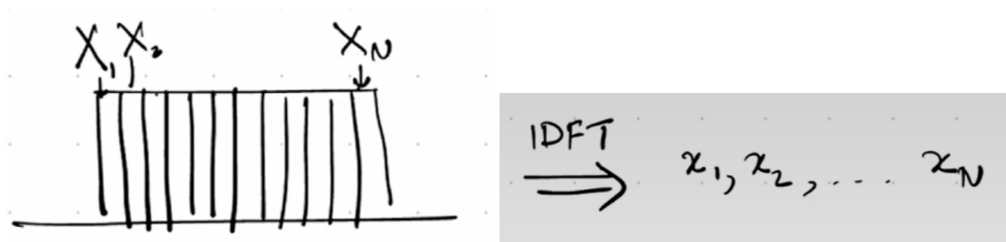
CS598 WSI Lecture 6 Scribe Notes

We continued our discussion on Orthogonal Frequency Division Multiplexing (OFDM). The previous lecture focused on the motivation behind OFDM, discussing both its advantages and disadvantages. This lecture focused on the steps involved in implementing OFDM, particularly how it can be applied in lab work and its mathematical underpinnings.

OFDM:

1. Pipeline



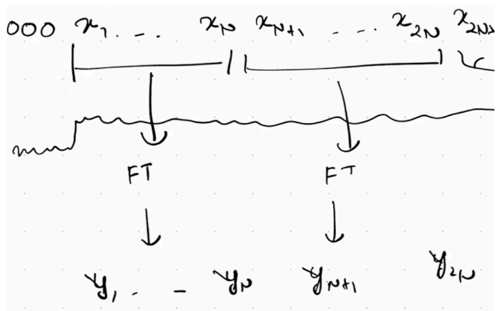
- Dividing the wide band we want to transmit into multiple narrow bands (junc of frequency).
- Typical values for N are 64, 128, 256 for WiFi, and 1024 for LTE.
- Using IDFT (Inverse Discrete Fourier Transform) to convert from frequency domain to time domain.
- Ensures that parallel frequency chunks do not interfere with each other due to orthogonality.
- After the conversion, the symbols are transmitted sequentially in the time domain.

Receiver Side:

- The receiver captures the transmitted symbols Y_1, Y_2, Y_3, ….., Y_N.
- FFT is used to convert the captured time-domain symbols back to the frequency domain.
- Each symbol Y_i is influenced by its corresponding channel response and possible noise.

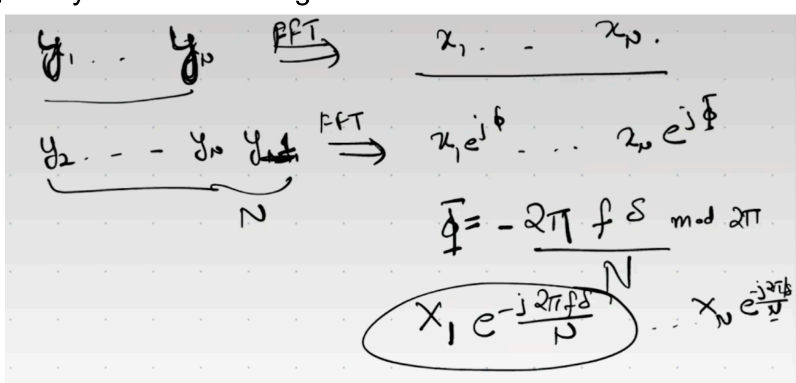
$$Y_i = H_i X_i + n_i$$

2. Packet Detection:

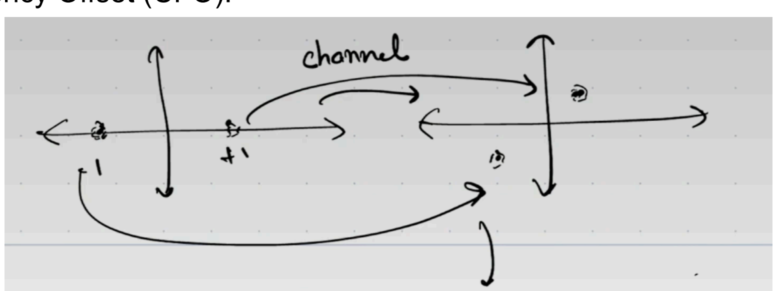


- Packets are detected by examining power levels (using a sliding window technique) and differentiating between noise and signals.
- Accurate detection is crucial, as any misalignment can lead to problems in decoding the received symbols.
- Sometimes it could be hard to detect where the packet starts.

