Propagation Models

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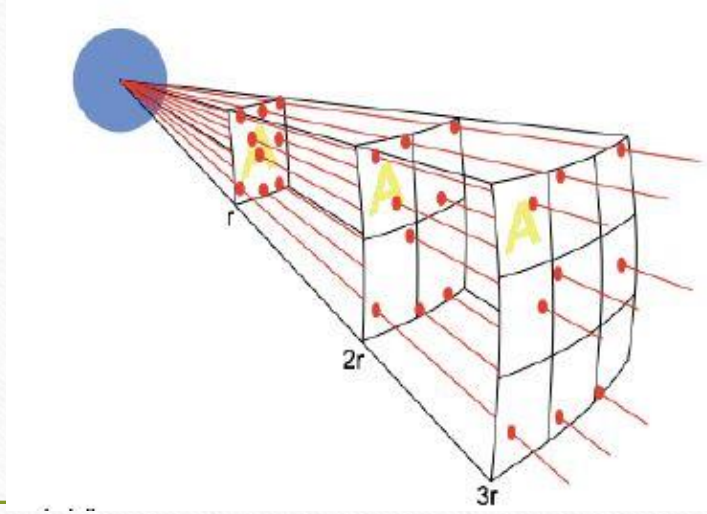
Free Space Propagation Model

Free Space Loss

- Signal power is diminished by geometric spreading of the wave front, commonly known as ***Free Space Loss***.
- The **power of the signal is spread over a wave front,** the area of which increases **as the distance from the transmitter increases**. Therefore, the power density diminishes.



- For an Example:

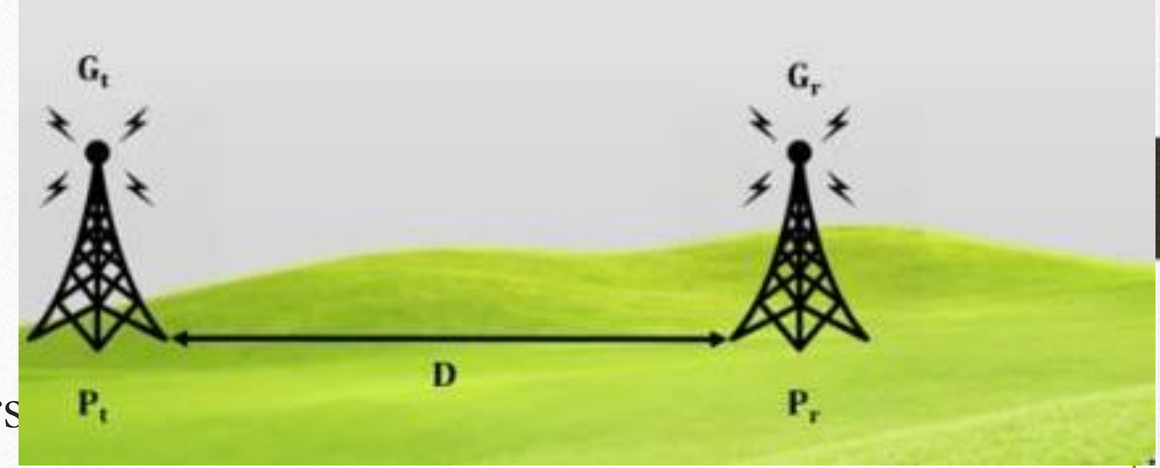
- **Light bulb** will help understand this. If we watch the quantity of light shed over a piece of paper, we will notice that this diminishes as we take it further away from a light bulb. This is a purely geometric phenomenon, it happens even in a vacuum where there is nothing that can absorb the EM radiation. That is why it is called free space loss. An even better term would be "**geometric spread loss**"

- The **free space propagation model** is used to **predict received signal strength** when the transmitter and receiver have a **clear, unobstructed line-of-sight (LOS) path** between them.
- Ex: **Satellite** Communication Systems & **Microwave** Communication Systems
- The **free space power received by a receiver antenna (as a function of - d)** which is separated from a radiating transmitter antenna by a **distance - d**, is given by the **Friis free space equation**,

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

Pr(d) - is the received power **which is a function of** the T-R separation

- **Pt** - is the transmitted power
- **Gt** - is the transmitter antenna gain
- **Gr -** is the receiver antenna gain
- **d** - is the T-R separation distance in meters
- - is the wavelength in meters
- **L** - is the System Loss Factor (L >1 or L=1), **not related to propagation**
  - **L >1** indicates loss due to **transmission line attenuation, filter losses & antenna losses**
  - **L = 1** indicates **no loss** in the system hardware



- Gain of **receiving antenna** is related to its effective aperture **Ae** by

$$G = \frac{4\pi A_e}{\lambda^2}$$

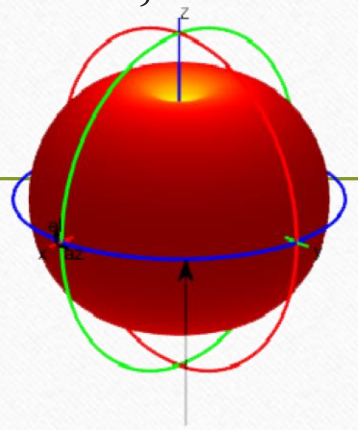
- The **effective antenna aperture/area** - is a theoretical value which is a measure of **how effective an antenna** is at **receiving power**. The effective aperture/area can be calculated by knowing the gain of the receiving antenna.

- Effective Aperture **Ae** is related to physical size of antenna.
- is related to the carrier frequency by : $\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c}$

  : where **f** - is the carrier frequency in Hertz and $\mathbf{w_c}$ - is the carrier frequency in radians per second, and **c -** is the speed of light given in meters per second.

- The values for **Pt** and **Pr must be expressed in the same units.**
- **Gt and Gr - are Dimensionless** Quantities
- The Friis free space equation shows that the **received power falls off** as the square of the T-R Separation Distance.

- An **isotropic radiator**, an ideal radiator which radiates power with unit gain **uniformly in all directions**, and is often used as reference antenna gain in wireless Systems.

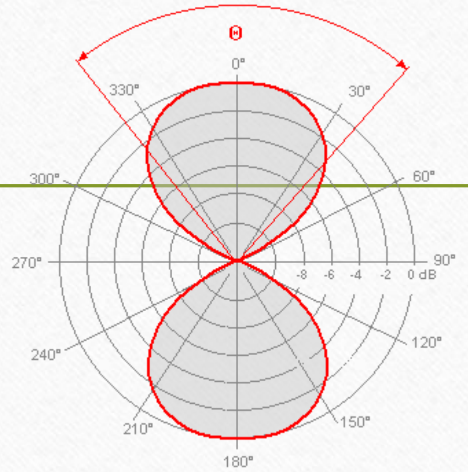


- **Equivalent Isotropic Radiated Power** (**EIRP**) is defined as :

$$\textbf{EIRP} = \textbf{Pt.Gt}$$

- **Represents the maximum radiated power** available from a transmitter in direction of maximum antenna gain, as compared to an isotropic radiator

- In practice, **Effective Radiated Power (ERP)** is used **instead of EIRP** to denote the maximum radiated power as compared to a half-wave dipole antenna (instead of an isotropic antenna)



- In practice, antenna gains are given in units of dBi (dB gain **with respect to an isotropic source**) or dBd (dB gain with **respect to a half-wave dipole**)

- The ERP will be 2.15 dB smaller than the EIRP for the same transmission system

  ERP=EIRP-2.15(dB)

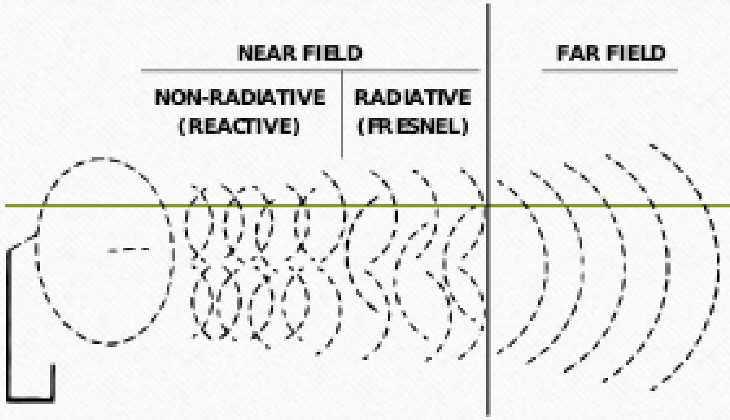
- **Path Loss (PL) represents signal attenuation** and is **defined as difference between the effective transmitted power and received power**

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right]$$

- Without Antenna gains (with unit antenna gains):

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right]$$

- **Friis free space model is valid predictor** for Pr for values of **d** which are in **the far-field of transmitting antenna.**



- The far **field or Fraunhofer** region that is beyond far field distance **df** given as :

$$d_f = \frac{2D^2}{\lambda}$$

  - **D is the largest physical linear dimension** of the transmitter antenna
  - Additionally, **df>>D** and **df>>λ**

- The Friis free space equation **does not hold** for **d=0**
- For this reason, large-scale propagation models use a close-in distance **d0** as a known received power reference point.

