

# **Non-Orthogonal Multiple Access for 5G and Beyond**

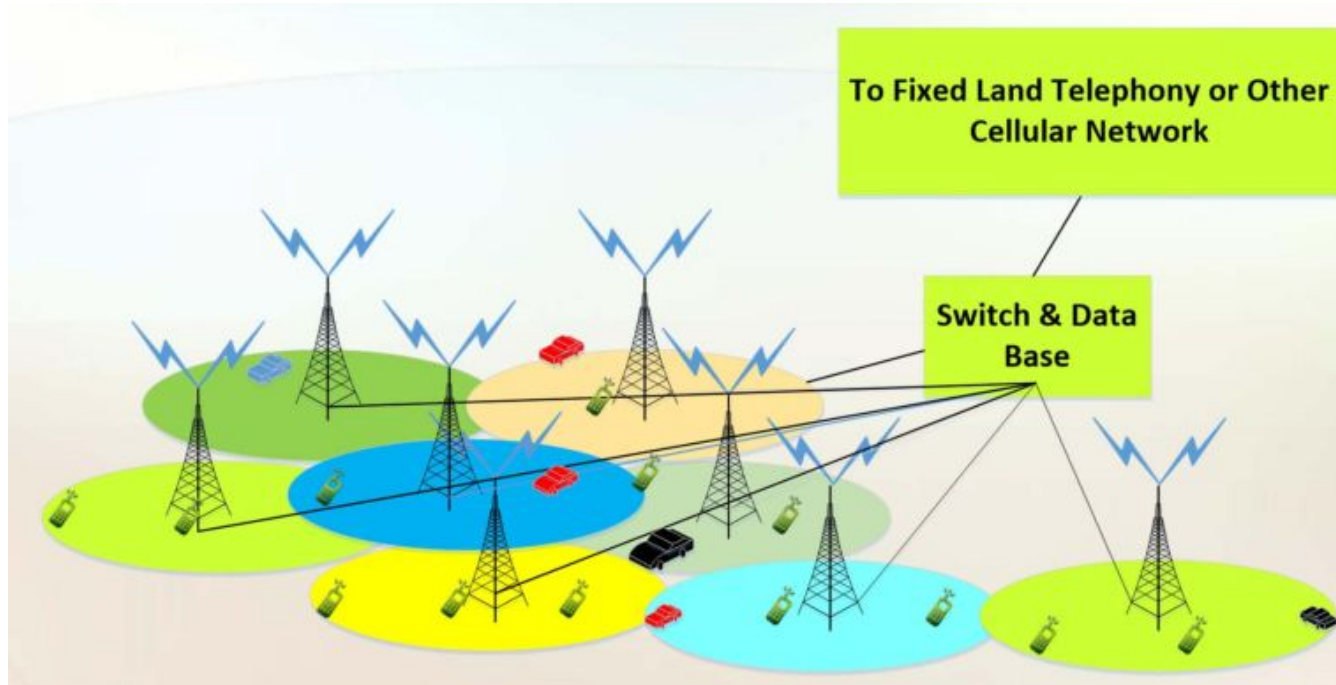
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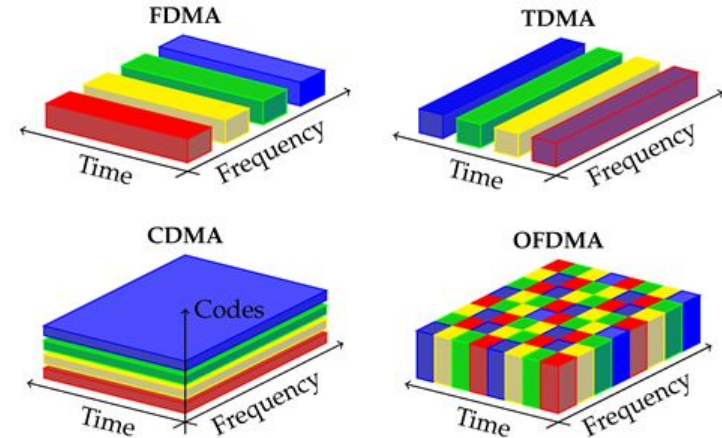


