Lecture 2: Channel Modeling

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You see, wire telegraph
is a kind of a very, very
long cat. You pull his
tail in New York and his
head is meowing in Los
Angeles. Do you
understand this? And
radio operates exactly
the same way: you send
signals here, they
receive them there. The
only difference is that
there is no cat.
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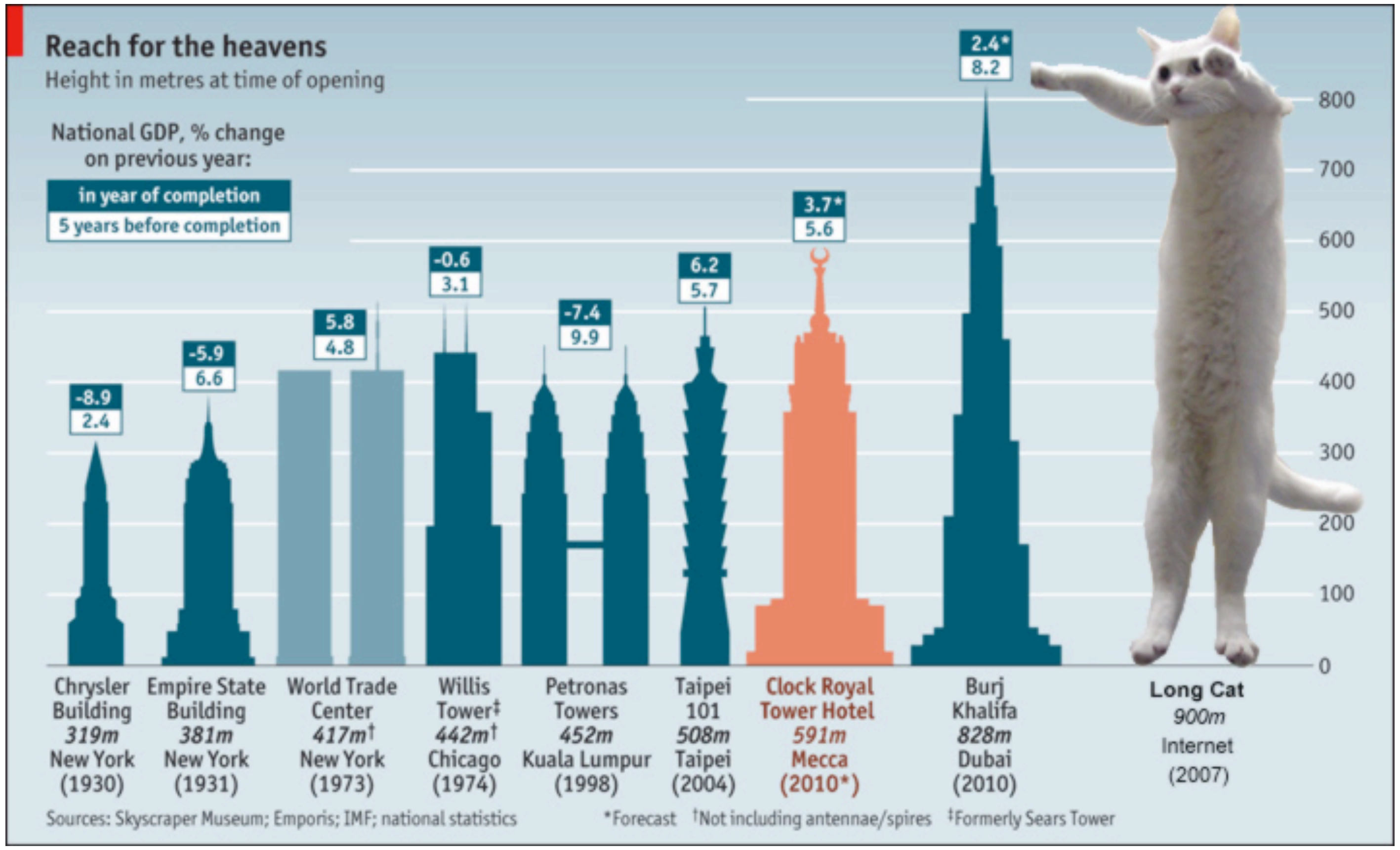
- supposedly Albert Einstein



But probably not!