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2 \qquad d \geq d_0 \geq d_f$$

$$P_r(d)\ \mathrm{dBm} = 10\log\left[\frac{P_r(d_0)}{0.001\ \mathrm{W}}\right] + 20\log\left(\frac{d_0}{d}\right) \qquad d \geq d_0 \geq d_f$$

- **Qu-1**: Find the far-field distance for an antenna with maximum dimension of 1 m and operating frequency of 900 MHz.
- **Qu-2:** If a transmitter produces 50 watts of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50 watts is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna, What is P (10 km)? Assume unity gain for the receiver antenna.
- **Qu-3:** The transmission power is 40 W, under a free space propagation model,

  (a) What is the transmission power in unit of dBm?

  (b) What is the transmission power in unit of dBw?

  (b) The receiver is in a distance of 1000 m, what is the received power, assuming that the carrier frequency fc = 900 MHz and Gt = Gr = 1?

  (c) Express the free space path loss in dB.

Solution – Qu 1

Given:

Largest dimension of antenna, $D = 1$ m

Operating frequency $f = 900$ MHz, $\lambda = c/f = \dfrac{3 \times 10^8 \text{ m/s}}{900 \times 10^6 \text{ Hz}}$ m

Using equation (3.7.a), far-field distance is obtained as

$$d_f = \frac{2(1)^2}{0.33} = 6 \text{ m}$$

Solution – Qu 2

Given:
Transmitter power, $P_t = 50$ W.
Carrier frequency, $f_c = 900$ MHz

Using equation (3.9),
(a) Transmitter power,

$$P_t(\text{dBm}) = 10\log[P_t(\text{mW})/(1\text{ mW})]$$
$$= 10\log[50 \times 10^3] = 47.0\text{ dBm.}$$

(b) Transmitter power,

$$P_t(\text{dBW}) = 10\log[P_t(\text{W})/(1\text{ W})]$$
$$= 10\log[50] = 17.0\text{ dBW.}$$

The received power can be determined using equation (3.1).

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50(1)(1)(1/3)^2}{(4\pi)^2(100)^2(1)} = 3.5 \times 10^{-6}\text{ W} = 3.5 \times 10^{-3}\text{ mW}$$

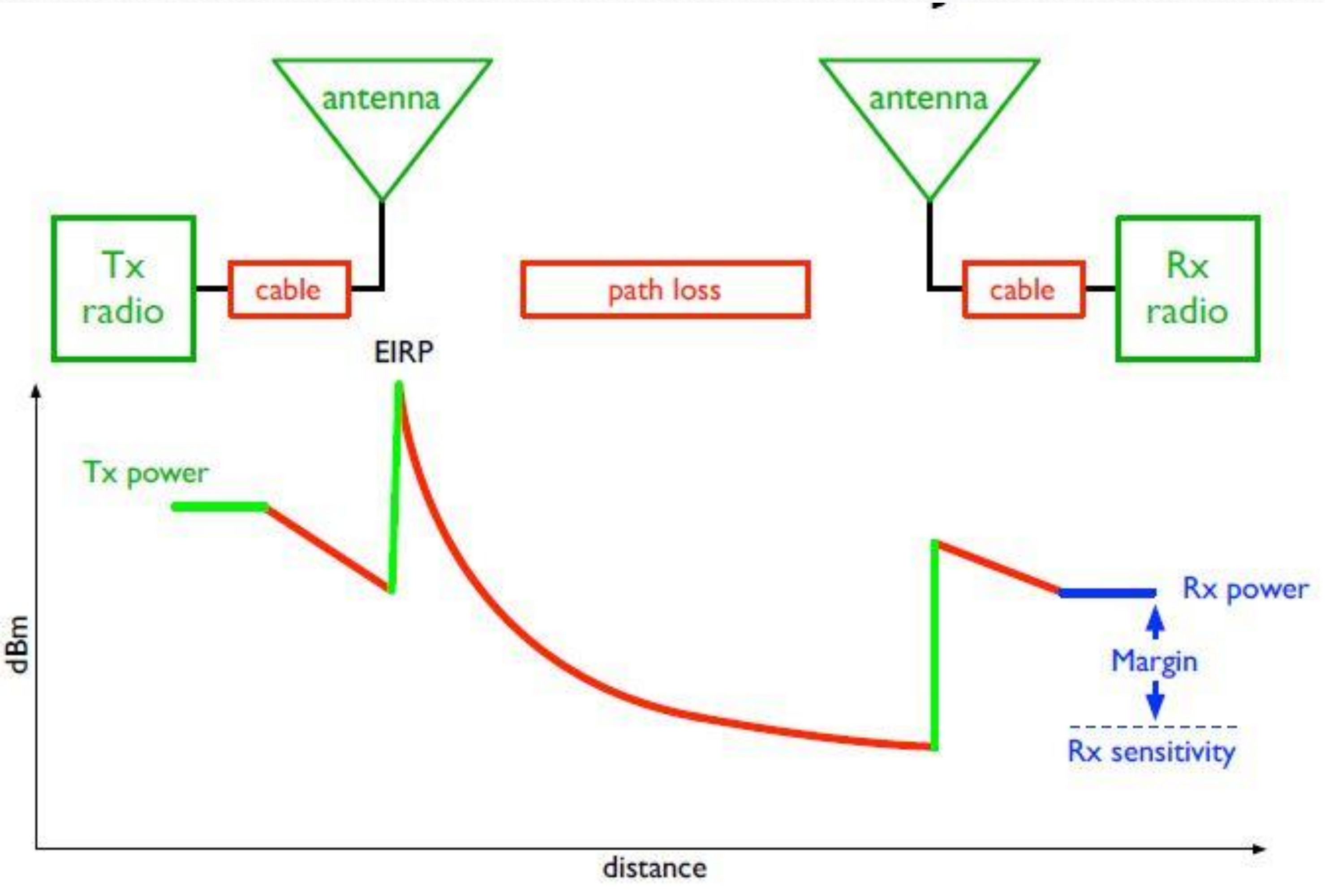
$$P_r(\text{dBm}) = 10\log P_r(\text{mW}) = 10\log\left(3.5 \times 10^{-3}\text{ mW}\right) = -24.5\text{ dBm.}$$

The received power at 10 km can be expressed in terms of dBm using equation (3.9), where $d_0 = 100$ m and $d = 10$ km

$$P_r(10\text{ km}) = P_r(100) + 20\log\left[\frac{100}{10000}\right] = -24.5\text{ dBm} - 40\text{ dB}$$
$$= -64.5\text{ dBm.}$$

Link Budget Model

Power in a wireless system



- This graph shows the **relative amount of gains and losses** as well as the absolute power at each point in a wireless link.
- The transmitter provides **some amount of power**. A small amount is lost in attenuation(**At Cable**) between the transmitter and the antenna.
- The antenna then **focuses the power**, providing a gain.
- This power is called **EIRP (Equivalent Isotropic Radiated Power).** Most regulators impose a limit on the maximum allowable value of EIRP **in a given country**.
- Then there are **free space and environmental losses** (which together form the path loss), which **increase with the distance** between the link endpoints.

- The receiving antenna provides **some additional gain**. Then there is a small amount of loss between the receiving antenna and the receiving radio.
- If the received amount of power at the far end **is greater than the receive sensitivity of the radio**, by a certain margin M, **then the link is possible**.
- The **value of M** will determine the reliability of the link, a good starting point is to have **at least 10 dB margin**. For critical links, it is better to strive for a 20 dB margin.

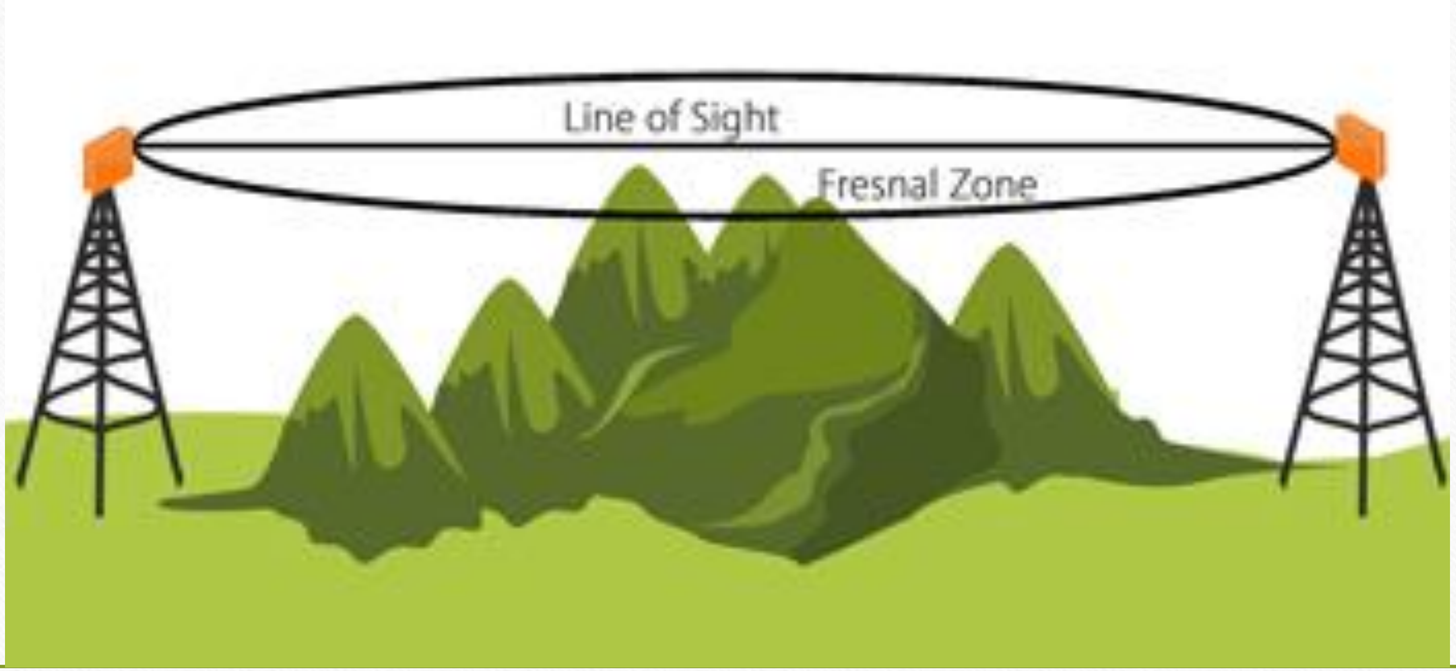
What is Link Budget?

