

# Teleoperating Autonomous Vehicles over *Vertical-Aware* 5G/NextG Networks using *the NSF POWDER Testbed*

Zhi-Li Zhang

Distinguished McKnight University Professor  
& Qwest Chair Professor

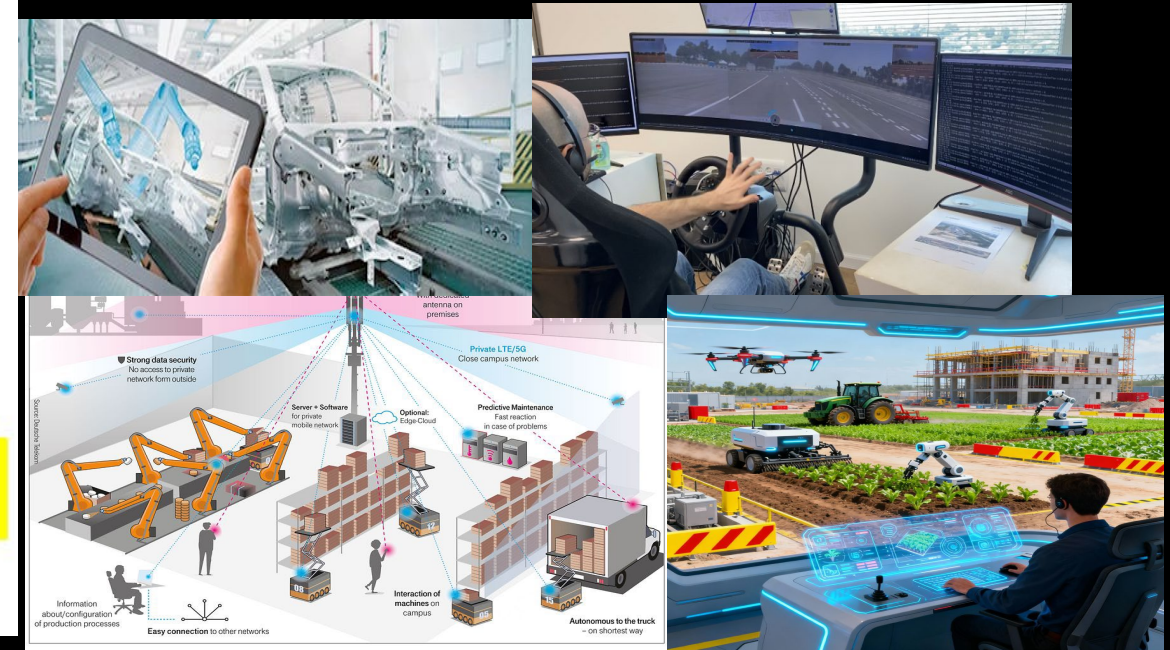
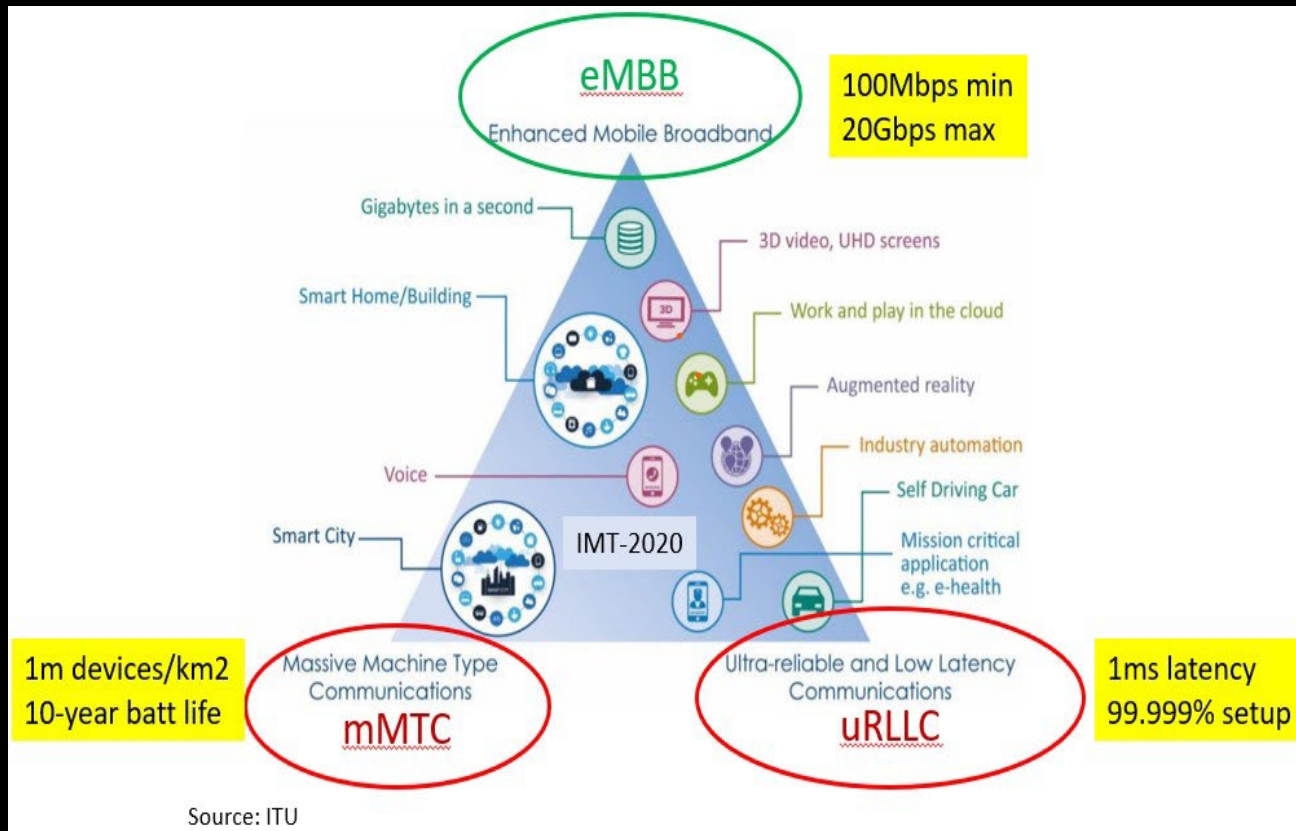
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# 5G and Its Many Promises ...

