A Simplified Analytical Urban Propagation Model (UPM) For Use in CJSMPT

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Urban Propagation Model

- Need for a fast Urban Propagation Model (UPM) appropriate for the interference and de-confliction analysis in Coalition Joint Spectrum Management Tool (CJSMPT)
  - Capability to address mobile-to-mobile applications
  - Capability to use data as input parameters for the UPM that represents the actual urban environment under analysis
  - Minimal computational time and complexity
- No commercially available urban propagation models have such capabilities
- This work was a product of collaboration with Penn State University

Shortcomings of Current Urban Propagation Models

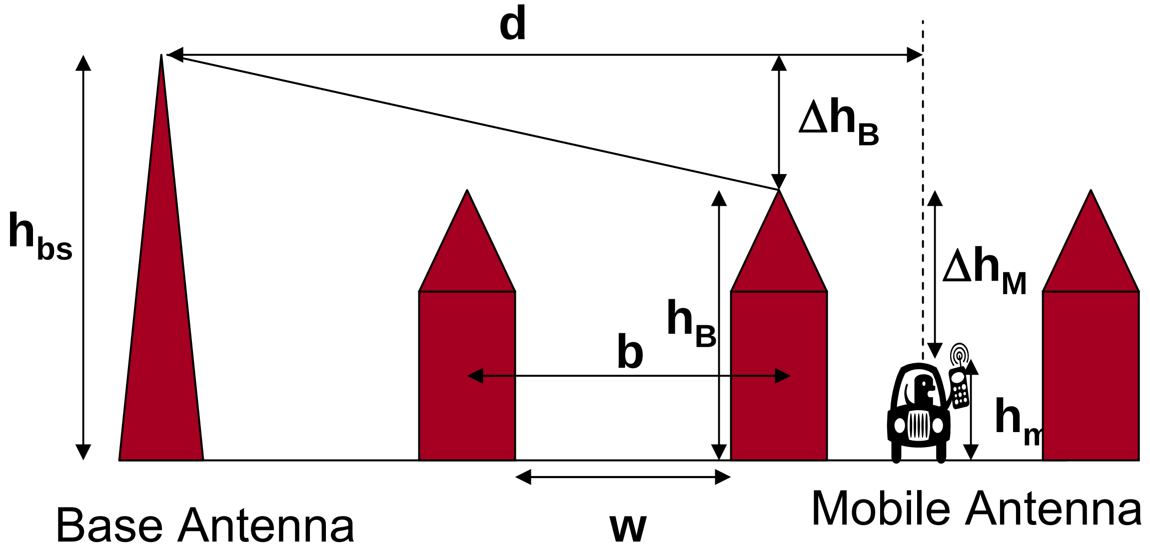
- Most of the existing urban propagation models are designed for cellular applications
  - Base antennas much higher than rooftops
    - » Okumura-Hata (Empirical), Walfisch-Ikegami (Semi-Empirical)
  - Not applicable for antennas lower than rooftops (mobile to mobile case)
- Urban propagation is primarily influenced by urban parameters such as building heights and road widths
  - Different from city to city
  - Actual data is not easily accessible

Challenges for Urban Propagation Model (UPM)

- Create a model that is valid for all heights of base antenna relative to rooftop level
  - From low-high antennas (mobile) to very high antennas (cellular)
  - Implement the software code with minimal computational time and complexity
- Use of actual data that represents the environment under study

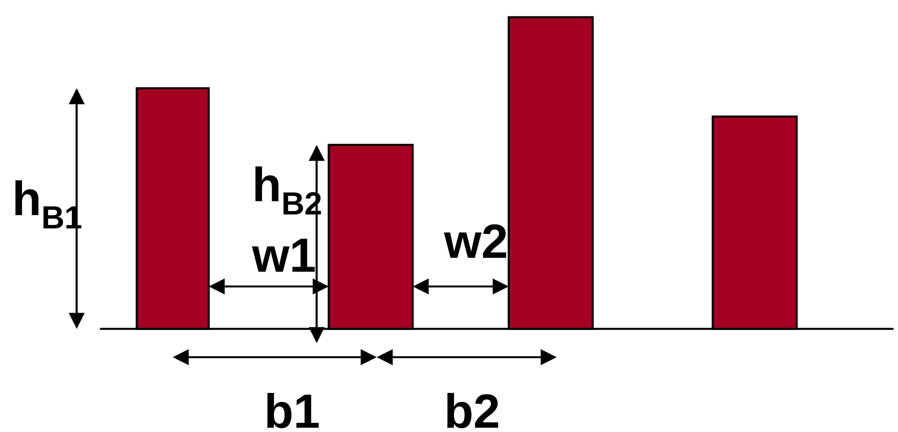
Input Parameters for UPM

- UPM requires input parameters such as
  - Frequency, transmitter and receiver antenna heights provided from CJSMPT SKR database
  - Average values of building height, building separation, and road width
    - » Extracted from Urban Technical Planner (UTP) from US Army Topographical Engineering Center (TEC) that provides data in shapefiles of key aspects of the urban environment

