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Electromagnetic Simulation Software

Simulating use of LEO Satellites to Extend NB-IoT Coverage to Rural Areas

Speakers: Greg Skidmore, Tarun Chawla

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Content from Paper by Ken O'Hara, G. Skidmore

Wireless InSite™

Extending NB-IoT with LEO Satellites

Non-terrestrial networks (NTN), e.g. satellites and high-altitude platforms, are key component of 5G

LEO Satellites offer unique advantages

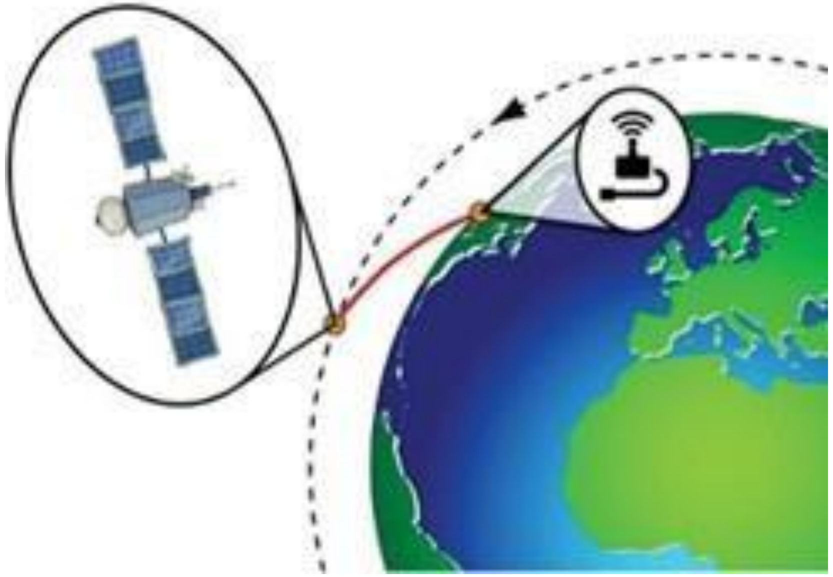
- Wide area service coverage
- Long-term reliability

One NTN use case: service continuity for machine-to-machine (M2M) or IoT devices as they move out of 5G terrestrial network coverage

- Applications: eHealth, vital asset tracking, etc.

This talk demonstrates use of Wireless InSite® ray-tracing simulations to predict how a LEO satellite link can augment terrestrial 5G networks to improve NB-IoT coverage

- ***Based on study Remcom published in 2019[1]***



1. K. O'Hara, G. Skidmore, "Providing Narrowband IoT Coverage with Low Earth Orbit Satellites," Microwave Journal, Vol 62, No. 12, Horizon House®, Dec 2019.

Narrowband IoT

Key requirements for M2M and IoT

- Low power-consumption
- Reliable connectivity
- Low data rates acceptable

Can be solved with narrow bandwidth, low-power, wide area network (WAN)

Narrowband IoT (NB-IoT) is an example

- Incorporated in 3GPP Rel 13 and enhanced in releases 14, 17, and 18 to ensure support within the 5G ecosystem, and to enhance for NTN
- Low bandwidth (max of 200 kHz) reduces noise, allowing for lower power
- Peak UL or DL rates of 250 kbps (via QPSK modulation)

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LEO Satellites

Advantages

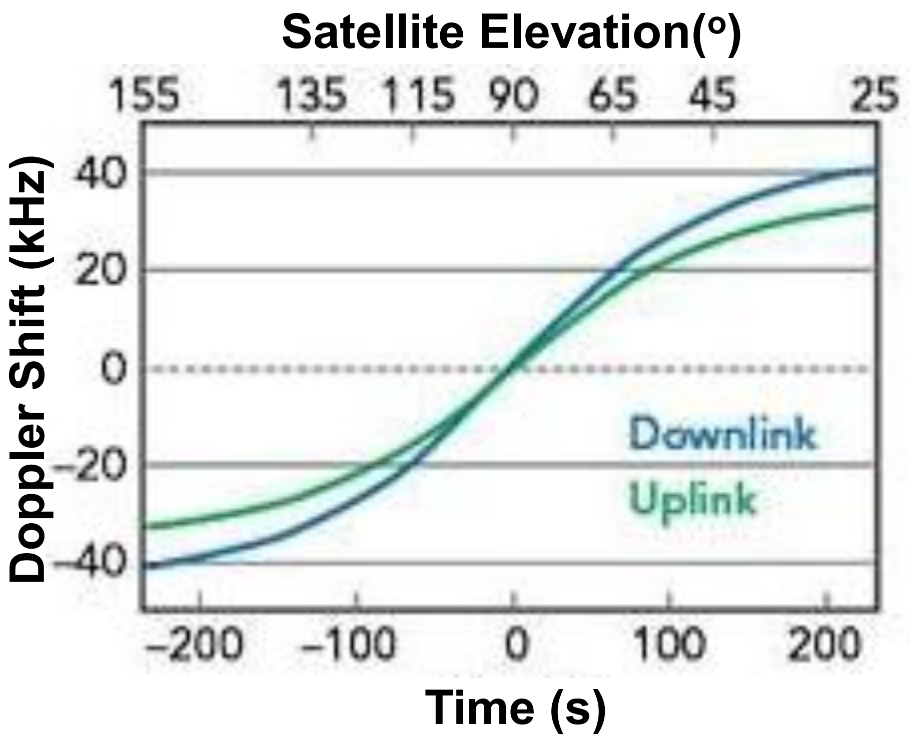
- Constellations can offer wide service coverage and reliability
- Low earth orbits (e.g., 1000 km) reduce latency over other satellite alternatives
  - Round-trip latency at 1000km is < 10 ms when satellite directly overhead
- Also lower path loss due to shorter distance (approx. 160dB at S-Band)

