Overcoming the Digital Divide by Large-Scale Coverage Analyses for mmWave Cellular Networks

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Oct. 30, 2022

The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

Asilomar Conference on Signals, Systems, and Computers

OVERVIEW

- Millimeter Wave (mmWave) Measurements
  - Extremely sensitive to blockages
- Channel Charting (CC) may be a good fit
  - But there are many new challenges
- Dense network is impractical in near future
  - Especially for ubiquitous coverage in rural areas
- Research Opportunities in Overcoming Digital Divide
  - Site-specific channel modeling & simulation
  - On-demand facility deployment

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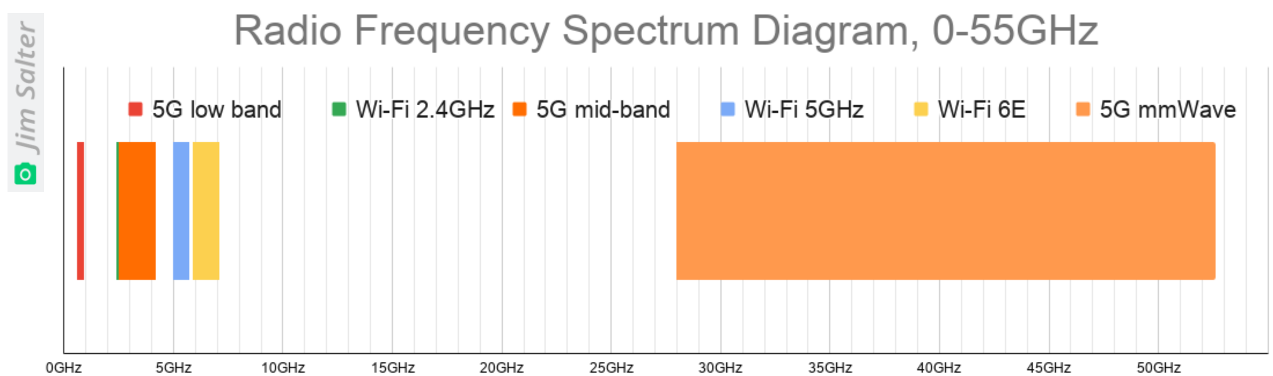
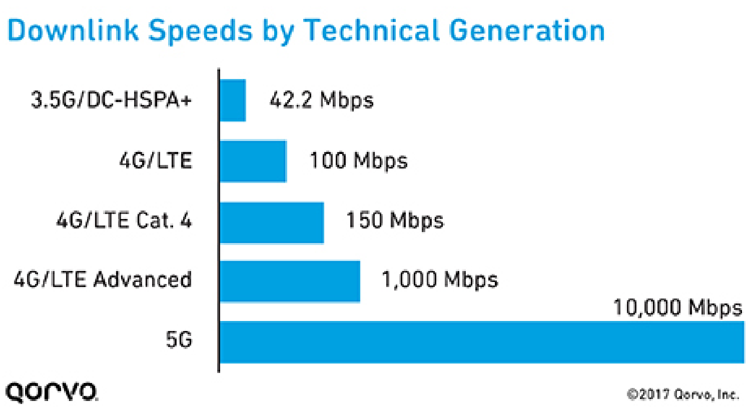
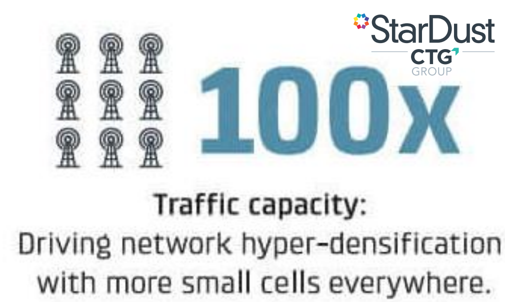
BACKGROUND

- Motivations
    - Urban: higher speed & bigger network capacity
      - mmWave: underutilized spectrum resource







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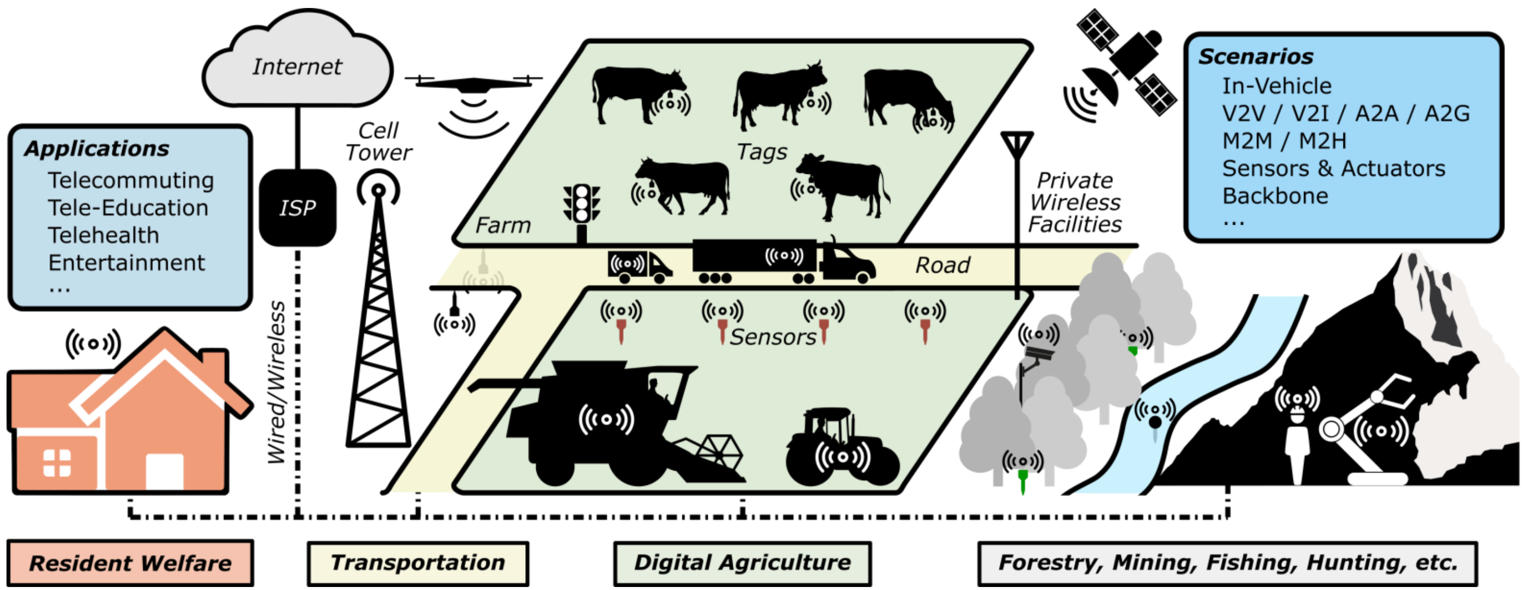
BACKGROUND

- Motivations
  - Urban: higher speed & bigger network capacity
  - Rural: “ubiquitous” coverage
    - New vision: connecting ~~people~~ things



The illustration is from: Y. Zhang, D. J. Love, J. V. Krogmeier, C. R. Anderson, R. W. Heath and D. R. Buckmaster, "Challenges and Opportunities of Future Rural Wireless Communications," in IEEE Communications Magazine, vol. 59, no. 12, pp. 16-22, December 2021, doi: 10.1109/MCOM.001.2100280.

