Mobile Radio Propagation

Lecture 2

Lecturer Madeeha Owais
Acknowledgements

• The content for these slides have been taken from Wireless Communication by Rappaport and Antennas and Propagation for Wireless Communication Systems by Simon R. Saunders.

• I am thankful to the authors for making the figures/support material easily accessible.

• I have typed in all the text and equations myself. I have tried my level best to avoid any typographical errors. However, in case you find and errors in the text or the equations please do let me know.
Types of Propagation Models

• **Empirical Model**: Based only on data and is used to predict, not explain, a system. An empirical model consists of a function that captures the trend of the data.

• Sometimes it is difficult or impossible to develop a mathematical model that explains a situation. However, if data exists, we can often use this data as the sole basis for an **empirical model**. The empirical model consists of a function that fits the data.
Types of Propagation Models

• Physical Model:

• Physical modelling refers to the design and implementation of systems that are based on or derived from physical phenomena.

• A physical model may be developed from a rigorous mathematical analysis of a system, whereby mathematical expressions are derived, discretized, and then implemented with signal processing techniques.
Propagation Models for Macrocells

- This portion of slides have been made from Rappaport Book page 150-154
Propagation Models for Macrocells

- Radio transmission in a macrocells takes place over irregular terrain
- Terrain profile of area needs to be taken into account for estimating path loss
- Important parameter for macrocell designer is overall area covered, rather than specific field strength at particular locations
Okumura Model

- Most widely used models for signal prediction in urban areas
- Applicable for:
  - Frequencies in the range 150MHz to 1920MHz
  - Distance Range of 1 km to 100km
  - Base station antenna heights from 30m to 1000m
- Provides a set of curves based on extensive measurements
Okumura Model

Urban Area

\( h_t = 200 \text{ m} \)
\( h_r = 3 \text{ m} \)

Median Attenuation, \( A(f, d) \) (dB)

Frequency \( f \) (MHz)

Distance \( d \) (km)
Okumura Model

Terrain related parameters

- Terrain undulation height ($\Delta h$)
- Isolated ridge height
- Average slope of terrain
- Mixed land-sea parameter

Correction factor, $G_{\text{AREA}}$, for different types of terrain [from [O].]
Okumura Model

- **Finding Path loss using Okumura Model**
  - Find free space loss between two points of interest
  - Value of median attenuation, $A_{\mu}(f,d)$ is added
  - Correction factor to account for the type of terrain is applied

\[
L_{50}(dB) = L_F + A_{\mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{\text{AREA}}
\]

- **where**
  - $L_{50}$ is 50\textsuperscript{th} percentile (median) value of propagation path loss
  - $L_F$ is free space propagation loss
  - $A_{\mu}(f,d)$ is median attenuation relative to free space
  - $G(h_{te})$ is base station antenna height gain factor
  - $G(h_{re})$ is mobile antenna height gain factor
  - $G_{\text{AREA}}$ is the gain due to type of environment
Okumura Model

\[ G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) \]

\[ 1000m > h_{te} > 30m \]

\[ G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right) \]

\[ h_{te} < 3m \]

\[ G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) \]

\[ 10m > h_{re} > 3m \]
Okumura Model

Solve Example 4.10 of your book
Okumura Model

• Okumura’s model is wholly based on measured data and does not provide analytical explanation
• Okumura model considered among simplest and best in accuracy in path loss prediction for mature cellular systems in cluttered environment
• Major disadvantage is its slow response to rapid changes in terrain
• Fairly good in urban and suburban areas and not rural areas
Okumura Model

• Run MATLAB file.....!
Hata Model

• Empirical formulation of Okumura graphical path loss curves by Hata
• Valid from 150 MHz to 1500MHz
• Transmitter antenna height range is from 30 m to 200m
• Receiver antenna height range is from 1m to 10m
• Standard formula provides urban area propagation loss and corrections are applied for other area

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

• where
  • \( f_c \) is the frequency in MHz
  • \( h_{te} \) is base station antenna height
  • \( h_{re} \) is mobile antenna height
  • \( d \) is T-R separation in km
  • \( a(h_{re}) \) is the correction factor for effective mobile antenna height
Hata Model