# Cellular Mobile Communications



# Demand on Cellular Mobile Communications

- Demand on cellular mobile communications is increasing
- 1G, 2G and 3G systems provided voice services
  - 2G deployed in 1990 (TDMA & FDMA)
  - 3G deployed in 2000 (CDMA)
  - 4G deployed in 2010 (OFDMA)
- The 3.5G (HSPA) and the 4G (LTE) focused on data services
- 4G LTE provided data rate up to 1 Gbps
- Still a dramatic increase in mobile users and wireless devices is anticipated



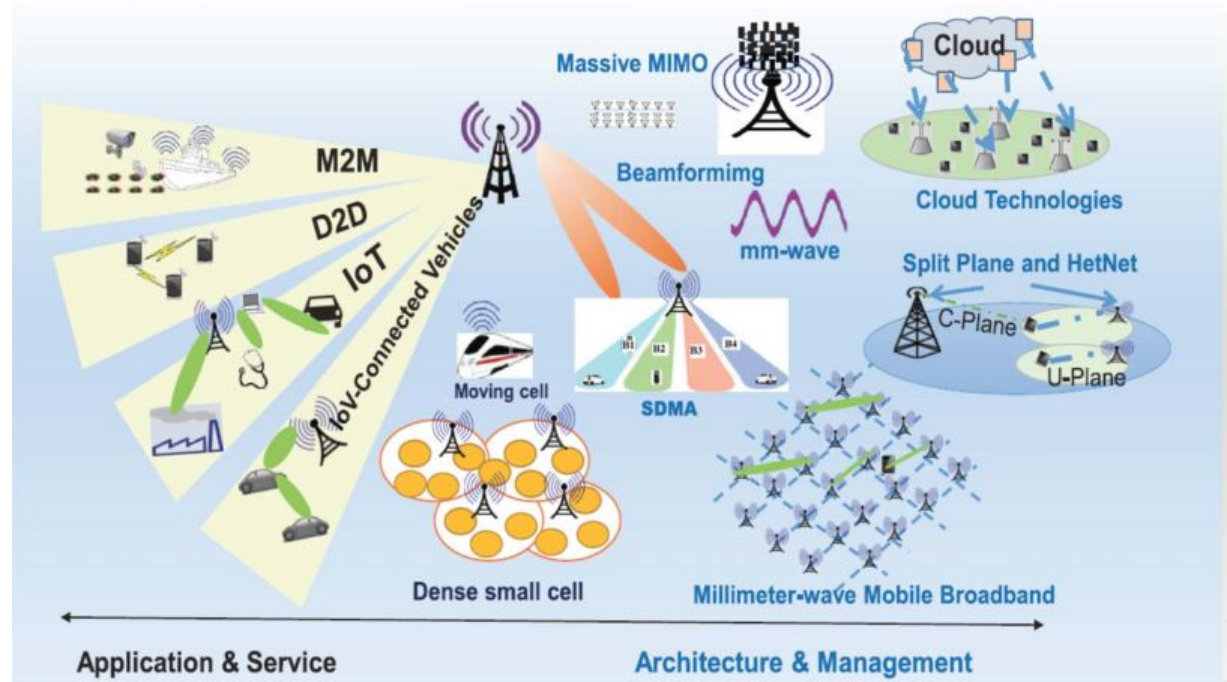
# Demand on Cellular Mobile Communications (Continued)

- Powerful smartphones, tablet PCs and laptops are popular
- Demanding real time video and multimedia capabilities
- Number of wireless connected devices increasing
- 5G systems are expected to exceed 4G:
  - 1000 times increase in capacity (connected devices/cell)
  - 10 times increase in data rate (10 Gbps)
  - 10 times spectral efficiency (data rate per Hz)
  - 25 times cell throughput ( data rate per cell)
- Several candidate technologies are under research

