

Modeling the communication process at the deep physical layer level

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From the lecture of Sergey Maksimenko, 31 May 2021

Sergey Maksimenko sta presentando

Jyothiswarar e altre 19 pe

Opening up the mm-Wave & THz frequency ranges

2Sense
next about sensing

Frequency, Hz

Wavelength, m

radio waves

TV, FM

Microwave

Infrared

Ultra

Visible light

THz range:	300 GHz	10 THz
	1 mm	30 μ m

The wireless community has announced the 5G – a new generation of mobile wireless technology that will deliver **multi-gigabit-per-second data speeds**, with orders of magnitude more capacity and lower latency than today's wireless systems. Millimeter-wave (mmWave) and THz frequencies are considered as basic ones for 5G

Data rate

Year

10⁰

10¹

10²

10³

10⁴

10⁵

10⁶

10⁷

10⁸

10⁹

10¹⁰

10¹¹

10¹²

10¹³

10¹⁴

10¹⁵

10¹⁶

1980

1985

1990

1995

2000

2005

2010

2015

2020

FUJITSU

Antenna

Photo from side

Resonant circuit

Pump resonator

Output terminal unit

Photo from top

Metalic receiver module housing

Polyimide circuit substrate

Connecting circuit

Cross section of internal construction

The terahertz-band high-sensitivity receiver and a cross section of its construction

<http://www.fujitsu.com/global/about/resources/news/press-releases/2015/0908-02.html>

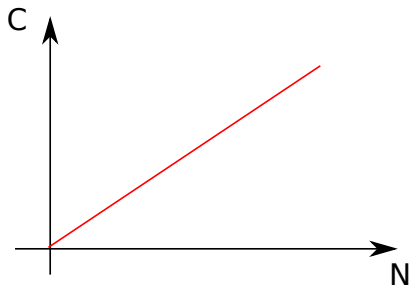
S. Maksimenko, INP RSI

20

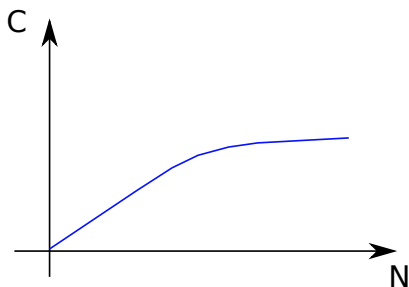
How fast can we run ?



Something missed?

