LEO Satellite Coverage in Urban and Suburban Environments

Effect of Wavelength, Building Blockage and Terminal Antenna Pattern

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Agenda

- Introduction
- Theory
- Research methods
- Simulation results
- Key findings

ORBCOMM System Introduction

- Developed between 1992 and 1995, put into service in 1996
- Consist of 36 Leo satellites running on 6 orbit planes
- Offer non-real-time messaging and data communication service
- Satellite altitude: 780 km
- Up link frequency: 148-150 MHz
  Down link frequency: 138-139 MHz

Objective and Approach - 1

- During the initial operation of ORBCOMM system, two major user segments are
  - Operators of fixed assets in remote locations
  - Operators of trucking fleets
- Both cases are close to ideal from propagation perspective
  - In the first case, users had the option of placing the ORBCOMM terminal antenna in optimal locations that were generally free from blockage
  - In the second case, large trucks and other major transportation assets operated on open highways tend to have fairly unobstructed views of the sky

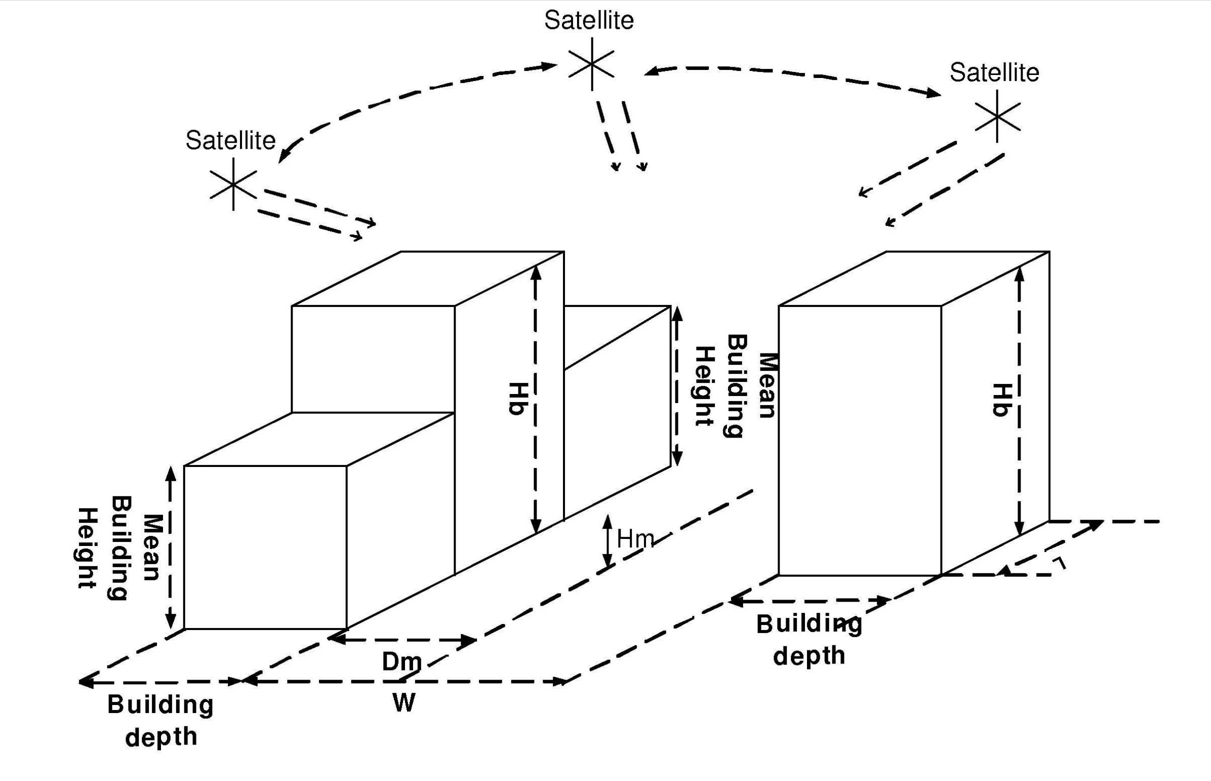
Objective and Approach - 2

- As ORBCOMM user base expands, a growing number of terminals are being operated by mobile users in suburban and urban environments where blockage by buildings is more significant
- However, most previous propagation measurement campaigns and channel modeling studies for LMSSs have been conducted at UHF, L, S and higher frequencies. Very little information exists to support LMSS system planning and performance prediction at VHF