# What Does 5G Look Like?

## Reliable connection, anytime, anywhere

- Machine to machine
- Device to device
- Internet of things
- Internet of vehicles
- HD real time video
- Mobile gaming
- High energy efficiency
- Green systems
- Lower latency
- Higher reliability
- Wi-Fi integration

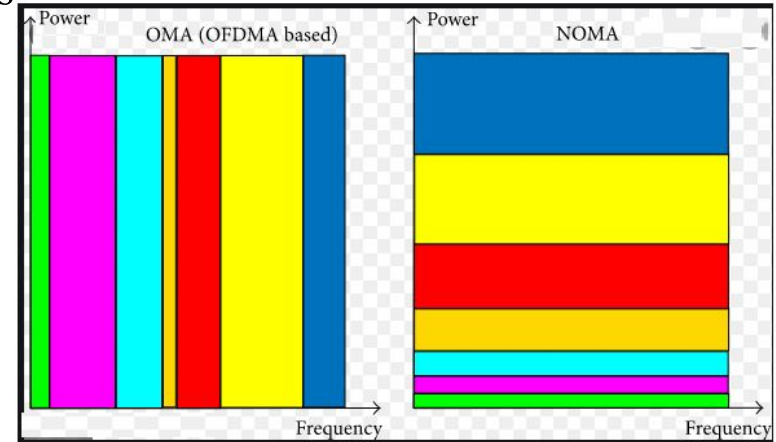


# How Can 5G Do That?

- Dense microcells
- Relay stations
- Massive number of antennas per base station and devices
- Beamforming antenna patterns
- Using millimeter waves (frequencies bands 30 to 300 GHz)
- Cognitive radio
- Non-Orthogonal Multiple Access (NOMA)

# OMA vs. NOMA

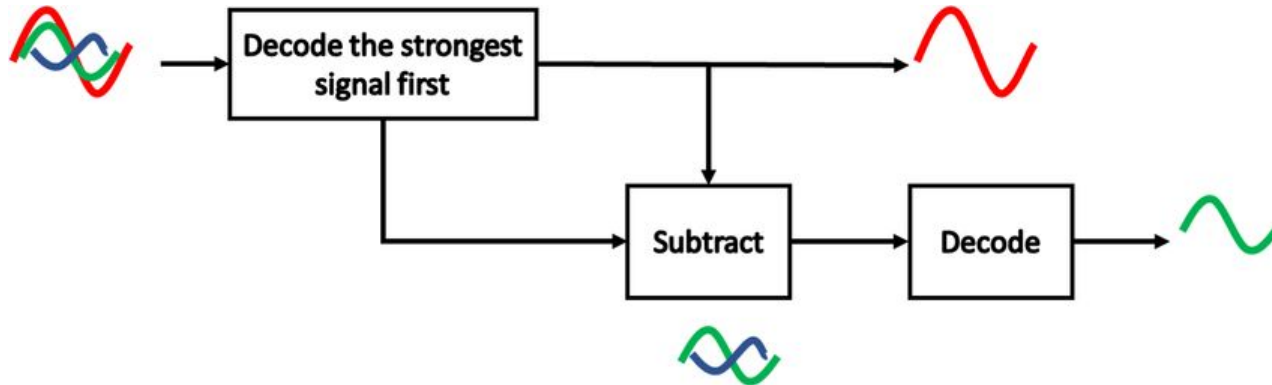
- 2G, 3G and 4G are mainly OMA systems
- Users are allocated orthogonal resources
  - Separate time slots, and
  - Separate frequency allocation



- OMA avoids inter-user interference
- Fast growth in mobile devices vs. limited available spectrum
- NOMA: new signal design, users share time & frequency