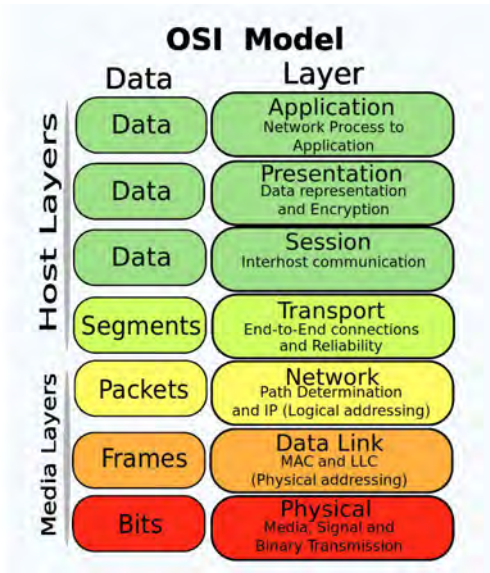


Expectation



Real word

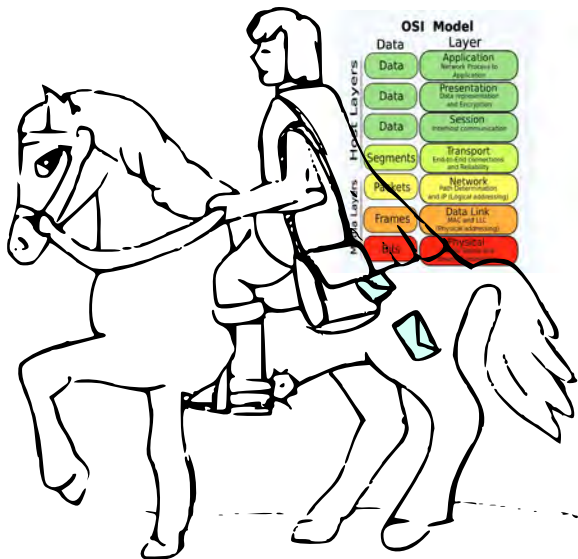




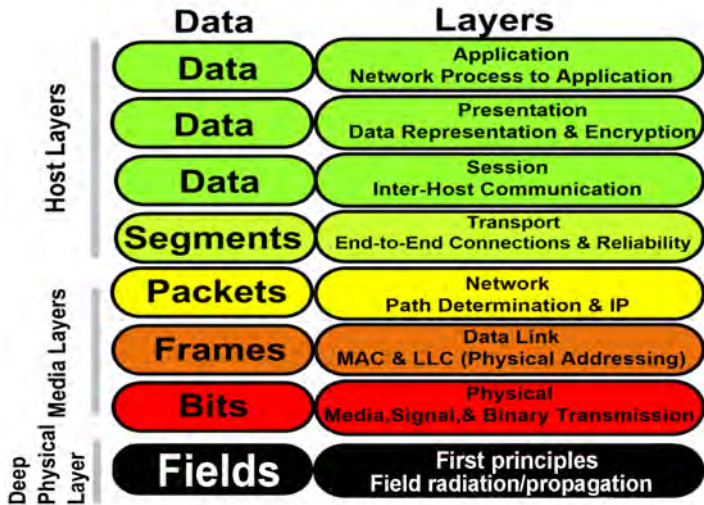
Horse and horseman



Horse and horseman



The deep physical layer



Some cornerstones in the history of communication



James Clerk Maxwell

1873

A treatise on electricity and magnetism

1948

A mathematical theory of communication



Some cornerstones in the history of communication



1873

A treatise on electricity and magnetism



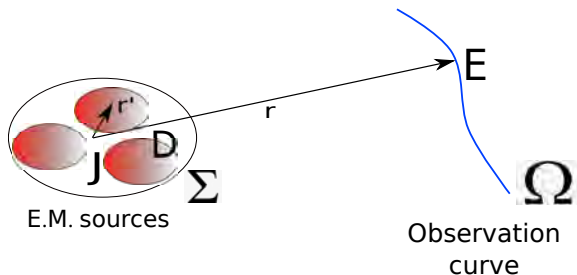
1959 ϵ -entropy and
 ϵ -capacity sets in functional
spaces



1948

A mathematical theory of
communication

The radiation operator



$$E(r) = \int_D G(r, r') \cdot J(r') dr' \quad r' \in \Omega$$

J : current distributions in D , E : field distribution on Ω
The radiation integral is a linear operator that maps current distributions into field distributions

The functional approach

Let us introduce a complete orthonormal basis for the current distribution on D and a complete orthonormal basis for the field distribution on Ω

$$J(r') = \sum_1^{\infty} x_k f_k(r')$$
$$E(r) = \sum_1^{\infty} y_k g_k(r)$$

Geometrically, x_k can be seen as the k – th coordinate of a point x belonging to the infinite-dimensional Hilbert space having $f_1(r), f_2(r), \dots, f_k(r), \dots$ as basis functions. The same for y_k

An important property of the radiation operator

\mathcal{A} is a **compact operator**. The Hilbert-Schmidt decomposition of \mathcal{A} gives a basis v_k for the currents and a basis u_k for the field that allows the **diagonalization** of the infinite matrix A

$$y_1 = \sigma_1 x_1$$

$$y_2 = \sigma_2 x_2$$

....

$$y_k = \sigma_k x_k$$

....

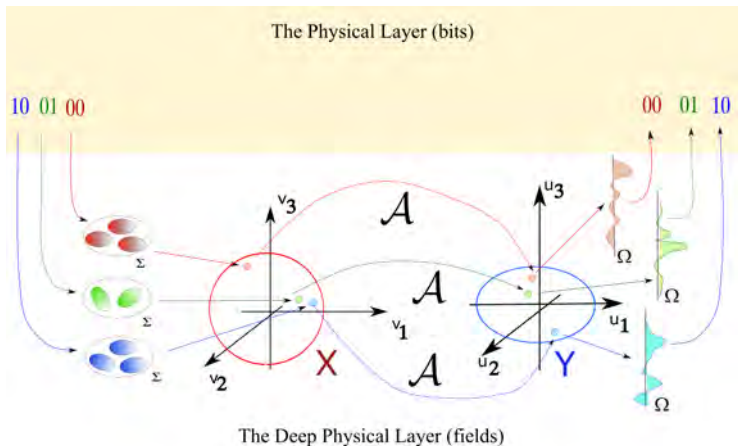
σ_k are the singular values of \mathcal{A}

$$\lim_{k \rightarrow \infty} \sigma_k = 0$$

The matrix A has an **almost finite rank** !

