



5G 与无线通讯技术

5G and Wireless Communication Technology

#1. 课程背景及简介



通信工程是一门以电气和计算机工程为核心的交叉工程学科,其关注的是通信过程中的信息传输和信号处理的原理和应用,旨在支持和加强电信系统。通信工程的基础建立于应用数学中的数理方程,研究范围从基本的电路设计到战略性质的大规模设备研究与部署。通信工程师还需要提供围绕无线通信和信息传输模式的解决方案,例如无线电话服务,无线电和卫星通信以及互联网和宽带技术。

无线通信是利用电磁波信号可以在自由空间中传播的特性进行信息交换的一种通信方式,近些年信息通信在领域中发展最快、应用最广的就是无线通信技术。在过去的几十年里,无线移动通信取得了诸多进展,如多输入多输出系统、多用户多输入多输出系统、网络多输入多输出系统、大规模多输入多输出系统、全双工无线电、非正交多址接入通信等。一些技术已经在蜂窝系统中实现,如LTE/LTE- A 和5G,而其它技术也有着超越5G的趋势。

本课程的主要目标是使学生们理解无线通信技术的基本原理,并探究与多输入多输出系统相关无线通信技术、空时编码、BLAST 架构、预编码技术和其它相关的理论。让学生对单用户、多用户、多载波通信、单蜂窝和多蜂窝(包括新兴的小蜂窝体系结构)以及自组网有清晰的认知。在理论基础的支持下,教授将带领学生们探索先进的移动通信技术,如大规模多输入多输出系统(MIMO)、非正交多址(NOMA)通信、全双工无线电和物联网(IoT)。同学们也将在授课内容中学习最新通信和信号处理技术的前沿实践经验。

#2. 学习目标



本课程将解决许多挑战,如:

- ★ 如何建模无线信道?
- ★ 如何解决无线通信的挑战?
- ★ 如何调和衰落,同信道干扰和噪声?
- ★ 如何利用空间、时间、频率等无线资源?
- ★ 如何计算不同无线场景下的信道容量?
- ★ 如何提升现有ITE网络和5G网络?
- ★ 如何设计强大的未来无线网络?

#3. 任课教师信息



Prof. T R

教授目前就职于英国爱丁堡大学数字通信研究所,于2016年到2018年担任



数字通信研究所所长，指导了 15 名博士生和 20 名博士后，并为研究所筹集到 1100 万美元的研究资金。教授作为国际知名学者一直活跃于无线通信，信号处理，信息理论和随机矩阵理论研究领域，受到 400 余篇同行评审论文的认可并获得四项美国国家专利。近些年来，他的论文被引用 6000 余次。教授还担任欧盟 ADEL 的项目协调员，《IEEE 信号处理学报》（世界上最大的非营利性专业技术学会）的副主编，第 17 届 IEEE 无线通信国际研讨会技术联席主席，美国数学学会和信息理论学会会员，以及高等教育学院（FHEA）院士。

#4.课程设置



周期	时间	课程设置内容	课时
第一周 学习指南 教授及助教辅导	7 月 18 日 周一	什么是 PBL 教学方法	1
	7 月 19 日 周二	PBL 教学的常见形式	1
	7 月 20 日 周三	教授课-1 交叉学科PBL 课程设计及知识点学习 学习目标：无线多径信道建模，包括大规模衰落，小规模多径衰落 描述：同学们将深入学习物理参数(如载波频率、移动速度、带宽、延迟扩展和角扩展)如何从通信系统的角度影响无线信道的行为。教授将带领同学们从确定性的物理模型入手，逐步过渡到统计模型的学习。本模块内容对于设计和性能的评估有很大价值。	3
	7 月 22 日 周五	助教课-1 知识点查漏补缺	2
	7 月 23 日 周六	教授课-2 制定小组项目方向 学习目标：点对点通信-检测，多样性和信道不确定性 描述：通过探究，同学们将发现在平坦衰落信道上的通信由于信道处于深度衰落的显著概率而具有较差的性能。可靠性可以通过	3

