Macrocells

Electromagnetics
and
Remote Sensing Lab
(ERSLab)

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Outline

What they are

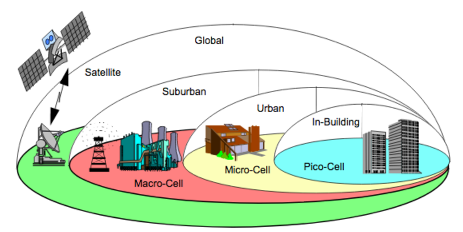
A multi-operator site on a strong tower with separate antennas for each service

Macrocells provide coverage larger than microcell. The antennas for macrocells are mounted on ground-based masts, rooftops and other existing structures, at a height that provides a clear view over the surrounding buildings and terrain. Macrocell base stations have power outputs of typically tens of watts

What they are

Why we do care

In a cellular system, cells operate in a hierarchical way

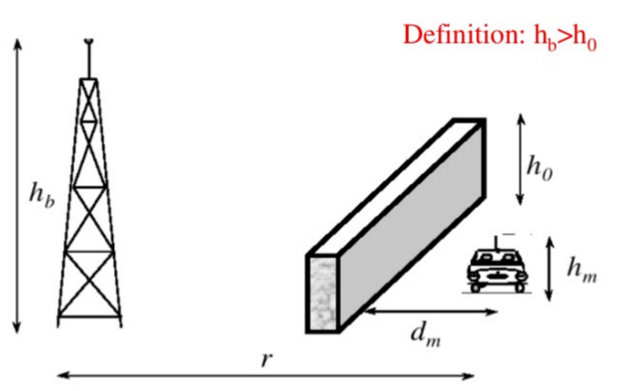


They are commonly encountered in:

- Cellular telephony.
- Broadcasting.
- Private mobile radio.
- WiMax.

The key parameter to design macrocells is the area coverage (rather than the specific field strength at a given location).

Macrocell geometry



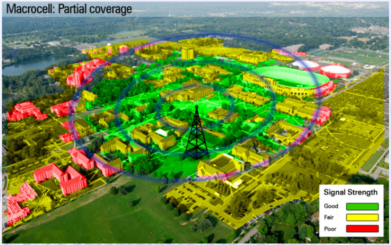
The basic definition of a macrocell is $h_b > h_o$; i.e., the transmitting station height is significant larger than the mean buildings height.

Path loss models

There are various types of models to predict path loss in a wireless channel that can be sorted as follows:

- Empirical: They are based on extensive in-field measurements campaigns. They parameters are linked to the environment and to the measurements.
- Deterministic: They rely on a specific fixed geometry (buildings, streets, etc.) and are generally used to analyze specific situations.
- Semi-empirical: They rely on the joint use of deterministic models and statistics of various parameters (building heights, street width, etc.).

Empirical models



- Free-space and plane Earth models cannot be used as they stand since a detailed knowledge of the scene is needed.
- The key outcome is the overall extent of the coverage area.
- Empirical models are useful to estimate the extent of the coverage area.

An extensive set of path loss measurements is needed

Empirical models

At the very root empirical models rely on the fitting of the path loss measurements with an appropriate function whose parameters are derived for the particular environment to minimize the error between measurements and the function.

- The simplest fitting function for a path loss model is given by:

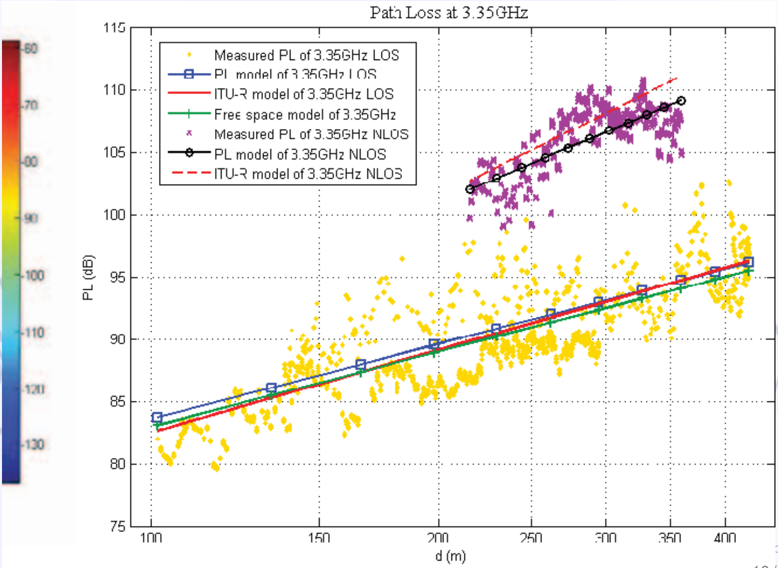
$$L = \frac{P_T}{P_R} = \frac{r^n}{k} \tag{1}$$

