BITS-Pilani, Hyderabad Campus
First Semester 2020-2021

Course Handout

Date: 12/08/2020

In addition to Part I (General Handout for all courses appended to the Timetable) this portion gives further specific details regarding the course.

Course Number : EEE G641 3 2 5
Course Title : Applied Estimation Theory
Course Coordinator : Dr. PRASHANT K WALI.

Review of random processes, linear algebra and matrix theory, ML phase and timing estimation in digital communication, Scalar estimation, estimation in real and complex vector space, Study of performance degradation due to estimation errors, Frequency diversity and equalization, Study of MLSE for equalization, Estimation of Single Input-Single Output (SISO) channel to very complex Multi Input-Multi Output (MIMO) channels, study of different estimators such as MMSE, linear
MMSE, orthogonal frequency division multiplexing (OFDM) basics, OFDM channel estimation, Channel quality estimation, Impact of channel estimation errors on performance, Introduction to WLAN standards, IEEE 802.11n, channel estimation, MATLAB experiments and projects

1. Course Description

The course starts with a brief overview of the following mathematical tools:

i) Probability, random variables (real and complex), random processes,
ii) Linear algebra and matrices

It then focusses on the fundamentals of estimation in additive white Gaussian noise (AWGN). We will cover the Maximum Likelihood Estimation concepts for both scalar and vector complex parameters, and the error associated with MLE. We derive Cramer Rao Bound to for parameter estimation. The concepts learnt will be applied to the channel estimation problems in a fading wireless channel for both SISO and MIMO cases. Then we will cover OFDM and channel estimation in OFDM, MLSE estimation and its application. Then the course covers the Bayesian Estimation framework and looks at MMSE estimation concepts and its applications to wireless fading channel. We will also briefly spend time understanding the wireless channel model in order to motivate the channel estimation problems.

The course has take-home lab assignments as well. It includes experiments on the review of probability, random variables, and, random processes, different types of estimation algorithms and their application in wireless/mobile communications.
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2. Scope and Objective of the Course:

Estimation theory is applied in various communication systems. The course mainly covers estimation techniques for different channels, namely, additive white Gaussian channels (AWGN), fading channel, and, OFDM channels. This course serves as a precious tool to learn

several advanced courses on communications such as MIMO wireless communication, advanced satellite communication, Adaptive signal processing and filter theory for advanced communication systems.
Expected outcomes of this course and manifold. Estimation is a fundamental tool to solve estimation problems arise in different modern communication systems. After the completion of the course, students gain conceptual knowledge and will be able to apply this powerful tool in their projects on communication and control. Some specific areas that involve application of estimation are MIMO wireless systems, MIMO-OFDM systems, wireless LANS, UWB communication systems, and many other fields.

iii) Text Books:

1. Probability Theory and Random Processes with Applications to Signal Processing and Communications by Scott Miller and David Childers, Elsevier.
2. Linear Algebra by Gilbert Strang.
3. Fundamentals of statistical signal processing, volume-I: estimation by S.M.Kay, Prentice-Hall
4. Wireless communications by Andrea Goldsmith, Cambridge university press, 2009.
5. Fundamentals of wireless communication, David Tse & Pramod Viswanath, Cambridge university press, 2006.
6. LTE-The UMTS Long Term Evolution, From Theory to Practice, Stefan Sesia, et.al, Wiley.

iv) Reference Books:

1. Probability, random variables, and stochastic processes, A. Papoulis, Mcgraw-Hill, 3rd Edition, 1991.
2. Decision and Estimation Theory, by James L. Melsa, David L. Cohn, McGraw-Hill book company.
3. Wireless communication, by Andreas.F.Molisch, Wiley, 2nd Edition.
4. LTE for 4G Mobile Broadband, Farooq Khan, Cambridge University Press
5. OFDM Baseband Receiver Design for Wireless Communications, Tzi-Dar Chiueh and Pei Yun Tsai, John Wiley and Sons.
6. Research Publications.

v) Course Plan / Schedule:

Sl. #	Learning objectives	Topics to be covered	Source	No. of lectures
1.	Review of Wireless Channel Behavior	Wireless Channel Modeling, Fading, Coherence Time, Coherence Bandwidth, Delay Spread, Doppler Spread.	T4/T5	3
2.	The Problem of Channel Estimation in 4G LTE Networks	LTE Physical Layer Frame Format, Time Frequency Grid, OFDM in LTE, Reference Signals and Channel Estimation, Channel Quality Indicator (CQI), CQI based Multi User Opportunistic Scheduling	T6/R4/R5/R6	3
3.	Introduction to the theory of	The mathematical estimation	T3	1

