# Wi-Go: Accurate and Scalable Vehicle Positioning using WiFi Fine Timing Measurement

**Slide credits: Ibrahim et al.**

Presented by:
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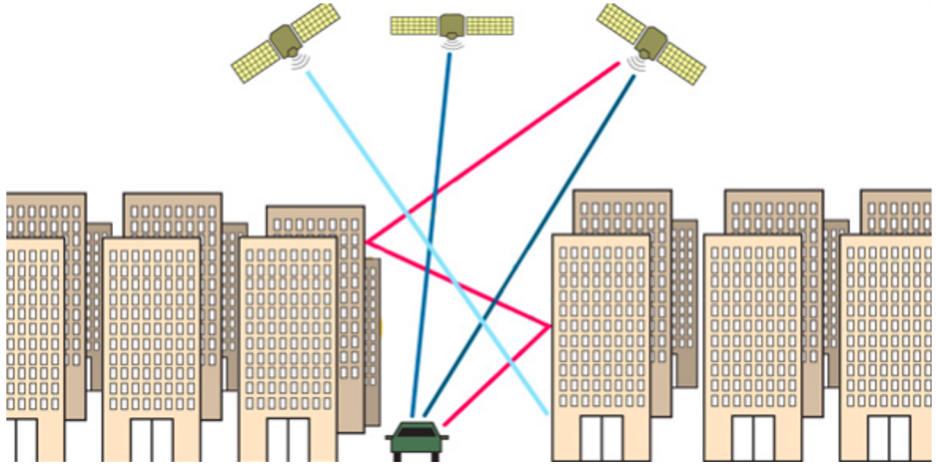
# Motivation

The rapid evolution of advanced driver assistance and vehicle automation systems have led to:

Increased demand for **lane-level vehicle positioning** that is accurate even in urban canyon environments.

# Today’s vehicle positioning

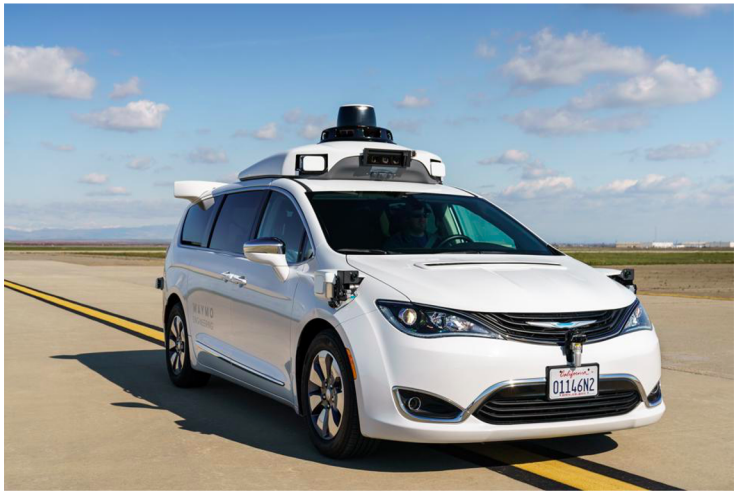
Today’s vehicles primarily use the Global Positioning System (GPS), often in conjunction with vehicle odometry for correcting short term GPS biases.



# Today’s vehicle positioning

Position accuracy can be further improved to a few meters with motion sensors and map matching.

For lane-level positioning, highly instrumented automated vehicle prototypes use **cameras** or **LiDAR** sensors to reference their measurements against available detailed models and imagery of the roadway.



# Can Wifi FTM help?

Single Burst with 3 FTMs per Burst

Wifi Fine Time Measurement (FTM)

$$RTT = \frac{1}{n}\left(\sum_{k=1}^{n} t_4(k) - \sum_{k=1}^{n} t_1(k)\right) - \frac{1}{n}\left(\sum_{k=1}^{n} t_3(k) - \sum_{k=1}^{n} t_2(k)\right)$$

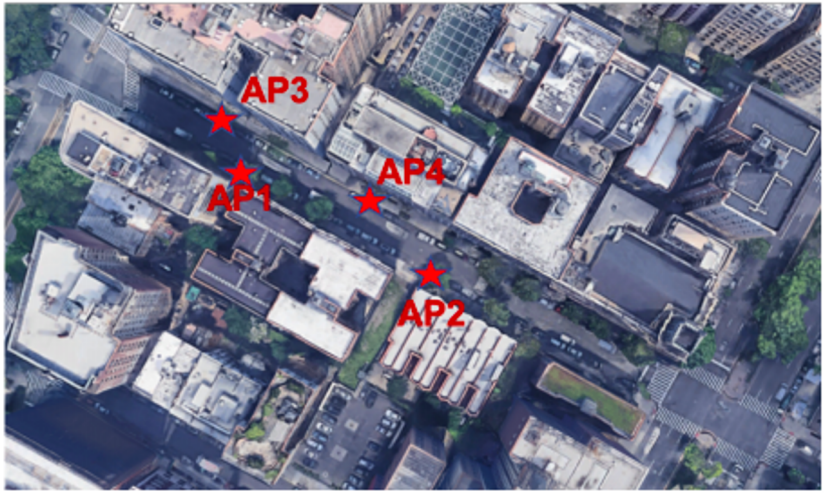
# Can Wifi FTM help?

Specially with high WiFi access points density

**Can WiFi FTM complement the existing GPS and odometry systems to achieve lane-level positioning in urban canyons?**


# Can Wifi FTM Augment GPS?

Upper Manhattan (Parked Cars)



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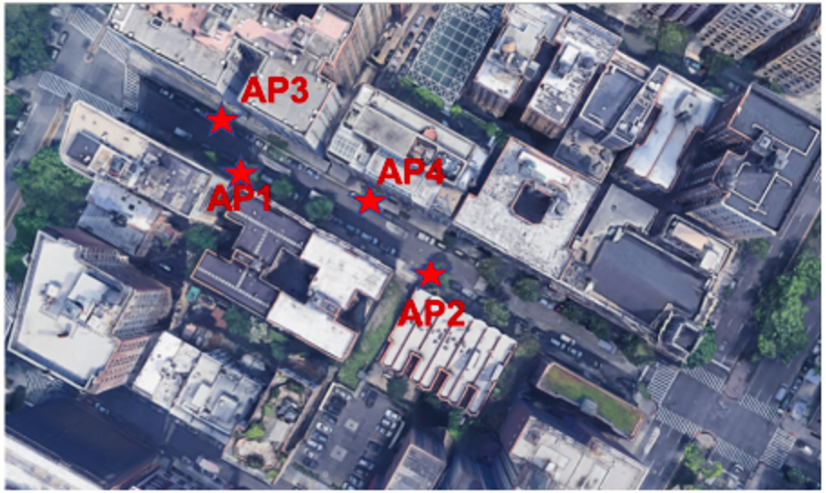


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**Table 1: Median tracking error of related technologies in Manhattan, NY.**

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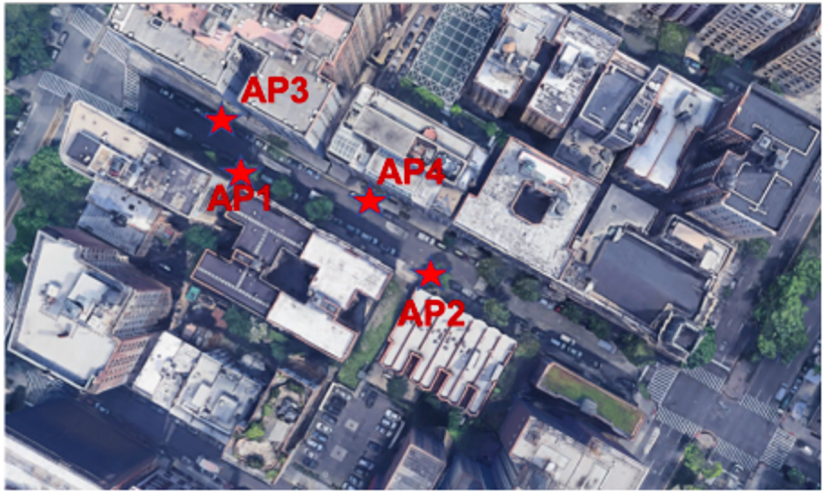


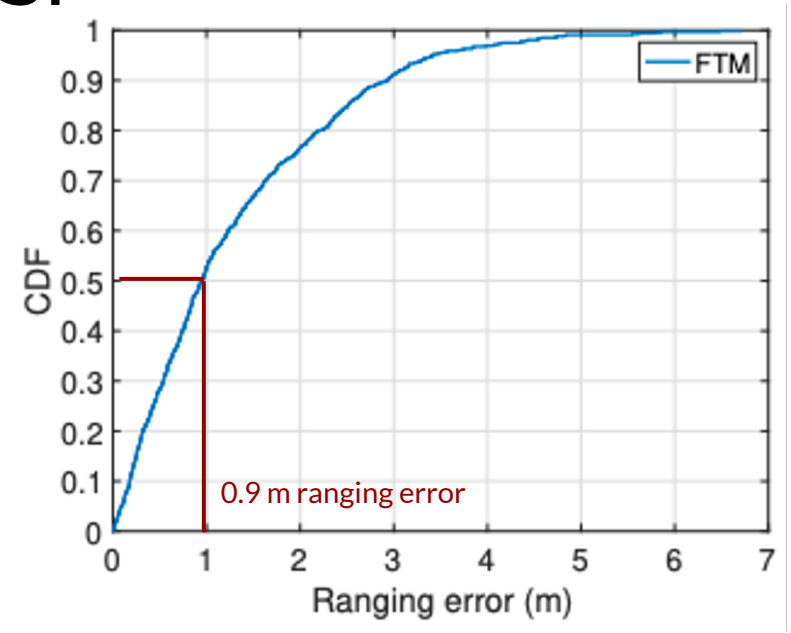


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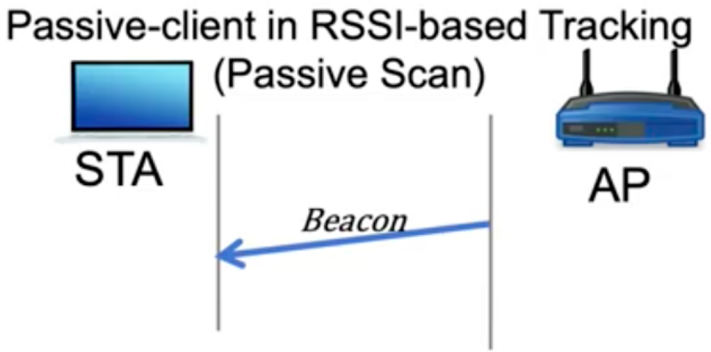