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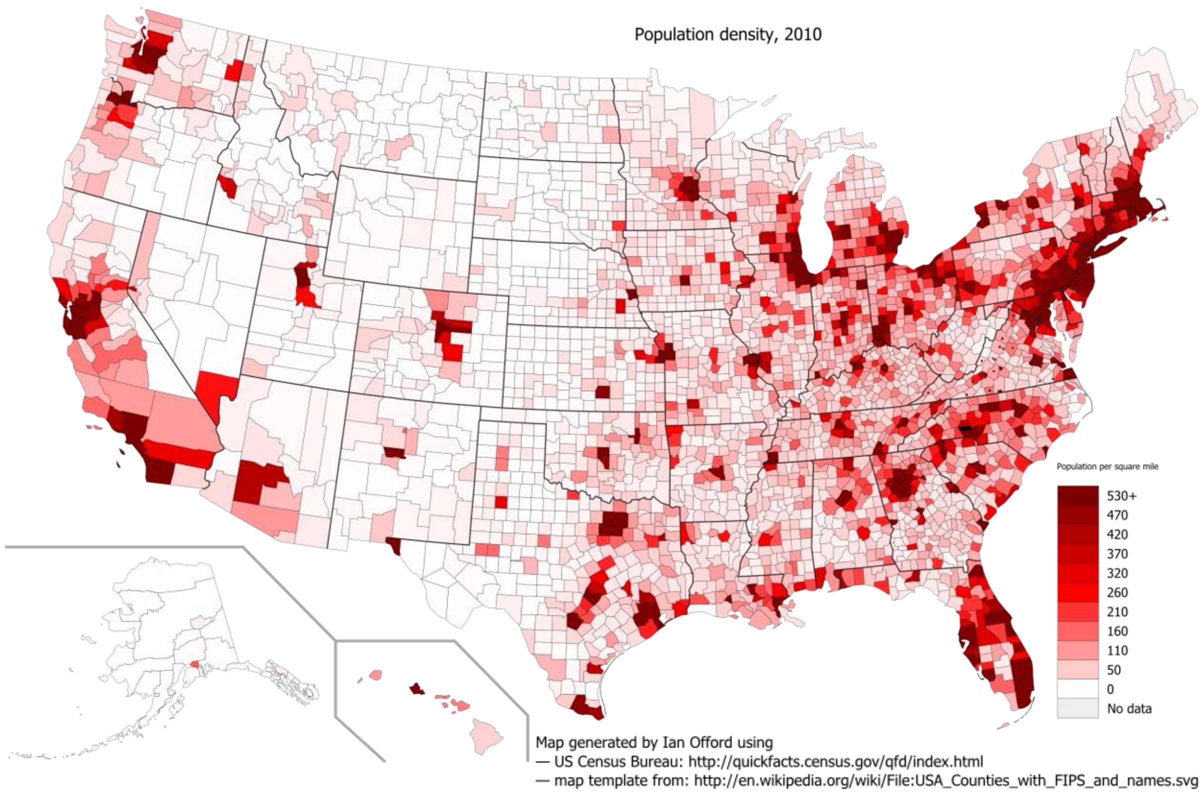
Ubiquitous Coverage

- Connecting People => Connecting Things
  - In the U.S., rural regions account for 97% of the land area but only 19.3% of the population.



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Ubiquitous Coverage

- Connecting People => Connecting Things
  - In the U.S., rural regions account for 97% of the land area but only 19.3% of the population.
  - Cisco is anticipating 29.3 billion devices connected to IP networks by the year of 2023, with around half of these connections being machine-to-machine.

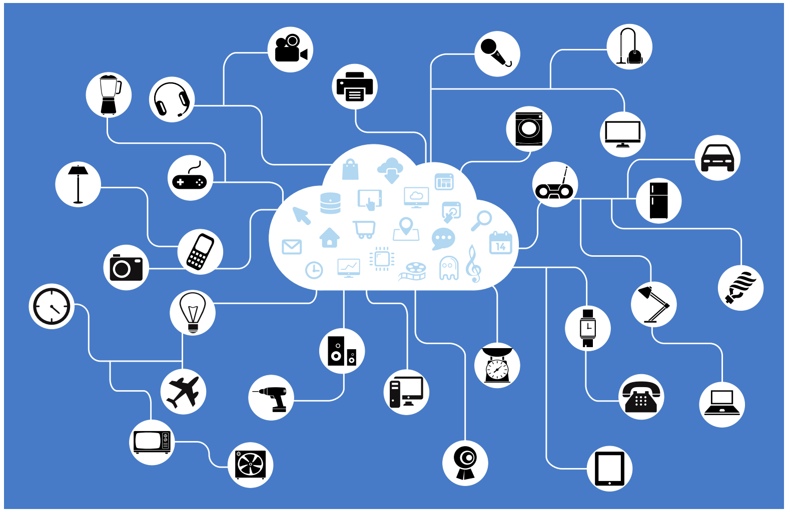
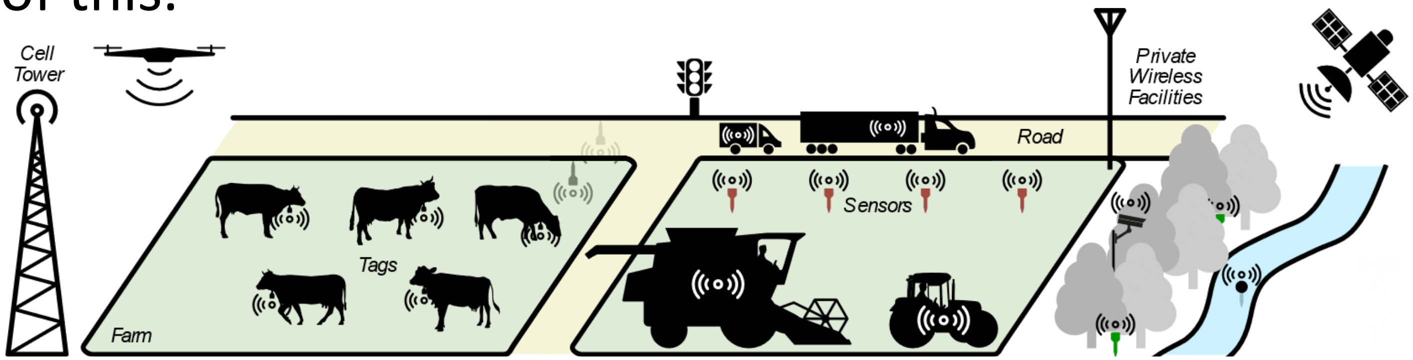


Image by jeferrb from Pixabay.

Ubiquitous Coverage

- Connecting People => Connecting Things
  - In the U.S., rural regions account for 97% of the land area but only 19.3% of the population.
  - Cisco is anticipating 29.3 billion devices connected to IP networks by the year of 2023, with around half of these connections being machine-to-machine.
  - In the U.S., digital agriculture could drive an annual additional gross benefit of US$47–65 billion, and rural broadband connectivity could contribute over one-third of this.

