CT216 Introduction to Communication Systems
Lecture 1: Introduction

Yash M. Vasavada

Professor, DA-IICT, Gandhinagar

3rd January 2024

Overview of Today's Talk

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About Myself

- Instructor: Yash M. Vasavada
  - → B.E. in Electronics and Communications from L. D. Engineering College, Gujarat University, Ahmedabad, India
  - → M.S. and Ph.D. in Electrical Engineering from Virginia Polytechnic Institute and State University, Blacksburg, VA, USA
  - → I was with Hughes Network Systems in Germantown, MD, USA until 2016
  - → Beginning of the year 2016, I have been with DA-IICT

My Research

I am interested in

- the confluence of Machine Learning with Digital and Wireless Communications
- development of new algorithms, a study of their properties, and a study of their applications in communications, signal processing and artificial intelligence

Overview

- This is a (L : T : P : Cr) 3 : 0 : 2 : 4 Course.
- Three lecture sessions per week, one lab session per week, three exams and a final project
- Assignments, Announcements and other communication will be through the Google Classroom. Pl. enroll there if you have not already done so

Textbooks and Software

1. Introduction to Communication Systems, Upmanyu Madhow, Cambridge University Press; First edition, 2015.
2. Information Theory, Inference and Learning Algorithms, David J. C. MacKay, Cambridge University Press; 1st edition, 2003.
3. Digital Communications, John Proakis, Fourth Edition.
4. Digital and Analog Communication Systems, Leon Couch, Pearson Education, India, 6th Ed, 2001.
5. (Software) Matlab, Python (Jupyter iPython Notebook), C++

Textbooks and Software

Several nice books that you should read

1. B. Sklar, Digital Communications, Second Edition.
2. S. Haykin, Digital Communications
3. S. Wicker, Error Control Coding for Digital Communication and Storage, 1994
4. S. Wilson, Digital Modulation and Coding

Use of Software

- In CT216, you will learn many new mathematical concepts. To gain full insight, the lecture sessions will need to be complemented by solving lab/homework assignments.
  - → Some of these assignments will require analytical problem solving on your part
  - → Many others will require you to develop programs and simulations in Matlab (or you can also use Python)
    - ▷ Become familiar with Matlab. Install Matlab on your machine right away if you have not used Matlab earlier.

Grading Policy

Weights are tentative and subject to change

1. Three Examinations: two mid-terms and one final (weight: 20% each)
2. Project and Lab Submissions: based on regularity of lab attendance and timely submissions of the lab report (weight: 10%)
3. Lab, Project and Homework Tests: based on student proactiveness and interactiveness (weight: 25%)
4. Quizzes: may be announced ahead of time, or may be surprise as well (weight: 5%)
5. Attendance: 75% attendance needed to take the final exam

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4. The mentor TA will promote the students who are consistently proactive, and are doing good work, and have interesting questions and comments during the Lab sessions. Only the promoted students will be given opportunity (at least once, possibly more number of times) to bring their work to me and show it to me.

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5. You are likely to get a good score in this grading category if you not only impress your mentor TA but also me throughout the semester.

Honor Code

If you are promoted and you would like to show your work (the homework, the labs and the project) to me, please come with the following statement.

- I, [place your name and student ID here], declare that
  - → the work that I am presenting is my own work
  - → I have not copied the work (Matlab code, results, etc.) that someone else has done
  - → Concepts, understanding and insights I will be describing are my own
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- Please note: cheating/plagiarism is your enemy, never a friend: cheaters never prosper. Those who get caught face great misfortune.

A Note on the Attendance Policy

1. Whether you like it or not, whether you find the lectures a refreshing cup of your favorite beverage or a bitter pill that you need to swallow, it is your responsibility – that you have opted to take on your shoulder when you took admission in this Institute – to attend the morning hour of 9 to 10 am on M-W-F, and the afternoon hours of CT216 Lab

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- Be curious, be interested, think about some fundamental questions of the life

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  - → "I will publish a paper on the communication theory with IEEE by the end of the year 2023"

Do You Know!


