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# Spectrum Sensing in the Vehicular Environment: An Overview of the Requirements

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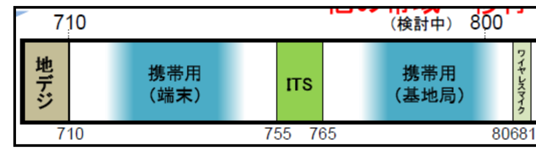
# Outline

- Motivation:
  - Why cognitive radio in the vehicular environment?
- Spectrum awareness:
  - Impact of mobility on sensing requirements
  - Sensing versus geolocation database lookup
- Utilization of temporal and spatial channel diversity:
  - Mobility versus collaboration
- Influence of sensing on MAC sublayer design:
  - Synchronization of sensing in vehicle-to-vehicle (V2V) networks

# Why cognitive radio in the vehicular environment?

- Scarcity of dedicated spectrum
  - in US 75 MHz around 5.9 GHz is dedicated to DSRC
    - considering 10 MHz to be dedicated to V2V communication [Kenney '11]
  - in Japan
    - 10 MHz between 755 and 765 MHz
    - 70 MHz around 5.8 GHz
      - for toll collection, road info,…
      - very short range
      - different PHY from DSRC

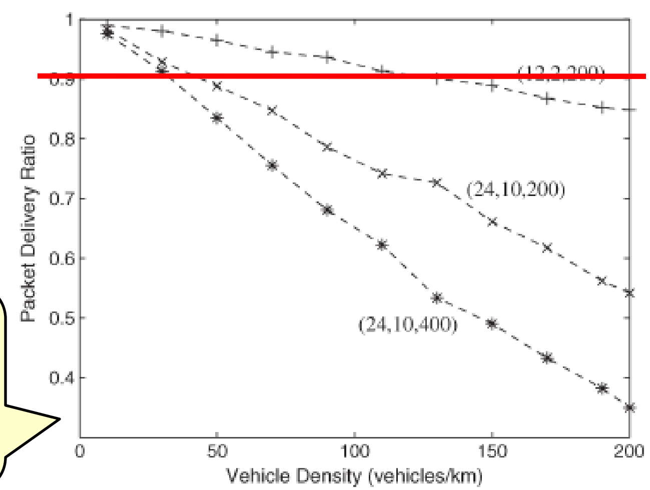



http://www.soumu.go.jp/main_content/000134495.pdf

- 802.11p performance
  - PHY efficiency less than 2.7 b/s/Hz
  - CSMA/CA MAC overhead further reduces that number

Packet Delivery Ratio vs vehicle density

linear formation, single lane, 500 m range
<u>no retransmissions</u>
(Mb/s, packets/s, bytes)




Hassan et al, Performance Analysis of the IEEE 802.11 MAC Protocol for DSRC Safety Applications, IEEE Transactions on Vehicular Technology, Vol. 60, No. 8, October 2011

# Emerging applications and proliferation of mobile devices

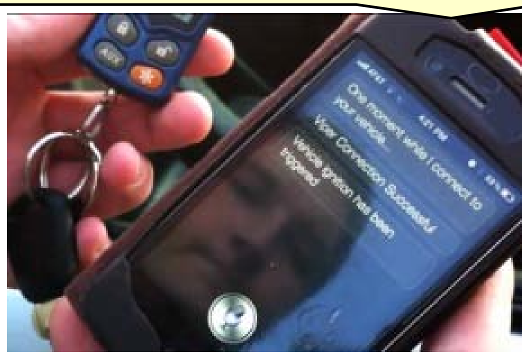
V2V: Blind spot alarm


http://www.worldcarfans.com/10510278356/general-motors-develops-vehicle-to-vehicle-communication

