FUNDAMENTALS OF WIRELESS COMMUNICATION

CELLULAR SYSTEMS: KEYNOTES

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OUTLINE OF PRESENTATION

- INTRODUCTION
- NARROWBAND CELLULAR SYSTEM
- WIDEBAND SYSTEMS
  - CDMA
  - OFDM

INTRODUCTION

- Focus is on cellular systems that are designed to work on licensed spectrum. Such cellular systems have been deployed nationwide and one of the driving factors for the use of licensed spectrum is the risk of huge capital investment if one must deal with malicious interference, as would be the case in unlicensed bands.
- At the physical and medium access layers, there are two main issues in cellular communication: multiple access and interference management. The first issue addresses how the overall system resource (time, frequency and space) is shared by the users in the same cell (intra-cell) and the second issue addresses the interference caused by simultaneous signal transmissions in different cells (inter-cell).

INTRODUCTION

- At the network layer, an important issue is seamless connectivity to the mobile as it moves from one cell to the other (and thus switching communication from one base station to the other, an operation known as handoff).
- A cellular network provides coverage of the entire area by dividing it into cells. We can carry this idea further by dividing each cell spatially. This is called sectorization and involves dividing the cell into, say 3, sectors.
- Sectorization is achieved by having a directional antenna at the base station that focuses transmissions into the sector of interest.

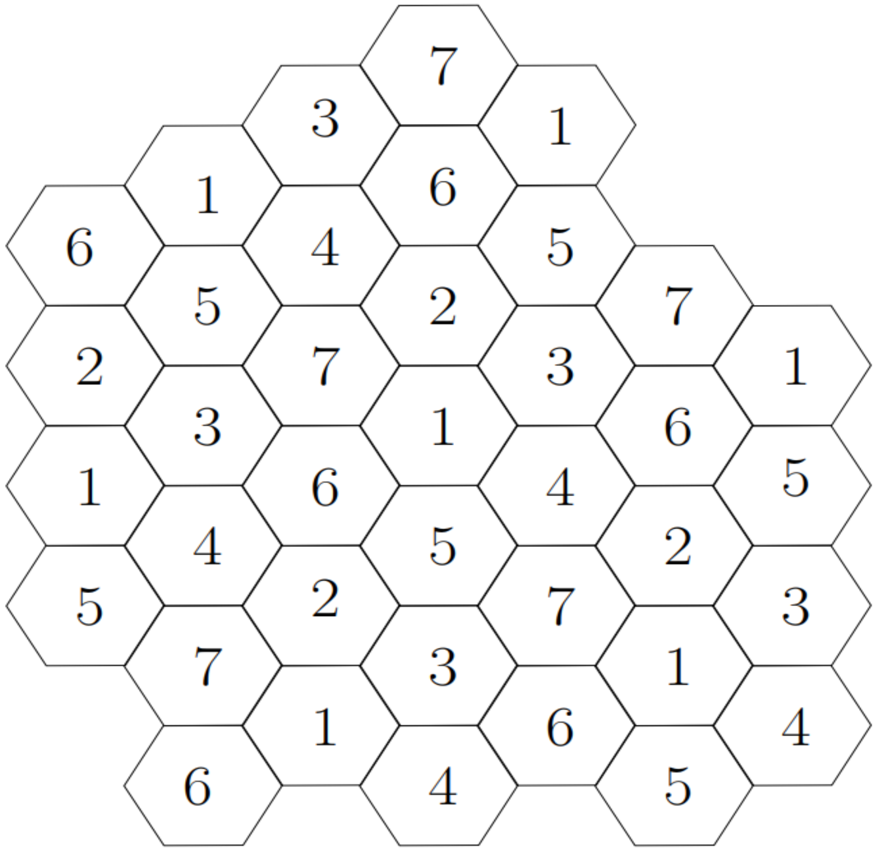
NARROWBAND CELLULAR SYSTEMS - DESIGN

- Identical uplink and downlink design of multiple access and interference management that can be termed narrowband to signify that the user transmissions are restricted to a narrow frequency band and the main design goal is to minimize all interference.
- We first divide the bandwidth into N narrowband chunks.
- Each narrowband channel has width $W/N\ Hz$. Each cell is allotted some n of these N channels.