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4. Do you know the above realization has made the engineers and scientists develop algorithms/techniques that allow the big data files with sizes in megabytes and gigabytes to be compressed and stored in an efficient manner?
   - → We will briefly study the topic of data compression (also known as source coding) in this course.

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4. Do you know that the data rate R in bits/second is equivalent to bandwidth W in Hertz, and received signal power P_S in watts (also the noise power P_N in watts)
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   - → This also touches upon the subject of Information Theory that we will briefly cover in this course.

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   - → What are the eigenvectors of a linear shift invariant system (LSI)?
   - → What is the OFDM technology?
7. Do you know that when you are able to decipher the meaning of what your friend or relative is trying to say in a noisy room or over a weak phone connectivity, or when you detect and correct the spelling of words that you read is what your phone also does continuously as it receives the signal over a noisy channel?

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- as a future ICT engineer, if you don't fully understand the concepts that underlie the I and the C, which T engineer you would be?! ☺

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   - ▷ What is highly informative for one could be non-informative for someone else
   - ▷ We tend to associate the subjective notion of utility to something that can be considered informative
     - → What is the benefit to me, whether this is of interest to me, etc.

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3. We will see that, despite these difficulties, there is indeed a nice, satisfactory and mathematical way of pinning down the engineering definition of the information
   - → This mathematical description of information and its transfer (i.e., the communication) avoids the subjective aspects of utility, but otherwise it provides an excellent engineering answer

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  - The definition will require us to crystallize our understanding of the mathematics that can be used to model the beliefs — i.e., the probability theory

How to Define the Information?

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- He essentially took a problem such as the one of the previous slide, and pursued it mathematically
- His work was entirely based on his own thinking — very much like Albert Einstein, who derived the theories of relativity while sitting at his desk in a patent office in Germany
  - Neither Shannon nor Einstein had any fancy computer or lab equipment; theirs was purely a thought-lead effort
  - At least their initial papers did not require any concepts beyond the high-school math
  - Still their works shattered the existing paradigms in their respective fields

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- The analogy continues — just as the speed of light cannot be violated as per Einstein's theories, the formulation developed by Shannon cannot be violated no matter how smart the designer of a communication system is

