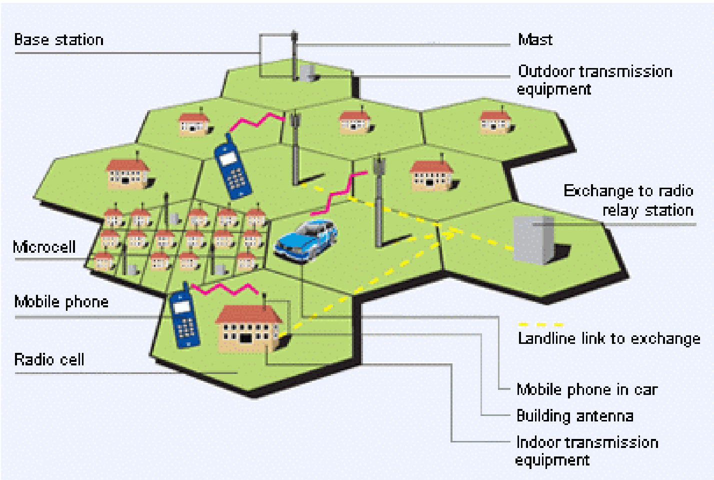
Cellular networks



- How do cellular networks manage spectrum access?
  - FDMA?
  - TDMA?
  - CDMA?
  - Power management?

All of the above!

History of cellular networks

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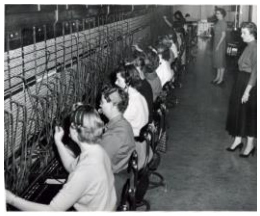

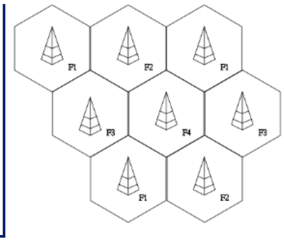

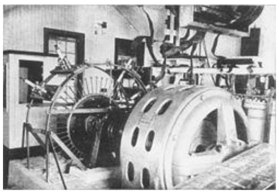

- Hexagonal cells
- Signaling standards
- Handoffs
- Handheld phone

1910

1947
MTS

1965
IMTS – 0G

1970s

Mountains & Minds

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History of cellular networks

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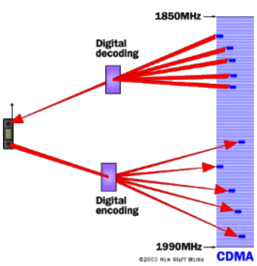

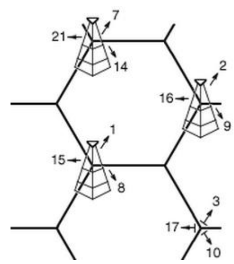

1980s 1G	1990s 2G	2.5G	2.75G	2000s 3G
Analog signal	GSM	GPRS	EDGE	HSPA
28kbit/s modem	CDMA	1xRTT	EV-DO	EV-DO
	SMS	144 kbit/s	236 kbit/s	2 Mbit/s indoors 384 kbit/s outdoors

Mountains & Minds

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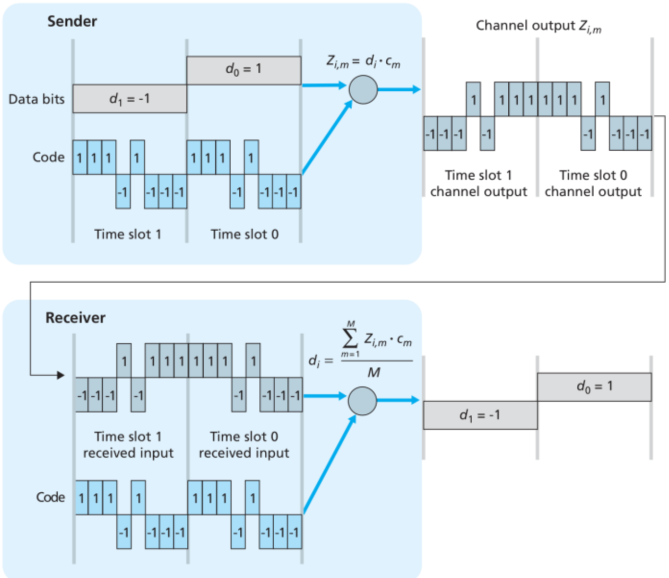
CDMA/CA (not CSMA/CA)