NARROWBAND CELLULAR SYSTEMS - DESIGN

- The idea behind this allocation is that all transmissions within this cell (in both the uplink and the downlink) are restricted to those n channels. To prevent interference between simultaneous transmissions in neighboring cells, a channel is allocated to a cell only if it is not used by a few concentric rings of neighboring cells.
- The maximum number n of channels that a cell can be allocated depends on the geometry of the cellular arrangement and on the interference avoidance pattern that dictates which cells can share the same channel.

NARROWBAND CELLULAR SYSTEMS - DESIGN



PERFORMANCE

- What is the reliability with which information is received?
- Since the slot length T is small, it is typically within the coherence time of the channel and there is not much time diversity.
- Further, the transmission is restricted to a contiguous bandwidth 200 kHz that is narrow. In a typical outdoor scenario, the delay spread is of the order of 1μs, and this translates to a coherence bandwidth of 500 kHz, significantly larger than the bandwidth of the channel. Thus, there is not much frequency diversity either.

SIGNAL CHARACTERISTICS AND RECEIVER DESIGN

- An engineering constraint is to design transmit signals with reduced peak power for a given average power level. Constraint is captured by studying the peak to average power ratio (PAPR) of the transmit signal
- For signals transmitted by mobile user in GSM, data is modulated on to this single carrier using constant amplitude modulation schemes. In this context, the PAPR of the transmitted signal is small and is not much of a design issue.
- On the other hand, the signal transmitted from the base station is a superposition of n such signals, one for each of the 200 kHz channels. The aggregate signal has a larger PAPR, but the base station is usually provided with an AC supply and power consumption is not as much of an issue as in the uplink.

IMPACT ON NETWORK AND SYSTEM DESIGN

- How does sectorization affect this design?
- Though sectored antennas are designed to isolate the transmissions of neighboring sectors, in practice, inter-sector interference is seen by the mobile users, particularly those at the edge of the sector.
- One implication of reusing the channels among the sectors of the same cell is that the dynamic range of SINR is reduced due to the intra-sector interference. This means that neighboring sectors cannot reuse the same channels while at the same time following the design principles of this system.
- To conclude, the gains of sectorization come not so much from frequency reuse as from an antenna gain and the improved capacity of the cell.

IMPACT ON NETWORK AND SYSTEM DESIGN

- How robust is this design towards allowing neighboring base stations to reuse the same set of channels?

$$\mathrm{SINR} = \frac{P \mid h \mid^2}{N_0 + I}.$$

- The interfering user I can be at a wide range of locations, the variance of I is quite high.
- The randomness in the interference I due to the interferer's location is inherent in this system and continues to remain.
- Due to this, we can conclude that narrowband systems are unsuitable for universal frequency reuse.