Objective and Approach - 3

- In this study, we seek to fill a gap in previous work by
  - determining the manner in which the coverage of LMSSs operating in urban and suburban environments are affected by both wavelength *and* building blockage
  - considering the manner in which changing the pattern of the terminal antenna affects system coverage
- Uniform Theory of Diffraction (UTD) based 3-D propagation model is
  - implemented based upon the NEC-BSC code developed at Ohio State University
  - validated with respect to measured data using the Feature Selective Validation (FSV) [1] method

Theory: Application Scenario in City Urban



- If line-of-sight (LOS) path is available, signal through LOS contribute the most significant to the total received power
- If LOS path is unavailable, previous study [2] has shown that diffractions from the nearest roof edge contribute the most to the total received power, since they have shortest propagation path and interact with scatters only one time

Theory: Wavelength Vs. Signal Strength

- Received diffraction power $E^d_{total} = \sum_i E^i D A_i e^{-jk_i d_i}$
  - E^i: incident electric field at diffraction point
  - A_i: spreading factor
  - k_i: wave number
  - d_i: distance between diffraction point and receiving antenna
  - D: diffraction coefficient, which is a function of diffraction geometry parameter vector η and wavelength λ, and is expressed as $D = \sqrt{\lambda} \cdot f(\eta)$ [3].
- With same geometry, longer wavelength signal has bigger diffraction coefficient, and gives stronger diffraction field.

Theory:

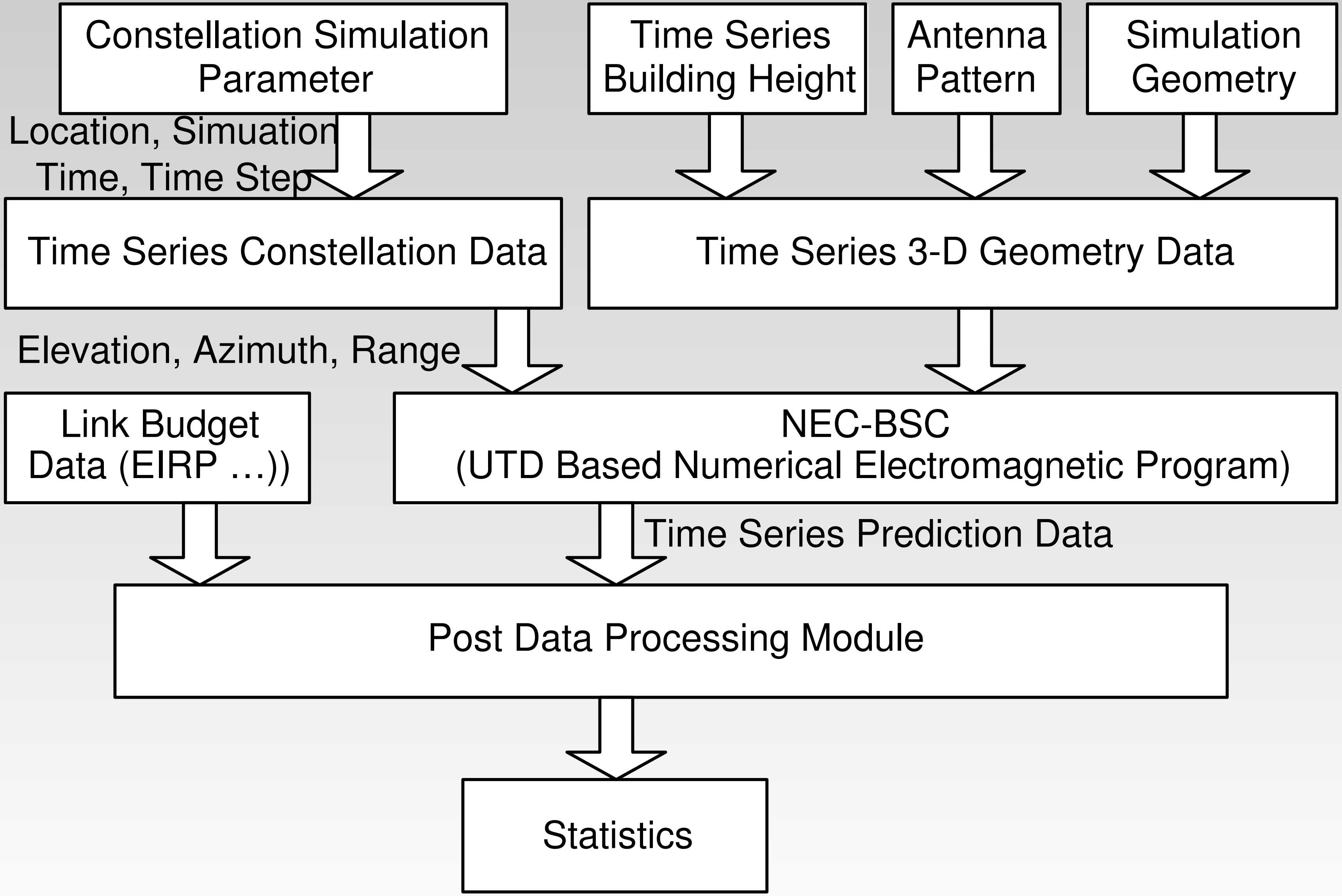
Terminal Antenna Pattern Vs. Signal Strength