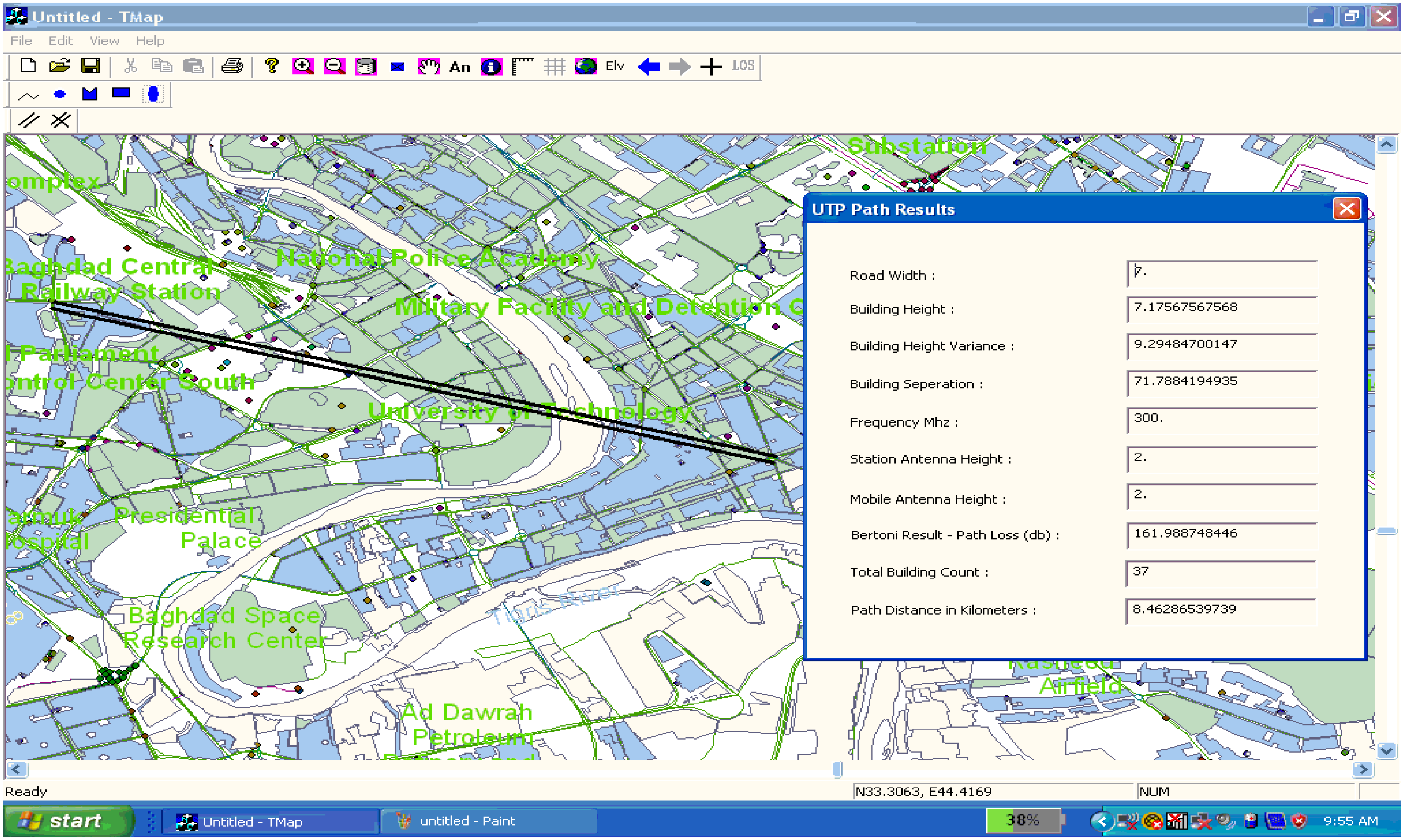


Methodology for Use of UTP data in UPM

- A Windows Dynamic Link Library (DLL) is developed in “C” to extract the required data from US Army TEC UTP database for use as primary input parameters for the UPM
- For a given path, described as two WGS-1984 geodetic points, determines appropriate data from the UTP products and computes and returns the UPM primary input parameters for the given path
  - Average height of building roofs (meters), average building separation (meters), average road width (meters) and path distance (meters)



Input UTP data into UPM Model



Urban Propagation Model (UPM) Approach

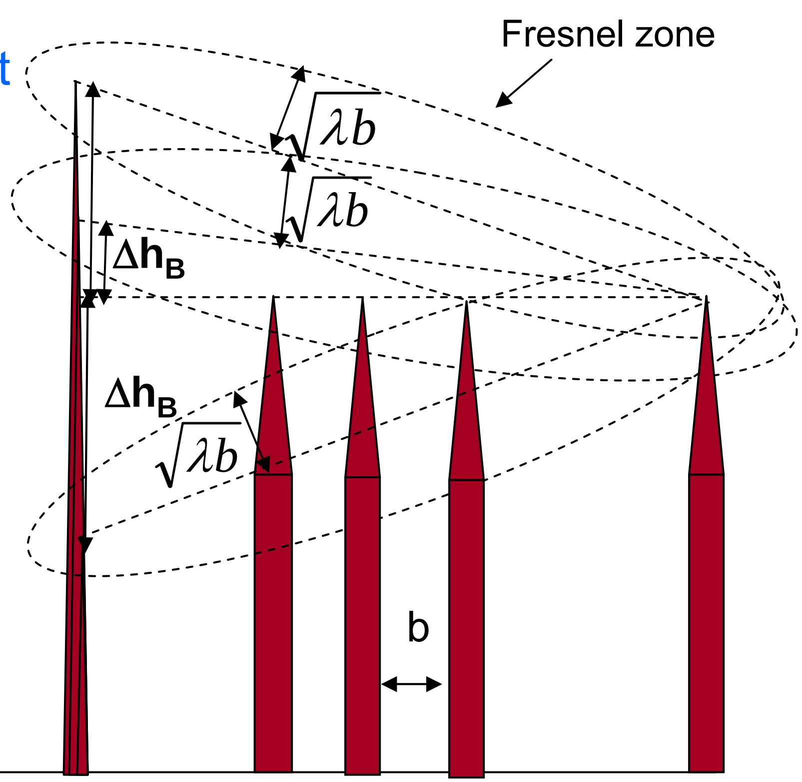
- UPM is based on Bertoni's book, *Radio Propagation for Modern Wireless Systems*
  - Theoretical approach to determine path loss in urban environments
  - Analysis for mobile-to-mobile applications
- Dominant propagation path occurs over rooftops
- Propagation mechanisms that contribute to the path loss
  - Free space path loss (PG_0)
  - Reduction in fields due to multiple diffractions of passed rows of buildings (PG_1)
  - Reduction due to diffraction from rooftop fields to ground level (PG_2)

Analysis of Multiple Diffractions over Rooftops

- Three models are used to analyze diffractions over rooftops considering the first Fresnel zone about the ray from the antenna to the last building
- A criterion is used to determine the appropriate model, $g_c = \frac{\Delta h_B}{\sqrt{\lambda b}}$

  - $\sqrt{\lambda b}$ is the width at the first building of the Fresnel zone

- Antenna is above the rooftop level and the first rooftop is outside the Fresnel zone (g_c>1)
  - Simplifying formula is used
- Antenna is near the rooftop level and the first rooftop level is within the Fresnel zone ($|g_c|\leq1$)
  - Accurate but complex formula is adopted
- Antenna is below the rooftop level and the Fresnel zone is blocked by the first building (g_c>-1)
  - Simplifying formula is developed



Modeling PG_1 – Transmitter antennas near rooftops

- A complex formula is used to determine the field reduction factor

$$Q_M(g_c) = \sqrt{M}\left|\sum_{q=0}^{\infty}\frac{1}{q!}(2\sqrt{j\pi}g_c)^q I_{M-1,q}(2)\right|$$

- Where M is the number of the buildings

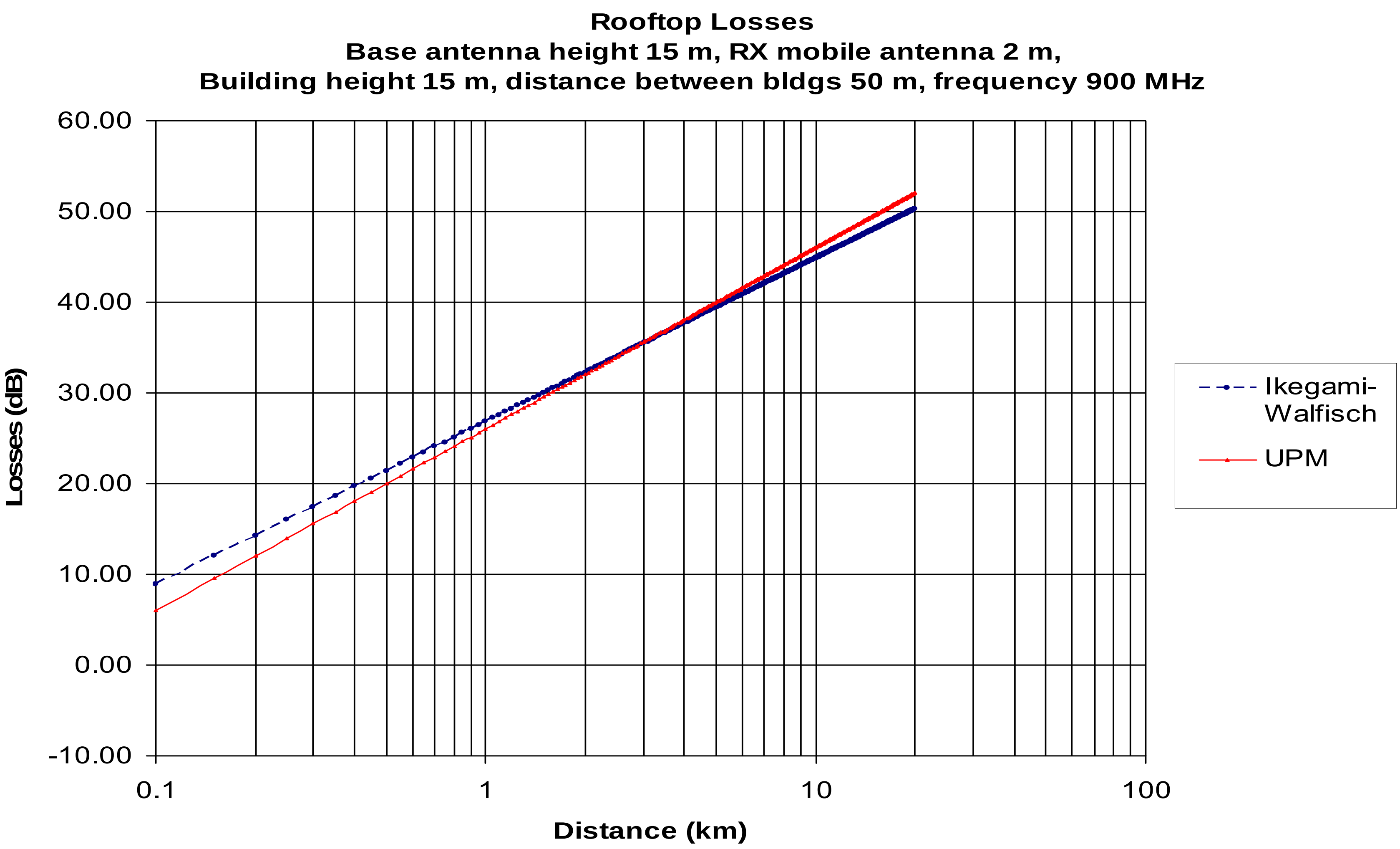
$$I_{M-1,q}(2) = \frac{(M-1)(q-1)}{2M} I_{M-1,q-2}(2) + \frac{1}{2\sqrt{\pi}M}\sum_{n=1}^{M-2}\frac{I_{n,q-1}(2)}{\sqrt{(M-1-n)}}$$