WIDEBAND SYSTEMS: CDMA

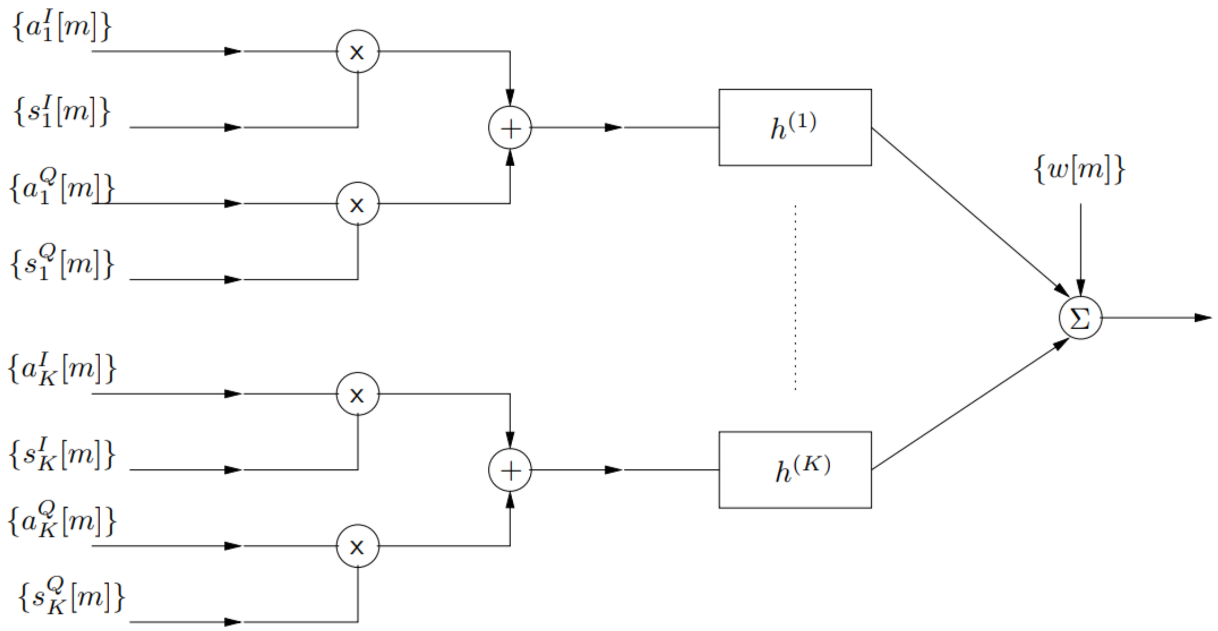
- The design philosophy of CDMA systems can be broken down into two design goals.
- First, the interference seen by any user is made as similar to white Gaussian noise as possible, and the power of that interference is kept to a minimum level and as consistent as possible.
- Tight power control among users within the same cell to ensure that the received power of each user is no more than the minimum level needed for demodulation.
- Averaging the interference of many geographically distributed users in nearby cells to reduce the randomness of the interference level due to varying locations of the interferers increases link reliability.
- Diversity is employed to improve the reliability of these point-to-point links., Since each user sees a point-to-point wideband fading channel with additive Gaussian noise.

WIDEBAND SYSTEMS: CDMA

- Increasing the number of users in a CDMA system increases the total level of interference. This allows a more graceful degradation on the performance of a system and provides a soft capacity limit on the system.
- Since all cells share a common spectrum, a user on the edge of a cell can receive or transmit signals to two or more base stations to improve reception. This is called soft handoff. It is an important mechanism to increase the capacity of CDMA systems.
- On the cons side, the performance of CDMA systems depends crucially on accurate power control, requires frequent feedback of power control information and incurs a significant overhead per active user.
- In contrast, tight power control is not necessary in narrowband systems, and power control is exercised mainly for reducing battery consumption rather than managing interference.

CDMA UPLINK

- General schematic of the uplink of a CDMA system with K users. A fraction of the K users is in the cell and the rest is outside the cell.



CDMA UPLINK

- Each sequence is modulated by a pseudonoise sequence, so that the transmitted complex sequence is:

$$x_k[m] = a_k^I[m]s_k^I[m] + ja_k^Q[m]s_k^Q[m], \qquad m = 1, 2 \ldots,$$

- The transmitted sequence of user k goes through a discrete-time baseband equivalent multipath channel h (k) and is superimposed at the receiver:

$$y[m] = \sum_{k=1}^{K} \left(\sum_{\ell} h_\ell^{(k)}[m] x_k[m - \ell] \right) + w[m].$$

- The receiver for user k multiplies the I and Q components of the output sequence $\{y[m]\}$ by the pseudonoise sequences to extract the coded streams of user k, which are then fed into a demodulator to recover the infor mation bits.

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POINT TO POINT LINK DESIGN

- In a CDMA system , we are now facing the aggregation of both interference and noise.
- The link level performance of user 1 depends on the SINR per chip:

$$\mathsf{SINR}_c := \frac{\mathcal{E}_1^c}{\sum_{k>1} \mathcal{E}_k^c + N_0}$$

- Observation: typically, the SINR per chip is very small.
- Obvious question: How can we demodulate the transmitted signal at such low SINR?

