

## Lecture 1:

In this course, we will understand wireless communication at three different levels.

- 1) Channel propagation characteristics & modeling.
- 2) Point-to-point communication 'link' design.
- 3) System design with multiple 'terminals' and 'links'.

Emphasis will be on cellular wireless systems while recognizing that there could be other system architectures. (e.g. AM/FM radio, TV, wireless LAN, ad hoc networks, etc.)

There are two key aspects of wireless communication.

- 1) Fading (or) time-variations of the channel
- 2) Interference.

How we deal with these two aspects is central to the design of wireless communication systems. In order to understand this, we need to first understand signal propagation in a wireless channel (which leads to fading and interference).

### The Wireless Channel:

- \* Main characteristic: Variation of channel strength over time and frequency.

Usually modeled using two types of variations:

- Large-scale fading.
- Small-scale fading.

We will soon discuss what "large scale" and "small-scale" are.

- \* Signals transmitted in wireless systems are electromagnetic (EM) waves. Received signal depends on how this EM wave propagates and the obstructions and terrain it sees on the way.

- \* Deterministic solutions using detailed geographic models and Maxwell's equations too complex and not practical.
- \* Statistical models will be used.
- \* Look at some simple examples before discussing statistical models (as motivation to define a simple set of parameters) and to develop some intuition

A simple calculation to start off:

- Common frequency bands of operation for cellular systems centred around 900 MHz, 1.9 GHz.

$$\lambda = \frac{c}{f} \text{ where } c = 3 \times 10^8 \text{ m/s.}$$

$$\text{At } f = 900 \text{ MHz, } \lambda = \frac{3 \times 10^8}{9 \times 10^8} \text{ m} = \frac{1}{3} \text{ m.}$$

$$f = 1900 \text{ MHz, } \lambda = \frac{3 \times 10^8}{19 \times 10^8} \text{ m} = \frac{3}{19} \text{ m}$$

"large-scale" and "small-scale" are w.r.t.  $\lambda$ .

"large-scale": Variations over distances much larger than  $\lambda$ .

"small-scale": Variations over distances of the order of  $\lambda$ .

Understanding large-scale variations helps in deciding

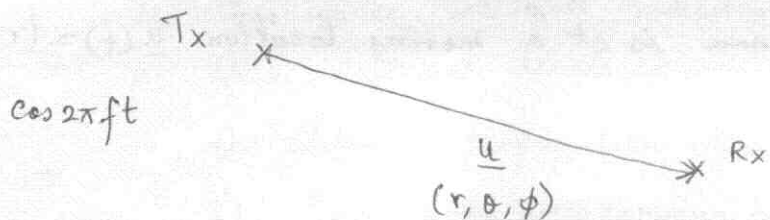
- coverage range of base-stations
  - power level required for transmission.
- } System planning

Understanding small-scale variations helps in designing

- modulation & coding for link design

Idealized examples:

- ① Free space, fixed transmit and receive antennas.



$c$ : Speed of light  
 $r$ : distance from  $T_x$  antenna to  $u$ .

Electric field measured at  $u$

$$E(f, t, \underbrace{(r, \theta, \phi)}_u) = \frac{\alpha_s(\theta, \phi, f) \cos 2\pi f(t - \frac{r}{c})}{r} \quad \text{--- (1)}$$

(Far field assumption)

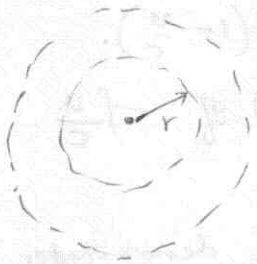
Delay in propagation:  $\frac{r}{c} \Rightarrow$  Phase shift of  $\frac{2\pi f r}{c}$ .

$\alpha_s(\theta, \phi, f)$ : Radiation pattern of the  $T_x$  antenna at freq.  $f$  in the direction  $(\theta, \phi)$ .

As  $r$  increases,  $E$  field decreases as  $r^{-1}$ .

$\Rightarrow$  Power per sq. m. decreases as  $r^{-2}$ .

As  $r$  increases, total power is the same, but surface area of sphere of radius  $r$  is  $4\pi r^2$ .



Response at a fixed  $R_x$  antenna at  $u$ :

$$E_r(f, t, u) = \frac{\alpha(\theta, \phi, f) \cos 2\pi f(t - \frac{r}{c})}{r} \quad \text{--- (2)}$$

$\alpha(\theta, \phi, f)$ : Product of the antenna patterns of  $T_x$  and  $R_x$  antennas at freq.  $f$  in the direction  $(\theta, \phi)$ .

In this free space example, with fixed  $T_x$  and  $R_x$  antennas, we can

define  $H(f) = \frac{\alpha(\theta, \phi, f) e^{-j2\pi f r/c}}{r}$ , so that  $E_r(f, t, u) = \text{Re}[H(f) e^{j2\pi f t}]$

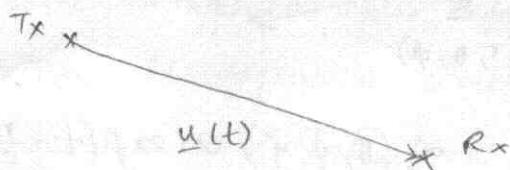
Linear and time-invariant (LTI).

For more complicated propagation scenarios, with obstructions, or moving antennas, we have linearity not time-invariance.



② Free space, moving antenna.

The receive antenna is at a moving location  $\underline{u}(t) = (r(t), \theta, \phi)$  with  $r(t) = r_0 + vt$ .



Similar to eqn. ② in the previous example, we can write

$$\begin{aligned} E_r(f, t, (r_0 + vt, \theta, \phi)) &= \frac{\alpha(\theta, \phi, f) \cos 2\pi f \left[ t - \frac{r(t)}{c} \right]}{r(t)} \\ &= \frac{\alpha(\theta, \phi, f) \cos 2\pi f \left[ \left(1 - \frac{v}{c}\right)t - \frac{r_0}{c} \right]}{r_0 + vt} \end{aligned}$$

This channel cannot be represented as an LTI channel.

— Sinusoid at  $f$  results in a sinusoid at  $f(1 - \frac{v}{c})$ .

There is a frequency shift (Doppler shift) of  $-f \frac{v}{c}$ .

Note that the Doppler shift depends on  $f$ .

— There is a time-varying attenuation (in the denominator we have  $r_0 + vt$ ). If  $vt$  is small compared to  $r_0$ , effect of this is not very significant.

Remark: Above analysis valid whether the transmitter (or) receiver (or) both are moving as long as the relative distance between them is <sup>the</sup>  $r(t)$  above.

Next, we will also consider obstacles.