$$I_{M-1,0}(2) = \frac{1}{M^{3/2}}$$

$$I_{M-1,1}(2) = \frac{1}{4\pi}\sum_{n=1}^{M-1}\frac{1}{n^{3/2}(M-n)^{3/2}}$$

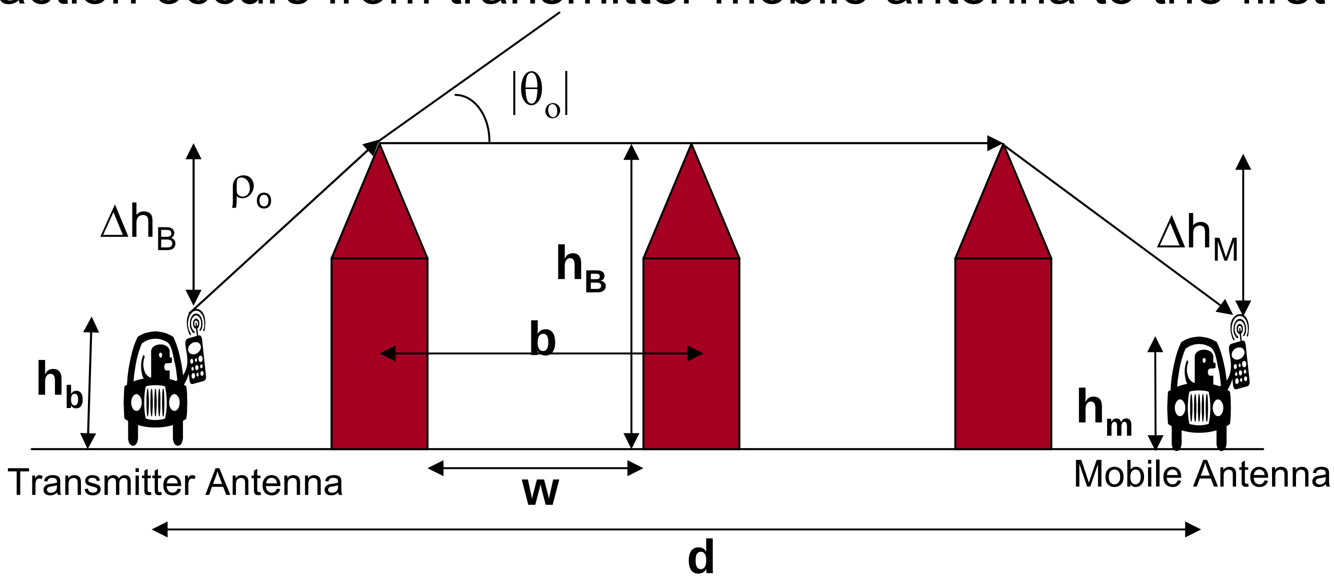
- Then $PG_1 = \left[Q_M(g_c)\right]^2$
- At rooftop, Q_M is 1/M

Diffraction losses, PG_1, for antenna at rooftop



Modeling PG_1 – Transmitter antenna well below rooftops

- Mobile-to-mobile scenario where both antennas are below rooftop levels
  - Diffraction occurs from transmitter mobile antenna to the first building



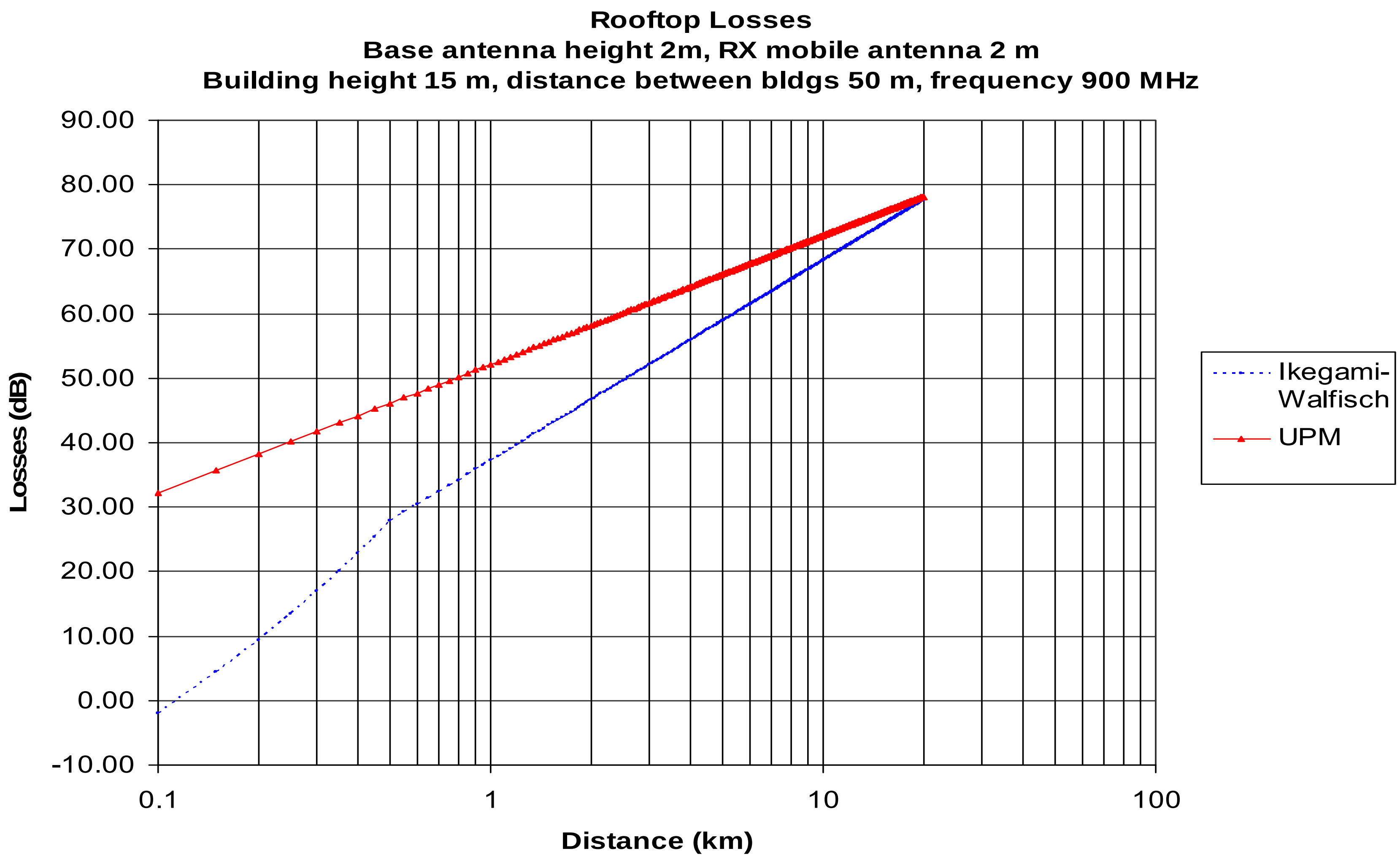
- A simplifying solution is realized by utilizing the field reduction at the rooftop