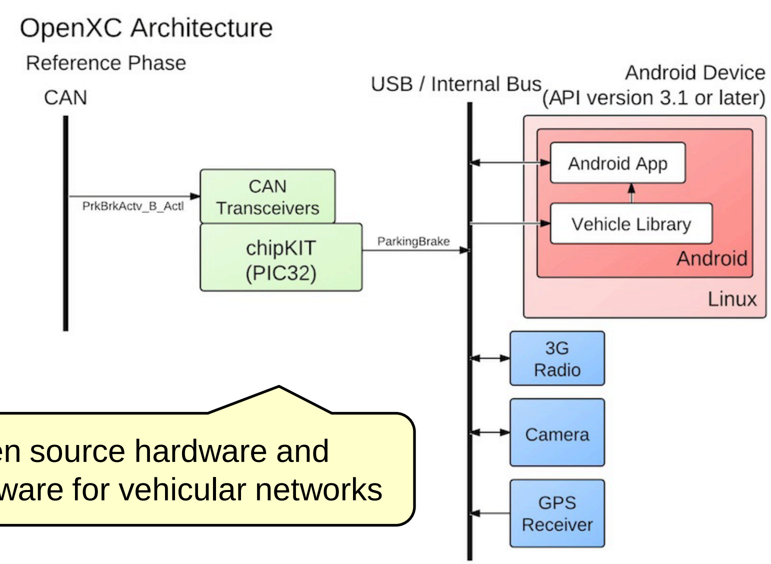
Telemetry feed from the CAN bus to a USB stick or a smartphone over Bluetooth

http://www.nikkei.com/article/DGXNASFK03012_T00C12A2000000
http://www.tune86.com/ft-86-news/908-toyota-gps-track-day-technology-ft-86

Voice commands to the car over a smartphone



http://techcrunch.com/2011/11/28/new-siri-hack-will-start-your-car-if-you-ask-nicely/




Open source hardware and software for vehicular networks

http://openxcplatform.com/getting-started/overview.html

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# Purpose of the cognitive vehicular networks

1. Satisfying capacity demand for Intelligent Transportation Systems (ITS) applications

2. Offloading of delay insensitive communications from the dedicated spectrum

# Advantages of the TV band:

1. Larger range due to larger antenna aperture

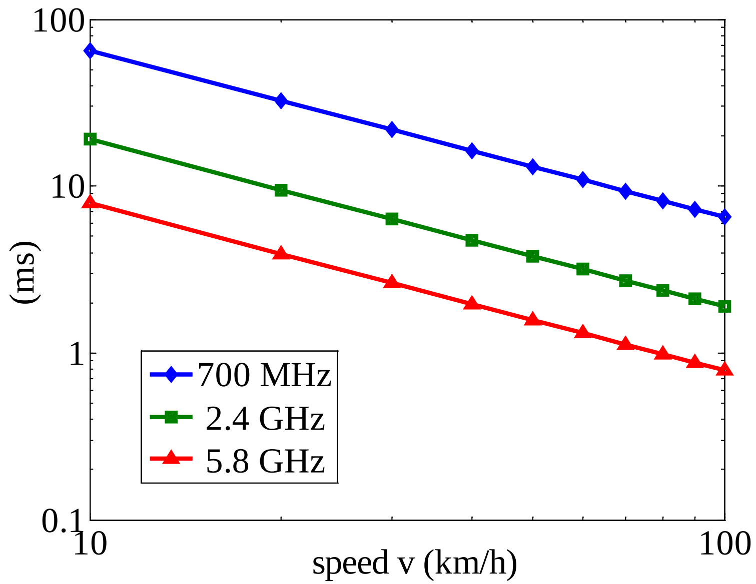
$$20\log_{10}\left(\frac{5900}{700}\right) = 18.5\,\text{dB}.$$