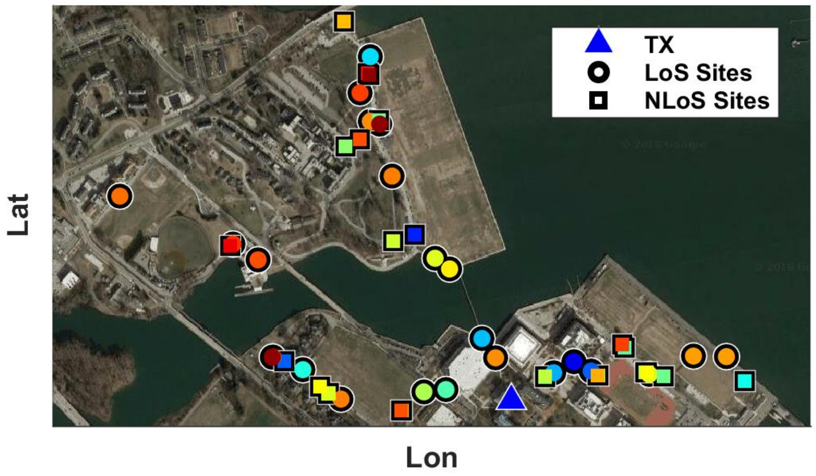


Ubiquitous Coverage

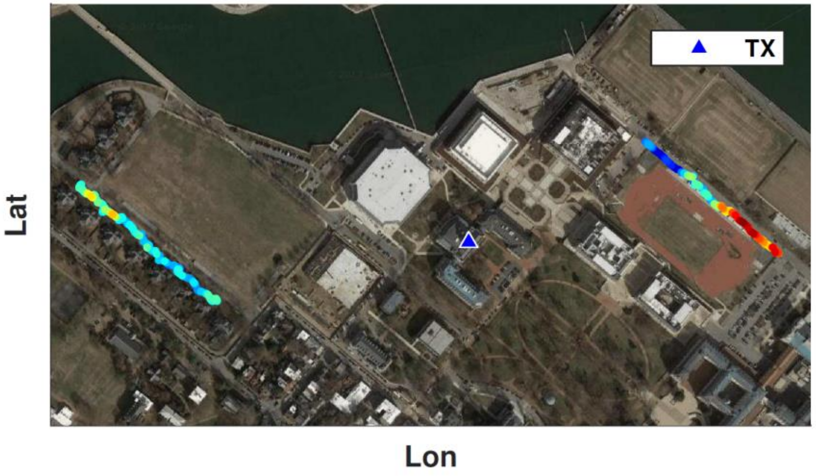
- Connecting People => Connecting Things
  - In the U.S., rural regions account for 97% of the land area but only 19.3% of the population.
  - Cisco is anticipating 29.3 billion devices connected to IP networks by the year of 2023, with around half of these connections being machine-to-machine.
  - In the U.S., digital agriculture could drive an annual additional gross benefit of US$47–65 billion, and rural broadband connectivity could contribute over one-third of this.
  - 49% of U.S. car crash fatalities in 2015 occurred in rural regions. Wireless connectivity could reduce these fatalities by 80%.

Effects of Local Blockages

- Suburban Measurement Campaign @ 28GHz
  - At United State Naval Academy (USNA)
  - 50 individual sites + 2 continuous tracks
  - Basic Transmission Losses in decibel (dB)



(a) Overview for the basic transmission losses of all 50 individual sites



(b) Overview for the basic transmission losses of the two continuous tracks

Satellite images courtesy of Google Maps.

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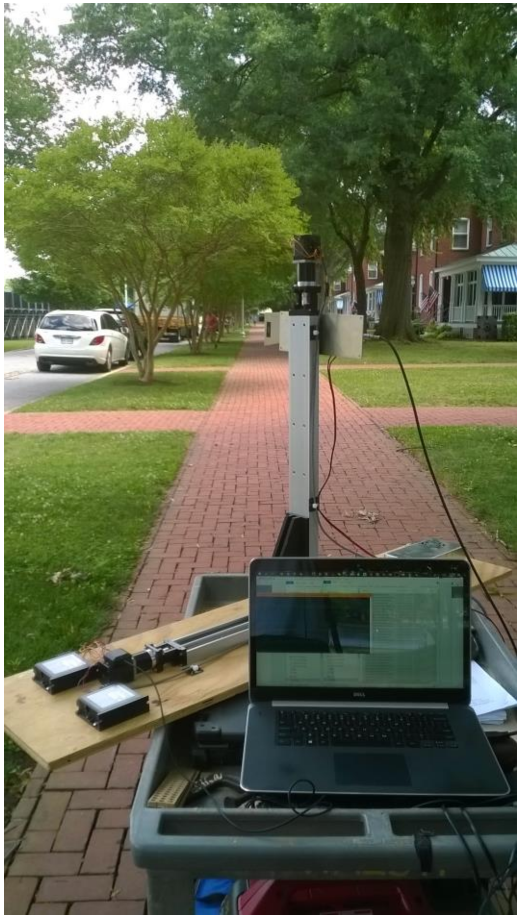
Measurement Setup

(a) RX on an electric car

(b) RX on a trolley



(c) Before a continuous signal recording for a pedestrian path

Effects of Local Blockages

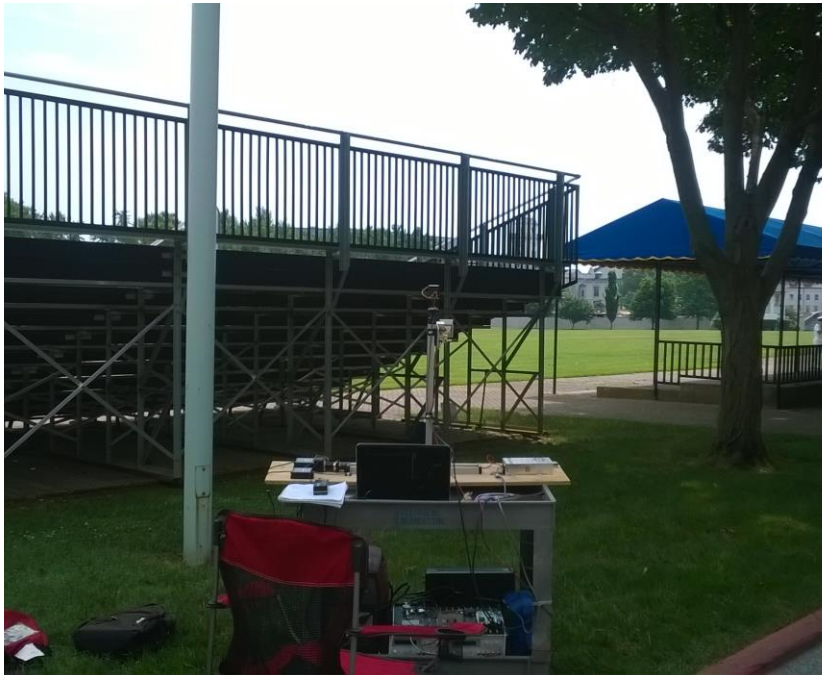
- A custom-designed positioning system
  - Receiver (RX) scanned over a "+" pattern

