Joint RADAR - Communication (JRC) based wireless localization

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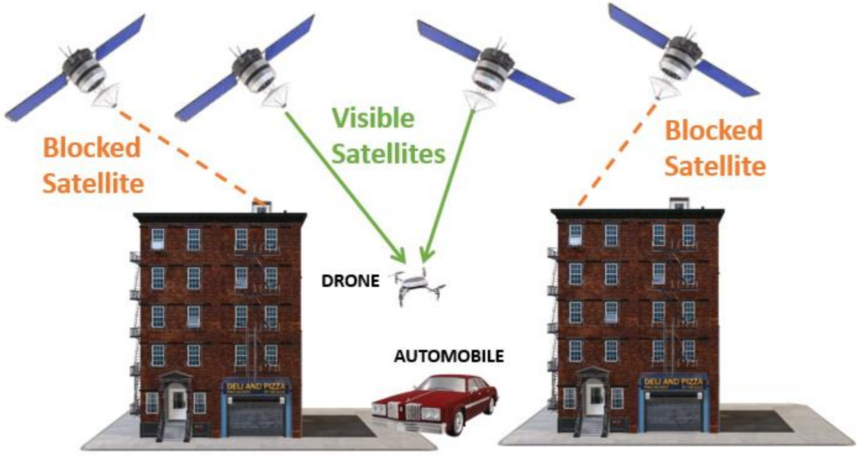
Student members: Gaurav Duggal & Charles Thornton
Advisors: Prof. Harpreet S. Dhillon & Prof. R. Michael Buehrer

VIRGINIA TECH.

Motivation

1. According to a PWC report, a portion of the Drone market is transportation sector, which includes parcel deliveries, is valued at $13bn[1]
2. Drones require localization for navigation which is provided by GNSS systems
3. GNSS systems are affected by blockages due to high rise buildings in urban environments.

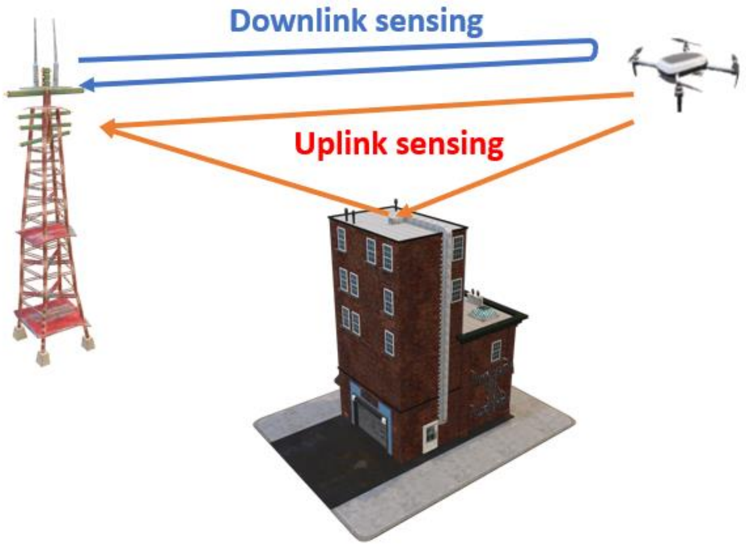


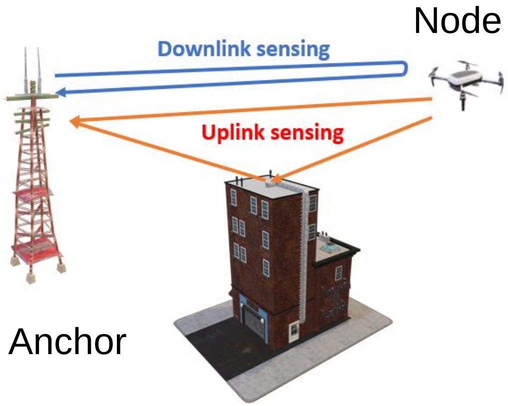
[1] "Welcome to the era of drone-powered solutions: a valuable source of new revenue streams for telecoms operators", PWC 2017

[2] Kuutti S, Fallah S, Katsaros K, Dianati M, Mccullough F, Mouzakitis A. A survey of the state-of-the-art localization techniques and their potentials for autonomous vehicle applications. IEEE Internet of Things Journal. 2018 Mar 5;5(2):829-46.