Full quote history here:

http://quoteinvestigator.com/2012/02/24/telegraph-cat/

The Wireless Channel

- So, is the wireless channel magical?

- That is, if we send a certain signal from the transmitter, will we see the exact same signal at the receiver?
- Clearly not!
- More realistically, we should expect to observe a weaker, noisier version of the transmitted signal.
- Today, we will focus on modeling the strength of the received signal.

Signal Strength: 3 Key Factors

- We can capture most of the signal strength degradation from the transmitter to the receiver in terms of 3 key factors.

1. Path Loss: As the distance between the transmitter and the receiver increases, we should expect the signal strength to decrease.

2. Shadowing: The path from the transmitter to the receiver may be obstructed by buildings, etc. that absorb part of the signal.

3. Multipath Fading: The signal will probably travel across multiple paths of different lengths leading to either constructive or destructive interference at the receiver.

Path Loss

- If the transmitting antenna radiates energy isotropically (i.e., equally in all directions), then the strength of the electromagnetic wave will decrease as the receiver moves farther away.

- For example, for a 2-dimensional spherical wave, the amplitude of the wave will decrease like $1/d$ where d is the distance. The power will decrease like $1/d^2$.

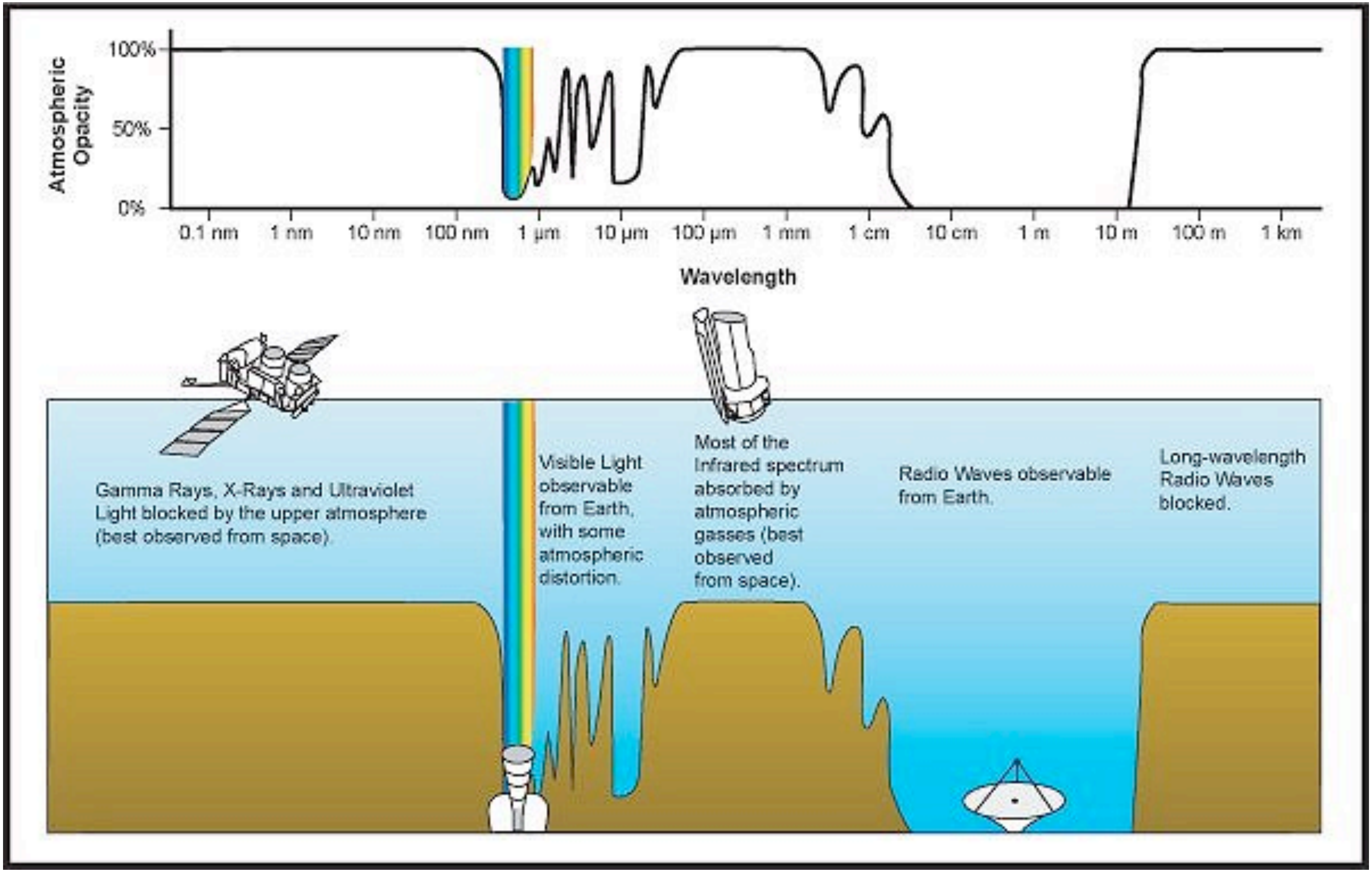
- Even if the transmitting antenna is directional, it is unlikely to pinpoint the receiver's location exactly (at the time scale we will need.)