\mathcal{A} maps a hypersphere in a hyperhellipsoid having almost **finite** dimensions

Geometrical interpretation in functional spaces

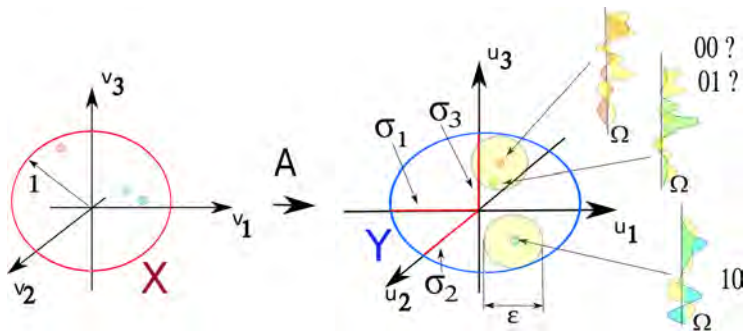


X : set of all the current distributions on D

Y : set of all the field distributions on Ω

The radiation operator \mathcal{A} maps elements of X into elements of Y

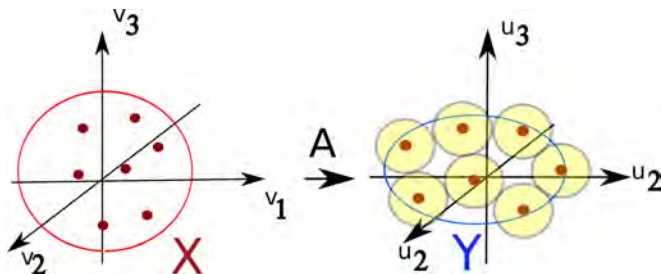
The presence of noise



Due to the presence of noise two field configurations whose distance is smaller than ϵ are indistinguishable.

The number of distinguishable configurations in presence of ϵ uncertainty is equal to **maximum number of ϵ -balls** that we can pack in Y

Kolmogorov ϵ -capacity



The \log_2 of the maximum number of distinguishable configurations in presence of ϵ uncertainty is called the **Kolmogorov ϵ -capacity**

The Kolmogorov ϵ capacity is the maximum amount of information expressed in bits that can be reliably transmitted along the spatial channel

The effective dimension of the Y set is called the Number of Degrees of Freedom of the field (NDF)

How much information can we transmit?

$$E(r) = \sum_k y_k u_k(r)$$

$$y_1 = \sigma_1 x_1$$

$$y_2 = \sigma_2 x_2$$

....

$$Y_{NDF} = \sigma_{NDF} X_{NDF}$$

The number of bits is equal to the **Kolmogorov ϵ -capacity**

$$C_\epsilon(Y) \simeq \sum_{k=1}^{NDF} \log_2 \left(\frac{\sigma_k}{\epsilon} \right)$$

The amount of information that can be reliably transmitted is limited by the ***NDF*** of the field.

How many NDF do we have?

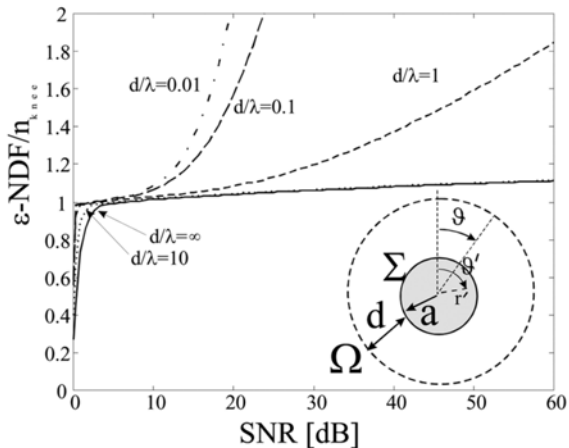


Fig. 5. $\epsilon - NDF$ as a function of the Signal/Noise Ratio (SNR) normalized to n_{knee} for different values of the distance d/λ of the observation circle from the circle including the sources; inset: geometry of the problem;

The Deep Physical Layer describes the physical mechanisms at the basis of the communication process using standard tools of functional analysis.

The Deep Physical Layer gives a framework to describe the physical process of communication at different details, up to quantum level.

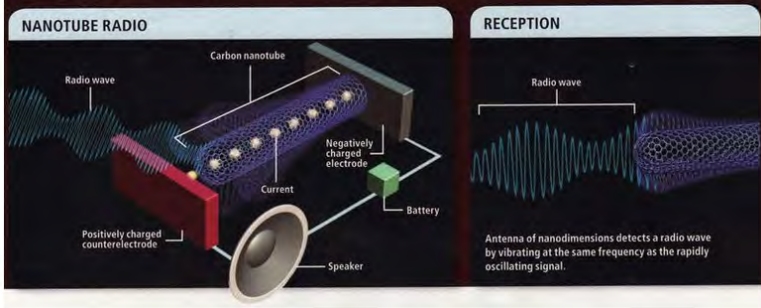
... is this something interesting?

