Mobile Communications (KECE425)

Lecture Note 1

03-03-2014

Prof. Young-Chai Ko

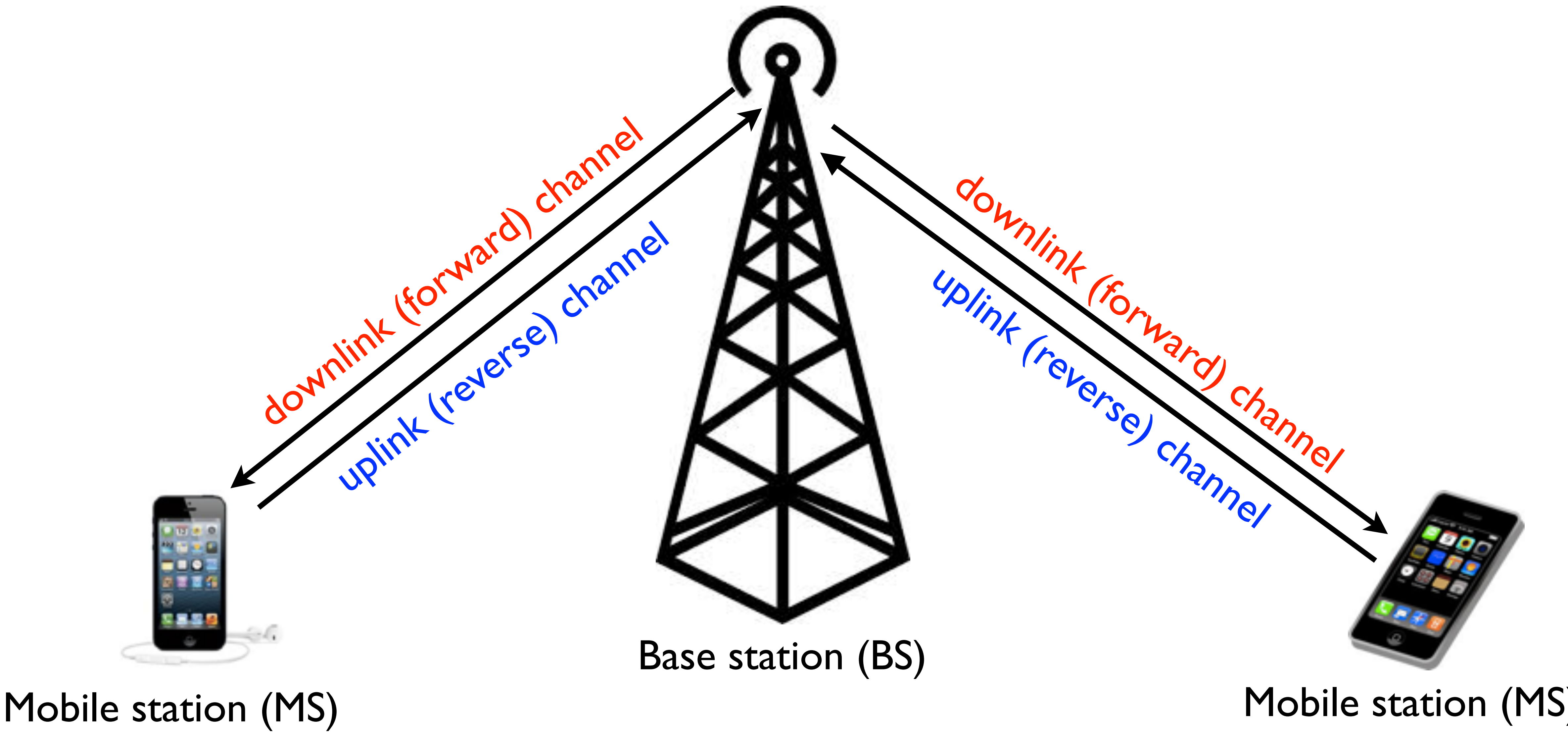
Course Information

- Instructor
  - Prof. Young-Chai Ko (koyc@korea.ac.kr, Tel: x3254, Room#416)
- Textbook
  - Principles of mobile communications (by G. Stuber)
  - Wireless communications (by A. Goldsmith)
- Grading
  - Midterm (40%), Final (45%), Homework (10%), Attendance (5%)
- Office Hour: (1:00-2:00 PM on Mon. and Wed.)
- TA
  - Young-Jun Kim and Sungkyung Jo (x3778)

Summary

- Introduction
- Downlink and uplink channels
- Half duplex division (HDD) and full duplex division (FDD)
- TDD and FDD
- Cellular concept

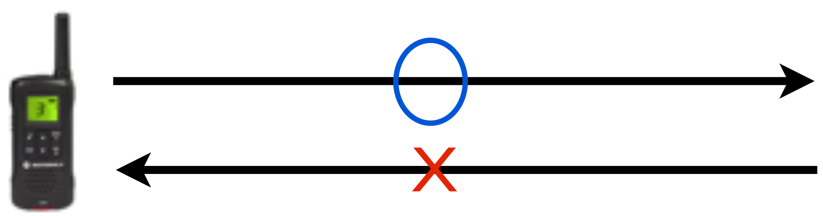
Basic Mobile Communications



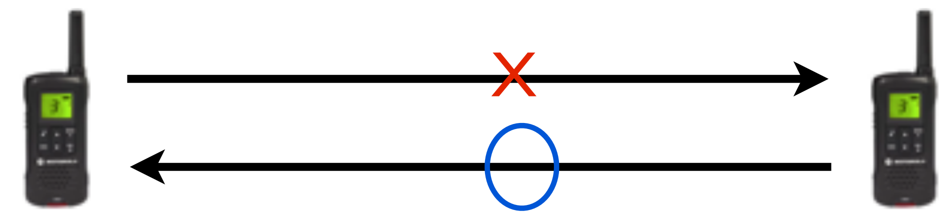
A direct link is not allowed yet between two communication parties !

Half Duplex and Full Duplex

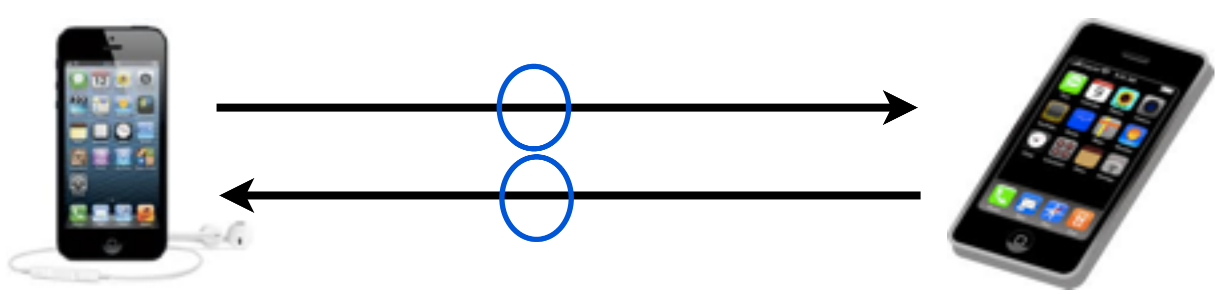
- Half-duplex
  - Walkie-Talkie (push and talk)



or



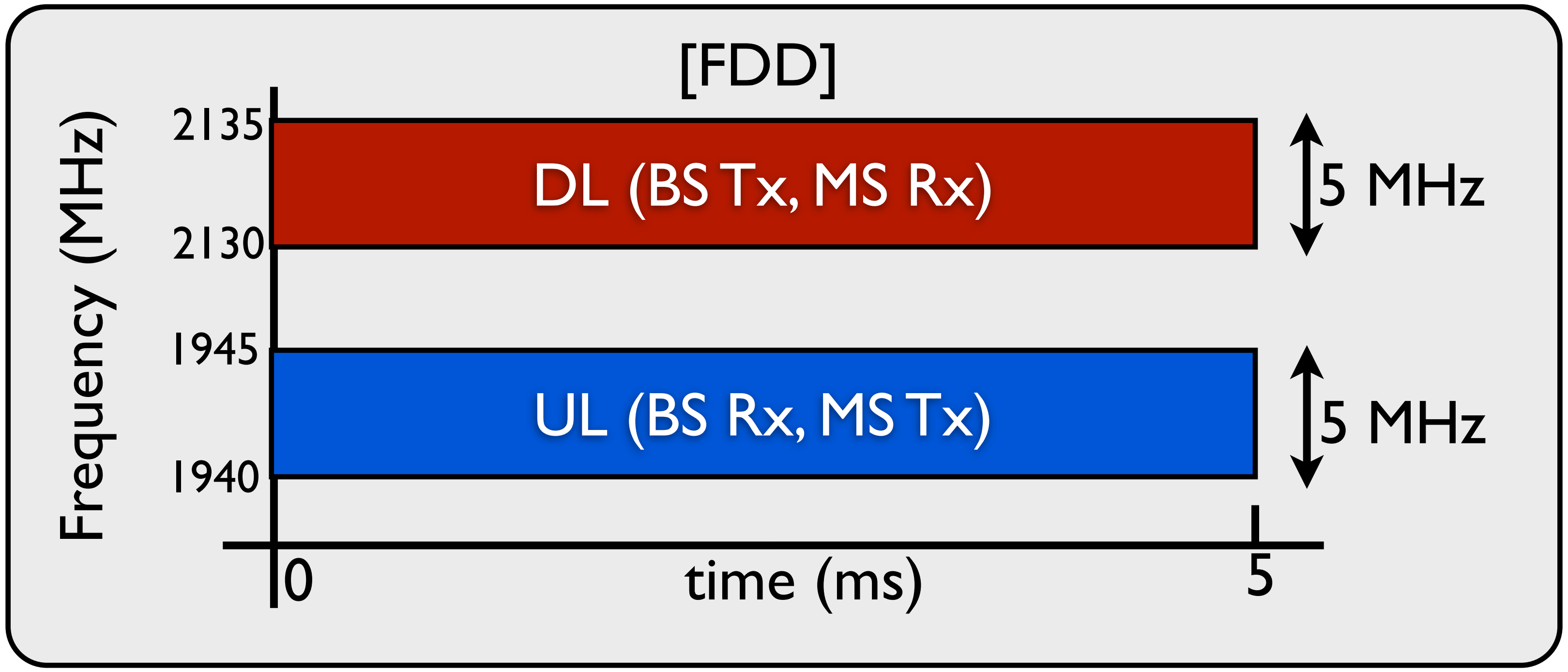
- Full-duplex
  - Full-duplex emulation
    - Time division duplex (TDD) or frequency division duplex (FDD)



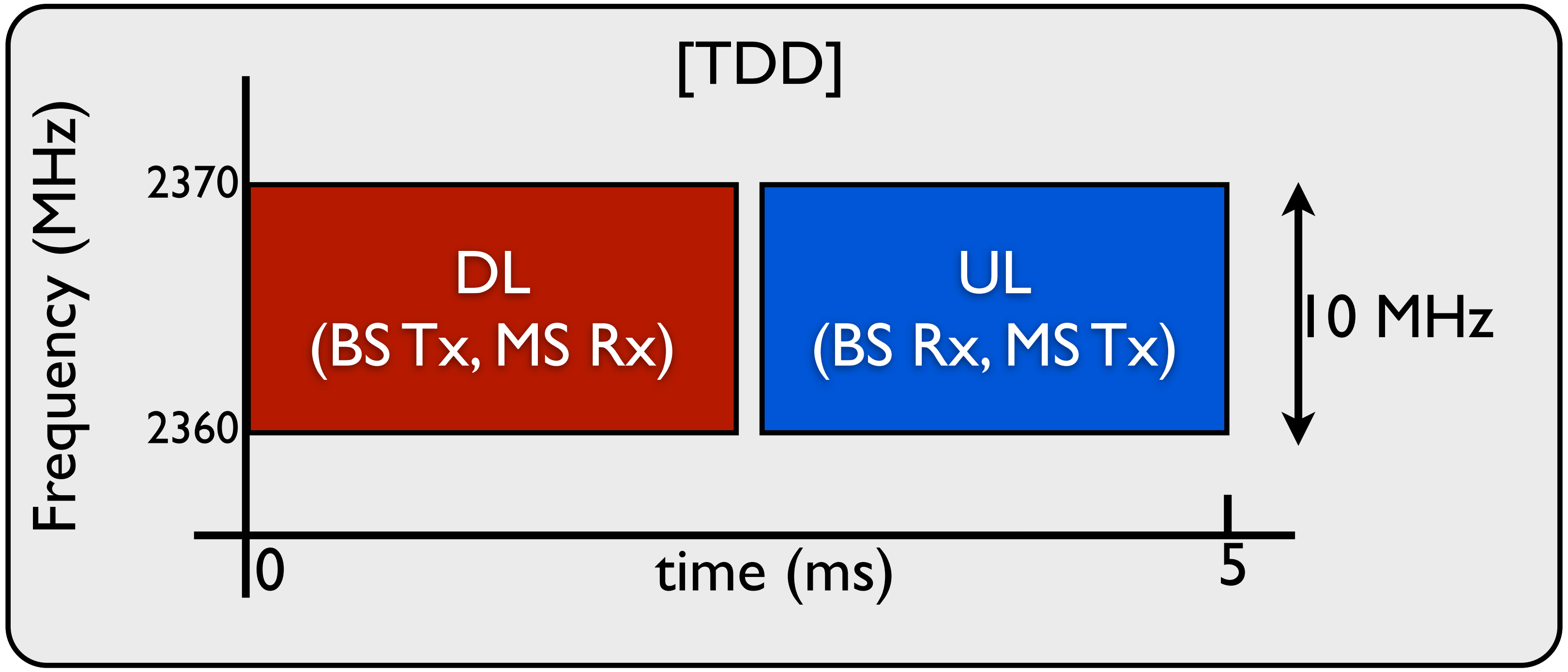
Frequency Band Allocation for Mobile Service Companies