The Model of a Communication System

Crystallized by Shannon

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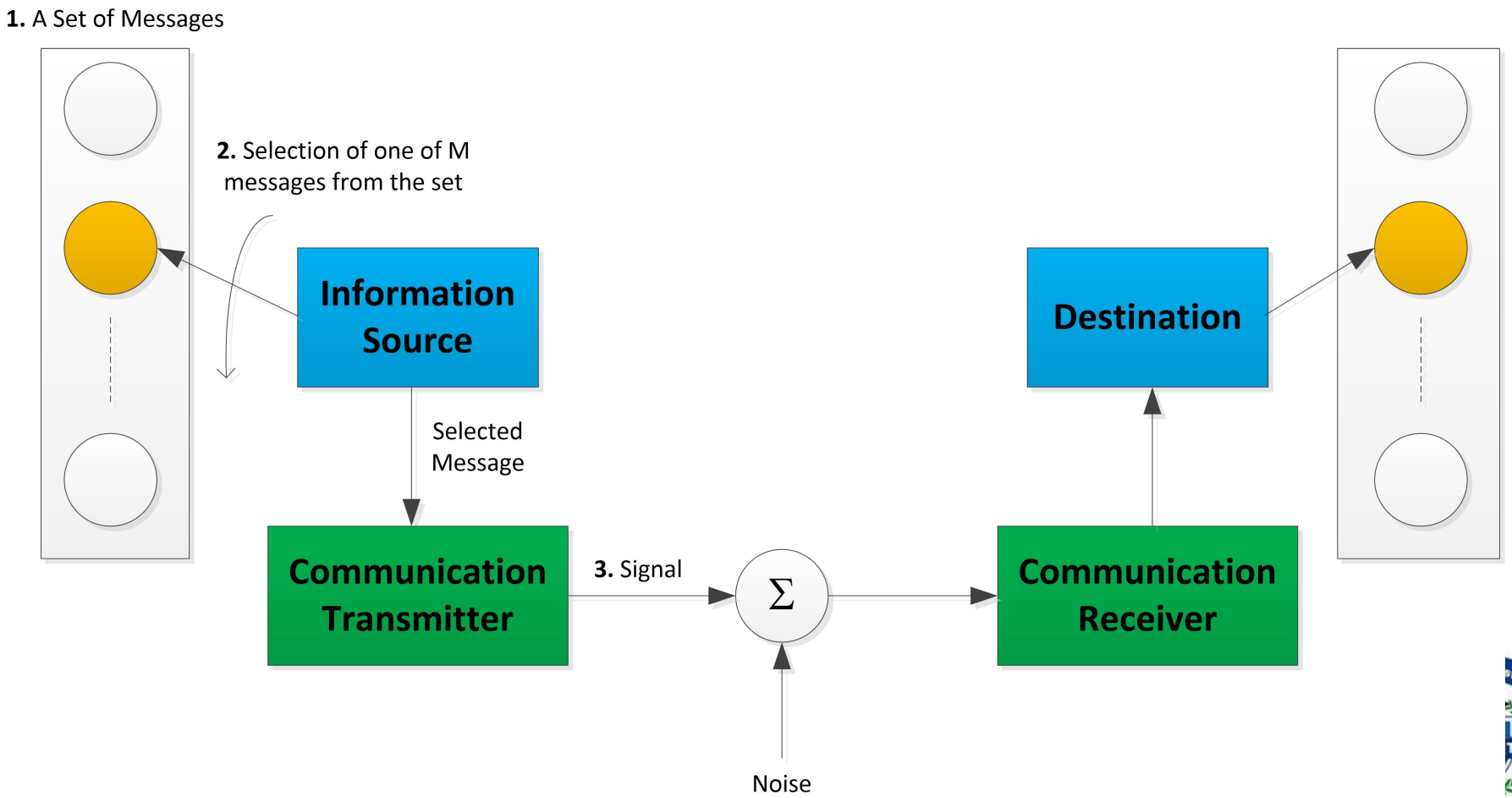

A Model of Digital Communication Systems

A Simple Block Diagram

Key design parameters:

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3. The power P_s that the communication receiver gets (determined by the power that the transmitter can put in the transmitted signal), the spectral bandwidth W that it has and the power P_n of the noise that the communication channel introduces

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Shannon Information Theory

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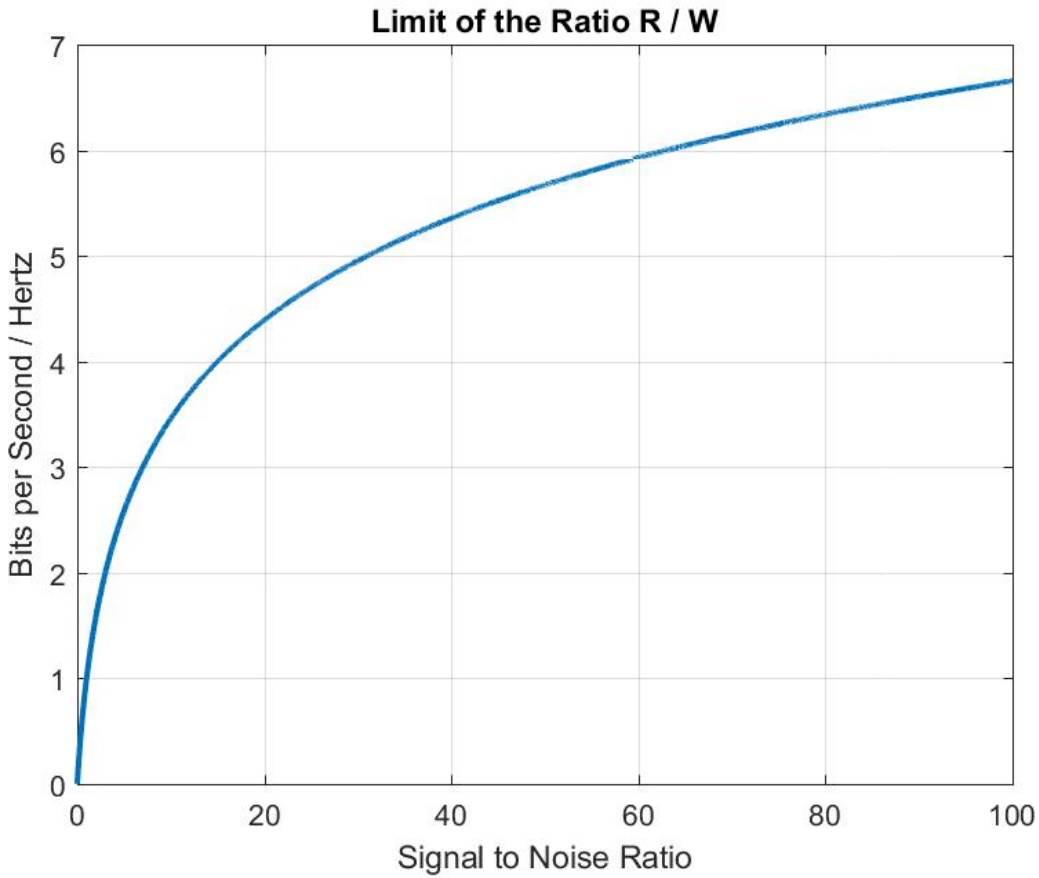