Radar vs Communication systems and JRC

1. Radars waveforms are designed to have good ambiguity functions which makes them unsuitable for communication systems
2. Communication system waveforms are designed to maximise information carrying capacity and are unsuitable for Radar systems
3. We look at a Joint Radar Communication (JRC) system with a shared TX waveform between the radar and communication system





S. No.	Uplink sensing	Downlink sensing
1	Node - TX Anchor - RX	Anchor - TX Anchor - RX Node - reflector
2	Symbols are not known a priori at the RX	Symbols are known a priori at the RX
3	Half duplex transceiver	Full duplex transceiver to resolve signal leakage problem
4	RX-TX are not time and phase synchronised	RX-TX are time and phase synchronised
6	Clutter not a major issue	Clutter removal required
7	One sided propagation of signal	Two way propagation of signal

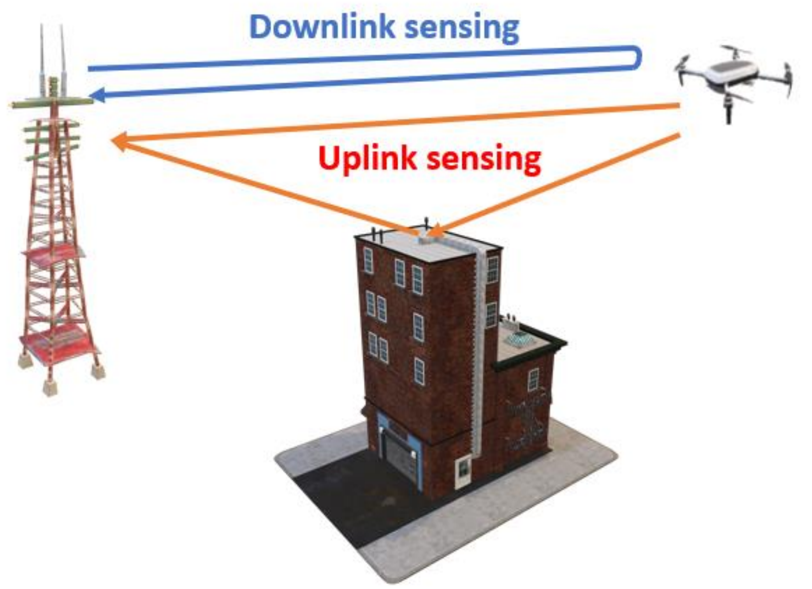
From Sensing to Localization in a JRC

1. The goal is to estimate the position of the node based on the underlying channel parameters like propagation delay, Doppler and AoA

2. The anchors transmit a communication waveform and using reflected signal from the node we estimate the two way propagation delay and AoA at the anchor

3. In uplink sensing the node transmits a signal and the one way propagation delay to each anchor is estimated at the anchor

4. The NLoS bias is the difference between the euclidean distance between the node and the anchor and the multipath.



Zhang, J. Andrew, et al. "Enabling joint communication and radar sensing in mobile networks-a survey." ***IEEE Communications Surveys & Tutorials*** **(2021).**

Research challenges for localization in a JRC network

1. Downlink sensing needs techniques for clutter suppression.
2. Urban and Rural scenarios offer different Line of Sight (LoS) probabilities and NLoS bias which can significantly impact localization performance
3. Localization performance is affected by different RF propagation characteristics for mmwave/cmwave e.g. different Attenuation, AoA spread.
4. CRLB Localization bounds in various environments need to be developed to help guide system and algorithm design
5. Waveforms are spatially, temporally and frequency fragmented which impacts all the above

