Fundamentals of Wireless Communication

Cellular Systems: Multiple Access and Interference Management

Edward Kwao

Hanbat National University

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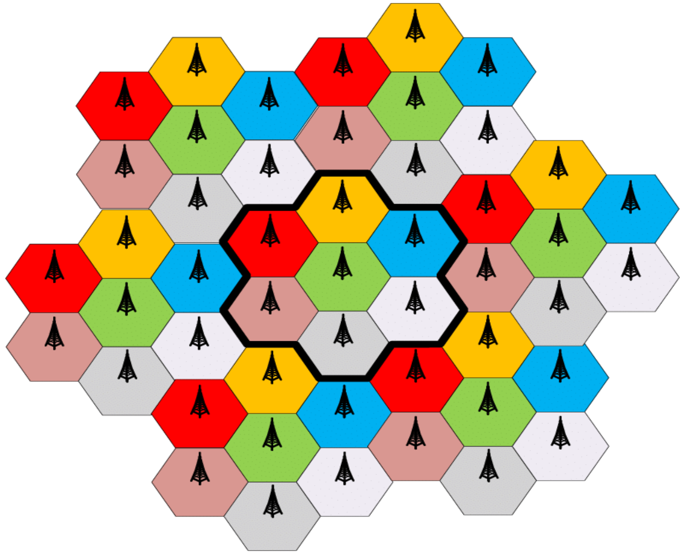
Contents

Introduction

- Cellular system is a term in wireless communication that explains how signal coverage area is split into smaller divisions called cells, each with a serving BS.
- This idea was to increase capacity(number of users) because the same radio channels can be reused by another base station that is sufficiently far away.



- Two issues come into action with this system:
- Multiple Access (how resources are shared with users within the cell)
- Inter-cell interference management (addressing interference between different cells)

Narrowband GSM

- The entire bandwidth is chopped into chunks of narrowbands each with bandwidth of $200\ \mathrm{KHz}$.
- Each of the narrowbands are further divided into time slots. The time slots are then divided into 8 for eight users.
- At the end of the day, users in the same cell are orthogonal to each other, hence do not interfere with each other.
- This is because, they are either occupying different time slots and or different frequency bands.
- However, there may be interference between adjacent cells. These are typically avoided by doing reduced frequency reuse.
- In GSM, frequencies are not reused by immediate cells.
- Therefore, within the cell, users operate with high SINR.
- Price to pay: Degrees of freedom are lost. Why can’t the same frequency be used in adjacent cells?
- Lack of interference averaging prevents frequency reuse in adjacent cells.

Wideband Systems: CDMA

- The goal of wideband CDMA systems is to make the whole bandwidth available to all users in every cell (ie. maximizes the degree of freedom). This is known as universal frequency reuse.

- All the users in all cells share the same bandwidth.
- Advantages:

• Maximizes the degree of freedom

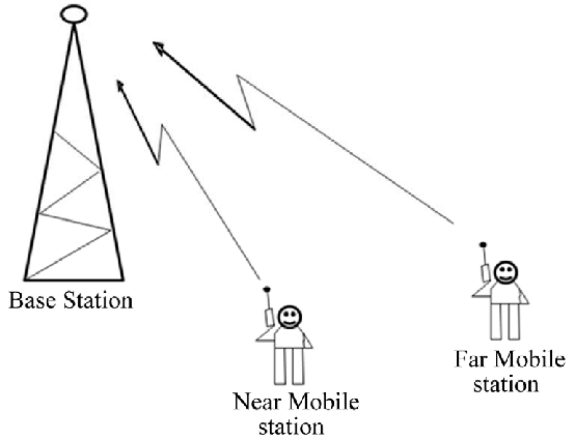
• This is possible because of better interference averaging across many users.

• Reliable handoff

• Deployment: no frequency planning

- Major challenges:

1. Near-far field problem (Power control)
2. Signal recovery when buried in huge interference and noise



CDMA Design Goals

- To do power control and interference averaging:

- We know how to design point-to-point communication systems with white gaussian noise. Now we have interference plus the white Gaussian Noise.

- Make the interference look as much like a white gaussian noise as possible.