- Carrier signal generated at a *chipping rate* faster than transmission rate
- Data bits $d_0, d_1, \ldots$ represented as ± 1
- Transmissions can deal with interference

Decode d_i from the following received symbols: `1,1,1,1,1,-1,-1,-1`

$$d_i = \frac{\sum_{m=1}^{M} Z_{i,m} \cdot c_m}{M}$$

$$d_i = \frac{1*1+1*1+1*1+1*(-1)+1*1+(-1)*(-1)+(-1)*(-1)+(-1)*(-1)}{8}$$

$$d_i = \frac{7}{8} \approx 1 \text{ not } -1$$

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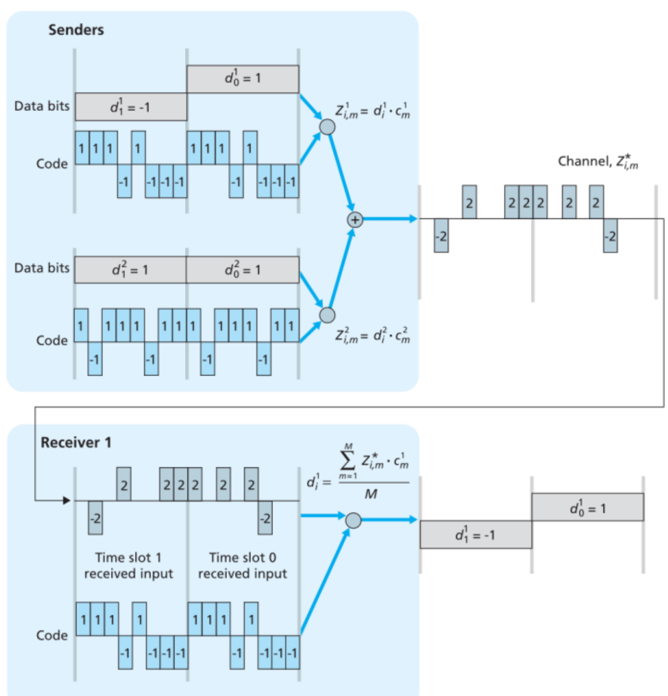
CDMA/CA with multiple senders

- Transmissions from senders, using different codes, combine at the receiver
- CDMA partitions the code space into orthogonal codes
  - 1 -1 -1 1 and 1 -1 1 -1 when multiplied together give 1 1 -1 -1 which gives the sum zero
  - Pseudo-random number (PN) codes, random numbers, are close to orthogonal
- Receiver uses same code as sender 1 to decode

$$d_i = \frac{\sum_{m=1}^{M} Z_{i,m} \cdot c_m^1}{M}$$

$$d_i = \frac{-2*1+2*(-1)+2*(-1)+2*(-1)}{8}$$

$$d_i = \frac{-8}{8} = -1$$



Mountains & Minds

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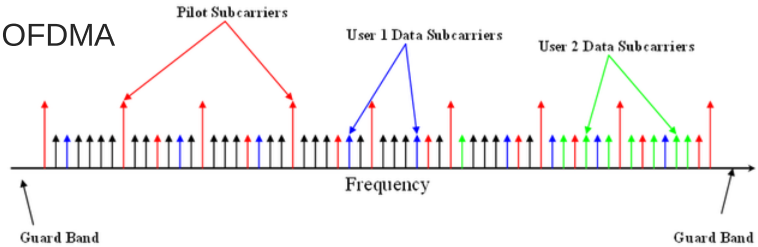
History of cellular networks

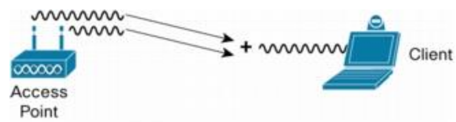
OFDMA



Disadvantages:

- Sensitive to frequency shifts
- Complex scheduling
- Difficult to coordinate between adjacent cells

MIMO



No static assignment of spectrum to cells!