Power law model

$$L = 10n \log r + K \tag{2}$$

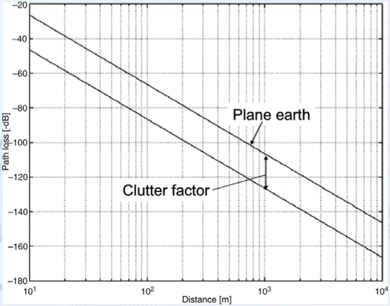
It is a power law model where $K = -10 \log k$ and n are the clutter factor and the path loss exponent, respectively.

Empirical models



Empirical models

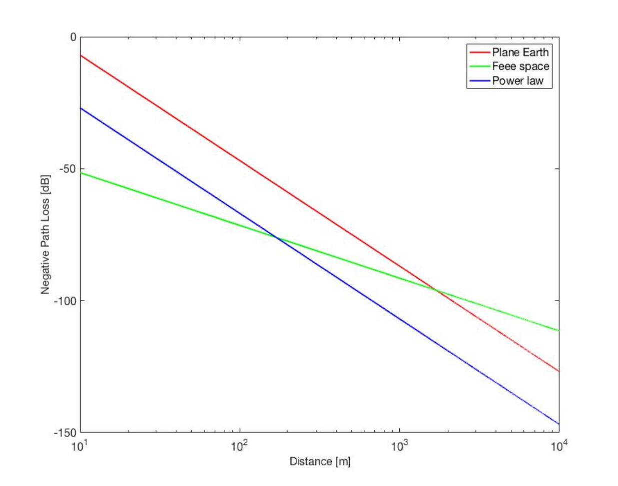
The values assigned to n and K determine the specific empirical model.



- Measurements undertaken in both urban and suburban areas show that n is typically close to the plane Earth one, i.e.; $n \approx 4$.

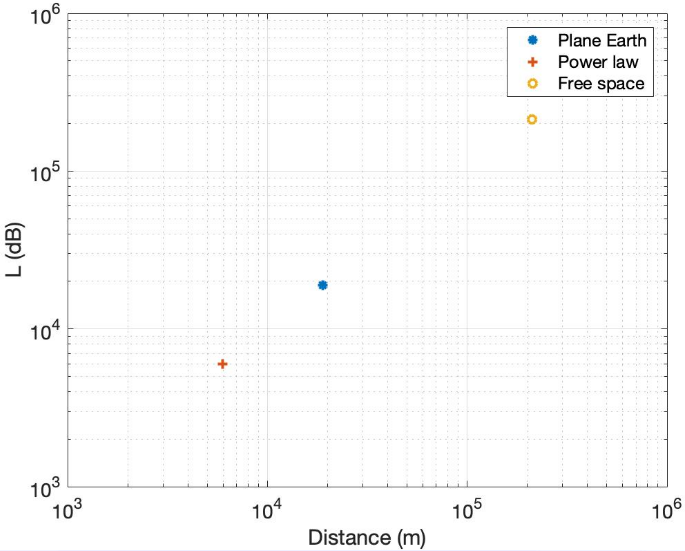
Hence, typically, empirical models are based on plane earth loss plus (in dB) a clutter factor K.

Power law models: do it yourself

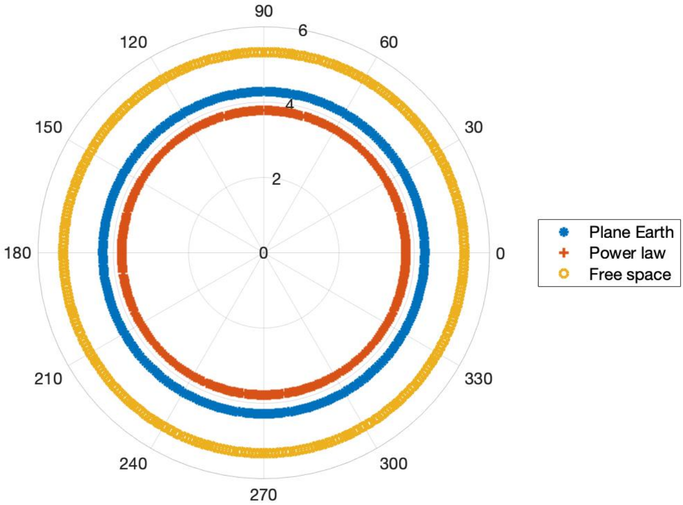


f=900MHz, hm=1.5m, hb=30m

Range predicted by the models: $L = 138\text{dB}$



Polar view


90
60
30
0
330
300
270
240
210
180
150
120
6
4
2
0
Plane Earth
Power law
Free space