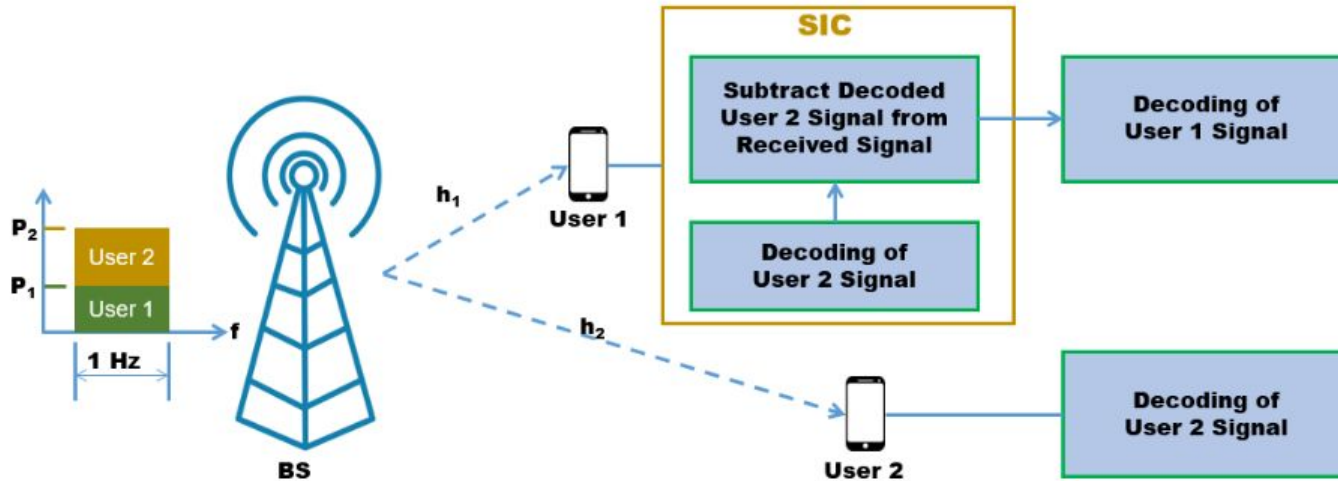
# Superposition coding & Successive interference cancellation(SIC)

- Superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver makes it possible to utilize the same spectrum for all users.
- At the transmitter site, all the individual information signals are superimposed into a single waveform, while at the receiver, SIC decodes the signals one by one until it finds the desired signal.



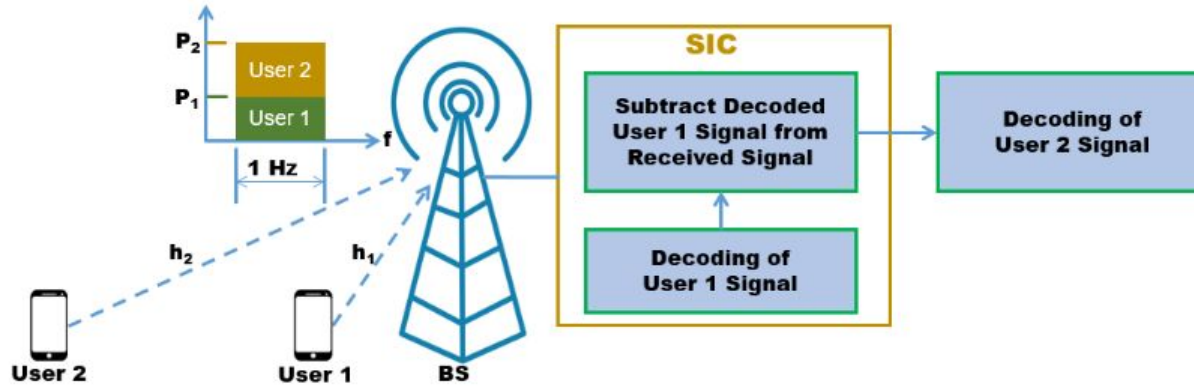
# How NOMA Works (Downlink)