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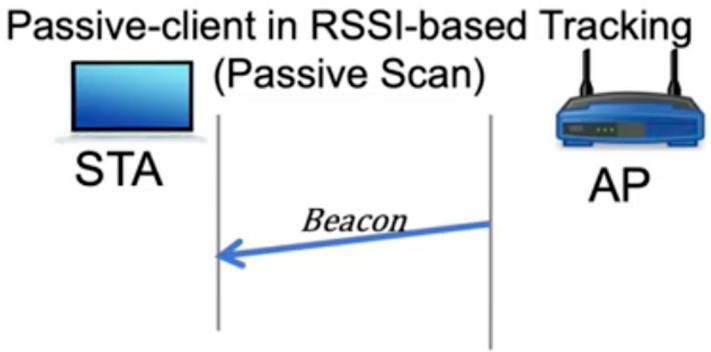
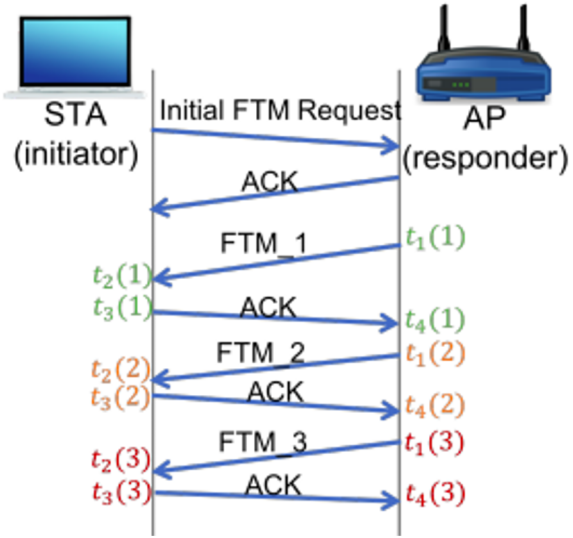



**Actively signaling client in FTM**



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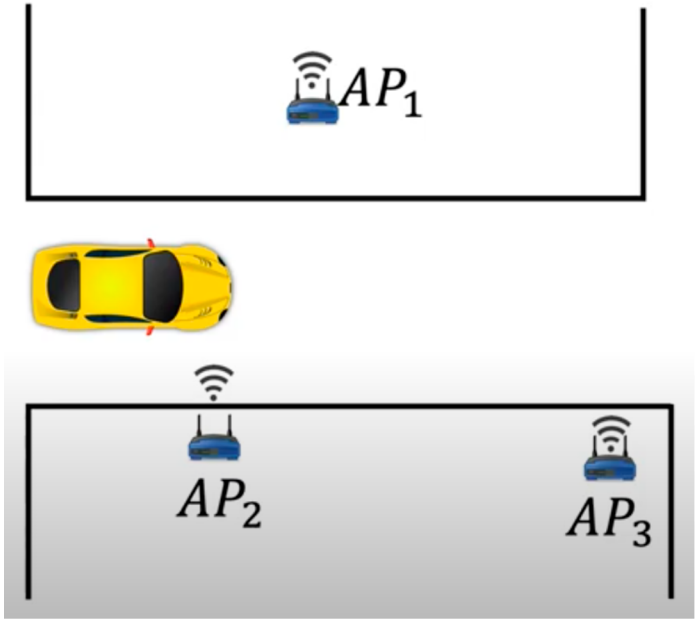


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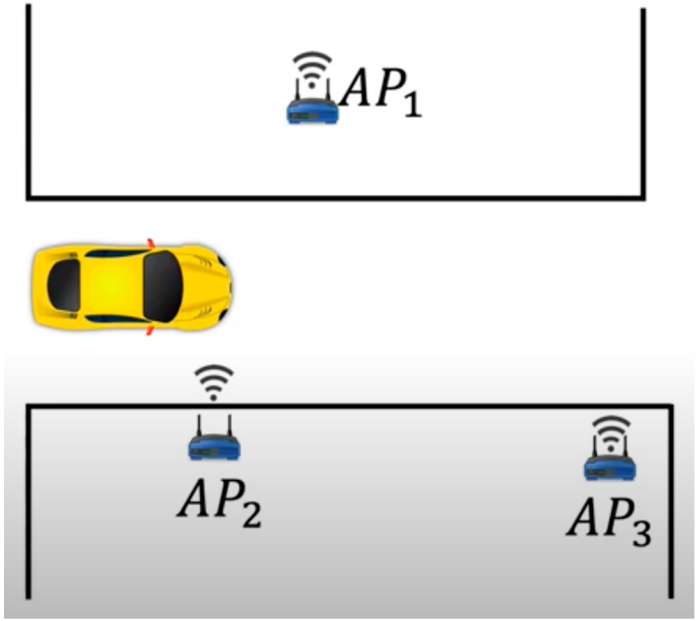


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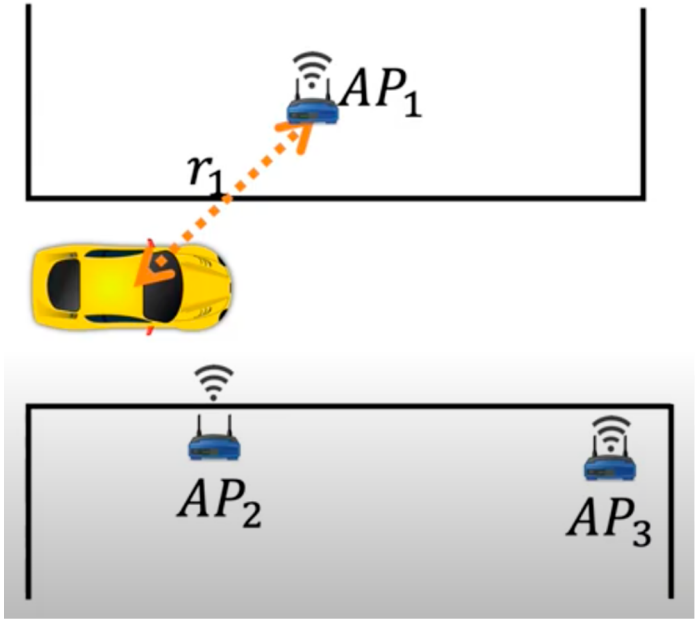


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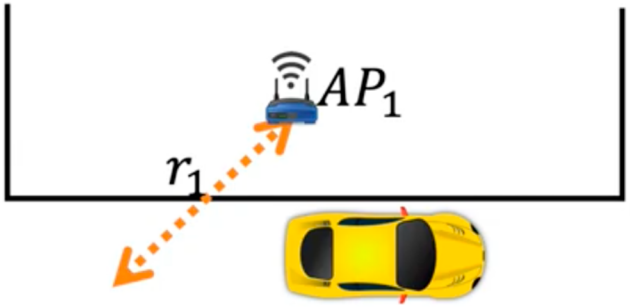


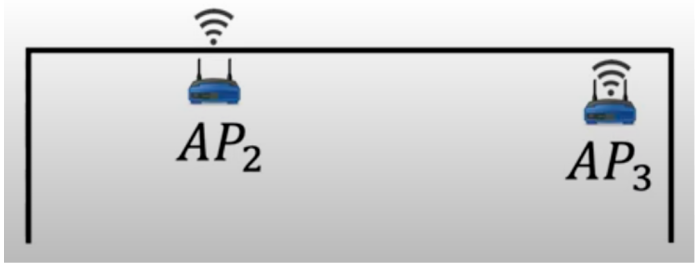


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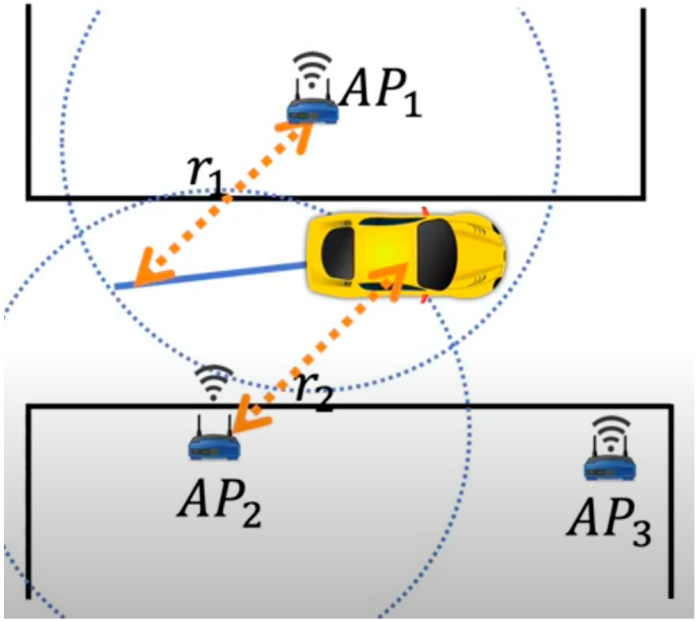