Power Control

- The link-level performance of a user is a function of its SINR.
- To achieve reliable communication, the SINR($^{\varepsilon_b}/_{I_o}$) should be above a certain threshold.
- This threshold depends on the specific code used, as well as the multipath channel statistics.
- Formulation:
- Suppose there are k users in the system and a number of cells (base stations).
- Let P_k be the transmit power of user k, and g_{km} be the attenuation of user k's signal to base station m.
- Suppose user k is assigned to base station C_k.
- The received energy per chip for user k at base station m is given by $P_k g_{km}/W$.
- If each user's target $^{\varepsilon_b}/_{I_o}$ is β, then the transmit powers of the users should be controlled such that:

$$\frac{G P_k g_{k,c_k}}{\sum_{n \neq k} P_n g_{n,c_k} + N_0 W} \geq \beta, \qquad k = 1, \ldots, K \qquad \text{................(1)}$$

Where $G = W/R$ is the processing gain of the system

Interference Averaging

- Consider the specific example of averaging of users' burstiness. For simplicity, consider a single cell situation with K users power controlled to a common base station and no out-of-cell interference.
- From (1), β requirement of all users is

$$\frac{GQ_k}{\sum_{n\neq k} Q_n + N_0 W} \geq \beta, \qquad k = 1, \ldots, K$$

where $Q_k := P_k g_k$ is the received power of user k at the base station. Equivalently:

$$GQ_k \geq \beta\left(\sum_{n\neq k} Q_n + N_0 W\right) \qquad k = 1, \ldots, K$$

- Summing up all the inequalities, we get the following necessary condition for the Q_k's:

$$[G - \beta(K-1)] \sum_{k=1}^{K} Q_k \geq K N_0 W \beta. \quad \text{.................................(2)}$$

- Condition for existence of realistic powers: G - β(K – 1) > 0 OR $K < \frac{G}{\beta} + 1$ ....(3)

- (3) shows the interference-limited system capacity of the single cell.
- It shows that because of the interference between users, there is a limit on th e number of users a cell can admit.
- Substituting the processing gain, $G = W/R$ into (3) yields,

$$\frac{KR}{W} < \frac{1}{\beta} + \frac{1}{G} \qquad \text{..(4)}$$

- $\frac{KR}{W}$ = overall spectral efficiency
- G of CDMA is very large → $\frac{KR}{W} \approx \frac{1}{\beta}$
- Therefore, the maximum spectral efficiency = $\frac{1}{\beta}$

- To illustrate the effect of user burstiness on the system capacity and the spectral efficiency in the single cell setting,
- Suppose now that each user is active and has data to send only with probability p, and users' activities are independent of each other.
- If we let v_k be the indicator random variable for user k's activity, i.e., v_k = 1 when user k is transmitting, and v_k = 0 otherwise, using (3), the SINR requirement of the users can be met if:

$$\sum_{k=1}^{K} \nu_k < \frac{G}{\beta} + 1 \quad \text{.....................................(5)}$$

- If this condition is not satisfied, then the system is in outage.
- If the system wants to guarantee that no outage can occur, then the maximum number of users admissible in the network is $\frac{G}{\beta} + 1$, same as the case when users are active all the time
- However, more users can be accommodated if a small outage probability P_{out} can be tolerated: this number $K*$ (P_{out}) is the largest K such that

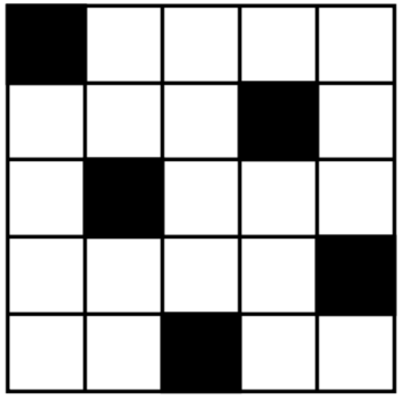
$$\Pr\left[\sum_{k=1}^{K} \nu_k > \frac{G}{\beta} + 1\right] \le p_{\text{out}} \quad \text{..............................(6)}$$

Wideband Systems: OFDM

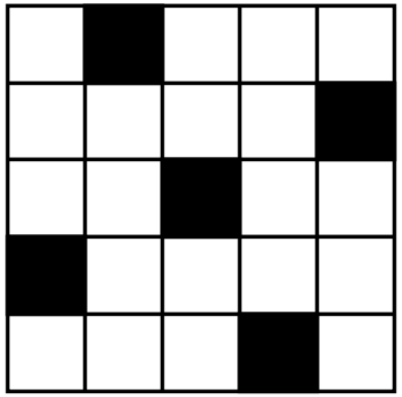
- Narrowband systems are ill suited for universal frequency reuse since they do not average interference.
- In CDMA, inter-cell interference reduces capacity and power control is expensive.
- OFDM achieves universal frequency reuse and also keep users orthogonal within the cell.
- We describe an allocation of sets of OFDM sub-carriers as the user signals.
- The bandwidth W is divided into Nc sub-carriers.
- The number of sub-carriers N_c is chosen to be as large as possible.
- The OFDM symbol period $\frac{N_c}{W} < T_c$.
- In each cell, we would like to distribute these N_c sub-carriers to the users.
- The n sub-carriers should be spread out in frequency to take advantage of frequency diversity.