- Signal power at receiving antenna output can be expressed as $P_r(d) = P_{\textit{Free Space}}(d) \cdot \alpha(\theta, \phi) \cdot g_r(\theta, \phi)$ [4]
  - $\theta,\ \phi$: elevation and azimuth angle of incoming wave
  - $P_{\textit{Free Space}}(d)$: power at receiving antenna through free space propagation
  - $\alpha(\theta, \phi)$: loss factor dependent on the signal angle of arrival
  - $g_r(\theta, \phi)$: receiving antenna gain factor, which is expressed as $\frac{k_1}{4\pi} \int_0^{2\pi} \int_0^{\pi} G_r(\theta, \phi) \rho_r(\theta, \phi) \sin\theta \, d\theta \, d\phi$
  - $G_r(\theta, \phi)$: radiation pattern of receiving antenna
  - $\rho_r(\theta, \phi)$: p.d.f. of incoming wave angle of arrival, which is greatly influenced by environment.

Method: Physical Statistical Approach

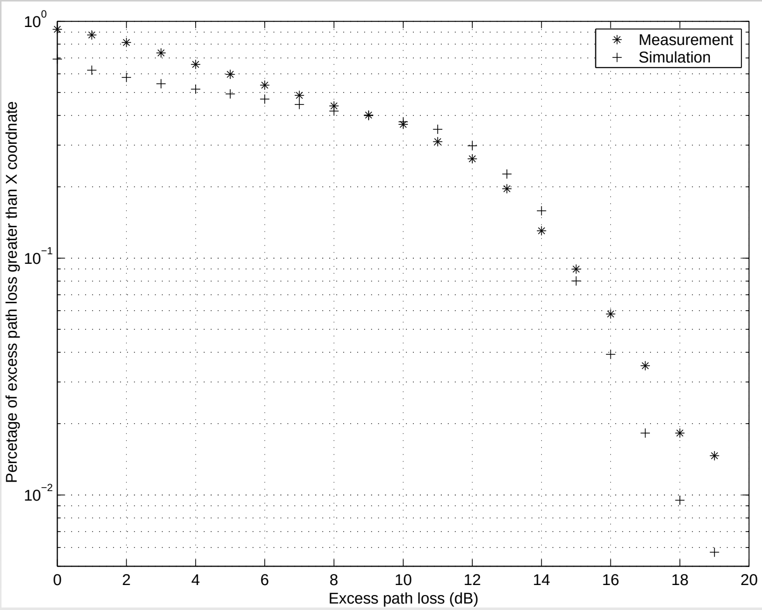
- Physical-Statistical approach combines computational electromagnetic tool with statistical input data that describe the physical environment [2].
- The output is a statistical distribution of the parameter of interest for certain type of region.
- Mathematical formulation $P(x) = \int p(x|\xi) \cdot T_N(\xi) d\xi$
  - ξ is the vector of physical parameters influencing signal strength
  - T_N is the joint p.d.f. of the physical parameters

Method: Propagation Model Signal Flow



Method: Propagation Model Validation

Statistics of excess path loss



Feature selective validation

- A point by point comparison between two data sets, i.e. simulation data and measurement data
- Amplitude Difference Measure (ADM): a measure to compare amplitude and trend of two data sets
- AMD results for our signal strength data is 0.0724 (Very good agreement)