- The performance of any communication link depends on the **quality of the equipment** being used.
- ***Link budget*** is a way of quantifying the **link performance.**
- The received power in a wireless link is determined by three factors: ***transmit power***, ***transmitting antenna gain***, and ***receiving antenna gain***.
- If that power, minus the ***free space loss*** of the link path, is greater than the ***minimum received signal level*** of the receiving radio, **then a link is possible**.

- The difference between the minimum received signal level and the actual received power is called the ***link margin.***
- The link margin must be positive, and should be maximized (**should be at least 10dBm or more for reliable links**).

- **Do not confuse the link budget with the cost** to obtain the equipment! We are **not dealing with money** here but with dB.
- The link budget **reflects the impact of different variables** in the ultimate power that reaches the receiver.
- Keep in mind that the **receiver sensitivity is strongly dependent on the transmission rate**: the **higher the transmission rate the higher the receiver power required for acceptable performance**.
- If one **cannot obtain an acceptable margin at a given transmission rate**, it might be required to work at **a lower transmission rate**.

- The **free space loss applies when there is a completely unobstructed path between the transmitter and the receiver**, with clearance of at least 60% of the first Fresnel Zone.
- Partial obstruction of **the 1st Fresnel Zone or the presence of walls or other objects will cause** additional losses to be added to the free space loss to calculate the total path attenuation.



- In essence the link budget will take the form of the equation below:

$$\text{Received power (dBm)} = \text{Transmitted power (dBm)} + \text{Gains (dB)} - \text{Losses (dB)}$$

- A typical link budget equation for a radio communications system may look like the following:

https://5g-tools.com/5g-nr-link-budget-calculator/

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - L_{TX} - L_{FS} - L_P - L_{RX}$$

Where:

P_{RX} = received power (dBm)

P_{TX} = transmitter output power (dBm)

G_{TX} = transmitter antenna gain (dBi)

G_{RX} = receiver antenna gain (dBi)

L_{TX} = transmit feeder and associated losses (feeder, connectors, etc.) (dB)

L_{FS} = free space loss or path loss (dB)

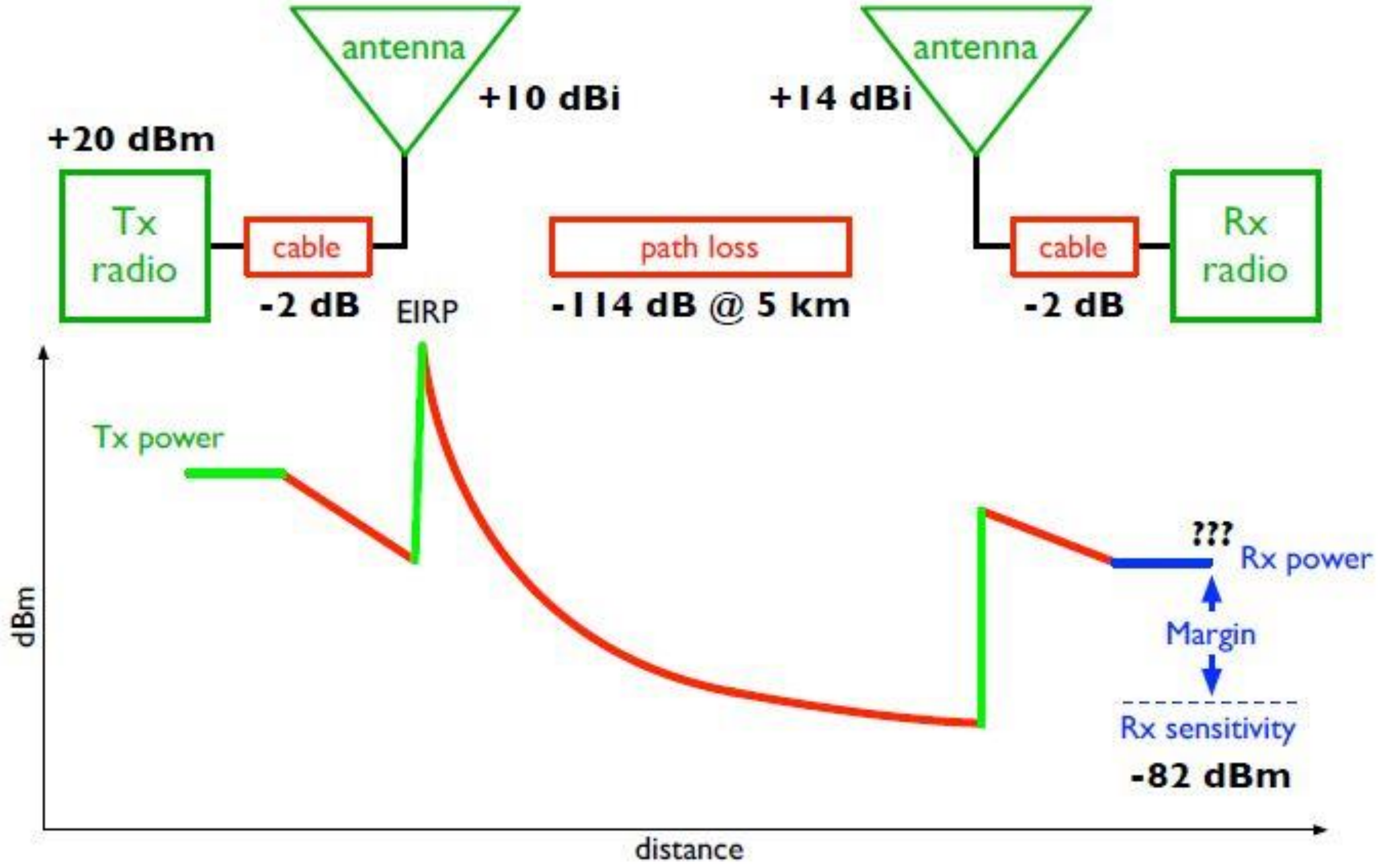
L_P = miscellaneous signal propagation losses (these include fading margin, polarization mismatch, losses associated with medium through which signal is travelling, other losses...) (dB)

L_{RX} = receiver feeder and associated losses (feeder, connectors, etc.) (d)B

Example link budget calculation

- Let's estimate the feasibility of a **5 km** link, with one access point and one client radio.
- The access point is connected to an antenna with **10 dBi** gain, with a transmitting power of **20 dBm** with a receive sensitivity of **-89 dBm**.
- The client is connected to an antenna with **14 dBi** gain, with a transmitting power of **15 dBm** and a receive sensitivity of **-82 dBm**.
- The cables in both systems are short, with a loss of **2dB** at each side at the 2.4 GHz frequency of operation with **114 dB** total path loss.

AP to Client link



20 dBm (TX Power AP)
+ 10 dBi (Antenna Gain AP)
- 2 dB (Cable Losses AP)
+ 14 dBi (Antenna Gain Client)
- 2 dB (Cable Losses Client)

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40 dB Total Gain
-114 dB (free space loss @5 km)

-74 dBm (expected received signal level)
--82 dBm (sensitivity of Client)