$$Q_e^{\,2} = \frac{1}{\rho_o}\left|D(\theta_o)\right|^2\left(\frac{1}{M-1}\right)$$

- Then

$$PG_2 = \left\lfloor 2Q_e^{\,2} \right\rfloor$$

Diffraction losses, PG_1, for mobile to mobile case



Modeling PG_1 – Transmitter antennas well above rooftops

- A simplifying formula is used to determine the field reduction factor
  - Utilized for cellular applications

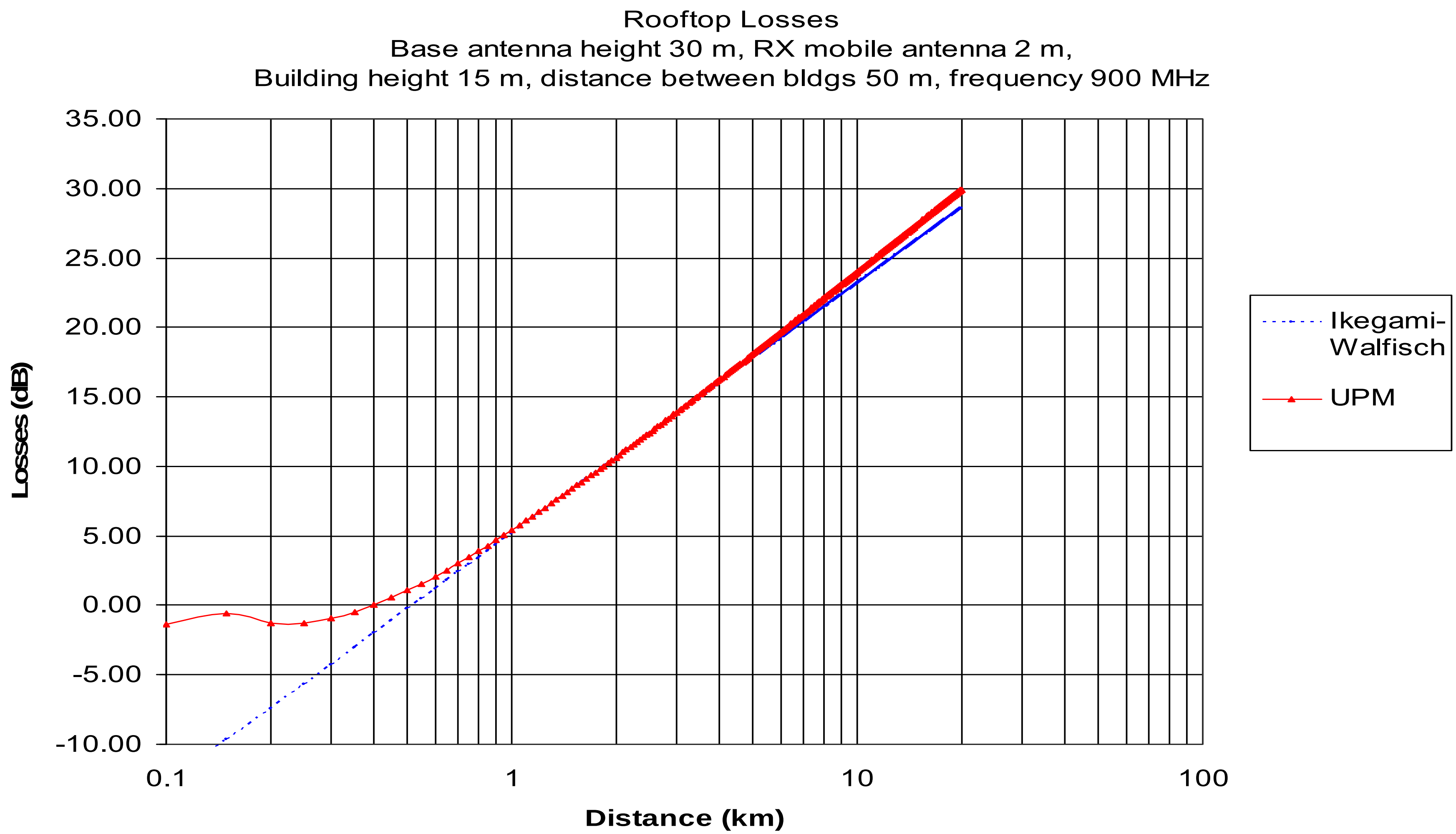
$$Q(g_p) = 3.502 g_p - 3.327 g_p{}^2 + 0.962 g_p{}^3$$

- Where α is the angle from the horizontal at which an incident plane wave propagates

$$g_p = \sin\alpha \sqrt{\frac{b}{\lambda}} \approx \frac{\Delta h_B}{d}\sqrt{\frac{b}{\lambda}}$$