Shadowing

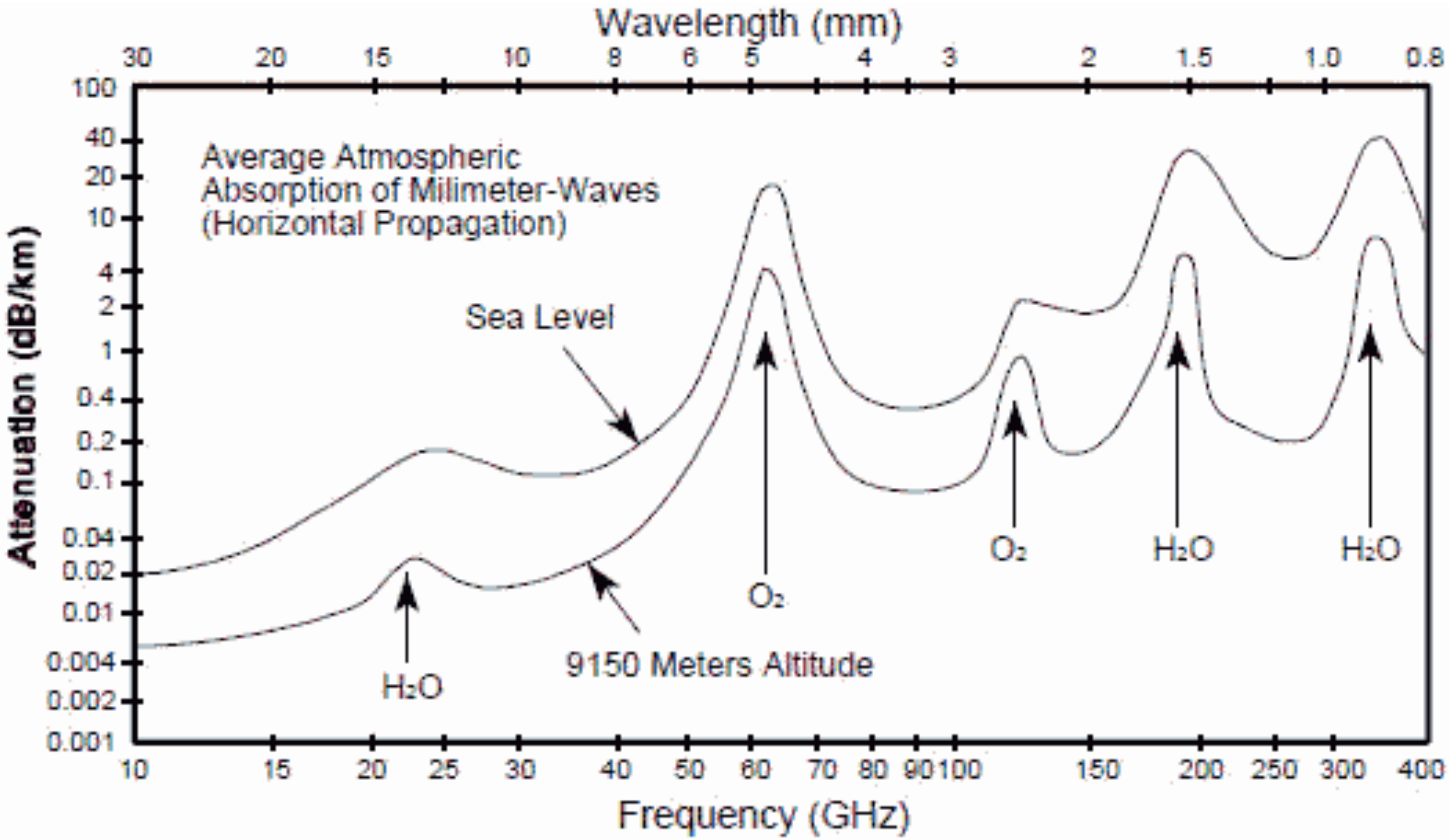
- The signal may have to pass through buildings, trees, and other obstacles to get from the transmitter to the receiver.