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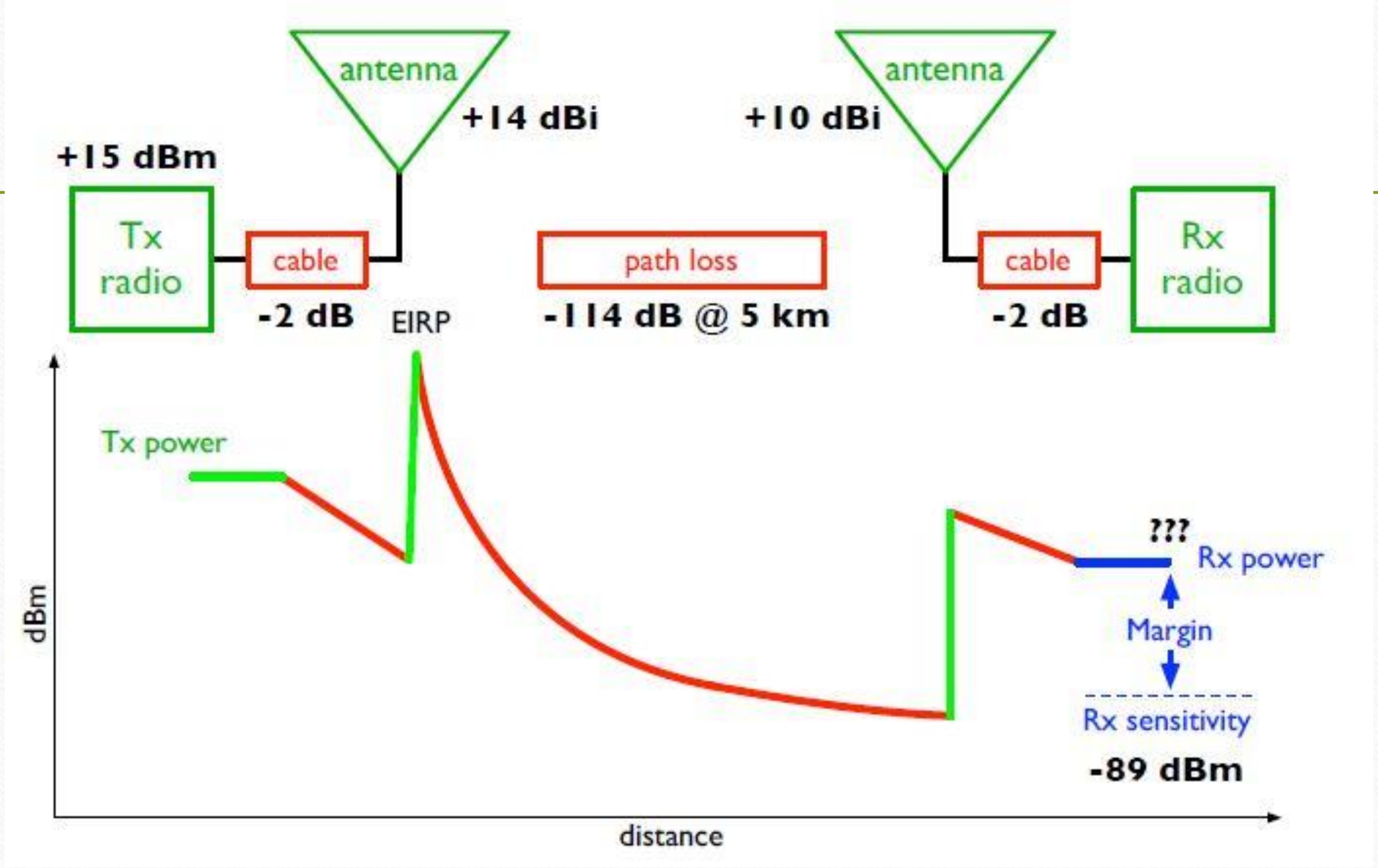
8 dB (link margin)

The AP to Client link is possible, but below 10 dB. This link could be improved.

Opposite direction: Client to AP



15 dBm (TX Power at Client)
+ 14 dBi (Antenna Gain Client)
- 2 dB (Cable Losses Client)
+ 10 dBi (Antenna Gain AP)
- 2 dB (Cable Losses AP)

---

35 dB Total Gain
-114 dB (free space loss @5 km)

-79 dBm (expected received signal level)
--89 dBm (sensitivity of AP)

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10 dBm (link margin)

The Client to AP link is better, at 10 dB, even though the transmit power is lower. This link is possible but it could still be improved by using higher gain antennas, more sensitive radios, or more powerful transmitters.

Example:1

- Estimate the feasibility of a **1 km** link, with one access point and one client radio and consider only AP to Client direction. The Access Point is connected to an antenna with **5 dBi** gain, with a transmitting power of **18 dBm**. The client is connected to an antenna with **7.85 dBd** gain, with a transmitting power with a receive sensitivity of **-92 dBm**. The cables in both systems are law quality and consisted a loss of 5**dB** at each side at the 2.4 GHz frequency of operation with **100 dB** total path loss.

Example:2

- Estimate the feasibility of a **50 km** link, with one access point and one client radio and consider only AP to Client direction. The Access Point is connected to an half wave dipole antenna with **21.85 dBd** gain, with a transmitting power of **15 dBm**. The client is connected to an half wave antenna with **21.85 dBd** gain, with a transmitting power with a receive sensitivity of **-85 dBm**. The cables in both systems are consisted a loss of **3dB** at each side at the 2.4 GHz frequency of operation with **134 dB** total path loss.

Out Door Propagation models

- Radio transmission in mobile communication takes place **over irregular terrain**
- There are different propagation models available to **predict the received signal strength, *Pr(d)*,** by **estimating the path loss** at a particular sector
- Models used are based on systematic interpretation of measurement data obtained in the service area
- They may vary **in complexity and accuracy**
- **Many wireless systems** use these models as **a basis for performance analysis**

Types of Out door propagation Models

- Okumura Model
- Hata Model

Okumura Model

- Okumura's model is one of the most widely used models **for signal prediction** in **large urban macro-cells**.
- This model is applicable over distances of **1-100 Km** and frequency ranges of **150-1920 MHz**.
- Okumura used extensive measurements of **base station-to-mobile signal attenuation** throughout **Tokyo** to develop a set of curves giving median attenuation relative to **free space of signal propagation** in irregular terrain
- Transmit antenna effective height : **30 m to 1000 m** the **upper end of which is higher** than typical base stations today, and Mobile Antenna height **1 m** to **10 m**.

- Okumura's model is considered to be among **the simplest and best in terms of accuracy** in **path loss prediction for mature cellular and land mobile radio systems** in cluttered environments.
- It is very **practical and has become a standard for system planning** in **modern land mobile radio systems in Japan**.
- The major disadvantage with the model is **its slow response to rapid changes in terrain.**
- Therefore, **the model is fairly good in urban and suburban areas**, but **not as good in rural areas.**

Okumura Model

- The **path loss formula** of Okumura is given by:

L50(dB) = LF + Amu(f,d) – G(hte) – G(hre) – GAREA

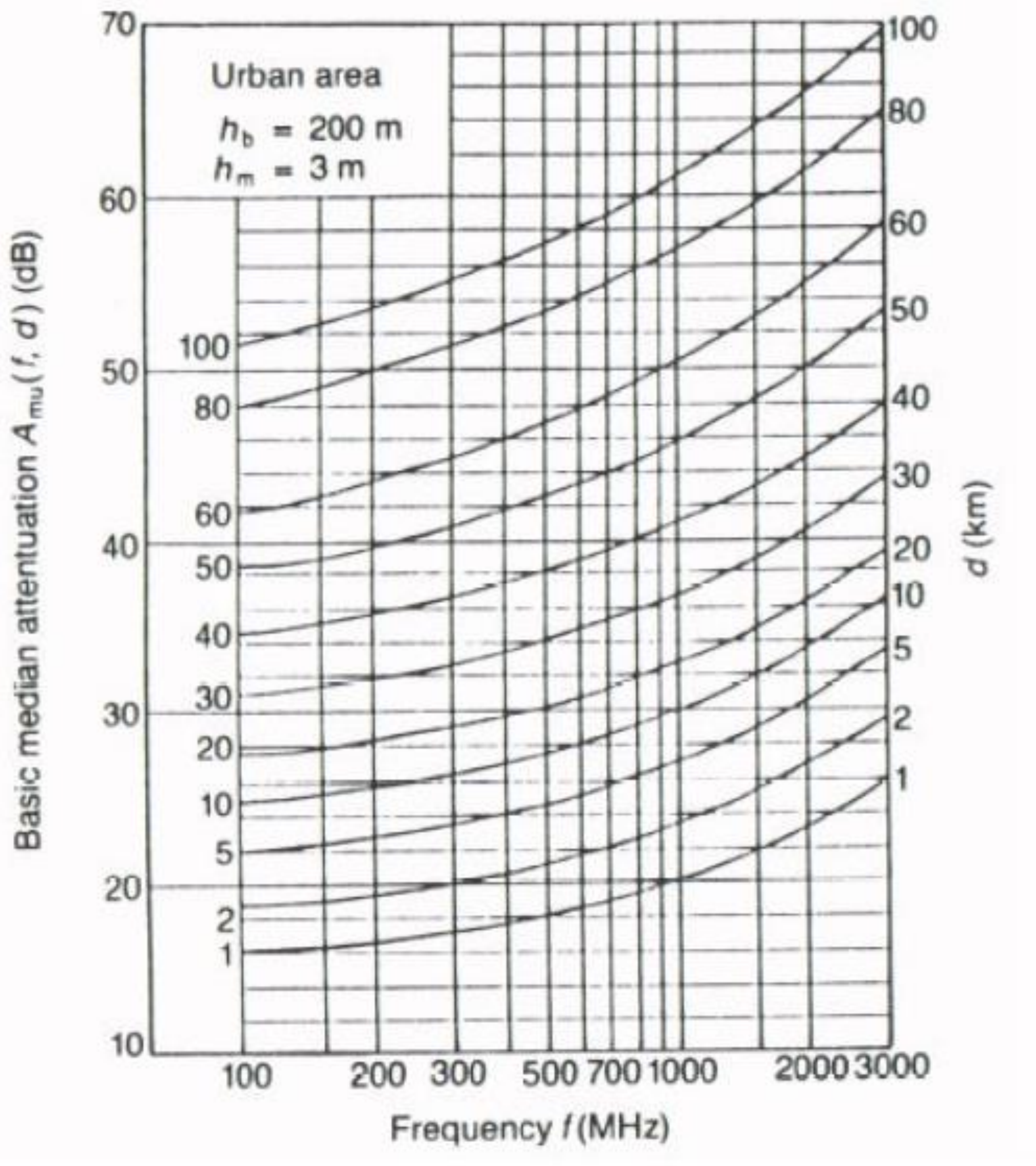
- ***L50*** = **50% Median path loss** between the TX and RX **expressed in dB**
- ***LF*** = Free space propagation loss **in dB**
- ***Amu(f,d)***= **Median attenuation** in addition to **free space path loss** across all environments **in dB**
- ***G(hte)*** = Base station antenna height gain factor **in dB**
- ***G(hre)*** = Mobile antenna height gain factor **in dB**
- ***GAREA*** = Gain due to type of environment **in dB**
- ***d*** is the distance between transmitter and receiver **in m**