February 27, 2009

World's smallest radio consists of 1 carbon nanotube – listen to it play 'Layla'

Anatomy of the Tiniest Radio

Just one nanotube can perform all the functions of a standard radio with many parts. Its tiny dimension enables it to vibrate rapidly in the presence of a radio signal. Connected to an electrical circuit, this nanoantenna can then be tweaked to tune, amplify and isolate just the audio component from the rest of the radio wave so that the sounds of the Beach Boys or George Frideric Handel can be discerned.



Nanoradio - Alex Zettl's group, University of California, Berkeley

(image from <https://www.bookofjoe.com/2009/02/nanotube-radio.html>)



A nanonetwork or nanoscale network is a set of interconnected nanomachines which are able to perform only very simple tasks such as computing, data storing, sensing and actuation.

Nanonetworking is one of the newest research trends in communication networks!

The screenshot displays the IEEE Access journal homepage. At the top, the 'IEEE Access' logo is prominent, with the tagline 'Multidisciplinary | Rapid Review | Open Access Journal' below it. A search bar is located in the upper right corner. A dark blue navigation bar contains links for 'About IEEE Access', 'Rapid Peer Review', 'Benefits of Publishing', and 'Topical Sections'. Below this, a breadcrumb trail reads 'Home » Topical Sections » Closed Special Sections » Protocols for Nanocommunication Networks'. The main heading is 'Protocols for Nanocommunication Networks'. The ScienceDirect logo is visible on the left, and 'Journals & Books' with a search icon is on the right. A green banner at the bottom features a book cover titled 'Nano Com...' and the text 'Nano Communication Networks'.

IEEE P1906.1 - Recommended Practice for Nanoscale and Molecular Communication Framework



IEEE Communications Magazine May 2021

SPECIAL ISSUE

Nano-Networking for Nano-, Micro-, Macro-Scale Applications

SERIES TOPIC

Data Science and Artificial Intelligence for Communications

YOU MUST BE [SIGNED IN](#) AND SUBSCRIBED IF YOU'D LIKE TO DOWNLOAD THIS ISSUE.

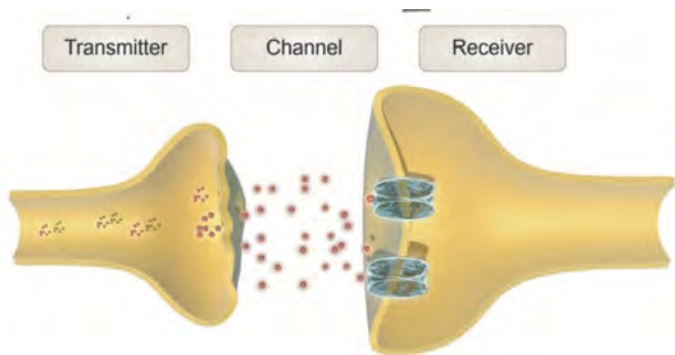
IEEE XPLORE VERSION



In electromagnetic nanonetworks, artificial nanomachines communicate using electromagnetic radiation emitted by nanoantennas.

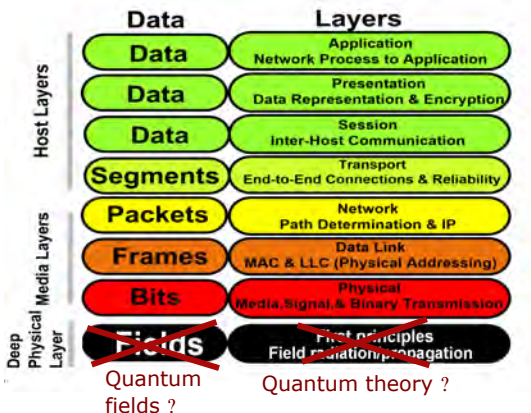
The Deep Physical Layer gives a natural framework for EM-based nanonetworks.

Nanonetworking



The Deep Physical Layer approach can be extended to include molecular nanonetworks (wave equation \rightarrow diffusion equation)
Is it enough?

Beyond classic electrodinamics communication systems



What does happen in the nano-world communications? I have no idea, but surely...

there's plenty of room at the bottom!



<https://youtu.be/8qp7GzIIKHI>.