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- the ratio P_s/P_n: called the signal to noise ratio or SNR. The absolute values of P_s and P_n are immaterial, instead P_s *relative* to P_n, i.e., the SNR P_s/P_n drives the comm. system throughput. We would like to operate the system at as low value of SNR as possible – since reducing the SNR translates to increased energy efficiency

Bandwidth Efficiency η_B

- As data rate R increases, the pulse width of transmitted signal reduces and therefore the bandwidth B, which is inversely proportional to the transmitted pulse width, increases.
- This cannot be avoided; however some schemes use the available bandwidth more efficiently than the others
- The bandwidth efficiency η_B is the ratio R/W – the greater its value, the greater the amount of data in bps that can be pumped through a communication channel with a given bandwidth W Hz
- It is obviously better to have η_B as large as possible. However, there is a cost associated to making η_B large.

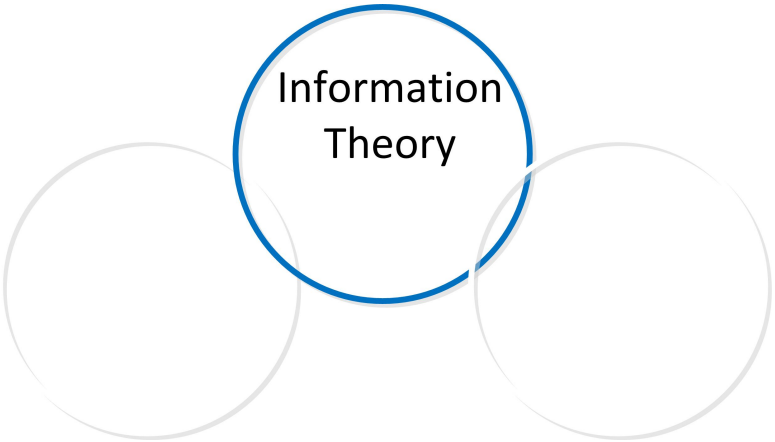
Energy Efficiency η_E

- Communication systems are characterized by the signal to noise ratio (SNR) P_s/P_n required to attain a certain performance
  - $\rightarrow$ Often an equivalent metric E_b/N_0, which can be thought of as SNR per transmitted bit, is used
- Typically making η_B large requires E_b/N_0 to be large; this entails a corresponding increase in transmit energy E_b.
- We will define energy efficiency η_E as $\left(\frac{E_b}{N_O}\right)^{-1}$ required to attain the desired performance
- Greater the required $\frac{E_b}{N_O}$, the smaller the energy efficiency.

