OFDMA-CDMA

Computer Networks, Lecture 13

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Overview

1. Recap of the previous lecture
2. Medium Access Control
   - Unlicensed Bands
   - Licensed Bands
     - TDMA
     - FDMA
3. OFDMA
4. CDMA

Recap of the previous lecture

- CSMA-CD in Ethernet
- Virtual Carrier Sensing in WiFi to avoid collisions
- RTS, CTS, CSMA-CA in WiFi

Unlicensed Bands

CSMA-CD/CA protocols are used when there is no centralised coordinator. For instance, in case of WiFi, given a particular frequency band, the govt. has freed a set of spectrum (unlicensed free-for-all) provided the power level is below a certain specified level.

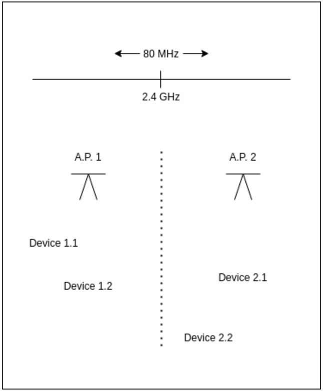


Figure: CSMA has no central coordinator

Hence, CSMA is a decentralised protocol and has turned out to be quite successful in using these unlicensed bands.

Useful for technologies such as WiFi, bluetooth, etc.

Licensed Bands

The govt. sells the licensed band spectrums to the companies (Airtel, Jio). Only the companies who got the spectrum, are allowed to transmit in that range exclusively. Different companies are allocated different bands, and in different regions of the country, they may use different sets of bands.

CSMA is not a very efficient protocol. For instance in WiFi, suppose a frame is successfully transmitted. Then all the devices wait for DIFS time followed by a random wait time. All this time is wasted. There could be collisions which further reduces the efficiency.

What can we do?

Suppose, Airtel sets up a 4G tower. Now, there are several mobile users connected to this tower. This tower, therefore, acts as a central controller.

(Even if a Jio tower is nearby, Airtel need not worry since Jio uses a different frequency range. Airtel can simply use a bandpass filter to remove other frequencies.)

Airtel itself can have multiple 4G towers. We divide the geographical regions in **cells**, each corresponding to one Airtel 4G tower.

Preventing interference among cells is also a challenge.

We will focus on a single cell. We will assume there is no interference from other cells.

Time Division Multiple Access

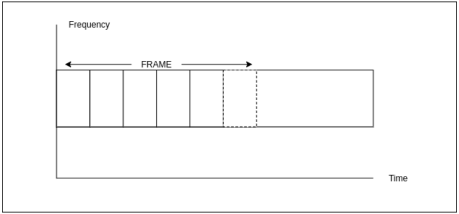
Uplink (UL)

A user transmits to the base station.

Downlink (DL)

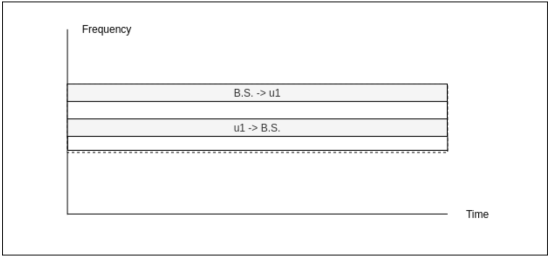
The base station transmits to a user.

We divide time into **slots** and allocate them to different users. Repetitive set of slots is called a **frame**. Some slots in the frame can be used to give the schedule (DL-MAP, UL-MAP) to the users.



Frequency Division Multiple Access

We divide frequency into narrow bands and allocate them to different users. Each user can filter the useful frequency ranges (DL, UL for that user).



Orthogonal Frequency Division Multiple Access

4G-LTE uses **OFDMA**. lte vs wimax
OFDMA uses a combination of **TDMA** and **FDMA**.

The frame begins with **preamble**, used for:

- Clock Synchronization (to the base station clock)
- Frame starts
- Channel estimation (attenuation, phase)

This is followed by the DL/UL MAP.