LTE

WiMAX

100 Mbps

2008 4G

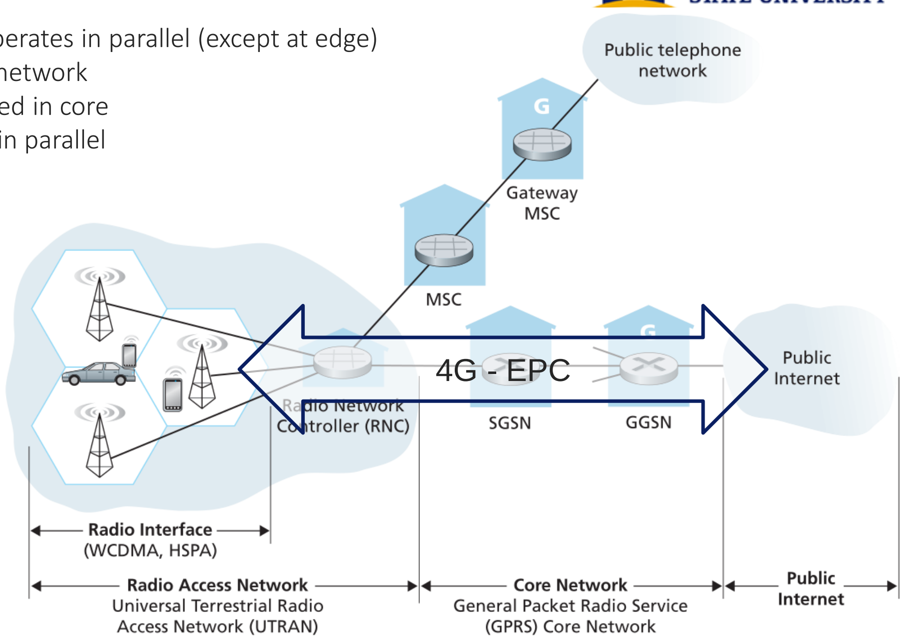
Cellular Network Architecture

3G cellular data network operates in parallel (except at edge) with existing cellular voice network

- Voice network unchanged in core
- Data network operates in parallel

4G networks are all-IP

- Evolved Packet Core (EPC) provides QoS for VoIP
- Voice and data sent through the Internet, rather than the public telephone network
- OFDMA radio network



5G

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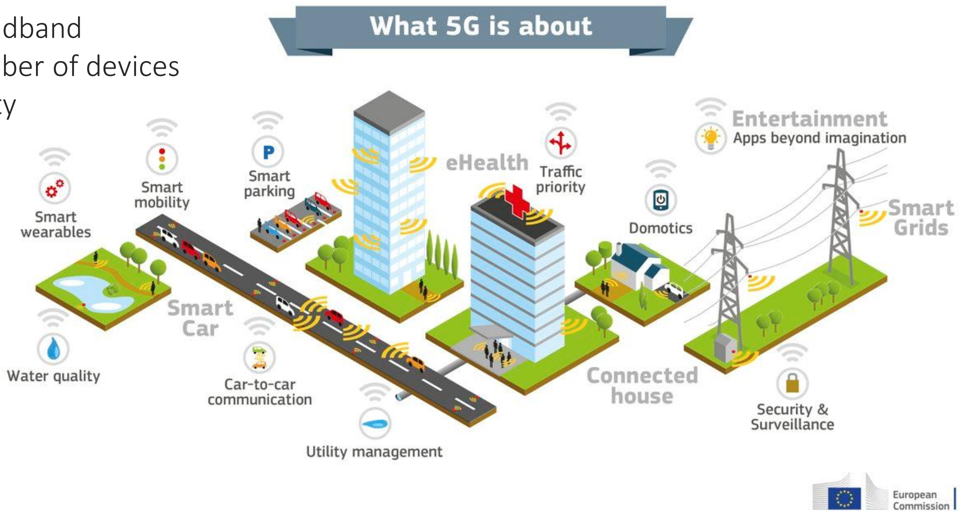
Support for:
- Massive broadband
- Massive number of devices
- High reliability