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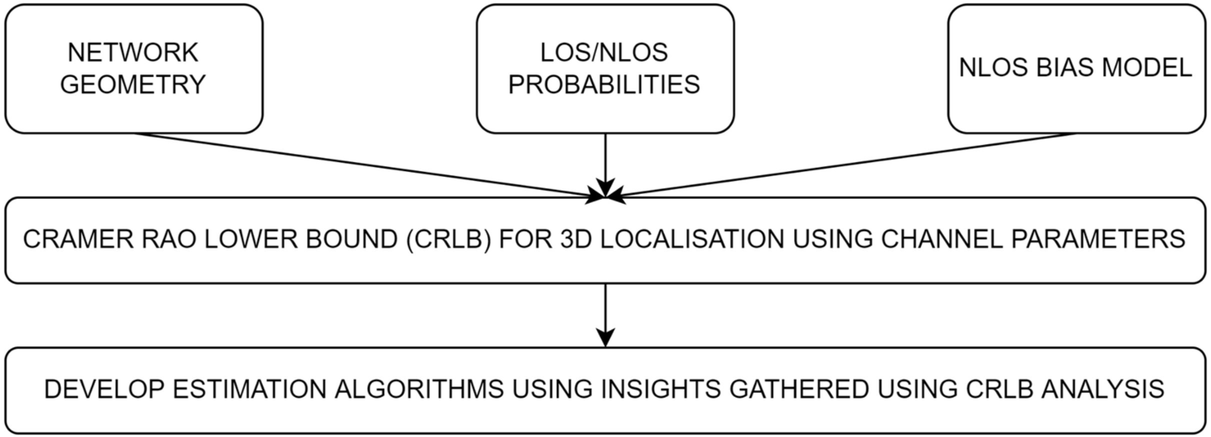
Research Plan



1. **NETWORK GEOMETRY:**
   a. 3D modelling[1]
   b. Stochastic geometry[2,6]

1. **LOS/NLOS PROBABILITIES:**
   a. RayTracing[3]
   b. Stochastic geometry[2,6]

1. **NLOS BIAS MODEL**
   a. Stochastic geometry[4]

[1]OpenStreetMap contributors. (2017). Planet dump retrieved from https://planet.osm.org

[2]H. S. Dhillon and V. V. Chetlur, Poisson Line Cox Process: Foundations and Applications to Vehicular Networks. Morgan & Claypool, Jun. 2020.

[3]Nuckelt J, Rose DM, Jansen T, Kürner T. On the use of OpenStreetMap data for V2X channel modeling in urban scenarios. In2013 7th European Conference on Antennas and Propagation (EuCAP) 2013 Apr 8 (pp. 3984-3988). IEEE.

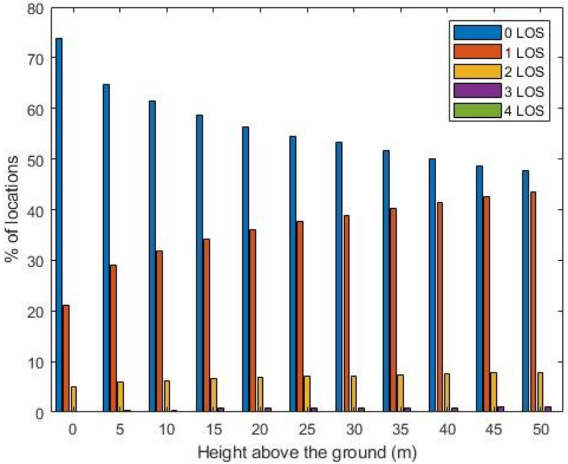
[4]C. E. O’Lone, H. S. Dhillon, and R. Michael Buehrer, “Characterizing the first-arriving multipath component in 5g millimeter wave networks: Toa, aoa, and non-line-of-sight bias,” IEEE Transactions on Wireless Communications, pp. 1–1, 2021.

[5]J. G. Andrews, A. K. Gupta, A. M. Alammouri and H. S. Dhillon, *An Introduction to Cellular Network Analysis using Stochastic Geometry*. Morgan & Claypool Publishers, in press.