❖ 5G introduces three new services, aiming to support new use cases

**Example use cases:**

- remote monitoring
- tele-operations & remote control
- remote diagnostics & troubleshooting

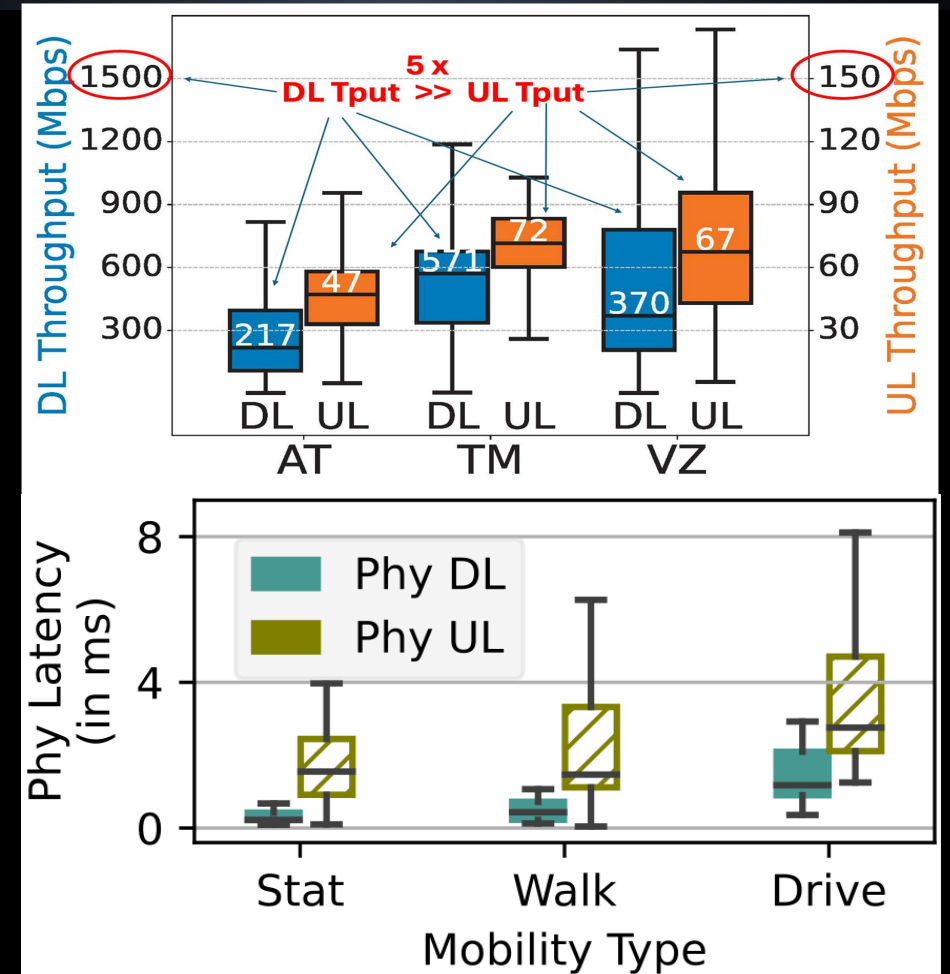




# But What Have Been Deployed Are Quite Different!

MNOs largely still focus on 5G eMBB service for smart phone users !