Challenges

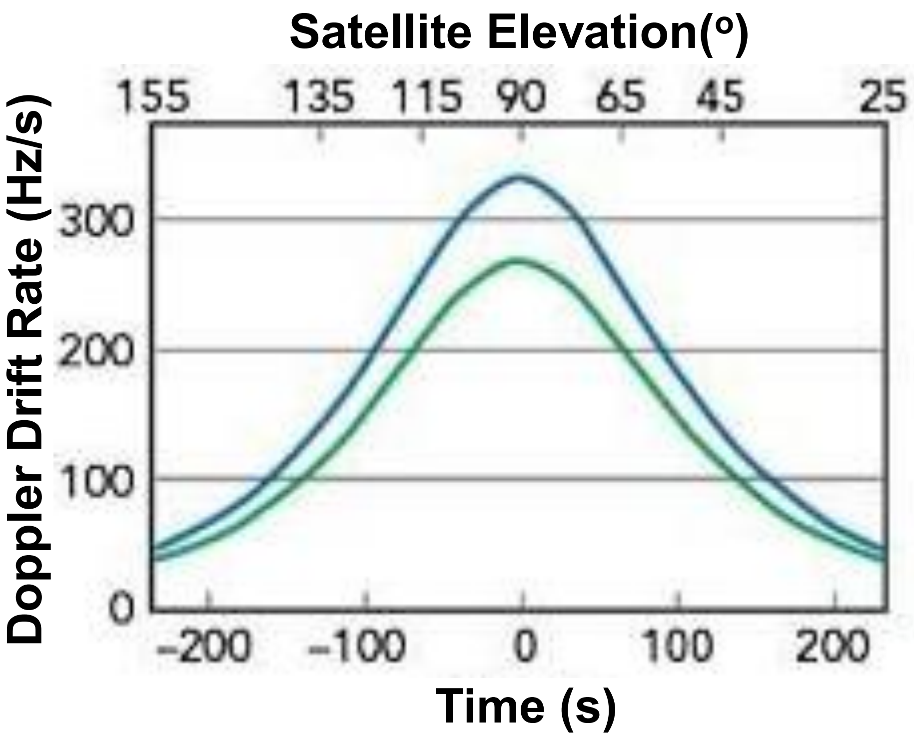
- Large Doppler shifts (±40 kHz @S-Band) due to higher velocity (7.4 km/s), closer ranges
  - To avoid inter-carrier interference, satellite must compensate most common mode component, while UE must compensate for remaining shift across a coverage area
- Challenges at lower elevations
  - Latency increases due to longer paths
  - Path loss increases due to refraction and atmospheric absorption, though relatively small at S-Band
  - Terrain shadowing and foliage loss can also increase
- Ionospheric scintillation (can cause deep time-dependent fades during hours following sunset for UEs near equator or high latitudes)

Doppler Shift at S-Band for LEO

Doppler Shift



Doppler Drift Rate



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Wireless InSite® Ray-Tracing

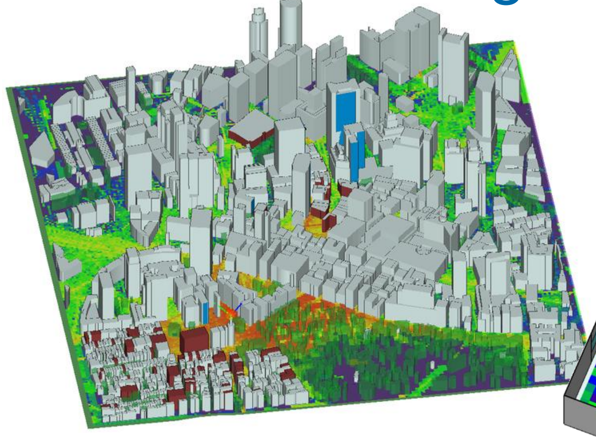
Used Wireless Insite ray-tracing to predict propagation and multipath for terrestrial and SATCOM links

- Suite of propagation models and comms post-processing (MIMO/throughput)
- Validated, deterministic models, GPU accelerated 3D ray-tracing
- 5G/MIMO beamforming, multiplexing
- Extensions for mmWave, diffuse scatter

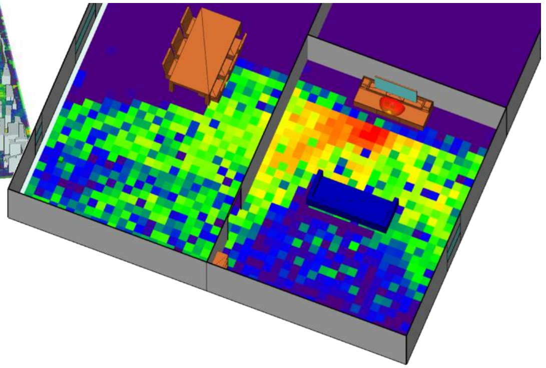
Applications

- 5G/6G Coverage (SINR, throughput) in dense urban outdoor, indoor, out-to-in
- SATCOM (plane waves or LEO points)
- Long-range, rugged terrain, earth/lunar
- WiFi or BT coverage in complex indoor