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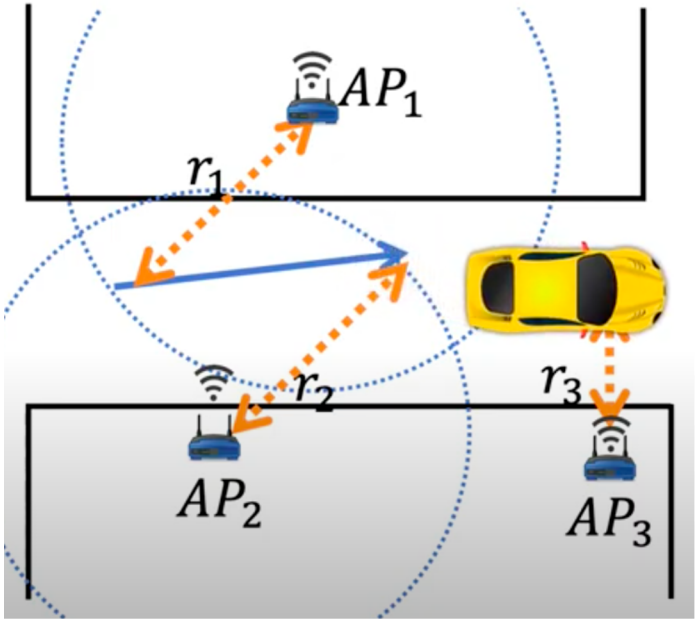


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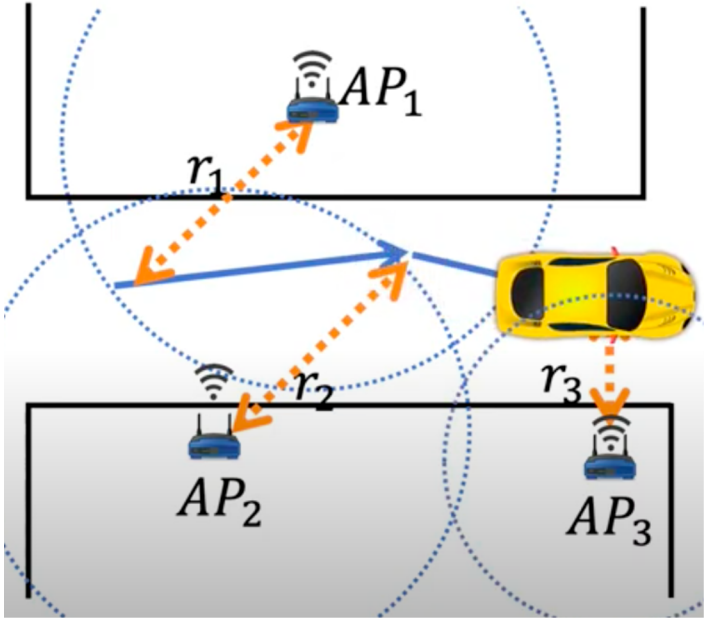


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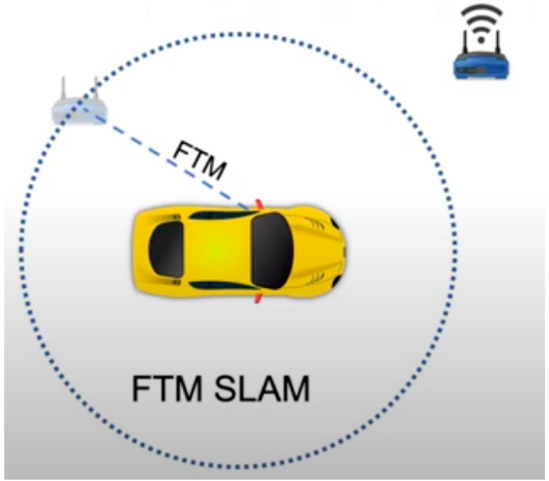

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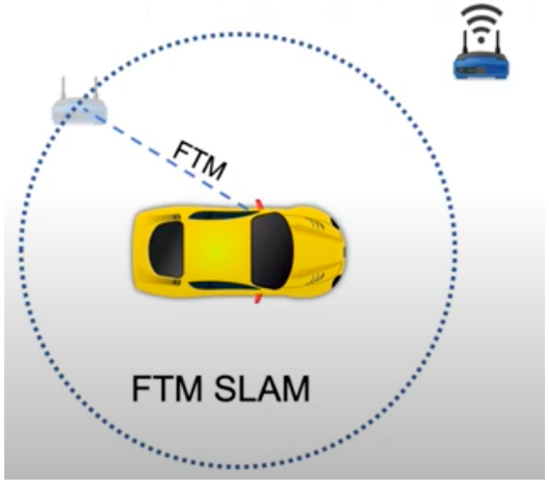


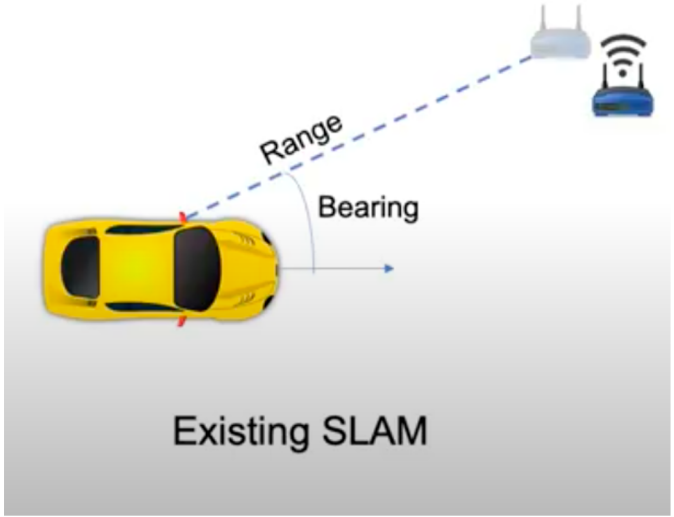

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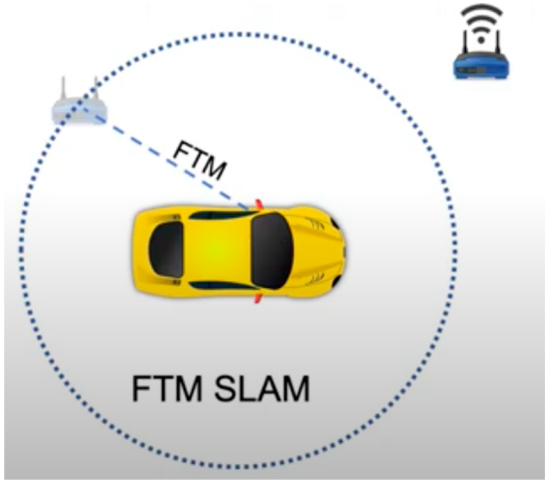
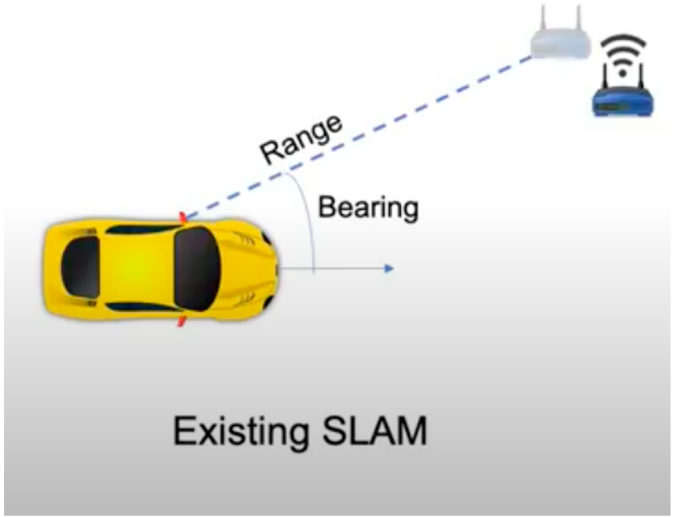
- In urban canyons, WiFi communication can be heavily affected by multipath fading and shadowing.



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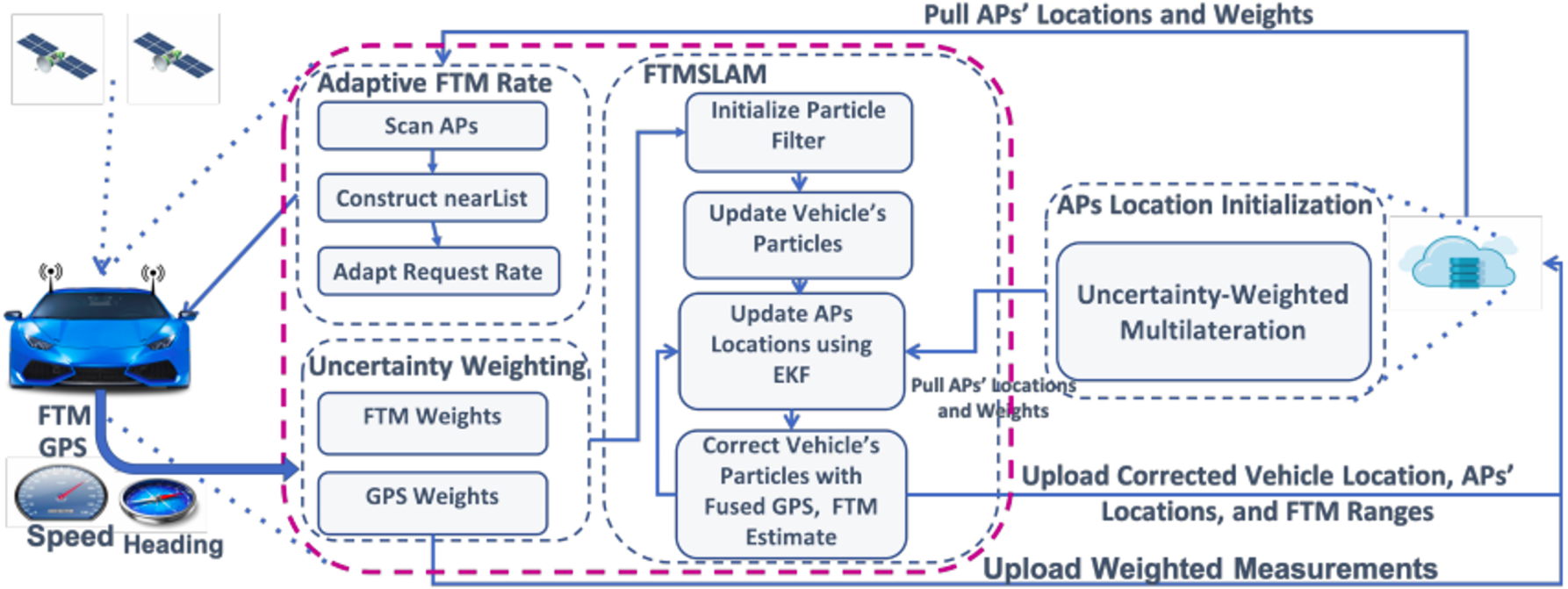
- FTM causing WiFi congestion
- Noisy FTM
- Unknown AP locations
- Range-only