- Most improvements manifest in downlink (DL)
- *Uplink (UL) performance is still limited!*
- **Downlink/Uplink Bandwidth Asymmetry:**
  - downlink (DL) “heavy”
  - *but many emerging applications need more bandwidth (bw) for uplink (UL) sensor data*
- **DL/UL Asymmetry: Latency**
  - Uplink latency is also worse than downlink
- **(High) mobility in particular poses many serious challenges!**
- **Especially, handovers have significant impact!**



DL vs. UL latency  
(T-Mobile 5G standalone (SA))

# 5G Networks: Limitations & Major Challenges

- ❖ Existing (*deployed*) 5G networks are designed primarily for mobile broad access (eMBB) and smart phones!
  - “one size fits all”



## **NSF 24-545: Ideas Lab: Breaking the Low Latency Barrier for Verticals in Next-G Wireless Networks**

*TIP is seeking to identify and address critical architectural, technical and technological issues that must be resolved in the fifth generation (5G) and next generation (Next-G) wireless networks to provide the necessary low-latency performance that is required for the success of key emerging vertical industries. starting on August 15, 2025*

# NSF Ideas Lab: Breaking Low: *DRIVE-SAFE*: Remote and Cooperative Autonomous Driving in Dynamic Environments using 5G/NextG Technology



*two-year project starting on August 15, 2025*

<https://nsf-breaking-low-drive-safe.net/>

## ***Goal of DRIVE-SAFE project:***

- ***Tackling the challenges posed by vehicle mobility to enable safe remote driving***
- ***develop solutions using open-source 5G/O-RAN stack***
- ***conduct pilot demos using NSF POWDER Testbed***



# PIs/co-PIs and Partner Organizations

- ❧ *Zhi-Li Zhang*: lead PI, University of Minnesota
- ❧ *Kobus Van der Merwe*: PI, University of Utah
- ❧ *Hang Qiu*: PI, University of California, Riverside
- ❧ *Fan Bai*: co-PI, General Motors
- ❧ *Nakjung*: co-PI, Nokia Bell Labs



<https://nsf-breaking-low-drive-safe.net/>

# Quickly: Why AV Teleoperations (Remote Driving)?

- Today's so-called level-4 (or lower-level) autonomous vehicles (AVs) are limited to specific "operational design domain" (ODD)
  - Requires massive amounts of data, training, testing, etc.
  - Requires detailed mapping of the *designated* operational environments
- While working well in most "normal" situations, have trouble with "unseen" edge cases or "rare" events – *whereas human drivers often have no issues*
  - *e.g., accidents on the road, construction zones, parking lots, ...*

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The screenshot shows a web browser displaying a The Verge article. The navigation bar at the top includes 'Home / Car Culture / Tech' and 'The Verge / Tech / Reviews / Science / Entertainment / AI /'. The article title is 'Here's a running list of all of Tesla's robotaxi mishaps so far', with sub-navigation links for 'NEWS', 'TRANSPORTATION', and 'AUTONOMOUS CARS'. The byline is 'By Tolu Akinshete' and the publication date is 'Published Jan 15, 2025'. A sidebar on the left shows social media sharing options and a '8 Times' counter. The main text snippet reads: 'Driving on the wrong side of the street, phantom braking, dropping passengers off in busy intersections – and it's just been three days!'. A partial article snippet on the right mentions 'Self-driving' and 'ng lot in'. Social media icons for Facebook, X, and YouTube are visible at the bottom right.

Home / Car Culture / Tech

The Verge / Tech / Reviews / Science / Entertainment / AI /

8 Times

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By Tolu Akinshete

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NEWS TRANSPORTATION AUTONOMOUS CARS

## Here's a running list of all of Tesla's robotaxi mishaps so far

Driving on the wrong side of the street, phantom braking, dropping passengers off in busy intersections – and it's just been three days!

Self-driving  
ng lot in

f X

# *Remote Driving Comes to Rescue !?*

- These challenges have given rise to the notion of remote driving --- an alternative and *complementary* approach

*But is today's 5G up to the task?*

TIMES INSIDER

Published Sept. 11, 2024 Updated Sept. 21, 2024

## *When Self-Driving Cars Don't Actually Drive Themselves*

An immersive article shows readers what a New York Times reporter has tracked for nearly a decade: Robot taxis still need human help.