in free space

2. Longer coherence time

channel coherence time
for flat Rayleigh fading

$$T_c = \frac{0.423 \cdot c}{v \cdot f}.$$




3. Diffraction: “easier bending around corners”
   - better coverage at urban intersections

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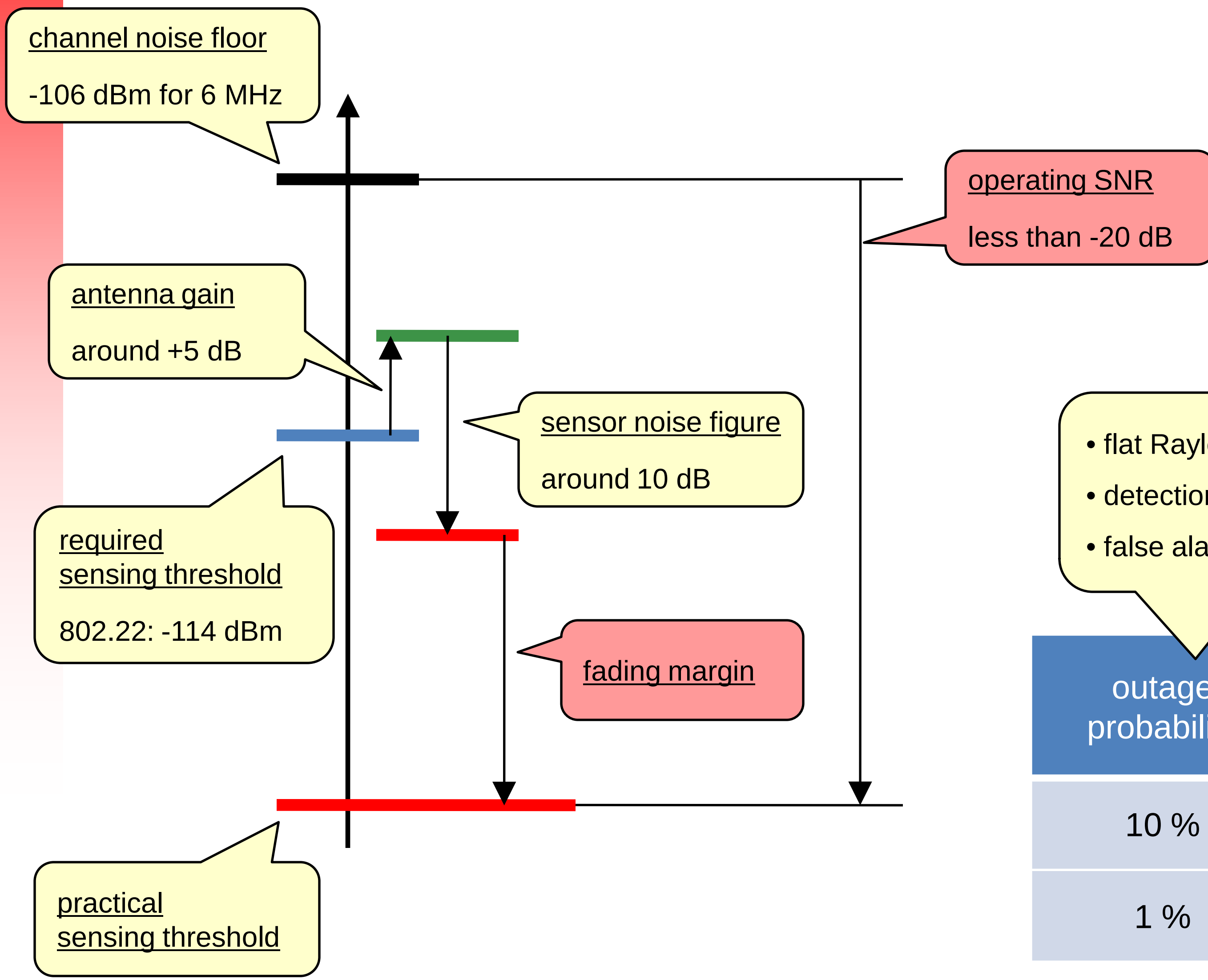
# Comparison with IEEE 802.22 cognitive WRANs