Exchange of Power and Bandwidth

- As it often is the case in the life, it is hard to get best of both the worlds. Typically an increase in η_B translates to a decrease in η_E and vice versa.
- This trade-off between bandwidth and energy efficiencies can be viewed as the *equivalence* between the power and the bandwidth
- If the system designer has a fixed transmit power (i.e., the design is limited or handicapped by the transmit power), this limit can be overcome to some extent by increasing the bandwidth
- Vice versa, if the bandwidth is limited, the power can be increased to obtain the desired data rate

Topics of CT216



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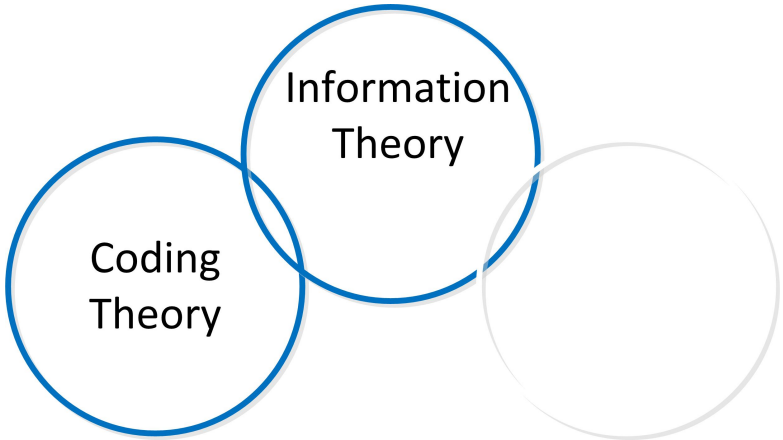

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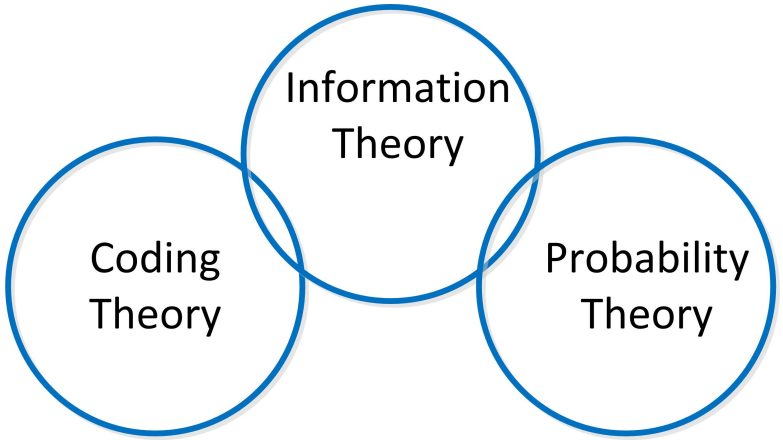

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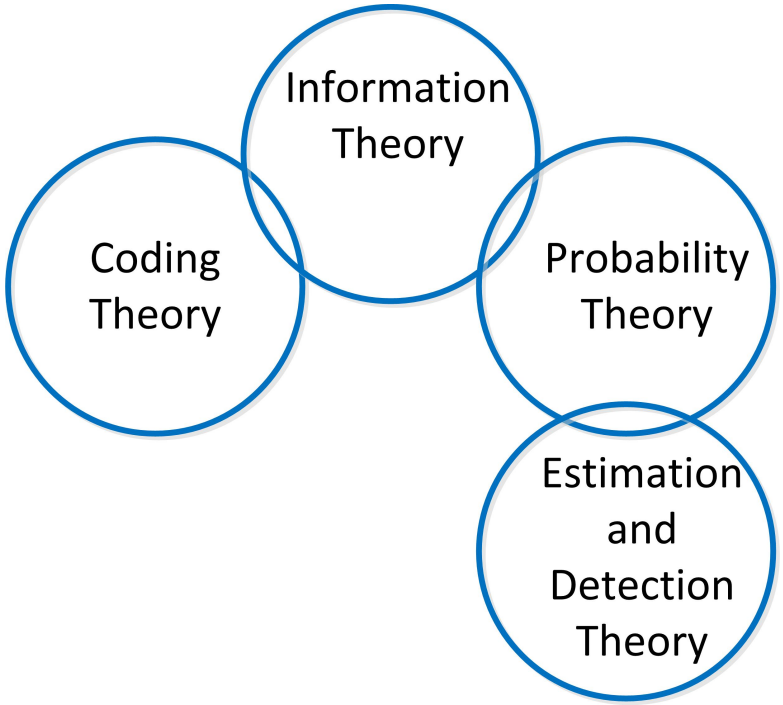

