Wireless and Mobile Communication

Short notes for B.Tech ECE · IT · GATE EC

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1. Introduction and Evolution

- **Wireless communication**: information sent over radio waves without wires. **Mobile communication**: the user can move while connected.
- **Duplexing**: FDD (separate frequencies for uplink and downlink) or TDD (same frequency, separate time slots).

Generation	Main technology	Access method	Key idea
1G	AMPS (analog voice)	FDMA	Analog FM voice
2G	GSM, IS-95 (cdmaOne)	TDMA / CDMA	Digital voice, SMS
2.5G	GPRS, EDGE	TDMA	Packet data over GSM
3G	UMTS (WCDMA), CDMA2000	CDMA	Mobile internet, video calls
4G	LTE, LTE-Advanced	OFDMA (downlink), SC-FDMA (uplink)	All-IP, high data rates
5G	NR (New Radio)	OFDMA (flexible numerology)	mmWave, massive MIMO, low latency, IoT

- 5G use cases: **eMBB** (enhanced mobile broadband), **URLLC** (ultra-reliable low latency), **mMTC** (massive machine-type communication).

2. Cellular Concept

- Divide the area into small **cells**, each served by a base station with low power.
- **Frequency reuse**: the same channels are used again in cells far enough apart.
- Cells are drawn as **hexagons** (cover area without gaps, close to a circle).

FORMULA Cluster size $N = i^2 + ij + j^2$ ($i, j = 0, 1, 2 \ldots$). Possible $N = 1, 3, 4, 7, 9, 12, 13, 19 \ldots$

FORMULA Co-channel reuse ratio $Q = D / R = \sqrt{3N}$. Signal-to-interference $S/I = (\sqrt{3N})^n / i0$, $i0 = 6$ (first tier), n = path loss exponent.

- Bigger $N \rightarrow$ less interference, but fewer channels per cell (lower capacity).
- Channels per cell = total channels / N.

➤ Solved example (S/I and channels)

- $N = 7$, path loss exponent $n = 4$, 6 co-channel interferers.
  - $Q = \sqrt{3 \times 7} = \sqrt{21} = 4.583$
  - $Q^4 = 21^2 = 441$, $S/I = 441 / 6 = 73.5$
  - S/I in dB $= 10 \log 73.5 =$ 18.7 dB (meets the common 18 dB target for analog systems)
- Total spectrum 33 MHz, each duplex channel = 2 x 25 kHz = 50 kHz.
  - Total channels = 33 MHz / 50 kHz = 660
  - With $N = 7$: channels per cell = $660 / 7 \approx$ 94

➤ Improving capacity

Method	Idea	Effect
Cell splitting	Divide a cell into smaller cells with lower power	More reuse, more capacity
Sectoring	Use directional antennas (3 x 120° or 6 x 60°)	Fewer interferers ($i0 = 2$ for 120°), better S/I
Microcells / zone concept	Small zones served by one base station	Less interference, fewer handoffs

➤ Handoff (handover)

- **Handoff** = moving an ongoing call from one base station (or channel) to another.
- **Hard handoff**: break before make (GSM). **Soft handoff**: make before break, connected to several cells (CDMA).
- Handoff margin Δ = Pr(handoff) − Pr(minimum usable). Too small → too many handoffs; too large → dropped calls.

➤ Trunking and grade of service

- **Erlang** = traffic intensity. One channel busy all the time = 1 Erlang.

FORMULA Traffic per user Au = λ H (λ = calls per hour, H = holding time in hours). Total A = U Au.

EXAMPLE 100 users, each 2 calls/hour of 3 minutes: Au = 2 x 3 / 60 = 0.1 E, total A = 10 E.

- **GOS** (grade of service) = probability of a call being blocked. **Erlang B** (blocked calls cleared), **Erlang C** (blocked calls delayed).

3. Large-Scale Propagation (Path Loss)

FORMULA Free space: Pr = Pt Gt Gr λ^2 / ((4π)^2 d^2). Power falls as 1/d^2 (20 dB per decade).

FORMULA Two-ray ground reflection (large d): Pr = Pt Gt Gr ht^2 hr^2 / d^4 (40 dB per decade, independent of frequency).

- **Log-distance model**: PL(d) = PL(d0) + 10 n log(d / d0). n = 2 free space, about 2.7 to 3.5 urban, 4 to 6 inside buildings (approx).
- **Shadowing**: buildings and hills cause random variation around the mean → **log-normal** distribution (in dB).
- Empirical models: **Okumura** (curves), **Hata** (formula for Okumura data), **COST-231** (extension to higher frequencies).
- Mechanisms: **reflection** (large smooth surfaces), **diffraction** (edges, lets signal reach shadow regions), **scattering** (rough surfaces, small objects).

4. Small-Scale Fading

- **Multipath**: many copies of the signal arrive with different delays and phases and add up → fast fading.
- **Delay spread** στ (rms) → **coherence bandwidth** Bc. **Doppler spread** fd → **coherence time** Tc.

FORMULA $B_c \approx 1 / (50\,\sigma_\tau)$ (90% correlation) or $1 / (5\,\sigma_\tau)$ (50% correlation).

FORMULA Doppler shift $f_d = (v / \lambda)\cos\theta$. Max Doppler $f_m = v / \lambda$. Coherence time $T_c \approx 0.423 / f_m$.

