NRI: FND: Action-perception loops over 5G millimeter wave wireless for cooperative manipulation

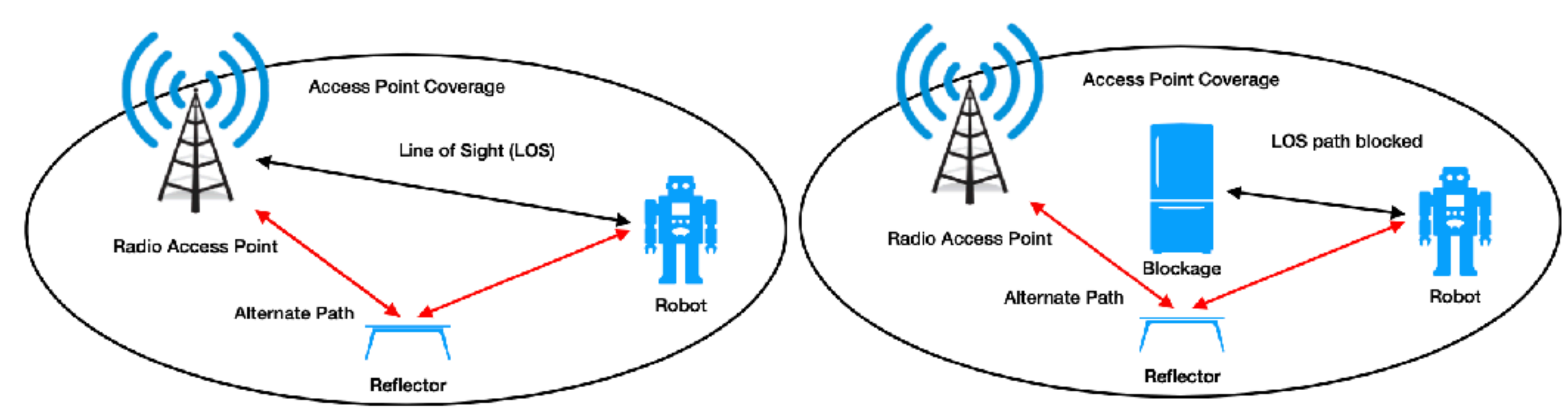
Ludovic Righetti, Sidharth Garg, Elza Erkip and Sundeep Rangan
New York University

https://www.machinesinmotion.org/projects/5G_robotics.html

Motivation autonomous robots need increasing access to computation but available on-board computing is limited. The high bandwidth and low latency communication offered by 5th generation wireless technology can help offload real-time action-perception loops to the network edge.

mmWave Wireless opportunities and issues

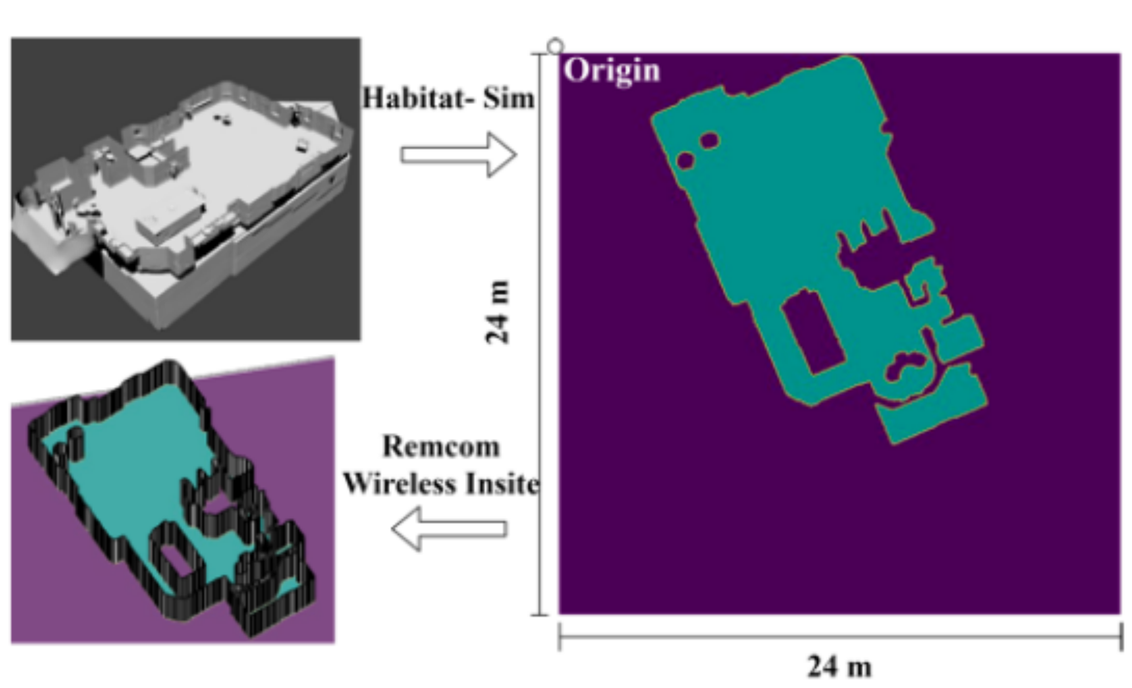
Massive data rates (>25Mbps/user > 1Gpbs peak rate)
Low airlink latency (1-2ms)
Directional signal (line of sight)
+ Opportunities for high frequency real-time loops
+ mmWave receiver as a directional sensor
- easy signal blockage and difficult to predict delays