Company	Frequency band (MHz)	Bandwidth	Systems
SKT	824~834 (10) / 869~879 (10)	20 MHz	2G (CDMA)
	834~839(5) / 879~884(5)	10 MHz	3G or LTE
	1755~1765(10) / 1850~1860(10)	20 MHz	3G or LTE
	1930~1940(10) / 2120~2130(10)	20 MHz	3G or LTE
	1940~1960(20) / 2130~2150(20)	40 MHz	3G or LTE
	2300~2327(27)	27 MHz	WiBro
	Total	137 MHz	
KT	819~824(5) / 864~869(5)	10 MHz	3G or LTE
	905~915(10) / 950~960(10)	20 MHz	3G or LTE
	1745~1755(10) / 1840~1850(10)	20 MHz	2G, 3G or LTE
	1960~1980(20) / 2150~2170(20)	40 MHz	3G or LTE
	2331.5~2358.5(27)	27 MHz	WiBro
	Total	117 MHz	
LGU+	839~849(10) / 884~894(10)	20 MHz	3G or LTE
	1779~1780(10) / 1860~1870(10)	20 MHz	2G, 3G or LTE
	1920~1930(10) / 2110~2120(10)	20 MHz	3G or LTE
	Total	60 MHz	

FDD vs. TDD



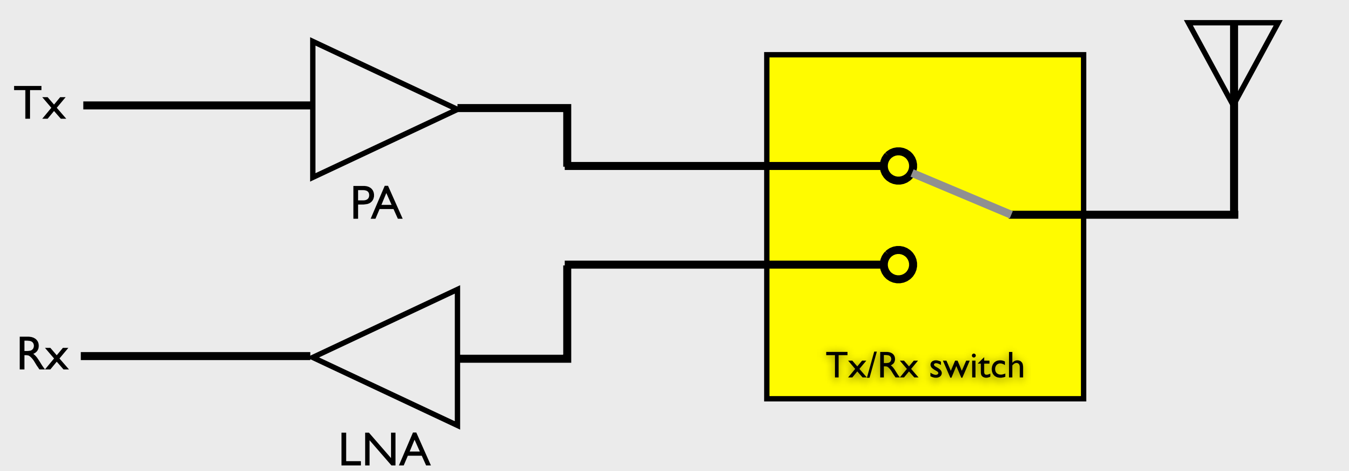
- FDD transmits and receives on two frequency bands simultaneously.
  - 2X5MHz so total bandwidth is 10MHz.
  - For binary modulation, total data transmitted is 5MbpsX5ms
  - Total data received is 5MbpsX5ms



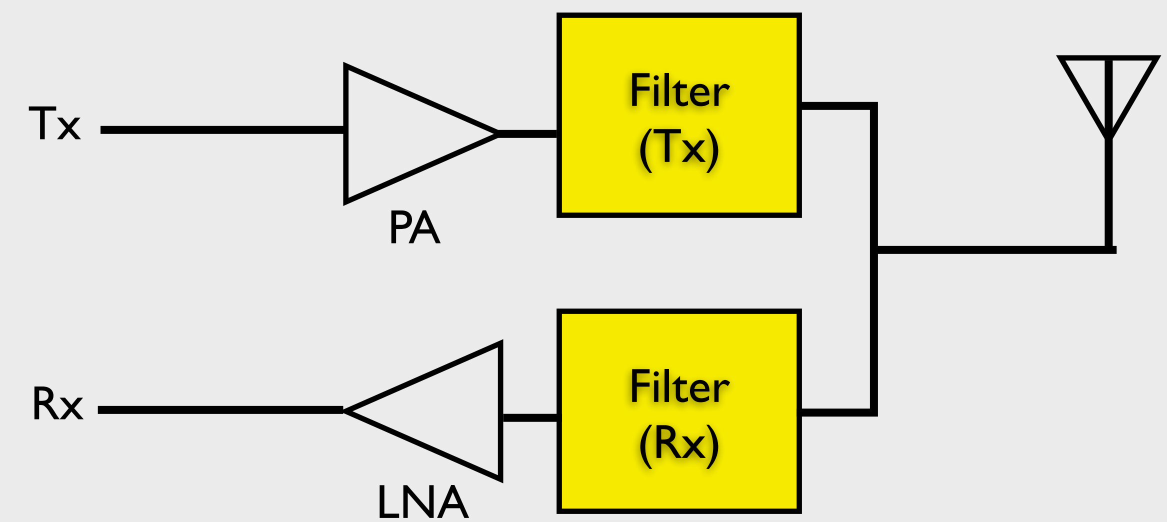
- TDD transmits and receives on two time slots simultaneously.
  - Total bandwidth is 10MHz.
  - Total data transmitted is 10MbpsX2.5ms
  - Total data received is 10MbpsX2.5ms

FDD vs. TDD

- In terms of data throughput, FDD and TDD are identical.
- FDD uses half the bandwidth for twice the time compared to TDD, so overall data transmitted is the same whether TDD or FDD is used.



[TDD RF front end]

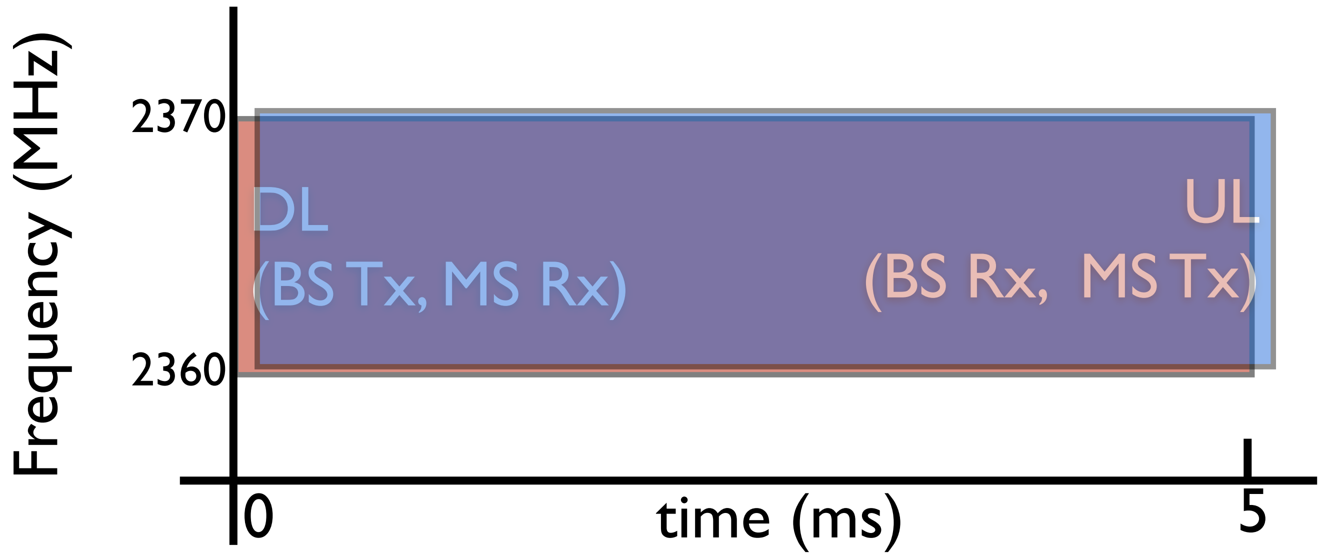


[FDD RF front end]