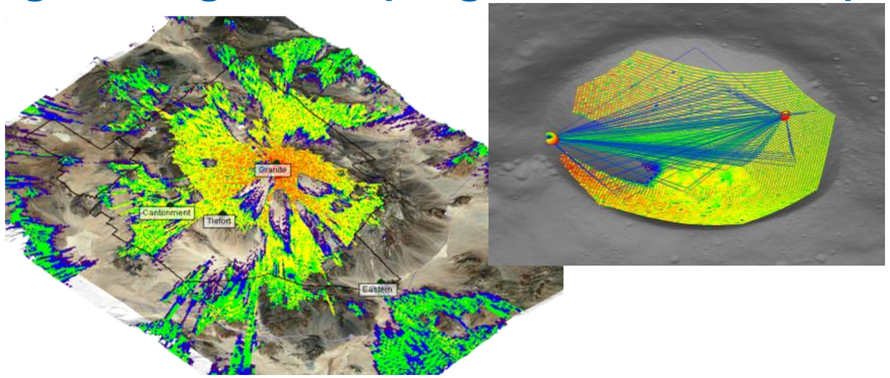
MIMO/5G Coverage



Indoor WiFi



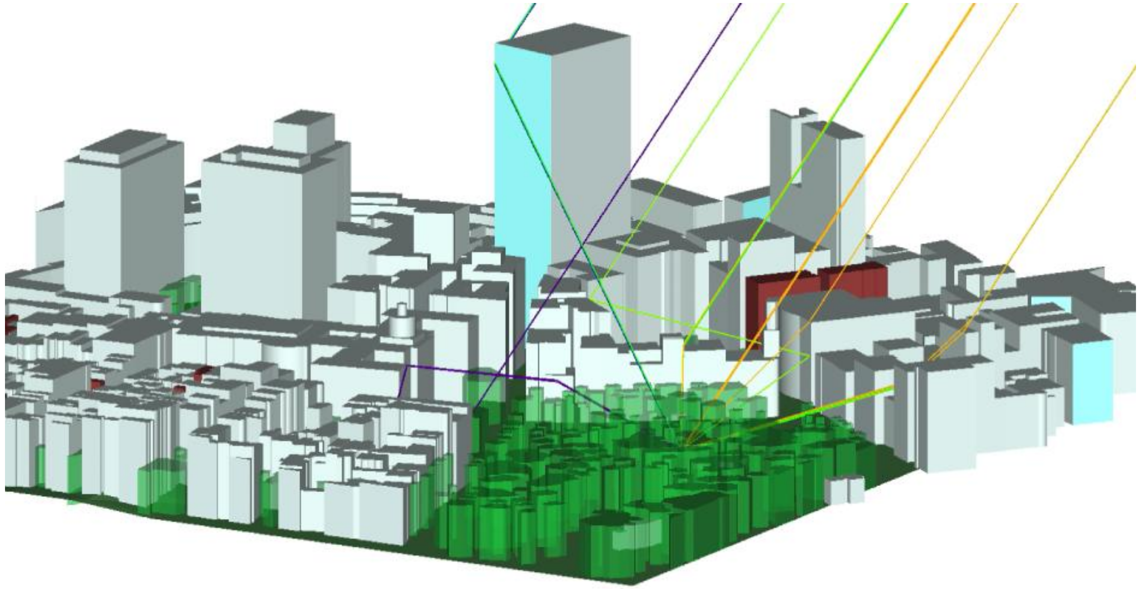
Long-Range Propagation & Multipath



Satellite-to-Mobile Device in Urban Area using Plane Waves in Wireless InSite

Zoomed-In View

City View



Augmented with SATCOM Prototype Model

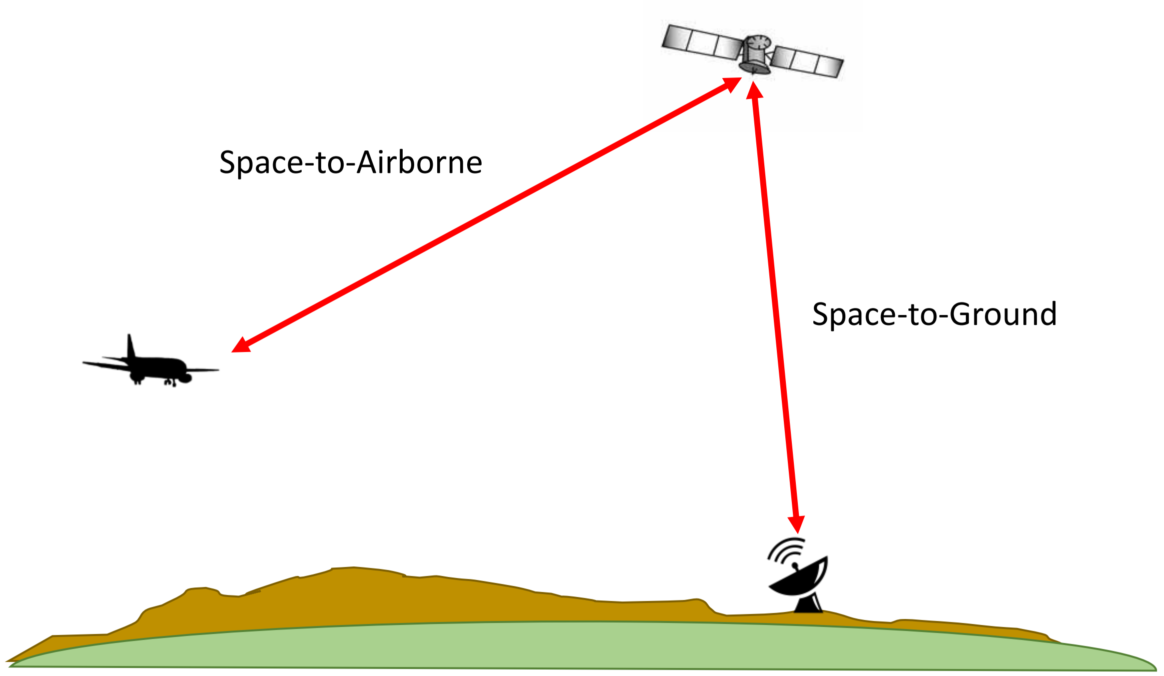
Remcom augmented calculations using prototype SATCOM model