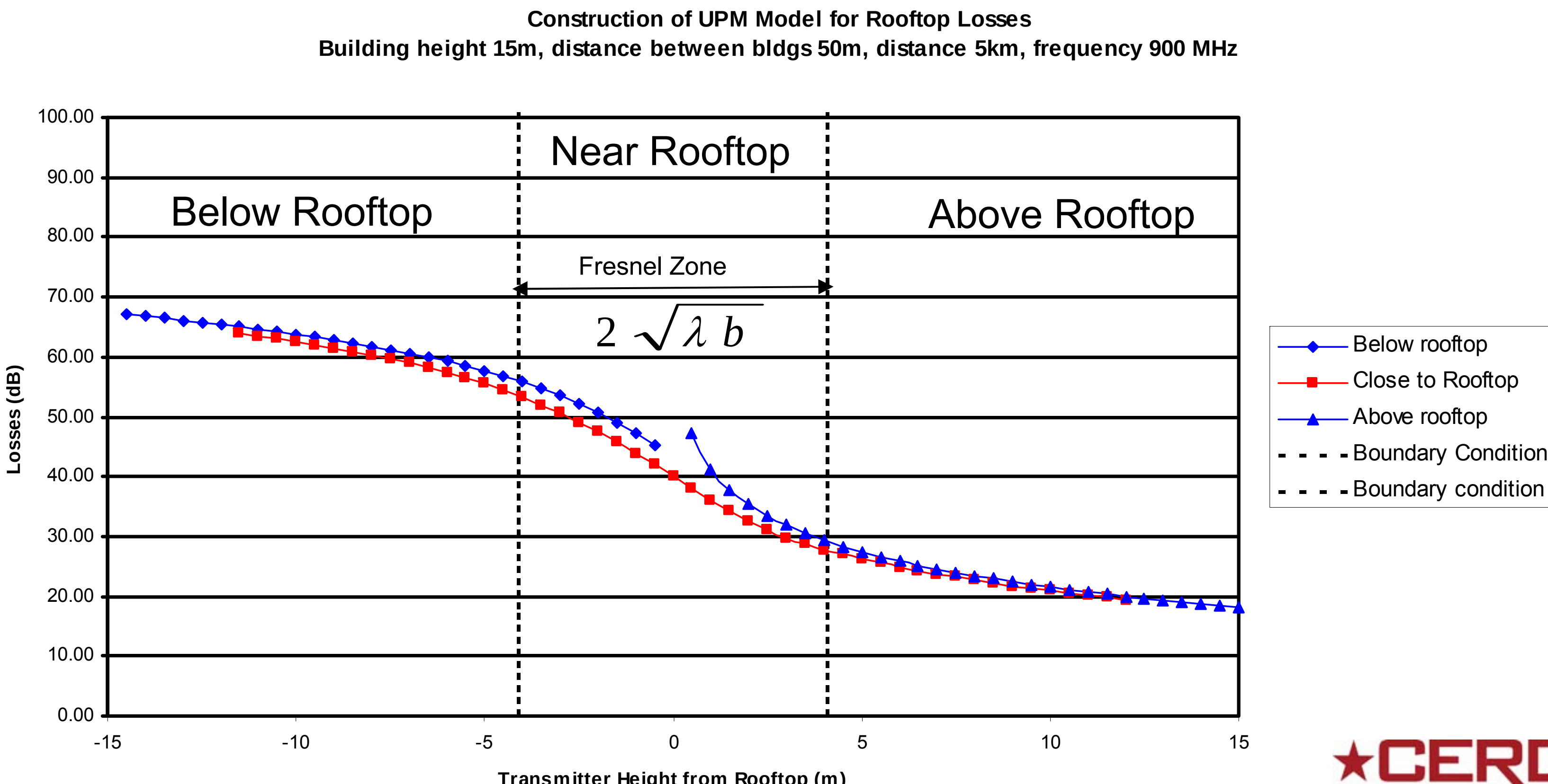
- Then $PG_1 = \left[Q(g_p)\right]^2$

Diffraction losses, PG_1, for antenna well above rooftop

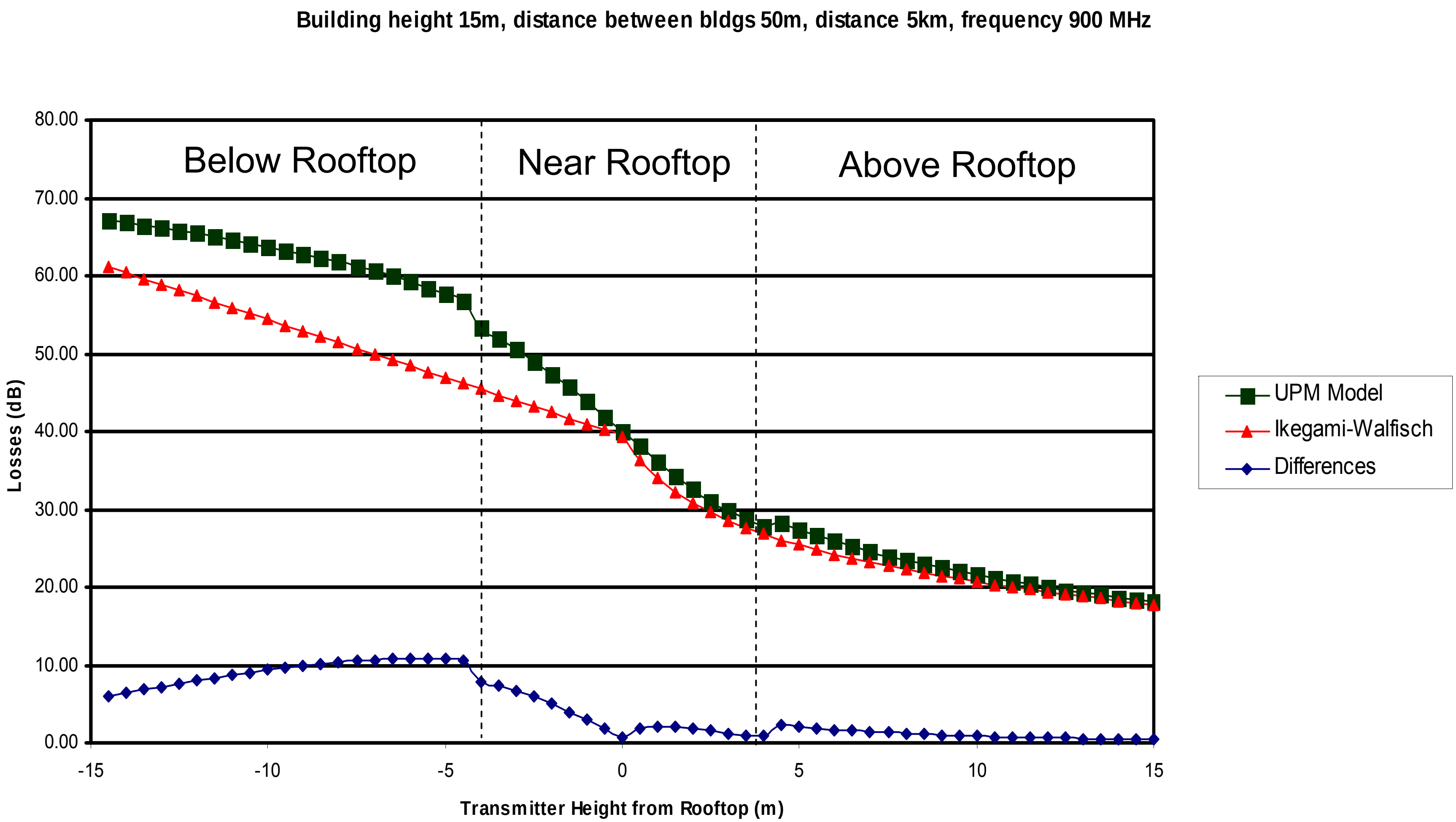


Validation of Multiple Diffraction Analysis in UPM

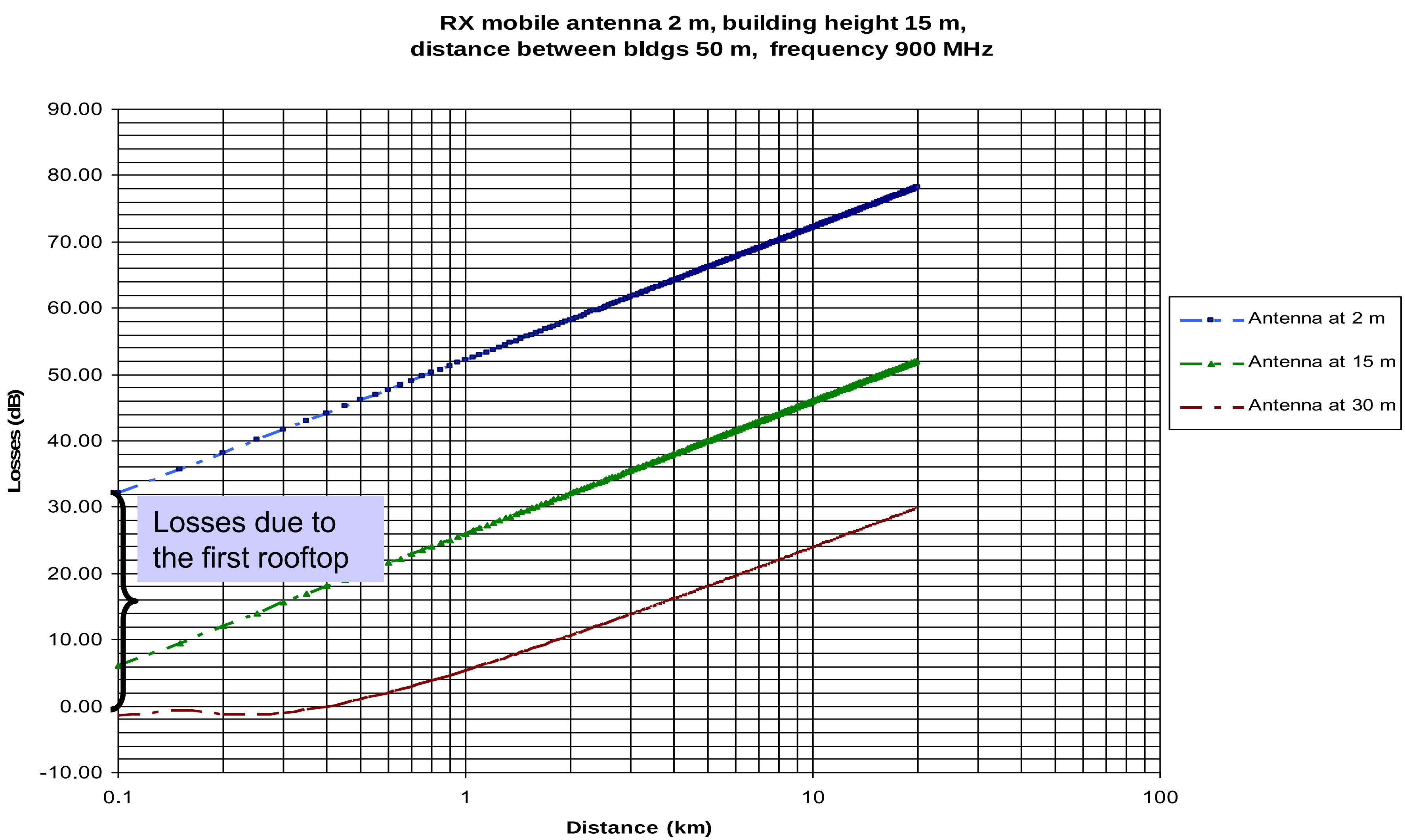
- Smooth transition from one model to another for the multiple diffraction analysis
  - Accurate but complex solution for antennas near the rooftop level
  - Simplifying antennas for well below and above the rooftop level



