# ECE5884 Wireless Communications

## Week 1: Overview of Wireless Communications



Saman Atapattu

ARC Future Fellow at The University of Melbourne
Sessional Lecturer at Monash University



July 25, 2022

# The evolution of wireless communications

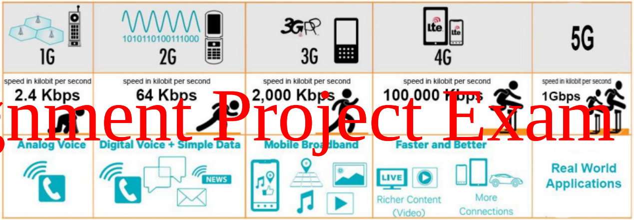



Figure 1: Wireless journey from 1G to 5G (“G” means “generation”).
http://ioarp.org/ioarp-admin-panel/upload/articles/1460357886_IDL-ICCN15-011.pdf

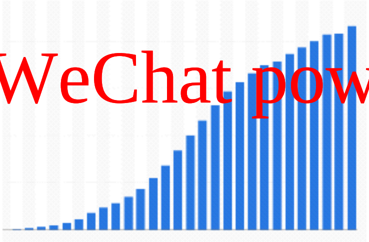


Figure 2: Mobile subscriptions 1993–2021 https://www.statista.com/.

# The evolution of wireless capabilities

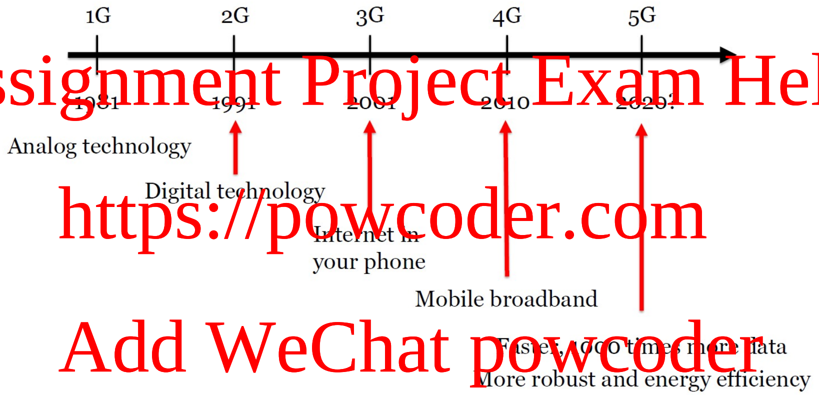





Figure 3: Key features of different Gs. https://github.com/emilbjornson/presentation_slides.

To achieve higher data transfer speeds (*n* Gbit/s to *N* Tbit/s).

# The evolution of wireless capabilities



1. 1G: purely analog systems; for making voice calls.
2. 2G: the first digital cellular networks; improved sound quality, greater security and increased performance, Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Enhanced Data Rates for GSM Evolution (EDGE); TDMA-based GSM and CDMA $W9 - W11\checkmark$.
3. 3G: Universal Mobile Telecommunications System (UMTS, 3GPP in 2001), CDMA2000;
4. 4G: WiMAX and Long-Term Evolution (LTE); multiple-input multiple-output (MIMO) communications $W9 - W11\checkmark$.
5. 5G: International Telecommunication Union's IMT-2020 standard and 5G NR (5G New Radio); Enhanced Mobile Broadband (eMBB); mmWave bands, Massive MIMO, Small cell, Beamforming, non-orthogonal multiple access (NOMA), ... $W9 - W12\checkmark$.
6. 6G: Smart wireless radio environment! $W11 - W12\checkmark$.

# Global forecast

- Eg: Cisco Annual Internet Report (2018–2023) White Paper `https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html`
- Nearly two-thirds of the global population will have Internet access by 2023. There will be 5.3 billion total Internet users (66% of global population) by 2023.



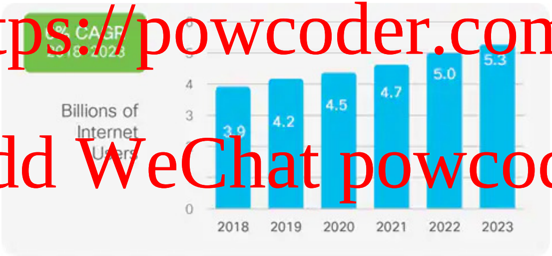
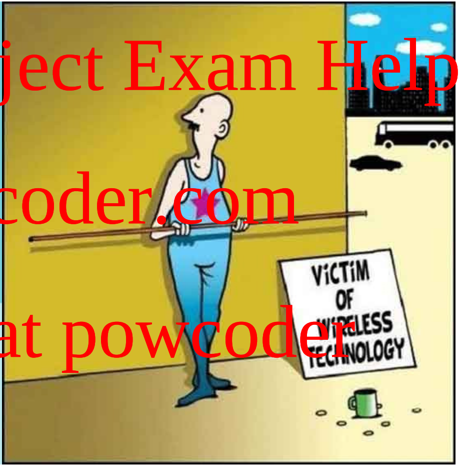



Figure 4: Global Internet user growth.