		提供更多的可分辨信号路径来提高。多样性可以跨越时间、频率和空间提供。在本模块中，教授也将讲解如何以一种有效的方式利用增加的多样性。	
第二周 教授及助教辅导	7 月 25 日 周一	助教课-2 知识点查漏补缺	2
	7 月 26 日 周二	教授课-3 交叉学科课程知识点学习 学习目标：蜂窝系统-多路访问和干扰管理 描述：在蜂窝系统中，最重要的问题是：多路访问和小区间干扰管理。本节课将详细研究这些主题，并考虑实际的 LTE, LTE-A 和 5G NR 应用场景。	3
	7 月 27 日 周三	助教课-3 知识点查漏补缺& 跟进小组项目调研进度	2
	7 月 29 日 周五	教授课-4 互动与项目设计跟进答疑	1.5
	7 月 30 日 周六	助教课-4 跟进小组项目调研进度	2
	7 月 31 日 周日	教授课-5 交叉学科课程知识点学习 学习目标：无线信道容量 描述：信息理论为编码性能提供了基本的限制，简明地确定了信道资源对性能的影响，并提出了通过无线信道进行通信的新方法，为无线通信的现代发展提供了基础。	2
第三周	8 月 2 日 周二	助教课-5 跟进小组项目调研进度	2
	8 月 3 日 周三	教授课-6 交叉学科课程知识点学习 学习目标：容量和多路复用架构；分集复用权衡和通用空时码；多用户通信；大规模多输入多输出 描述：单输入多输出（SIMO）和多输入单输出（MISO）通道提供了多样性和功率增益，却没有自	2

教授及助教辅导 未来展望		由度 (D.o.f) 增益。自由度增益在高 SNR 方案中最有用。多输入多输出信道具有提供自由度增益的潜力。基于此，同学们将了解自由度增益如何被物理环境所影响，并通过统计模型简洁地捕获属性，还将学习 V-BLAST 和 D-BLAST 架构，以及其它接收器信号处理技术，例如 ZF, MMSE, 连续干扰消除等。教授还将和同学们一起研究 5G NR 标准和 5G 大规模 MIMO 基站以及 UE 信号处理等内容。	
	8 月 5 日 周五	助教课-6 知识点查漏补缺& 指导小组项目成果展示	2
	8 月 6 日 周六	教授课-7 教授点评小组项目成果	1.5
	8 月 7 日 周日	升学与就业方向展望 个人规划及发展建议	1 1
总课时	32		

#5. 阅读材料

PBL

- ★ David Tse and Pramod Viswanath, Fundamentals of Wireless Communication, Cambridge University Press, 2005.
- ★ Internet of Things (IoT) in 5G Mobile Technologies Constandinos X. Mavromoustakis, George Mastorakis, Jordi Mongay Batalla
- ★ 5G Mobile and Wireless Communications Technology Afif Osseiran, Jose F. Monserrat, Patrick Marsch

#6. 项目主题

PBL

本课程使用 PBL 教学法，PBL 即项目式学习，是一种以学生为中心的教学方法，教师提供关键素材构建学习环境，学生组建团队通过在此环境里解决一个开放式项目的经历来学习。以下为本课程可选的项目主题：

- 5G NR 小区搜索技术
- 大规模 MIMO 网络的性能分析
- 预编码技术的性能分析



- 无线接收机信号处理分析
- 无线网络容量分析

英文版教学大纲



Course Title	5G and Wireless Communication Technology
Credit Hours	32 (one credit hour is 45 minutes)
Course Objectives	<p>This class will address many challenges such as:</p> <p>How to model the wireless channels?</p> <p>How to address the challenges in wireless communications?</p> <p>How to mediate fading, co-channel interference, and noise?</p> <p>How to leverage wireless resources such as space, time and frequency, etc.?</p> <p>How to work compute the channel capacity in different wireless scenarios?</p> <p>How to enhance the current LTE-advanced and 5G networks?</p> <p>How to design robust future wireless networks?</p>
Course Description	<p>The primary objectives of the course are as follows. Exposing participants to the fundamentals of wireless communication techniques. Providing a deep understanding of wireless communication techniques associated with MIMO communications systems, space-time coding, BLAST architectures, precoding technique, and related information-theoretic capacity limits. Providing the students with a clear idea of single- user, multi-user, and multicarrier communications, single and multi-cell (including the emerging small cell architectures), and ad-hoc networks. Exposing the students to advance mobile communication techniques such as massive MIMO, non-orthogonal multiple access (NOMA) communications, full-duplex radio,</p>

	and the Internet of Things (IoT). Providing hands-on experience on the latest communication (LTE, massive MIMO) and signal processing techniques through labs and tutorials.
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The topic in the global context

This course takes a unified view of the fundamentals of wireless communication and the recent developments and explains the concepts underpinning these advances at a level accessible to an audience with a basic background in digital communications.

Brief introduction of the course

The few past decades have seen many advances in wireless communication theory such as multiple-input multiple-output (MIMO), multi-user MIMO, Network MIMO, massive MIMO, full-duplex radio, NOMA communications, etc., have recently gained considerable research attention. While some of the technologies have been implemented in cellular systems such as LTE/LTE-A and 5G, others are being considered for beyond 5G. This course takes a unified view of the fundamentals of wireless communication and the recent developments and explains the concepts underpinning these advances at a level accessible to an audience with a basic background in digital communications.