# Developing a Remote Driving System



- Our lab has been building a tele-operation systems in the past 2 years  
--- funded by an ongoing NSF CISE Large project (CNS-2321531)

<https://avteleoperation.umn.edu>

<https://networking.umn.edu/areas/autonomous-vehicles>



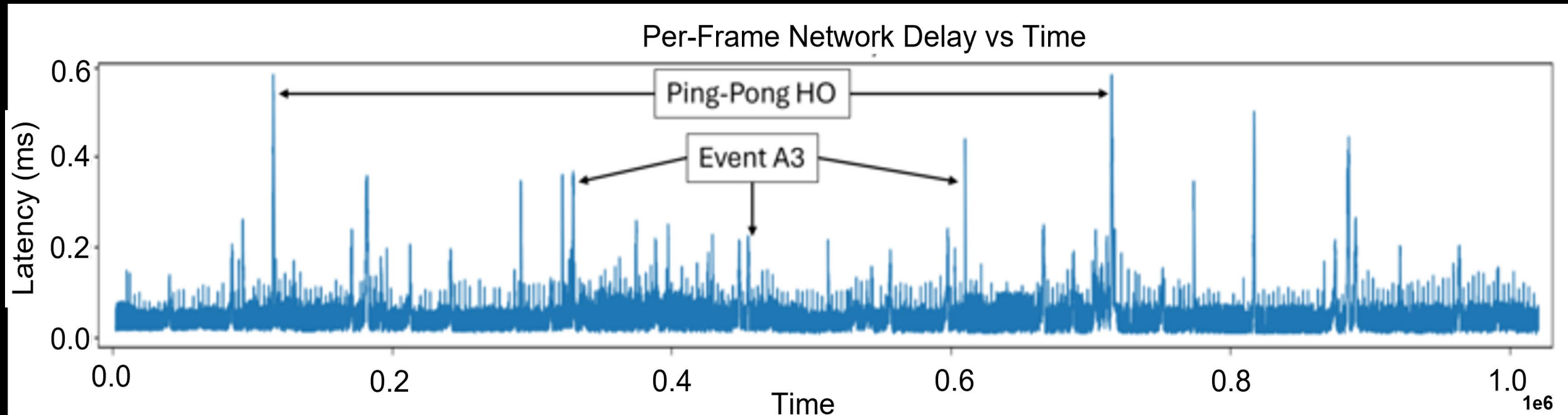
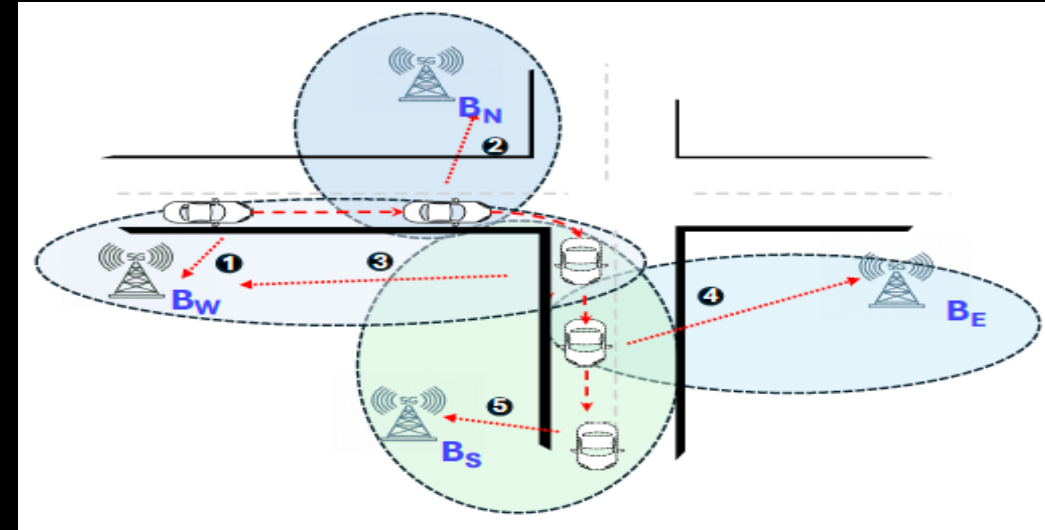
UMN Level-3 Research  
Vehicle (MnCAV)