PA: Power amplifier

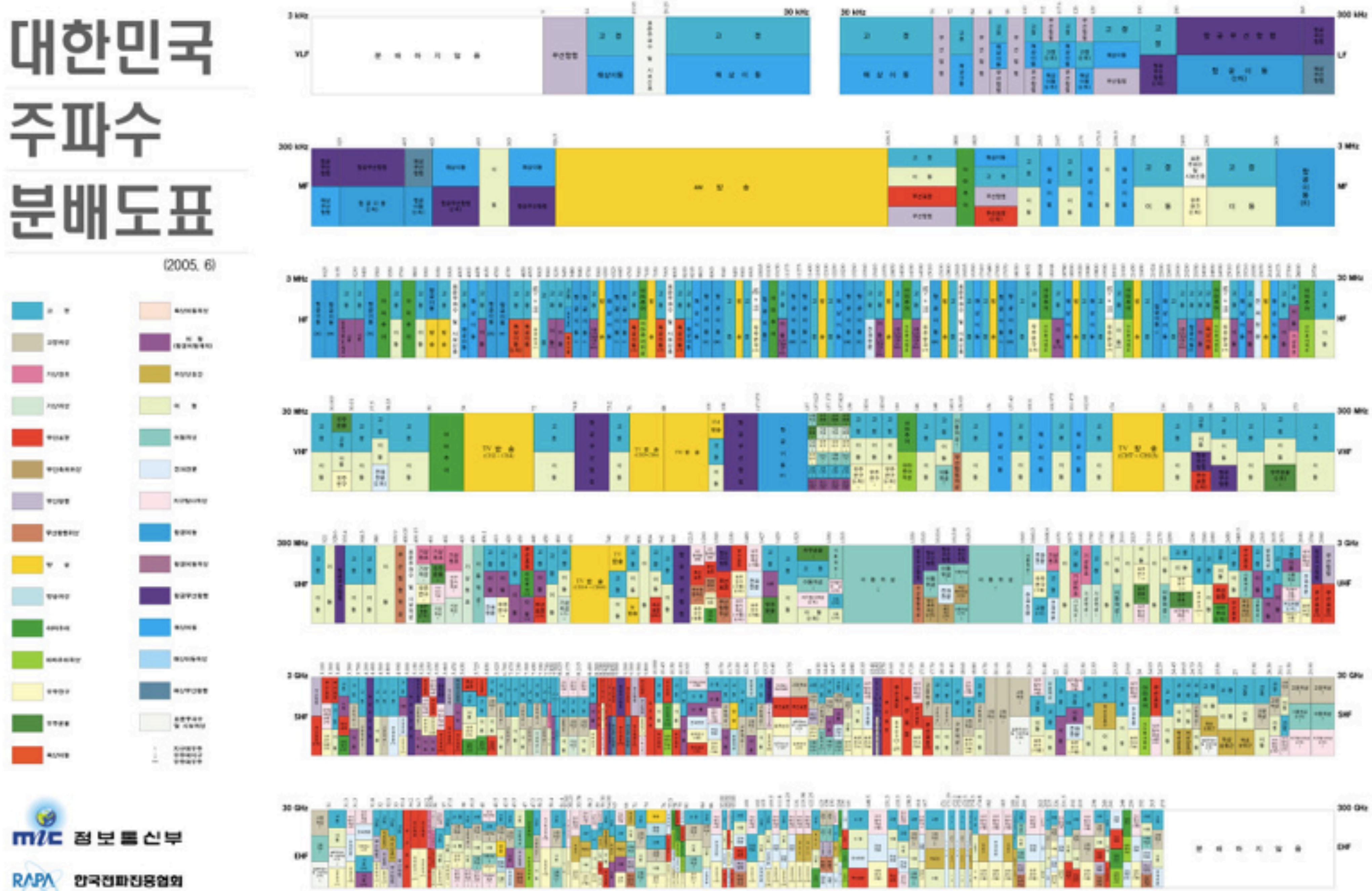
LNA: Low noise amplifier

“Real” Full-Duplex

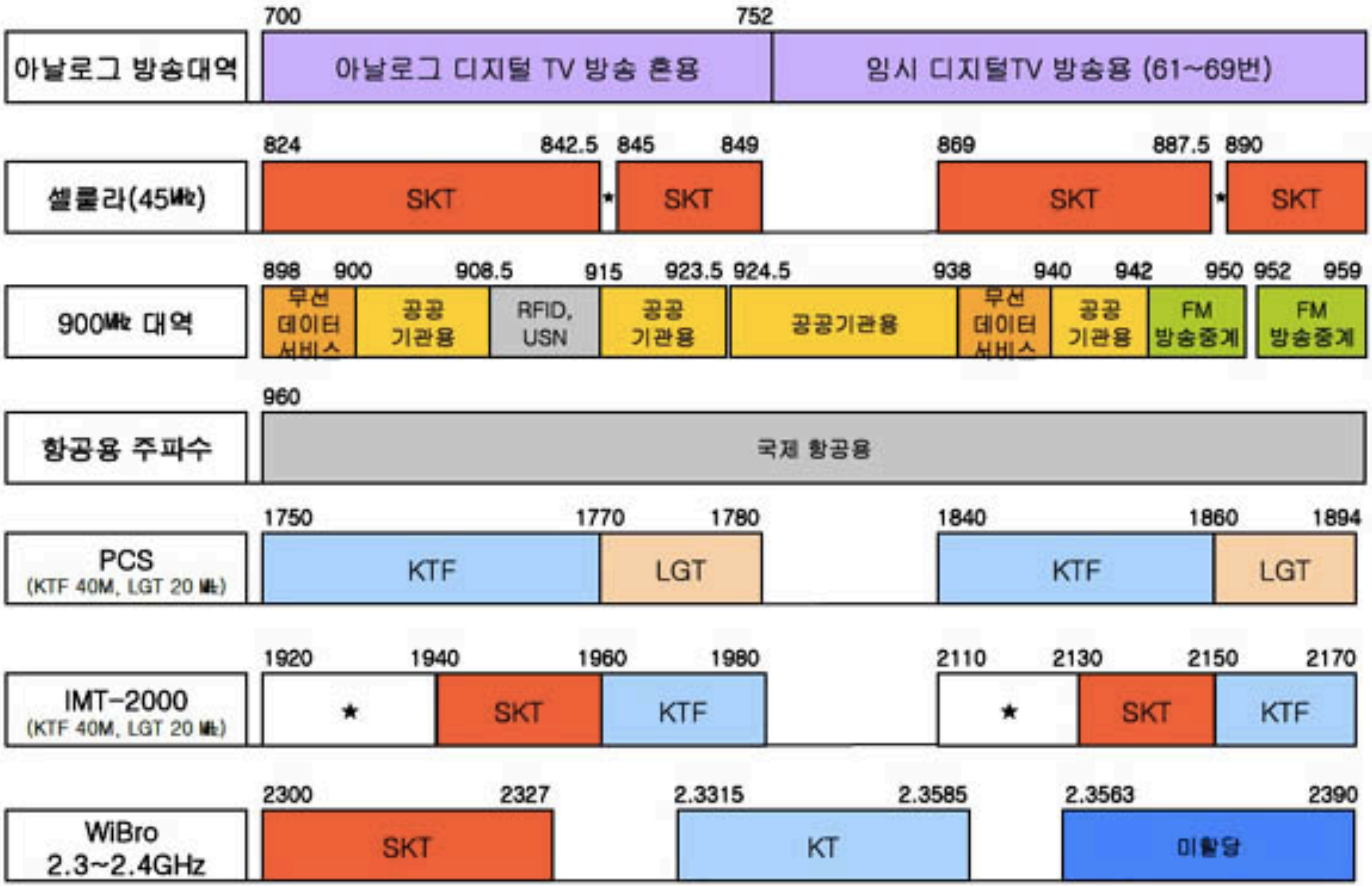


Co-time and co-frequency transmission/reception will be “real” implementation of full-duplex!

Frequency Allocation per Frequency Band

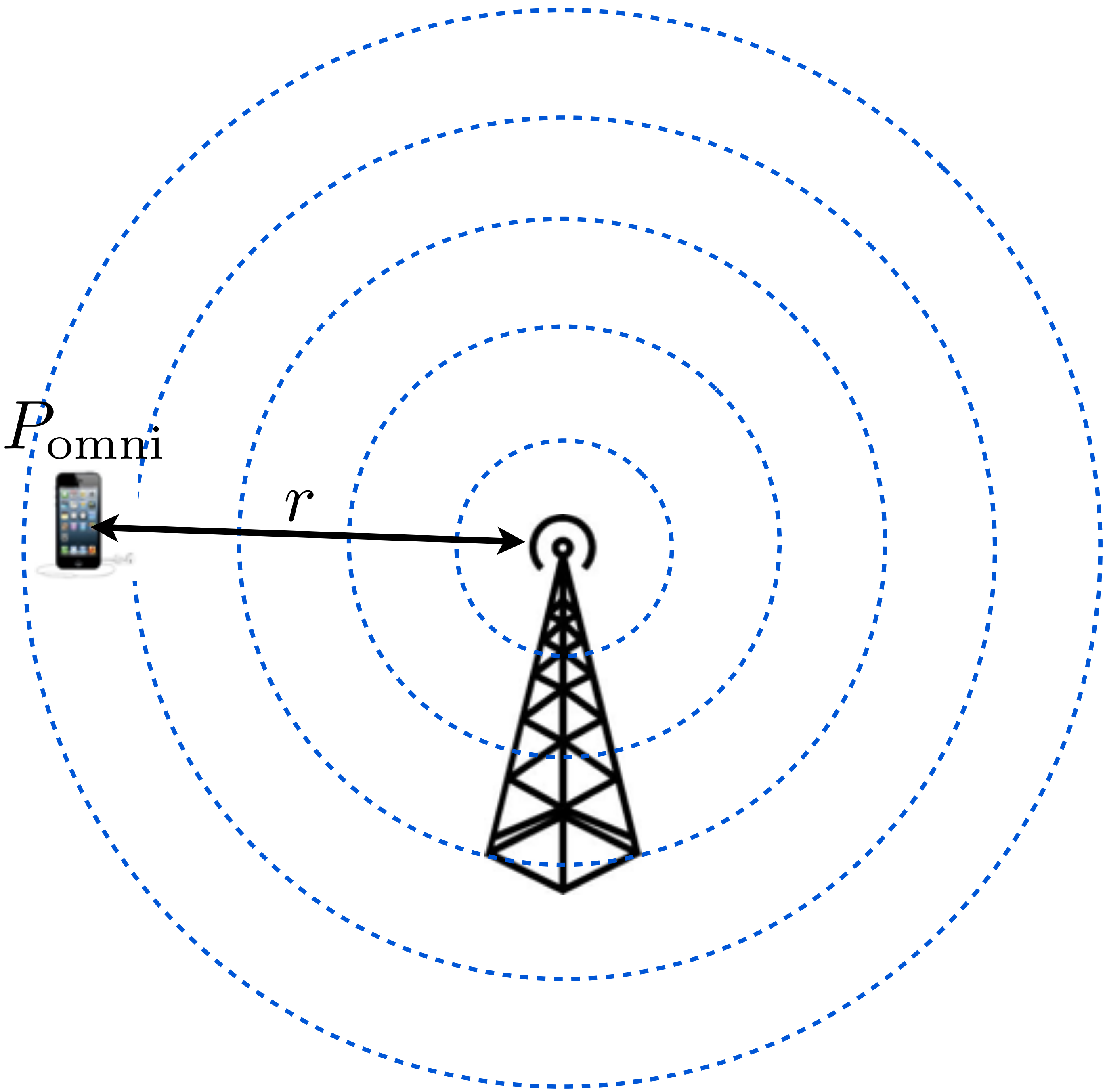


[Ref: 한국전파진흥협회, http://www.rapa.or.kr]

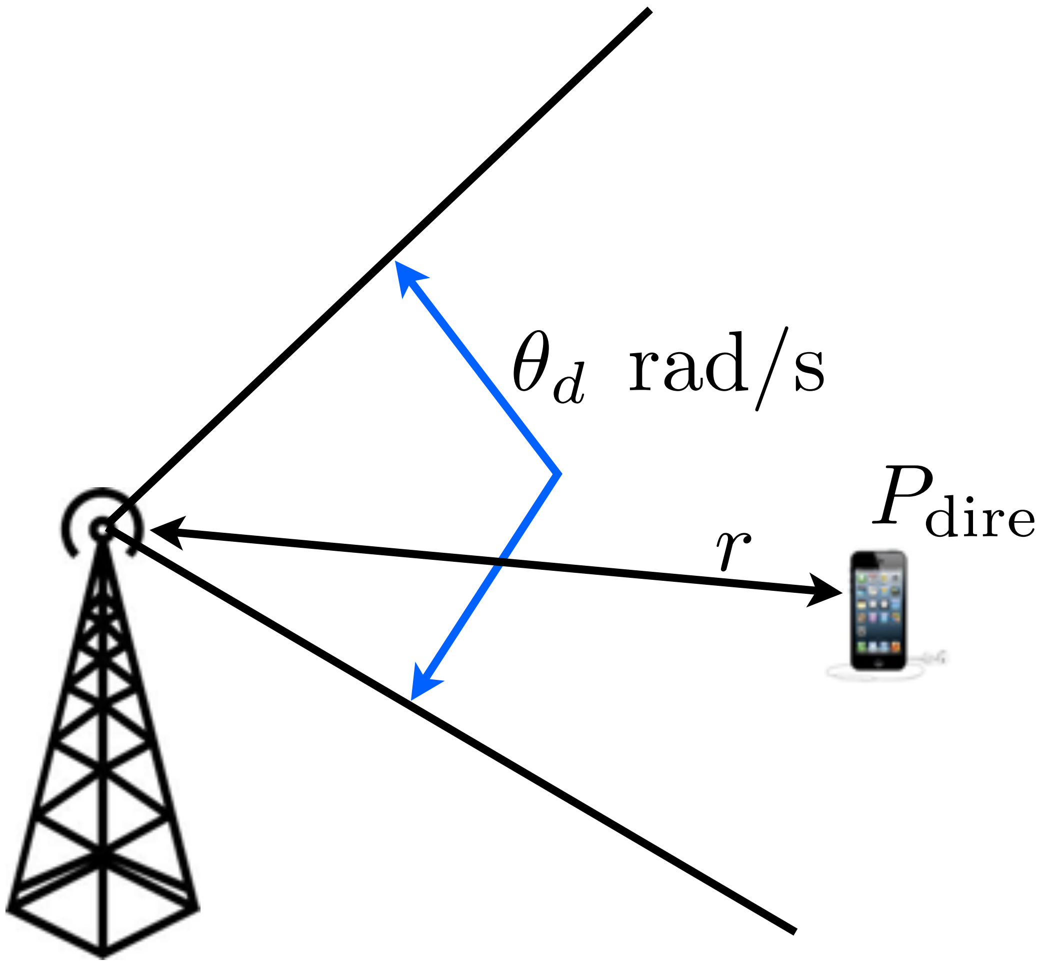


[Ref: 한국전파진흥협회, http://www.rapa.or.kr]

Omni-Directional and Directional Antennas



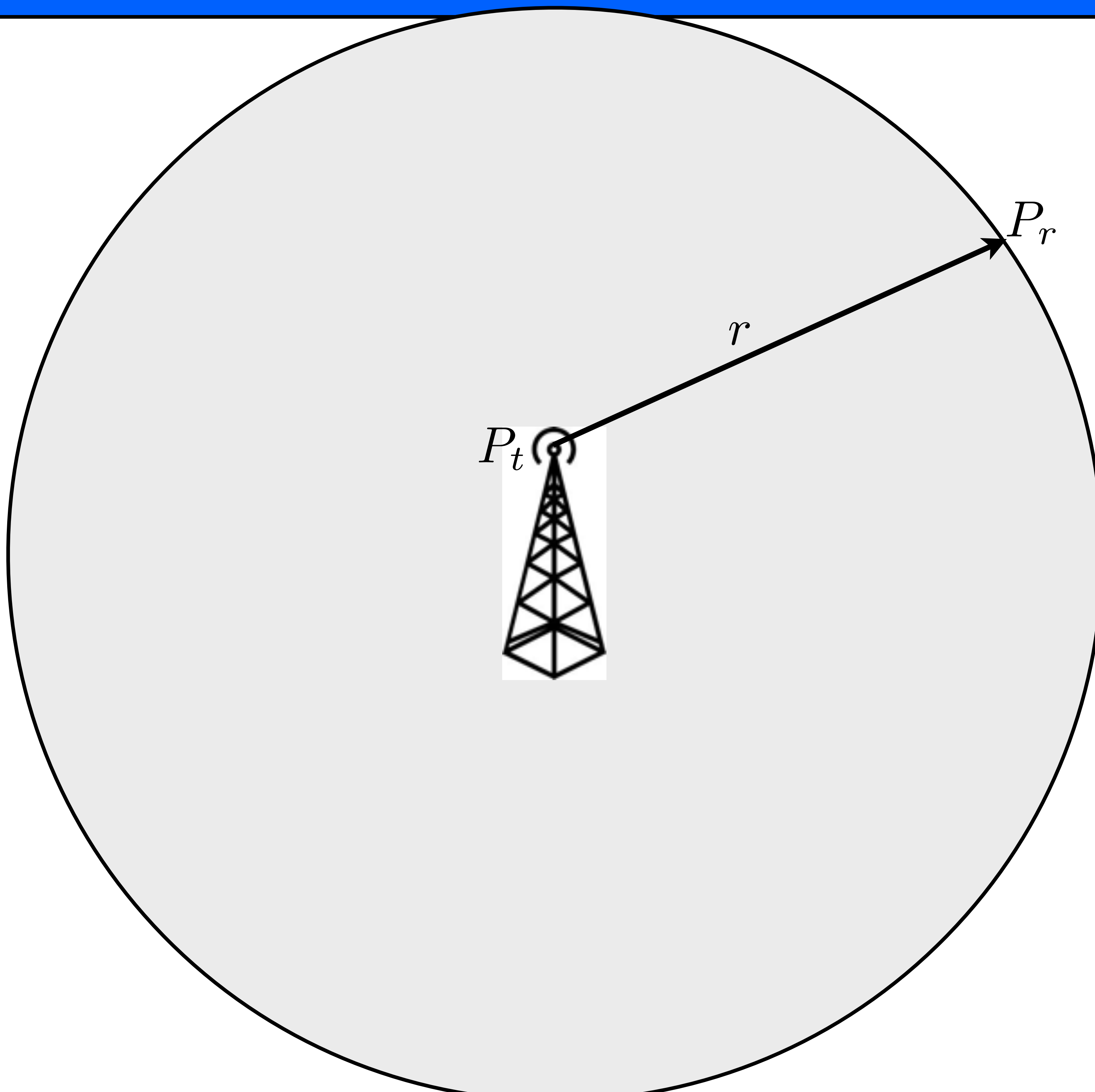
[Omni-directional antennas]



$$P_{\text{dire}} = \frac{2\pi}{\theta_d} P_{\text{omni}}$$

[Directional antennas]

Path loss



$$P_r \sim \frac{P_t}{r^2}$$

or

$$P_r = k\frac{P_t}{r^2}$$

where k is a constant.