- (in-house R&D model, not yet released)

Key capabilities

- Atmospheric refraction, using standard or custom atmospheres
- Ionospheric scintillation, depolarization
- Rain/cloud/fog attenuation
- Low-elevation effects (beam-spreading, multipath fading, tropospheric scintillation)

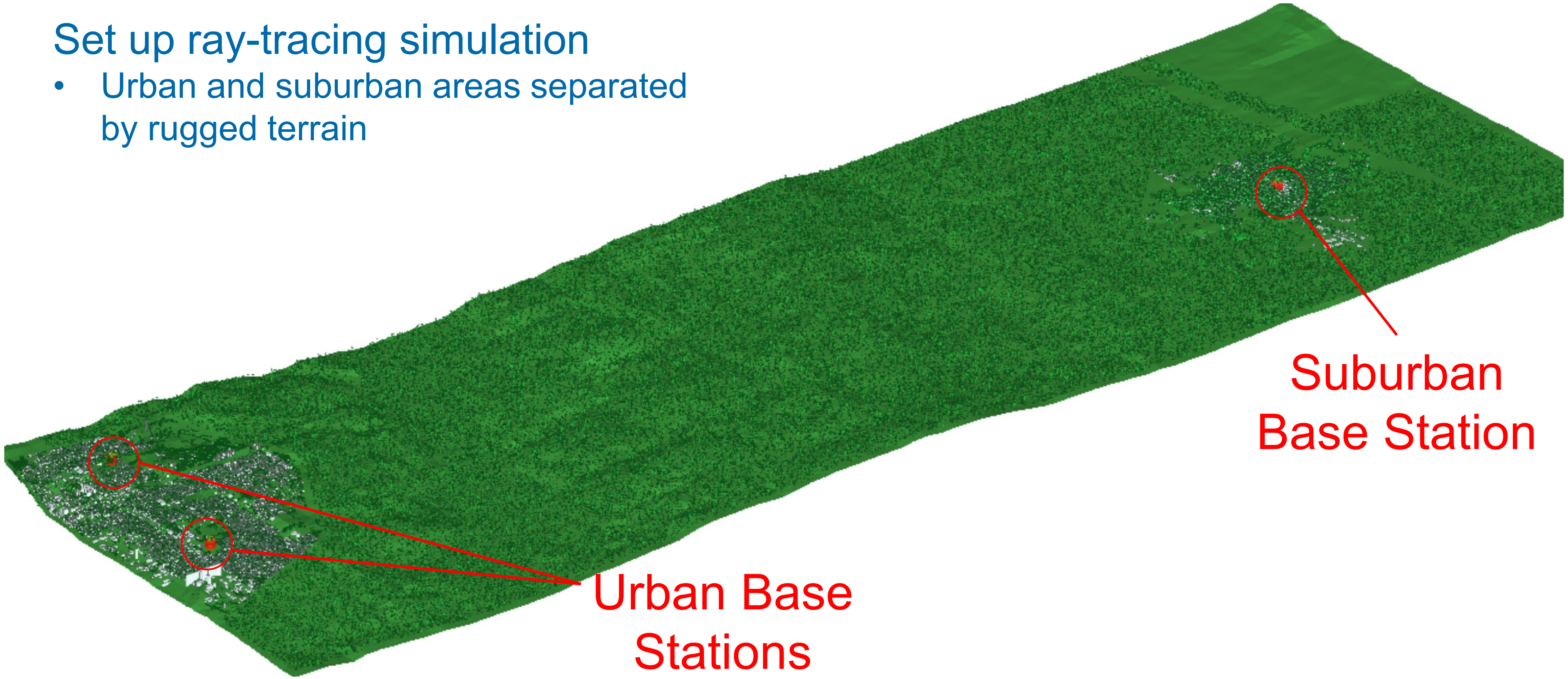
Main effects in this study were refraction (bending of paths) and minor atmospheric absorption