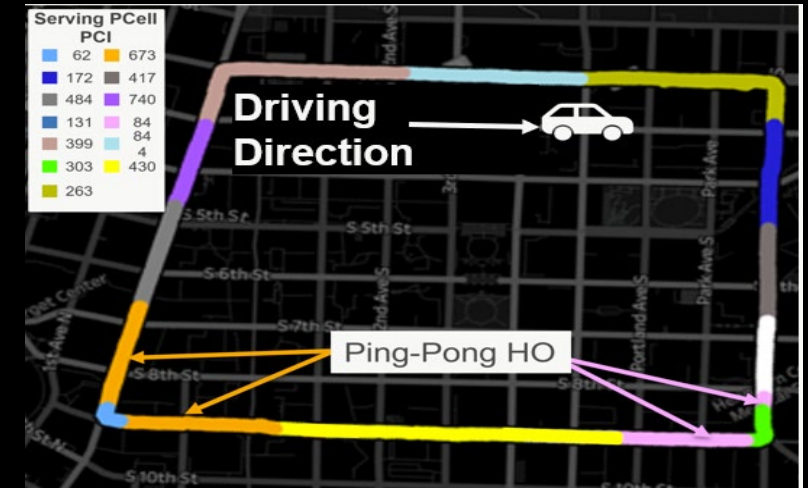
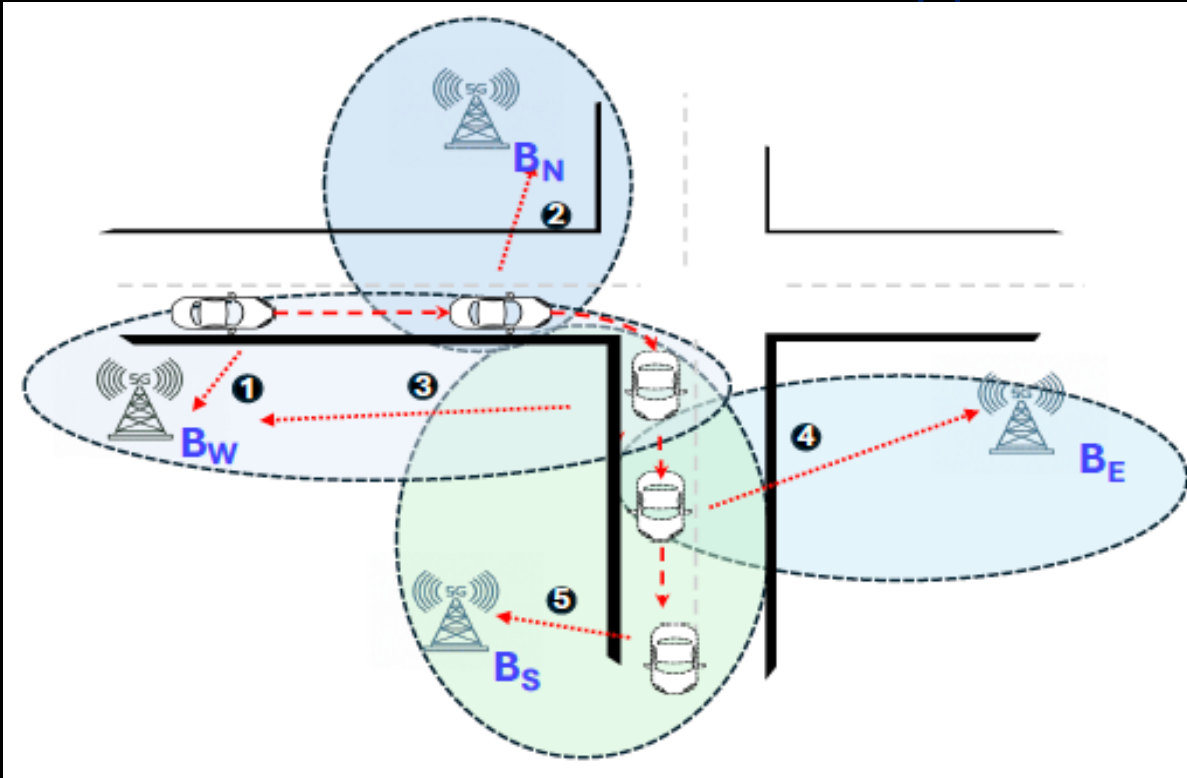
# Frequent 5G Handovers and Their Impacts

- Handovers (HOs) are inevitable when (remote) driving!
- they incur significant latency spikes!
- Further worsen end-to-end latency performance!



# Worse: “Ping-Pong” Handovers and Their Impacts

- “Ping-Pong” or *unnecessary* HOs – hand-over to a “wrong” base station that causes additional HOs (switching back or to another base station quickly)
- Further worsen end-to-end latency performance!