Hopping Pattern

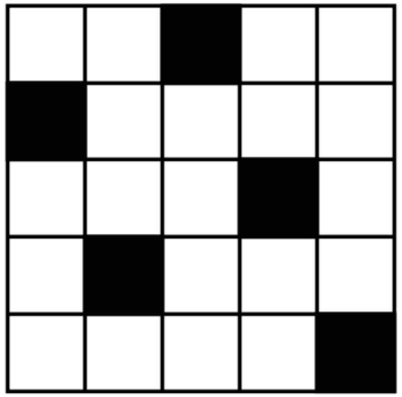
Virtual Channel 0

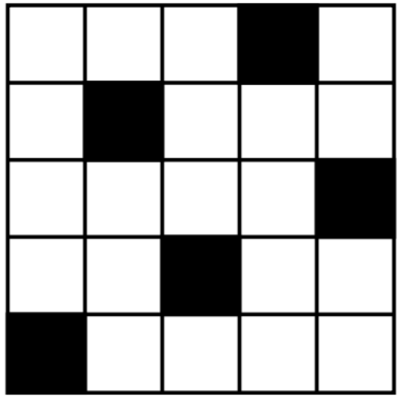


Virtual Channel 1

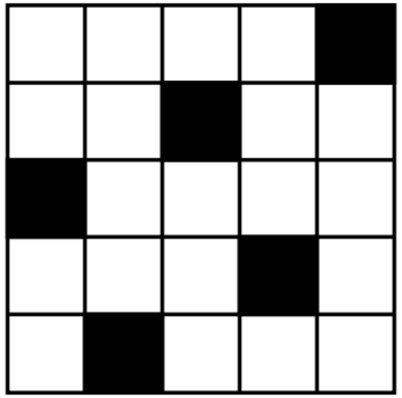


Virtual Channel 2





Virtual Channel 3



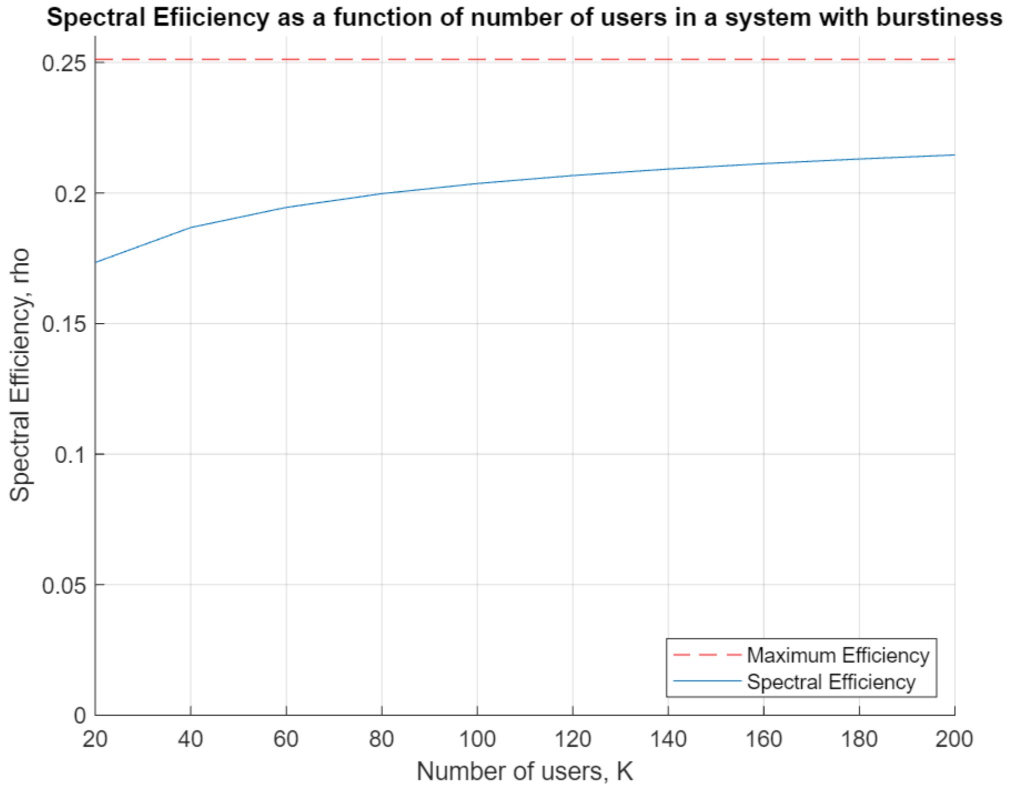
Virtual Channel 4

MATLAB Plot

- Plot of the spectral efficiency as a function of the number of users in a CDMA system with burstiness ,

$$\rho \leq \frac{1}{\beta}\left[1 + Q^{-1}(p_{\text{out}})\sqrt{\frac{1-p}{pK} - \frac{1}{Kp}}\right]^{-1}$$

- Here, p = 3/8
- Probability of outage, p_{out} = 0.01
- SINR, β = 6 dB.