Home is where the wifi connects automatically.
RD


VICTIM OF WIRELESS TECHNOLOGY

# Wireless communications

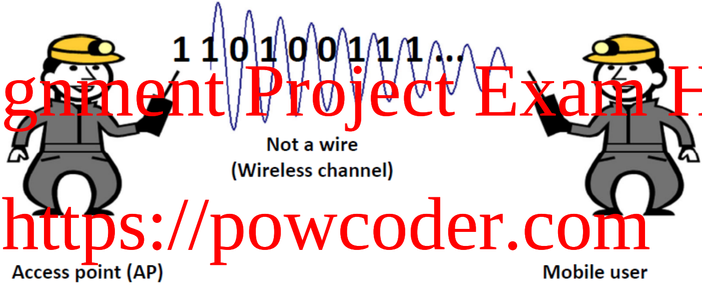



Figure 5: A simple point-to-point wireless communications system.

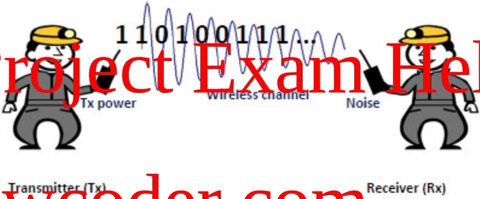


- Wireless communication is the transfer of information between two or more points without the use of wires (base station, WiFi router, etc.).
- Digital: zeros and ones describe text, sound, image,video, etc
- Wireless transmission (Electromagnetic signals).

# Data rate/Capacity/Throughput




(a) Water pipe.




(b) Wireless data communication.



Figure 6: Capacity



- Water flow: Diameter, surface, pressure, etc..
- Data flow:Tx power, wireless channel, additive noise, bandwidth, etc.
- Channel capacity $C$: The maximum rate at which information/data can be transmitted through a wireless communication channel.

# Wireless channel capacity

Claude Elwood Shannon (April 30, 1916 – February 24, 2001) was an American mathematician, electrical engineer, and cryptographer known as a "father of information theory".



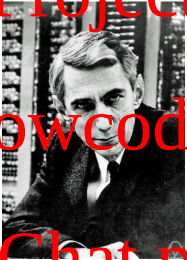
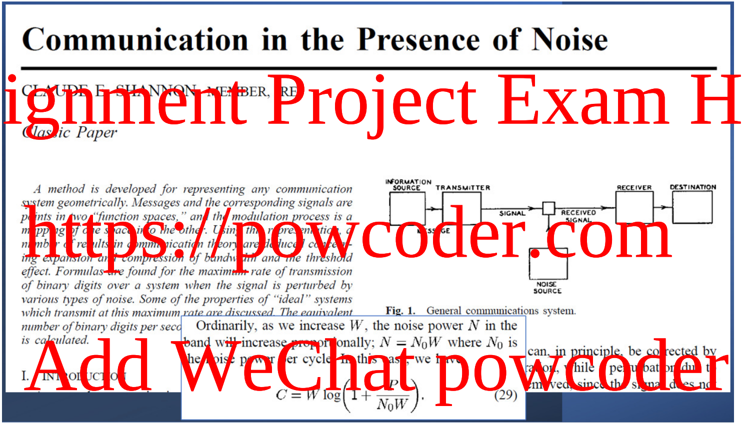


Figure 7: Claude Elwood Shannon.

- Shannon–Hartley theorem: the maximum rate at which information can be transmitted over a communications channel of a specified bandwidth in the presence of noise.

Source: `https://en.wikipedia.org/wiki/Claude_Shannon`

# Classic paper (1948)


**Communication in the Presence of Noise**

CLAUDE E. SHANNON, MEMBER, IRE

*Classic Paper*

*A method is developed for representing any communication system geometrically. Messages and the corresponding signals are points in two "function spaces," and the modulation process is a mapping of one space into the other. Using this representation, a number of results in communication theory are deduced concerning expansion and compression of bandwidth and the threshold effect. Formulas are found for the maximum rate of transmission of binary digits over a system when the signal is perturbed by various types of noise. Some of the properties of "ideal" systems which transmit at this maximum rate are discussed. The equivalent number of binary digits per second is calculated.*



Fig. 1. General communications system.