POINT TO POINT LINK DESIGN

- To see this in the simplest setting, let us consider an unfaded channel for user 1 and consider the simple example of BPSK modulation with coherent detection. Each information bit is modulated onto a pseudonoise sequence of length G chips.
- The error probability is

$$p_e = Q\left(\sqrt{\frac{2\|\mathbf{u}\|^2\mathcal{E}_1^c}{\sum_{k>1}\mathcal{E}_k^c + N_0}}\right) = Q\left(\sqrt{\frac{2G\mathcal{E}_1^c}{\sum_{k>1}\mathcal{E}_k^c + N_0}}\right) = Q\left(\sqrt{\frac{2\mathcal{E}_b}{\sum_{k>1}\mathcal{E}_k^c + N_0}}\right)$$

- Thus, we see that while the SINR per chip is low, the SINR per bit is increased by a factor of G, due to the averaging over the G chips over which we repeat the information bits. $G = W/R$, where W Hz is the bandwidth and R $bits/s$ is the data rate. This parameter is called the processing gain of the system.

POINT TO POINT LINK DESIGN

- G is increasing the effective SINR against a large amount of interference that the user faces.
- As we scale up the size of a CDMA system by increasing the bandwidth W and the number of users in the system proportionally but keeping the data rate of each user R fixed, we see that the total interference and the processing gain G increase proportionally as well.
- This means that CDMA is an inherently scalable multiple access scheme.

POWER CONTROL

- To achieve reliable communication, the SINR per chip should be above a certain threshold.
- In a mobile communication system, the attenuation of both the user of interest and the interferers varies as the users move, due to varying path loss and shadowing effects. To maintain a target SINR, transmit power control is needed.
- The actual power control in IS-95 has an open-loop and a closed-loop component. The open-loop sets the transmit power of the mobile user at roughly the right level by inference from the measurements of the downlink channel strength via a pilot signal.
- Closed-loop control is needed to adjust the power more precisely.

SOFT HANDOFF

- Traditionally, handoffs are hard: users are either assigned to one cell or the other but not both.
- In CDMA systems, since all the cells share the same spectrum, soft handoffs are possible: multiple base stations can simultaneously decode the mobile's data, with the switching center choosing the best reception among them.
- Soft handoffs provide another level of diversity to the users.
- If we view the base stations as multiple receive antennas, soft handoff is providing a form of receive diversity
- We know that the optimal processing of signals from the multiple antennas is maximal-ratio combining; this is however difficult to do in the handoff scenario as the antennas are geographically apart.
- Instead, what soft handoff achieves is selection combining.

SOFTER HANDOFF

- In IS-95, there is another form of handoff, called softer handoff, which takes place between sectors of the same cell. In this case, since the signal from the mobile is received at the sectored antennas which are co-located at the same base station, maximal-ratio combining can be performed.

CDMA DOWNLINK

- Near-far problem does not exist for the downlink hence power control is less crucial. Rather, the problem becomes that of allocating different powers to different users as a function of the amount of out-of-cell interference they see.
- Since signals for the different users in the cell are all transmitted at the base station, it is possible to make the users orthogonal to each other, something that is more difficult to do in the uplink, as it requires chip-level synchronization between distributed users. This reduces intra-cell interference.
- Intercell interference is more prevalent in downlink, since transmission is on a very high frequency.