Signal-to-Noise Ratio

- In digital communications, we study that the bit-error-rate (BER) or symbol-error-rate (SER) is a function of only the signal-to-noise ratio.
  - For example, BER of BPSK is

$$P_b = Q\left(\sqrt{2\gamma}\right)$$

where γ is the received signal-to-noise ratio (SNR) defined as

$$\gamma = \frac{P_r}{N_0 W}$$

- P_r: received signal power
- N_0: one-sided noise power spectral density
- W: signal's bandwidth

BER of BPSK versus Distance

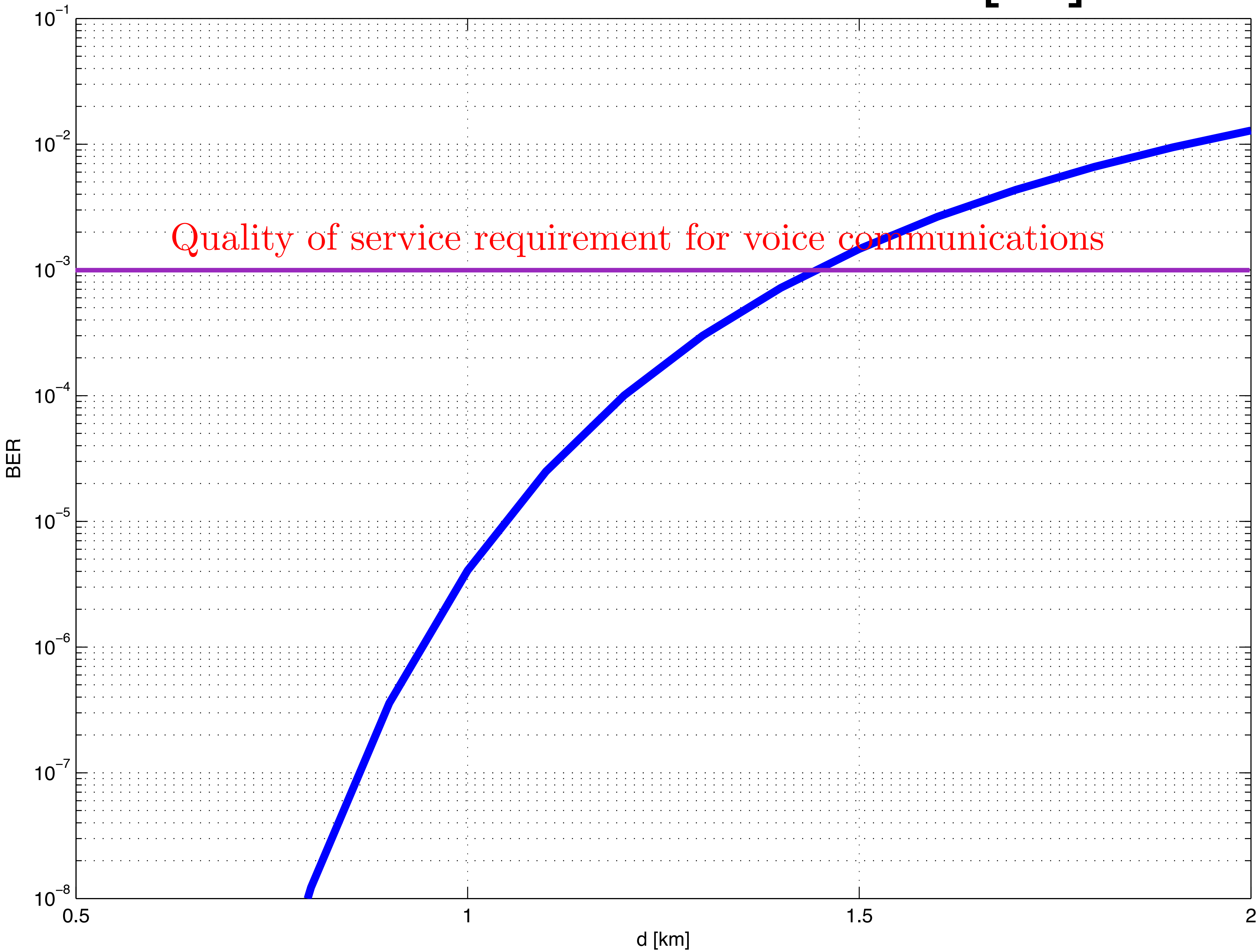
- Let $\gamma(0.5\text{km})_{\text{dB}} = 10\log_{10}\left(\frac{P_r(0.5)}{N_0 W}\right) = 16\ [\text{dB}]$ at 500 m distance long.

  - where $P_r(d)$ is the received power at the distance d.

- Then we can easily show that $\gamma(d)_{\text{dB}} = 10\log_{10}\left(\frac{0.5^2}{d^2}\right) + 16$

  or $\gamma(d) = 10^{\gamma(d)_{\text{dB}}/10}$ in linear scale.

BER of BPSK versus the distance [km]



SER of M-QAM

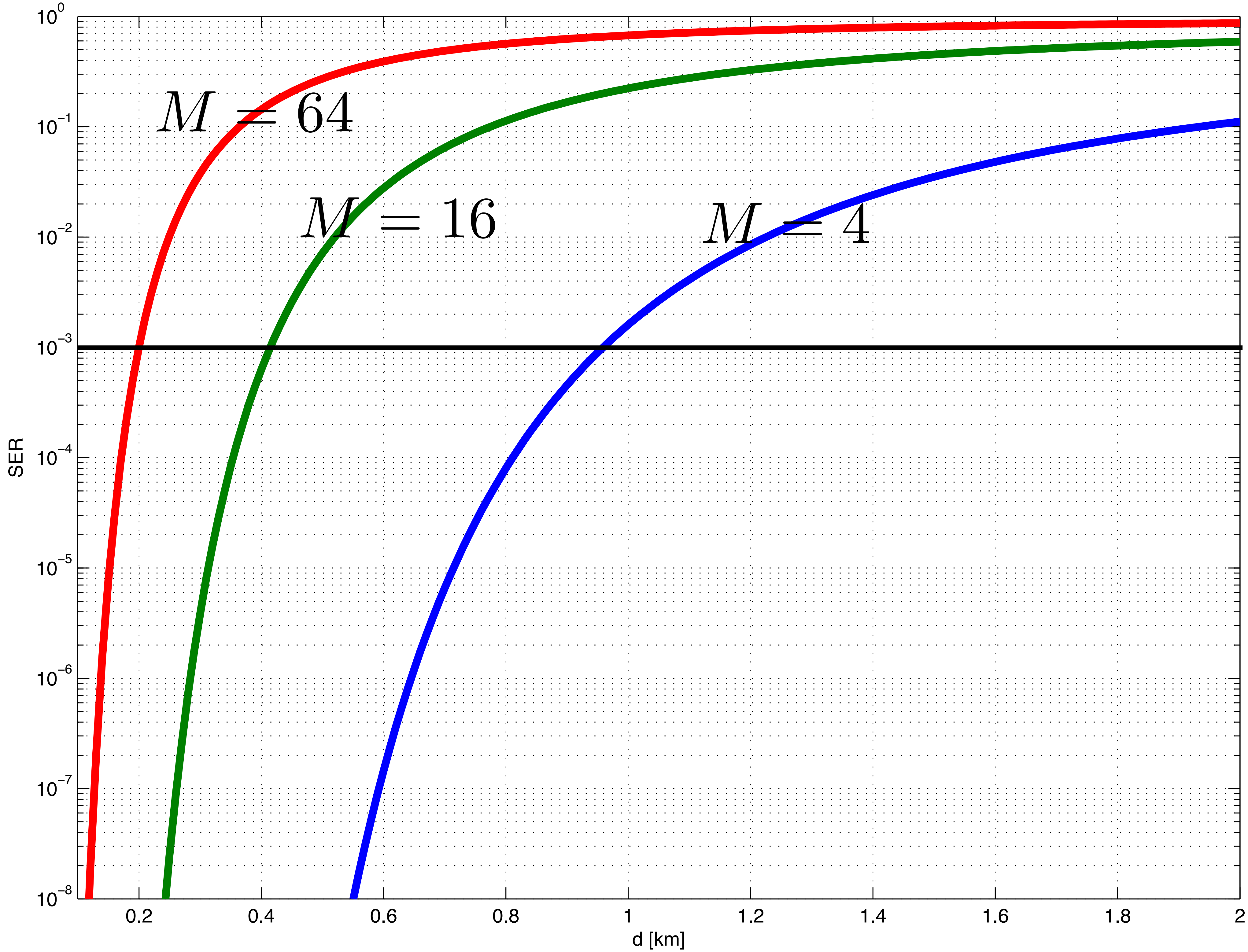
- M-QAM transmits $\log_2 M$ bits for the time symbol interval T.

- For a given time T, as M increases, the spectral efficiency gets higher.
    - which means we can transmit more data (bits) given a certain time duration.

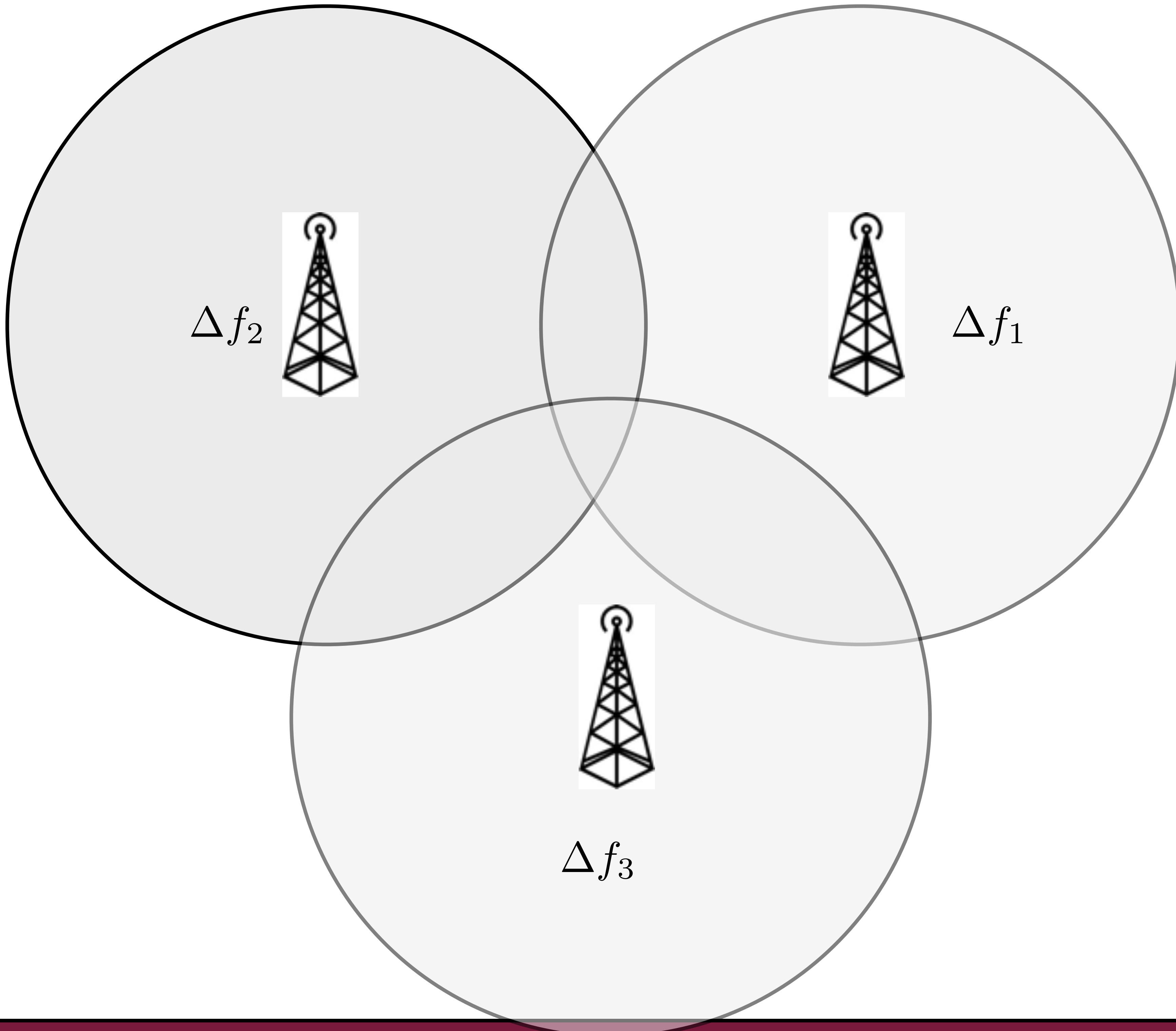
- Symbol error rate

$$
\begin{aligned}
P_e &= 4\left(1-\frac{1}{\sqrt{M}}\right)Q\left(\sqrt{\frac{3}{M-1}\frac{\mathcal{E}_{av}}{N_0}}\right) \\
&\quad -4\left(1-\frac{1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3}{M-1}\frac{\mathcal{E}_{av}}{N_0}}\right)
\end{aligned}
$$

BER of M-QAM versus the distance [km]