A model test case: Urban environment

LEFT: 3D model of Lower Manhattan

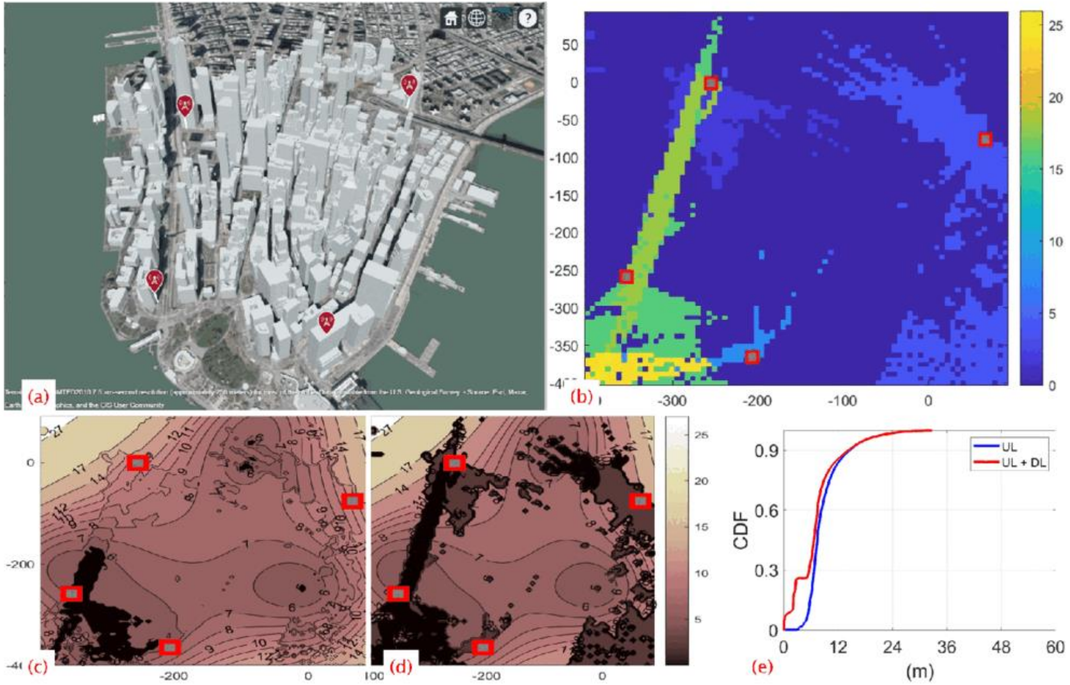
RIGHT: LoS probabilities to anchors increases for a node varied in the X-Y plane with increasing heights above the ground



1. Four anchors are placed in the urban environment and the node is varied along an X-Y plane at various height above the ground

1. The NLoS bias has an exponential distribution.

CRLB for joint Uplink & Downlink localization in an urban environment

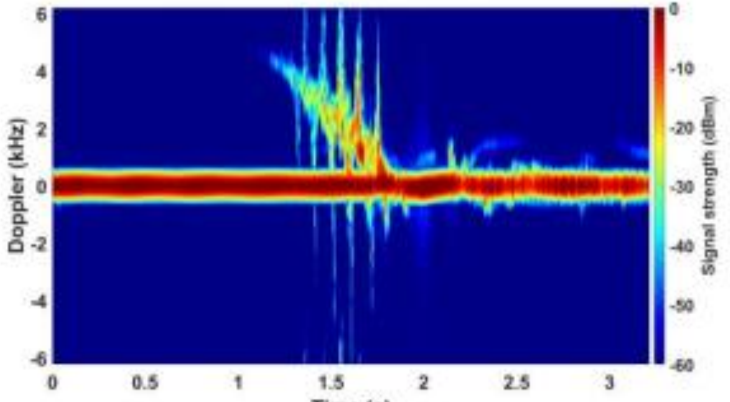


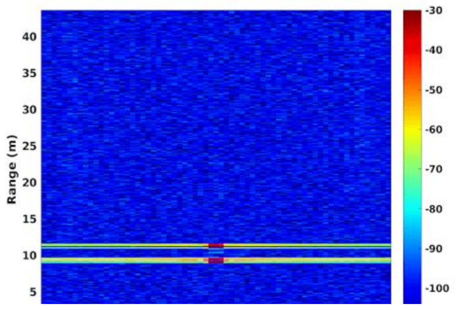
S. No.	Parameter	Value
1.	Uplink Bandwidth	50 MHz
2.	Downlink Bandwidth	50 MHz
3	Array size	4x4
4	NLoS bias	0.2
5.	Downlink TX power	0 dBW
6.	Uplink TX power	0 dBW
7.	Noise power	-126 dBW

1. A closed form expression for CRLB for Uplink/Downlink sensing was derived and compared with a traditional uplink ToA system at heights between 0-60m above the ground.