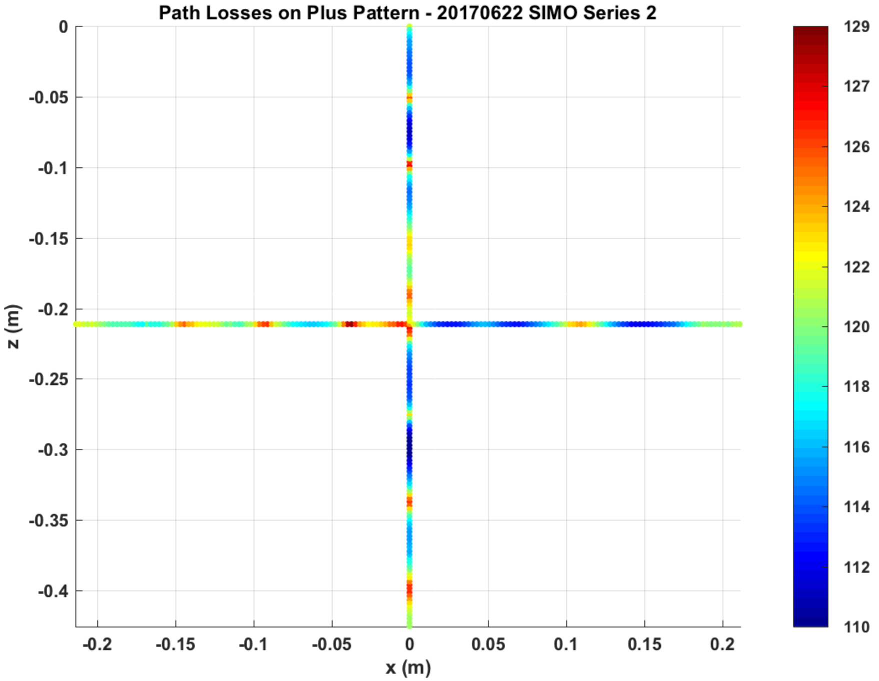
(a) Under development

(b) Under deployment at RX

EFFECTS OF LOCAL BLOCKAGES

- A custom-designed positioning system
  - Receiver (RX) scanned over a "+" pattern





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Effects of Local Blockages

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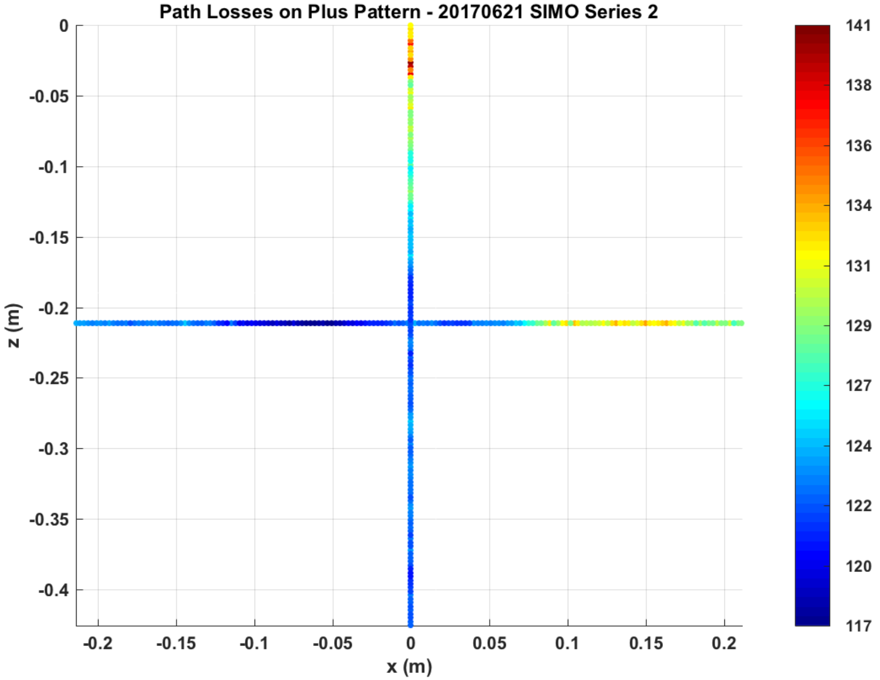

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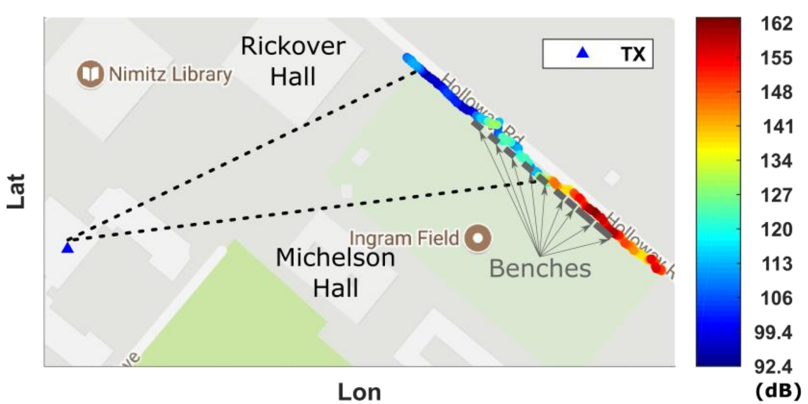
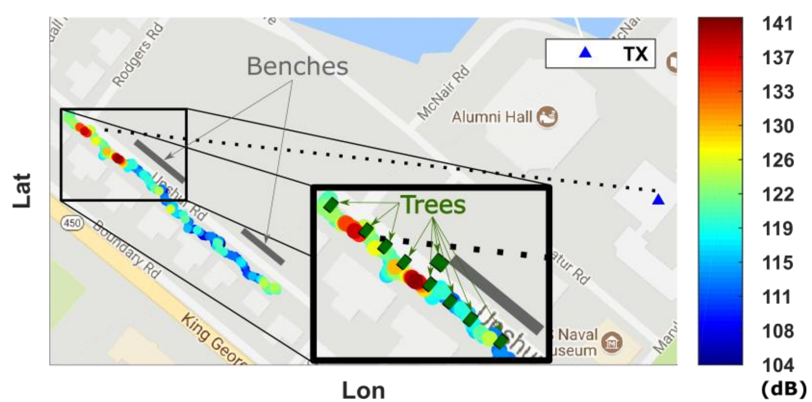
EFFECTS OF LOCAL BLOCKAGES

- Blockage happens “everywhere”
- The influence is huge
  - Bleacher: 19 dB => ~79.4 fold
  - Tree: 24 dB => ~251.2 fold



(a) Track on Holloway Road



(b) Track on Upshur Road

Road maps courtesy of Google Maps.

DISCUSSION

- High sensitivity on local blockages is an issue
  - Frequent high-accuracy location information is needed for optimizing resource management
- Channel Charting (CC) may be useful
  - Self-supervising
  - Geographical information not required
- But there are more challenges
  - High-dimension “latent” space
  - Requirements on precision and accuracy

=> Semi-supervised learning with geo info?