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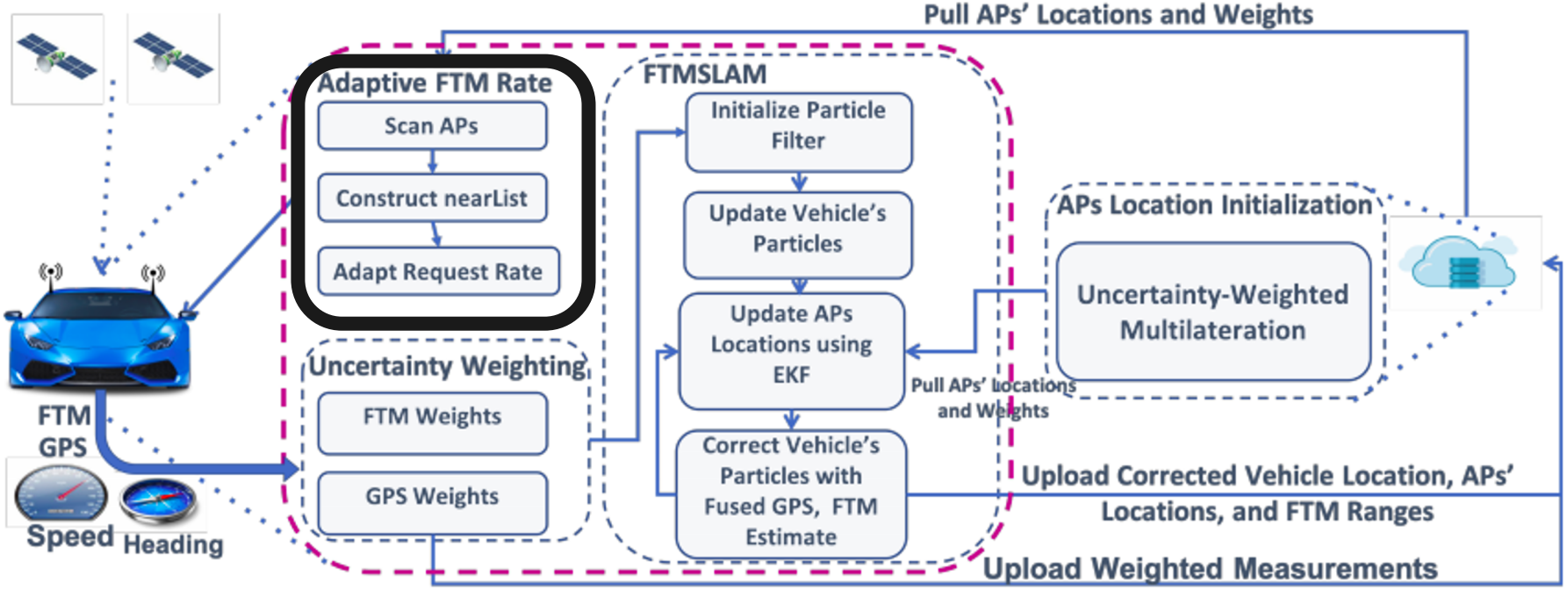

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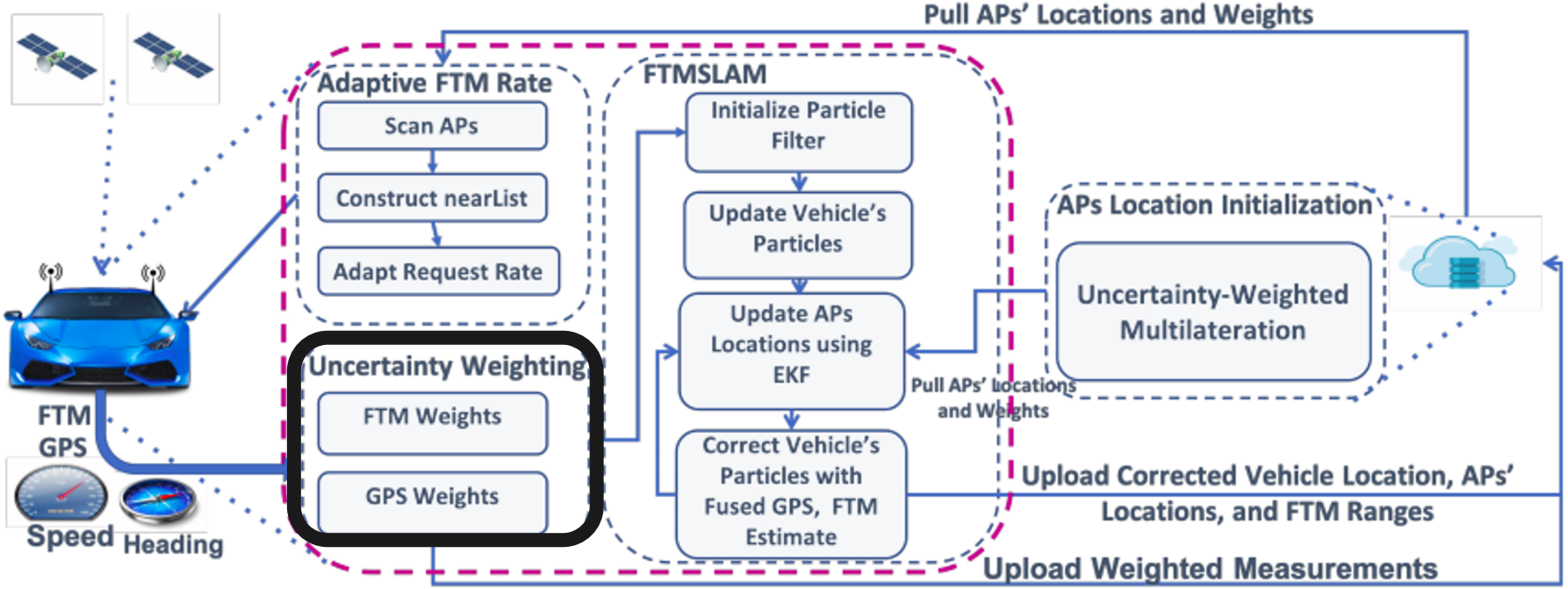

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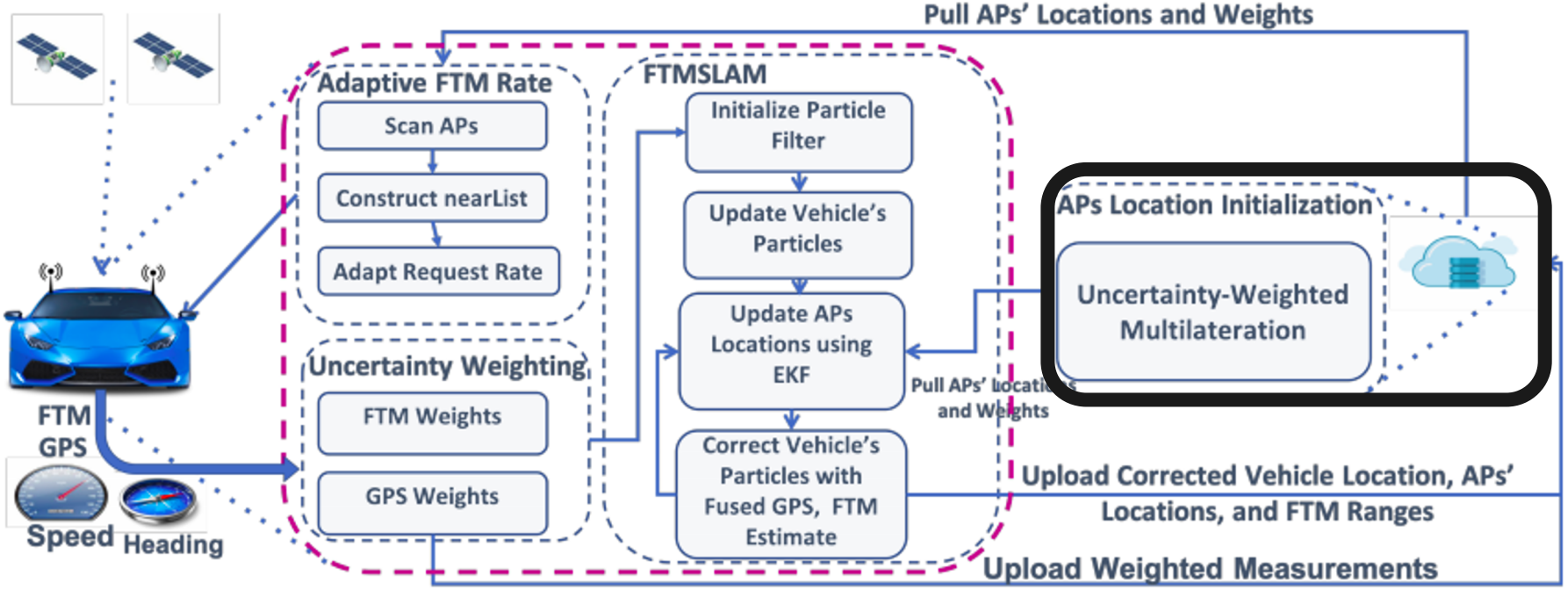

