants to be a "Quantum Engineer"? Why study Quantum Communications and Quantum networks? What's wrong with classical networks? What Quantum physics will we cover in the course? What "real engineers" are now building? Overview of current Quantum networks both deployed commercially and those currently in prototype.
Week 2	**Photon Polarization -** Maxwell's equations revisited**.** Applications of polarization in Quantum Networks. **General Quantum Variables and Qubits** - Applications of quantum variables in Quantum Networks
Week 3	**Composite Quantum Systems** - Applications of quantum systems in Quantum Networks.
Week 4	**Quantum Entanglement**. Why Einstein was wrong and right at same time. Why entanglement important for Quantum Communications. **Quantum Teleportation** - An application of composite qubits and entanglement
Week 5	**Experimental Quantum Teleportation of Qubits** - Engineering sources of Entangled Photons. Why is this hard? **The No Cloning Theorem** - Copying classical information is easy, but try copying quantum information.
Week 6	Review of the story so far. **Mid-session test**
Week 7	**Review of Classical Cryptography -** Algorithms and why classical encryption is defeated by Quantum Computers. **Quantum Cryptography**. The Bennett-Brassard Protocol for Quantum key distribution. Eckert's Protocol for Quantum key distribution using entanglement.
Video Lecture	**Review of Classical Error Correcting Codes -**Hamming distance, Linear Codes, Generator Matrices, and all that jazz.
Week 9	**Error Corrections for Quantum Keys.** Error correcting codes once quantum physics is thrown in.
Week 10	**Privacy Amplification.** Why error correction leaks information to a potential adversary and how to combat this with privacy amplification.
Video Lecture	**Moving from Qubits to Lasers** - Continuous variable quantum communications – an overview.

Assessment

Mid-Semester Exam	20%

Assignment	20%
Final Exam (2 hours)	60%

Course Details

Credits

This is a 6 UoC course and the expected workload is 10–12 hours per week throughout the 13 week semester.

Relationship to Other Courses

This is an elective postgraduate course in the School of Electrical Engineering and Telecommunications.

Pre-requisites and Assumed Knowledge

There are no perquisites for this course. It is assumed that all students have qualifications equivalent to an Electrical Engineering undergraduate degree from UNSW.

Following Courses

The course is a not pre-requisite for any other course.

Learning outcomes

After successful completion of this course, you should be able to:

1. Understand the theory, concepts and challenges of quantum mechanics as applied to communications.
2. Understand the theory, concepts and challenges of transferring quantum information over a network.
3. Understand how applications actually operate over quantum a communication channel.
4. Understand why quantum communications is a vital new technology that will only grow in importance within the engineering world.
5. Understand and participate in discussions on the underlying principles of quantum networks.
   Be able to design and simulate the behavior of quantum networks.
6. Be able to carry out calculations which determine the performance of a quantum network.
7. Be able to read and understand quantum communication research papers appearing in engineering journals.

This course is designed to provide the above learning outcomes which arise from targeted graduate capabilities listed in ***Appendix A***. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate capabilities (listed in ***Appendix B***). This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in ***Appendix C***.

Syllabus

Designed from an engineering perspective the course will first introduce the basic quantum physics that underlies quantum communication principles. It will then introduce and explore the key concepts that drive quantum communications such as Quantum Entanglement, Quantum Teleportation, The No Cloning Theorem, Quantum Cryptography; Privacy Amplification and Error Correction for Quantum Keys.

Teaching Strategies

Delivery Mode

The teaching in this course aims at establishing a good fundamental understanding of the areas covered using:

- Formal face-to-face lectures, which provide you with a focus on the core analytical material in the course, together with qualitative, alternative explanations to aid your understanding;
- Tutorials (during regular class), which allow for exercises in problem solving and allow time for you to resolve problems in understanding of lecture material;

Learning in this course

You are expected to attend <u>all</u> lectures and mid-semester exams in order to maximise learning. You must prepare well for your laboratory classes and your lab work will be assessed. In addition to the lecture notes/video, you should read relevant sections of the recommended text. Reading additional texts will further enhance your learning experience. Group learning is also encouraged. UNSW *assumes* that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

Class attendance is especially important for this class as you will be presented with brand new concepts that you have likely never come across before. This makes the class very interesting for you – but it does require your participation in class. There will be no formal notes handed out that covers all the class material in detail, There will be power-points put on the class web site for download but these will not be sufficient for you to cover the class material. The lectures will consist of some power-point presentations, discussion of material in prescribed texts, and discussion of case studies. You are strongly encouraged to participate in class by interacting through questions and discussions of class material, and to prepare before class by reading relevant work packages ahead of time. There will be plenty of problem sets that will be reviewed in class.