- Comparing system engineering level features of
  1. Existing cognitive solutions in the TV white space versus
  2. Vehicular cognitive networks

| | IEEE 802.22 WRANs | Cognitive vehicular networks |
|---|---|---|
| Application | Internet access | ITS, possibly Internet access |
| Range | ~ 30 km | at most a few km |
| Mobility | low: stationary, pedestrian | can exceed 100 km/h |
| Topology | centralized with base station | I2V: centralized<br>V2V: ad-hoc |
| Population density | ~ 5 users/km$^2$ | up to 200 cars/km/lane |
| Propagation environment | • likely LOS<br>• large delay spread<br>• large propagation delay<br>• slow time variations | • LOS, NLOS<br>• fast time variations |

# Influence of mobility on the sensing link budget




- flat Rayleigh fading
- detection probability $P_d$ = 0.9
- false alarm rate $P_{fa}$ = 0.1

| outage probability | fading margin |
|---|---|
| 10 % | 10 dB |
| 1 % | 20 dB |

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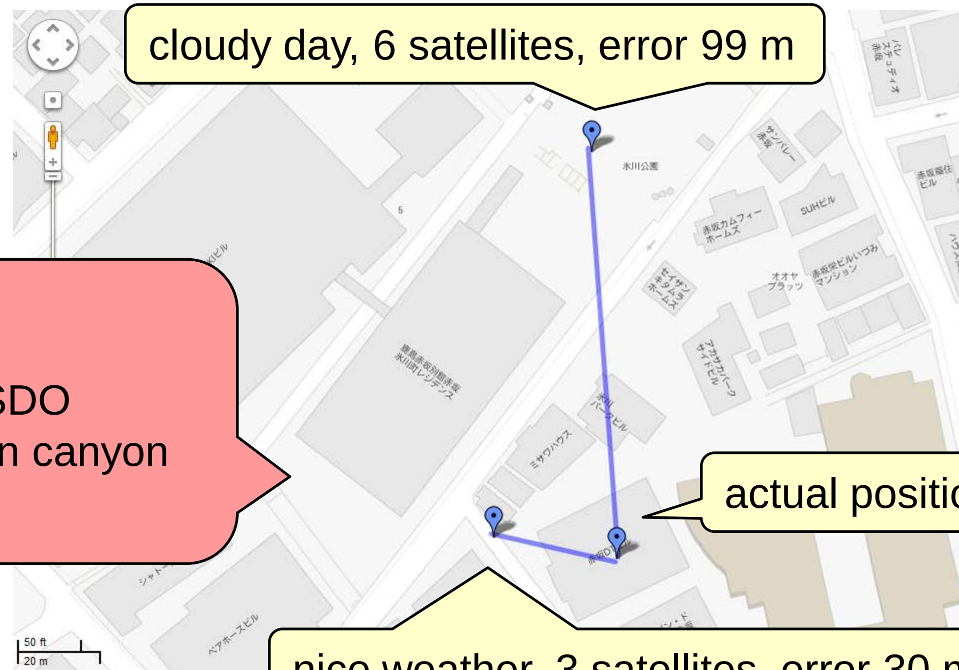
# Geolocation database lookup

- Alternative to challenging sensing requirements:
  1. Form a database of primary users
  2. Calculate protected areas using some propagation model
  3. Secondary users
     - Estimate their location
     - Query the database to determine free channels

- Preferable spectrum awareness method in the US and UK
- FCC and IEEE 802.22:
  - spectrum occupancy must be assessed **every time you move more than 50 m**
  - FCC accuracy requirement: < 50 m
  - 802.22 accuracy requirement: < 100 m with 67% reliability

# Database lookup issue 1:
## GPS localization accuracy

```
$GPGGA,071106.00,3540.2356,N,13944.2119,E,1,06,2.0,165.1,M,39.4,M,,*64
```




