

MODELLING OF WIRELESS CHANNELS

TEXTBOOK - TSE & VISWANATH

ECE525E – WIRELESS & MOBILE COMMUNICATION

Wednesday, 27 February 2019

WHY DO WE NEED PROPAGATION MODELS IN CELLULAR COMMUNICATION?

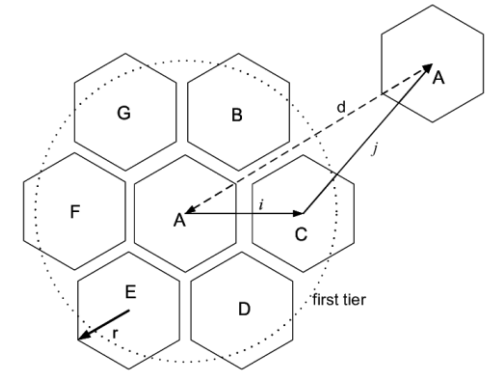
1. Cellular communications are regulated by the Communication Authority and operate in the following frequency bands.

MOBILE SYS	BAND	CENTRE FREQUENCY	WAVELENGTH
GSM 900 MHz	880 – 960 MHz	920 MHz	0.33m
GSM 1800 MHz	1710 – 1880 MHz	1795 MHz	0.167m
UMTS/WCDMA	2110 – 2200 MHz	2155 MHz	0.139m

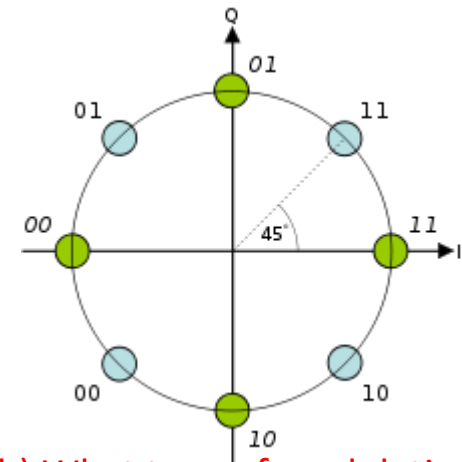
2. The wavelength in these cellular bands is a fraction of a meter, so to calculate the electromagnetic field at a receiver, the locations of the receiver and the obstructions would have to be known within centimetre accuracies.
3. The electromagnetic field equations are therefore too complex to solve, especially on the fly for mobile users.
4. Thus, we have to ask what we really need to know about these channels, and what approximations might be reasonable?
5. The key parameters that we should know are then used to model the cellular communication channel.

TWO KEY ISSUES IN MOBILE CELLULAR COMMUNICATION

1. During the design of a mobile communication system, two important questions must be answered, i.e.
 - a) Where to place the base stations, and what range of power levels are then necessary on the downlink and uplink channels.
 - b) What types of modulation and detection techniques look promising.
2. In both cases, we need a sense of what types of phenomena to expect.
3. To address this, we will construct stochastic models of the channel, assuming that different channel behaviours appear with different probabilities, and change over time (with specific stochastic properties).



(a) Where to place base stations?



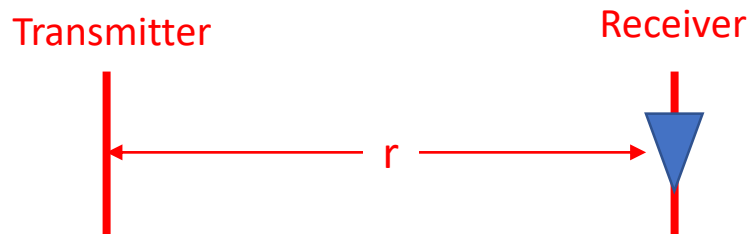
(b) What type of modulation Scheme?

FREE SPACE, FIXED TRANSMITTING AND RECEIVE ANTENNAS /01

1. Consider a fixed antenna radiating into free space.
2. In the far field, the electric field and magnetic field at any given location are perpendicular both to each other and to the direction of propagation from the antenna.
3. They are also proportional to each other, so it is sufficient to know only one of them (just as in wired communication, where we view a signal as simply a voltage waveform or a current waveform).
4. We can express therefore the electric far field at time t as

$$E(f, t) = \frac{\alpha_s \cos 2\pi f \left(t - \frac{r}{c} \right)}{r}$$

The phase of the field varies with fr/c , corresponding to the delay caused by the radiation travelling at the speed of light.