Mountains & Minds

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5G development objectives

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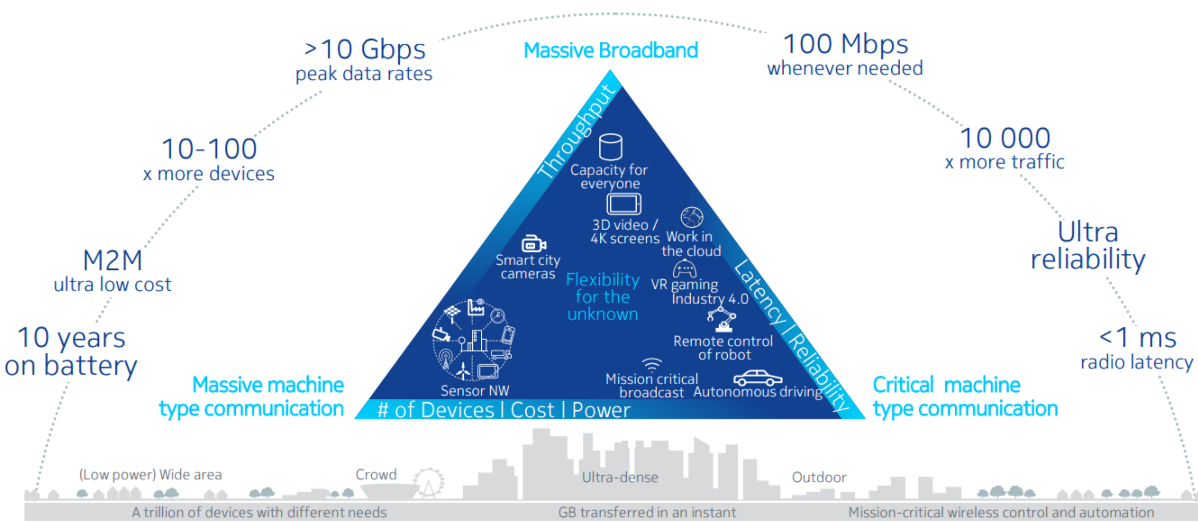

Mountains & Minds

NOKIA

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Cloud/Centralized RAN (C-RAN)

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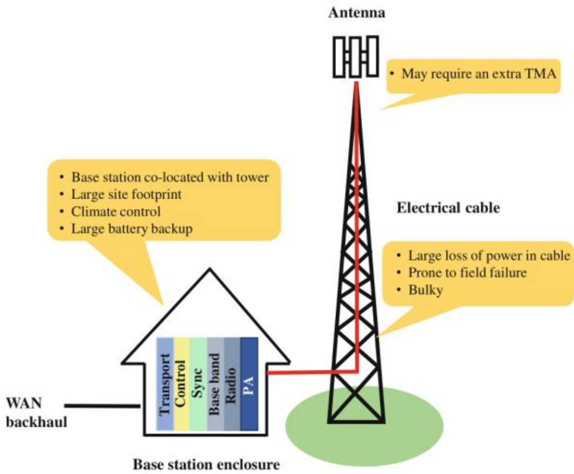
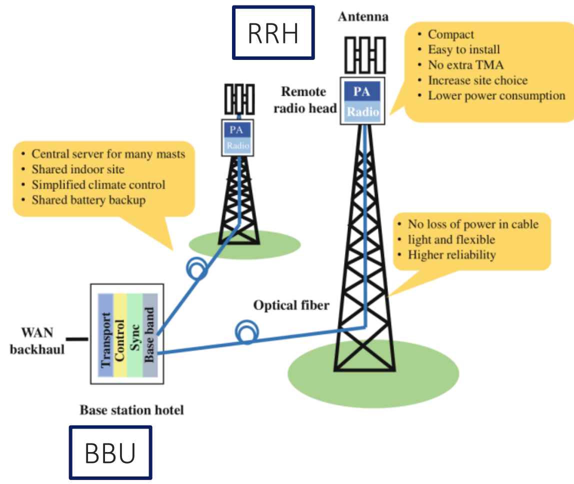
Macro-base station



