Objectives, History, Transmission Fundamentals

Handouts: Preliminaries, Credit, Tentative Outline

Lecture Outline:

- Administrivia; honor code for problem sets.
- Objectives

1 Objectives

By the end of this course, we should be able to answer the following questions:

1. How much information can a channel send?

   Shannon's capacity theorem describes the maximum theoretical data rate of a medium given a certain transmission power and noise levels. Therefore, as more capacity is needed, more spectrum is required to satisfy those rates. Spectrum, however is a finite resource, and as such the cost to obtain new sections of it is high.

2. Imagine a wireless network in which the devices (e.g. cell phones) can not only speak to the base station, but also among themselves, and relay each other's messages to the base if needed. Then the obvious question to ask is if it is possible to add capacity to such a network indefinitely by adding more devices.

3. What happens to capacity when mobility is assumed?

   Tipically this is a store-and-forward scenario (e.g. delay-tolerant networks) where the sender transmits its data to an intermediate node (a satellite of instance), and the receiver must wait until the satellite is within range to download the data. We will study some ways in which this can be improved.

2 History and Future

Figure 1 illustrates the history and the future of wireless transmissions.

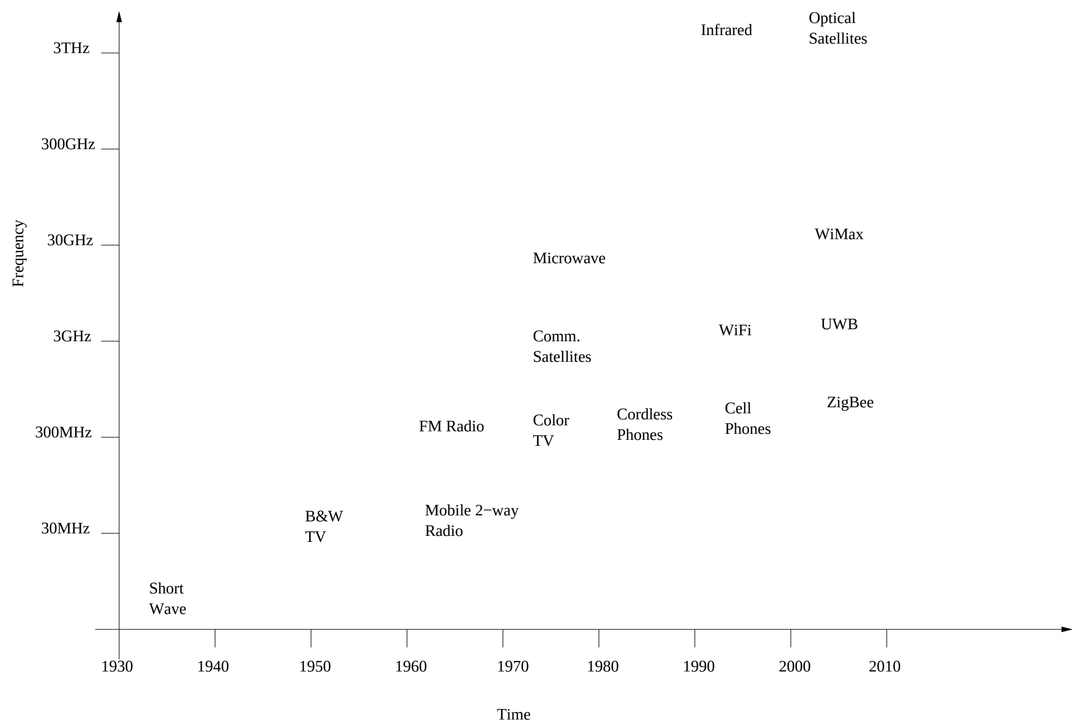

Figure 1: History Chart

- the bigger the frequency, the lesser the diffraction
- light has a shorter wavelength and it can only operate in the line of sight
- the advantage of small frequencies is that they have a longer wavelength
- wireless devices have the nice property of being able to operate out of line of sight
- it is difficult to generate frequencies bigger then 60GHz; the reason is that transistors cannot be turned on and off at such a high rate

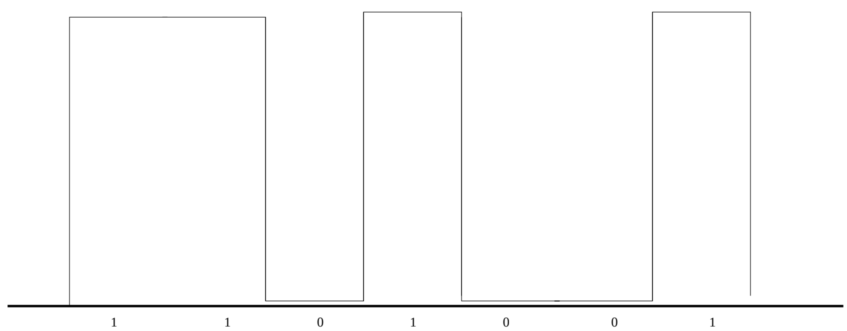

Figure 2: Digital data

- notice the gap around 300GHz in Figure 1. The reason for that is that we cannot generate such high frequencies and that above a certain threshold we reach infrared colored spectrum which is easy to generate.