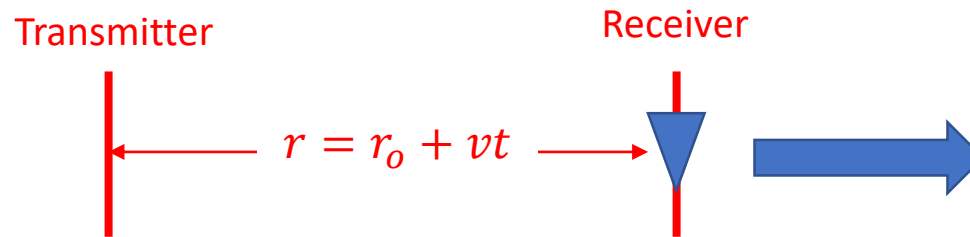


FREE SPACE, FIXED TRANSMITTING AND RECEIVE ANTENNAS /02

1. It is important to observe that, as the distance r increases, the electric field decreases as r^{-1} and thus the power per square meter in the free space wave decreases as r^{-2} .
2. This is expected, since if we look at concentric spheres of increasing radius r around the antenna, the total power radiated through the sphere remains constant, but the surface area increases as r^2 .
3. Thus, the power per unit area must decrease as r^{-2} .
4. The r^{-2} reduction of power with distance is often not valid when there are obstructions to free space propagation.

FREE SPACE, MOVING ANTENNA / 01

1. Consider the fixed antenna and free space model above with a receive antenna that is moving with speed v in the direction of increasing distance from the transmitting antenna.
2. The receive antenna is at a moving location described as $u(t) = (r(t), \vartheta, \psi)$ with $r(t) = r_0 + vt$.



$$E(f, t) = \frac{\alpha_s \cos 2\pi f \left(t - \frac{r_0}{c} - \frac{vt}{c} \right)}{r_0 + vt}$$

3. we can rewrite $f \left(t - \frac{r_0}{c} - \frac{vt}{c} \right)$ as $f \left(1 - \frac{v}{c} \right) t - \frac{fr_0}{c}$
4. Thus, the sinusoid at frequency f has been converted to a sinusoid of frequency $f \left(1 - \frac{v}{c} \right)$;
5. This means there has been a Doppler shift of $-\frac{fv}{c}$ due to the motion of the receiver.