Simulating Gaps in IoT Coverage Between Urban and Sub-Urban Areas

Set up ray-tracing simulation

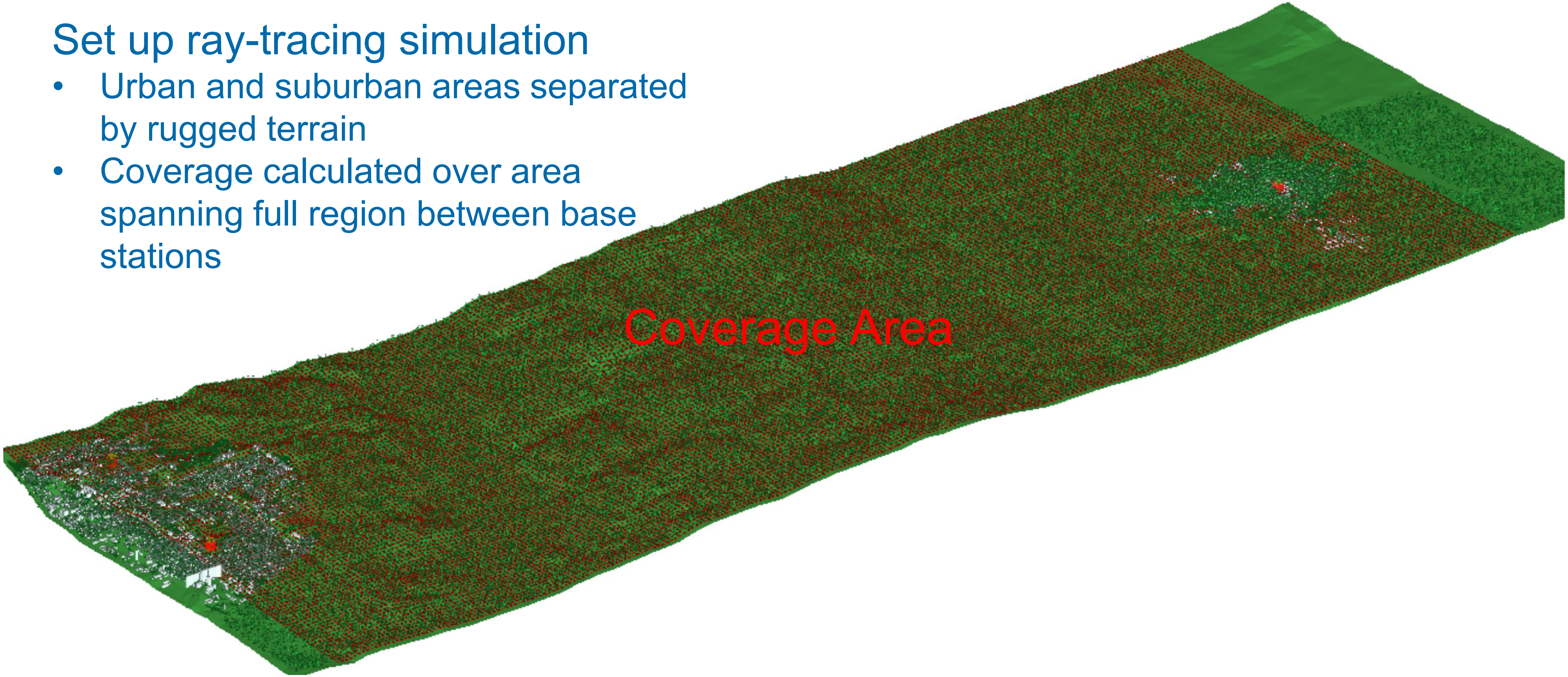
- Urban and suburban areas separated by rugged terrain



Simulating Gaps in IoT Coverage Between Urban and Sub-Urban Areas

Set up ray-tracing simulation

- Urban and suburban areas separated by rugged terrain
- Coverage calculated over area spanning full region between base stations



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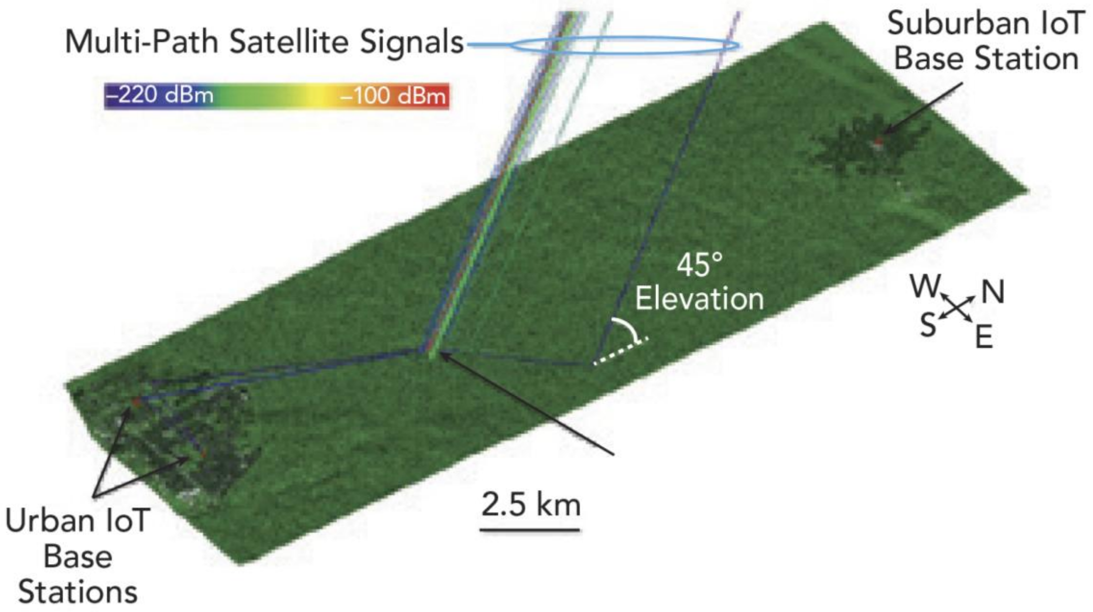
Modeling Satellite Coverage at Various Elevations

NB-IoT Scenario

- FDD: 2.1 GHz DL, 1.7 GHz UL
- NB-IoT: 180 kHz bandwidth
- **System Specs:**

System	Tx EIRP (dBmi)	Noise Figure (dB)
5G Base Station	66	3
Satellite	40	3
IoT Receivers	23	9