C-RAN



Cloud/Centralized RAN (C-RAN)

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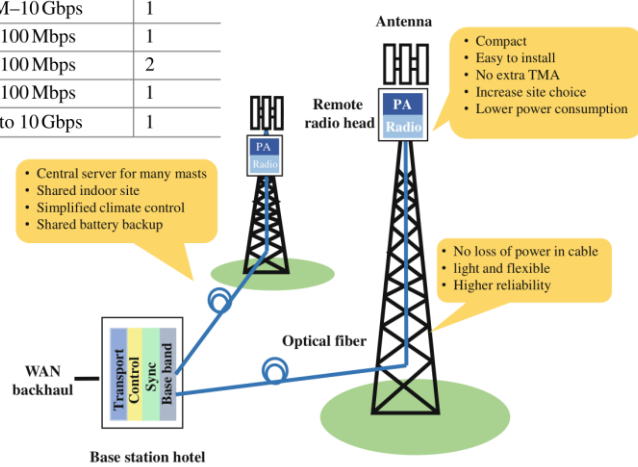
- How far can we place the BBU?

Backhaul type	Access technology	Latency (one way)	Throughput	Priority
Non-ideal	Fiber 1	10–30 ms	10 M–10 Gbps	1
	Fiber 2	5–10 ms	100–1000 Mbps	2
	Fiber 3	2–5 ms	50 M–10 Gbps	1
	DSL	15–60 ms	10–100 Mbps	1
	Cable	25–35 ms	10–100 Mbps	2
	Wireless	5–35 ms	10–100 Mbps	1
Ideal	Fiber 4	Less than 2.5 µs	Up to 10 Gbps	1

- C-RAN needs fast front haul
  - Digital radio over fiber (D-RoF) technologies such as common public radio interface (CPRI) or open base station architecture initiative (OBSAI)
  - Latency has to be low enough to process multipath/multipoint



Cloud/Centralized RAN (C-RAN)

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Feature	Benefit
BBU and RRH can be spaced miles apart	• Higher degree of deployment flexibility
Reduced space (footprint)	• Lower rental costs
	• Easier site acquisition
Lightweight RRH	• Easier installation
	• No need for feeders
Better coverage than old-style macro sites when deployed in tower-top (no feeder loss)	• Reduced total number of sites
	• No need for TMAs
Integrated maintenance and administration when	• Reduced OPEX
Reduc natural heat dissipation mode)	
	• Reduced OPEX

Enable spectrum sharing between operators. Why?

Future Trends

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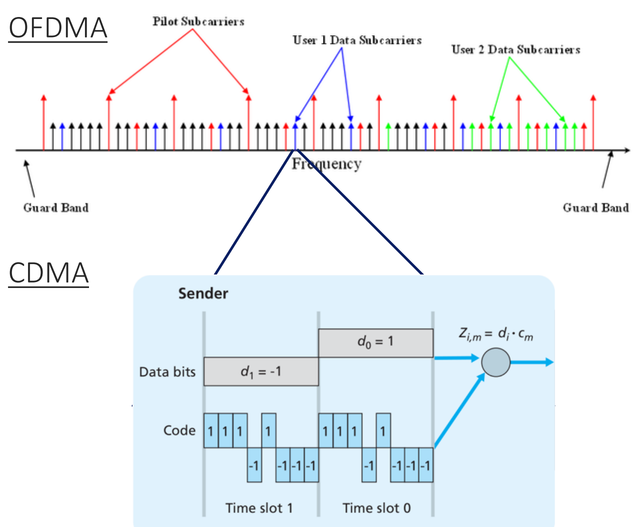
Non-orthogonal multiple access (NOMA)

- Code domain NOMA uses spreading sequences for sharing the resources.
- Power domain NOMA exploits the channel gain differences between the users for multiplexing via power allocation
- The new wave of research on NOMA is motivated by the advance of processors which make it practically implementable.



Future Trends

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Small cells

Distributed Antenna Systems

Which architecture is better?