- 2-user power-domain downlink NOMA



# How NOMA Works (Uplink)

- 2-user power domain uplink NOMA



# Is NOMA Beneficial?

□ Performance is measured by the Shannon channel capacity

$$C = W \log_2(1 + SNR) \text{ bits/s}$$

□ Shannon capacity (bits per second) gives the achievable data rate

- In a certain channel with bandwidth  $W$
- Certain signal to noise ratio (SNR)

□ Note that the bandwidth has a higher impact on capacity than SNR

# Capacity Comparison

In OMA each user takes half the bandwidth, but no interference

$$\text{OMA: } SNR_{near} = \frac{P_{near}}{noise} \quad \text{and} \quad SNR_{far} = \frac{P_{far}}{noise}$$

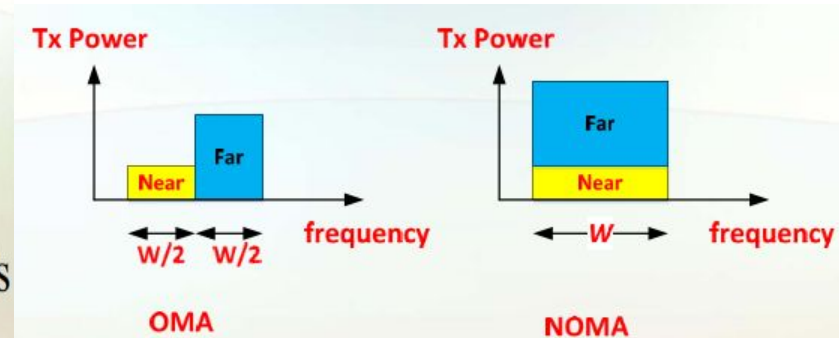
NOMA Near-user can cancel Far-user signal:  $SNR_{near} = \frac{P_{near}}{noise}$

NOMA Far-user can't cancel Near-user signal:  $SNR_{far} = \frac{P_{far}}{P_{near} + noise}$

$$C_{OMA} = \frac{W}{2} \log_2 \left( 1 + \frac{P_{near}}{noise} \right) + \frac{W}{2} \log_2 \left( 1 + \frac{P_{far}}{noise} \right) \text{ bits/s}$$

$$C_{NOMA} = W \log_2 \left( 1 + \frac{P_{near}}{noise} \right) + W \log_2 \left( 1 + \frac{P_{far}}{P_{near} + noise} \right) \text{ bits/s}$$

$$P_{far} + P_{near} = P_{total} = \text{constant}$$

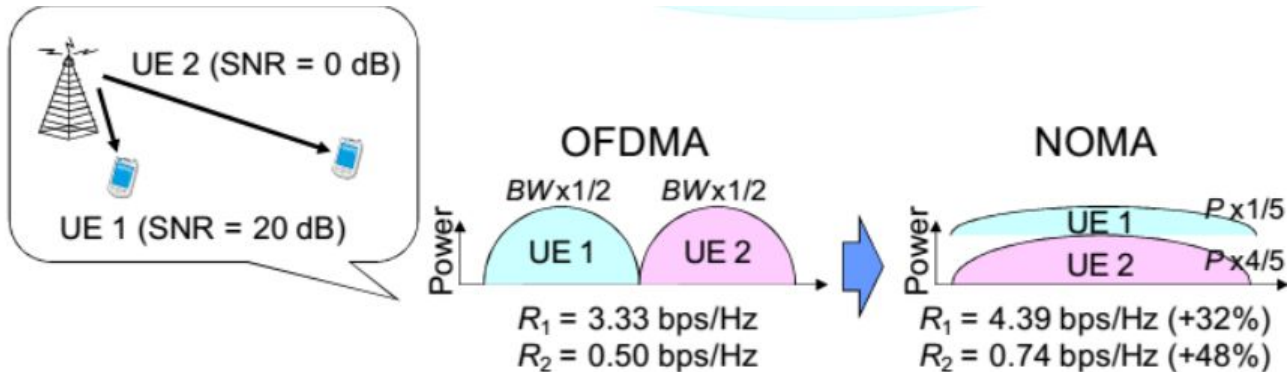


# Capacity Comparison (continued)

$$C_{OMA} = \frac{W}{2} \log_2 \left( 1 + \frac{P_{near}}{noise} \right) + \frac{W}{2} \log_2 \left( 1 + \frac{P_{far}}{noise} \right) \text{ bits/s}$$