Measured in Tokyo

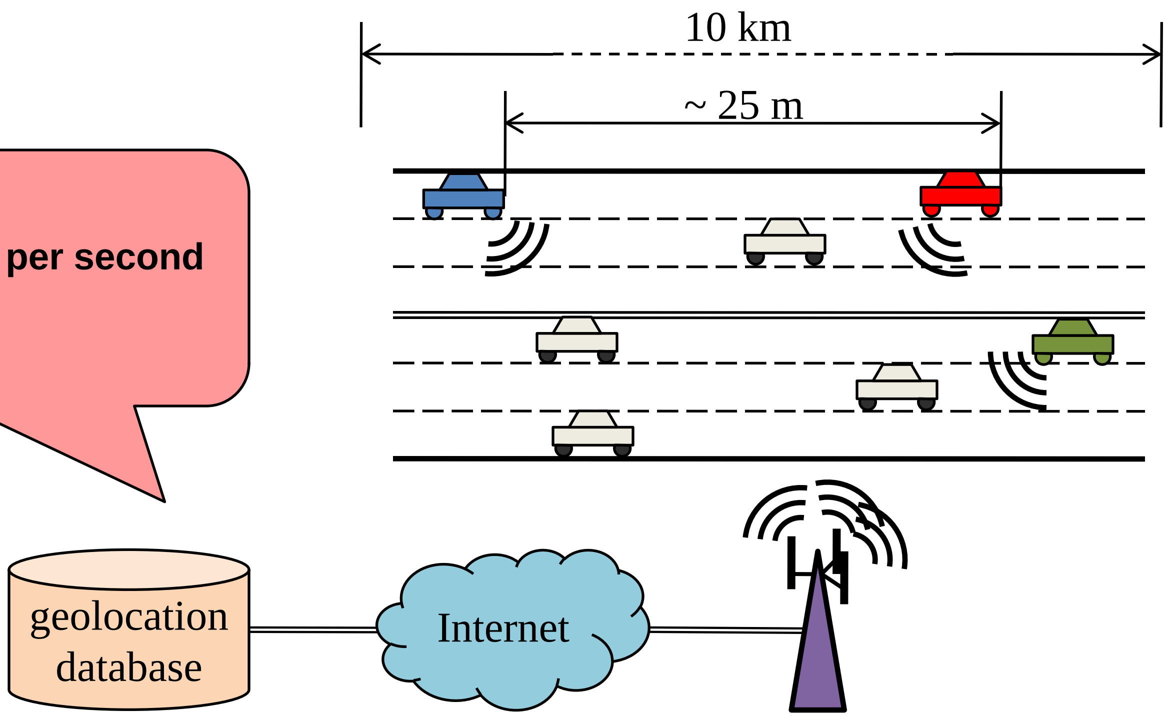
- using Ettus USRP and GPSDO
- environment similar to urban canyon
- under the glass roof

```
$GPGGA,001007.00,3540.1865,N,13944.1963,E,1,03,3.6,4.4,M,39.4,M,,*6C
```

# Database lookup issue 2:
## Mobility induced congestion

- Assume average speed 100 km/h
  - a car traverses 50 m in 1.8 s
- Assume average distance between cars 25 m
- Assume 10 km base station range
  - 400 cars in a lane across 10 km: 2400 cars on a six-lane freeway

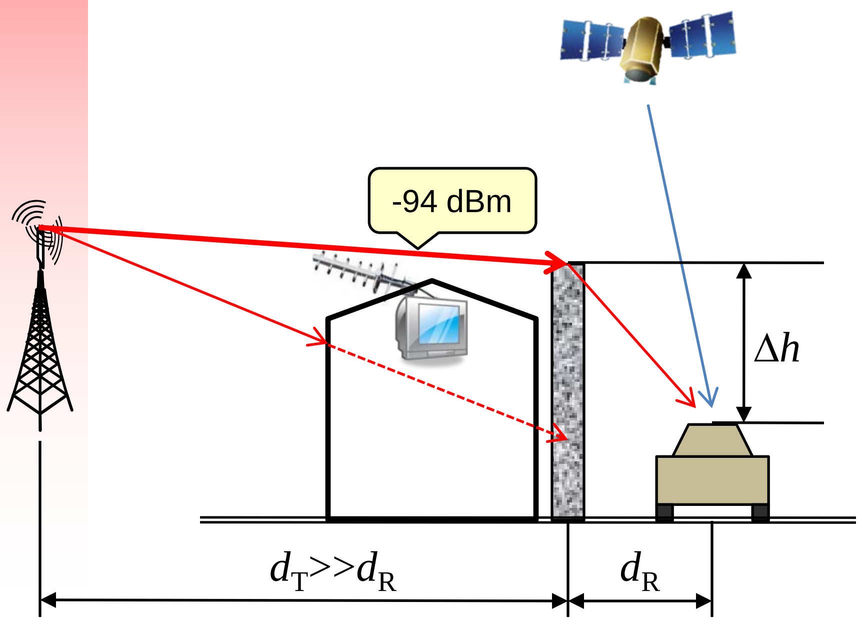
More than **1300 queries per second per base station**