Technique

- Find free space path loss, *LF* ***(using equation)***
- Determine median attenuation relative to free space ***Amu*(*f,d*)** ***(from curves)***
- Add correction gain factors for transmitter and receiver antenna heights ***(from curves or using their equations)*** and area gain factor ***(from curves)***

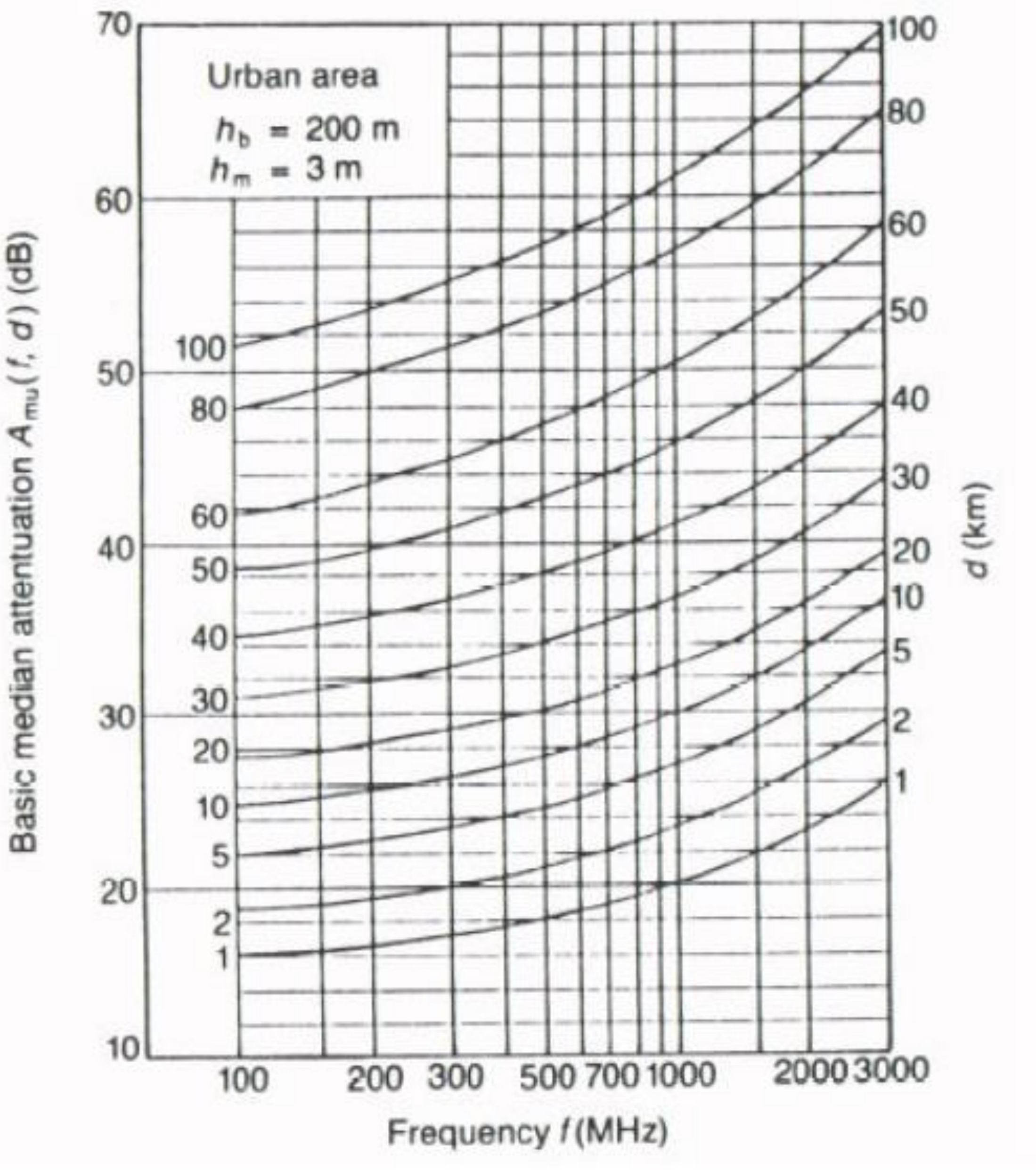
Basic Median Attenuation (*Amu(f,d)*)

- This term models **additional propagation losses** due to the signal propagation in a terrestrial urban environment
- The curves in Figure were derived for **TX height reference of 200m** and **RX height of 3m**
- If the actual heights of the TX and RX differ from those referenced, the **appropriate correction needs to be added**.

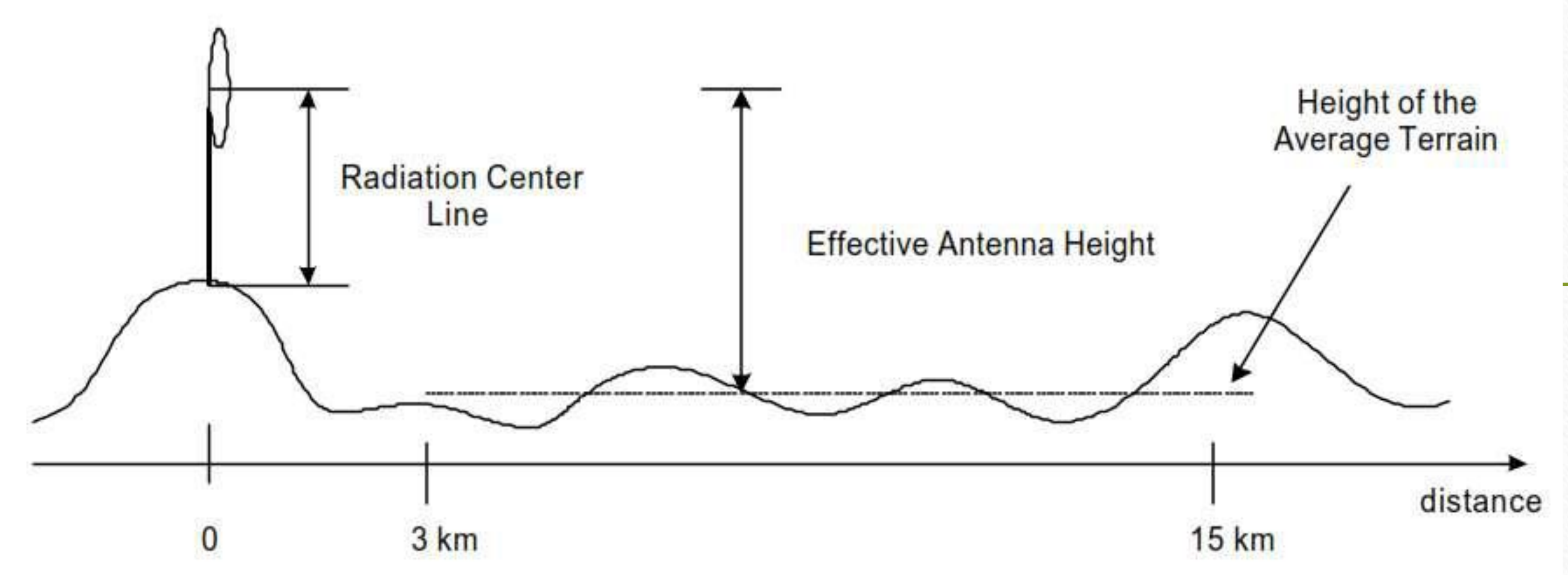


Basic Median Attenuation (*Amu(f,d)*)

- For example**, at 850MHz frequency** and the **transmitter-receiver distance of 5km**, the **attenuation is close to 26dB**.
- This value is read from the leftmost scale in Figure at the point where constant vertical line at **850MHz intersects with the parametric 5km distance curve**.
- The **projection of this intersection on the basic median attenuation** scale gives the **resulting attenuation of approximately 26dB**.



Okumura Model (Effective Transmitter Antenna Height)