Tutorials

Each week we will go over a short tutorial problem set. Some of the tutorial set may be given to you during the class and worked on during the same class. Others may be done in class one week after being released. These tutorials are not compulsory, will not be marked and do not form any part of the final class mark. **You are strongly encouraged to attempt these tutorials - if you do not you will likely struggle in this class**.

Assessment (details)

- **Final Examination (60%):** The examination is of two-hour duration, covering all aspects of the course that have been presented in lectures. This exam will assess both understanding and analytical skills. You must pass this exam to pass course.

- **Mid-Session Test (20%):** The mid-session test will last about 45 minutes and will be held in week 6. It will cover material covered in the course in week 1 to 5, and will test your conceptual understanding of this material, as well as your ability to apply the concepts to solving problems. This is a compulsory test.
- **Class Assignment (20%):** Student groups (maximum three) will be charged with reviewing a research paper chosen from a list (to be given in class), or choosing a substantial simulation project which covers some aspects of the class work (this substantial simulation needs to be agreed to by me). This assignment is related to the learning outcome of being able to comprehend current research papers in the area. A formal 10 page report on the research paper or the simulation will be required by week 11. The assignment will be marked on the following criteria; Presentation (15%) depth of technical content (30%), independent critical thinking (40%). technical writing (15%). Students may do both a review of a paper and add some small Matlab simulation related to that paper (generally reviews that include a small Matlab simulation obtain higher marks).The students may present a power-point presentation on his/her report (although encouraged to do so the presentation is optional). The assignment will be due by end of week 11 – delivery will be electronic. Each member of the group should be prepared for oral examination by me on any part of the report. Individual marks may be given for the assignment.
- **Bonus Marks**. A few bonus marks may be available for additional class participation – details in class. Note the combined bonus marks for any student will not exceed 5% of final class mark.
- **Late reports and missed tests.** There will be zero marks awarded for late reports, or missed tests.

Final Exam

The exam in this course is a standard closed-book 2 hour written examination, comprising five compulsory questions. Calculators are not allowed. The examination tests analytical and critical thinking and general understanding of the course material in a controlled fashion. Questions may be drawn from any aspect of the course unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses. *Please note that you must pass the final exam in order to pass the course.*

Relationship of Assessment Methods to Learning Outcomes

	Learning outcomes						
Assessment	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Mid-semester exam	✓	✓	✓	-	-	✓	✓
Assignment	-	-	-	✓	✓	-	✓
Final exam	✓	✓	✓	-	-	✓	-

Course Resources

Textbooks

Prescribed textbook

Protecting Information: From Classical Error Correction to Quantum Cryptography, S. Loepp & W. K. Wooters, Cambridge Press, 2006

Reference books

- Quantum Computation and Quantum Information, M. Nielsen and I. L. Chuang, Cambridge Press, 2006.

On-line resources

Moodle

As a part of the teaching component, Moodle will be used to disseminate teaching materials, host forums and occasionally quizzes. Assessment marks will also be made available via Moodle: https://moodle.telt.unsw.edu.au/login/index.php.

Mailing list

Announcements concerning course information will be given in the lectures and/or on Moodle and/or via email (which will be sent to your student email address).

Other Matters

Academic Honesty and Plagiarism

Plagiarism is the unacknowledged use of other people's work, including the copying of assignment works and laboratory results from other students. Plagiarism is considered a form of academic misconduct, and the University has very strict rules that include some severe penalties. For UNSW policies, penalties and information to help you avoid plagiarism, see https://student.unsw.edu.au/plagiarism. To find out if you understand plagiarism correctly, try this short quiz: https://student.unsw.edu.au/plagiarism-quiz.

Student Responsibilities and Conduct

Students are expected to be familiar with and adhere to all UNSW policies (see https://student.unsw.edu.au/guide), and particular attention is drawn to the following:

Workload

It is expected that you will spend at least **ten to twelve hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both face-to-face classes and *independent, self-directed study*. In periods where you need to need to complete assignments or prepare for examinations, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

General Conduct and Behaviour

Consideration and respect for the needs of your fellow students and teaching staff is an expectation. Conduct which unduly disrupts or interferes with a class is not acceptable and students may be asked to leave the class.