3. Cyclic Prefix:
    - To avoid packet detection issues and mitigate inter-symbol interference (ISI), we add a cyclic prefix.
    - A portion of the beginning of the symbol is repeated at the end to provide tolerance for timing errors.
    - The cyclic prefix allows the receiver to correct errors introduced by incorrect packet detection.
    - Due to the nature of Mathematics, the receiver could have the correct sequence of the original symbols after doing the FFT/DFT.



4. Carrier Frequency Offset (CFO):

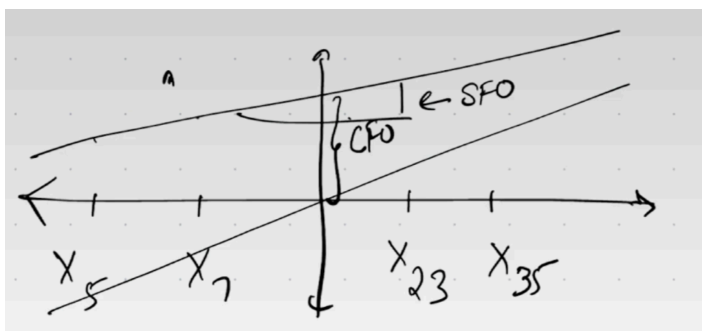


CFO arises when the transmitter and receiver are not perfectly synchronized in terms of their carrier frequencies. This frequency mismatch, denoted as Δf, causes a phase rotation in the received signal, which grows over time.

- CFO must be estimated and corrected, otherwise, it leads to significant demodulation errors.
- A known sequence (preamble) is sent by the transmitter, which is also known by the receiver. By comparing the received sequence over time, the receiver can estimate how much the phase is drifting due to CFO.
- Once the CFO is estimated, the receiver applies a phase rotation in the opposite direction to cancel the effect of the CFO. This brings the received signal back into phase alignment with the transmitted signal.

5. Channel Estimation:
   Channel estimation is crucial in OFDM systems because the transmitted signal passes through a channel that can cause distortions due to multipath fading. The channel's impact on each subcarrier is different.
   - Known sequences (preamble) are sent, and the receiver uses these known symbols to estimate the channel's effect on each subcarrier.
   - Once the channel's effect is known, the receiver divides the received symbols by the estimated channel coefficients to retrieve the original transmitted symbols.

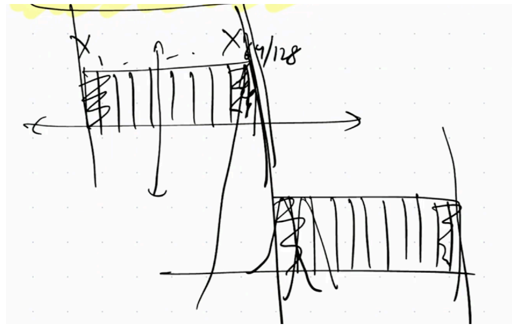
6. Residual CFO / SFT:



Even after initial CFO correction, some small errors (residual CFO) and sampling frequency offsets (SFO) can still remain, leading to further phase distortions over time.
   - If the CFO is not fully corrected, there will still be a small, slow phase rotation that accumulates across symbols. This is particularly problematic for long data transmissions because even a small residual phase error can build up and corrupt the data.
   - SFO occurs when the transmitter and receiver are not synchronized in terms of their sampling rates. This causes the timing of the samples to drift. For instance, if the transmitter is sending samples at 1 microsecond intervals and the receiver samples at 1.001 microseconds, over time, this tiny error will accumulate, leading to timing mismatches.
   - Pilot subcarriers (known subcarriers that are embedded within the data transmission) are used to monitor and correct these residual errors. By observing

how the phase of the pilot symbols evolves over time, the receiver can detect and adjust for any remaining CFO or SFO.

7. Guard Bands:



Guard bands are portions of the frequency spectrum at the edges of the OFDM signal that are left unused to prevent interference with neighboring signals or systems.

- In OFDM, subcarriers are closely packed, but there is still some “leakage” of energy into adjacent frequencies. Guard bands are used to absorb this leakage, preventing interference with adjacent channels or systems operating in nearby frequencies. For example, in a WiFi system, if two adjacent access points are operating on neighboring channels, the guard bands ensure that the signals from one access point do not spill over into the other’s operating bands.
- The transmitter sets certain subcarriers to zero, meaning no data is transmitted on those subcarriers. These zeroed subcarriers act as a buffer zone, ensuring that energy leakage from active subcarriers doesn’t interfere with adjacent frequency bands.