Outline

The Okumura-Hata model

- Okumura collected path loss measurements (in Tokyo city) and plotted a set of curves for path loss in urban areas:
  - Frequency range: 100MHz to 1920MHz.
- Hata came up with an empirical model for Okumura's curves:

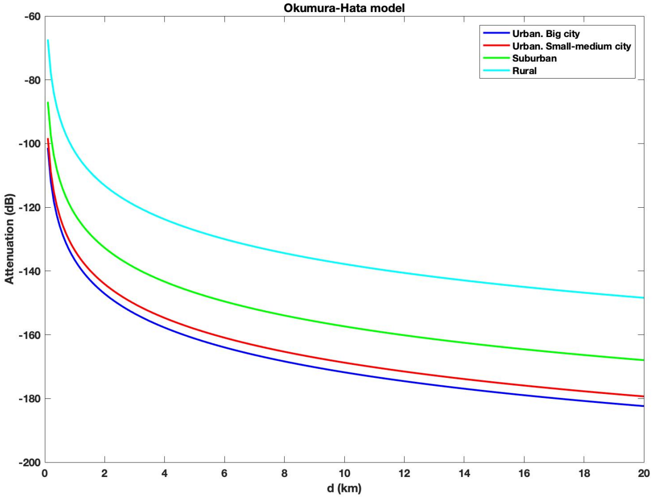
$$L = A + B \log r - C \tag{3}$$

- where A depends on the carrier frequency and TX height, B depends on the RX height and C depends on the kind of clutter and terrain category, namely: open area; suburban area and urban area.

Comparisons of empirical models in urban area

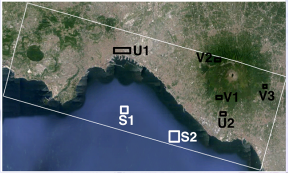
- Open area: there are no tall trees or buildings in the path.
- Suburban area: There are small villages or highways with some obstacles. The scenario is not congested.
- Urban area: High-density urbanized areas with tall buildings.

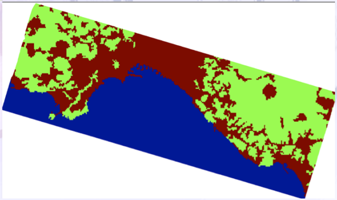
Okumura-Hata model



Comparisons of empirical models in urban area

Remotely sensed data can be of some help allowing a less subjective clutter classification.





Comparisons of empirical models in urban area

Empirical models are widely used since they do not require a detailed knowledge of the scenario and they are computer-time effective. However, they exhibit some drawbacks:

- They rely on the specific parameters used in the measurement campaign.
- Quite subjective partitioning of the environment.
- No physical understanding of the mechanisms involved in the propagation.

Physical models

They are physically based on propagation theory

Rationale

They estimate propagation of radio waves analytically. Two approaches are adopted:

- Solving the electromagnetic problem: it is a complex procedure that very often relies on simplifying assumptions.
- Ray tracing: much easier and commonly adopted. However, it requires a large computational effort.

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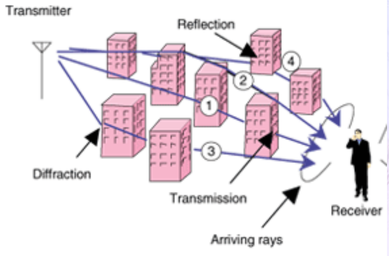
Outline

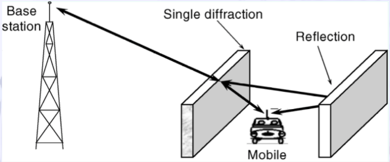
Ray tracing

It is a technique based on Geometric Optic



- It can be used to predict reflected and transmitted rays.
- Diffraction models are added to extend GO.

Ikegami deterministic model



- Detailed maps of building heights, shapes and positions are needed to trace ray paths between TX and RX.
- Only single reflections from walls are included and a fixed reflection loss is assumed.
- Diffraction calculated using single edge approximation.
- Reflected and diffracted rays are power summed.

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Ikegami deterministic model

Pros

- It is a first attempt to provide a physical explanation of phenomena involved in NLOS propagation in macrocells.
- It succeeds in predicting fairly well intensity variations of the field within the street.

Cons

- It is physically and experimentally untenable that propagation is not affected by h_b.
- It basically predicts a $n \approx 2$ exponent, which results in underestimations at larger distances.
- The variation with frequency is underestimated.