- The strength of the resulting signal will depend on the absorption properties of the materials from which these obstacles are made.
- Don't forget that we are not communicating in a vacuum! The air can absorb wireless signals as well.
- This makes certain frequencies more desirable than others for wireless communication.

Absorption of EM Waves by the Atmosphere



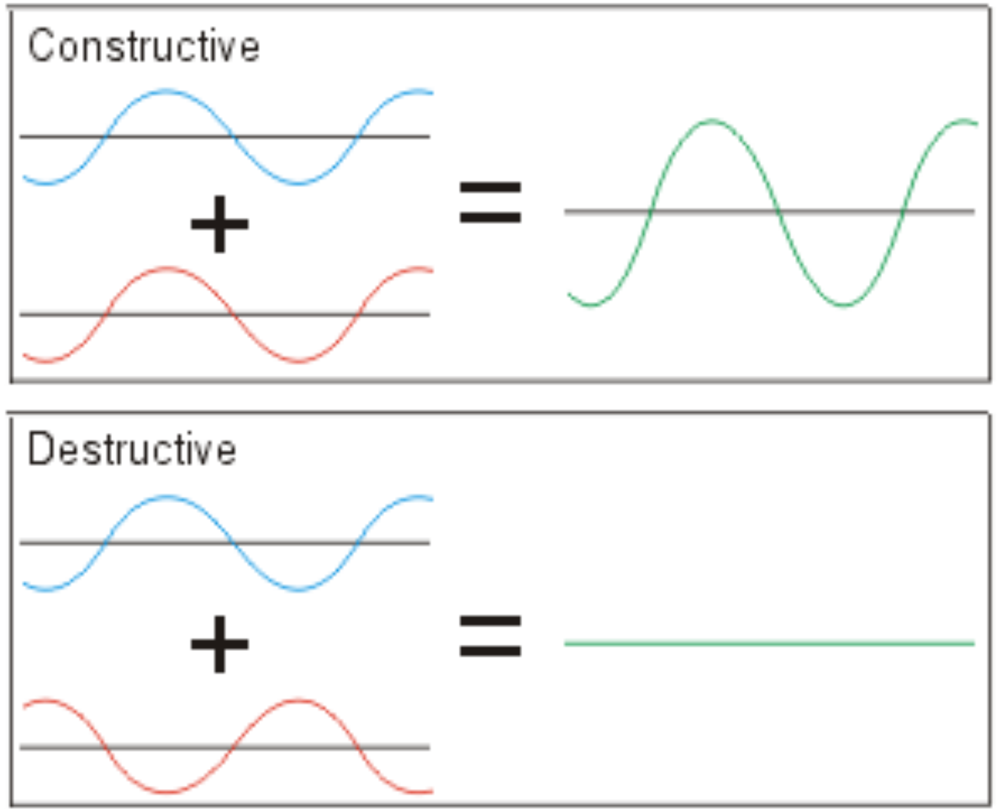
Absorption of EM Waves by the Atmosphere