Comparison of UPM and Ikegami-Walfisch Rooftop Losses

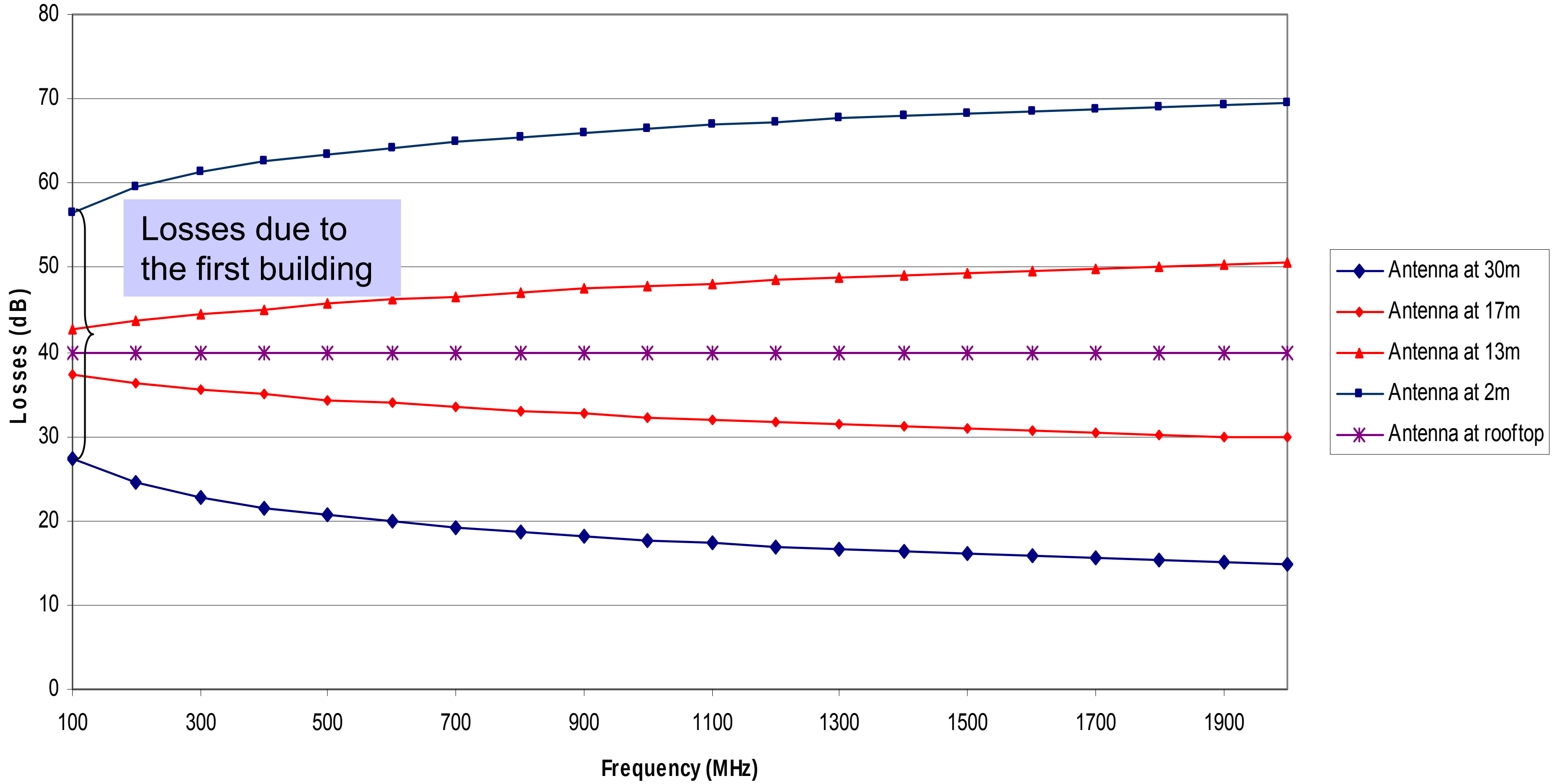


UPM Rooftop Losses vs distance



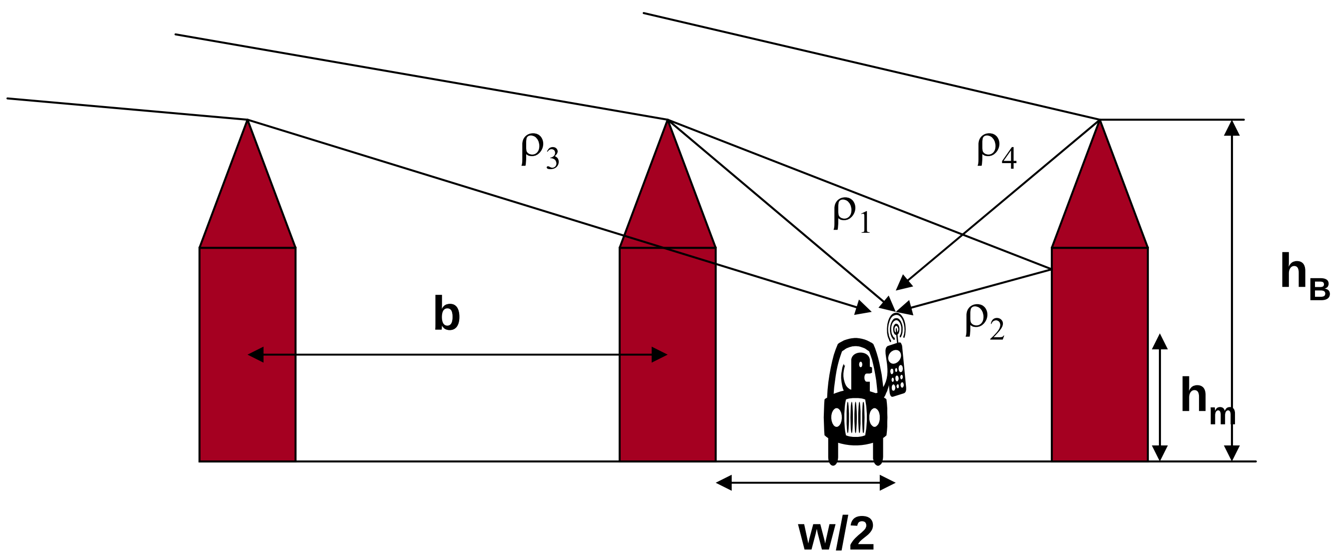
UPM Rooftop Losses vs frequency

RX mobile antenna 2 m, distance between antennas 5 km,
Building height 15 m, distance between bldgs 50 m