# ***DRIVE-SAFE: Proposed Solution***

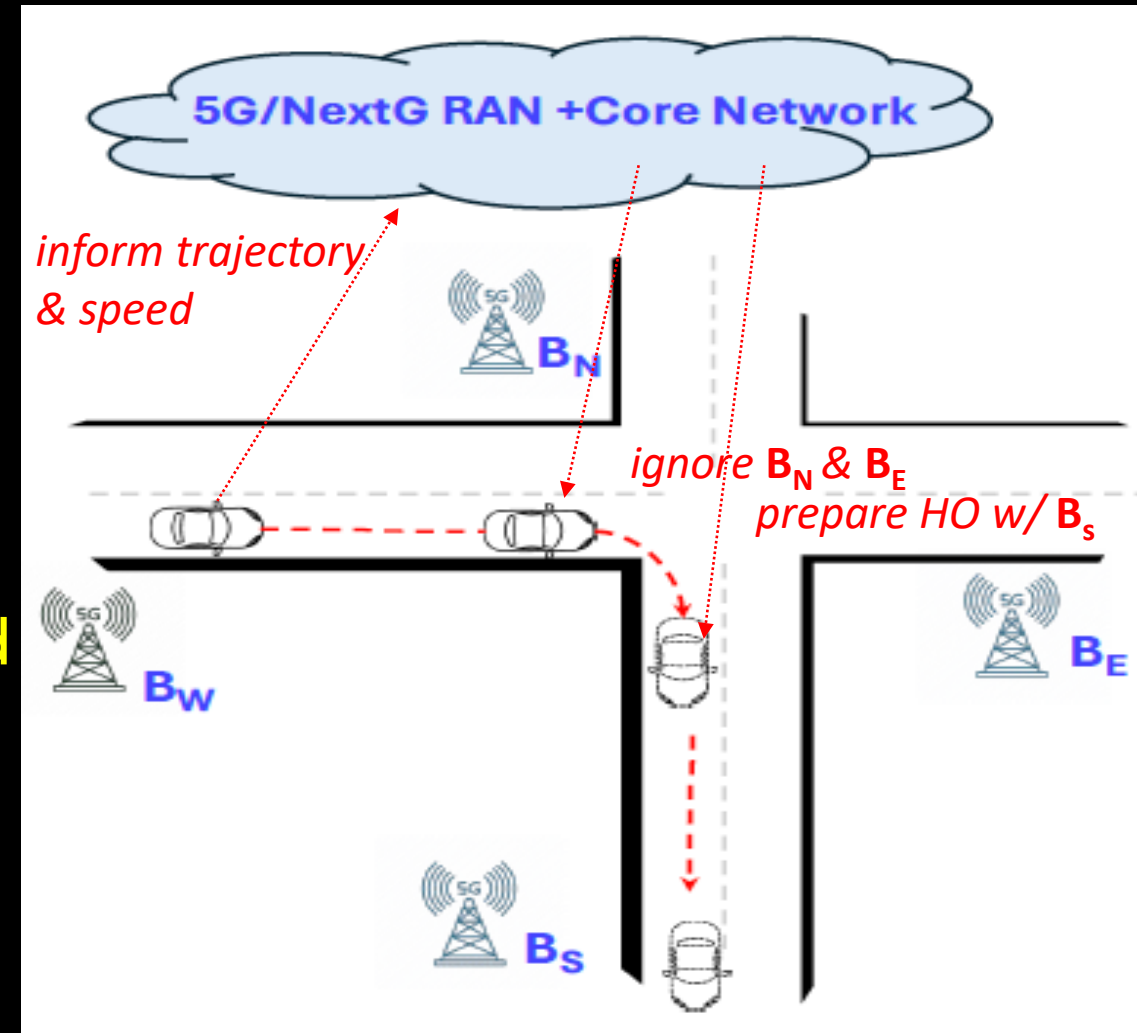
## ***Vertical-Driven NextG Co-Design***

***Focusing in particular on the challenges posed by***

- ***Frequent handovers (HOs), esp. “ping-pong” HOs***
- ***Latency induced by transmission errors/packet losses caused by vehicle mobility***