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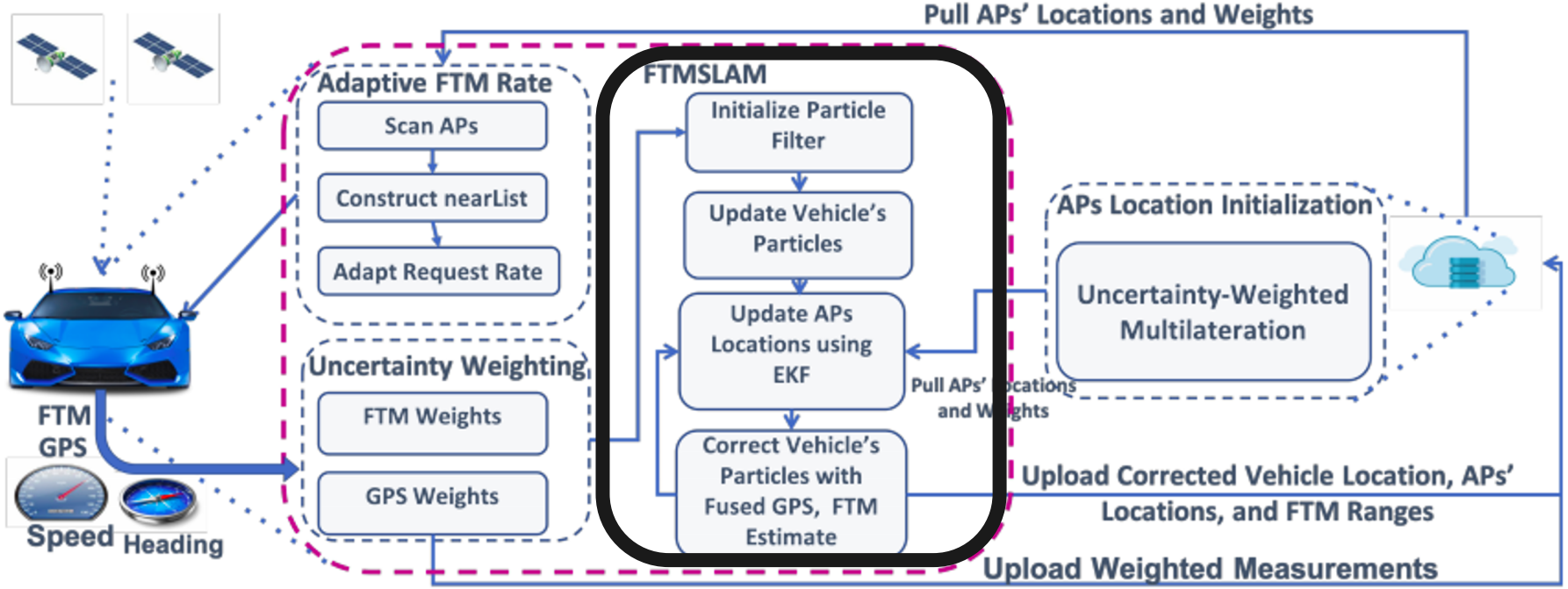

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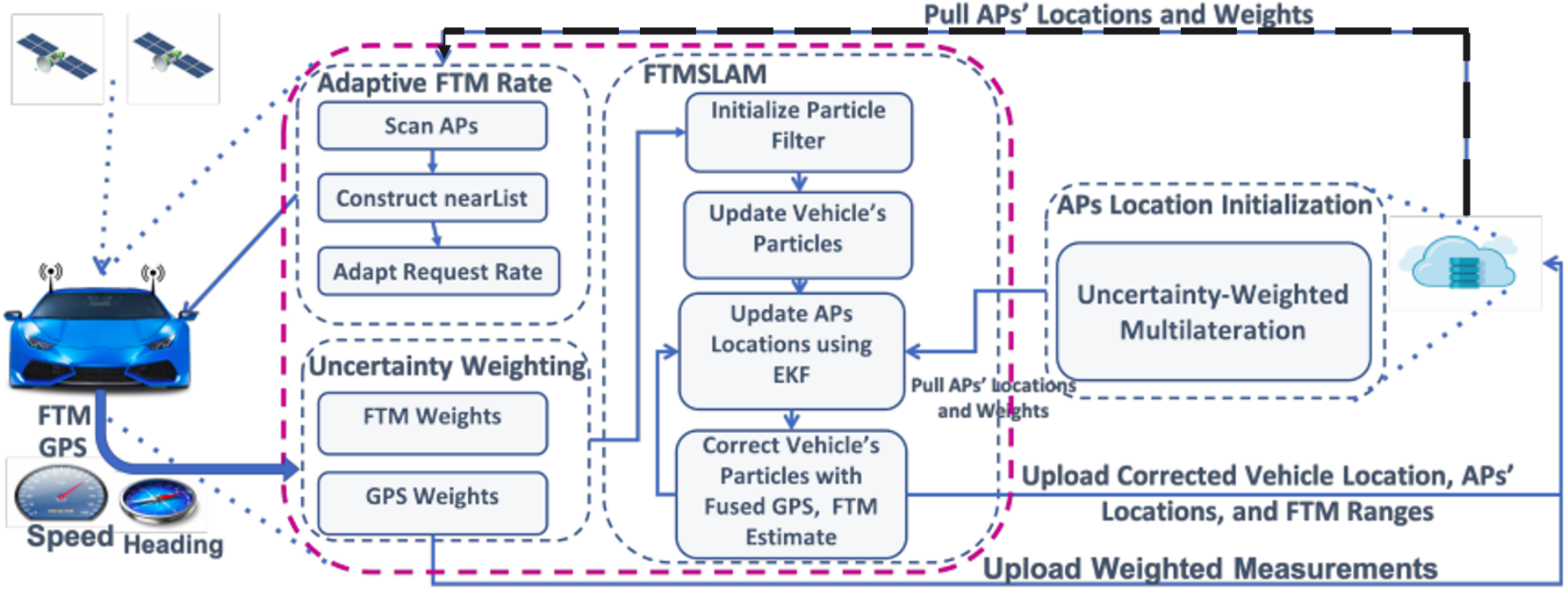

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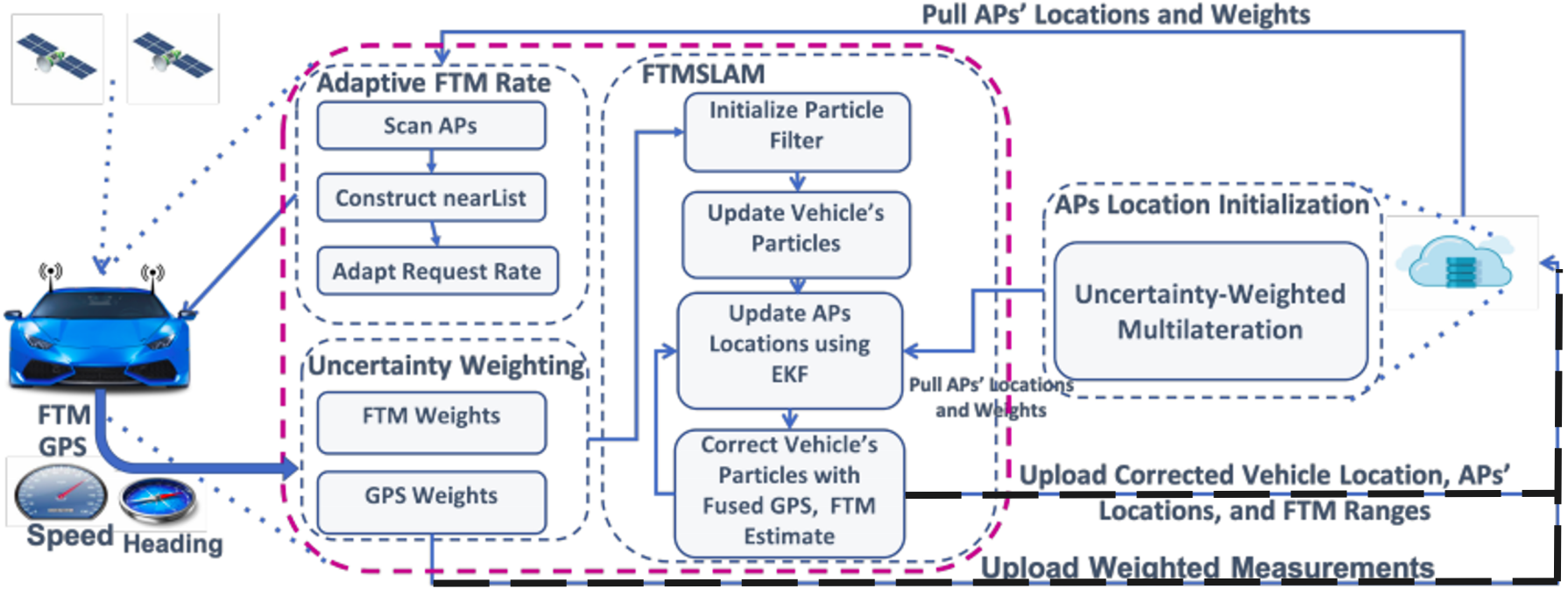

# FTMSLAM

The vehicle and the surrounding WiFi APs are localized and tracked, by incorporating **WiFi FTMs**, **GPS**, and **on-board sensor** measurements.

