Lecture 34: 4.5 OFDM Technology (Basic concept and Advantages)

4G and 5G Networks

DI05011011: Mobile Communication

Agenda for Today

- 1. The Problem: Multipath Fading & ISI
- 2. Evolution: From FDM to OFDM
- 3. Basic Concept of OFDM
- 4. What does 'Orthogonal' mean?
- 5. How OFDM Works
- 6. The Role of the Cyclic Prefix
- 7. Advantages of OFDM
- 8. Summary and Q&A

The Problem: Multipath Fading and ISI

- In a wireless channel, signals bounce off buildings, trees, and cars.
- **Multipath:** The receiver gets multiple delayed copies of the same signal.
- **Inter-Symbol Interference (ISI):** At high data rates, symbols are very short. A delayed copy of Symbol 1 can overlap with Symbol 2, causing interference and errors.
- Traditional single-carrier systems require complex equalizers to fix this.

From FDM to OFDM

- **FDM (Frequency Division Multiplexing):**
- - Divides the total bandwidth into non-overlapping sub-bands.
- - Requires large 'guard bands' between channels to prevent interference.
- - Inefficient use of the spectrum.
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- **OFDM (Orthogonal FDM):**
- - Allows subcarriers to overlap tightly without interfering with each other.
- - Saves massive amounts of spectral space (no large guard bands needed).

Basic Concept of OFDM

- Instead of transmitting a high-speed data stream over a single wideband carrier, OFDM divides the stream.
- - The high-rate data stream is split into multiple parallel low-rate data streams.
- - Each low-rate stream is modulated onto a separate, narrow subcarrier.
- - Because the data rate on each subcarrier is low, the symbol duration is long.
- - **Result:** Long symbol durations are highly resistant to multipath delay (ISI).

Understanding 'Orthogonality'

- In mathematics, orthogonal means independent or uncorrelated.
- In OFDM, subcarriers are mathematically orthogonal to each other.
- - The peak of one subcarrier perfectly aligns with the nulls (zero-crossings) of all other subcarriers.
- - When the receiver samples a specific frequency, the interference from all other overlapping subcarriers is mathematically zero.

The Role of the Cyclic Prefix (CP)

- While OFDM is robust against ISI, it isn't perfect.
- To completely eliminate ISI, OFDM adds a **Cyclic Prefix (CP)**.
- - The end of an OFDM symbol is copied and appended to the front of the symbol.
- - This acts as a 'guard time' between symbols.
- - As long as the multipath delay is shorter than the CP length, there is zero ISI.

Advantages of OFDM (Part 1)

- 1. **High Spectral Efficiency:** Overlapping subcarriers save significant bandwidth compared to traditional FDM.
- 2. **Robustness to Multipath Fading:** The combination of parallel low-rate streams and the Cyclic Prefix makes it highly immune to ISI.
- 3. **Simple Equalization:** Because each subcarrier is narrow, the channel response across it is flat. This eliminates the need for complex time-domain equalizers.

Advantages of OFDM (Part 2)

- 4. **Scalability:** OFDM can easily scale to different channel bandwidths (e.g., 1.4 MHz to 20 MHz in LTE) simply by changing the number of active subcarriers.
- 5. **Flexibility:** Different modulation schemes (QPSK, 16-QAM, 64-QAM) can be applied to different subcarriers based on channel conditions (Link Adaptation).
- 6. **Synergy with MIMO:** OFDM is naturally suited to be combined with MIMO technology to further boost data rates.

Real-World Application: Wi-Fi and 4G

- OFDM isn't just for cellular networks.
- - **Wi-Fi:** 802.11a/g/n/ac/ax all use OFDM.
- - **Broadcasting:** Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB-T) use OFDM to handle multipath from tall buildings and mountains.
- It is the universal standard for high-speed wireless data today.

Lecture Summary

- OFDM mitigates multipath ISI by splitting a high-rate data stream into many low-rate parallel streams.
- Orthogonal subcarriers can overlap without interference, maximizing spectral efficiency.
- The Cyclic Prefix provides a guard time to completely absorb multipath delay.
- OFDM offers high scalability, simple equalization, and excellent synergy with MIMO.
- It is the foundational physical layer technology for LTE, Wi-Fi, and 5G.

Next Lecture Preview

- In the next lecture, we will explore the perfect companion to OFDM:
- **4.6 MIMO Technology (Multiple Input Multiple Output)**
- - How can using multiple antennas increase data rates?
- - Spatial Multiplexing vs. Transmit Diversity.
- - The advantages of MIMO in 4G networks.