**BITS-Pilani, Hyderabad Campus**
**First Semester 2019-2020**
**Course Handout**

**Date:**
**19/07/2019**

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.**

## 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.

**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.

**v) Course Plan / Schedule:**

| Sl. # | Learning objectives | Topics to be covered | Source | No. of lectures |
|---|---|---|---|---|
| 1. | Introduction | Introduction to the course & motivation for estimation | | 1 |
| 2. | Review of linear algebra and probability theory: Probability space, axioms, events, random variables, random processes, summary | To apply linear algebra and probability concepts to handle estimation theory problems in communication systems | [R1]/ [R2]/ [R3] | 6 |
| 3. | Maximum likelihood (ML) estimation | Theory of MLE and Properties of Maximum Likelihood (ML) | T3/T4/ T5 | 3 |

| | | | | |
|---|---|---|---|---|
| | | Estimate-Mean, Variance, Unbiasedness, Reliability of the Maximum Likelihood (ML) Estimate - Number of Samples Required | | |
| 4. | Wireless Fading Channel | Wireless channel Model, Path Loss, Slow and Fast Fading, coherence time and bandwidth, Rayleigh channel etc. | T3/T4/ T5 | 3 |
| 5. | Wireless Fading Channel Estimation | Pilot Symbols and Likelihood Function, Pilot Training based Maximum Likelihood ML Estimate, Mean and Variance of Pilot Training Based Maximum Likelihood | T4/T5 | 3 |
| 5. | Cramer Rao Bound (CRB) for Parameter Estimation | Goodness of an Estimator and Upper Bound on Performance. | T3/T4/ T5 | 2 |
| 6. | Vector Parameter Estimation | System Model for Multi Antenna (MIMO) Downlink Channel Estimation, Least Squares Cost Function for Vector Parameter Estimation, Gradient Method, Pseudo Inverse, Properties like Mean Covariance and Distribution. | T3/T4/ T5 | 3 |
| 7. | Channel Estimation for OFDM | Review of OFDM, Channel Estimation across each subcarrier, Comb Type Pilot CTP Based Channel Estimation. | T3/T4/ T5 | 4 |
| 8. | MLSE | Introduction to Sequential Estimation - Application in Wireless Channel Estimation | T3/T4/ T5 | 3 |
| 9. | MMSE Framework | Introduction to Bayesian Minimum Mean Squared Error, Optimal Bayesian Minimum Mean Squared Error (MMSE) Estimate, Derivation of Minimum Mean Squared Error MMSE Estimate for Gaussian Parameter | T3/T4/ T5 | 3 |
| 10. | Minimum Mean Squared Error MMSE Estimation | Wireless Fading Channel Estimation for scalar and | T3/T4/ T5 | 3 |

| | | | | |
|---|---|---|---|---|
| | Application | vector observation, reliability, | | |
| 11. | Linear MMSE (LMMSE) | Motivation, LMMSE Estimate for Multi Antenna Downlink Wireless Channel | T3/T4/ T5 | 3 |
| 12 | LMMSE Performance | Derivation and Example of Error Covariance of Multi Antenna LMMSE Channel Estimation | T3/T4/ T5 | 3 |
| 13 | Channel Estimation in 4G LTE | 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 | Material on LTE, Published Articles, Google. | 2 |
| | | **Total no. of classes planned** | | **42** |

**vi) Evaluation Scheme:**

| Component | Duration | Weightage | Marks | Date & Time | Remarks |
|---|---|---|---|---|---|
| Mid Sem | 90 mts. | 16.66% | 50 | - | Closed Book |
| Surprise Quizzes | - | 13.33% | 40 | To be decided in Class | Closed Book |
| Laboratory Component | | 20% | 60 | 2 Hr Lab Session per week + 2Hr End semester Practical Exam | Open Book |
| Term Project | | 20% | 60 | Weekly interaction + End semester Project presentation | Open Book |
| Comprehensive | 3 Hrs | 30% | 90 | To be Announced | 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

**Instructor-in-Charge**
**EEE G641**