Controlling Volume Levels

Q1.1 What exactly is a frequency channel?

With FDMA, frequency is the resource split among different users. Each connection uses a different **frequency channel**, which encapsulates a range of frequencies, defining the **channel width**. For instance, if the channel for our call was between 40 MHz and 60 MHz, its width would be $60 - 40 = 20$ MHz. But we only have a certain amount of frequency that we can divide into channels to start with. As such, there is a limit to the number of links the network can support at one time. We illustrate this idea in Figure 1.

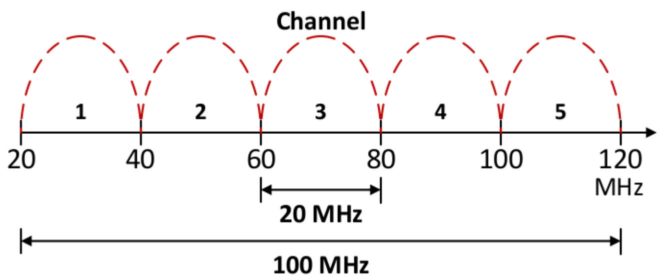

Illustration 1: Each frequency channel has a certain width that it needs to operate. Here, we show the spectrum between 20 and 120 MHz, or 100 MHz total. If each channel requires a width of 20 MHz, this means we can have at most $100/20 = 5$ channels, as shown.

Q1.2 What is the FCC licensing process?

The FCC was established in 1934 to oversee the development of communications technologies in the US. As such, it has been in charge of *licensing* spectra to service providers. Some portions of the spectrum, like the part WiFi uses, is unlicensed and can be used by anyone. But most portions, including that for cellular, require a license to use. Operators need to go through a long, grueling process with the FCC to get these licenses. Depending on the number of petitioning operators and the availability of additional spectra, this process can take years and be quite expensive.

Q1.3 How does CDMA work?

The idea behind CDMA is as follows. The transmitter multiplies the signals with a **spreading code**, which is simply a sequence of 1's and -1's. Each bit in the transmission is multiplied separately and sent as a much larger, composite stream. We illustrate this in Figure 2. Once the "coded" message arrives, the receiver uses the spreading code to recover the original message.

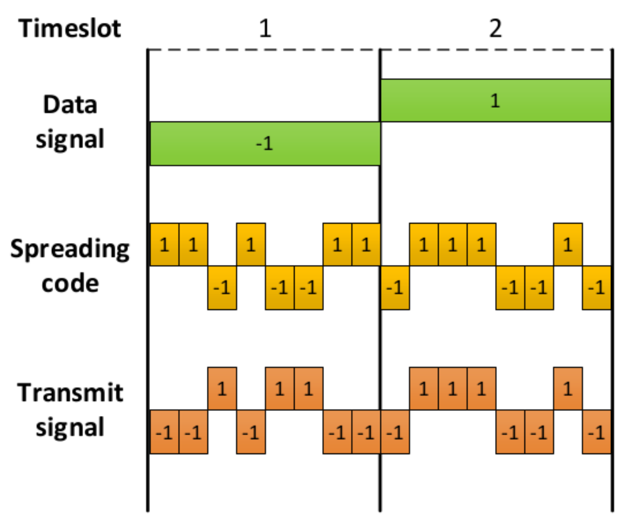

Illustration 2: An example of how CDMA converts a data signal into the transmit signal using a spreading code. The 0 bit is represented as -1 for mathematical convenience (1 and -1 can also be thought of as "high" and "low"). In this example, the spreading code changes eight times more rapidly than the data signal. During the second timeslot, the data signal is 1: each value of the spreading code is multiplied by 1, which gives us the spreading code back. Conversely, in the first timeslot the data signal is -1: the spreading code is multiplied by -1, which makes the transmit signal the inversion of the spreading signal.

Q1.4 What is the measured SIR and next power level from where we left off in the DPC example?

The current power levels are 1.40, 1.50, and 2.68 mW for A, B, and C. Let's look at Link A:

- *Signal*: As before, the direct gain is 0.9. With the updated transmit power of 1.40 mW, the received signal power is 0.9×1.40 mW $= 1.26$ mW.
- *Interference*: Again, the indirect gains from Transmitters B and C are 0.1 and 0.2, respectively. With the updated transmit powers of 1.50 mW and 2.68 mW, the interfering power becomes 0.1×1.50 mW $+ 0.2 \times 2.68$ mW $= 0.686$ mW.
- *Noise*: This is 0.1 mW, as before.

The updated measured SIR value for Link A is then

$$\frac{0.9 \times 1.40}{0.1 \times 1.50 + 0.2 \times 2.68 \ + 0.1} = \frac{1.26}{0.786} = 1.60.$$

We can similarly find the new SIR values for Links B and C:

$$\begin{aligned}\frac{0.8 \times 1.50}{0.1 \times 1.40 + 0.1 \times 2.68 \ + 0.2} &= \frac{1.20}{0.608} = 1.97, \\ \frac{0.9 \times 2.68}{0.2 \times 1.40 + 0.2 \times 1.50 \ + 0.3} &= \frac{2.412}{0.880} = 2.75.\end{aligned}$$

Each of the SIRs are closer to their target values than they were initially: Links A and B are now lower by $1.8 - 1.6 = 0.2$ and $2.0 - 1.97 = 0.03$ than the desired values, and Link C is higher by $2.75 - 2.2 = 0.55$. Initially, we saw that Link C was in need of higher SIR, while the other two links had an abundance, but now their statuses have switched. This characteristic of overshooting and undershooting the target values will likely occur in many of the iterations until convergence.

We continue now to the second iteration, this time using the transmit powers and measured SIRs from the first iteration in our calculations. The new transmit powers are

$$\begin{aligned}\frac{1.80}{1.60} \times 1.40 \text{ mW} &= 1.58 \text{ mW}, \\ \frac{2.0}{1.97} \times 1.50 \text{ mW} &= 1.52 \text{ mW}, \\ \frac{2.2}{2.75} \times 2.69 \text{ mW} &= 2.15 \text{ mW},\end{aligned}$$

resulting in measured SIRs of

$$\begin{aligned}
\frac{0.9 \times 1.58}{0.1 \times 1.52 + 0.2 \times 2.15 \ + 0.1} &= \frac{1.422}{0.682} = 2.08, \\
\frac{0.8 \times 1.52}{0.1 \times 1.58 + 0.1 \times 2.15 \ + 0.2} &= \frac{1.216}{0.573} = 2.13, \\
\frac{0.9 \times 2.15}{0.2 \times 1.58 + 0.2 \times 1.52 \ + 0.3} &= \frac{1.935}{0.920} = 2.10.
\end{aligned}$$

As before, the overshoot/undershoot pattern has reversed. Now Links A and B are too high by 0.28 and 0.13, and Link C is too low by 0.1.

Q1.5 Where do smartphones fit in to the picture?

Adoption of the 3G standard and the entry of Apple into the wireless industry gave rise to the commercial **smartphone**. According to comScore, as of 2015, roughly 75% of mobile subscribers in the US owned smartphones, with the penetration of smartphones having eclipsed the older "feature" phones for the first time back in 2012. The iPhone and Android brands dominate the market, each having about half of the share.