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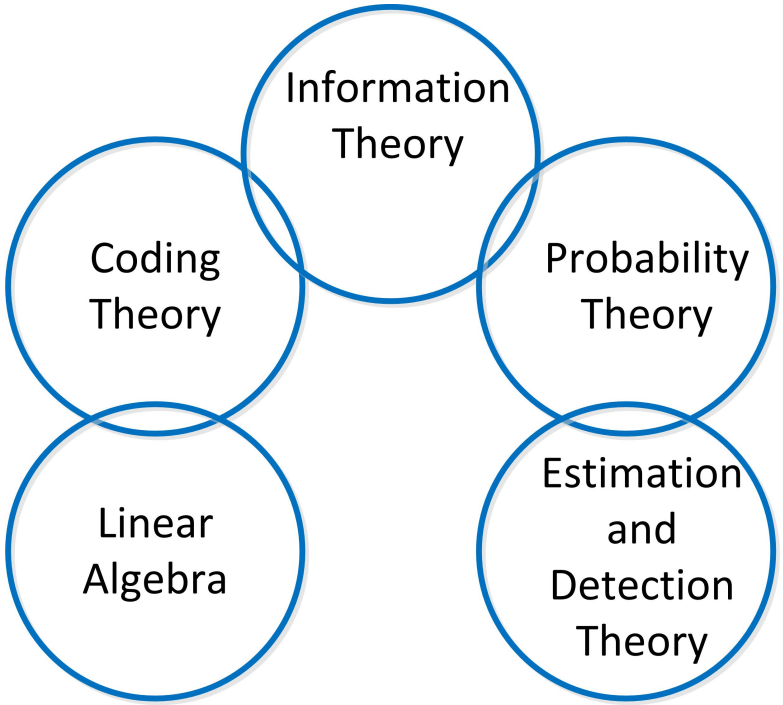

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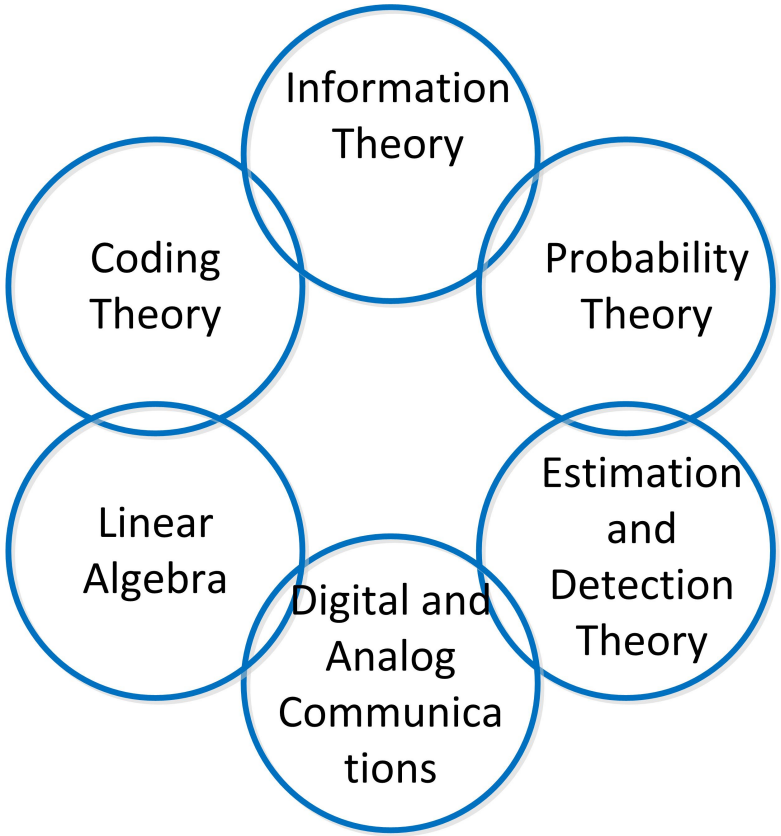

