RADIO WAVE PROPAGATION MODELS

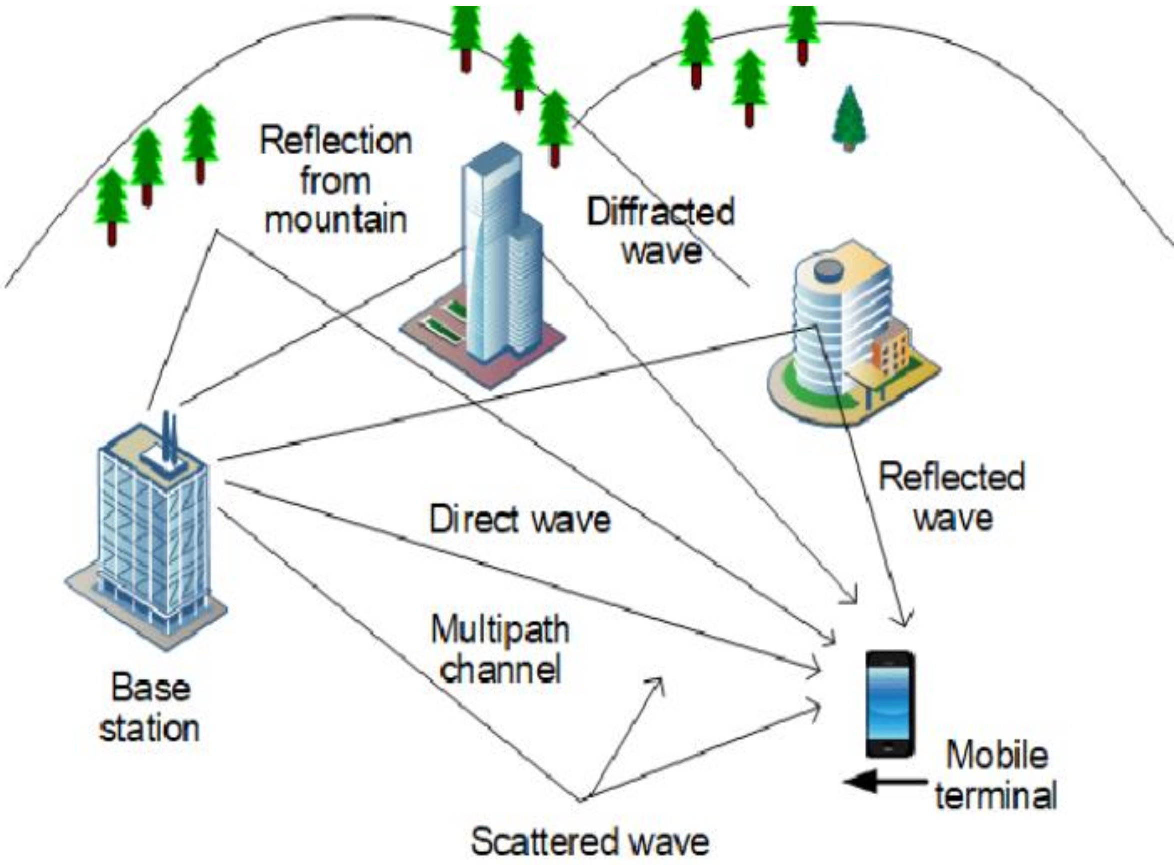
ECE 516E – ANTENNA & RADIO WAVE PROPAGATION

Monday, January 19, 2026

WHAT ARE RADIO WAVE PROPAGATION MODELS?

Radio wave propagation models are mathematical tools that predict how radio signals travel and lose power (path loss) in different environments, using formulas based on:

1. Frequency
2. Distance
3. terrain, and
4. Obstacles.

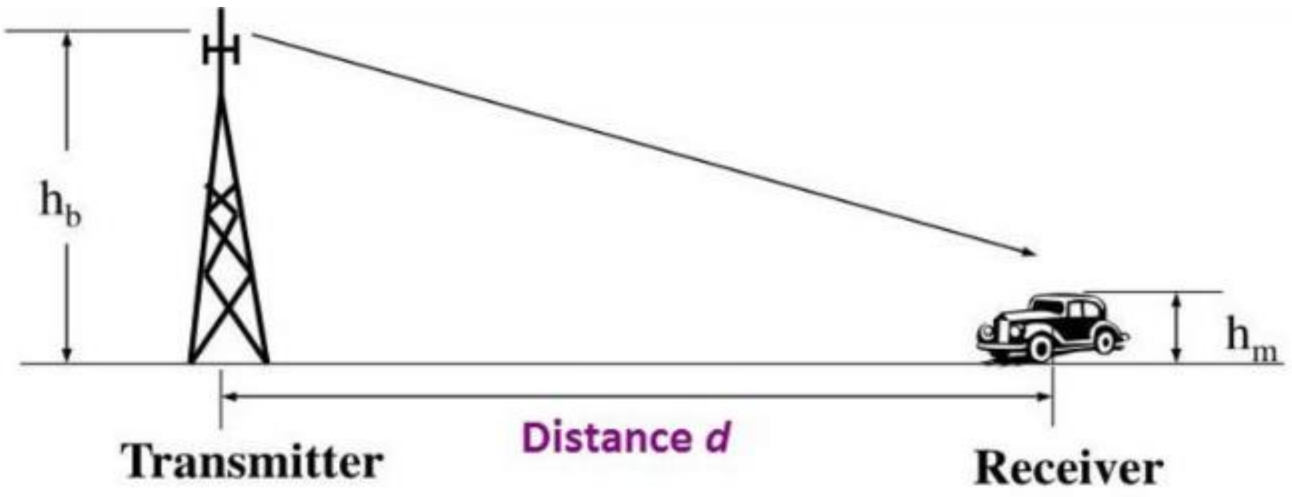


TYPES OF RADIO WAVE PROPAGATION MODELS

1. **Free Space Model**
   - Ideal propagation in vacuum with no obstructions
2. **Two-Ray Ground Reflection**
   - Direct path plus ground-reflected path
3. **Log-Distance Path Loss**
   - General model for various environments
4. **Okumura Model**
   - One of the most widely used models in urban areas
5. **Hata Model**
   - Empirical model for urban/suburban/rural areas
6. **Small-Scale Fading**
   - Rayleigh and Rician fading models

FREE SPACE PROPATION MODEL /01

1. **Free Space Propagation Model** assumes a clear, unobstructed line-of-sight path between transmitter and receiver.



2. **It's the simplest propagation model** and serves as a baseline for comparison with more complex models.

FREE SPACE PROPATION MODEL /02

Free Space Path Loss Equation:

$$PL(d) = PL(d_0) + 10n\ \log_{10}(d/d_0)$$

Friis Transmission Equation:

$$P_r = P_tG_tG_r(\lambda/(4\pi d))^2$$

where

L(d) is Path loss at distance d (dB)

d_0 is Reference distance (usually 1m or 1km)

n is Path loss exponent (2 for free space)

λ is Wavelength (m)

FREE SPACE PROPATION MODEL - APPLICATIONS & LIMITATIONS

Free Space propagation Model is used in environments where there are little orno obstacles, such as:

(a) Satellite communication systems

(b) Deep space communication

(c) Baseline for other propagation models

(d) Microwave line-of-sight links

Limitations:

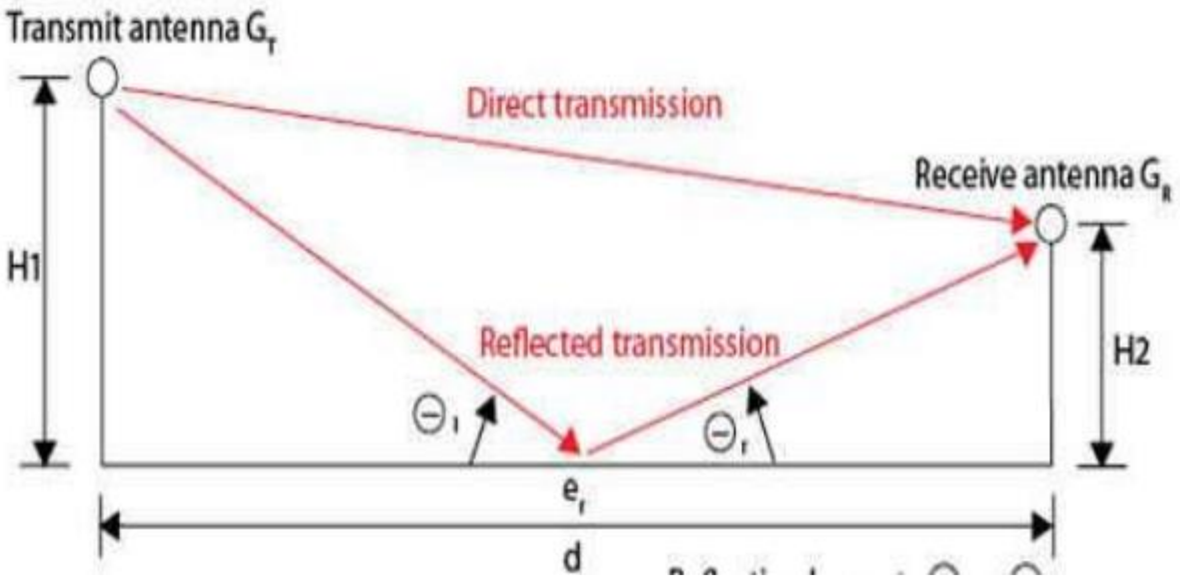
(a) Does not account for reflection, diffraction, or scattering