FREE SPACE, MOVING ANTENNA / 02

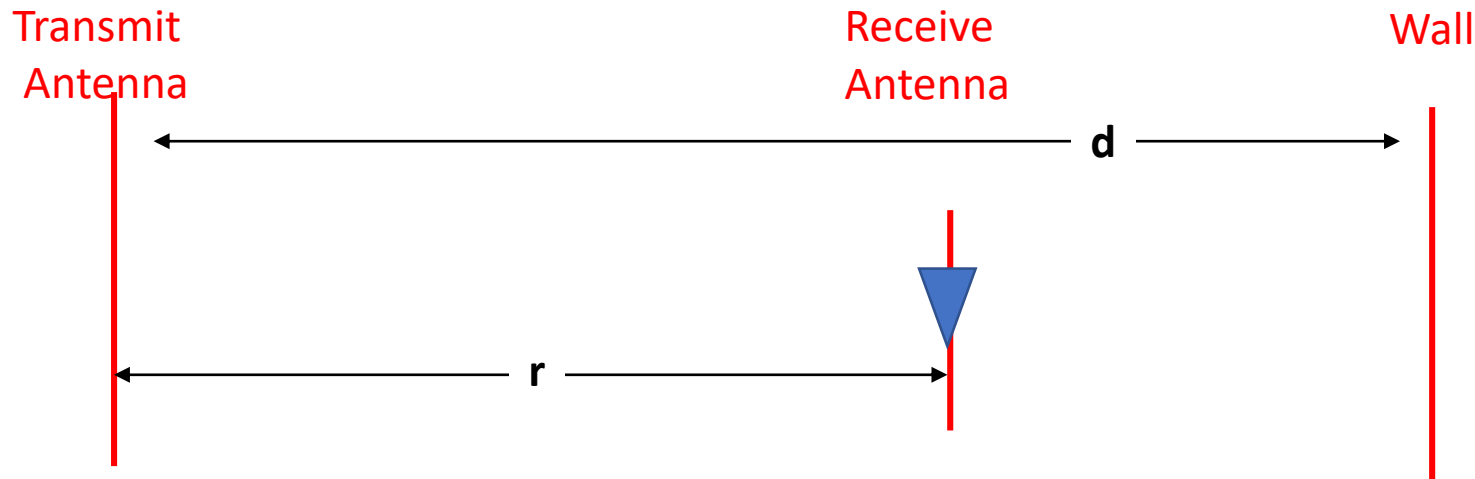
1. This channel cannot be represented as a Linear Time Invariant (LTI) channel.
2. If we ignore the time varying attenuation in the denominator, however, we can represent the channel in terms of a system function followed by translating the frequency f by the Doppler shift $-\frac{fv}{c}$.
3. The above analysis does not depend on whether it is the transmitter or the receiver (or both) that are moving. So long as $r(t)$ is interpreted as the distance between the antennas (and the relative orientations of the antennas are constant

$$E(f, t) = \frac{\alpha_s \cos 2\pi f \left(t - \frac{r_0}{c} - \frac{vt}{c} \right)}{r_0 + vt}$$

REFLECTING WALL WITH FIXED ANTENNA /01

Assumptions

1. In the absence of the receive antenna, the electromagnetic field at the point where the receive antenna will be placed is the sum of the free space field coming from the transmit antenna plus a reflected wave coming from the wall.
2. The presence of the receive antenna does not appreciably affect the plane wave impinging on the wall.



$$E_r(f, t) = \frac{G_r \cos \left(2\pi f \left(t - \frac{r}{c} \right) \right)}{r} - \frac{G_r \cos \left(2\pi f \left(t - \frac{2d - r}{c} \right) \right)}{2d - r}$$

$$\Delta\theta = 2\pi f \left(t - \frac{2d - r}{c} \right) + \pi - \left(2\pi f \left(t - \frac{r}{c} \right) \right) = \frac{4\pi f}{c} (d - r) + \pi$$

REFLECTING WALL WITH FIXED ANTENNA /02

1. The received signal is a superposition of two waves, both of frequency f .
2. When the phase difference is an **integer multiple of 2π** , the two waves add constructively, and the received signal is strong.
3. When the phase difference is an **odd integer multiple of π** , the two waves add destructively, and the received signal is weak.
4. As a function of r , this translates into a spatial pattern of constructive and destructive interference of the waves.
5. The distance from a peak to a valley is called the **coherence distance, x_c** and is given by:

$$x_c = \frac{\lambda}{4}$$

DELAY SPREAD

- Delay spread is the difference between the propagation delays along the two signal paths and is (in the wall reflection case above) given by

$$T_d = \frac{2d - r}{c} - \frac{r}{c}$$

COHERENCE BANDWIDTH

1. **Coherence bandwidth** is a statistical measurement of the range of frequencies over which the channel can be considered "flat", or in other words the approximate maximum **bandwidth** or frequency interval over which two frequencies of a signal are likely to experience comparable or correlated amplitude fading.
2. Coherence bandwidth is given by

$$B_{coherence} = \frac{1}{2\pi T_d}$$

1. Where T_d is the delay spread.

REFLECTING WALL, MOVING ANTENNA /01

1. Suppose the receive antenna is now moving at a velocity v .
2. As it moves through the pattern of constructive and destructive interference created by the two waves, the strength of the received signal increases and decreases.
3. This is the phenomenon of multipath fading.
4. The time taken to travel from a peak to a valley is now $\frac{c}{4fv}$
5. This is the time-scale at which the fading occurs, and it is called the coherence time of the channel.