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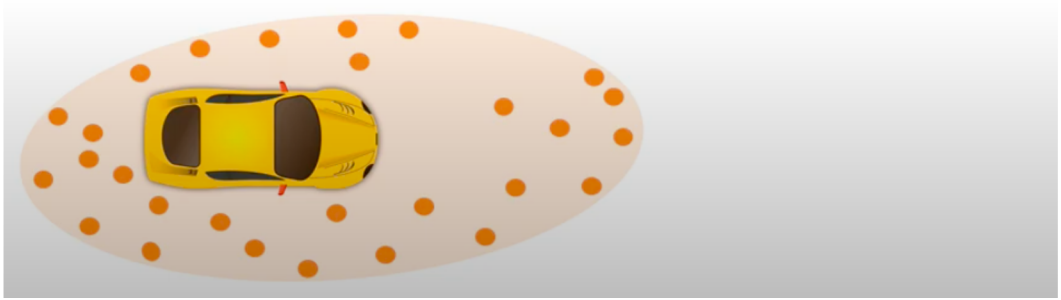

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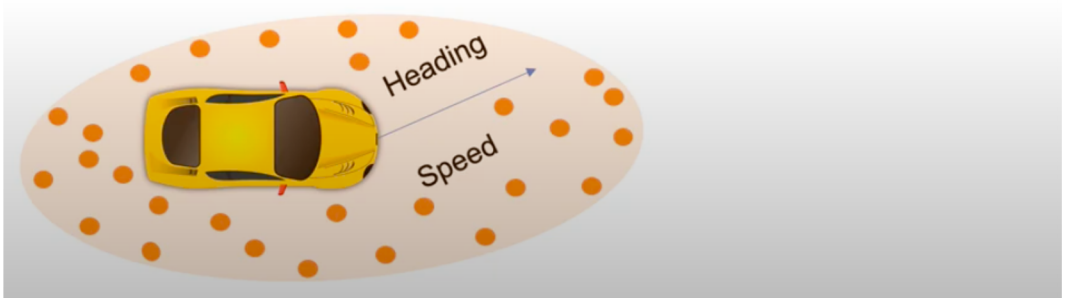

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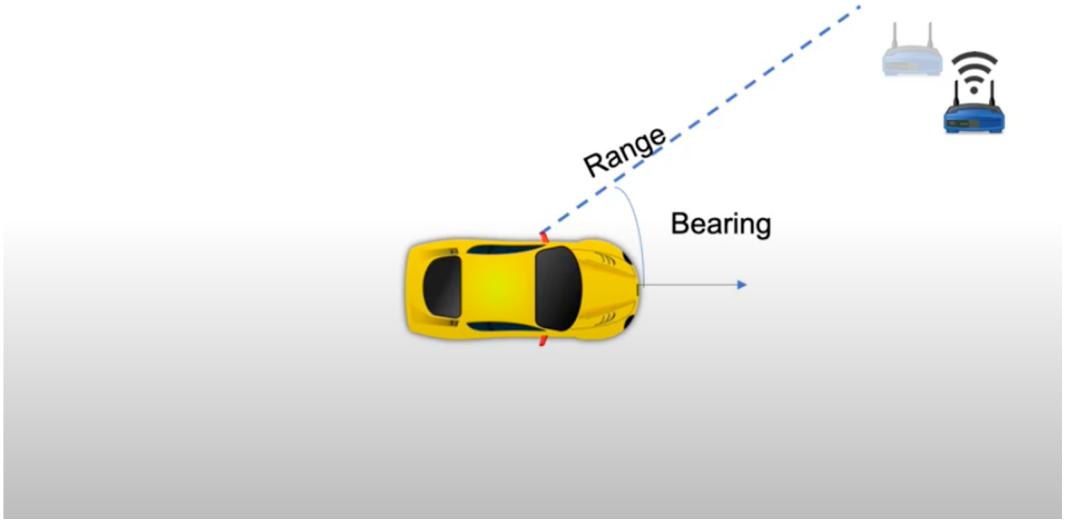

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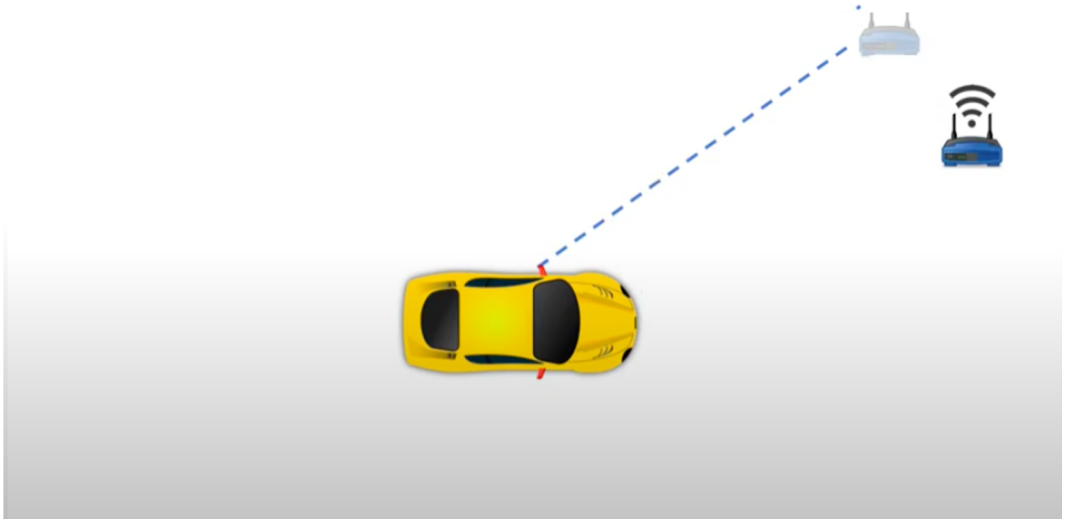

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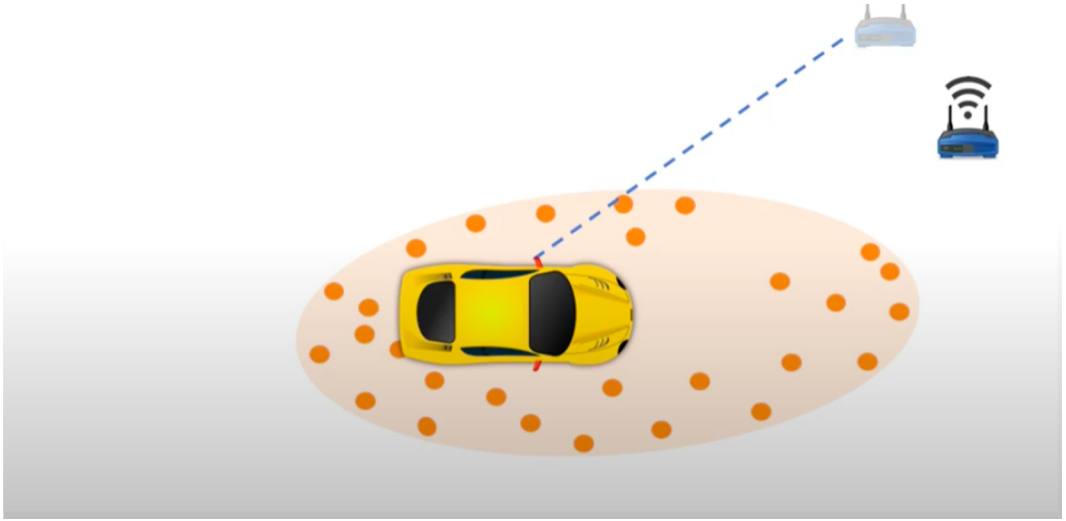

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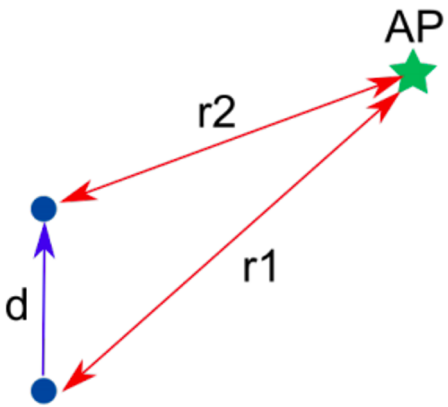

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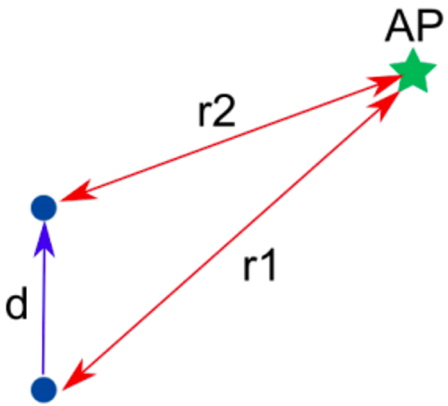

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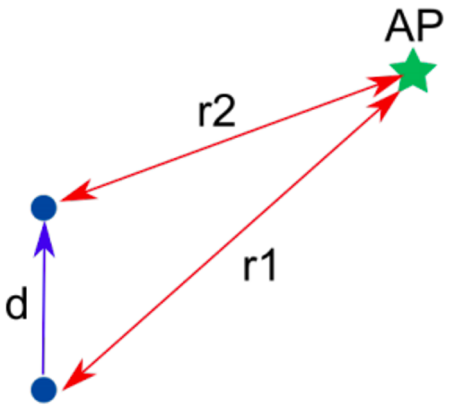

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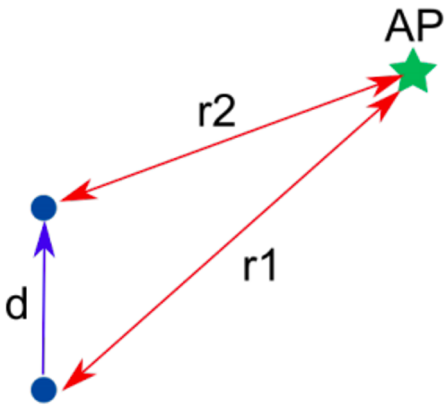
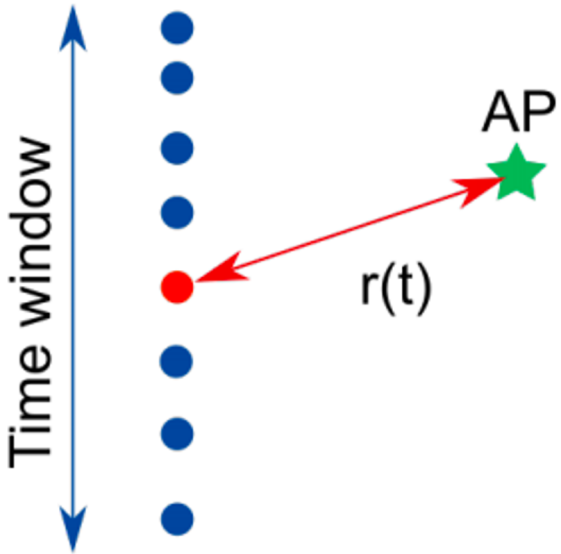
- the following triangular inequality must be satisfied:
  $|r1-r2| \leq d \leq r1+r2$



# FTM Weighting

**Algorithm:**

- For each FTM measurement r(t), we evaluate the triangle inequality of r(t) with another FTM measurement within a small time window.
- The weight for measurement r(t) is thus the ratio of measurement pairs that satisfy the triangle inequality over the total number of pairs.