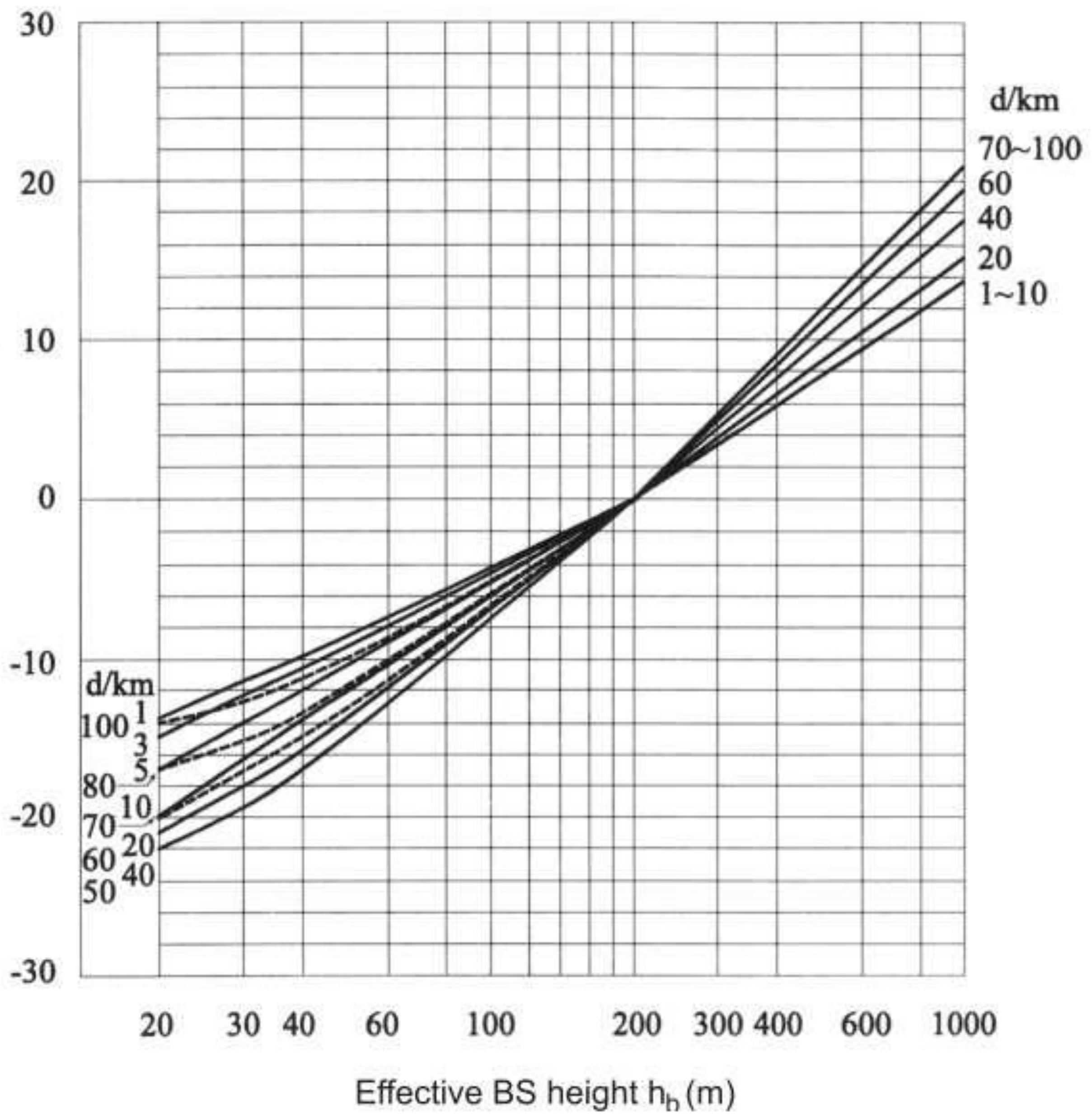


- The terrain is averaged along the direction of radio path over the distances between **3 and 15 kilometers**.
- Effective antenna height is determined as the **difference** between the height of the **BTS antenna** and the height of the **average terrain**.

Okumura Model (Base Station Effective Height Gain (G_{hte})

- At the effective height of 200m, all curves meet and no correction gain is required ($G_{hte} = 0\ dB$)
- Base station antennas above 200m, introduce **positive gain** and antennas lower than 200m have **negative gain** factor.
- The parameter of the family of the curves is the **distance between the transmitter and receiver**.

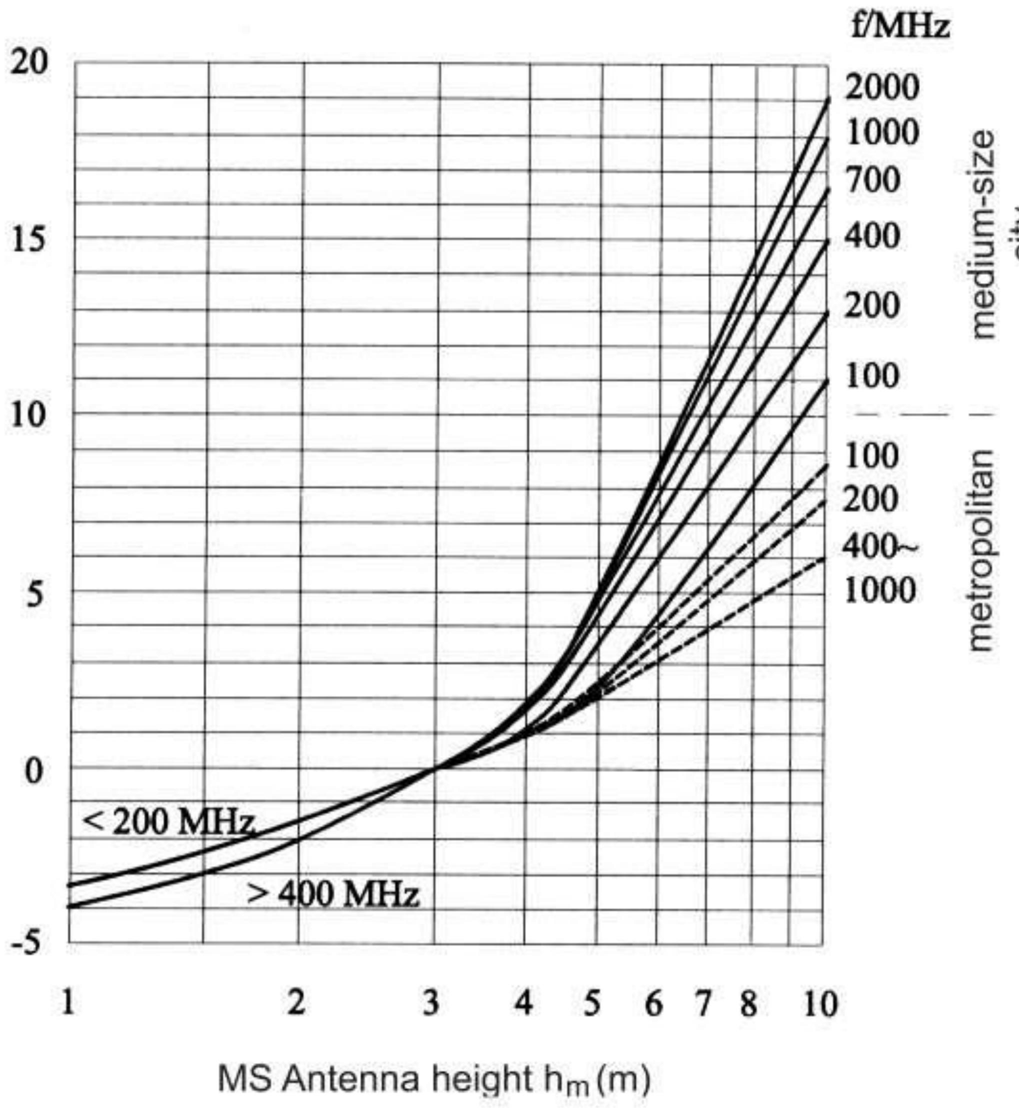
$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) \qquad 1000\ \text{m} > h_{te} > 30\ \text{m}$$



Note that the **antenna height gains are strictly a function of height** and have **nothing to do with antenna patterns**.

Okumura Model (Mobile Station Height Gain Factor ($G\ hre$))

- **All curves meet** at the referent 3m horizontal coordinate.
- Higher antennas introduce **gain** and lower cause **loss** of referent signal level.
- The parameter for this family of curves is **operating frequency**.
- Mobile height gain factor is also separated according to **the size of the city in two clusters**: **medium** and **large cities**.