- Noise floor
  - Terrestrial: -167 dBm/Hz
  - Satellite: -174 dBm/Hz



Ray-tracing

- Predict propagation, multipath, and shadowing from buildings, terrain, foliage

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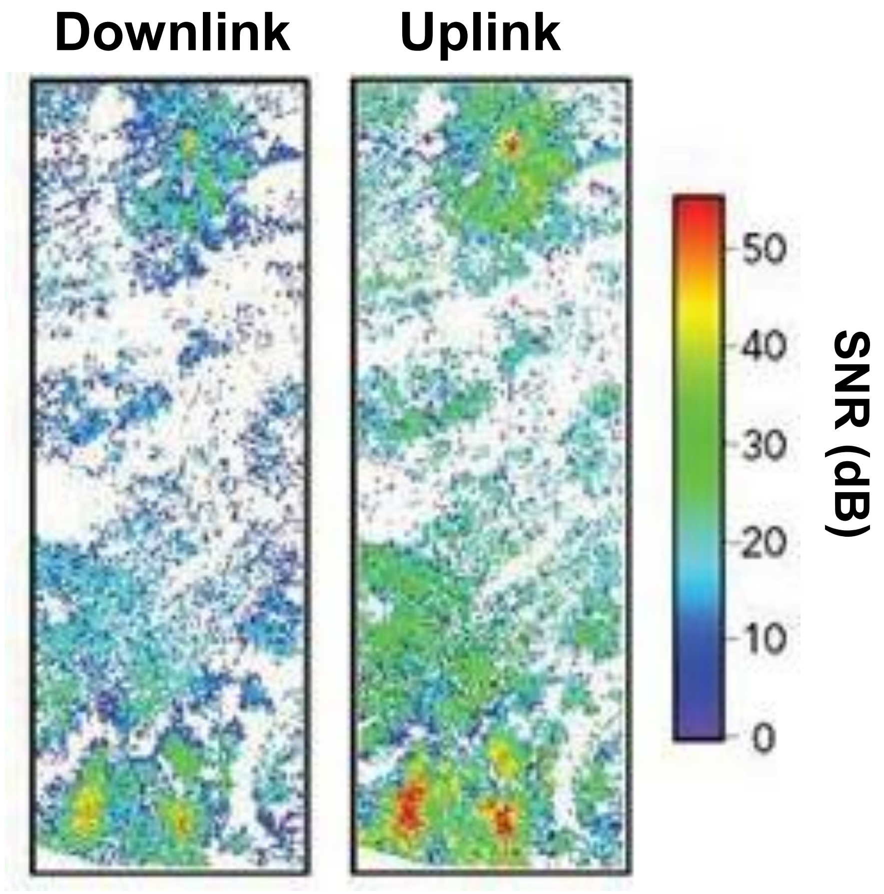
NB-IoT Coverage from Terrestrial Network

Results show signal coverage over area for DL and UL

- UL higher for this case due to better noise figures and higher power within small band
- SNR in 10’s of dB over much of region; > 50dB near base stations
- However, significant fraction of area < 0 dB (below noise floor)

NB-IoT SNR shows Significant Gaps in Terrestrial Network Coverage



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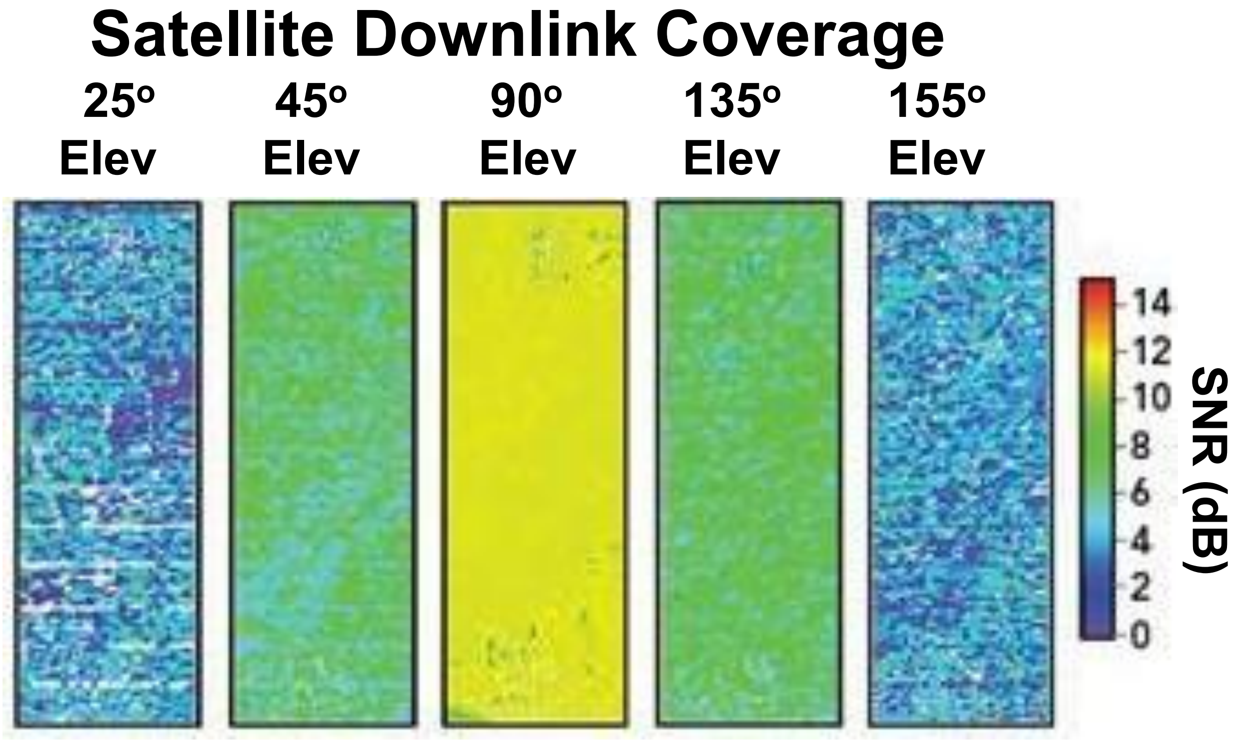
NB-IoT Coverage from Satellite: Downlink

Results images show downlink coverage from satellite as function of elevation angle