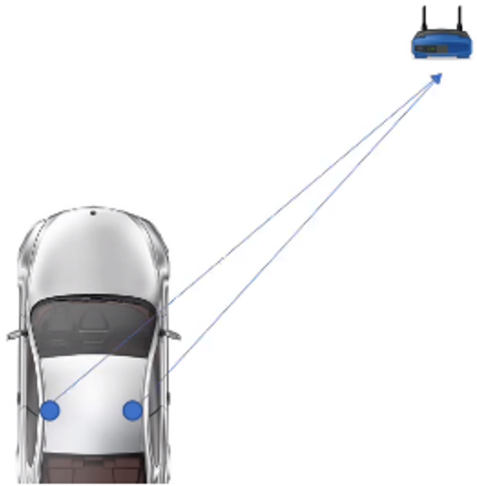
# APs Location Estimation

Location is estimated by solving the following weighted nonlinear least square optimization problem. They called it **Uncertainty-Weighted Mobile Multilateration** problem.

$$\min_{\boldsymbol{x_j}} \sum_i^n \sum_t^T w_{ij}^{FTM}(t) \left( distance\left(\boldsymbol{x_j}, \boldsymbol{v_i}(t)\right) - r_{ij}(t) \right)^2$$

Where $x_j$ is the AP location, $v_i(t)$ is the location of vehicle 'i' at time stamp 't', $r_{ij}(t)$ is the collected FTM range, and $w_{ij}$ is the computed weight.

# Bearing estimation



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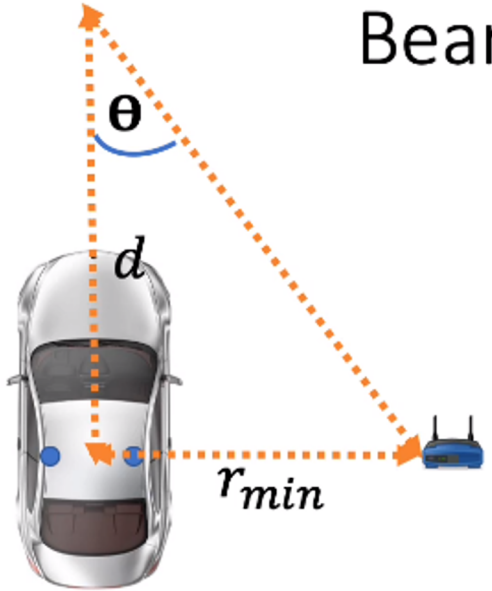


$$\theta_i = tan^{-1} \frac{r_{min}}{d_i}$$

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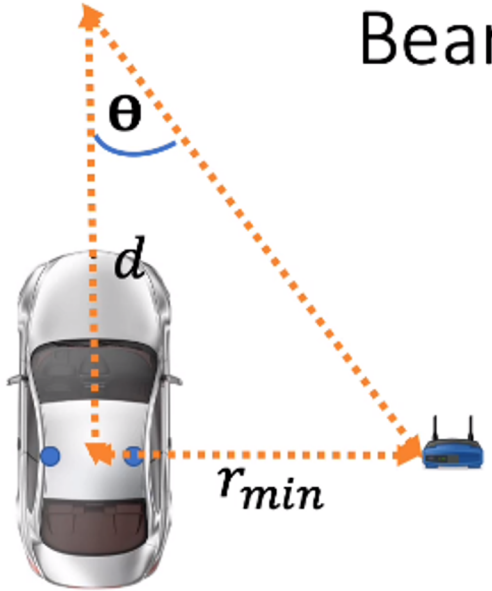


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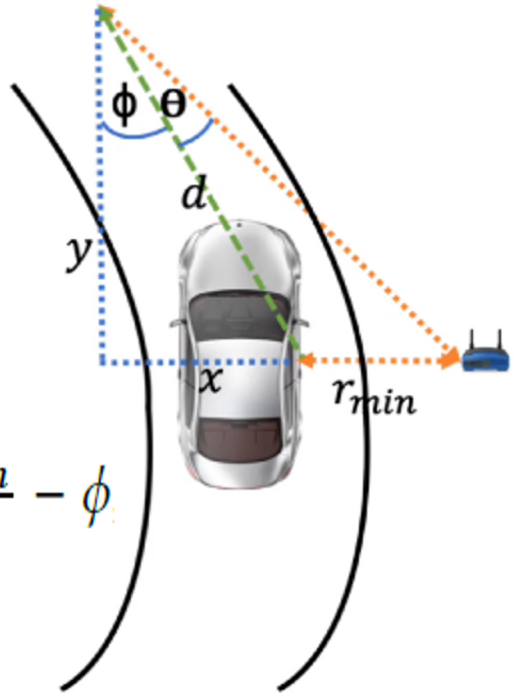



$$\theta_i = tan^{-1}\frac{x+r_{min}}{y} - \phi$$

# Congestion-Aware Adaptation of FTM Request Transmission

- Adapt FTM request rate (spb) for surrounding APs, in order to maximize the tracking accuracy while remaining under the maximum message rate constraint.
- Vehicle networks estimate the maximum message rate that is allowed to send messages without causing congestion

# Congestion-Aware Adaptation of FTM Request Transmission (Cont'd)

- **Aim:** minimize the vehicle localization error while avoiding congestion
- **Error Contributing Factor:**
  - Geometry of chosen subset of APs (HDoP)
  - Error model in AP location ($e_{AP}$)
  - FTM ranging error ($e_r$)

# Congestion-Aware Adaptation of FTM Request Transmission (Cont'd)

- Optimization Problem:

$$\underset{\boldsymbol{spb}}{\operatorname{argmin}}\ VehicleLocError(HDoP, \boldsymbol{e}_{AP}, \boldsymbol{e}_{r},)$$

$$s.t. \qquad \sum spb_i = rate_{limit}$$

$$spb_i \geq 0, \qquad 1 \leq i \leq |APs|$$

# Experimental Setup

- **Vehicles**
  - Small form factor computer
  - WiFi Card: 2x Intel Dual Band Wireless-AC 8260
  - WiFi external antennas: 4x 6dBi RP-SMA Dual Band 2.4GHz, 5GHz with 1.637m cable to attach antennas on the roof
  - Linux FTM tool to initiate and extract FTMs from these WiFi cards
- **WiFi APs**
  - ASUS Wireless AC1300 RT-ACRH13 APs

# Experimental Setup (Cont'd)

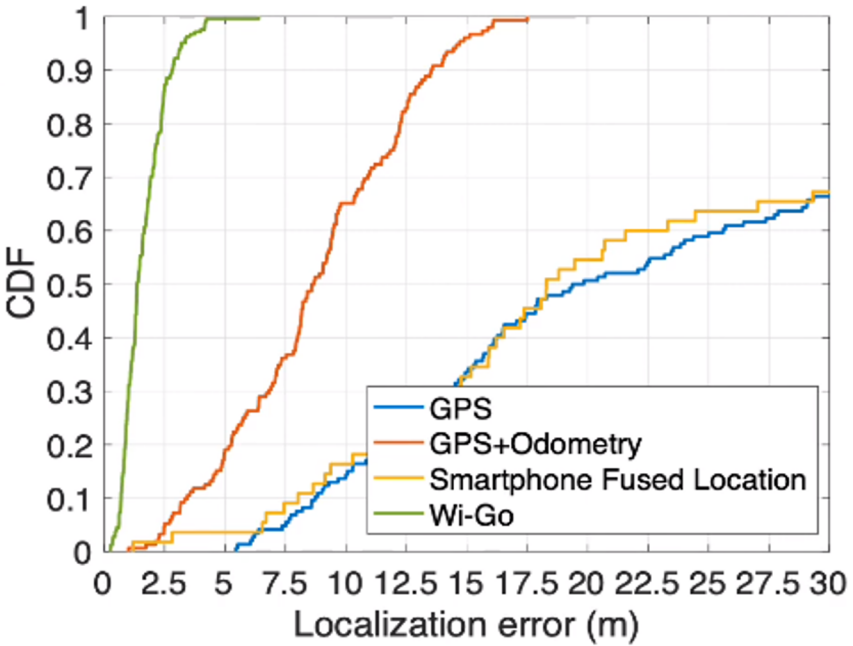
- **Ground Truth**
  - High precision GPS (< 1m error)
  - Intel RealSense Depth Cameras (<0.7 m error)
- **Existing Technologies**
  - Standalone GPS
  - Vehicle GPS (GPS + Odometry)
  - Android Fusion Location API