- For a small to medium sized city, the correction factor is

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

- For a large city

\[
a(h_{re}) = 8.29(\log 1.54 h_{re})^2 - 1.1 dB \quad f_c \leq 300MHz
\]

\[
a(h_{re}) = 3.2(\log 11.75 h_{re})^2 - 4.97 dB \quad f_c \geq 300MHz
\]
Hata Model

- As seen before the standard formula, For Urban Areas

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

- For Suburban Areas

\[ L_{50}(dB) = L_{50}(urban) - 2 \left[ \log \left( \frac{f_c}{28} \right) \right]^2 - 5.4 \]

- For Open/Rural Areas

\[ L_{50}(dB) = L_{50}(urban) - 4.78 \left( \log f_c \right)^2 + 18.22 \log f_c - 40.94 \]
Hata Model

- The predictions of Hata Model compare closely with original Okumura model, as long as $d$ exceeds 1km
- Model well suited for large cell mobile systems
- Not suitable for PCS (personal communication systems) which have cells on order of 1km radius
COST-231 Model

- Run MATLAB file.....!
PCS Extension to Hata Model (COST-231)

- EURO-COST formed a working committee to develop extended version of the HATA model
- COST-231 proposed following formula to extend Hata’s model to 2 GHz

\[ L_{50}(dB) = 46.3 + 33.9 \log f_c - 13.82 \log h_t e - a(h_{re}) + \left( 44.9 - 6.55 \log h_t e \right) \log d + C_M \]

- where \( a(h_{re}) \) is same as described in previous slides

- \( C_M = 0 dB \) For medium sized city and suburban areas
- \( C_M = 3 dB \) For metropolitan centers
PCS Extension to Hata Model (COST-231)

- COST-231 extension of Hata Model is restricted to following range parameter
  - $f_c$ : 1500 MHz to 2000 MHz
  - $h_{te}$ : 30m to 200m
  - $h_{re}$ : 1m to 10m
  - $d$ : 1km to 20km
COST-231 Model

• Run MATLAB file..... !
Conclusion

• Propagation path loss modelling is fundamental method of predicting the range of a mobile radio system
• Accuracy of path loss predictions is crucial in determining whether a particular system design will be viable
• In macrocells, empirical models have been used great success, but deterministic physical models are being increasingly investigated to improve accuracy. However this accuracy comes at expense of increased input data requirements and computational complexity
• Another generation of models is expected to appear which combine sound physical principles with statistical parameters, to provide optimum balance between accuracy and complexity
Prediction Tools for Mobile Propagation

C.1 INTRODUCTION

This appendix consists of a list of software packages known to be useful for mobile radio propagation prediction, together with notes concerning the origins and contents. Lists such as this one become out of date as soon as they are created. I would therefore be grateful to receive any comments or suggestions for additions and I apologise for any inaccurate or misleading information. Note that all details of algorithms have been found in the open literature.

Since these packages are concerned essentially with creating and manipulating geographically referenced information, there is a general tendency for such prediction tools to become part of wider geographical information systems (GIS). This enables them to be used for wider application within the cellular planning process, including frequency management, traffic prediction, population density, etc. These aspects have not been specifically considered in this list, but result in the propagation-related aspects of some of these packages being a minor part of their total functionality.