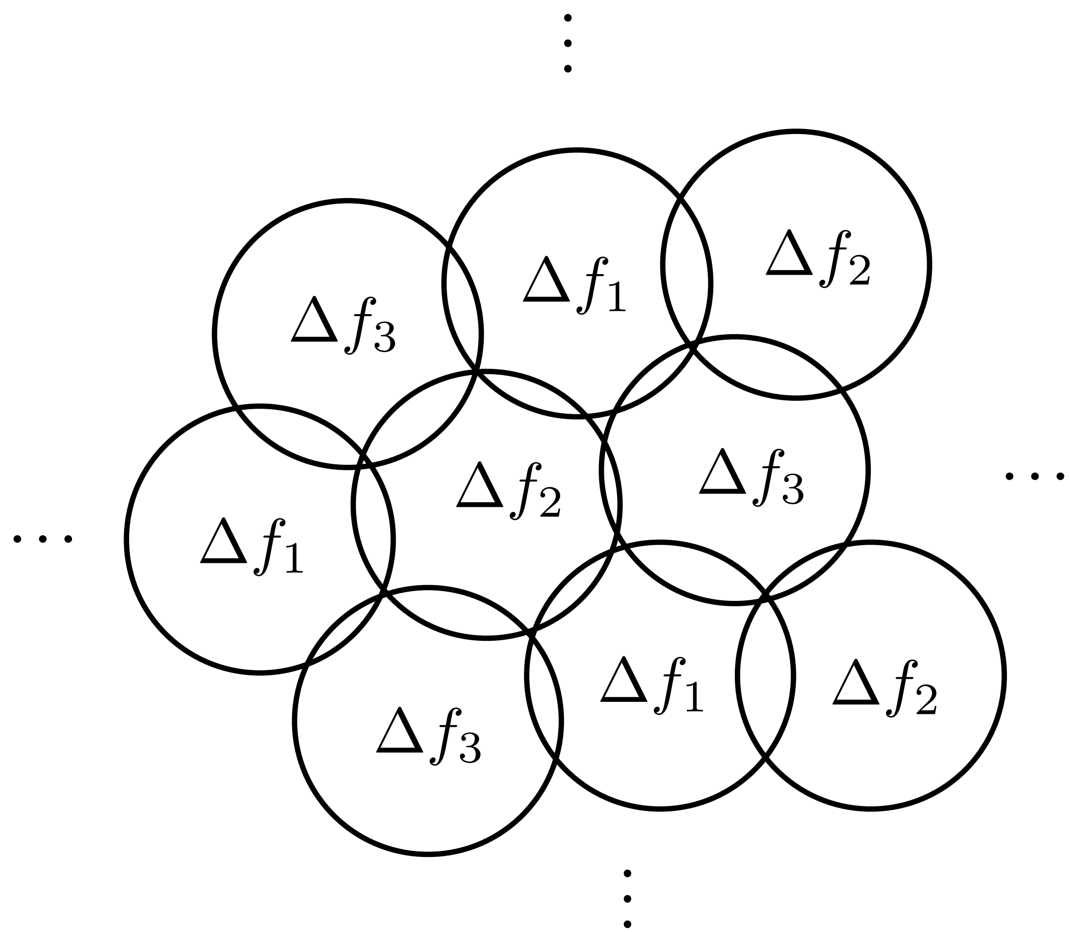
Cellular Systems



$$\Delta f_1 + \Delta f_2 + \Delta f_3 = \Delta f$$

Total bandwidth

Cellular Concept



$$\Delta f_1 + \Delta f_2 + \Delta f_3 = \Delta f$$

Total bandwidth

Key idea of cellular system: frequency reuse

Mobile Communications (KECE425)

Lecture Note 2

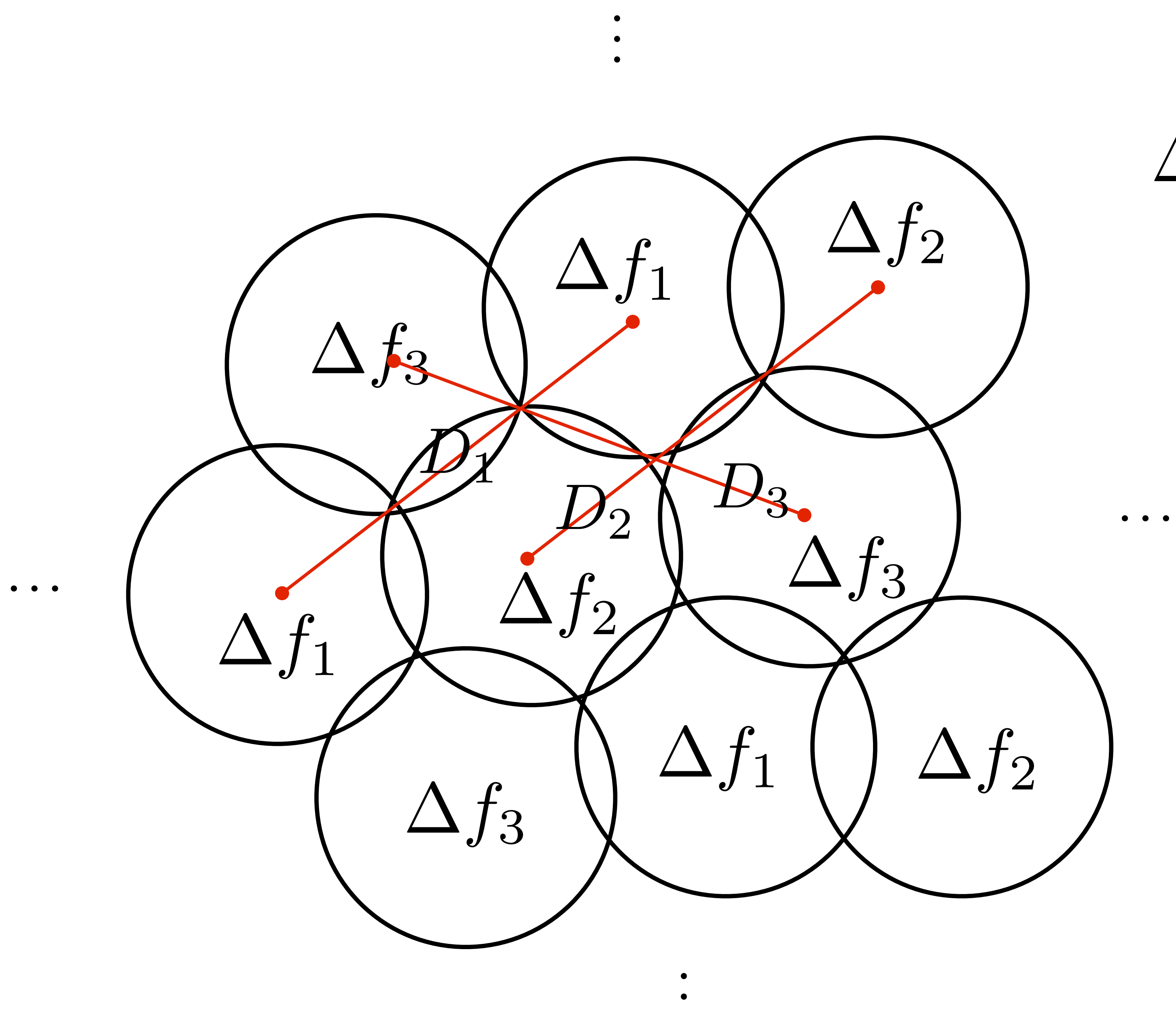
03-05-2014

Prof. Young-Chai Ko

Summary

- Cellular concept
- Co-channel interference
- Cellular size and capacity
- Path loss model

Cellular Concept



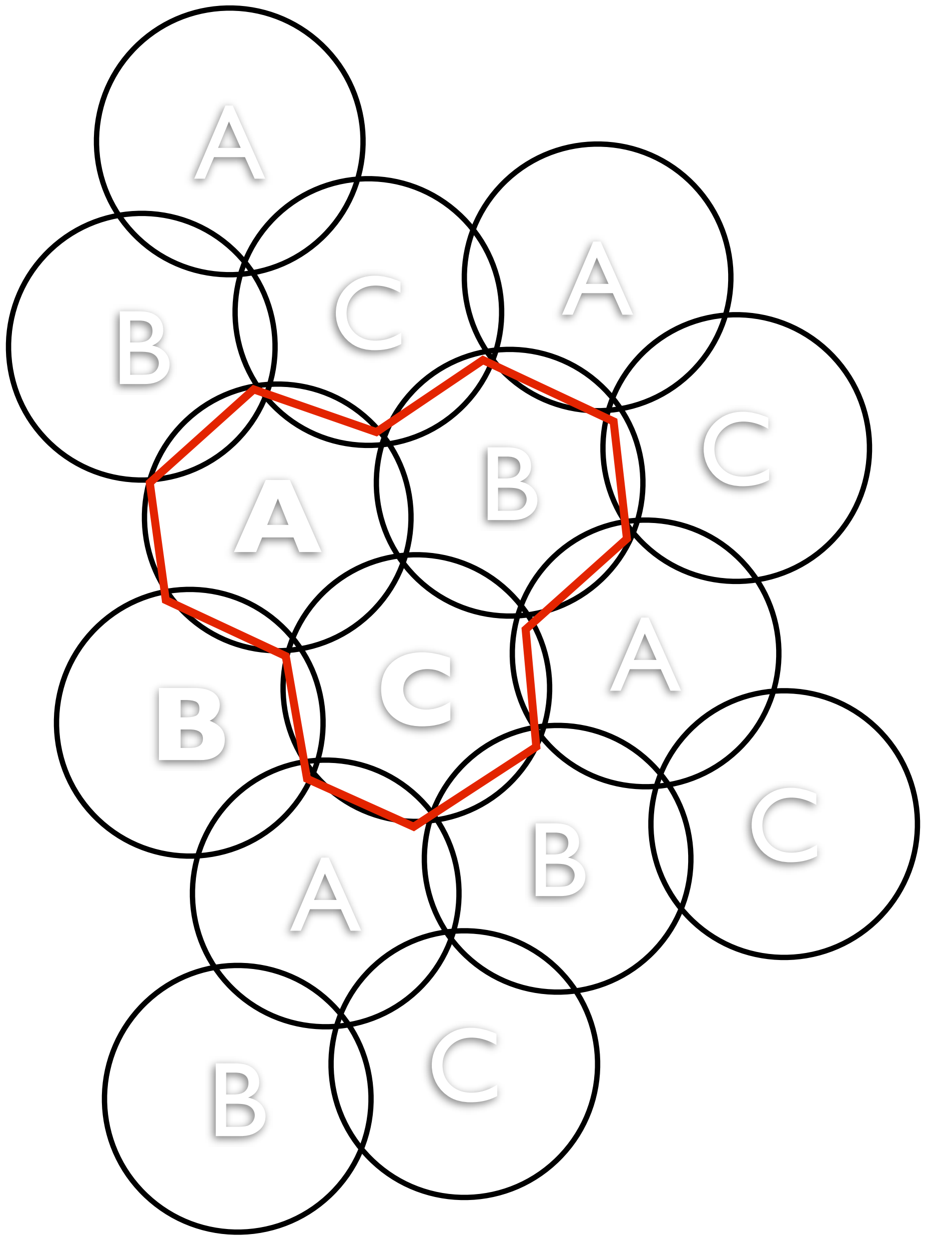
$$\Delta f_1 + \Delta f_2 + \Delta f_3 = \Delta f$$

Total bandwidth

$$D_1 = D_2 = D_3$$

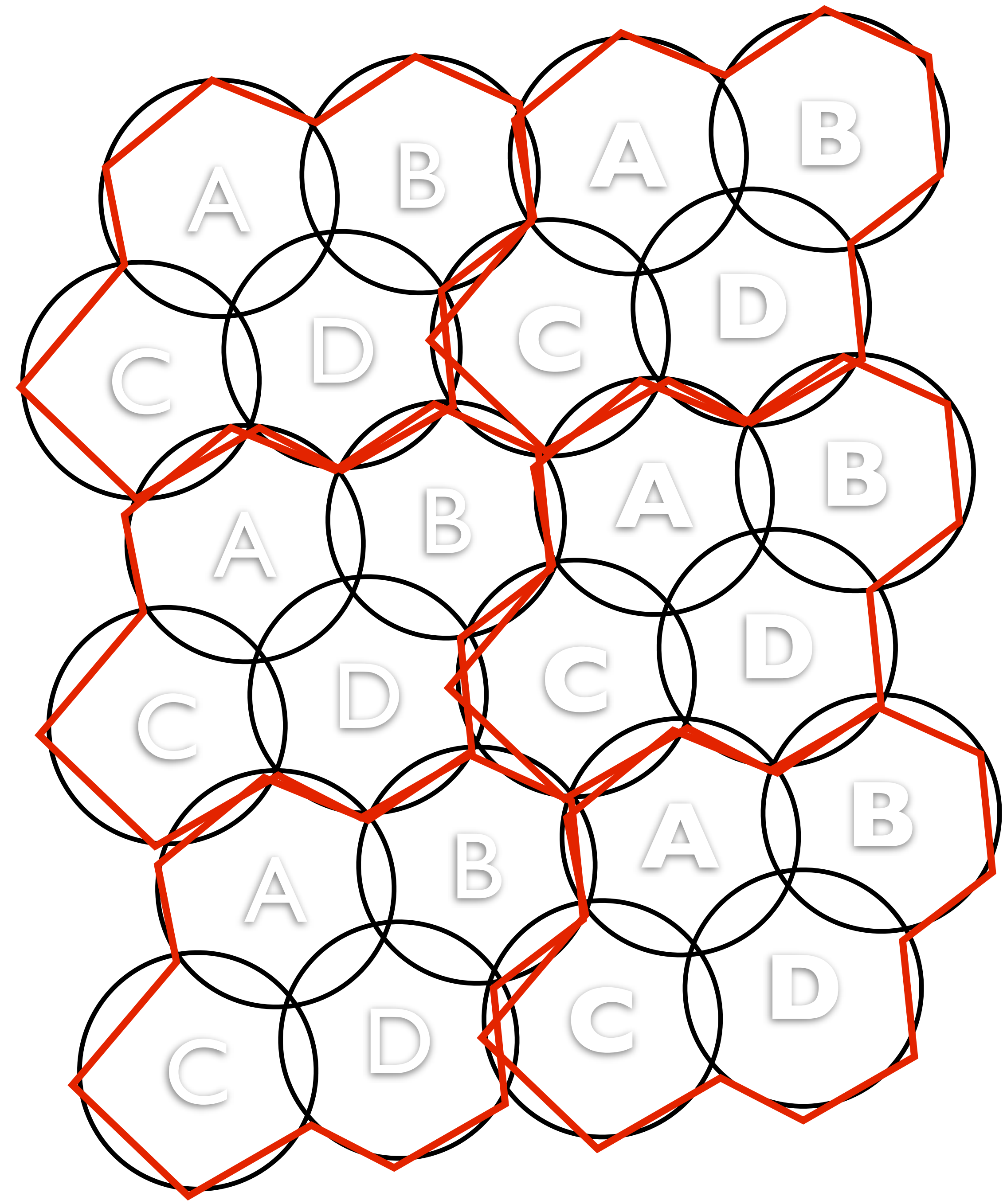
Key idea of cellular system: frequency reuse