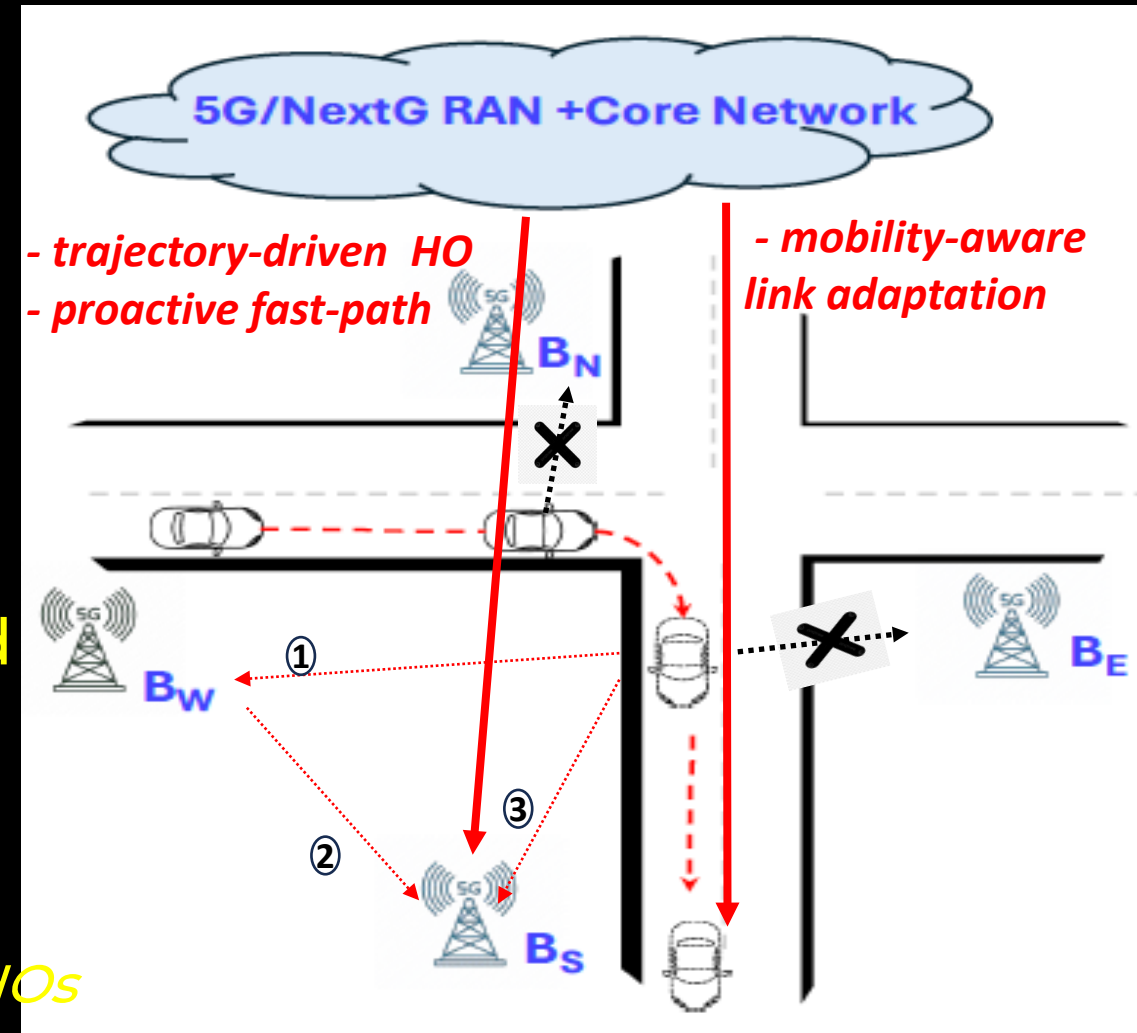
# Basic Ideas: Vertical-Aware NextG Networks

- Vehicle knows where it is going, and how fast it is going
  - inform the NextG network of its trajectory, speed, etc.
- NextG network knows where base stations are located, radio bands used
  - can predict when handover events might happen and inform the vehicle



# Basic Ideas: Vertical-Aware NextG Networks

- Vehicle knows where it is going, and how fast it is going
  - inform the NextG network of its trajectory, speed, etc.
- NextG network uses the info to
  - ✓ control which base station to handover to, *thus avoiding “ping-pong” HOs*
  - ✓ perform *speed-aware* link adaptation to *minimize transmission errors*, etc.
- NextG network knows where base stations are located, radio bands used
  - can predict when handover events might happen and inform the vehicle
- Vertical application uses the info to
  - ✓ *intelligently decides when or not to transmit & how much to transit before HOs*



# ***Proposed Vertical-Aware 5G/NextG Architecture***

We leverage the Open-RAN (radio access network) architecture and make both O-RAN and 5G/NextG networks *vertical-aware*!

- *application-network mapping services* + vertical-network info exchange APIs
- *vertical-aware RICs* (and vertical-aware E2 service models + policies)



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We leverage the Open-RAN (radio access network) architecture and make both O-RAN and 5G/NextG networks *vertical-aware*!

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*Made possible thanks to*

- ❖ *open-source 5G/O-RAN software stacks (e.g., OCUDU & DURANTA)*
- ❖ *and NSF PAWR POWDER testbed !*