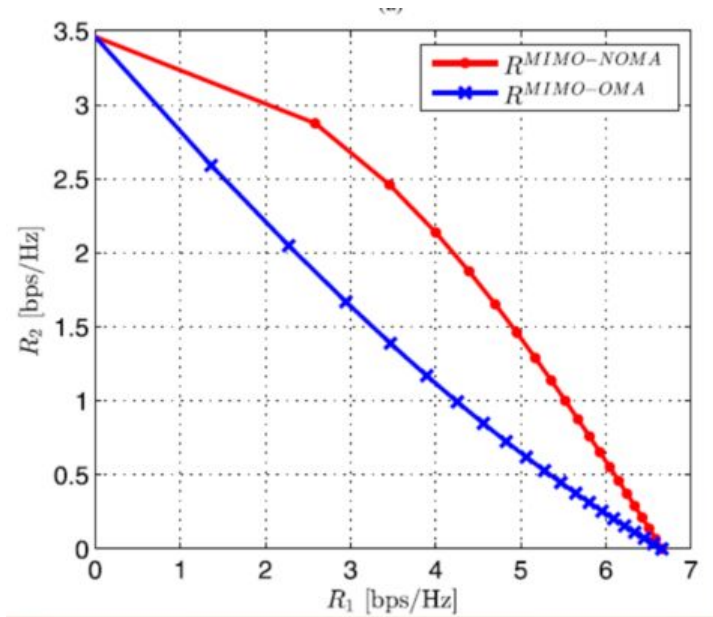
$$C_{NOMA} = W \log_2 \left( 1 + \frac{P_{near}}{noise} \right) + W \log_2 \left( 1 + \frac{P_{far}}{P_{near} + noise} \right) \text{ bits/s}$$

$$P_{far} + P_{near} = P_{total} = \text{constant}$$

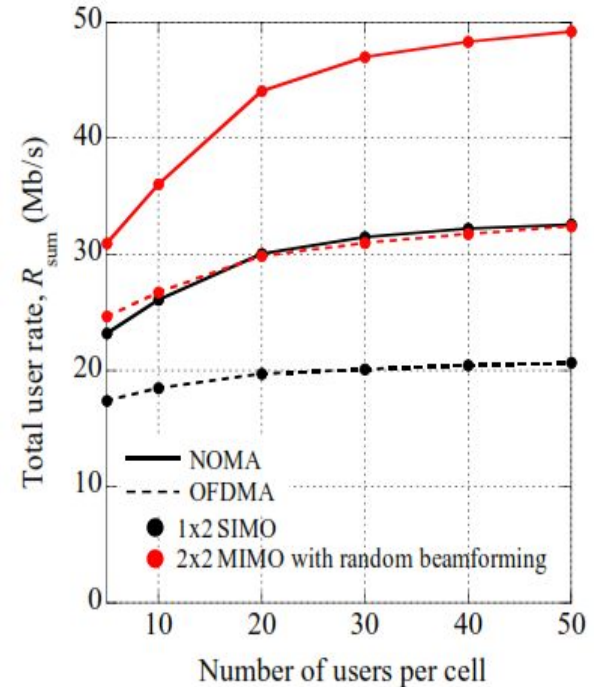


# Capacity Comparison (continued)

The trade-off between Near-user and Far-user is better in NOMA



System-level evaluation for proposed NOMA/MIMO scheme applying opportunistic random beamforming in downlink



# Conclusions

- NOMA is based on sharing resources between users
- Sharing allows higher sum of data rate
- Can help increase number of users and higher data rate
- Adopted as a candidate for 5G
- Considerable research is going on to put it into practice