Cluster



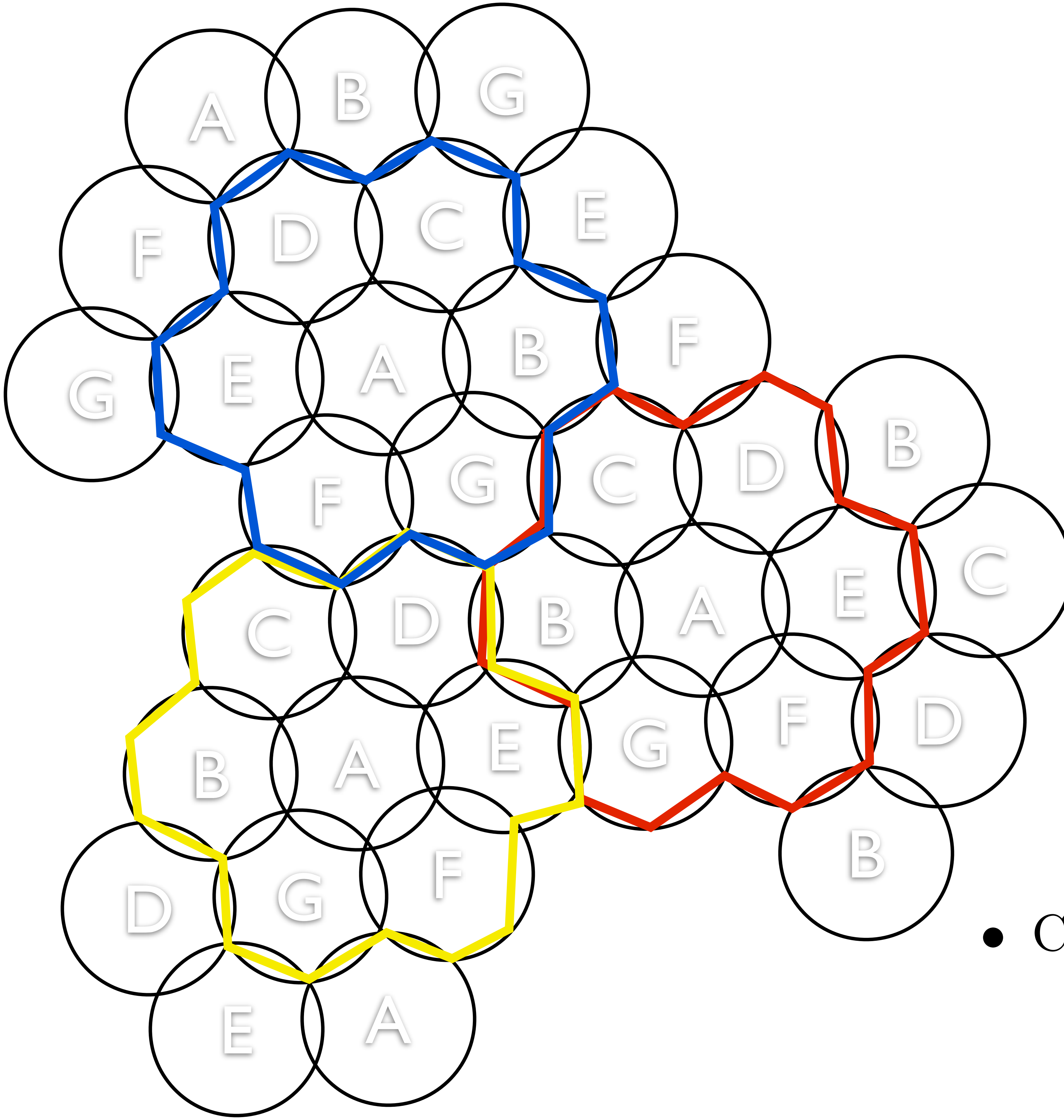
- Cluster size N=3

  3-cell reuse pattern



- Cluster size N=4

  4-cell reuse pattern



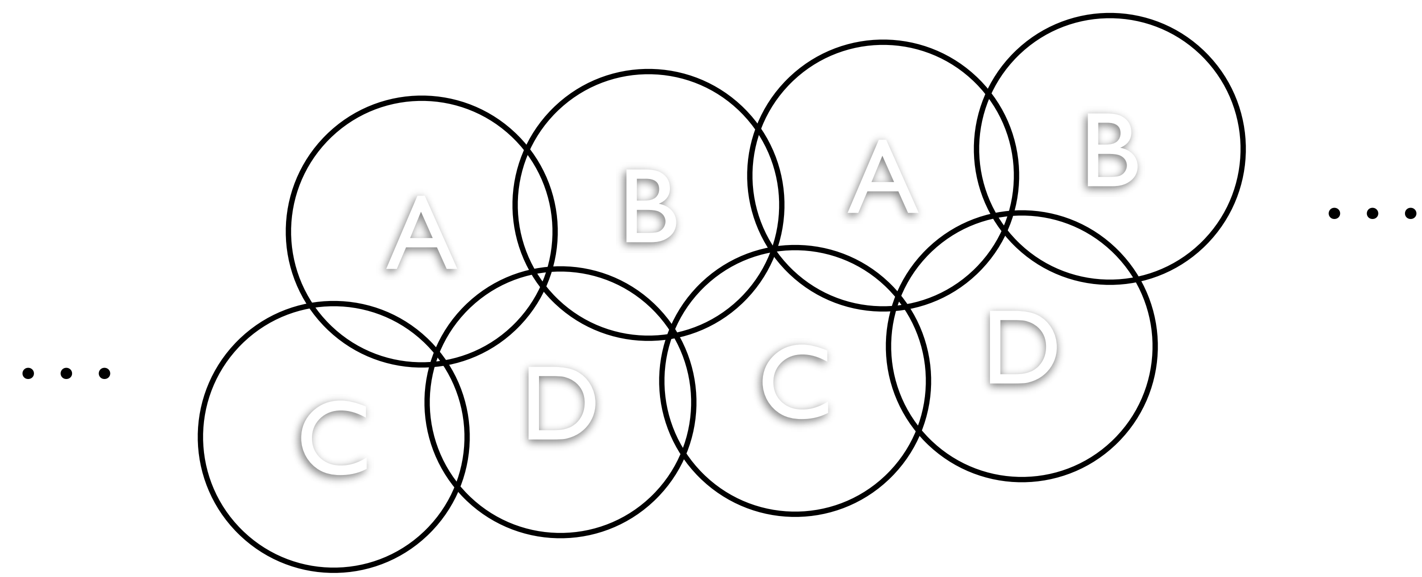
- Cluster size $N=7$

7-cell reuse pattern

Example of Frequency Reuse

- KTF: 1960 MHz $\sim$ 1980 MHz for uplink and 2150 MHz $\sim$ 2170 MHz

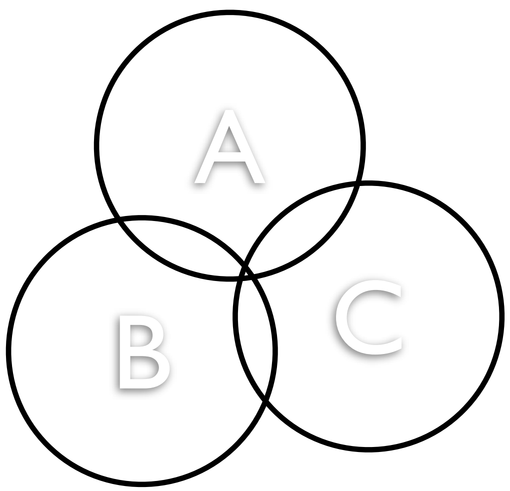
Example for N=4



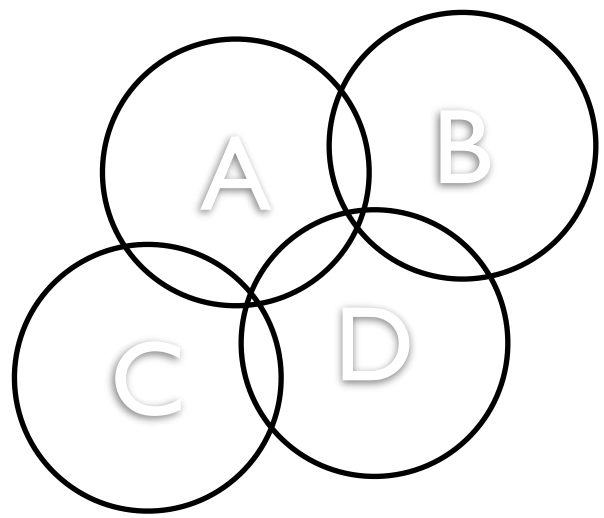
- A in MHz: 1960 $\sim$ 1965 and 2150 $\sim$ 2155 for UL and DL, respectively.
- B in MHz: 1965 $\sim$ 1970 and 2155 $\sim$ 2160 for UL and DL, respectively.
- C in MHz: 1970 $\sim$ 1975 and 2160 $\sim$ 2165 for UL and DL,
- D in MHz: 1975 $\sim$ 1980 and 2165 $\sim$ 2170 for UL and DL, respectively.

Cellular Reuse Cluster

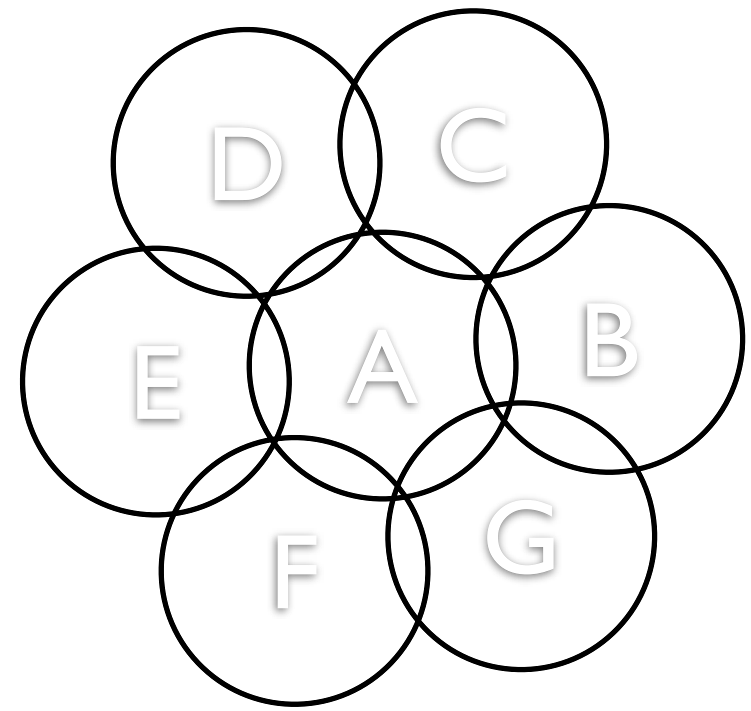
A *tessellating* reuse cluster of size N