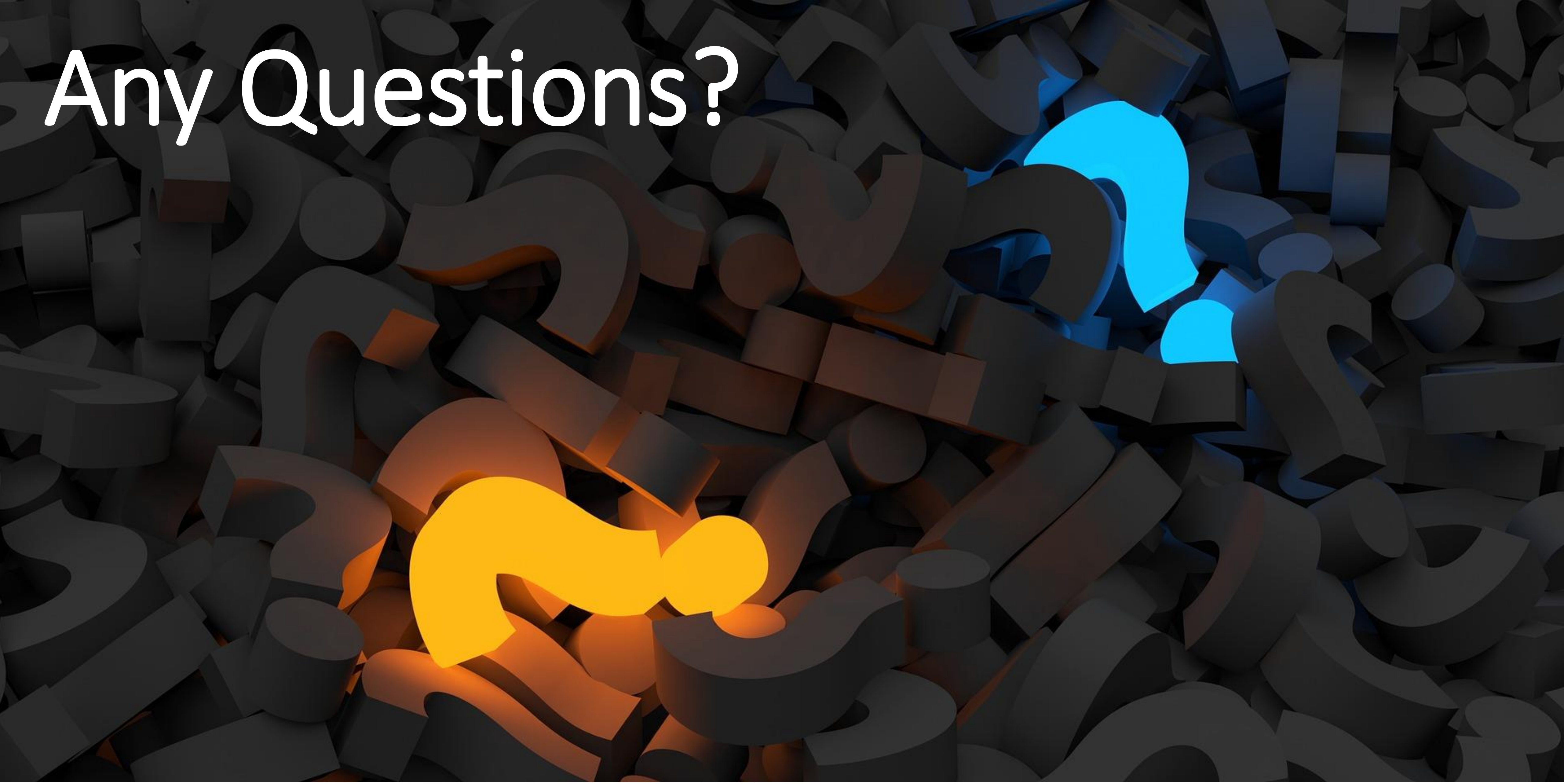
OFDM

- Maintain orthogonality of transmissions within the cell and have universal frequency reuse across cells.
- The sub-carriers of the OFDM scheme for the multipath channel provide a set of orthogonal signals over an OFDM block length.
- The subcarriers should be spread out in frequency to take advantage of frequency diversity. Hence there is no interference among user transmissions within a cell by this allocation.
- OFDM is design to implement hopping and coding across the sub-carriers in other to harvest interference diversity. (Free from severe neighboring cell interference and degraded performance).

SUMMARY

	Narrowband System	Wideband CDMA	Wideband OFDM
Signal	Narrowband	Wideband	Wideband
Intra-cell BW Allocation	Orthogonal	Pseudorandom	Orthogonal
Intra-cell Interference	None	Significant	None
Inter-cell BW Allocation	Partial reuse	Universal reuse	Universal reuse
Inter-cell Uplink Interference	Bursty	Averaged	Averaged
Accuracy of Power Control	Low	High	Low
Operating SINR	high	low	range: low to high
PAPR of uplink signal	low	medium	high
Example System	GSM	IS-95	Flash-OFDM

Any Questions?



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