	Estimation	problem, Assessing Estimator Performance		
4.	Mathematical Prerequisites for the study of Estimation Theory	Review of linear algebra: Inverse, Pseudo Inverse, Eigen Values, Eigen Vector. Review of probability theory: Probability space, axioms, events, random variables, random processes.	T1/T2/R 1	3
5.	Minimum Variance Unbiased Estimator (MVUE) and Cramer Rao Lower Bound (CRLB)	Unbiased Criterion, Minimum Variance Criterion, existence and finding, CRLB, Fisher Information	T3	3
6.	Linear Models	Linear Model Definition and Properties, Examples.	T3/T4/T 5	3
7.	General Minimum Variance Unbiased Estimation	Sufficient Statistics, Finding sufficient statistics, using sufficiency to find the MVU Estimator.	T4/T5	3
8.	Best Linear Unbiased Estimators (BLUE)	Definition of BLUE, Finding the BLUE	T3/T4/T 5	3
9	Maximum Likelihood Estimation (MLE)	Finding the MLE, Properties of the MLE, Examples	T3/T4/T 5	3
10	Least Squares	The Least Squares Approach, Linear Least Squares, Sequential Least Squares, MLSE	T3/T4/T 5	3
11	The Bayesian Philosophy	Prior Knowledge and Estimation, Choosing a prior PDF, Properties of the Gaussian PDF, Bayesian Linear Model	T3/T4/T 5	3
12	General Bayesian Estimators	Risk Functions, Minimum Mean Square Estimator (MMSE), Maximum A Posteriori Estimator (MAP), Examples	T3/T4/T 5	3
13	Linear MMSE (LMMSE)	Linear MMSE Estimation, Geometrical Interpretations, The Vector LMMSE Estimator, Sequential LMMSE Estimation	T3/T4/T 5	3
14	Application of the theory to Channel Estimation in 4G LTE	MLE, MMSE, LMMSE techniques to estimate channel using pilot subcarriers in LTE frame, interpolation to non non-pilot (data) subcarriers, some interpolation techniques.	T6/R5/R 6	4
		Total no. of classes planned		**42**

Practical No	**Date**	**Name of the experiment**	No of sessions
1.	18/08/2020	**Introduction to estimation theory**	1

2.	21/08/2020	Operations on matrices	2
3.	25/08/2020		
4.	28/08/2020	Operations on probability and random processes	2
5.	01/09/2020		
6.	04/09/2020	Estimating the value of desired parameter using the given model	1
7.	08/09/2020	Verifying the given estimator is Minimum variance unbiased estimator (MVUE) or not	1
8-10	**11-18/09/2020**	**Test 1**	
11	22/09/2020	Verification of Cramer-Rao lower bound (CRLB) for the desired parameter using the given model	1
12	25/09/2020	Determine the Best linear unbiased estimator (BLUE) of the desired parameter using the given model	1
13	29/09/2020	Find the Maximum likelihood estimator (MLE)of the desired parameter using the given model and verify its properties	1
14	06/10/2020	Find the least square estimate (LSE) of the desired parameters using the given model, also verify whether the computed LSE is linear or nonlinear?	1
15-18	**09-20/10/2020**	**Test 2**	
19	23/10/2020	Find the maximum a posteriori (MAP) estimator of the desired parameter using the given model and plot the distribution of the resultant estimator	1
20	27/10/2020	Find the minimum mean square error (MMSE) estimator of the desired parameter using the given model and plot the distribution of the resultant estimator	1
21	30/10/2020	Find the linear minimum mean square error (LMMSE) estimator of the desired parameter using the given model and plot the distribution of the resultant estimator	1
22	03/11/2020	**Channel estimation in LTE**	2
23	06/11/2020		
24-27	**10-20/11/2020**	**Test 3**	
28	24/11/2020	**Channel estimation in LTE**	2
29	27/11/2020		
		Total number of experiments planned	**13**

vi) Evaluation Scheme:

Component	Duration	Weightage	Marks	Date & Time	Remarks
Test 1	30 mts.	10%	30	To be annoucned	Open Book
Test 2	30 mts	10%	30	To be announced	Open Book
Test 3	30 mts	15%	45	To be announced	Open Book
Lab Experiments + Project	NA	30%	90	Lab sessions	Open Book
Comprehensive	120 mts	35%	105	16/12 AN	Closed Book
Totals		**100%**	**300**		

vii) **Chamber Consultation Hour:** To be announced in Class

viii) **Make-up Policy:** Make-up will be given on extremely genuine grounds only. Prior application should be made for seeking the make-up examination.

ix) **Notices:** Notices, if any, concerning the course will be put up on CMS only

Academic Honesty and Integrity Policy: Academic honesty and integrity are to be maintained by all the students throughout the semester and any mode of academic dishonesty will not be acceptable.

Instructor-in-Charge
EEE G641