3-cell, $N = 3$



4-cell, $N = 4$



7-cell, $N = 7$

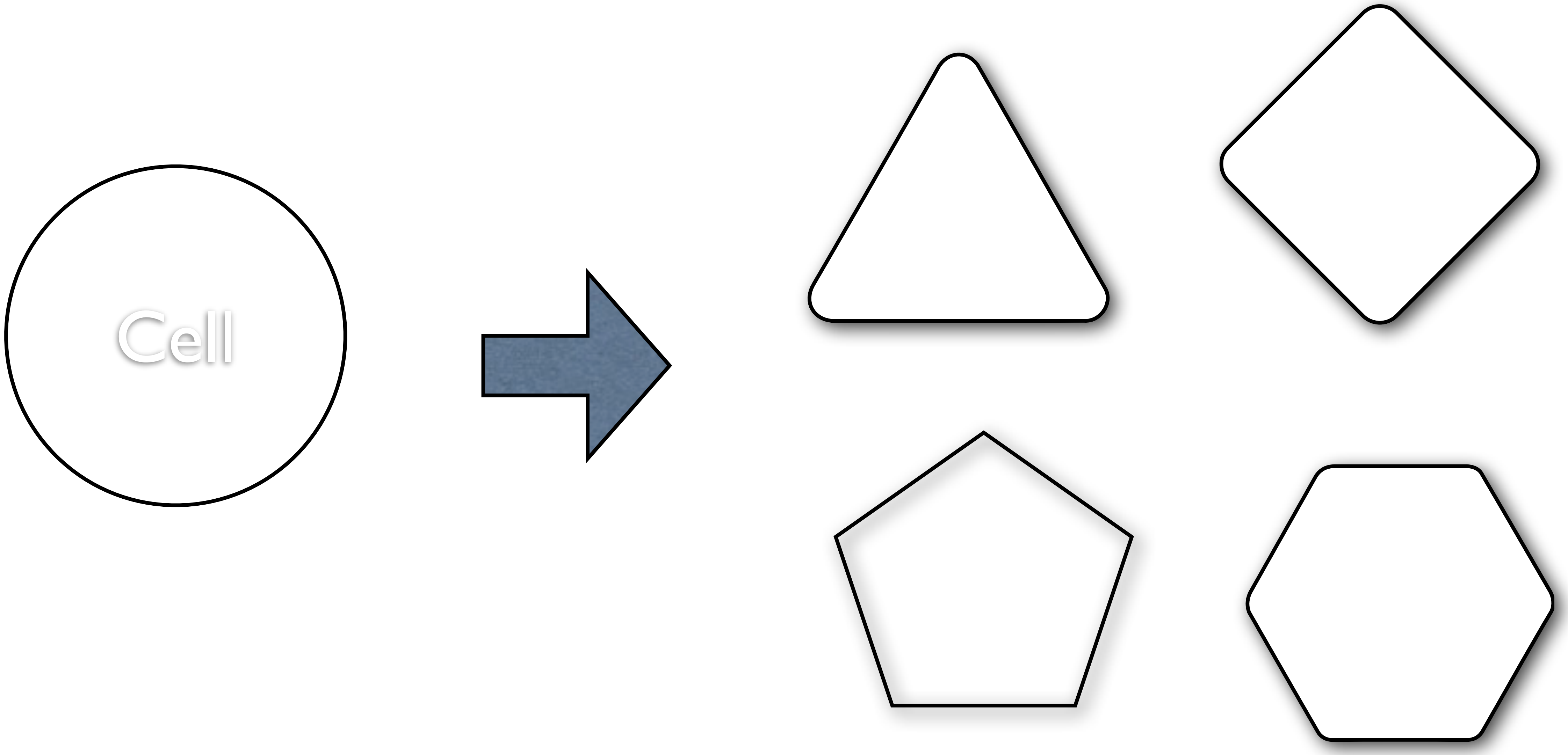
$$N = i^2 + ij + j^2, \qquad \{i, j \in \mathcal{I} | \; i \geq j\}$$

$$N = 1^2 + 1 \cdot 0 + 0^2 = 1 \qquad N = 2^2 + 2 \cdot 0 + 0^2 = 4$$

$$N = 1^2 + 1 \cdot 1 + 1^2 = 3 \qquad N = 2^2 + 2 \cdot 1 + 1^2 = 7$$

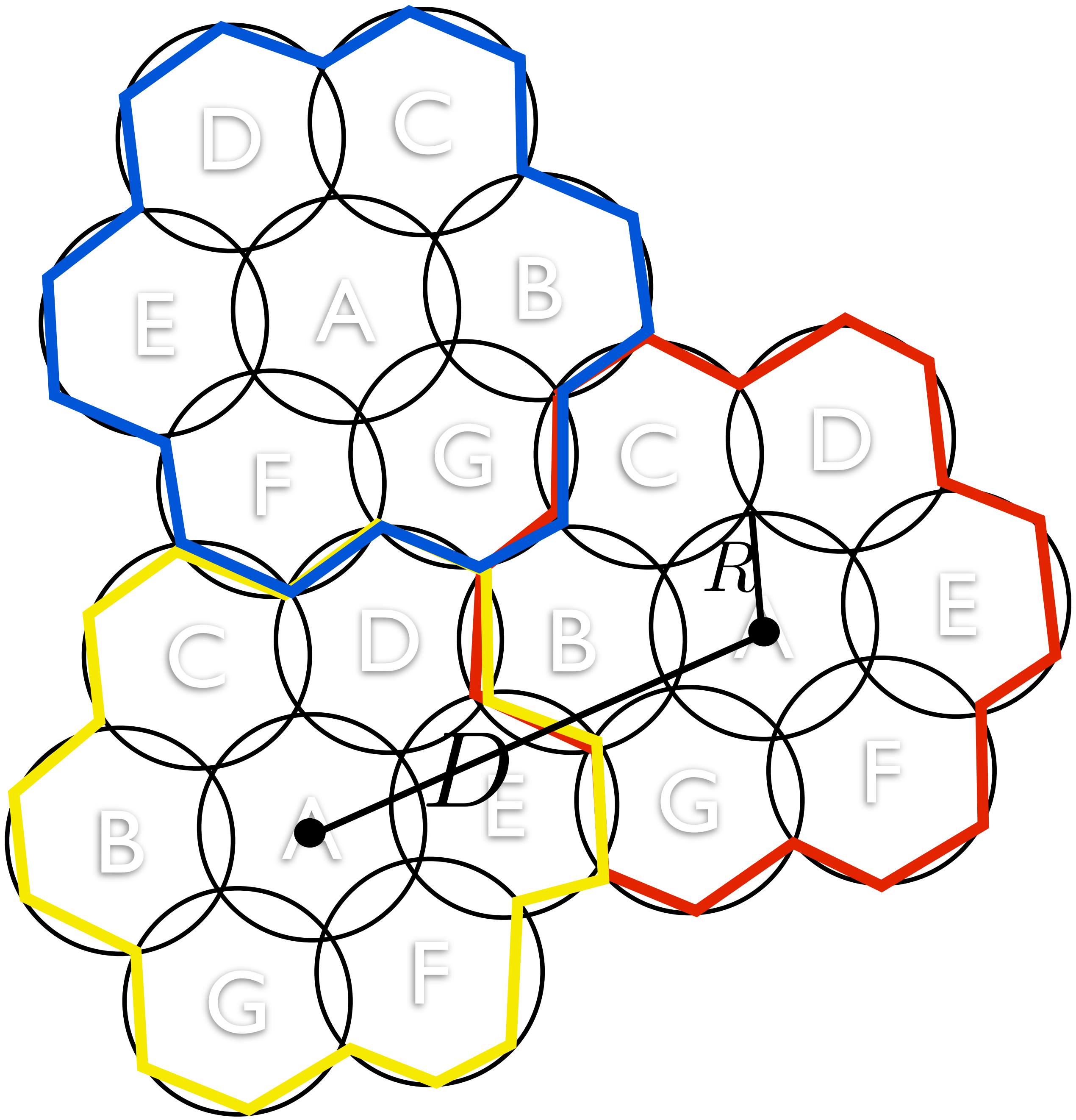
$\ldots$

Shapes of Cellular: Tessellating shapes



Hexagons are typically used as models for wireless systems.

Co-Channel Reuse Factor



D : Reuse distance

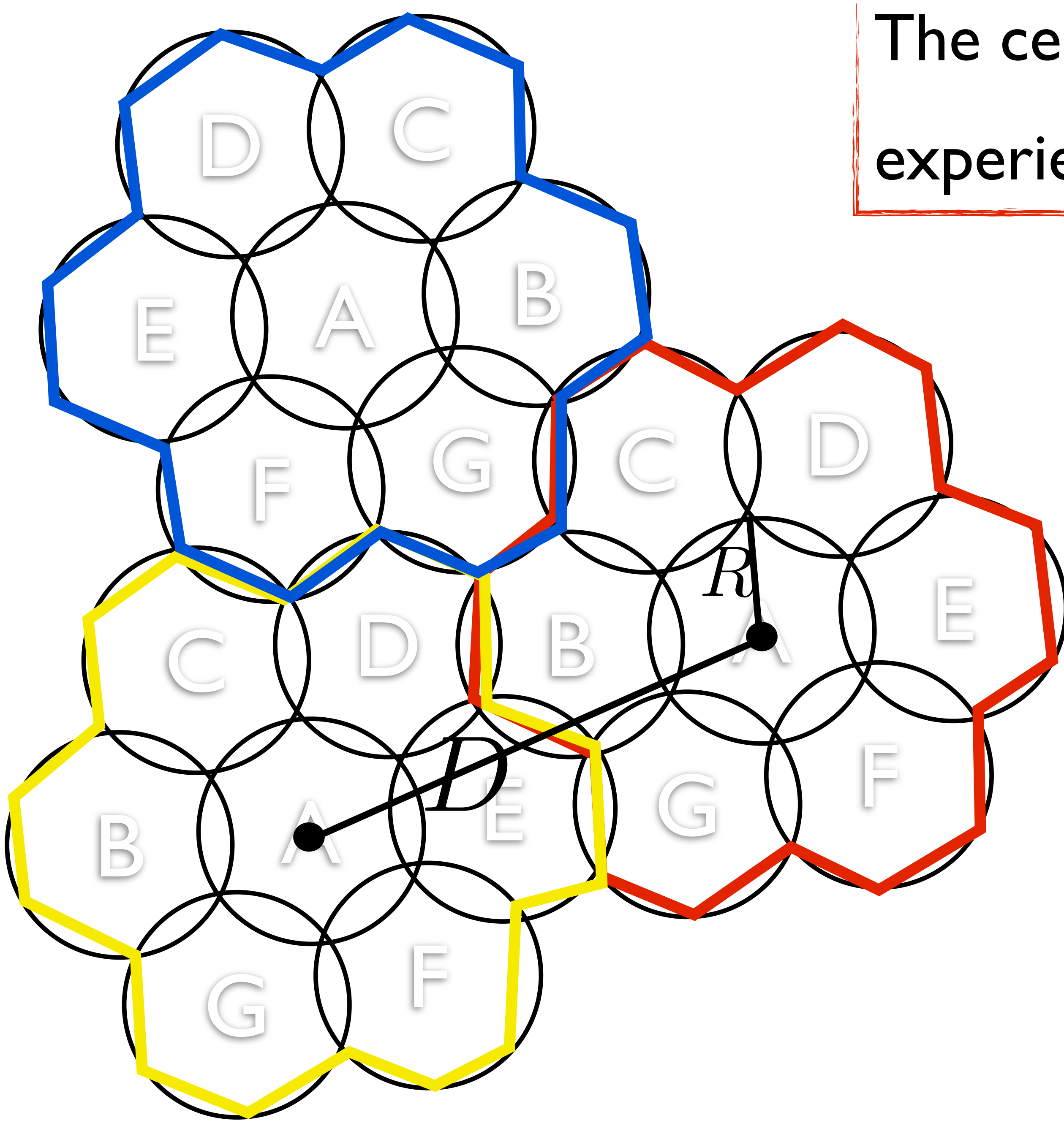
R : Cell radius

N : Cluster size

Co-channel reuse factor

$$Q = \frac{D}{R} = \sqrt{3N}$$

Co-Channel Interference



The cells with same frequency band experiences the co-channel interference!

Co-channel interference cells are separated by a "reuse distance" D .

Cluster Size and Duplex Channels

- Consider a cluster with N cells with S duplex channels/cluster.
  - KT: 1960 MHz $\sim$ 1980 MHz for uplink and 2150 MHz $\sim$ 2170 MHz.
  - Each user needs 1MHz for DL and 1MHz for UL.
  - Then we have 20 duplex channels/cluster.
  - If $N = 4$, there are 5 duplex channels/cell.
  - Hence, we have

$$S = k \times N$$

where k is the number of duplex channels/cell.