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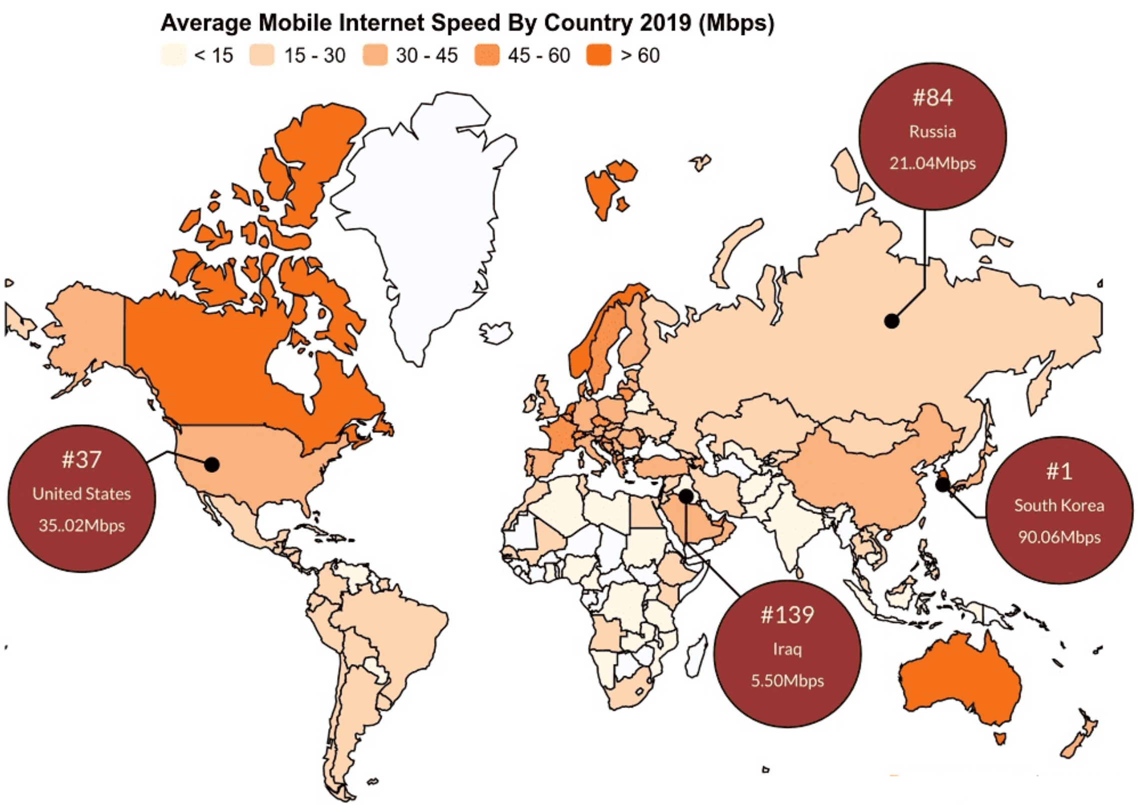
DISCUSSION

- High sensitivity on local blockages is an issue
  - Frequent high-accuracy location information is needed for optimizing resource management
- Broad application of mmWave may further broaden the digital divide

Digital Divide

- Communication infrastructure deployed in rural areas lags its urban counterparts
  - Throughout the world



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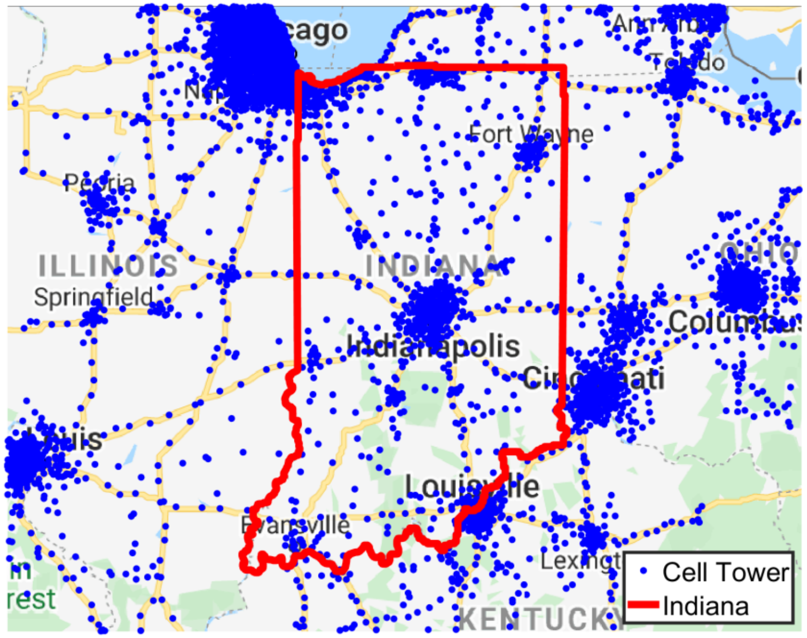
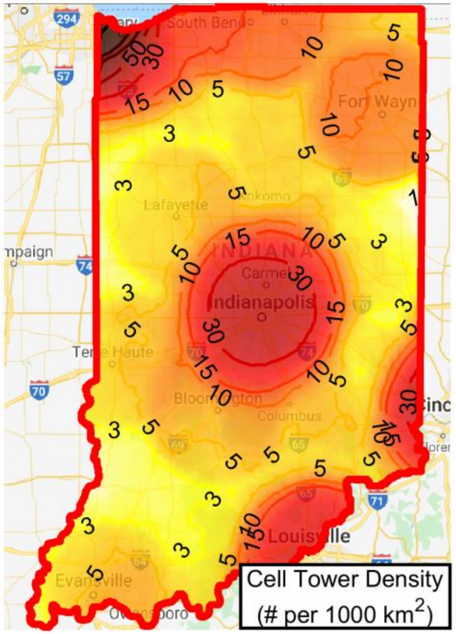
DIGITAL DIVIDE

- Communication infrastructure deployed in rural areas lags its urban counterparts
    - Throughout the world
    - Network operators prioritize urban tower density



(a) Tower laydown of one national carrier



(b) Tower density

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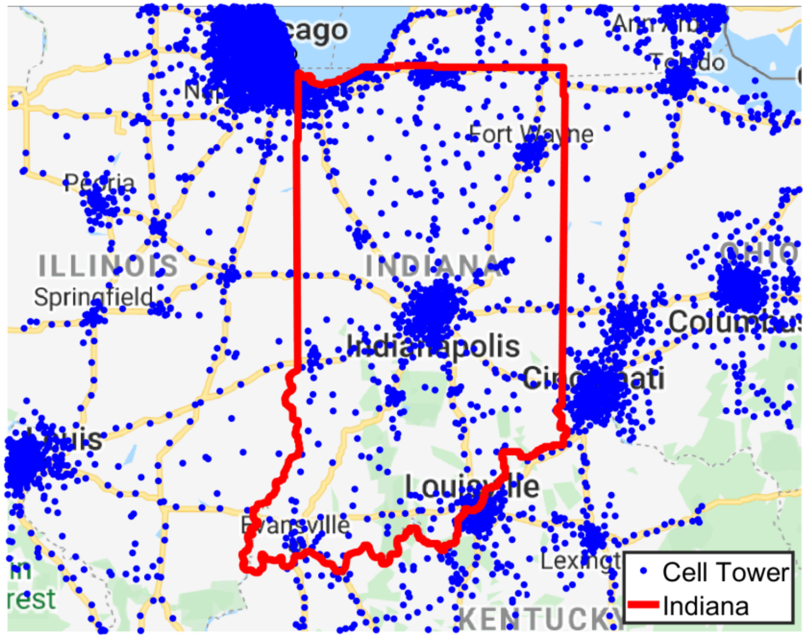

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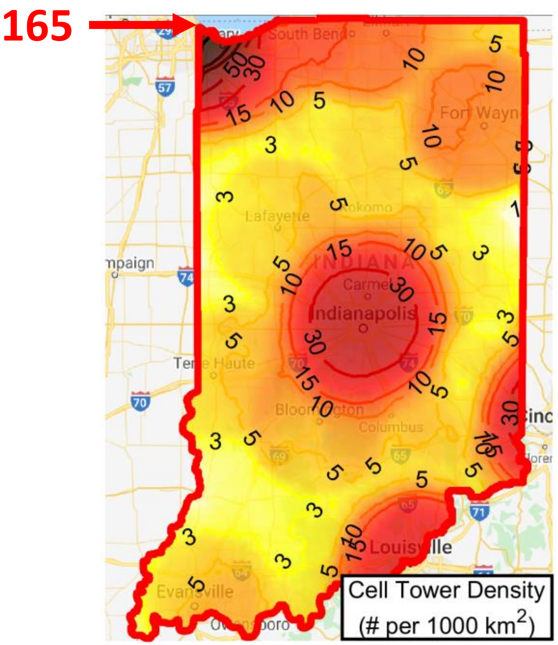