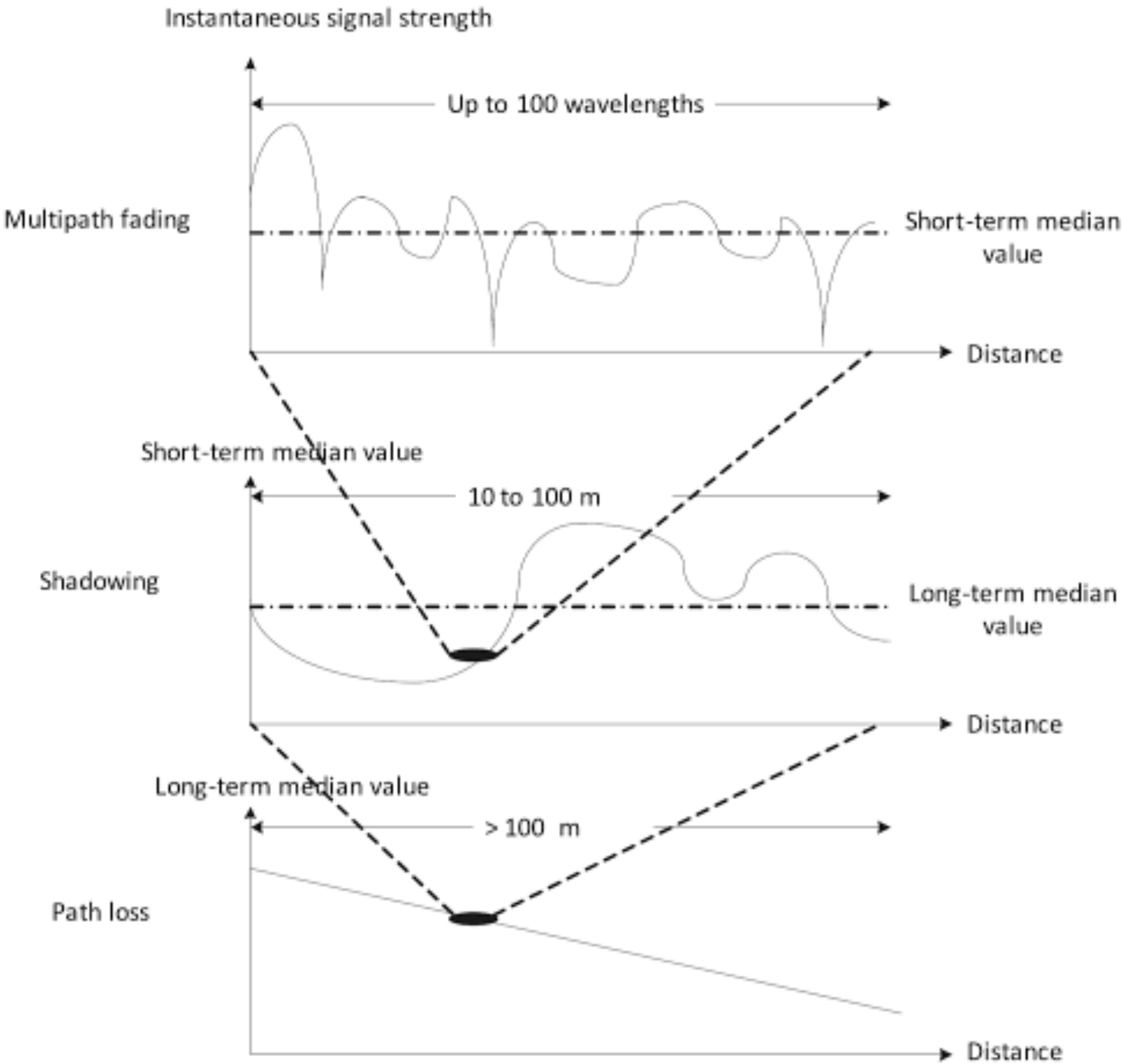


Multipath Fading

- Since the transmitting antenna is not emitting a focused beam, we should expect that the signal will travel across multiple paths to get to the receiver.

- Since these paths will be of different lengths, the phase of the arriving signals will differ as well. When these signals are combined, some may interference constructively and others destructively.