# Evaluation Metrics

- Localization Error

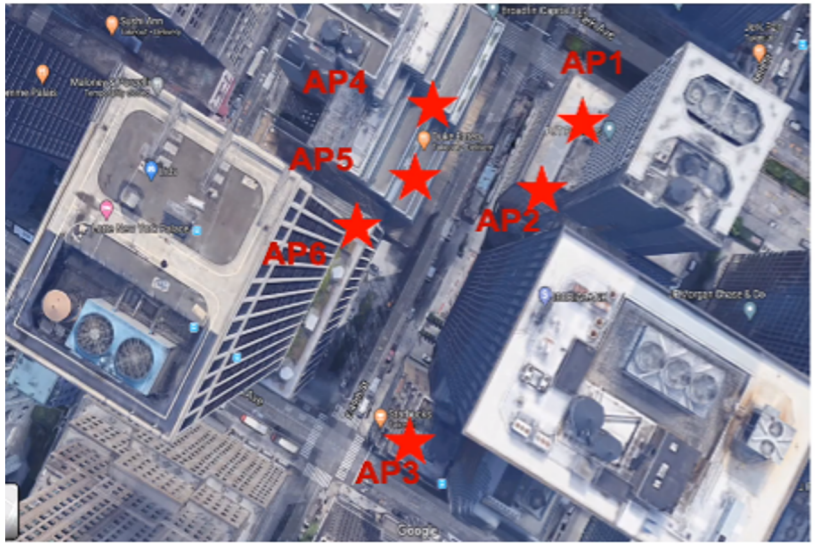
- FTM Latency

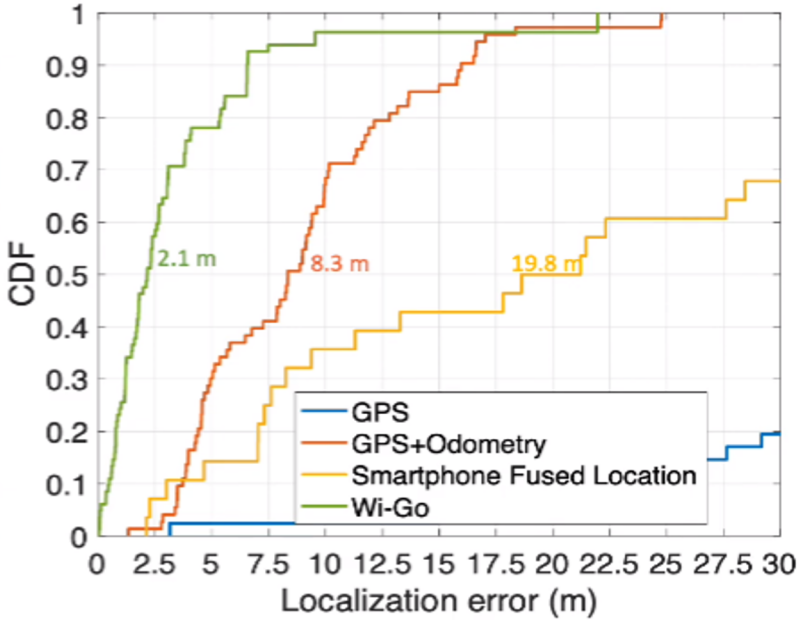
# Vehicle Localization Error

# Vehicle Localization Error

Midtown Manhattan (Indoor APs)



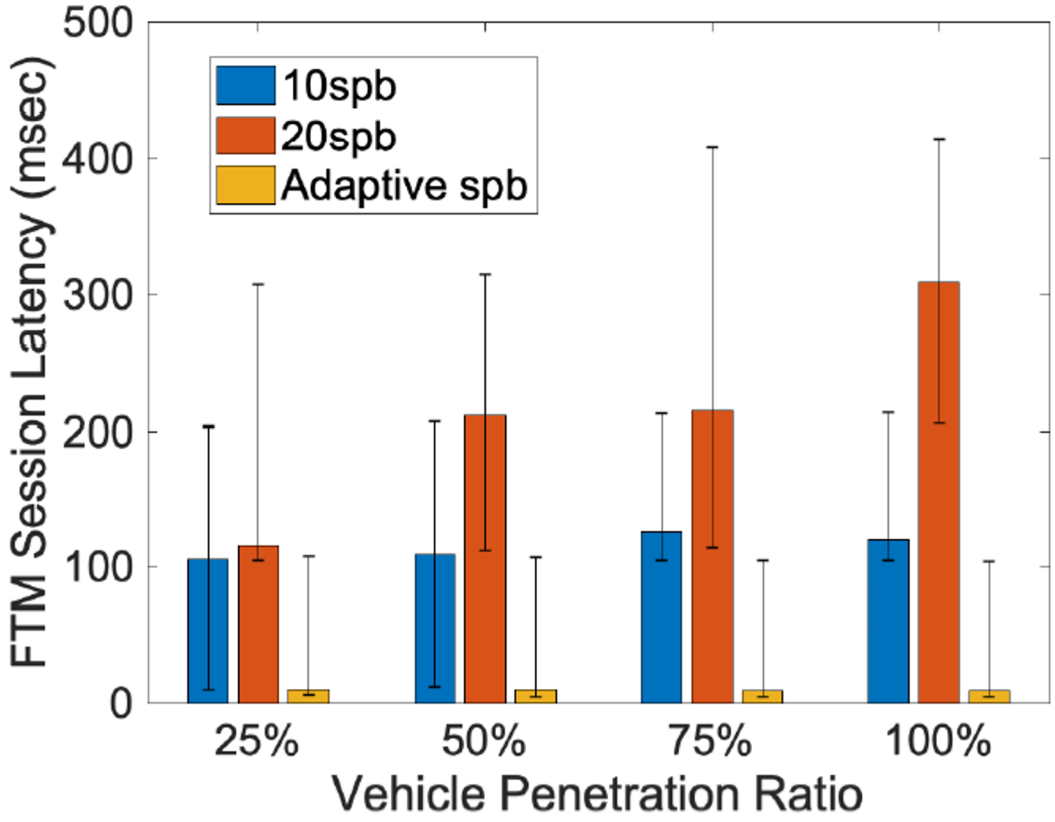



# Access Points Localization

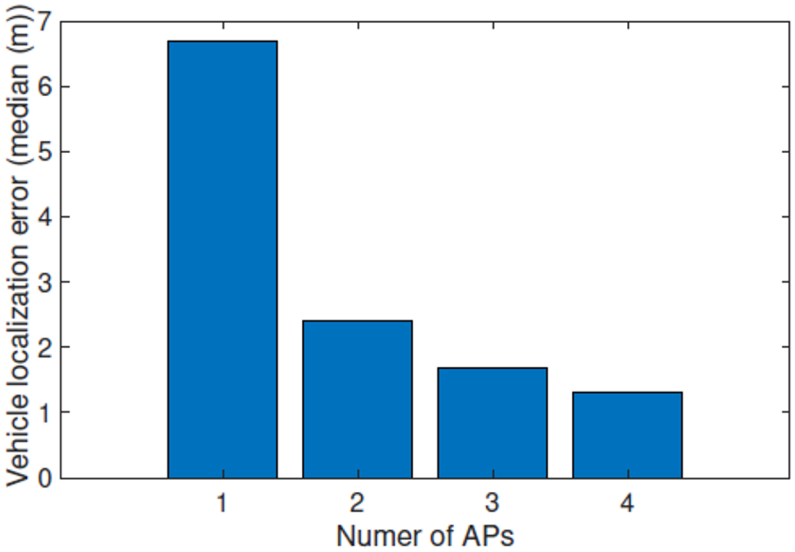
| Approach | Parked Cars | Indoor APs |
|---|---|---|
| Wi-Go | 1.9 m | 3.6 m |
| GPS+Odometry | 14.3 m | 16.4 m |
| GPS | 18.9 m | 27.4 m |
| Smartphone Fused Loc. | 17.8 m | 16 m |

# ns-3 Simulation Results

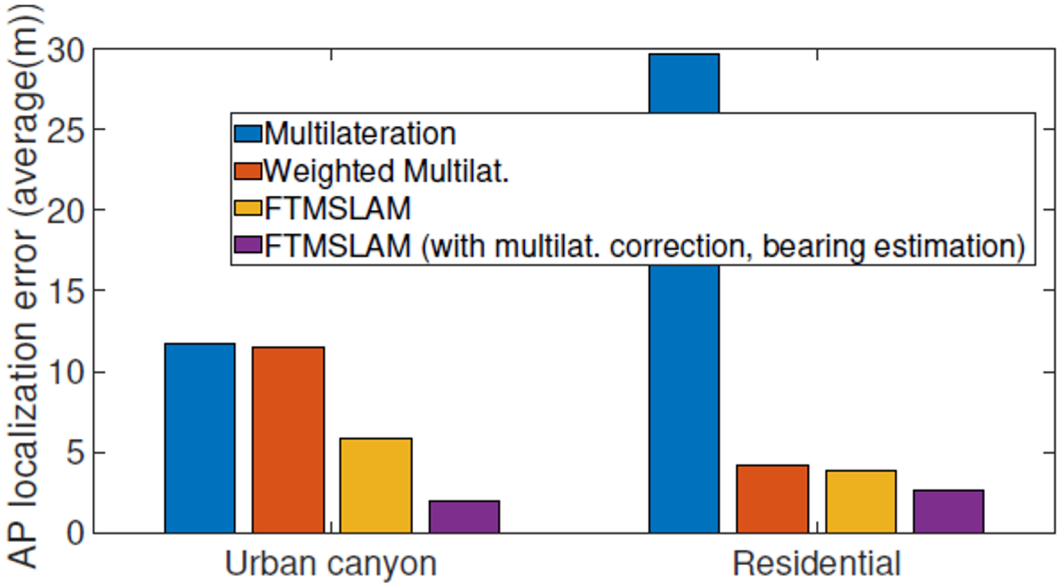
| Simulation Parameters | Values |
|---|---|
| Simulation time | 30 sec |
| Transmission Power | 16.5 dBm |
| Channel Bandwidth | 80 MHz |
| Channel number | 155 |
| LOS reference pathloss | 21.87 dB |
| LOS pathloss exponent | 3.39 |



# Micro Benchmark: Effect of number of APs



# Micro Benchmark: Comparing Approaches



# Conclusion

- A vehicle localization system that uses WiFi Fine Time Measurements to achieve lane level accuracy in challenging urban canyons.
- Simultaneously estimate vehicle and WiFi APs positions by fusing WiFi FTMs with GPS, and Odometry in FTMSLAM framework.
- Wi-GO achieves median localization error of 1.3m in urban canyons when WiFi APs are on parked vehicles,  and 2.1m when WiFi APs are in buildings.
- Wi-GO achieves median localization error of 0.8m in Suburban environments when APs are in apartment buildings.

# Insights!

- Use already converged Access points in estimating the position of the new APs.
- Self localization in indoor environments
- Range Only Bearing Estimation technique
- Latency vs Positioning Accuracy
- Computational complexity

# Thank You!

Any questions?