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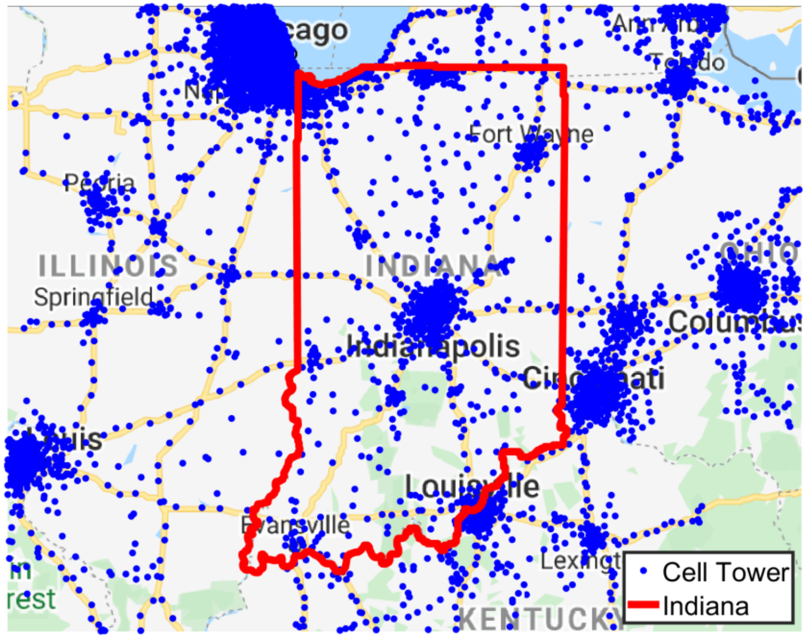

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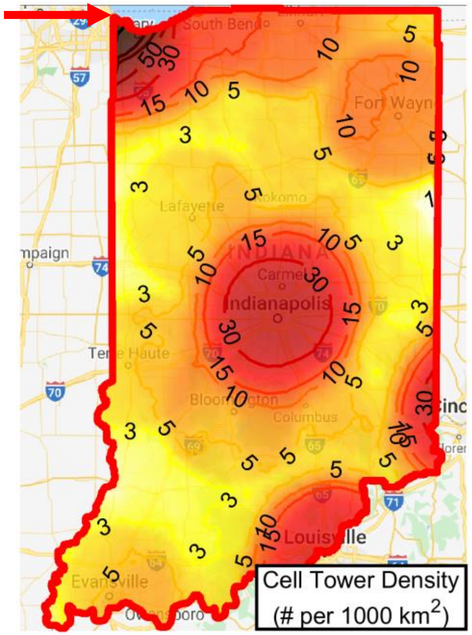

(b) Tower density

70.5% area: <10

44.5% area: <5

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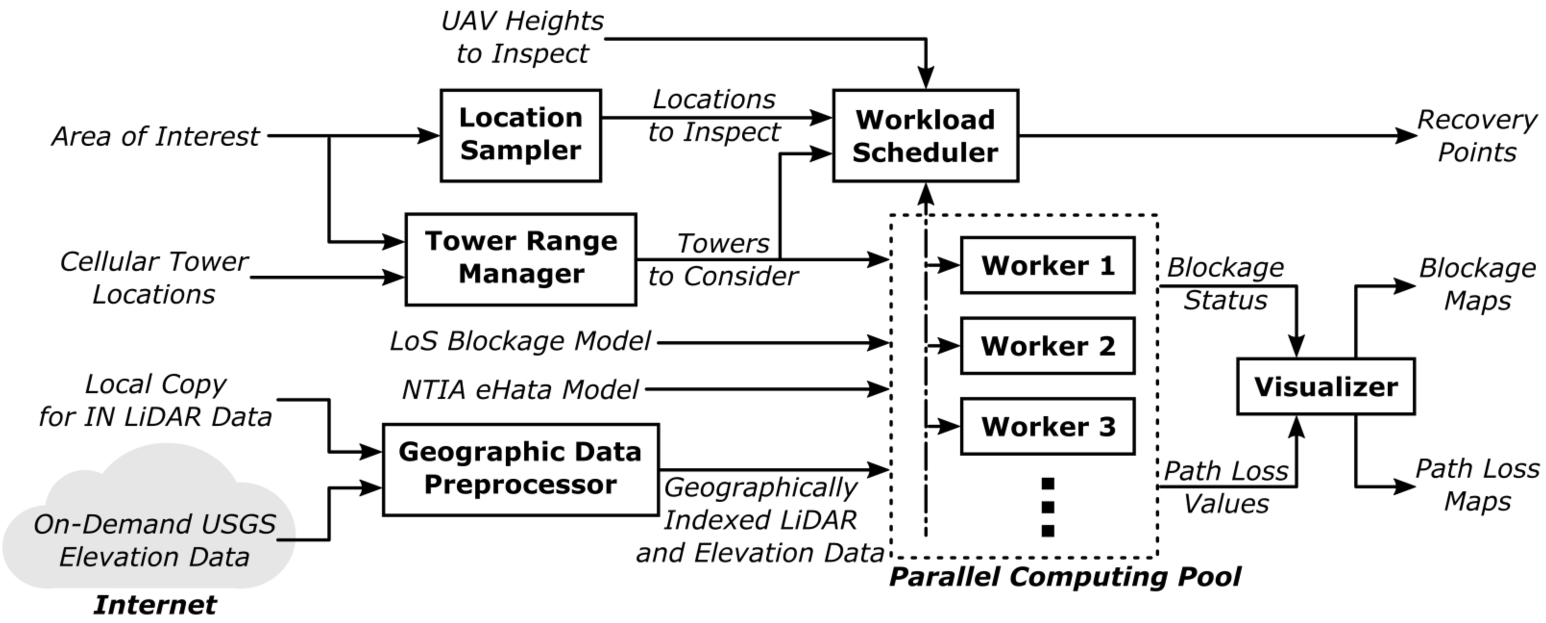
Digital Divide

- Communication infrastructure deployed in rural areas lags its urban counterparts
    - Throughout the world
    - Network operators prioritize urban tower density
    - mmWave will broaden the gap

Large-Scale Coverage Analyses

- Site-Specific Channel Modeling & Simulation
  - Cumulative blockage distance
  - Path loss



More details on the simulator implementation can be found in: Y. Zhang, T. Arakawa, J. V. Krogmeier, C. R. Anderson, D. J. Love and D. R. Buckmaster, "Large-Scale Cellular Coverage Analyses for UAV Data Relay via Channel Modeling," ICC 2020 - 2020 IEEE International Conference on Communications (ICC), 2020, pp. 1-6, doi: 10.1109/ICC40277.2020.9149403.