C.2 TABLE OF PREDICTION TOOLS

<table>
<thead>
<tr>
<th>Package</th>
<th>Originator</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VGIS / PACE2</td>
<td>Vodafone</td>
<td>1</td>
</tr>
<tr>
<td>Axis</td>
<td>Contactica</td>
<td>2</td>
</tr>
<tr>
<td>Tadiplan</td>
<td>Tadiran</td>
<td>3</td>
</tr>
<tr>
<td>ASTRIX</td>
<td>Teleplan AS</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>SINTEF Telecom &amp; Informatics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NetCom GSM</td>
<td></td>
</tr>
<tr>
<td>ICS Telecom</td>
<td>ATDI Ltd (Advanced Topographic</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Development and Images</td>
<td></td>
</tr>
<tr>
<td>CellOpt &amp; AFP</td>
<td>ComOpt AB</td>
<td>6</td>
</tr>
<tr>
<td>PathPro</td>
<td>MLJ Software</td>
<td>7</td>
</tr>
<tr>
<td>GRANET</td>
<td>GTE Laboratories</td>
<td>8</td>
</tr>
<tr>
<td>QEDesign</td>
<td>QUALCOMM Incorporated</td>
<td>9</td>
</tr>
<tr>
<td>CellPlanner &amp; CelTec</td>
<td>CellPlan Technologies Inc.</td>
<td>10</td>
</tr>
<tr>
<td>CRUMPET</td>
<td>DERA</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Science Systems (Industrial) Ltd</td>
<td></td>
</tr>
<tr>
<td>Package</td>
<td>Originator</td>
<td>Notes</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>WiSE</td>
<td>Lucent</td>
<td>12</td>
</tr>
<tr>
<td>Golf</td>
<td>LCC</td>
<td></td>
</tr>
<tr>
<td>NPS/i</td>
<td>Nokia</td>
<td>13</td>
</tr>
<tr>
<td>NPS/X</td>
<td>Nokia</td>
<td>14</td>
</tr>
<tr>
<td>Quantum</td>
<td>Quotient Communications Ltd</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Laser-Scan Ltd</td>
<td></td>
</tr>
<tr>
<td>CellCAD</td>
<td>LCC International Inc.</td>
<td></td>
</tr>
<tr>
<td>Wizard</td>
<td>SAFCO / TEC Cellular</td>
<td></td>
</tr>
<tr>
<td>Planet</td>
<td>Mobile Systems International (MSI)</td>
<td>16</td>
</tr>
<tr>
<td>ASSET</td>
<td>AirCom International</td>
<td></td>
</tr>
<tr>
<td>NetPlan</td>
<td>Motorola</td>
<td>17</td>
</tr>
<tr>
<td>Romulus and Spectrus</td>
<td>RCC Consultants Ltd (no info)</td>
<td></td>
</tr>
<tr>
<td>NP WorkPlace</td>
<td>Multiple Access Communications Ltd</td>
<td>18</td>
</tr>
<tr>
<td>DESIRE</td>
<td>Multiple Access Communications Ltd</td>
<td>19</td>
</tr>
<tr>
<td>Optair</td>
<td>Simoco Ltd</td>
<td></td>
</tr>
<tr>
<td>Aspect</td>
<td>National Transcommunications Ltd</td>
<td></td>
</tr>
<tr>
<td>ARTEMIS</td>
<td>Freshfield Communications Ltd</td>
<td></td>
</tr>
<tr>
<td>Odyssey</td>
<td>Aethos Ltd</td>
<td>20</td>
</tr>
<tr>
<td>Ericsson</td>
<td>TEMS CellPlanner</td>
<td></td>
</tr>
<tr>
<td>Decibel Planner</td>
<td>Northwood Geoscience</td>
<td>21</td>
</tr>
<tr>
<td>SignalPro</td>
<td>EDX</td>
<td>22</td>
</tr>
</tbody>
</table>

C.3 **NOTES**


2. Believed to have been developed by Cambridge Consultants.

3. Not strictly a mobile tool, as it is specific to a particular wireless local loop system.


5. ICS Telecom is a radio network planning and database management tool for all modern radio systems in the frequency range 30 MHz to 60 GHz. The tool performs automatic frequency assignment and calculates radio coverage based on map information that can have a resolution down to 1
metre in 2-D and 3-D. The software has a choice of propagation and
diffraction models and can also take account of earth curvature and rain
attenuation. Path loss and diffraction models: Fresnel, Okumura-Hata, UIT-
RP.370, Lambertian reflections, Deygout.
6. CellOpt includes the implications of multilayering, underlaid and overlaid,
multiple reuse patterns and hopping.
7. PathPro propagation models: geometric theory of diffraction (GTD),
COST231 microcell, COST231 macrocell, Hata, ITM (Longley–Rice
irregular terrain model).
8. Not being sold outside GTE. Consists of custom-tuned empirical models,
including enhanced Okumura–Hata at 900 MHz and enhanced COST231-
Hata at 1800 MHz.
9. QEDesign is specifically for the development of CDMA wireless systems.
10. CelPlanner propagation models: Lee–Picquenard, Okumura–Hata,
COST231, Korowajczuk, a microcell model and the ability to integrate a
user-defined model.
11. CRUMPET stands for Commercial Radio Utilisation Management
Planning and Engineering Tool and was produced by DERA for the armed
forces in collaboration with the University of York. CRUMPET predicts
the optimum location for either a single transmitter or a point-to-point link
within a given area. Propagation model: UK Army EMC Agency RP03.
12. Specifically intended for the design of indoor systems.
13. For indoor systems.
14. For macrocell systems.
15. Based on the Gothic geographical information system (GIS).
16. Planet supports mixed macrocells and microcells. Propagation models:
Okumura–Hata, Walfisch–Ikegami and the ability to integrate a user-
defined model.
17. Netplan uses the Xlos ray-tracing propagation model together with
COST231–Hata, Walfisch–Ikegami and Walfisch–Xia microcell models
can also be used.
18. For microcells. See S. Dehghan and R. Steele, Small cell city, *IEEE
19. For picocells.
20. For private mobile radio systems.
21. See www.ericsson.nl/BR/RQIS/cellplanner/
22. See www.northwoodgeo.com/decibel.htm
23. See www.edx.com
Propagation Models for Microcells