I. INTRODUCTION

Ordinarily, as we increase $W$, the noise power $N$ in the band will increase proportionally; $N = N_0 W$ where $N_0$ is the noise power per cycle. In this case, we have

$$C = W \log\left(1 + \frac{P}{N_0 W}\right). \quad (29)$$

can, in principle, be corrected by



- We do not know the Shannon capacity of most wireless channels.
- Shannon theory provides design insights and system performance upper bounds.

# Shannon–Hartley theorem

The channel capacity $C$: the theoretical tightest upper bound on the information rate of data that can be communicated:



$$C = W \log_2\left(1 + \frac{P_r}{W N_0}\right) \quad \text{bits/sec} \tag{1}$$

- $W$: the bandwidth of the channel in Hz
- $P_r$: the average received signal power over the bandwidth in watts
- $N_0$: the average noise power over the 1 Hz bandwidth



To increase $C$: $W \uparrow$, $P_r \uparrow$ and $N_0 \downarrow$



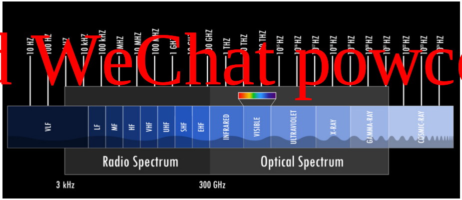



Figure 8: Radio frequencies.

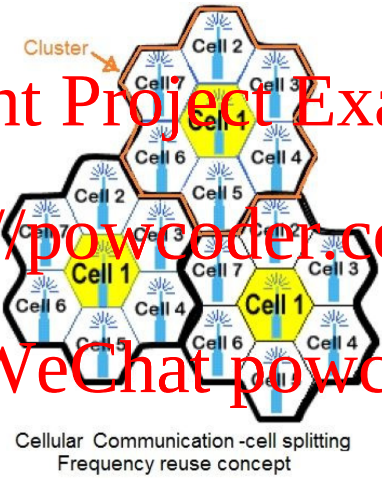





Figure 9: A cellular architecture: Geographic region divided into cell).

Reuse: Spectrum is reused due to scarcity.

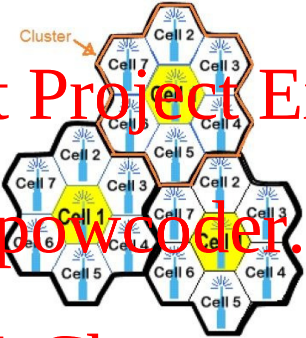





Figure 10: A cellular communications architecture.

- Freq./timeslots/codes/space reused in different cells.
- Interference between cells using same channel.
- Base station coordinate handoff.
- Small cell size increases capacity, as well as complexity.

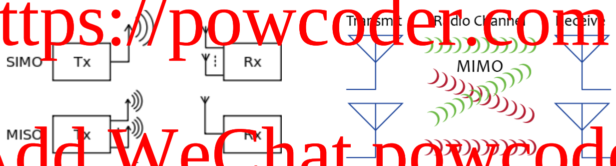
# Multiple antennas 4G

$$C = n \cdot W \log_2\left(1 + \frac{P_r}{W N_0}\right) \quad \text{or} \quad C = W \log_2\left(1 + \frac{n \cdot P_r}{W N_0}\right) \tag{2}$$



Sending/receiving more than one data signal on the same radio channel at the same time via multipath propagation.








(a) Tx/Rx Multiple antennas. (b) MIMO.

Figure 11: Different antenna configurations.

Smart antenna techniques: Beamforming and diversity.

# Beyond 4G

The 2010 Communication Theory Workshop




https://ctw2010.ieee-ctw.org/tues/plenary-CommTheoryDev-BestBehindOrAhead.pdf

# Beyond 4G

Current and future wireless networks (E.g., Smart cities) involve many aspects of daily life including e-businesses, intelligent transportation, telemedicine, ...