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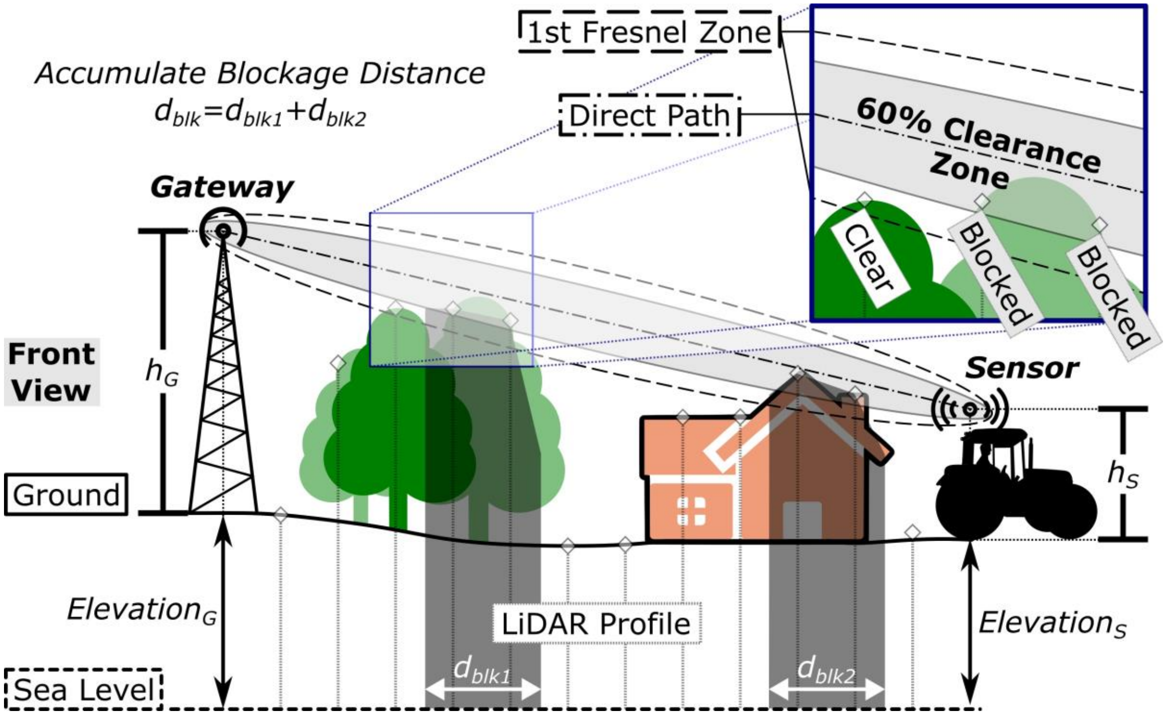
LARGE-SCALE COVERAGE ANALYSES

- Site-Specific Channel Modeling & Simulation
  - Cumulative blockage distance
  - Path loss



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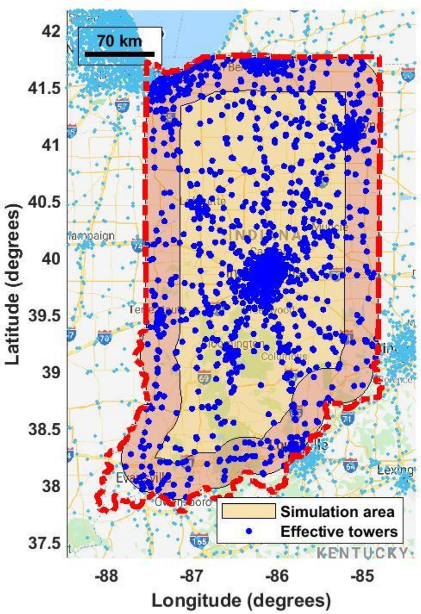
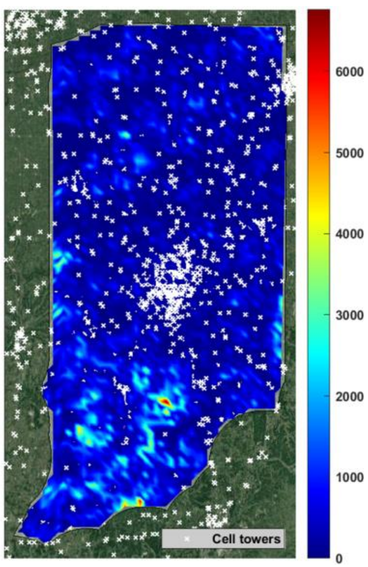
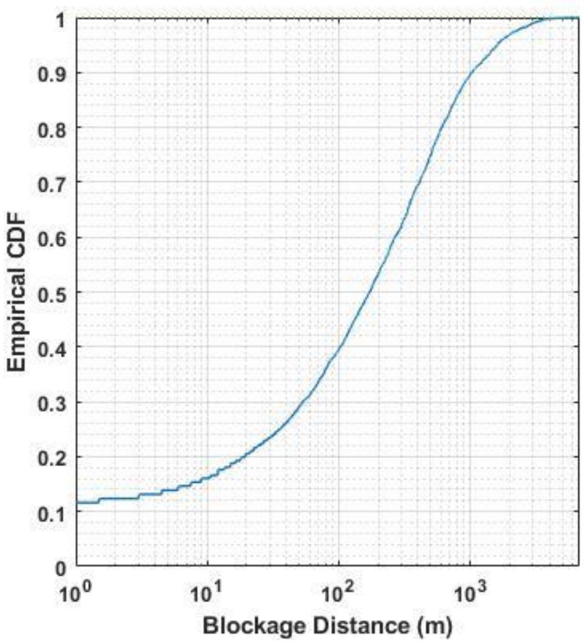


(a) Overview



(b) Best available blockage distance



(c) Distribution

DIGITAL DIVIDE

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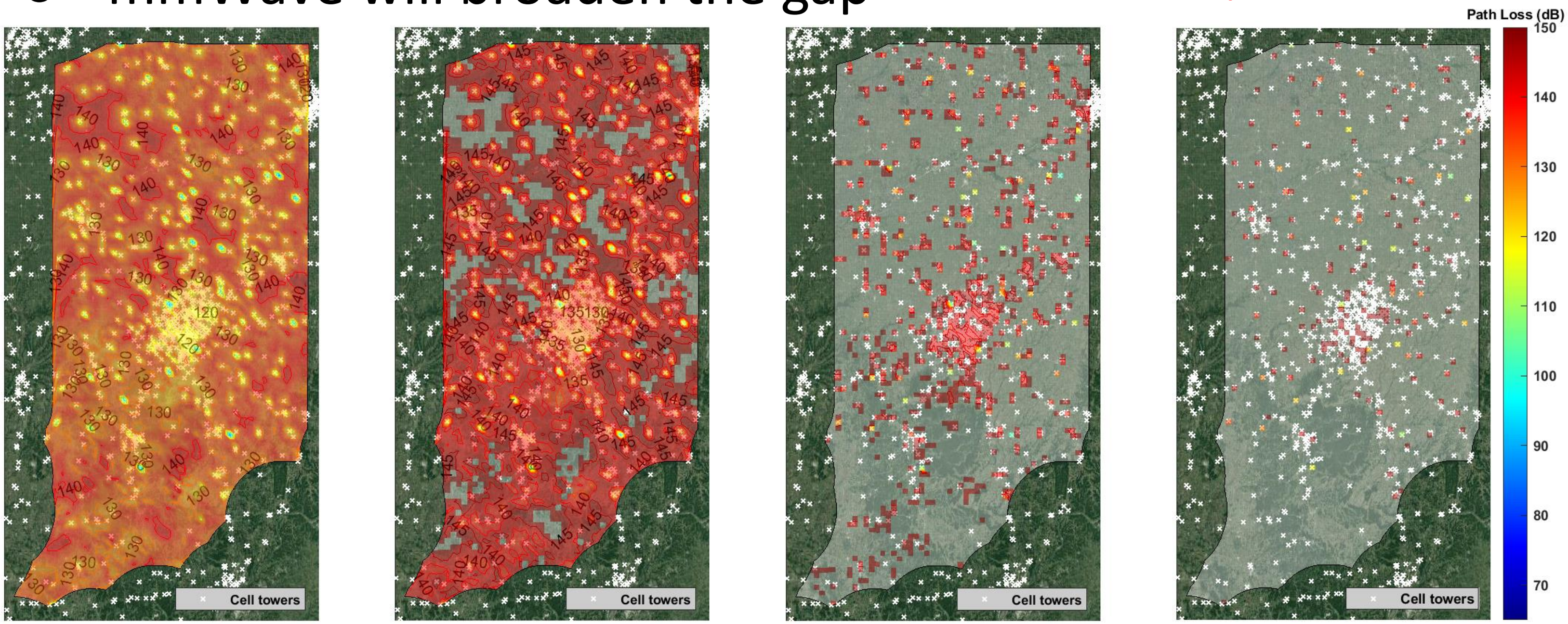
Max. allowed path loss = 150 dB