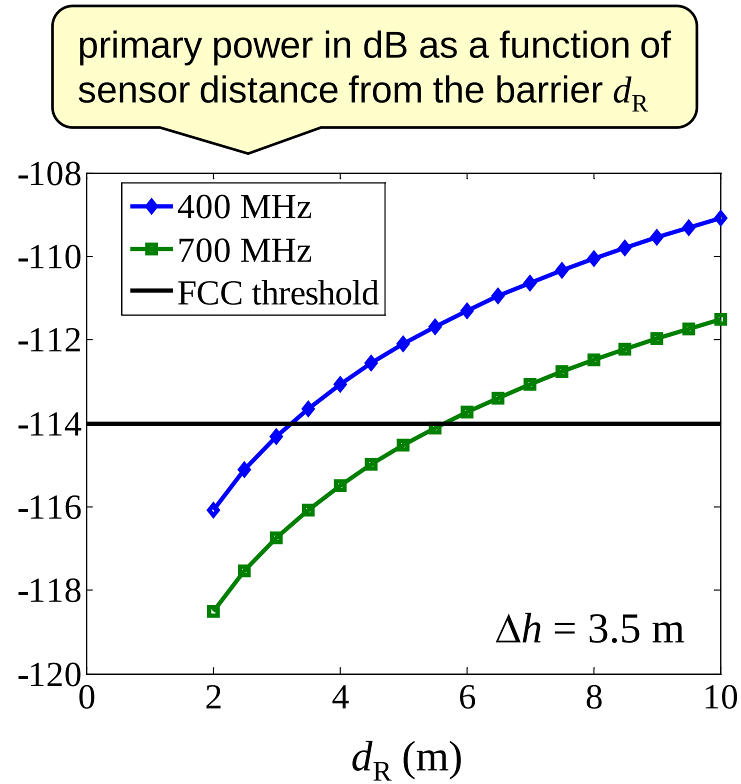


# Sensing versus database lookup 1:
## Sensing fails but GPS works

[Ikegami et al '84]

- Hidden node: Edge diffraction over the sound barrier
  - Assume just enough power for a TV in front to operate
  - Secondary is still close enough to create significant interference