This course will cover the current topics of interest in Advanced Wireless Communications.

- 1.The wireless channel
 - 2.Point-to-point communication: detection, diversity, and channel uncertainty
 - 3.Cellular systems: multiple access and interference management
 - 4.Capacity of wireless channels
 - 5.Multiuser capacity and opportunistic communication
 - 6.MIMO I: capacity and multiplexing architectures
 - 7.MIMO II: diversity-multiplexing trade-off and universal space-time codes
 - 8.MIMO III: Multi-user communications
 - 9.Massive MIMO
- Practical examples of the above concepts are presented throughout the course.

	Topics
Module 1	Objective: The wireless channel Description: Wireless multipath channel modeling, including



	<p>largescale fading, small-scale multipath fading. A detailed study on how physical parameters such as carrier frequency, mobile speed, bandwidth, delay spread, and angular spread impact how a wireless channel behaves from the communication system point of view.</p> <p>We start with a deterministic physical model and progress towards statistical models, which are more useful for design and performance evaluation.</p>
Module 2	<p>Objective: Point-to-point communication: detection, diversity, and channel uncertainty</p> <p>Description: We study that communication over a flat fading channel has poor performance due to the significant probability that channel is in a deep fade. Reliability is increased by providing more resolvable signal paths that fade independently. Diversity can be provided across time, frequency and space. Name of the game is how to exploit the added diversity in an efficient manner.</p>
Module 3	<p>Objective: Cellular systems: multiple access and interference management</p> <p>Description: So far we have focused on point-to-point communication. In a cellular system, additional issues come to the forefront: Multiple access and inter-cell interference management. We will study these topics in detail and consider practical LTE, LTE-A and 5G NR scenarios.</p>
Module 4	<p>Objective: Capacity of wireless channels</p> <p>Description: So far we have only looked at specific communication schemes. Here we study information theory, which provides a fundamental limit to (coded) performance. It succinctly identifies the impact of channel resources on performance as well as suggests new and cool ways to communicate over the wireless channel. It provides the basis for the modern development of wireless communication.</p>
Module 5	<p>Objective: MIMO I: capacity and multiplexing architectures</p> <p>Description: So far we have only considered single-input multi-output (SIMO) and multi-input single-output (MISO) channels. They provide diversity and power gains but no degree-of-freedom (d.o.f.) gain. D.o.f gain is most useful in the high SNR regime. MIMO channels have the potential to provide d.o.f gain. We would like to understand how the d.o.f gain depends on the physical environment and come up with</p>

	statistical models that capture the properties succinctly. Here we consider V-BLAST and D-BLAST architecture, and other receiver signal processing techniques, such as ZF, MMSE, successive interference cancellation, etc.
Module 6	Objective: MIMO II: diversity-multiplexing trade-off and universal space-time codes Description: Here we study the diversity-multiplexing trade-off and universal space-time codes
Module 7	Objective: MIMO III: Multi-user communications Description: Here we study pre-coding techniques such as zero-forcing, regularized zero-forcing, single and multi-cell MMSE, etc.
Module 8	Objective: Massive MIMO Description: Here we study the 5G NR standard and 5G massive MIMO base station and UE signal processing, etc.

Required Readings

David Tse and Pramod Viswanath, Fundamentals of Wireless Communication, Cambridge University Press, 2005.

Suggested list of the topics for the final project

- 1.5G NR cell search techniques
- 2.Performance analysis of massive MIMO networks
- 3.Performance analysis of pre-coding techniques
- 4.Analysis of wireless receiver signal processing
- 5.Capacity analysis of wireless networks

Criteria

Using mathematical modelling and Matlab programs
Theoretical analysis

Class Expectation

The students will understand fundamentals as well as advanced concepts in wireless communications. They will be able to understand the wireless channel characteristics and modeling; wireless communication concepts and techniques; and application of these concepts in a cellular system context. They will be able to learn the recent developments such as opportunistic and multiple-input multiple-output (MIMO) communication techniques. These techniques have brought completely new perspectives on how to communicate over wireless channels. They will be able to quantify the wireless



channel capacities and degrees of freedom regions for different channel models, such as point-to-point channels, multiple access channels, broadcast channels, interference channels, etc. Finally, they will be able to design and analyze the cellular systems, for example, interim of spectral and energy efficiencies, coverage, etc., and advanced topics mentioned above. This course very useful if you are seeking high study in signal processing and wireless communications, or jobs in wireless industry, such as Huawei, China mobile, etc.