There are two main technological hurdles that we experience:

- switching speed of the material (limited by silicon)
- lack of standards (different countries use different standards)

3 Transmission Fundamentals

Digital data is basically a series of 1s and 0s. For example, let's consider Figure 2.

However the real world is analog. During transmission the signal might be distorted to an extent that it might become unrecognizable (Figure 3).

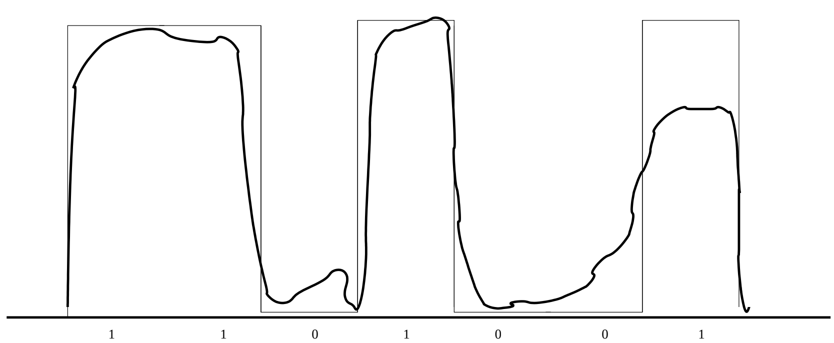

Figure 3: The above signal as seen by the receiver

A signal can be expressed mathematically in the following way:

$$\begin{aligned} \mathtt{s(t)} &= \mathtt{A}\sin(2\pi\mathtt{ft}+\phi),\ \ \mathtt{where} & (1)\\ \mathtt{A} &= \mathtt{amplitude,} & (2)\\ \mathtt{f} &= \mathtt{frequency,} & (3)\\ \phi &= \mathtt{phase} & (4)\\ & & (5) \end{aligned}$$

Also,

$$\begin{aligned} \mathtt{T} &= \frac{1}{\mathtt{f}},\ \ \mathtt{where} & (6)\\ \mathtt{T} &= \mathtt{time\ period} & (7)\\ & & (8) \end{aligned}$$

If $\phi = 0$ and $\mathtt{f} = 1$, then this is what we will see in Figure 4.

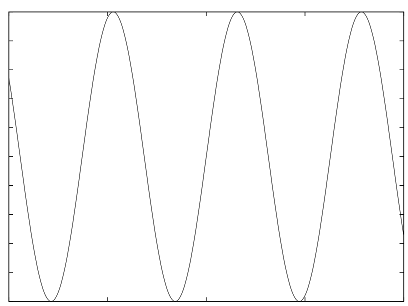

Figure 4: $\mathtt{s(t)} = \mathtt{A}\sin(2\pi\mathtt{t})$

Let's also look at the signal from Figure 5. It includes two frequency components: $\mathtt{f}$ and $3\mathtt{f}$.

Now let's consider a signal with 3 frequency components: $\mathtt{f}$, $3\mathtt{f}$ and $5\mathtt{f}$ (Figure 6).

If we keep considering a signal with k frequency components: $\mathtt{f}$, $3\mathtt{f}$, $5\mathtt{f}$, ... $(2k+1)\mathtt{f}$, then the signal will square out as $k \to \infty$.

Theorem 1 *Shannons Theorem (in words): given a channel with noise there exists a non-zero capacity of data rate achievable with arbitrarily low error.*

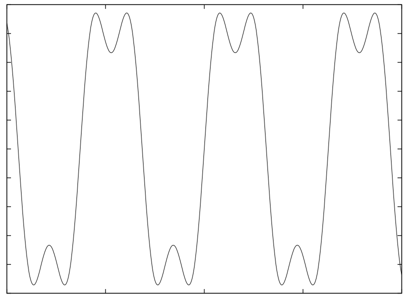

Figure 5: $\texttt{s(t)} = \texttt{A}[\sin(2\pi\texttt{t}) + \frac{1}{3}\sin(2\pi(3\texttt{f})\texttt{t})]$

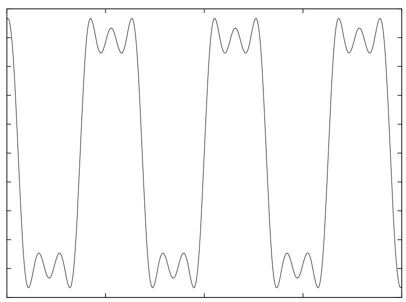

Figure 6: $\texttt{s(t)} = \texttt{A}[\sin(2\pi\texttt{t}) + \frac{1}{3}\sin(2\pi(3\texttt{f})\texttt{t}) + \frac{1}{5}\sin(2\pi(5\texttt{f})\texttt{t})]$

$$\begin{aligned}
\texttt{C} &= \texttt{B}\log 2\frac{\texttt{P}+\texttt{N}}{\texttt{N}}, \;\texttt{where} \\
\texttt{C} &= \texttt{capacity,} \\
\texttt{B} &= \texttt{bandwidth,} \\
\texttt{P} &= \texttt{power,} \\
\texttt{N} &= \texttt{noise}
\end{aligned}$$

Observations:

- spectrum is expensive
- spectrum cannot be manufactured

- spectrum is limited
- spectrum has a fixed data rate

Therefore wireless is a precious commodity.