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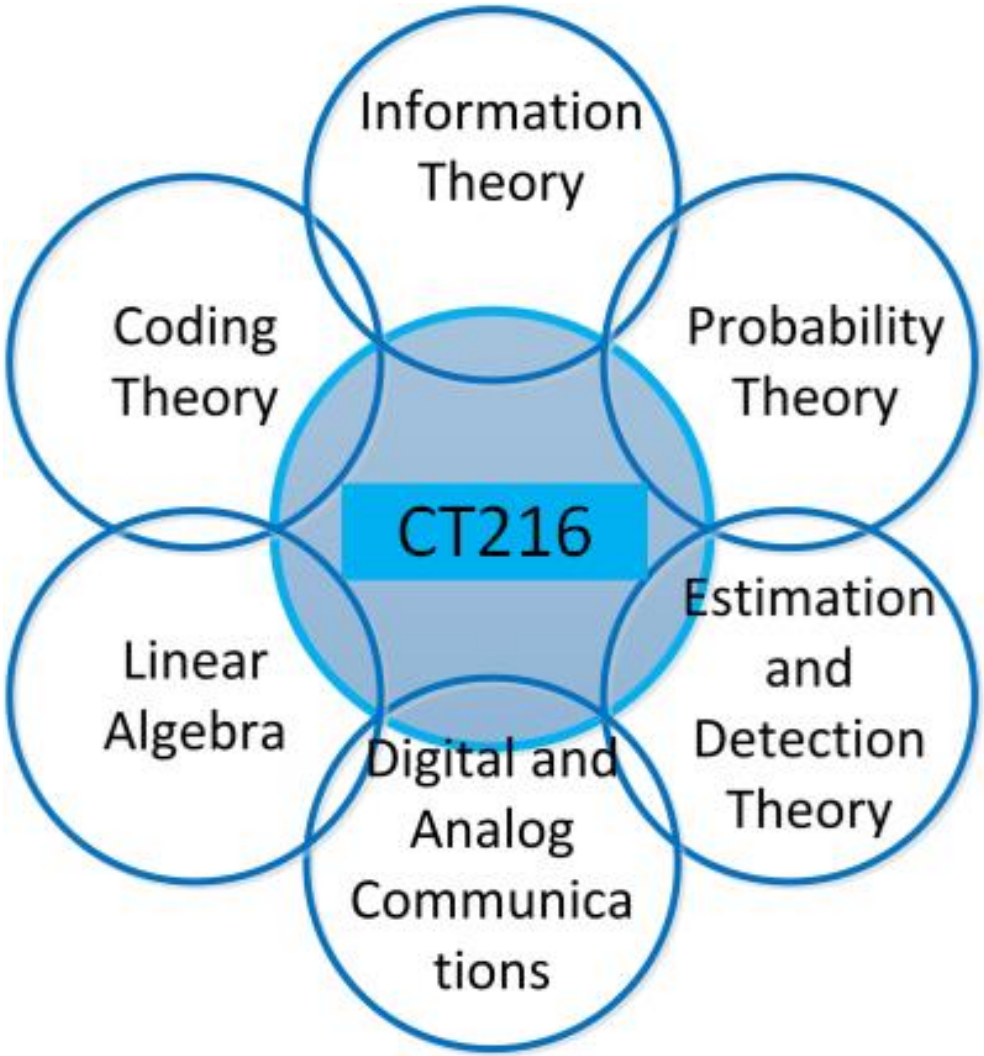

Why to Study CT216?

There are big developments and multi-national projects in 5G wireless systems

- The world is currently migrating from 4G to 5G
  - → Perfect time to get on the board.
  - → CT-216 would be the first step
- Let us see next what the research and the industry are targeting for