Instantaneous signal strength
Up to 100 wavelengths
Multipath fading
Short-term median value
Distance
Short-term median value
10 to 100 m
Shadowing
Long-term median value
Distance
Long-term median value
> 100 m
Path loss
Distance

Channel Modeling

- We will build up our models using basic physics.
- In principle, we could build extremely accurate models using Maxwell's equations:

Maxwell's Equations

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$$

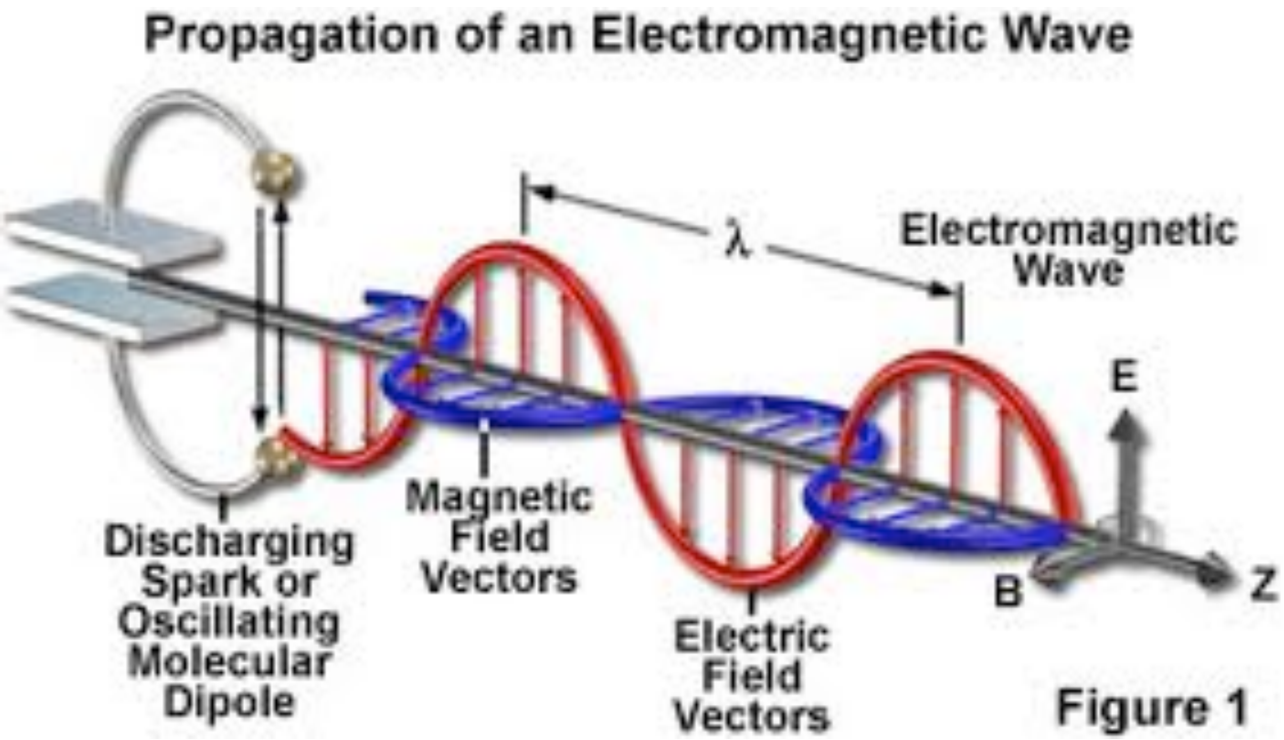


Figure 1

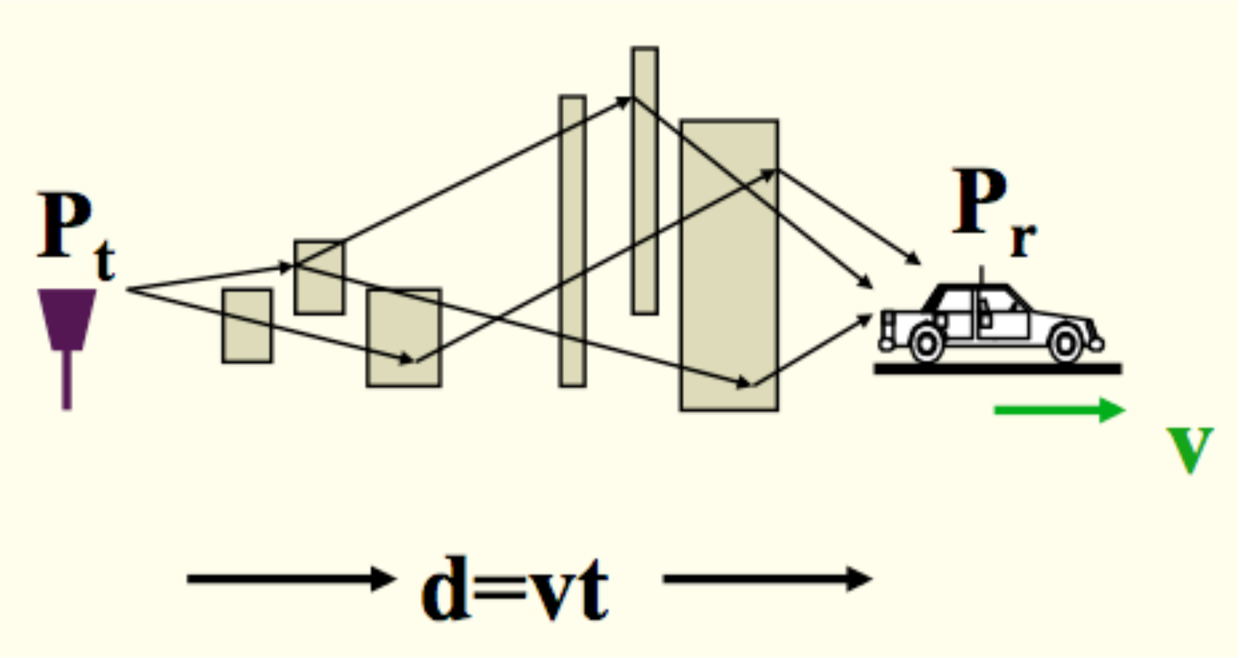
- However, this is very complicated, even for very simple environments.

Ray Tracing

- A simpler approach is to use ray tracing.