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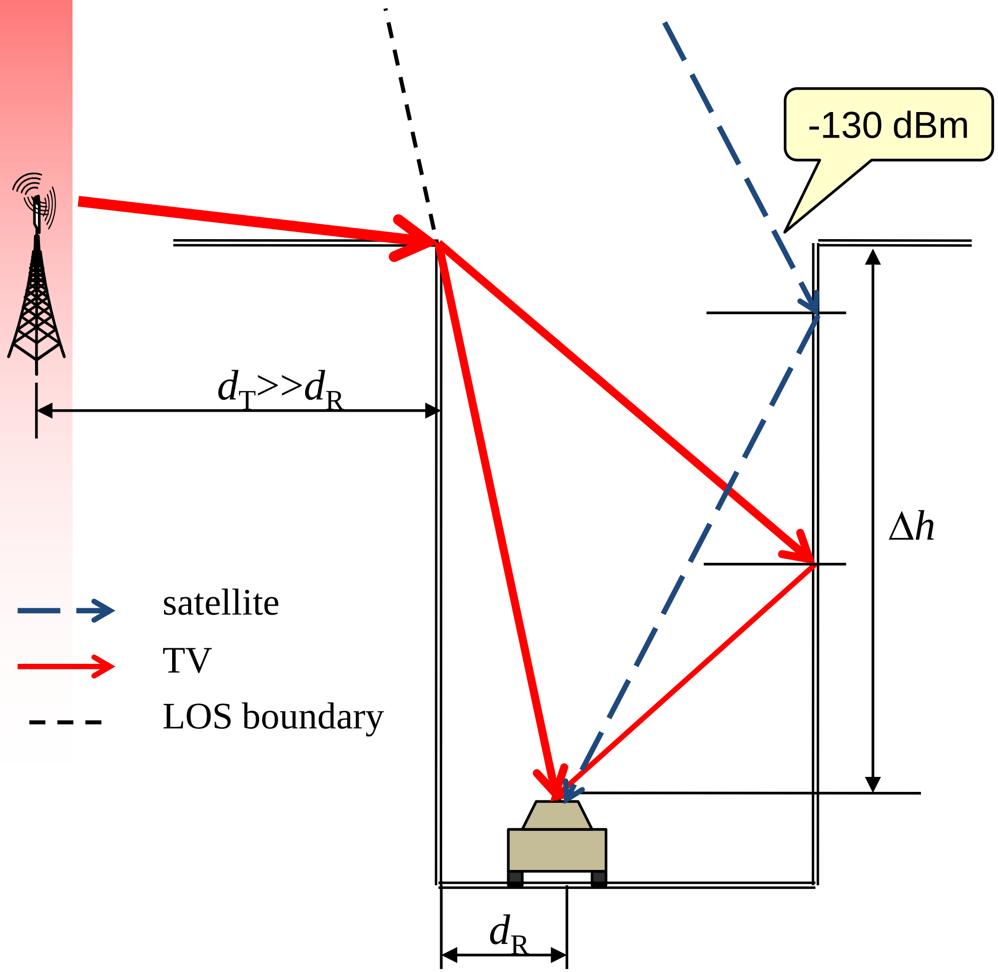
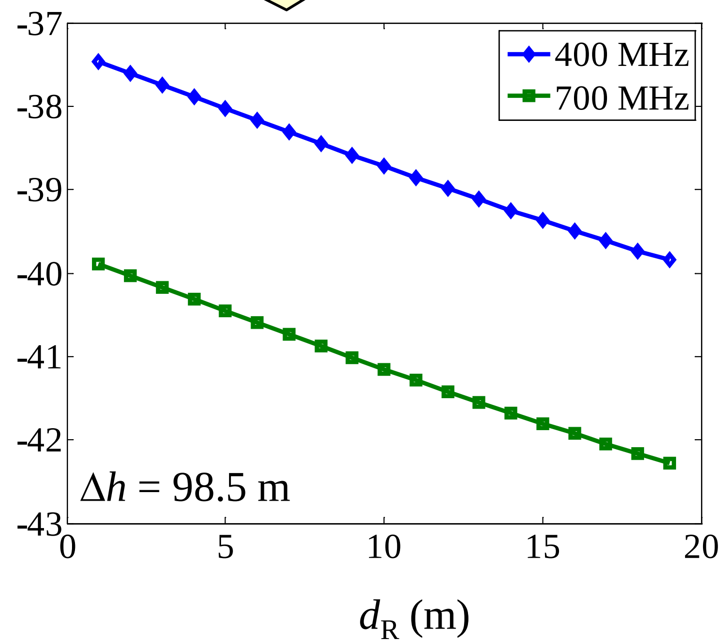
# Sensing versus database lookup 2:
## Sensing works but GPS fails

[Ikegami et al ‘84]