• This portion of slides have been made from Simon Saunders Book
• I have put all related material on the slides to help eliminate the need to read from book
• I think the slides should suffice however you can get chapter photocopied from me if you face any problem
Propagation Models for Microcells

• Smaller cells for increased capacity
• Base station height is typically about that as lamp posts in a street (3-6 m above ground level)
• Coverage is typically few hundred meters and is determined mostly by specific locations and electrical characteristics of surrounding buildings
• Dominant propagation mechanisms are:
  – Free space propagation + multiple reflection + scattering + diffraction around vertical edges of buildings and rooftops
Geometry
Dual Slope Empirical Model

• To model path loss in microcells, empirical models can be used
• Measurements indicate that simple power loss model cannot fit measurements with good accuracy
• A better empirical model is dual slope model
Dual-slope Empirical Models

- Two regimes of propagation for better agreement with measurements
- Typically $n_1 \approx 2$, $n_2 \approx 4$, $r_b = 200-500\, \text{m}$
Dual Slope Empirical Model

- Two separate path loss exponents are used to characterise the propagation, together with a breakpoint distance of a few hundred meters between them where propagation changes from one regime to other.

\[
L = \begin{cases} 
10n_1 \log r + L_1 & \text{for } r \leq r_b \\
10n_2 \log \frac{r}{r_b} + 10n_1 \log r_b + L_1 & \text{for } r > r_b 
\end{cases} \quad [\text{dB}]
\]

- where \( L_1 \) is the reference path loss at \( r=1\text{m} \),
- \( r_b \) is breakpoint distance,
- \( n_1 \) the path loss exponent for \( r \leq r_b \)
- \( n_2 \) the path loss exponent for \( r > r_b \)

Simple, but discontinuous at the breakpoint distance.
Dual-slope Empirical Models

- Two regimes of propagation for better agreement with measurements
- Typically $n_1 \approx 2$, $n_2 \approx 4$, $r_b = 200-500\text{m}$
Dual Slope Empirical Model

Continuous approach

\[ L = L_1 + 10n_1 \log r + 10(n_2 - n_1) \log \left(1 + \frac{r}{r_b}\right) \]  

[dB]

- \( n_1 \) = the path loss exponent for short distances
- \( n_2 \) = the path loss exponent for larger distance
Dual Slope Empirical Model

• Typical values for path loss exponents are found by measurements to be $n_1=2$ and $n_2=4$, with breakpoint distances of 200-500m

• But, it should be emphasized that these values vary greatly between individual measurements
Physical Models

• In creating physical models for microcell propagation, it is useful to distinguish two situations:
  – Line-of-sight (LOS)
  – Non-line-of-sight (NLOS)
• For LOS case, it is possible to make some reasonable generalizations
• NLOS case requires more site specific information
Practical Measurement Example

Routes A, B, and C are radial streets, often with a line of sight present.

Route D is a traverse street with most locations obstructed.

Let's see path loss profile!!!
Practical Measurement Example

Route D measurements vary over almost 45dB, despite range being almost constant at around 30m.

- High variability between routes at a given distance (see route D)
- Need to account for physical effects for greater accuracy
Practical Measurement Example

Obstructed path suffers far greater variability at a given range than others. Such effects must be accounted for explicitly in models!!!