- Each propagation path is treated like a particle. All we have to do is determine the attenuation and phase shift.
- Unfortunately, this is also extremely complicated as it requires very precise models of the physical environment as well as precise and timely location information for the mobile user.

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

$$f_c = \begin{array}{c} 900\text{MHz} \\ 1.9\text{GHz} \\ 5.8\text{GHz} \end{array} \quad \lambda_c = \begin{array}{c} 0.33\text{m} \\ 0.16\text{m} \\ 0.05\text{m} \end{array}$$



Example: Two-Ray Model

- Simple scenario: One signal path is direct, the other is reflected off the ground.

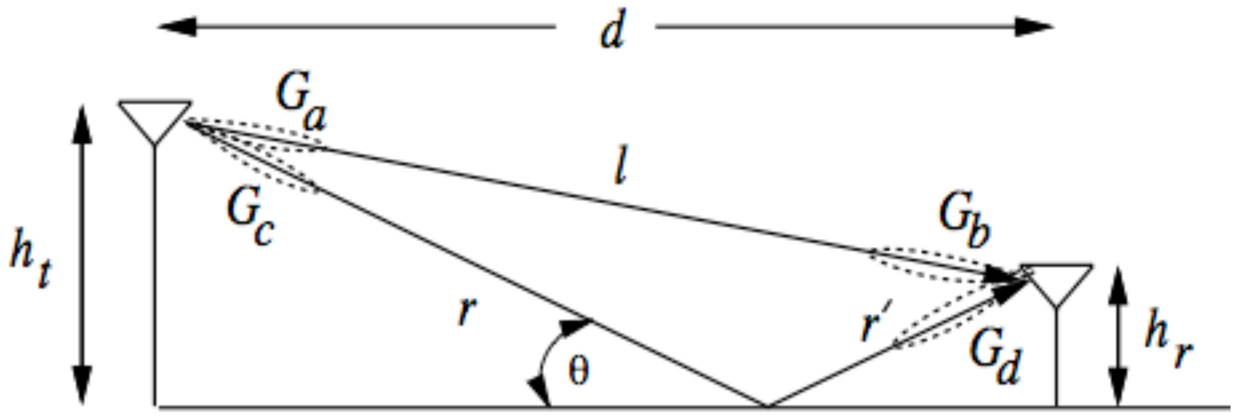


Figure 2.4: Two-Ray Model.