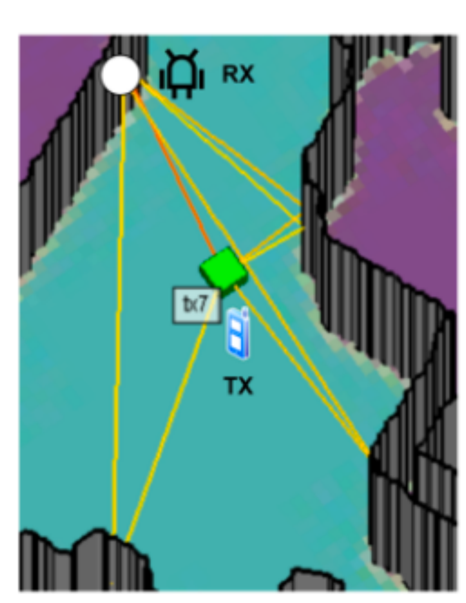


(a) No blockage (b) With blockage

open mmWave wireless modeling for robotics

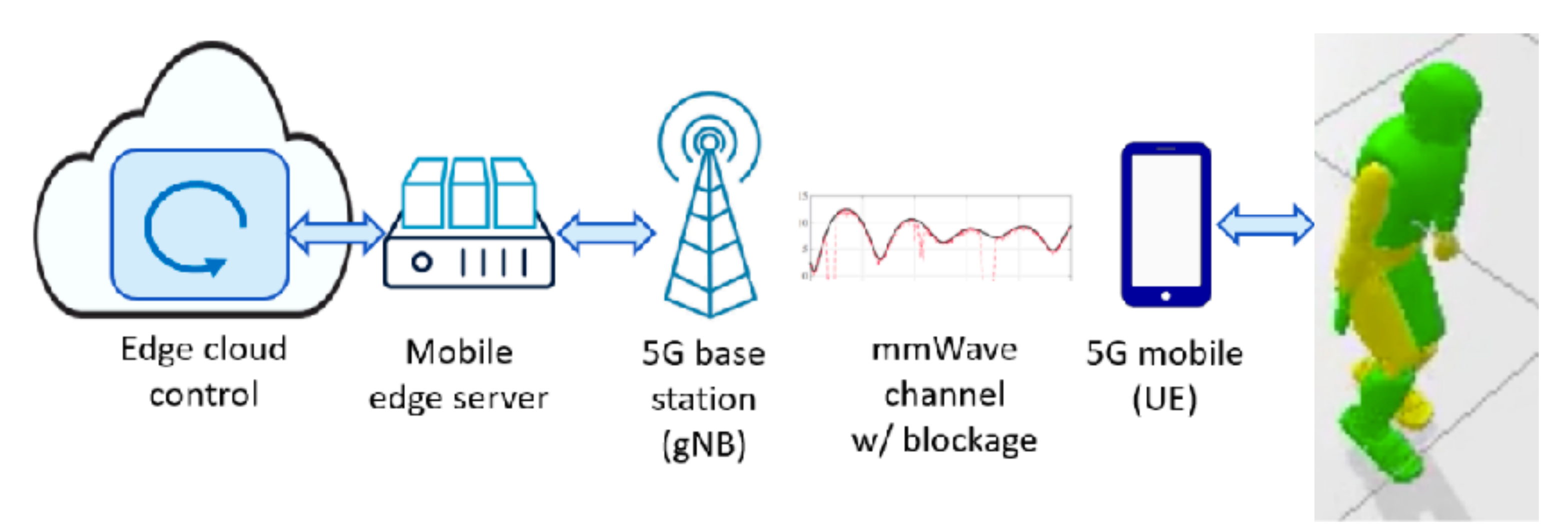
- Physics simulation with realistic 5G communication with blockage in indoor environments [Zhu et al. 2020]
- Detailed mmWave signal models for navigation, including antenna and multiple array modeling
- Indoor MmWave Robotic Data Sets [Yin et al. 2022]