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References

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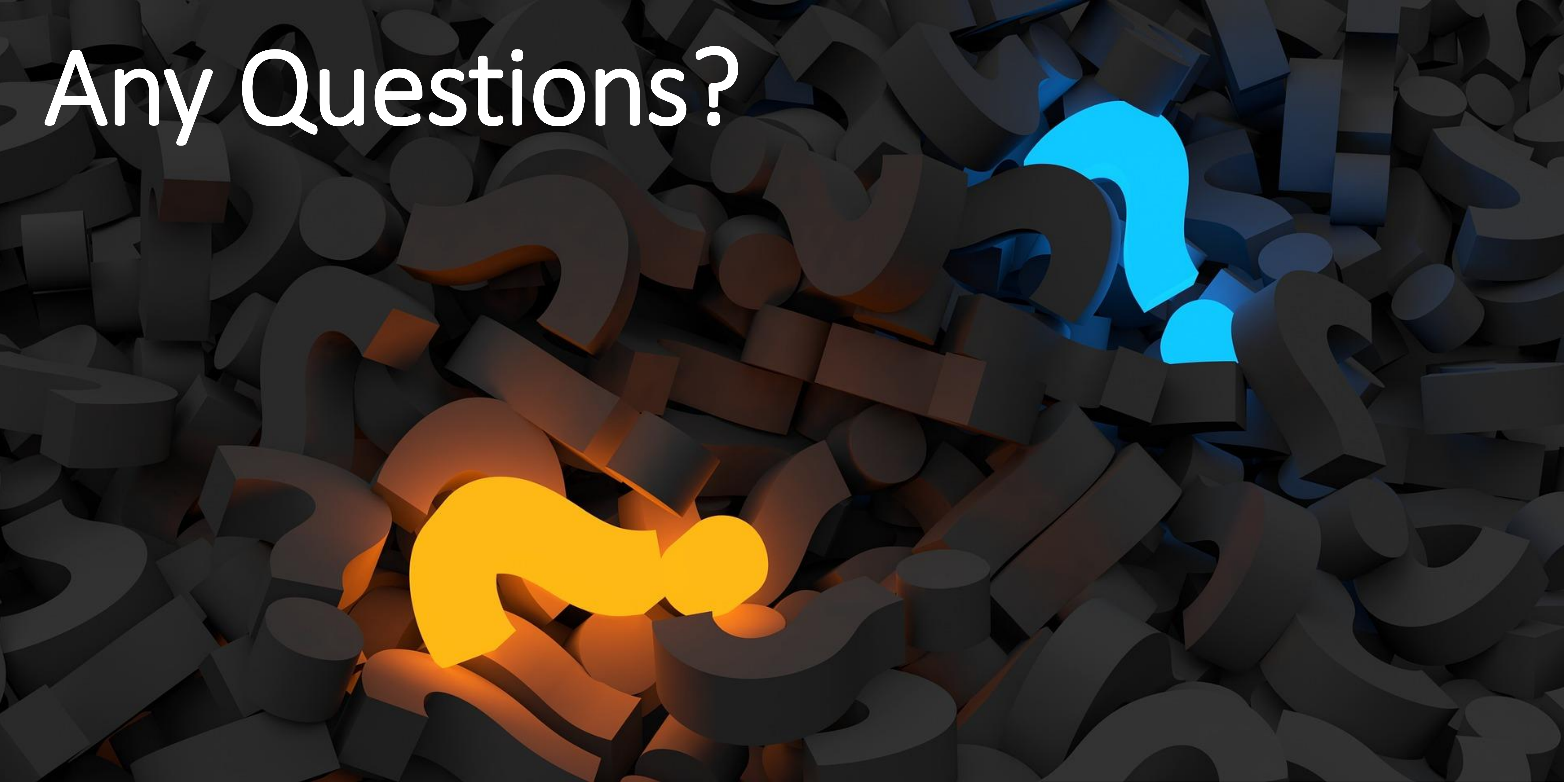
[2] T. S. Rappaport, "*Wireless communications—Principles and practice.*"

[3] A. J. Goldsmith, Wireless Communications, Cambridge University Press, 2005.

Any Questions?



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E-mail: edkwao10@gmail.com