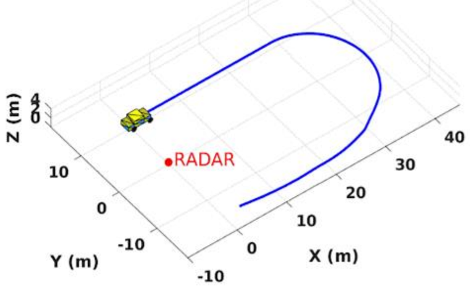
Association problem

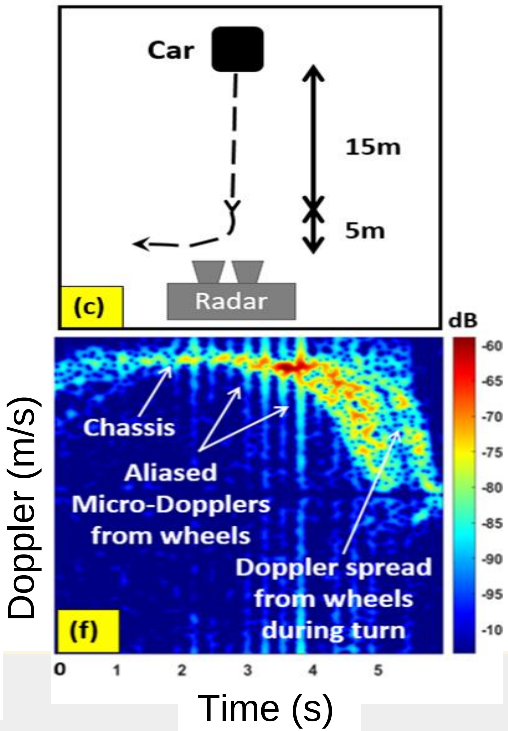
1. The CRLB analysis implicitly assumes that the uplink and downlink measurements for the same nodes are linked to each other.
2. The downlink sensing range-Doppler plot has micro-Doppler features which in conjunction with machine learning can be used to identify the target and hence associate the uplink and downlink measurements.





Range-Doppler plot for downlink sensing





Left: micro-Doppler features of a DJI Inspire drone
Middle: Range-Doppler plot of a car moving on a track
Right: microDoppler features of a car

Team

Gaurav Duggal is a first year PhD student at Virginia Tech with previous work experience in Qualcomm, India. His work in radar signal processing during his master's degree led to the publication of one first author journal paper in IEEE Transactions on Aerospace and Electronic Systems and two conference papers in IEEE radarconf 2019 and 2020.

Charles Thornton is a PhD Student at Virginia Tech. He has authored two journal articles, one magazine article, and a dozen conference papers in the areas of signal and information processing for cognitive radar systems. He is the recipient of the Vanu Bose best paper award at IEEE MILCOM for work on a universal learning scheme for adaptive target tracking.

Prof. Dhillon is an associate professor and the Elizabeth and James E. Turner Jr. '56 Faculty Fellow at Virginia Tech. His work on wireless communications and stochastic geometry has received six best paper awards including the prestigious IEEE ComSoc Leonard G. Abraham Prize in 2014, the IEEE ComSoc Young Author Best Paper Award in 2015, and the IEEE ComSoc Heinrich Hertz Award in 2016. He has supervised numerous PhD dissertations on various aspects of wireless communications, localization, and stochastic geometry.

Prof. Buehrer is an IEEE Fellow for his contributions in signal processing for wireless communication and geolocation and has also successfully supervised multiple PhD students in his field of expertise. He has co-authored a highly cited book in the field of localization in wireless networks titled Handbook of position location: Theory, practice and advances.

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