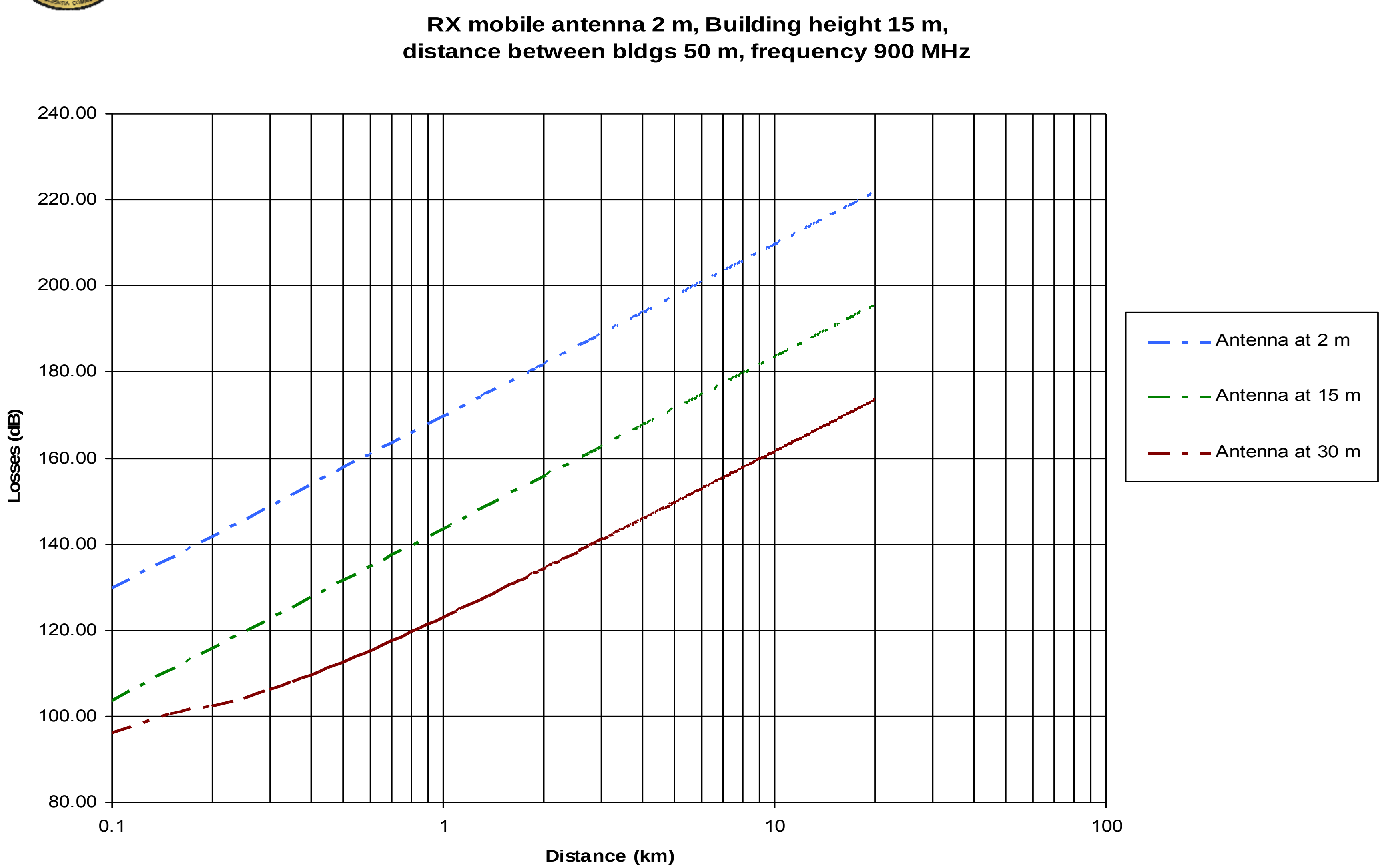


Diffraction of Rooftop Fields to Ground, PG_2

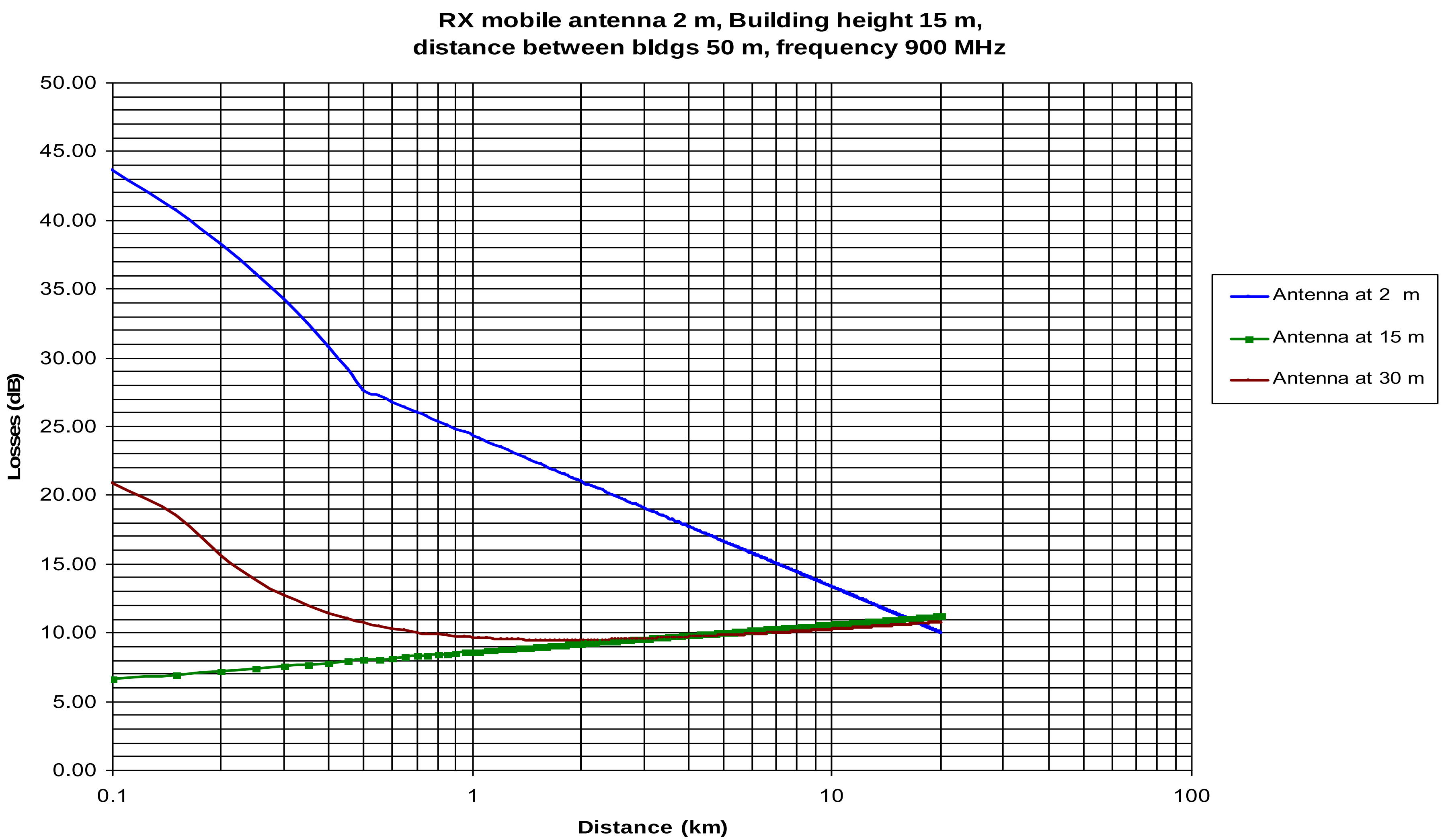
- Diffraction down to mobile antenna from buildings immediately near receiver
- Significant contributions are marked 1 – 4 in the illustration below
- Most significant contribution is from diffraction in front of receiver
- Walfisch-Ikegami and Bertoni models are similar for modeling PG_2



UPM Total Losses vs Distance



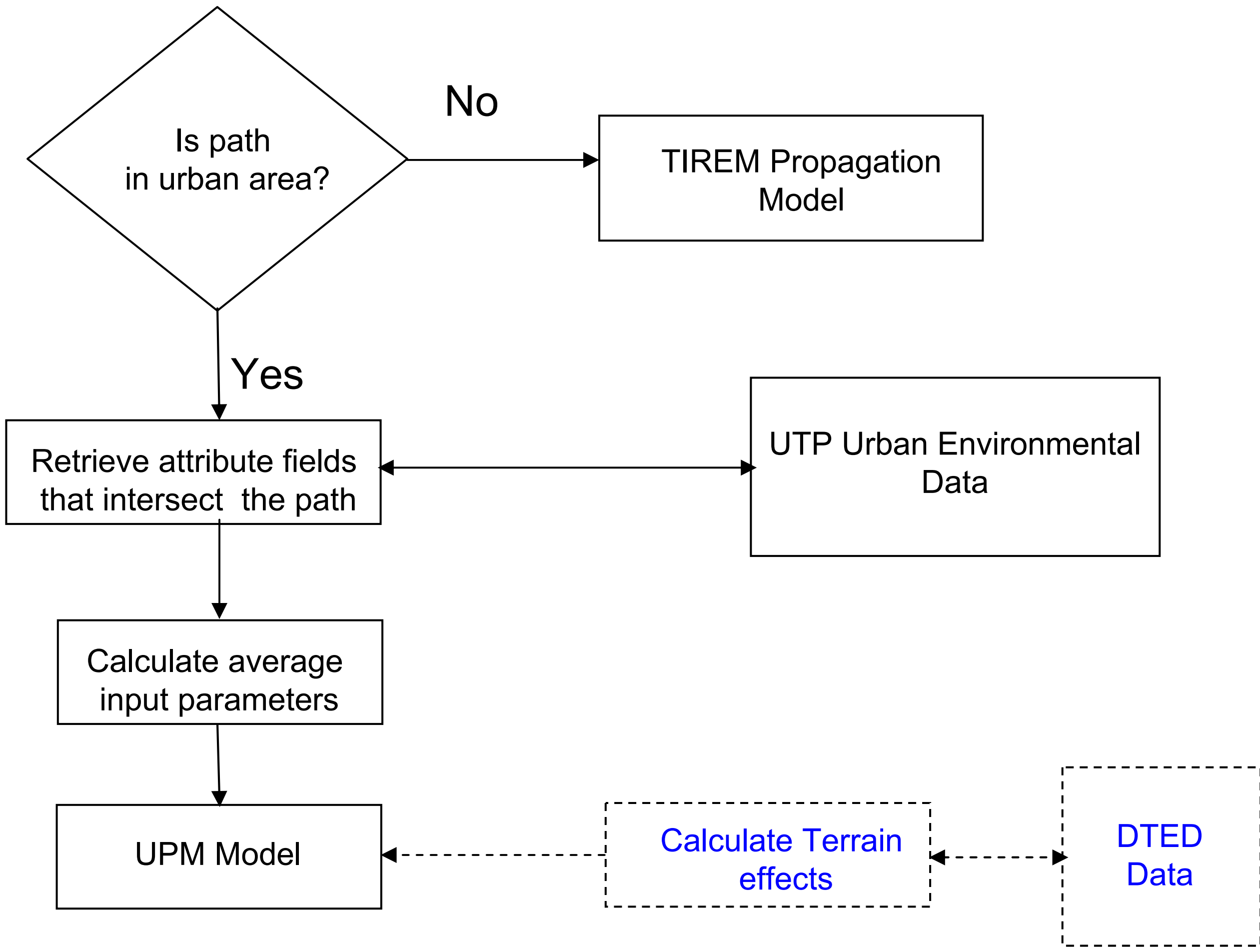
Total Losses Difference Between UPM and Ikegami-Walfisch



Methodology for Selecting the Propagation Model

- Software code for selecting automatically the optimal propagation model based on an input flag
  - UPM for urban environments and TIREM for rural environments
  - Differentiates mixed paths based on input flag
- Currently the UPM model is being integrated into CJSMPT under Phase II

Flowchart for Selecting the Propagation Model



Status - Terrain Effects in Urban Environments

- In collaboration with ACIN Drexel U., a code is currently being developed that considers the impact of terrains effects, e.g., hills, in urban environments using DTED data. The code computes
  - The effects of earth curvature and surface along the terrain profile
  - Elevations along the given path
  - Diffraction losses due to isolated edges
  - Angle of incidence and effective height of base antenna
- The code will be integrated into the UPM

Conclusions

- The UPM provides the capability for predicting reasonably accurate and fast the path loss in urban environments by
  - Utilizing data that represents the actual characteristics of the urban environment
  - Considering all the suitable scenarios in wireless networks