whole-body control over wireless

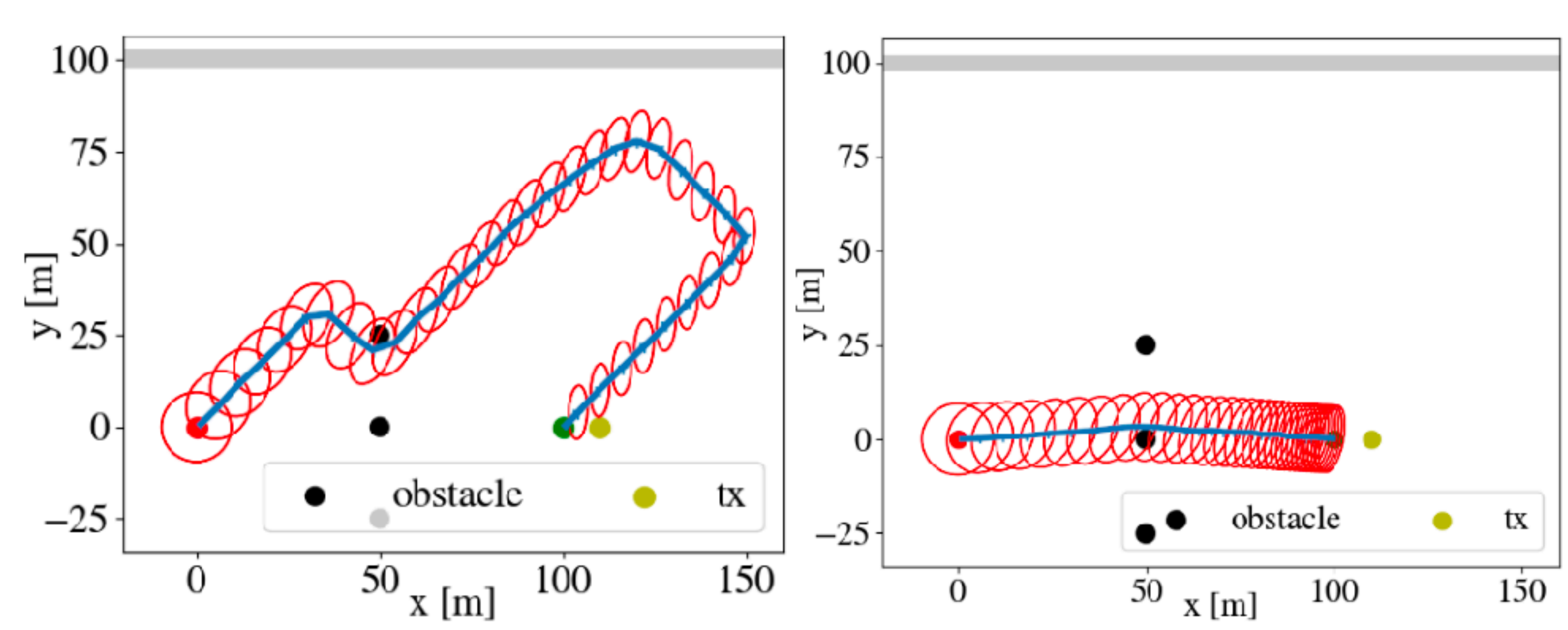
Blockage-robust remote hierarchical inverse dynamics control over mmWave
on the edge: compute control law + constraint-consistent first-order approximation of feedback control (KKT matrix)
on the robot use edge-computed approximation during delays and blockages to ensure 1KHz control



=> humanoid walking robust to blockages and delays with reduced cost local control [Zhu et al. 2020]

planning under uncertainty to localize mmWave sources

use mmWave directional signal to locate mmWave emitter (for rescue/localization scenarios) and lower probability of communication loss (for edge control applications)
mmWave signal classification [Yin et al. 2022]
use our open dataset and wireless models to build classifiers for line of sight and multi-paths mmWave reception
efficient belief-space trajectory optimization for MPC [Pfeiffer et al. 2023]
EKF + variance minimizing iLQR in a complete navigation pipeline
=> more efficient and reliable navigation (time to target + success rate)



Method	Success rate	Duration
LOS+1^{st}-NLOS EKF (Ours)	94.5%	76%
LOS+1^{st}-NLOS EKF T=0 (Ours)	94.5%	82%
LOS+1^{st}-NLOS AoA [11]	89.5%	100%

References

K. Pfeiffer et al., "Path Planning Under Uncertainty to Localize mmWave Sources," ICRA 2023.
M. Yin et al., "Millimeter Wave Wireless Assisted Robot Navigation with Link State Classification," IEEE Open Journal of the Communications Society, 2022
H. Zhu et al., "Enabling Remote Whole-Body Control with 5G Edge Computing," IROS 2020

2023 FRR & NRI Principal Investigators' Meeting
May 2-3, 2023
Award ID#:1925079