- High variability between routes at a given distance (see route D)
- Need to account for physical effects for greater accuracy

Route D measurements vary over almost 45dB, despite range being almost constant at around 30m
Line of Sight Models

Street Canyon Models

- Extend two ray model to four, six or more rays
Non-Line-of-Sight Models

• Possible Mechanisms
Non-Line-of-Sight Models

- Diffraction-dominated case

Base station

Shadow Boundary

Mobile
Non-Line-of-Sight Models

- Reflection-dominated case
Non-Line-of-Sight Models

Rooftop Diffraction

- Key mechanism for interference situations
Non-Line-of-Sight Models

- A, B strong paths, dominated by diffraction or reflection
- C involves multiple reflection so weak relative to D
Non-Line-of-Sight Models

Cell Shape

- Greater path loss across streets (diffraction) compared to along streets (reflection)

Equal path loss contours
Recursive Model

- Find illusory distance

\[ k_j = k_{j-1} + d_{j-1} \times q(\theta_{j-1}) \]

\[ d_j = k_j \times r_{j-1} + d_{j-1} \]

\[ k_0 = 1 \quad d_0 = 0 \]

- Distance increases with turning angle

\[ q(\theta_j) = \left( \frac{\theta_j q_{90}}{90} \right)^v \]

where \( q_{90} = 0.5 \) and \( v = 1.5 \)
Recursive Model

• Path loss has dual slope behaviour

\[ L = 20 \log \left( \frac{4\pi d^n}{\lambda} D \left( \sum_{j=1}^{n} r_{j-1} \right) \right) \]

\[ D (r) = \begin{cases} 
\frac{r}{r_b} & r > r_b \\
1 & r \leq r_b 
\end{cases} \]
Recursive Model

- This model is intermediate between an empirical model and a physical model.
- Effective sources are introduced for non-line-of-sight propagation at the street intersection where diffraction and reflection points are likely to occur.
- The model breaks down the path between the base station and the mobile into a number of segments interconnected by nodes.
- The nodes may be placed either just at the street intersections or else at regular intervals along the path, allowing streets which are not linear to be handled as a set of piecewise linear segments.
Recursive Model

- An **illusory distance** for each ray path considered is calculated according to recursive expressions

\[
\begin{align*}
    d_j &= k_j \times r_{j-1} + d_{j-1} \\
    k_j &= k_{j-1} + d_{j-1} \times q(\theta_{j-1}) \\
    k_0 &= 1 \quad d_0 = 0
\end{align*}
\]

- where \(d_n\) is the illusory distance calculated for the number of \(n\) of straight segments along the ray path (in above slides we saw example of \(n=3\)) and \(r_j\) is the **physical distance** [m] for the line segment following the jth node.

- The angle through which the path turns at node \(j\) is \(\theta_j\) [degrees]
Recursive Model

- As this angle increases, the illusory distance is increased according to
  \[ q(\theta_j) = \left( \frac{0.5\theta_j}{90} \right)^{1.5} \]

- Path loss is calculated as
  \[ L = 20\log\left[ \frac{4\pi d^n}{\lambda} D \left( \sum_{j=1}^{n} r_{j-1} \right) \right] \]
  \[ D(r) = \begin{cases} 
    r/r_b & \text{for } r > r_b \\
    1 & \text{for } r \leq r_b 
  \end{cases} \]

- The equation of path loss creates a dual slope behaviour with a path loss exponent of 2 for distances less than the breakpoint \( r_b \) and 4 for greater distances.
Recursive Model

• The overall model is simple to apply and accounts for the key microcell propagation effects, namely dual slope path loss exponents and street corner attenuation with an angle dependence which incorporates effects encountered with real street layouts.
Site-specific Ray Model

- GTD/UTD based
- Complex in terms of input data, computation time
Conclusion

• Propagation in microcells can be modelled using either empirical or physical models
• In either case, the clutter surrounding the base station has a significant impact on the cell shape and this must be accounted for to avoid serious prediction errors
• A simple path loss exponent model is inadequate and a dual behaviour must be accounted for
Next Class (Tomorrow) Agenda

- Will cover Pico cells (indoor) propagation models
- Will solve some numericals from propagation mechanism part
- Quiz shall be taken from today’s lecture