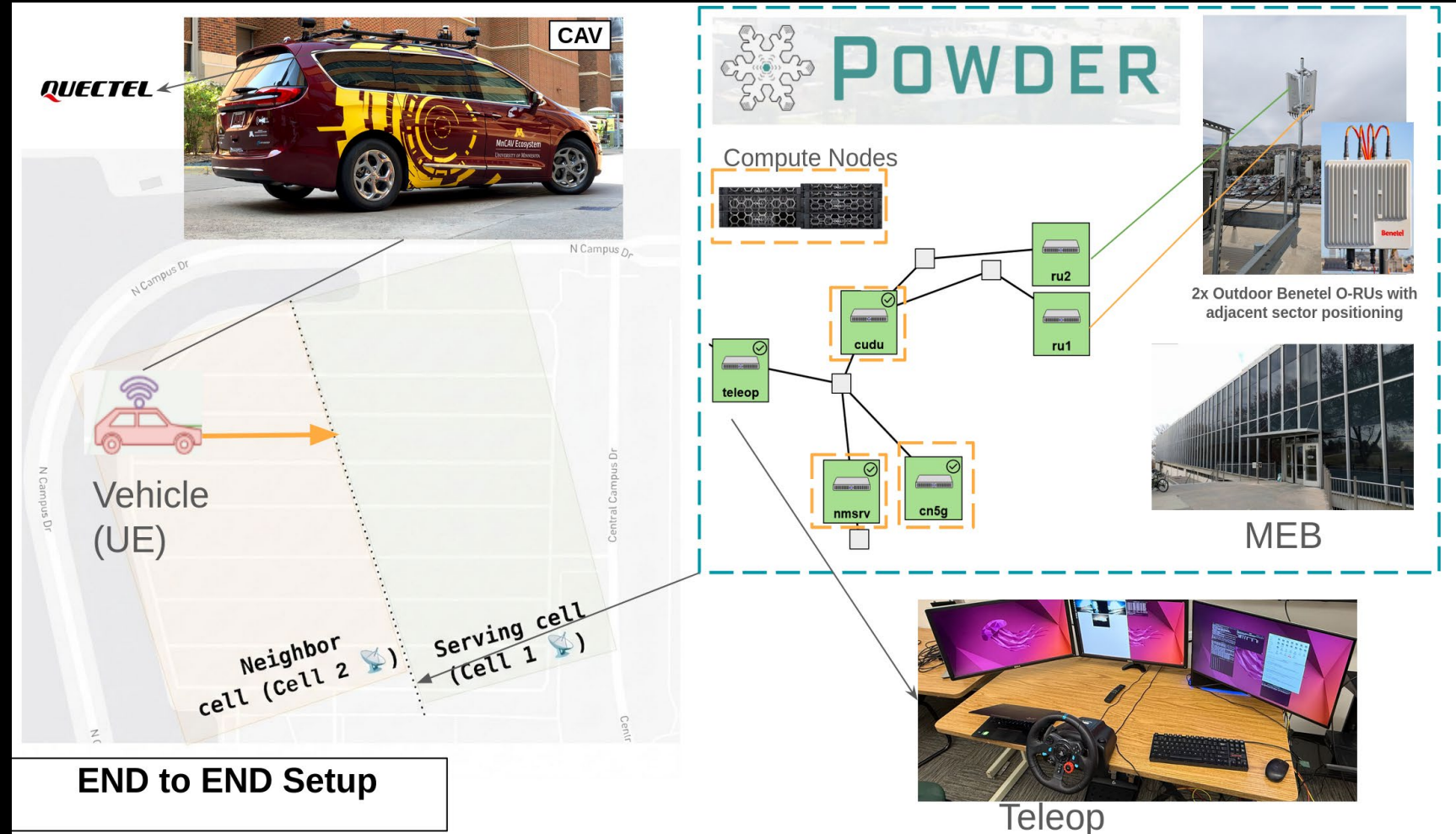
# NSF DRIVE-SAFE 9-Month Demos using POWDER

July 10-11 at Utah campus

- A lot of work spent on preparing the POWDER testbed
  - Big thanks to Kobus and his POWDER team!

## We Demonstrated:

- Trajectory-driven HO policy control
- Mobility-aware Link Adaptation
- End-to-end Remote Driving w/ vertical-aware O-RAN+5G networks



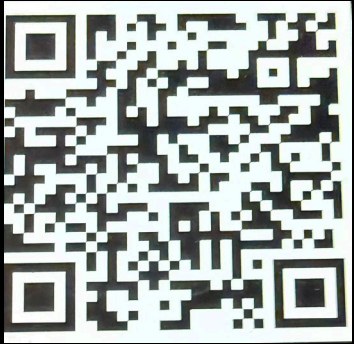
# ***NSF DRIVE-SAFE 9-Month Demos using POWDER***

- *“Official” Year 1 (12-month) demos: Oct 16-17*

*You are invited to join us!*



<https://nsf-breaking-low-drive-safe.net/>



*Thank You!*

*Questions?*

YouTube video link to our 9-month PR story:

[https://youtu.be/i40756I4J4g?si=1MSN\\_VGiuVBldBn0](https://youtu.be/i40756I4J4g?si=1MSN_VGiuVBldBn0)

*Many, many students (Ph.D, MS & undergrad), post-doc's  
and colleagues/collaborators contributed to the work!*

## *DRIVE-SAFE 9-month Demo Team Photo*