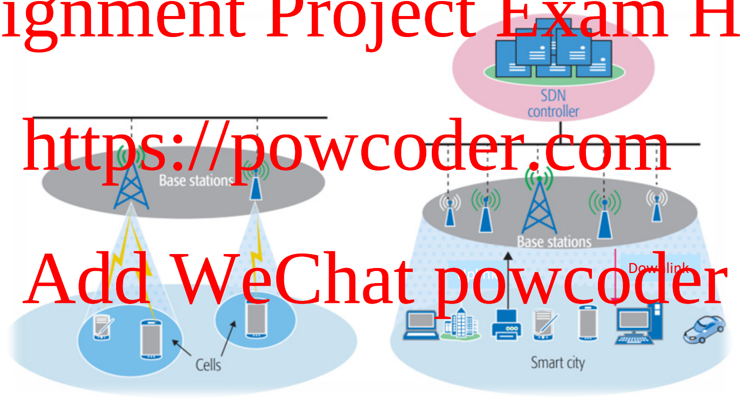



Figure 12: 4G to 5G and Beyond wireless network.

Source: T. Han, et al. “5G Converged Cell-Less Communications in Smart Cities,” in IEEE Commun. Mag., vol. 55, no. 3, pp. 44-50, March 2017.

# 5G capabilities

5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices.



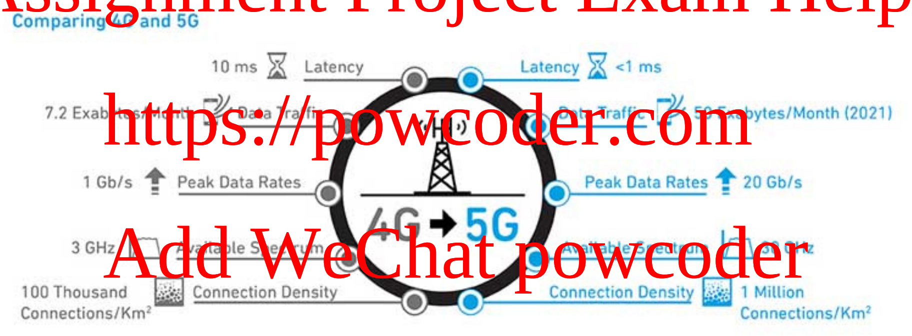



Figure 13: 4G to 5G https://www.iasgyan.in/blogs/the-evolution-of-5g-technology.

# 5G

Area throughput is highly relevant performance metric.



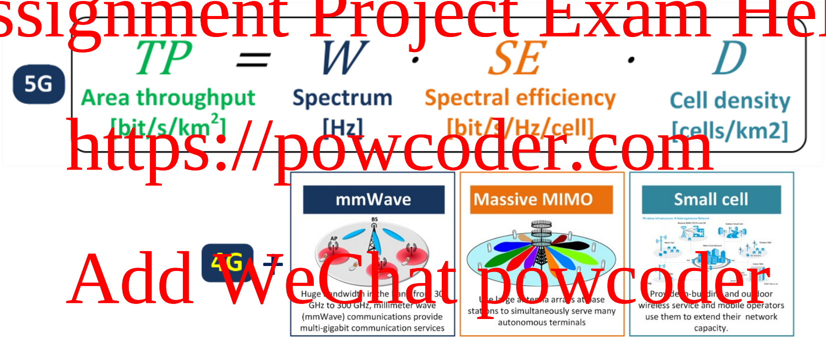
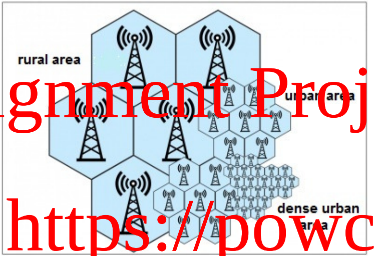


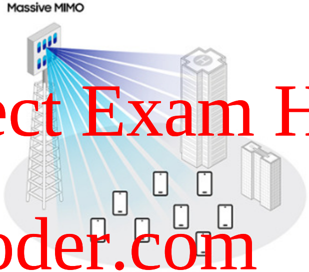




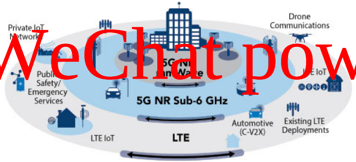

Figure 14: Big Picture – 5G and Beyond.




(a) Cell density.




(b) Massive MIMO.




(c) mmWave.

Figure 15: Different 5G technologies.

# Course outline

- Week 2: Wireless Channel (Path Loss and Shadowing)
- Week 3: Wireless Channel Models
- Week 4: Capacity of Wireless Channels
- Week 5: Digital Modulation and Detection
- Week 6: Performance Analysis
- Week 7: Equalization
- Week 8: Multicarrier Modulation (OFDM)
- Week 9: Diversity Techniques
- Week 10: Multiple Antenna Systems (MIMO Communications)
- Week 11: Multiuser Systems
- Week 12: Guest Lecture (Emerging 5G/6G Technologies)

Thank You!



See you again ☺