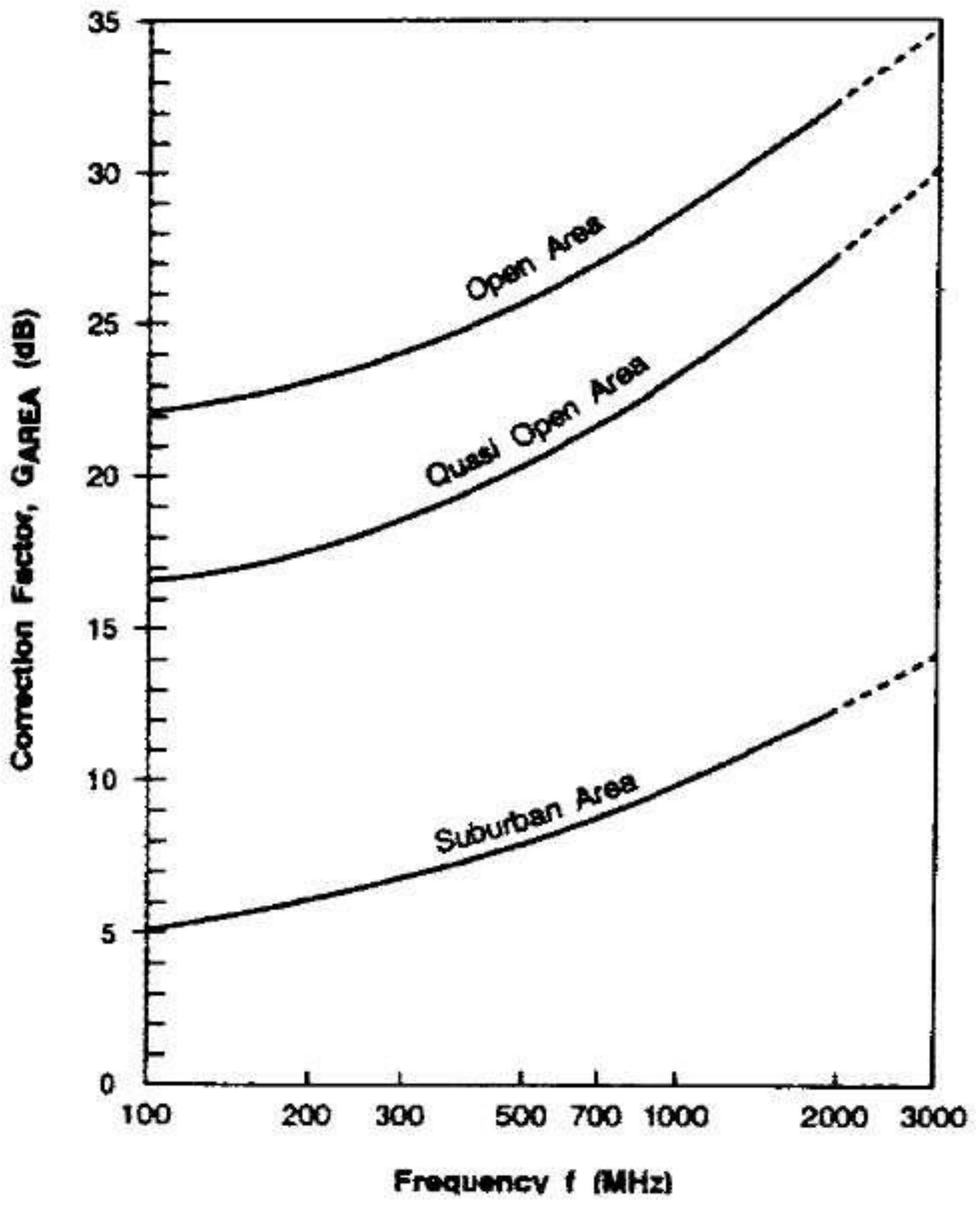


$$G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right) \quad h_{re} \le 3\ \text{m}$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) \quad 10\ \text{m} > h_{re} > 3\ \text{m}$$

Okumura Model (Environment Gain G_{AREA})

- For the **referent Urban terrain environment** the value of $G_{AREA} = 0\ dB$
- For Other terrain types; such as **Suburban**, **Quasi- Open** and **Open Areas**, the value of G_{AREA} can be read the curves.
- G_{AREA} values represent **an additional loss correction factor** due to propagation in different than Urban environment



Example 3.10

Find the median path loss using Okumura's model for $d = 50$ km, $h_{te} = 100$ m, $h_{re} = 10$ m in a suburban environment. If the base station transmitter radiates an EIRP of 1 kW at a carrier frequency of 900 MHz, find the power at the receiver (assume a unity gain receiving antenna).

Solution to Example 3.10

The free space path loss L_F can be calculated using equation (3.6) as

$$L_F = 10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] = 10\log\left[\frac{(3\times10^8/900\times10^6)^2}{(4\pi)^2\times(50\times10^3)^2}\right] = 125.5\text{ dB}.$$

From the Okumura curves

$$A_{mu}(900\text{ MHz}(50\text{ km})) = 43\text{ dB}$$

and

$$G_{AREA} = 9\text{ dB}.$$

Using equation (3.81.a) and (3.81.c) we have

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) = 20\log\left(\frac{100}{200}\right) = -6\text{ dB}.$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) = 20\log\left(\frac{10}{3}\right) = 10.46\text{ dB}.$$

Using equation (3.80) the total mean path loss is

$$\begin{aligned} L_{50}(\text{dB}) &= L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \\ &= 125.5\text{ dB} + 43\text{ dB} - (-6)\text{ dB} - 10.46\text{ dB} - 9\text{ dB} \\ &= 155.04\text{ dB}. \end{aligned}$$

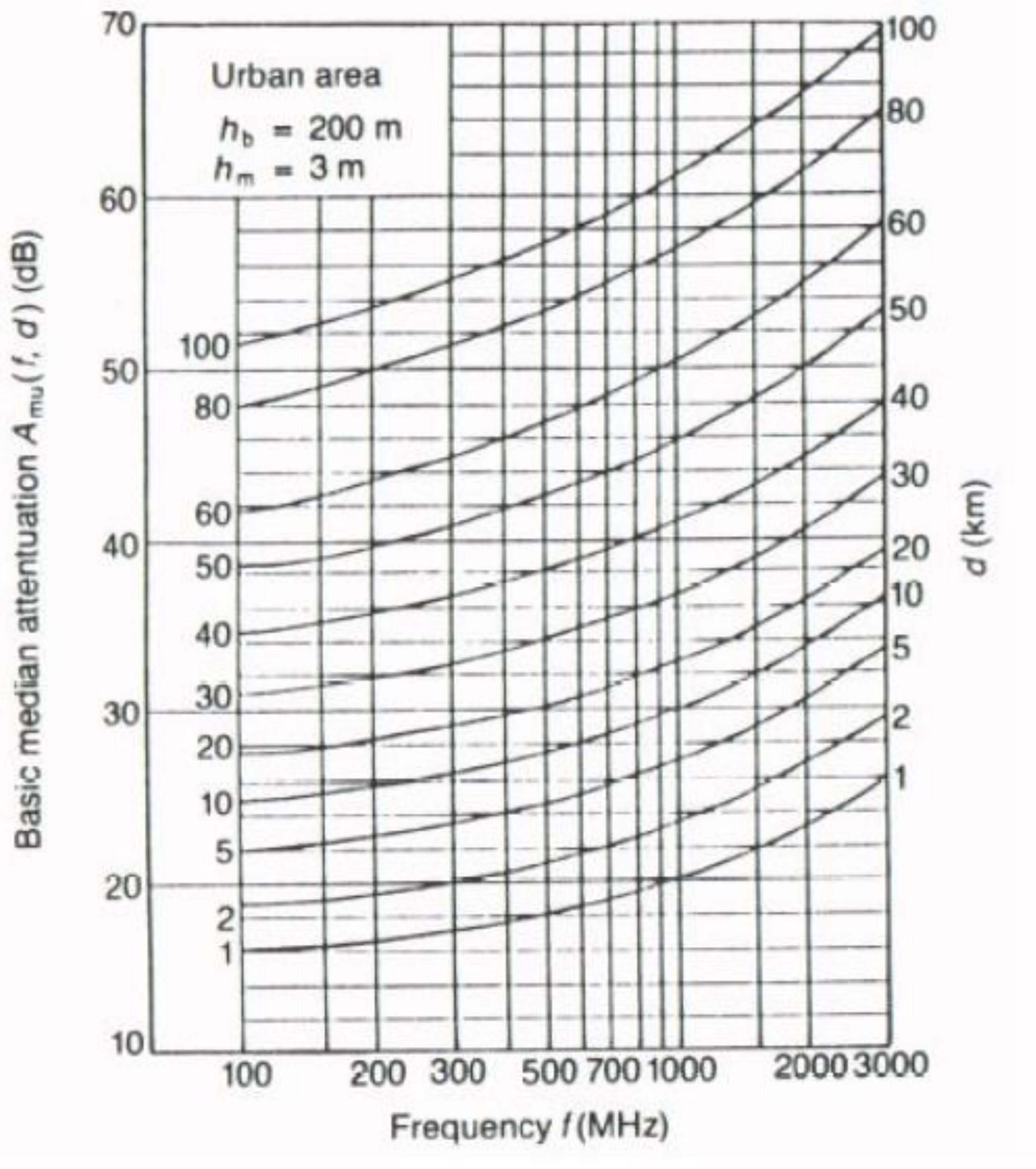
Therefore, the median received power is

$$\begin{aligned} P_r(d) &= EIRP(\text{dBm}) - L_{50}(\text{dB}) + G_r(\text{dB}) \\ &= 60\text{ dBm} - 155.04\text{ dB} + 0\text{ dB} = -95.04\text{ dBm}. \end{aligned}$$

Activ
Go to

Use Okumura model to determine the received signal level, 2.3 miles from the site operating at 870MHz. Evaluate the connection is feasible or not.

- The following numerical data is given:
- Radiation centerline of the BTS transmitter: **hbts** = 40m
- Height of the mobile receive antenna: **hr** = 3m
- Terrain elevation at the location of the BTS: **Ebts** = 340m
- Average height of the terrain in the area: **Eterrain** = 312m
- Power delivered to the BTS antenna: **PBTS** = 19.5W
- BTS antenna gain: 10log (**Gt**) = 10dB
- MS antenna gain: 10log (**Gm**) = 0dB
- Environmental gain as = 0dB
- Sensitivity of the MS antenna = -94.9 dBm
- Link Margin = 12 dBm (for a success full link)



Urban area
h_b = 200 m
h_m = 3 m
Basic median attenuation $A_{mu}(f, d)$ (dB)
d (km)
Frequency f (MHz)
70
60
50
40
30
20
10
100
200
300
500
700
1000
2000
3000

Hata Model

- The Hata model is an empirical formulation of the graphical path loss data provided by Okumura, and **is valid from 150 MHz to 1500 MHz.**

- Hata represented **urban area propagation loss** as a standard formula and supplied for correction equations for application to some situations

Hata Model

- **Standard formula for Median Path Loss**

$$L_{50}(urban)(dB) = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d$$

- **L50** - 50th % value (median) propagation path loss (urban)
- **fc** - frequency in MHz
- **hte – Effective Ba**se Station antenna height ranging from **30 m to 200 m**
- **hre – Effective receiver** antenna height (in meters) ranging from **1 m to 10m**
- **a(hre) -** correction factor for mobile antenna height.
- **d** - Tx-Rx separation distance in **Km**

- For **small to medium sized city,** mobile antenna correction factor is given by:

$$a(h_{re}) = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8)\ \text{dB}$$

- And **for a large city**; it is given by:

$$a(h_{re}) = 8.29(\log 1.54h_{re})^2 - 1.1\ \text{dB} \quad \text{for } f_c \le 300\ \text{MHz}$$

$$a(h_{re}) = 3.2(\log 11.75h_{re})^2 - 4.97\ \text{dB} \quad \text{for } f_c \ge 300\ \text{MHz}$$

- To obtain the path loss in a **sub-urban** area the standard Hata formula in Equation is modified **(Using Area Corrections) as**:

$$L_{50}(\text{dB}) = L_{50}(urban) - 2[\log(f_c/28)]^2 - 5.4$$

- And for **path loss in open rural areas**, the formula is modified as

$$L_{50}(\mathrm{dB}) = L_{50}(urban) - 4.78(\log f_c)^2 - 18.33\log f_c - 40.98$$

- Although Hata's model **does not have any of the path-specific corrections** which are available in Okumura's model. But, the above expressions have **significant practical value**.
- The predictions of the Hata model compare very closely with the original Okumura model, **as long as d exceeds 1 km.**
- This model is well suited for **large cell mobile systems,** but not **personal communications systems (PCS)** which have cells **on the order of 1km radius**.