System Capacity

- If cluster is replicated M times within the system, the total number of channels available for the cellular system is

$$C = MkN = MS$$

measure of capacity

Remark

$$C = MkN = MS$$

$$M \uparrow \Longrightarrow C \uparrow$$

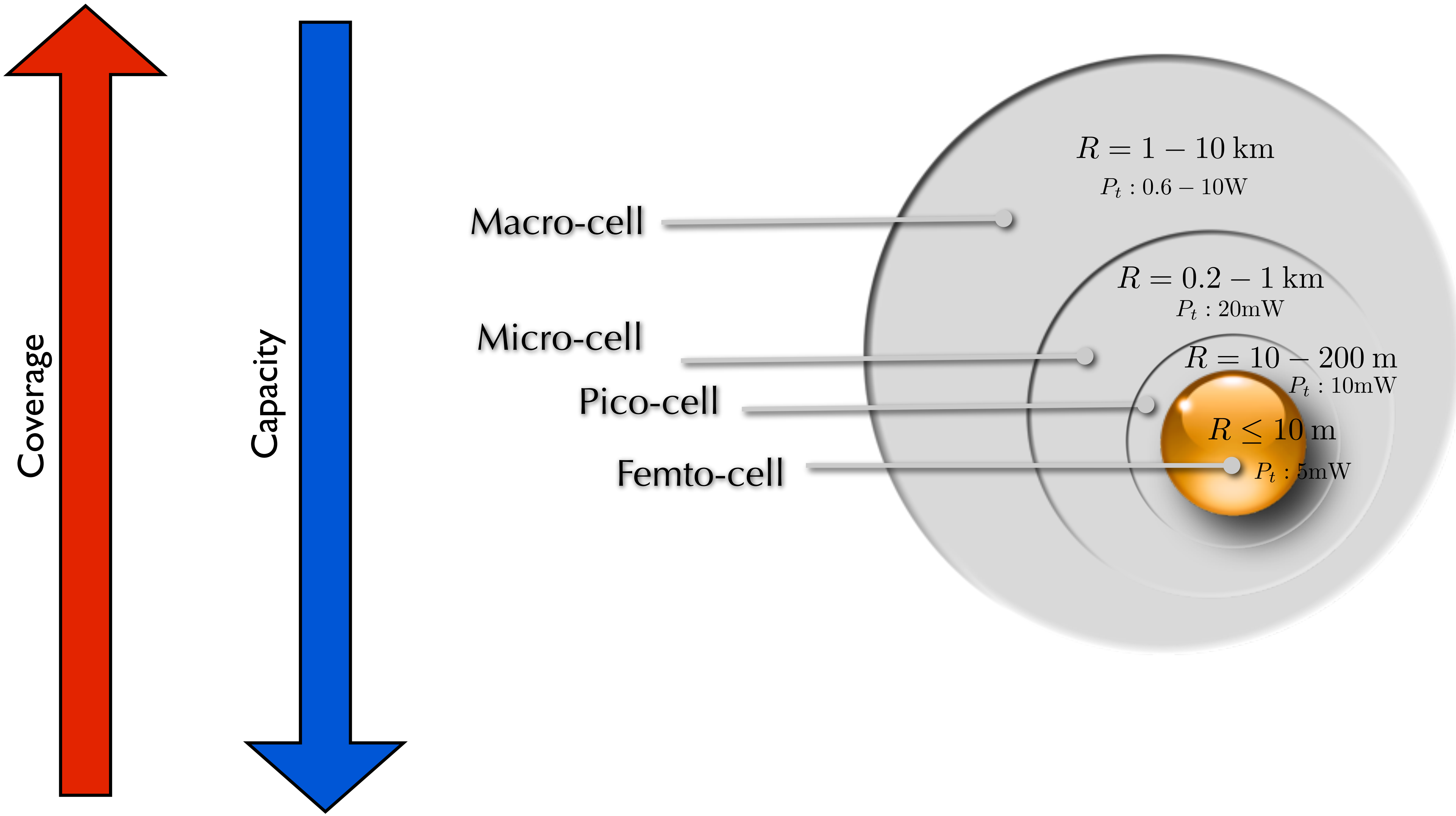
$$D \downarrow,\ M \uparrow \Longrightarrow C \uparrow$$

So choose the cluster size N as small as possible in order to increase capacity C.

Choose high N (high Q) to improve the QoS due to small level of CCI.

Trade-off between capacity and QoS

Cell Size vs. Cell Capacity

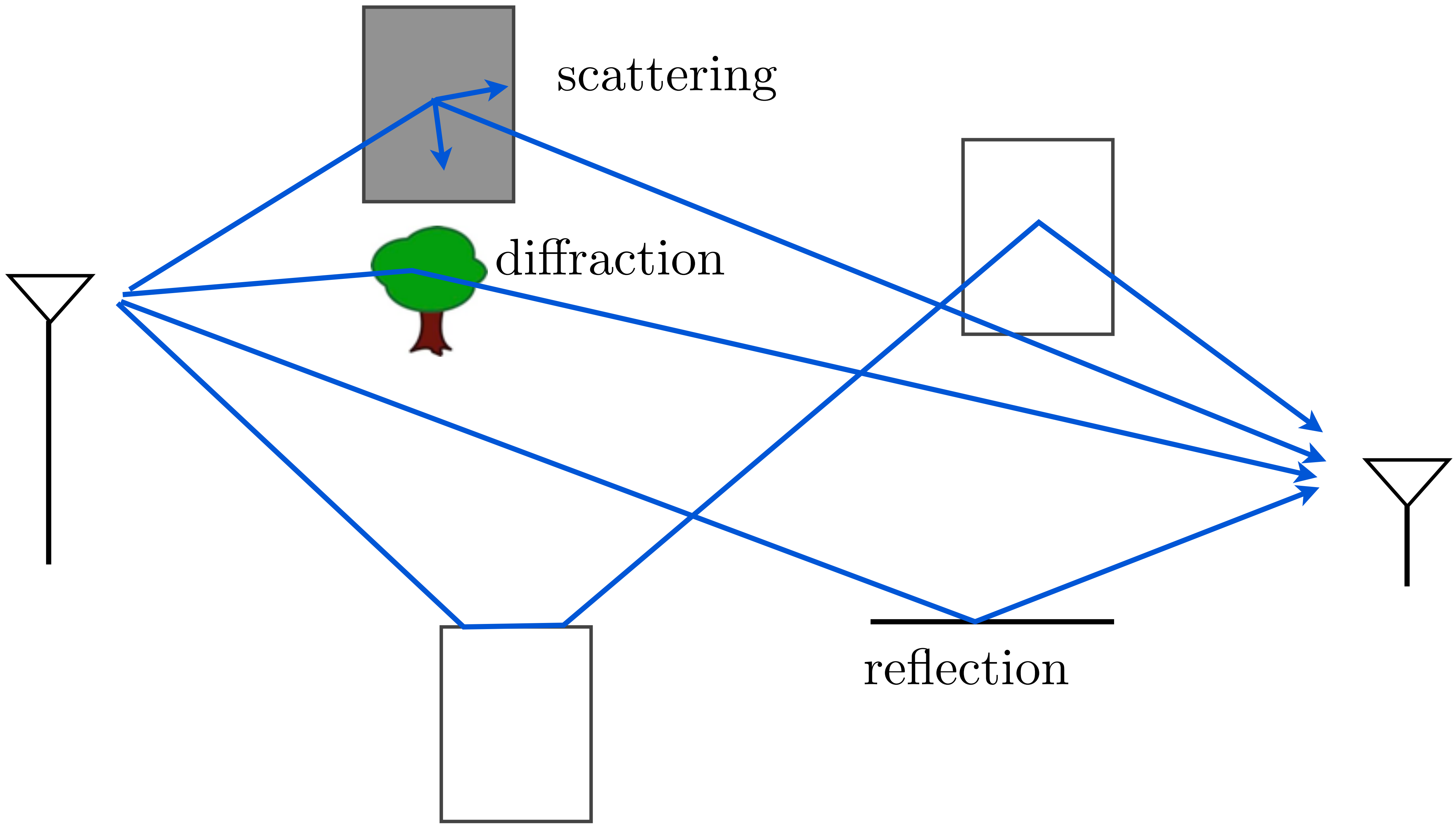


International Standards of Cellular Communications

1G (Macro-cell)	• Voice signals only • Analogue cellular phones • AMPS (analog mobile phone system)	
2G (Macro/ Micro-cell)	• Voice and data signals • Digital fidelity cellular phones • GSM (Europe), CDMA (US, Korea), TDMA (US, Japan)	9.6/14.4 kbps
3G (Micro/ Pico-cell)	• Voice, data, and video signals • Video telephony / internet surfing • W-CDMA	3.1 Mbps(peak) 500-700 kbps
4G (Pico/ Femto-cell)	• Enhanced 3G / Interoperability protocol • High-speed & IP-based • LTE (OFDM)	100 ~ 300 Mbps (peak) 3-5 Mbps

Mobile Radio Propagation

- Radio signals generally propagate according to three mechanisms:



Power Attenuation in Free Space

- Received signal power at d denoted as $\Omega_p(d)$ in free space

$$\Omega_p(d) = \Omega_t k \left(\frac{\lambda_c}{4\pi d} \right)^2$$

where

- Ω_t: transmit power
- λ_c: wavelength where $\lambda_c = \frac{c}{f_c}$.
- k: a constant of proportionality
- d: distance between the transmitter and the receiver

- In decibel domain, we have

$$\Omega_{p(\mathrm{dBm})}(d) = 10\log_{10}(\Omega_p(d) \times 10^3)$$

$$= 10\log_{10}\left[\Omega_t k \left(\frac{\lambda_c}{4\pi d}\right)^2 \times 10^3\right]$$

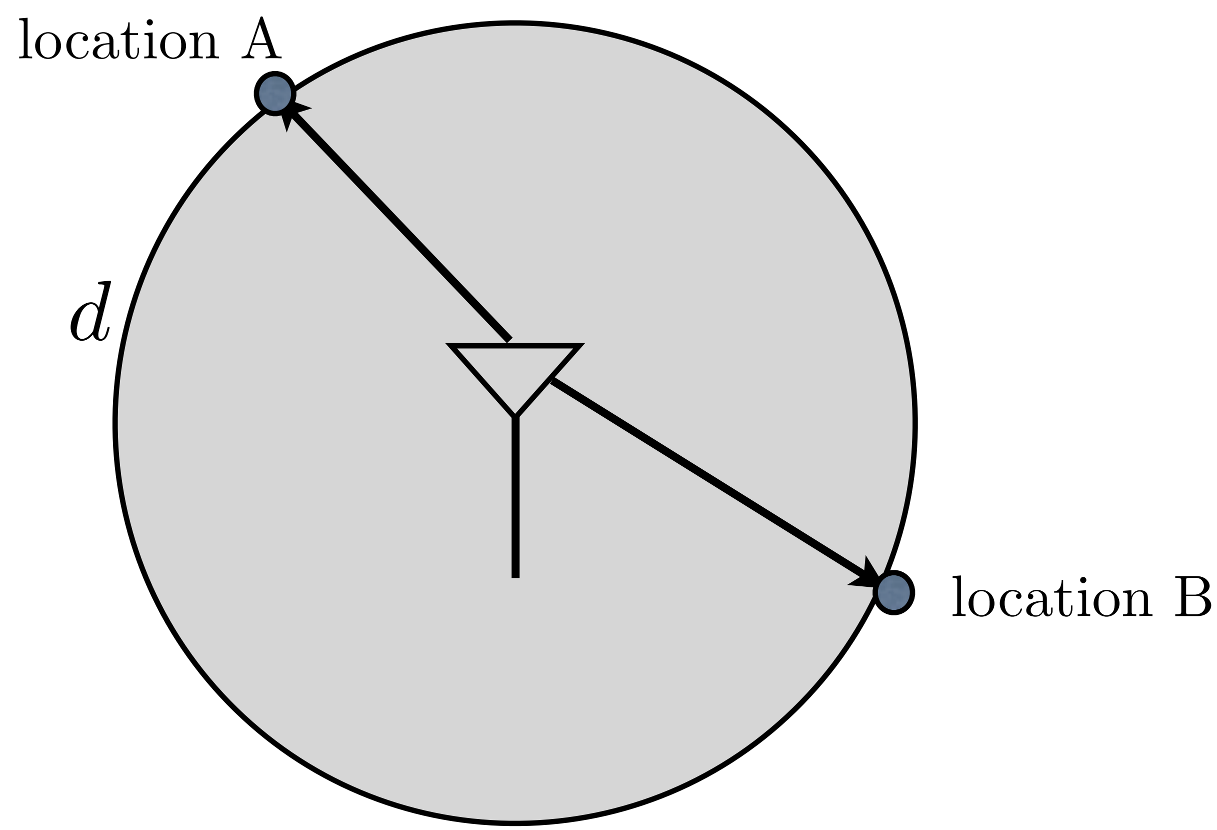
$$= \underbrace{10\log_{10}\left(\Omega_t \times 10^3\right)}_{=\Omega_{t(\mathrm{dBm})}} + 10 \times 2\log_{10}\left(\frac{\lambda_c}{4\pi d}\right) + 10\log_{10} k$$

$$= \Omega_{t(\mathrm{dBm})} - 20\log_{10}(d) + 10\log_{10}(k')$$

$$\text{where} \quad k' = \frac{\lambda_c^2}{16\pi^2}$$

- In free space, the received signals of the locations at the same distance are all the same as

$$\Omega_{p(\mathrm{dBm})}(d) = \Omega_{t(\mathrm{dBm})} - 20\log_{10}(d) + 10\log_{10}(k')$$



Power at A $=$ Power at B

- Let us assume that the power at the distance d_0 is $\Omega_{p(\text{dBm})}(d_0)$:

$$\Omega_{p(\text{dBm})}(d_0) = \Omega_{t(\text{dBm})} - 20\log_{10}(d_0) + 10\log_{10}(k')$$

or equivalently we can write

$$\Omega_{p(\text{dBm})}(d_0) + 20\log_{10}(d_0) = \Omega_{t(\text{dBm})} + 10\log_{10}(k')$$

- Then we can express the power at a certain distance d as $\Omega_{p(\text{dBm})}(d_0)$ as

$$\begin{aligned} \Omega_{p(\text{dBm})}(d) &= \Omega_{t(\text{dBm})} - 20\log_{10}(d) + 10\log_{10}(k') \\ &= \Omega_{p(\text{dBm})}(d_0) + 20\log_{10}(d_0) - 20\log_{10}(d) \\ &= \Omega_{p(\text{dBm})}(d_0) - 20\log_{10}(d/d_0) \end{aligned}$$

Path Loss Model in Mobile Radio Environment

- Free space propagation does not apply in a mobile radio environment.

  Instead, the following simple path loss model is often used:

$$\Omega_{p(\text{dBm})}(d_0) = \Omega_{t(\text{dBm})} - 20\log_{10}(d_0) + 10\log_{10}(k') + \epsilon_{(\text{dB})}$$

where $\epsilon_{(\text{dB})}$ is Gaussian random variable

with zero mean and variance σ_Ω^2.

- Then $\Omega_{p(\text{dBm})}$ is also Gaussian random variable such as

$$\Omega_{p(\text{dBm})}(d_0) \sim \mathcal{N}\left(\mu_{\Omega_{p(\text{dBm})}}(d_0), \sigma_\Omega^2\right)$$

where $\mu_{\Omega_{p(\text{dBm})}}(d_0) = \Omega_{t(\text{dBm})} - 20\log_{10}(d_0) + 10\log_{10}(k')$