➤ Types of fading

Based on	Type	Condition
Delay spread	Flat fading	Signal BW << Bc (symbol time >> σ_τ)
Delay spread	Frequency-selective fading	Signal BW > Bc → ISI
Doppler spread	Slow fading	Symbol time << Tc
Doppler spread	Fast fading	Symbol time > Tc

- **Rayleigh fading**: no line-of-sight path (many scattered paths). **Rician fading**: one strong LOS path + scattered paths (K-factor = LOS power / scattered power).

➤ Solved example (Doppler)

- Vehicle speed 72 km/h = 20 m/s, carrier 900 MHz.
  - $\lambda = 3 \times 10^8 / 9 \times 10^8 = 1/3$ m
  - $f_m = v / \lambda = 20 / (1/3) =$ 60 Hz
  - $T_c \approx 0.423 / 60 =$ 7.05 ms
  - A GSM time slot (about 0.577 ms) is much shorter than Tc, so the channel is slow fading within a slot.

5. Diversity and Equalisation

- **Diversity**: send or receive the same information over independent fading paths, so all paths are unlikely to fade together.
- Types: **space** (several antennas spaced apart), **frequency**, **time** (interleaving + coding), **polarisation**, **angle**.
- Combining: **selection** (pick strongest), **equal gain**, **maximal ratio combining (MRC)** (weights ∝ SNR of each branch; best). With MRC, output SNR = sum of branch SNRs.
- **RAKE receiver** (CDMA): separate fingers catch different multipath copies and combine them.

- **Equaliser**: removes ISI from frequency-selective channels (linear, decision feedback, adaptive LMS / RLS).

6. Multiple Access and Spread Spectrum

Method	Users share	Example	Note
FDMA	Frequency bands	AMPS	Guard bands needed, simple
TDMA	Time slots	GSM	Needs sync, guard times
CDMA	Codes (same time, same band)	IS-95, WCDMA	Soft capacity, needs power control (near–far problem)
OFDMA	Groups of orthogonal subcarriers	LTE, 5G, Wi-Fi 6	Handles multipath well
SDMA	Space (narrow beams)	Smart antennas, massive MIMO	Reuse in the same cell

➤ Spread spectrum

- Signal is spread over a band much wider than needed. Gives anti-jamming, low detectability, multiple access.
- **DSSS**: data multiplied by a fast PN chip sequence. **FHSS**: carrier hops between frequencies by a PN pattern (Bluetooth uses FHSS).

FORMULA Processing gain $PG = Rc / Rb$ = chip rate / bit rate (= spread BW / data BW).

EXAMPLE $Rc = 1.2288$ Mcps, $Rb = 9.6$ kbps: $PG = 128 \rightarrow 10 \log 128 = 21.1$ dB.

- PN sequences (maximal length): length $2^m - 1$ for an m-stage shift register.
- **Near–far problem**: a nearby user drowns a far user in CDMA; solved by fast **power control**.

➤ OFDM

- Splits a high-rate stream into many low-rate streams on **orthogonal subcarriers** spaced $\Delta f = 1 / Tu$ (Tu = useful symbol time).
- Implemented with **IFFT** at the transmitter and **FFT** at the receiver.
- **Cyclic prefix** (copy of the end of the symbol placed at the start) longer than the delay spread removes ISI.

- Drawbacks: high **PAPR** (peak-to-average power ratio), sensitive to frequency offset. That is why LTE uplink uses SC-FDMA.

➤ MIMO

- Multiple antennas at transmitter and receiver.
- **Spatial multiplexing** (more data rate), **diversity** (more reliability, e.g. Alamouti code), **beamforming** (more range).
- Capacity grows about linearly with min(Nt, Nr) in rich scattering.

7. GSM System

- Architecture: **MS** (mobile + SIM) → **BTS** → **BSC** (base station subsystem) → **MSC** (switching) with **HLR** (home register), **VLR** (visitor register), **AuC** (authentication), **EIR** (equipment identity).
- Channel spacing 200 kHz, 8 time slots per carrier, TDMA frame = 4.615 ms, slot ≈ 577 µs, modulation GMSK.
- Gross rate per carrier = 270.833 kbps.
- Logical channels: traffic channels (TCH) and control channels (BCCH, CCCH, DCCH).

EXAM POINT Do not mix HLR and VLR. HLR = permanent database of own subscribers. VLR = temporary data of users currently in the MSC area.

8. Wireless Networks (short)

Technology	Standard	Range	Note
Wi-Fi	IEEE 802.11	Tens of metres	WLAN, CSMA/CA
Bluetooth	IEEE 802.15.1 (origin)	About 10 m	WPAN, FHSS in 2.4 GHz
Zigbee	IEEE 802.15.4	Tens of metres	Low power, sensor networks
WiMAX	IEEE 802.16	Several km	Broadband wireless access

9. Most Asked Questions (practice)

1. Explain the cellular concept and frequency reuse. Derive Q = sqrt(3N).
2. Find S/I for a given cluster size and path loss exponent.

3. Explain cell splitting and sectoring; how they increase capacity.
4. Compare hard and soft handoff.
5. Define Erlang and GOS; solve a trunking numerical.
6. Derive the two-ray ground reflection model.
7. Explain coherence bandwidth and coherence time; classify fading.
8. Compare FDMA, TDMA, CDMA and OFDMA.
9. Explain OFDM and the role of the cyclic prefix.
10. Draw and explain the GSM architecture.

TIP GATE EC mostly asks Doppler, coherence time/bandwidth, processing gain and OFDM basics from this subject. For university exams, also learn cellular capacity numericals and GSM architecture.