Different slots in time and frequencies (**tiles**) are assigned to the users (like a jigsaw) in DL and UL. Multiple tiles can be assigned to the same user.

DL tiles are followed by a short gap, before UL.

Guard Band

An unused narrow frequency range used to separate two wider frequency ranges to ensure that both can transmit simultaneously without interfering with each other.

We cannot afford guard bands in the tiles or else we will be wasting a lot of bandwidth.

OFDM (Orthogonal Freguency Division Multiplexing) allows to transmit signals without guard bands, ensures that the signals are orthogonal to each other. (won't discuss in detail)

Why **OFDMA** ? The attenuation that different users face in different tiles is different (multipath, etc.). Continuously in time, users are estimating the attenuations they face, send the feedback to the b.s. in the allocated slots, and hence UL/DL MAP changes over time. Silent users may not be allocated any slots.

Contention Slots are the unallocated slots wherein users transmit to the b.s. and ask for allocation of tiles in the upcoming frames (using CSMA scheme). DL/UL MAP can be used for acknowledgements, or alternatively the b.s. can acknowledge in a DL slot (broadcast slot in DL). In case of collisions, they do a random backoff.

In **OFDM**, each narrow band has its own f_c'. Different narrow bands may have different modulation schemes. Used in WiFi, 4G.

Code Division Multiple Access

Used in 3G. Allows multiple users to use the same time-frequency tile.
How? It uses **spreading code**. Suppose, we are using BPSK,

$$u_1 = c_1(t) \times A \cos 2\pi f_c t$$
$$u_2 = c_2(t) \times -A \cos 2\pi f_c t$$

where $0 < t < \frac{N}{f_c}$ and, $c_1(t)$ and $c_2(t)$ are the spreading codes.

A spreading code is a series of bits (± 1 in terms of signal).

Notice, $c_1^2(t) = 1$ and $c_2^2(t) = 1$.

The codes are chosen such that $c_1(t)$ and $c_2(t)$ are orthogonal.
(If we generate bits ($\pm$ 1) randomly for sufficiently long strings, $c_1(t)$ and $c_2(t)$ will be orthogonal.) That is, $\int_0^T c_1(t)c_2(t)dt = 0$.

At the base station, $r(t) = \Sigma_{j=1}^{n} s_i(t)$.

$$\begin{aligned}
s_1(t) \times c_1(t)\cos 2\pi f_c t &= c_1^2(t) A \cos^2 2\pi f_c t \\
&= A\cos^2 2\pi f_c t \\
&= \frac{A}{2}\left(1 + \underset{\substack{\text{(can be removed by} \\ \text{low-pass filtering)}}}{\cos 4\pi f_c t}\right)
\end{aligned}$$

Low pass filter because, $2f_c$ is a high frequency.

$$\begin{aligned}
s_2(t) \times c_1(t)\cos 2\pi f_c t &= c_1(t)c_2(t)(-A)\cos^2 2\pi f_c t \\
&= -\frac{A}{2} c_1(t)c_2(t)\left(1 + \underset{\substack{\text{(can be removed by} \\ \text{low-pass filtering)}}}{\cos 4\pi f_c t}\right)
\end{aligned}$$

We are left with $\frac{A}{2} + -\frac{A}{2} c_1(t) c_2(t)$.

$$\int_0^T \left(\frac{A}{2} + -\frac{A}{2} c_1(t) c_2(t) \right) dt = \frac{\boldsymbol{A}T}{2}$$

This gives the symbol that the first user sent. Similarly, multiply by $c_2(t)$ for the second user.

CDMA, **OFDM** are robust to multi-path.
Reason:
For **CDMA**, $c(t) \perp c(t - \delta)$ for spreading code $c(t)$ and some δ (delay due to multipath). For **OFDM**, the signal still falls majorly in the tile.

References

CS224 Computer Networks
Lecture 13 (Spring 2021)
Prof. Vinay Joseph Ribeiro