- **Qu**: Consider the prediction problem described in Okumura Model. Assume that the propagation is an **urban area** of a **small city**.
- Find out the **Received Power Level and compare the value** with The value received from the Okumura Model.

Use Okumura model to determine the received signal level, 2.3 miles from the site operating at 870MHz. Evaluate the connection is feasible or not.

- The following numerical data is given:
- Radiation centerline of the BTS transmitter: **hbts** = 40m
- Height of the mobile receive antenna: **hr** = 3m
- Terrain elevation at the location of the BTS: **Ebts** = 340m
- Average height of the terrain in the area: **Eterrain** = 312m
- Power delivered to the BTS antenna: **PBTS** = 19.5W
- BTS antenna gain: 10log (**Gt**) = 10dB
- MS antenna gain: 10log (**Gm**) = 0dB
- Environmental gain as = 0dB
- Sensitivity of the MS antenna = -94.9 dBm
- Link Margin = 12 dBm (for a success full link)

Indoor Propagation models

- Outdoor **Models are not accurate for Indoor** scenarios
  - Home, Shopping mall, office building, etc.

- Indoor radio channel **differs from traditional mobile radio** channel in
  - Distances covered are much **smaller.**
  - **Variability of the environment is greater** for a much smaller range or T-R separation distances.

Propagation Influancement

- The propagation inside a building is influenced by:
  - **Layout of the building.**
  - **Construction Materials.**
  - **Building type**:
    - Traditional office building with fixed walls (Hard Partitions).
    - Open plan buildings with movable wall panels (Soft Partitions).
    - Sports Arena .
    - Residential Home.
    - Factory.

Similarity and Difference between Indoor and Outdoor Propagation

Difference in Conditions

- Doors/Windows open or not
- The mounting place of antenna
  - Desk
  - Ceiling
- The level of floors

Similarity in Mechanism

- Reflection
- Scattering
- Diffraction

Indoor models are classifies as:

- Line of sight (LOS)
- Obstructed (OBS) with varying degree of clutter

Indoor Propagation Events & Parameters

✕ Temporal fading for fixed and moving terminals

- **Motion of people** inside building causes Ricean fading for the stationary receivers.
- **Portable receivers** experience in general:
  - Rayleigh fading for OBS propagation paths.
  - Ricean fading for LOS paths.

✕ Multipath Delay Spread

- Buildings with fewer metals and hard-partitions typically have small rms **delay spread 30-60ns.**
  - Can support **data rates excess of several Mbps** without equalization.

- Larger buildings with great amount of metal may have rms delay spreads as **large as 300ns**.
  - **Can not support data rates more** than a **few hundred Kbps** without equalization

Path Loss Factors

- Partition Losses (**Same Floor**).
- Partition Losses **between floors**.
- Signal **Penetration into Buildings.**

Partition Losses (same floor)

- Buildings have a **wide variety of partitions** and **obstacles** which form the internal and external structure.
- Houses typically use a **wood frame partition with plaster board** to form internal walls and have wood or non reinforced concrete between floors.
- Office buildings, on the other hand, often **have large open areas (open plane)** which are constructed by using moveable office partitions, **so that the space may be reconfigured easily**, and use metal reinforced concrete between floors.

- Two types of partitions
  - **Hard partitions**: Partitions that are **formed as part of the building structure** (Walls of room).
  - **Soft partitions** : Moveable partitions **that not span to ceiling**.
- Partitions vary widely in their **physical and electrical characteristics**, making it **difficult to apply general models** to specific indoor installations.
- Path loss **depend upon the types of partitions.**

- Nevertheless, researchers have **formed extensive data bases** of losses for a great number of partitions:

Material Type	Loss (dB)	Frequency (MHz)
All metal	26	815
Aluminim Siding	20.4	815
Concerete Block Wall	3.9	1300
Loss from one Floor	20-30	1300
Turning an Angle in a Corridor	10-15	1300
Concrete Floor	10	1300
Dry Plywood (3/4in) – 1 sheet	1	9600
Wet Plywood (3/4in) – 1 sheet	19	9600
Aluminum (1/8in) – 1 sheet	47	9600

Partitions losses (between floors)

- Partition losses between the **two floors depend on:**
  - External dimension and material used for buildings
  - Types of construction used to create floors
  - External surroundings
  - No of windows used
  - Tinting on the windows
- Even the number of windows in a building and the presence of tinting (**which attenuates radio energy**) can impact the **loss between floors.**

- Table illustrates values for **floor attenuation factors (FAF**) in three buildings in **San Francisco**. It can be seen that for all three buildings, the attenuation between one floor of the building is greater than the incremental attenuation caused by each **additional floor**. Table illustrates very similar tendencies. After about five or six floor separations, very **little additional path loss is experienced**.

Table 3.4 Total Floor Attenuation Factor and Standard Deviation σ (dB) for Three Buildings. Each point represents the average path loss over a 20λ measurement track [Sel92a].

Building	915 MHz FAF (dB)	σ (dB)	Number of locations	1900 MHz FAF (dB)	σ (dB)	Number of locations
Walnut Creek						
One Floor	33.6	3.2	25	31.3	4.6	110
Two Floors	44.0	4.8	39	38.5	4.0	29
SF PacBell						
One Floor	13.2	9.2	16	26.2	10.5	21
Two Floors	18.1	8.0	10	33.4	9.9	21
Three Floors	24.0	5.6	10	35.2	5.9	20
Four Floors	27.0	6.8	10	38.4	3.4	20
Five Floors	27.1	6.3	10	46.4	3.9	17
San Ramon						
One Floor	29.1	5.8	93	35.4	6.4	74
Two Floors	36.6	6.0	81	35.6	5.9	41
Three Floors	39.6	6.0	70	35.2	3.9	27

Signal Penetration into Buildings

- RF signals can penetrate from outside transmitter to the inside of buildings:
  - However, the **signals are attenuated**.

- The path loss during penetration has been found to be a function of:
  - **Frequency** of the signal.
  - **The height** of the building

Log distance path loss model

Path loss can be given as

$$PL(\mathrm{dB}) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

PL= is the total path loss measured in Decibel (dB) •
PL(d0)=is the path loss at the reference distance d0 in (dB)
d = is the length of the path.
do= is the reference distance,

- Xa represents a normal **random variable loss in dB** having a standard deviation of **σ in** dB.
- Where **n is path loss exponent,** where the value of **n depends on the surroundings and building type**.
- **Note**: In the study of wireless communications, path loss can be represented by the path loss exponent, whose value is normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for relatively lossy environments. In some environments, such as buildings, stadiums and other indoor environments, the path loss exponent can reach values in the range of 4 to 6. On the other hand, a tunnel may act as a waveguide, resulting in a path loss exponent less than 2.

Table 3.5 Average Floor Attenuation Factor in dB for One, Two, Three, and Four Floors in Two Office Buildings [Sei92b].

Building	FAF (dB)	σ (dB)	Number of locations
Office Building 1:			
Through One Floor	12.9	7.0	52
Through Two Floors	18.7	2.8	9
Through Three Floors	24.4	1.7	9
Through Four Floors	27.0	1.5	9
Office Building 2:			
Through One Floor	16.2	2.9	21
Through Two Floors	27.5	5.4	21
Through Three Floors	31.6	7.2	21

model of equation (3.69.a). Typical values for various buildings are provided in Table 3.6 [And94].

Table 3.6 Path loss exponent and standard deviation measured in different buildings [And94]

Building	Frequency (MHz)	n	σ (dB)
Retail Stores	914	2.2	8.7
Grocery Store	914	1.8	5.2
Office, hard partition	1500	3.0	7.0
Office, soft partition	900	2.4	9.6
Office, soft partition	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/Cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8
Suburban Home			
Indoor Street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

ITU Indoor Path Loss Model

- To Predict propagation path loss inside buildings.
- The average path loss in dB is :

- $L_A\,(d)[dB] = 20\lg f + 10v\lg d + L_f(n) - 28$ Where
  - f is the frequency in MHz
  - d is the distance in m; d > 1 m;
  - v is the path loss exponent (found from measurements)
  - $L_f\,(n) is\ the\ floor\ penetration\ loss\ (measurements)$
  - n is the number of floors (penetrated)
- *Limits*
  - $900\ MHz \leq f \leq$ 5200 MHz
  - $1 \leq n \leq 3$
  - d > 1m