(b) Overly optimistic for terrestrial communication

(c) Assumes ideal conditions rarely found in practice

TWO-RAY GROUND REFLECTION MODEL /01

1. **Two-Ray Ground Reflection Model** considers both the direct path between transmitter and receiver and a ground-reflected path.
2. **It provides more accurate predictions** than free space for longer distances in terrestrial communication



TWO-RAY GROUND REFLECTION MODEL /02

Two-Ray Model Equation:

For large distance ($d \gg \sqrt{h_t h_r}$ the received power is given by:

$$P_r = P_t G_t G_r (h_t^2 h_r^2 / d^4)$$

Critical Distance:

$$d_c = (4\pi h_t h_r)/\lambda$$

Key Parameters:

- h_t, h_r - Transmitter and receiver heights (m)
- d_c - Critical distance (breakpoint)
- Γ - Ground reflection coefficient

APPLICATIONS OF 2-RAY MODEL

Applications:

- Mobile communication in flat terrains
- Microwave links over flat Earth
- Long-distance terrestrial communication

Characteristics:

- Path loss exponent of 2 for $d < d_c$
- Path loss exponent of 4 for $d > d_c$
- More accurate than free space for terrestrial microwave links

OKUMURA MODEL /01

- **Okumura Model is o**ne of the most widely used models for signal prediction in urban areas.
- It is based on extensive measurements in Tokyo, Japan, it's considered among the simplest and most accurate in cluttered urban environments.

OKUMURA MODEL /02

Okumura Model Equation:

$$L(dB) = L_{freespace} + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

Frequency Range: 100 MHz to 1920 MHz

Distance Range: 1 km to 100 km

where

- A_{mu} - Median attenuation relative to free space
- $G(h_{te})$ - Base station height gain factor
- $G(h_{re})$ - Mobile station height gain factor
- G_{AREA} - Gain due to type of environment

APPLICATIONS OF OKUMIRA MODEL

Applications:

- Urban and suburban mobile radio systems
- TV and FM broadcasting
- Land mobile radio systems

Advantages:

- Widely tested and verified
- Comprehensive (considers many parameters)
- Accurate for urban environments

HATA MODEL /01

1. **Hata Model is a**n empirical model based on Okumura's measurements, formulated by Hata for computer-based predictions.
2. **It's valid for frequencies from 150 MHz to 1500 MHz.**

Urban Area Path Loss:

$L_{urban}(dB) = 69.55 + 26.16\log_{10}f - 13.82\log_{10}h_b - a(h_m) + (44.9 - 6.55\log_{10}h_b)\log_{10}d$

Suburban Correction:

$L_{suburban} = L_{urban} - 2[\log_{10}(f/28)]^2 - 5.4$

Key Parameters:

- **f -** Frequency (MHz)
- **h_b -** Base station antenna height (m)
- **h_m -** Mobile station antenna height (m)
- **d -** Distance (km)

HATA MODEL APPLICATIONS

Hata model is used in the following applications:

- Macrocellular systems (cell size > 1km)
- GSM network planning
- Radio system design in various terrains

<u>Limitations:</u>

- Not suitable for microcells (d < 1km)
- Frequency limited to 150-1500 MHz
- Doesn't account for specific terrain features

SMALL-SCALE FADING MODELS

Small-Scale Fading Models describe rapid fluctuations of signal amplitude and phase over short distances or time intervals due to multipath propagation.

Rayleigh Fading:

$p(r) = (r/\sigma^2)\exp(-r^2/2\sigma^2)$ for $r \geq 0$

Rician Fading :

$p(r) = (r/\sigma^2)\exp(-(r^2+A^2)/2\sigma^2)\, I_0(Ar/\sigma^2)$ for $r \geq 0$, $A \geq 0$

Key Parameters:

K-factor Rician $K = A^2/2\sigma^2$ (ratio of dominant to scattered power)

σ^2 - Average power of scattered components

A - Amplitude of dominant component

SMALL-SCALE FADING MODEL APPLICATIONS

Small-scale fading model is used as follows:

- Rayleigh: No line-of-sight (urban canyons, indoor)
- Rician: Partial line-of-sight (suburban, rural)
- Diversity techniques to mitigate fading effects

Characteristics:

- Rayleigh: Worst-case fading, no dominant path
- Rician: Varies between Rayleigh and no fading based on K
- Both are used to model multipath effects in mobile channels

KEY CHARACTERISTICS OF 2-RAY MODEL

1. **Loss Exponent:** In this model, the power decreases with the fourth power of distance d^{-4}, or 40 dB per decade, which is faster than the free-space model's d^{-2}, or 20 dB per decade).
2. **Independent of Frequency:** At large distances, the path loss becomes independent of the carrier frequency.
3. **Interference Pattern:** At closer distances, the two rays interfere constructively or destructively, causing an oscillatory "up-fade" and "down-fade" pattern in signal strength.
4. **Critical Distance:** There is a "cross-over" or critical distance ($d_c = (4\pi h_t h_r)/\lambda$) beyond which the d^{-4} behaviour dominates and oscillations cease.