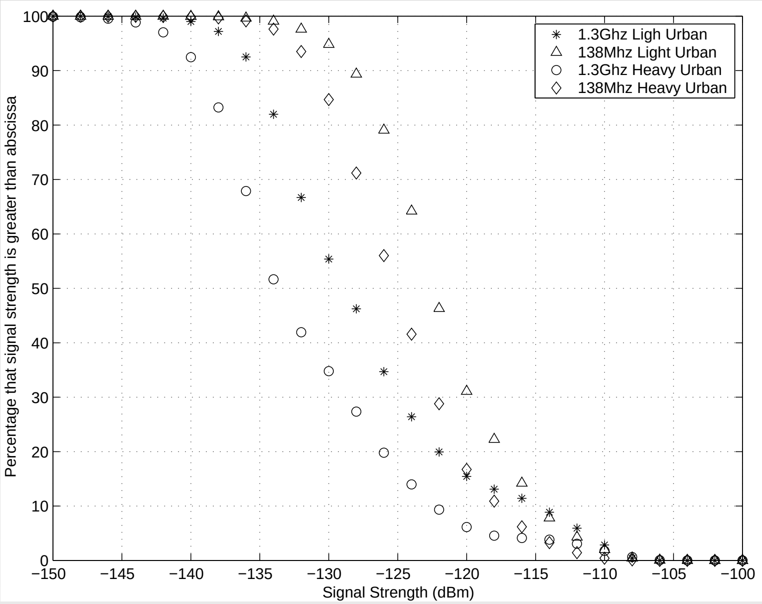
- From both eyeballing statistical distribution and quantitative FSV validation value, it can be concluded that there is a good agreement between computer simulation data and field measurements.

Method: Key Simulation Settings

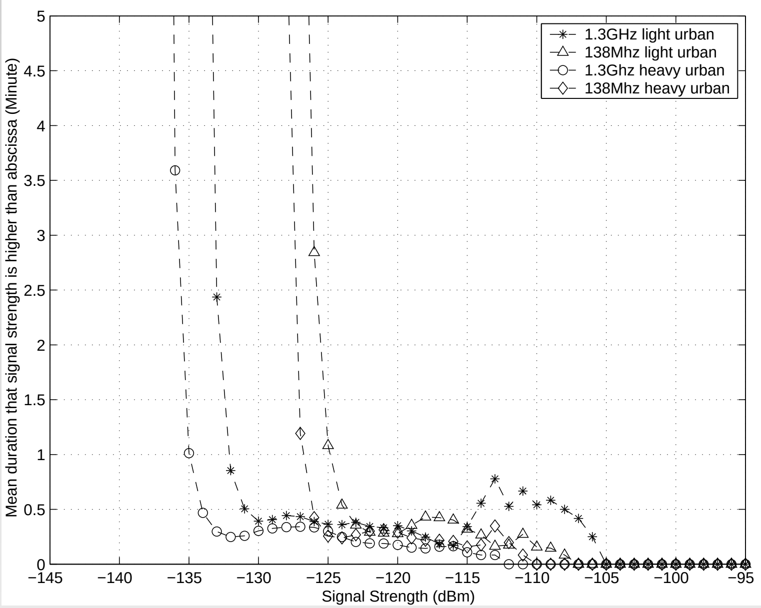
- Simulation time: 24 hours; Time step: 5 seconds; Location: Vancouver; Constellation: Orbcomm
- Frequencies: 138 MHz, 1.3 GHz
- Simulation geometry
- Degree of buildup: H_b =10 m, 20 m, 40 m, representing suburban (2 floors), light urban (4-5 floors) and heavy urban (8-9 floors)
- Terminal antenna patterns:
  - Vertical polarized $\lambda/4$ monopole $G_r(\theta) = 2\cos(\frac{\pi}{2} \cdot \cos\theta)/\sin\theta,\ \theta \in [0, \pi/2]$
  - Hemispherical pattern approximates Low Profile Antenna $G_r(\theta) = 2\cos\theta,\ \theta \in [0, \pi/2]$,