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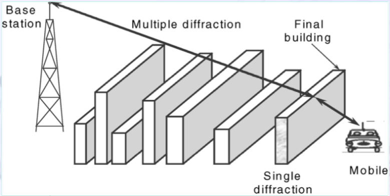
Introduction
Path loss
Empirical models
Okumura-Hata
Physical models
Ray tracing
Multiple diffraction integral
Semi-empirical models

Multiple diffraction over building rooftops

In built-up areas the key propagation mechanism is multiple diffraction from the rooftops of the buildings.



- Typically the diffraction angle is within 1°. This means that diffraction does not depend on the shape of the building that can be represented as a knife-edge.
- The only exception is the final building that diffracts down to the street-level.

The last building can be either considered as a knife edge or as more complex shape for which the diffraction is known.

Multiple diffraction over building rooftops

The key problem that arises from diffraction due to multiple edges is that methods based on single-edge diffraction are unreliable.

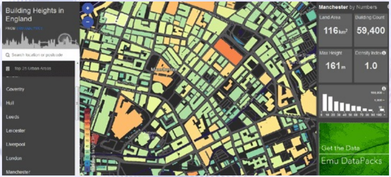
Single-edge methods do not work

Those methods are not applicable since the low diffraction angle implies that a large number of obstructions (i.e.; rooftops) affect the first Fresnel zone.

This implies that the full multiple edge diffraction integral must be solved.

Multiple diffraction over building rooftops

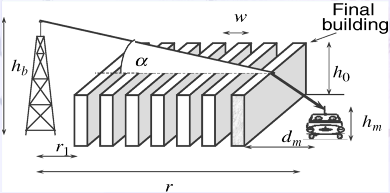
Solving the multiple edge diffraction integral problem is a very time consuming procedure that needs detailed information on buildings heights and positions.



- Special methods have been developed to enable reasonably effective calculations.
- They are typically used when accurate results are needed.

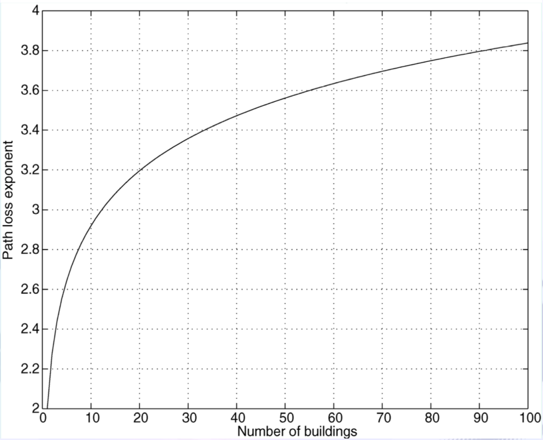
The flat edge model

All the buildings are assumed equally spaced and of equal height



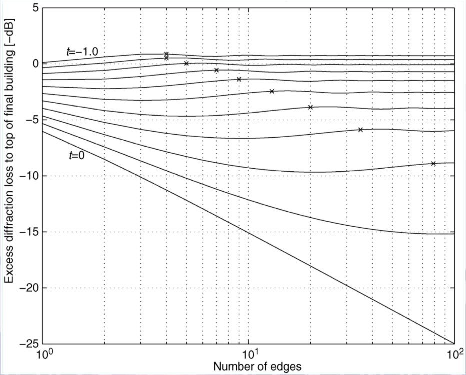
- $L_{ex} = L_{n-1}(t) + L_{ke}$
- To evaluate L_{n-1} multiple diffraction integral is solved and a closed-form solution is found.
- t depends on the TX elevation angle α, the spacing and the wavelength.
- The approach can be used even when a large number of buildings

The flat edge model - path loss exponent



There is a good matching to what experimentally measured. Hence, multiple building diffraction is the driver to the variation of path loss with range in macrocell

The flat edge model - L_{ex} to the top of the last building



When $h_b > h_o$, i.e.; $t < 0$, the field achieves a constant value as the number of buildings increases. There are enough edges to fill the 1st Fresnel zone from the TX to the last building.

Semi-empirical models

They combine the analytical formulation of physical phenomena, e.g.; reflection, transmission and diffraction or scattering, with a statistical fitting by variable adjustment using experimental measurements.

- Those methods are more robust than purely empirical ones.
- The statistical optimization relies on linear regression techniques or more sophisticated approaches based on neural networks.

The most employed semi-empirical method

The COST 231/Walfisch-Igekami model combines: the flat edge model, Igekami model to predict diffraction down to street-level and empirical correction factors to fit actual measurements.