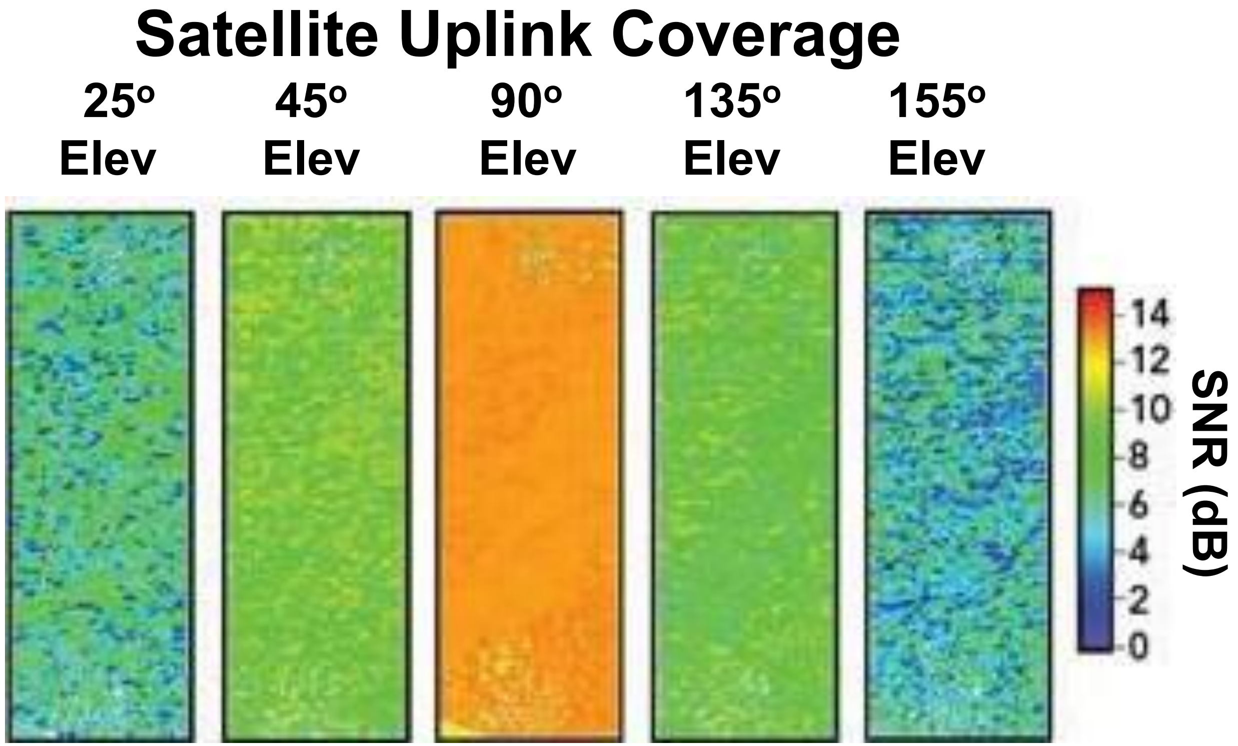
- Best SNR at 90º elevation
  - Minimizes propagation loss and atmospheric absorption
  - Lower elevations also suffer from terrain and foliage shadowing
- Despite losses, SNR generally above noise floor (>0 dB) for elevations evaluated



NB-IoT Coverage from Satellite: Uplink

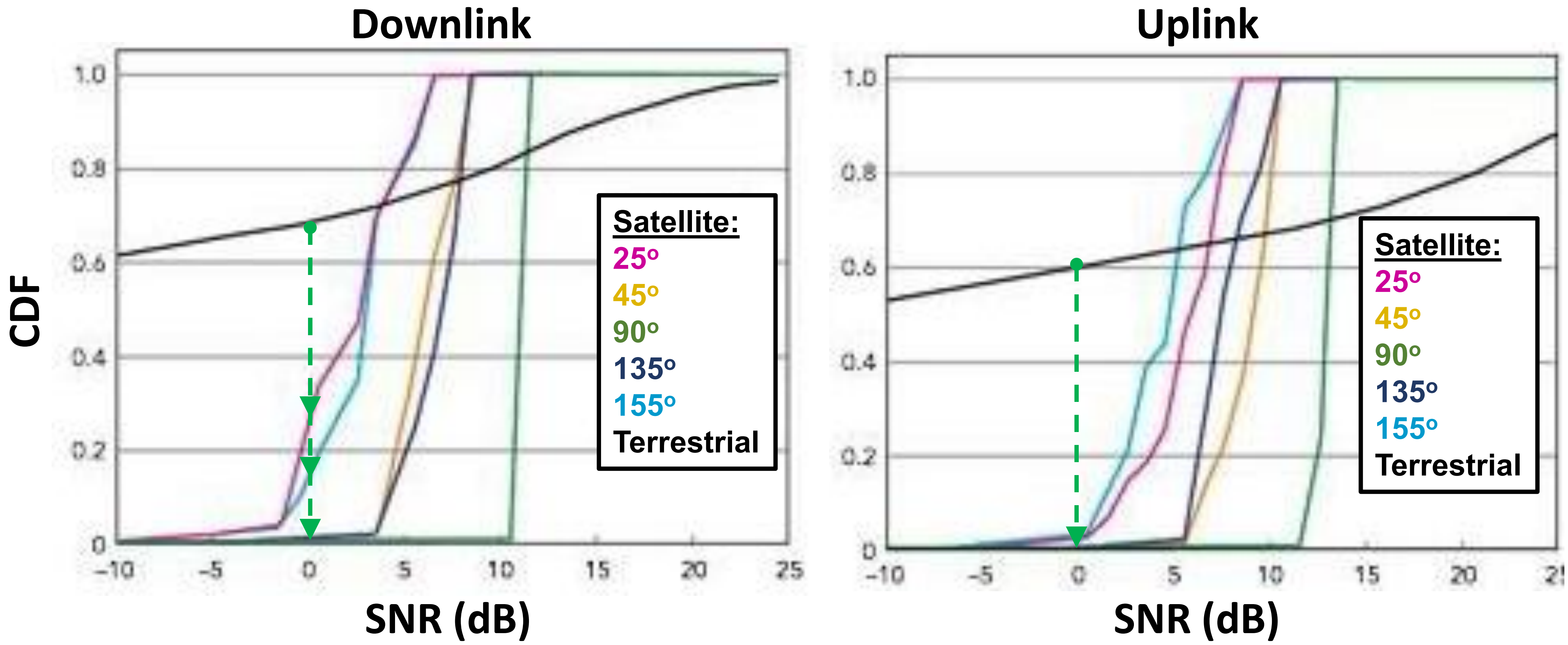
Results images show uplink coverage from satellite as function of elevation angle