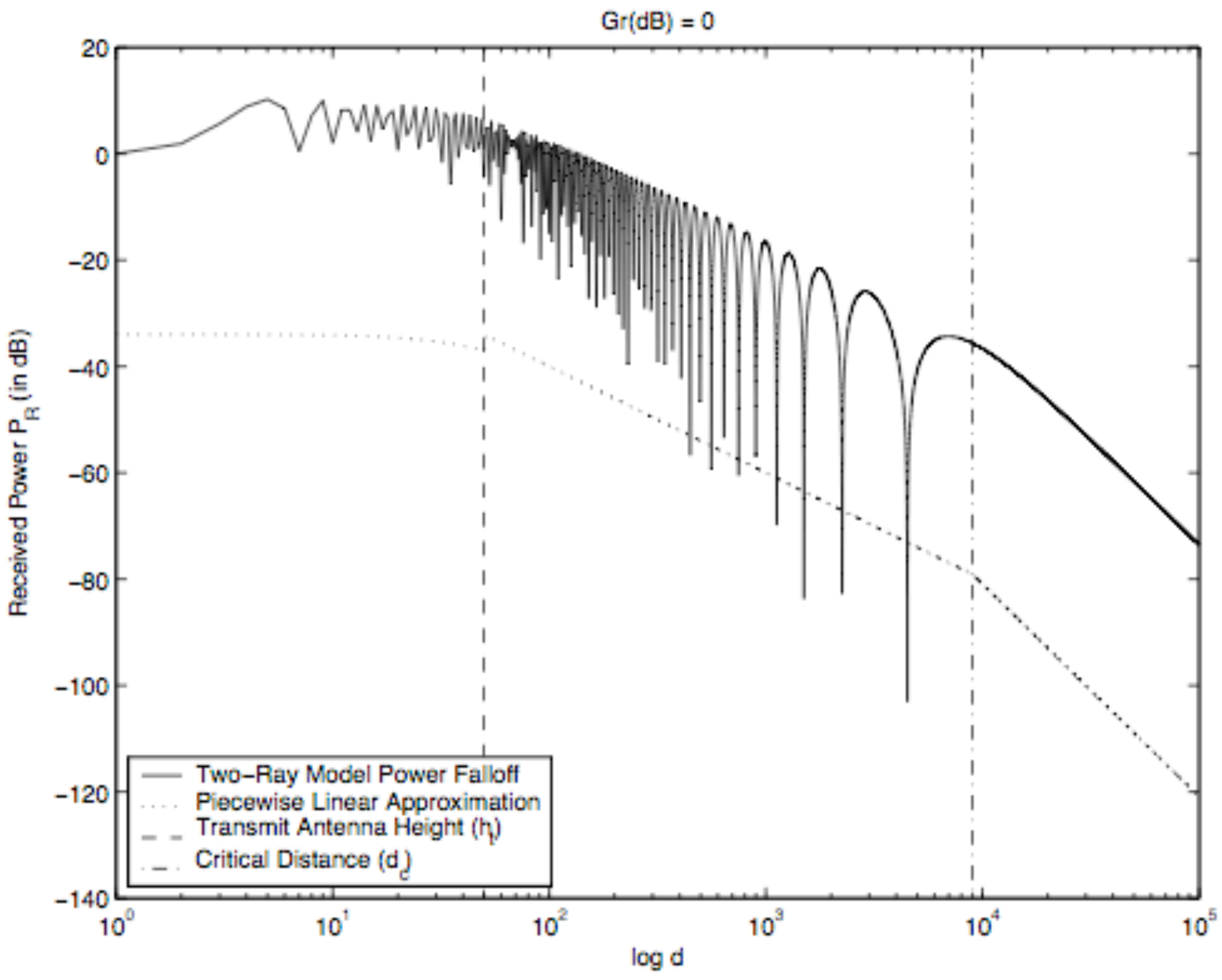


Figure 2.5: Received Power versus Distance for Two-Ray Model.

Statistical Models

- We will approximate the channel using a statistical model.
- Assume random placement of obstacles and reflectors.
- Derive the probability of seeing a certain channel.
- Find a reasonable approximation to this probability using a closed-form probability distribution.
- Different models for different environments (urban, rural).
- Tell us what channel quality to expect on average.
- But they do not tell us the channel itself. This information is collected in real-time using measurements (that are tailored to the assumed channel model).

Roadmap for Today

- To get started on our channel model, we will derive (on the board) basic channel models for propagation in:
  - Free space with a fixed receive antenna.
  - Free space with a moving receive antenna.
  - Reflection off a wall to a fixed receive antenna.
  - Reflection off a wall to a moving receive antenna.
- This will give us a good idea for how to formulate the general model (which we will do next time).