Work Health and Safety

UNSW policy requires each person to work safely and responsibly, in order to avoid personal injury and to protect the safety of others.

Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. As of Term 1 2019, assessment of applications for Special Consideration will be managed centrally and the University has introduced a “fit to sit/submit” rule. You will no longer be required to take your original documentation to The Nucleus for verification. Instead, UNSW will conduct source checks on documentation for verification purposes. You can apply for special consideration when illness or other circumstances beyond your control interfere with an assessment performance. If you need to submit an application for special consideration for an exam or assessment, you must submit the application **prior to the start** of the exam or before the assessment is submitted, except where illness or misadventure prevent you from doing so. If you sit an exam or submit an assignment, you are declaring yourself well enough to do so.

Continual Course Improvement

This course is under constant revision in order to improve the learning outcomes for all students. Please forward any feedback (positive or negative) on the course to the course convener or via the via the myExperience process. You can also provide feedback to ELSOC who will raise your concerns at student focus group meetings. As a result of previous feedback obtained for this course and in our efforts to provide a rich and meaningful learning experience, we have continued to evaluate and modify our delivery and assessment methods.
Based on feedback from previous year, additional in class tutorial material has been added to this years course.

Administrative Matters

On issues and procedures regarding such matters as special needs, equity and diversity, occupational health and safety, enrolment, rights, and general expectations of students, please refer to the School and UNSW policies:
http://www.engineering.unsw.edu.au/electrical-engineering/policies-and-procedures
https://my.unsw.edu.au/student/atoz/ABC.html

Appendix A: Targeted Graduate Capabilities

Electrical Engineering and Telecommunications programs are designed to address the following targeted capabilities which were developed by the school in conjunction with the requirements of professional and industry bodies:

- The ability to apply knowledge of basic science and fundamental technologies;
- The skills to communicate effectively, not only with engineers but also with the wider community;
- The capability to undertake challenging analysis and design problems and find optimal solutions;

- Expertise in decomposing a problem into its constituent parts, and in defining the scope of each part;
- A working knowledge of how to locate required information and use information resources to their maximum advantage;
- Proficiency in developing and implementing project plans, investigating alternative solutions, and critically evaluating differing strategies;
- An understanding of the social, cultural and global responsibilities of the professional engineer;
- The ability to work effectively as an individual or in a team;
- An understanding of professional and ethical responsibilities;
- The ability to engage in lifelong independent and reflective learning.

Appendix B: UNSW Graduate Capabilities

The course delivery methods and course content directly or indirectly addresses a number of core UNSW graduate capabilities, as follows

- Developing scholars who have a deep understanding of their discipline, through lectures and solution of analytical problems in tutorials and assessed by assignments and written examinations.
- Developing rigorous analysis, critique, and reflection, and ability to apply knowledge and skills to solving problems. These will be achieved by the laboratory experiments and interactive checkpoint assessments and lab exams during the labs.
- Developing digital and information literacy and lifelong learning skills through assignment work.
- Developing independent, self-directed professionals who are enterprising, innovative, creative and responsive to change, through challenging design and project tasks.

Appendix C: Engineers Australia (EA) Professional Engineer Competency Standard

	Program Intended Learning Outcomes	
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	✓
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	✓
	PE1.3 In-depth understanding of specialist bodies of knowledge	✓
	PE1.4 Discernment of knowledge development and research directions	✓
	PE1.5 Knowledge of engineering design practice	✓
	PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice	

PE2: Engineering Application Ability	PE2.1 Application of established engineering methods to complex problem solving	✓
	PE2.2 Fluent application of engineering techniques, tools and resources	✓
	PE2.3 Application of systematic engineering synthesis and design processes	
	PE2.4 Application of systematic approaches to the conduct and management of engineering projects	
PE3: Professional and Personal Attributes	PE3.1 Ethical conduct and professional accountability	
	PE3.2 Effective oral and written communication (professional and lay domains)	✓
	PE3.3 Creative, innovative and pro-active demeanour	✓
	PE3.4 Professional use and management of information	✓
	PE3.5 Orderly management of self, and professional conduct	
	PE3.6 Effective team membership and team leadership	✓