- Best SNR again at 90º elevation
  - Minimizes propagation loss and atmospheric absorption
  - Lower elevations also suffer from terrain and foliage shadowing
- Overall, results higher than for DL due to improved NF and higher power within smaller band
- For UL, SNR nearly always above noise floor (>0 dB) for elevations evaluated



CDF's of SNR with and without LEO Satellite

CDF of SNR: Addition of LEO Significantly Improves Fraction above 0dB



Throughput shows Substantial Improvement with LEO Satellite

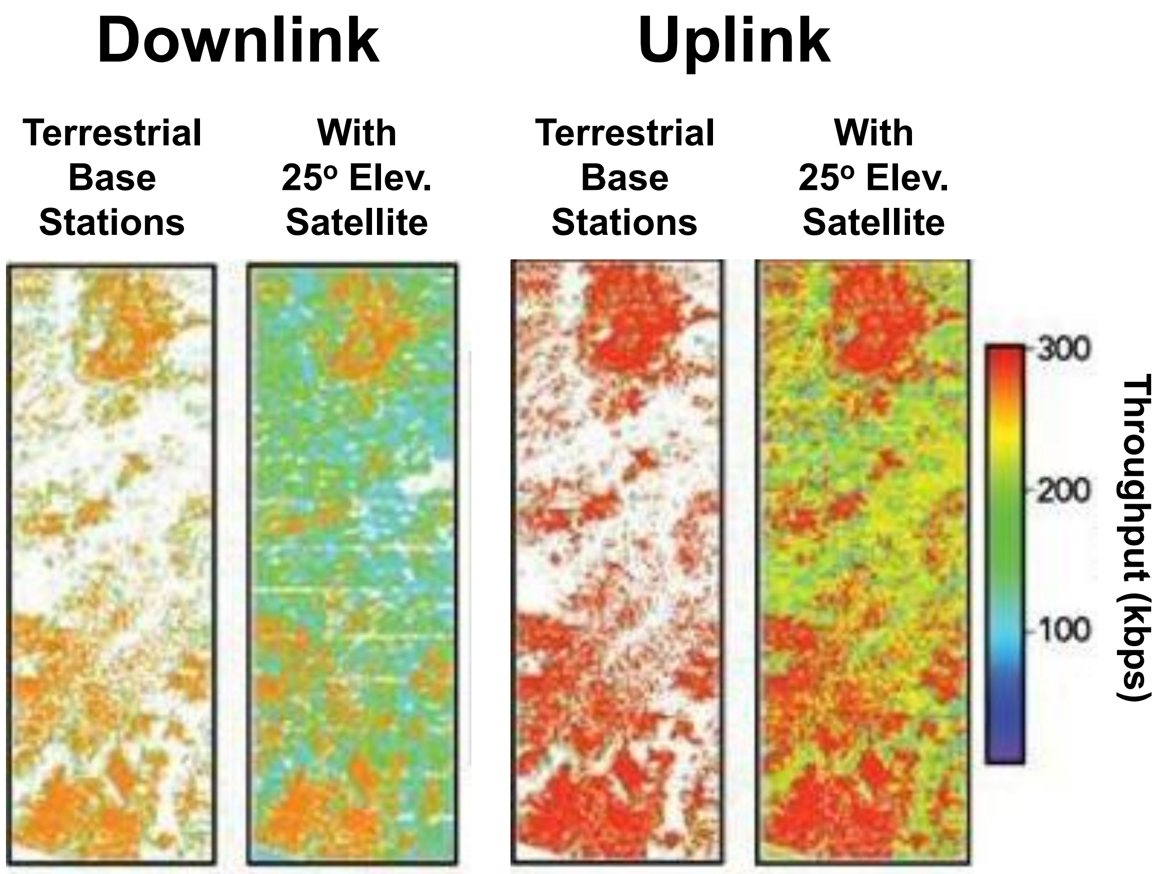
Calculated throughput based on QPSK and SNR thresholds consistent with 5GNR

- Results in throughput up to approximately 250 kbps

Images compare coverage with and without satellite at 25^{o} elevation

- Highest throughputs are when systems are within coverage of 5G base stations
- However, most of area achieves > 100-200 kbps when LEO satellites are included

Increase in Throughput with LEO Satellite



Conclusion

Study demonstrates

- Ability of simulation to show gaps in coverage from terrestrial networks for applications such as NB-IoT
- Use of simulation to evaluate benefits of satellite NTN to augment terrestrial networks to improve coverage in rural areas
- Impacts of shadowing from terrain and foliage, multipath fading

Results show the value of augmenting coverage with LEO satellites

- Can provide coverage with relatively low latency
- However, some added complexity, as large Doppler shifts must be compensated by the satellite and/or UE

Simulations can help evaluate cost/benefit of these and other tradeoffs for satellite/NTN applications