(a) 1900 MHz (b) 4700 MHz (c) 13 GHz (d) 28 GHz

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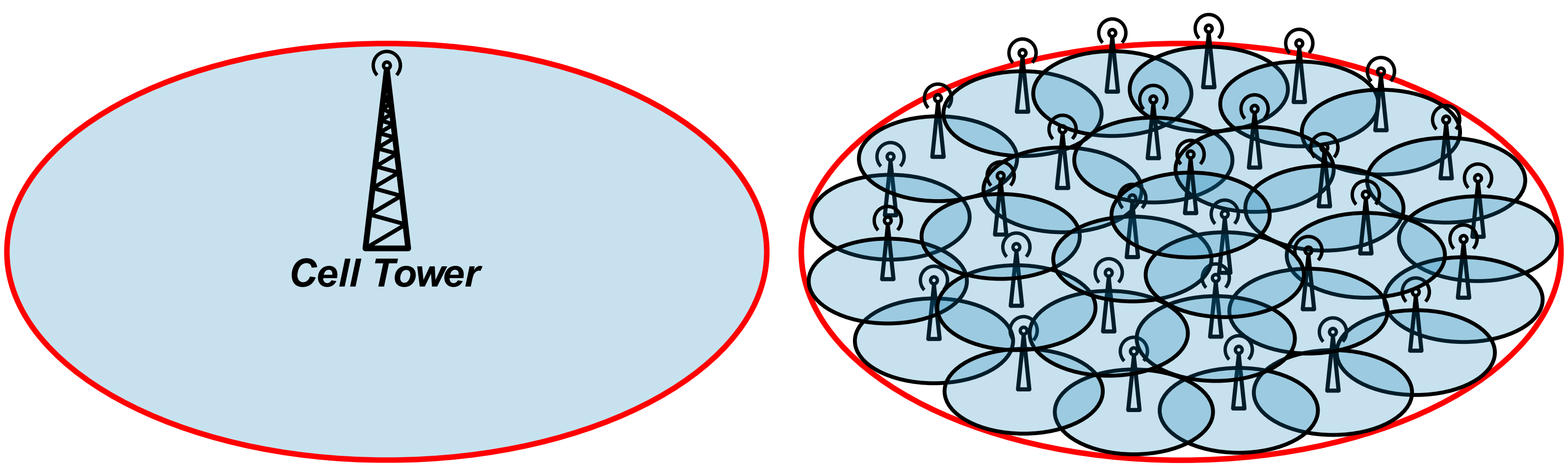

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IN Area (km^2)	Sim. Area (km^2)	Carrier Freq. (MHz)	Max. Allowed Loss (dB)	Covered Area (km^2)	Max. Cell Radius (km)	Max. Cell Area (km^2)	Min. # of New Towers Needed	# of Existing Towers
94,321	52,348	1900	150*	52,348	2.44	18.7	0	819
		3700		51,044	1.49	7.0	187	
		4700		47,159	1.25	4.9	1064	
		7000		34,187	0.98	3.0	6029	
		13,000		10,312	0.86	2.3	18,062	
		28,000		2291	0.69	1.5	32,988	

* The typical max. allowed path loss for LTE systems is 140 dB: Y. Zhang, T. Arakawa, J. V. Krogmeier, C. R. Anderson, D. J. Love and D. R. Buckmaster, "Large-Scale Cellular Coverage Analyses for UAV Data Relay via Channel Modeling," ICC 2020 - 2020 IEEE International Conference on Communications (ICC), 2020, pp. 1-6, doi: 10.1109/ICC40277.2020.9149403.

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x US$200,000–250,000/tower

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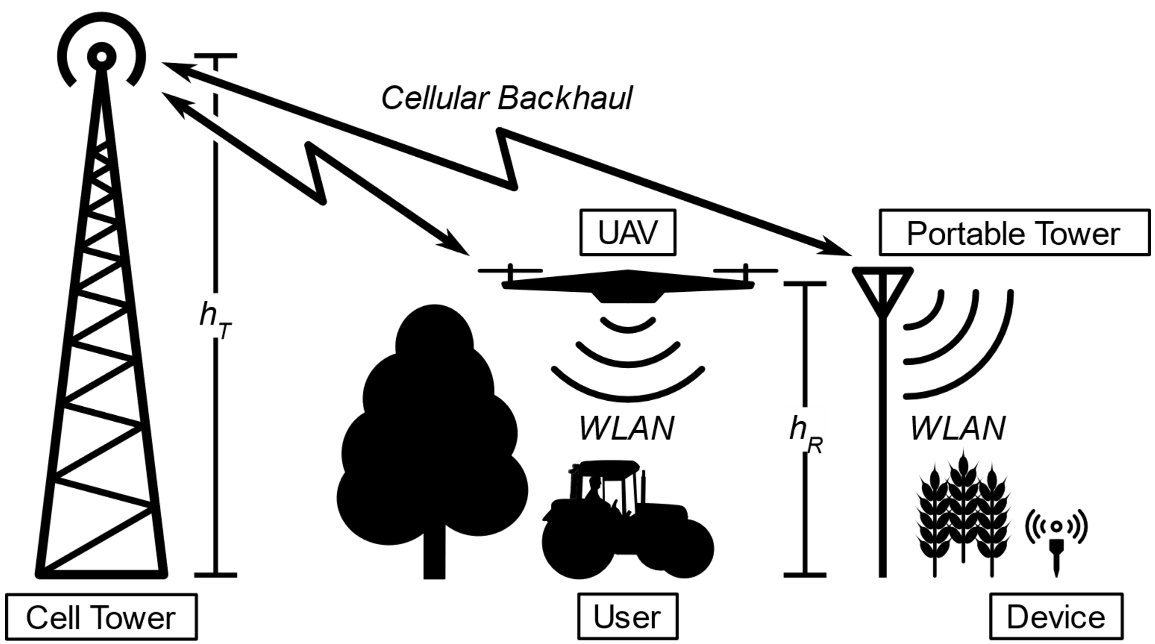
Digital Divide

- Key Rural Wireless Communications Characteristic to Take Advantage of...
    - Temporary Coverage
      => On-demand Facility Deployment



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SUMMARY

- Millimeter Wave (mmWave)
  - Extremely sensitive to blockages
- Channel Charting (CC)
  - Advantage: Unsupervised learning
  - New challenge: Higher precision required
- Dense network is impractical in near future
  - Especially for ubiquitous coverage in rural areas
  - Potential solutions
    - Site-specific channel modeling & simulation
    - On-demand facility deployment

Thank you!

Sponsorship for this work was provided by the Foundation for Food and Agriculture Research (FFAR) under Award 534662, and the NSF under grants CNS-1642982 and EEC-1941529.

Thanks to Professor Jinha Jung at Purdue University for assisting with the Indiana statewide LiDAR data set.

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IoT4Ag
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an NSF Engineering Research Center

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