Simulation Result: Wavelength Vs. Coverage

Complementary cumulative probability of signal strength



Mean connection duration at different signal strength

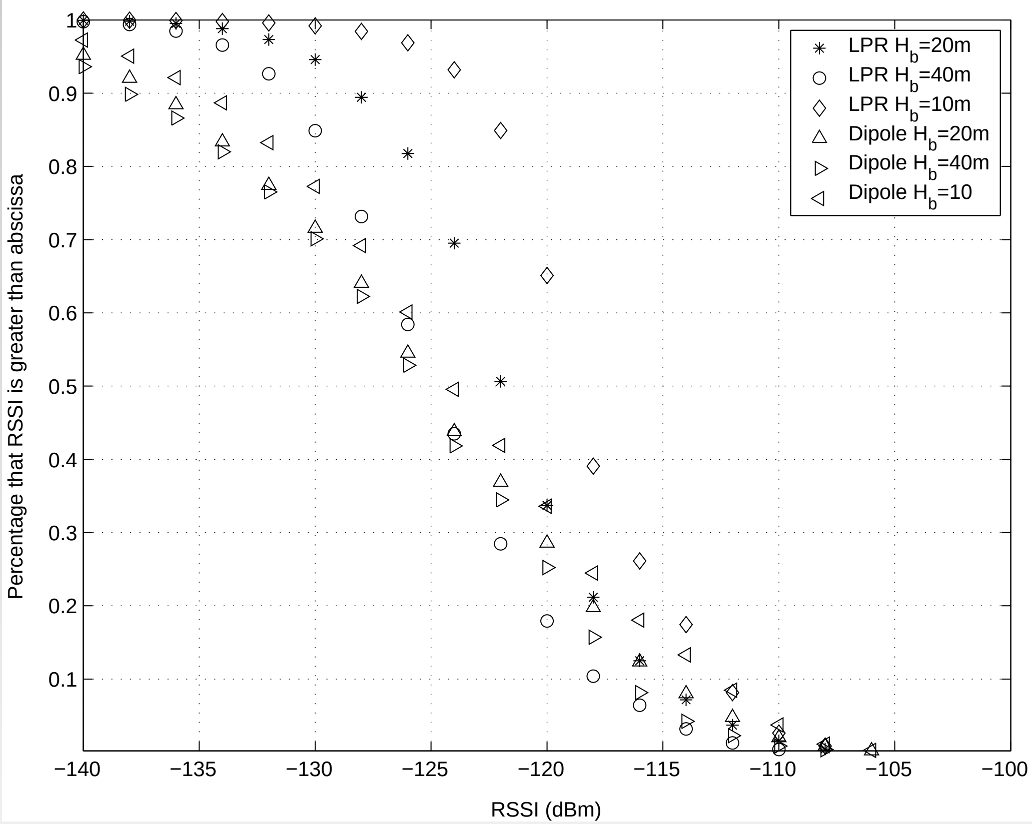


Mean RSSI	Light Urban	Heavy Urban	**Std.Dev.**	Light Urban	Heavy Urban
138 MHz	-120.7 dBm	-123.7 dBm	138 MHz	5.12 dB	5.33 dB
1.3 GHz	-126.4 dBm	-130.8 dBm	1.3 GHz	7.5 dB	7.3 dB

Simulation Result:

Antenna Pattern Vs. Coverage

Complementary cumulative probability of signal strength with different antenna pattern



Mean RSSI	Suburban	Light Urban	Heavy Urban
Low Profile	-117.4 dBm	-120.7 dBm	-123.7 dBm
$\lambda/4$ Monopole	-122.9 dBm	-124.4 dBm	-125.2 dBm

Key Findings: Propagation Modeling

- Our NEC-BSC based physical-statistical 3-D satellite propagation model
  - gives reasonable accuracy and ease of use
  - saves us the time and efforts required to develop a custom UTD-based electromagnetic tool.

Key Findings:
Effect of Wavelength and Building Blockage

- Through extensive computer simulations, we have determined the manner in which wavelength and building blockage jointly affect LMSS system coverage
  - Under LOS or slight blockage scenario, the difference due to wavelength is negligible. As degree of buildup increases, VHF coverage degrades less than L-band coverage
  - Under light urban environment, the difference of mean signal strength is almost 6 dB; Under heavy urban environment, the difference increases slightly to 7 dB; As building height increases still further, the difference remains constant
  - Standard deviation of 138 MHz signal strength is around 2 dB less than that observed at 1.3 GHz, which is indicative of higher coverage probability

Key Findings:

Effect of Terminal Antenna Pattern

- In most environments, an antenna with a hemispherical pattern provides more effective reception than the $\lambda/4$ monopole antenna which has traditionally been the most popular antenna pattern for ORBCOMM applications.
  - In suburban environments, the difference of the mean signal strength is the most 5.5 dB
  - In light urban environments, this difference is nearly 4 dB
  - In heavy urban environments, this reduces to only 1.5 dB

References

[1] A. Duffy, D. Coleby, A. Martin, M. Woolfson, and T. Benson, "Progress in quantifying validation data," in *Proc. 2003 IEEE International Symposium on Electromagnetic Compatibility*, vol. 1, Aug. 2003, pp. 323– 328.

[2] C. Oestges, S. Saunders, and D. Vanhoenacker-Janvier, "Physical statistical modelling of the land mobile satellite channel based on ray tracing," *IEE Proceedings on Microwaves, Antennas and Propagation*, vol. 2, pp. 554–558, Oct. 2002.

[3] C. A. Balanis, *Advanced Engineering Electromagnetics*. Wiley, 1989, pp. 782–783.

[4] W. C. Y. Lee, *Mobile Communication Engineering*. McGraw-Hill, 1982, pp. 146–147.