- Urban canyon with TV station in relative proximity

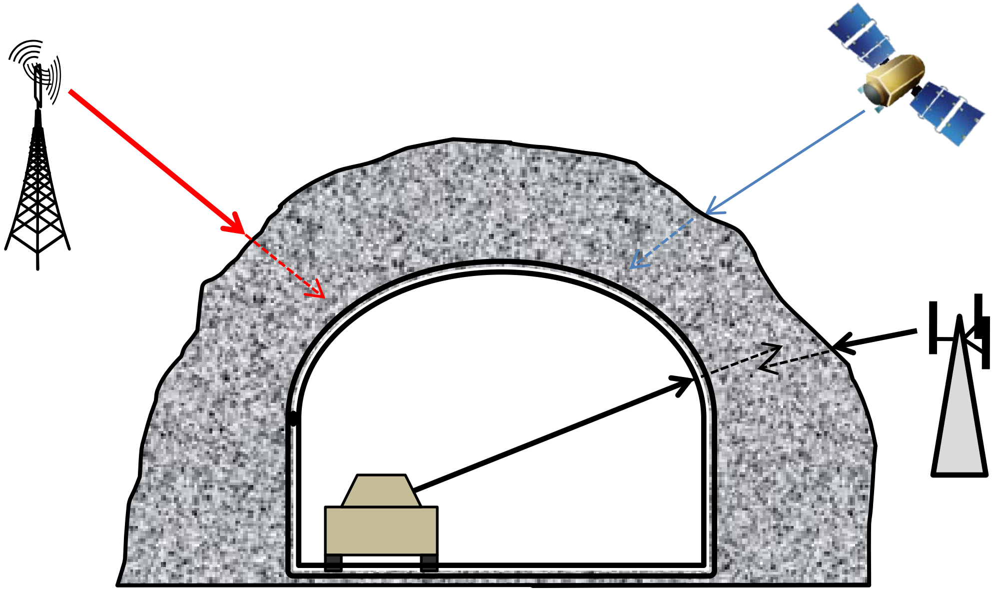



diffraction **loss** might not be large enough to hide primary user from the sensor



# Sensing versus database lookup 3:
## Both sensing and GPS localization fail

- Long tunnel: plenty of spectrum
- But inside the tunnel
  - Cannot sense
  - No GPS signal
  - Typically no access to Internet (including the geolocation DBs)
- Spectrum occupancy at the tunnel exit is unknown

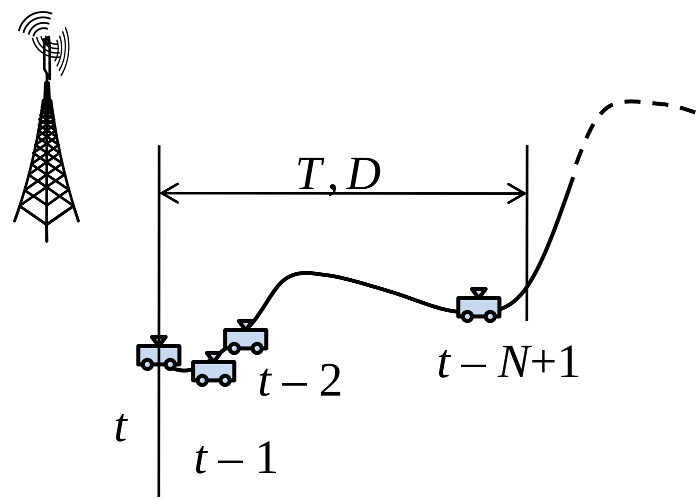


# Improving sensing through utilization of diversity

- Sensing over $N$ independent channel fades reduces outage probability
  - Spatial diversity: collaboration of multiple sensors
  - Temporal diversity: moving sensor experiences channel variations
- Temporal diversity is preferable
  - Hard to maintain connectivity in a vehicular network

- Regulatory domain requirements could be
  - Perform sensing every $T$ seconds
  - Perform sensing every $D$ meters

- How to determine $N$?
  - If too large
    - increases sensing overhead
    - mixing correlated values not helpful
  - If too small
    - diversity is not exploited

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# Temporal diversity

- Channel coherence is described by
  - decorrelation distance $D_c$
  - decorrelation time $T_c$
  - they are related through vehicle speed $v$

$$T_c = \frac{D_c}{v}$$

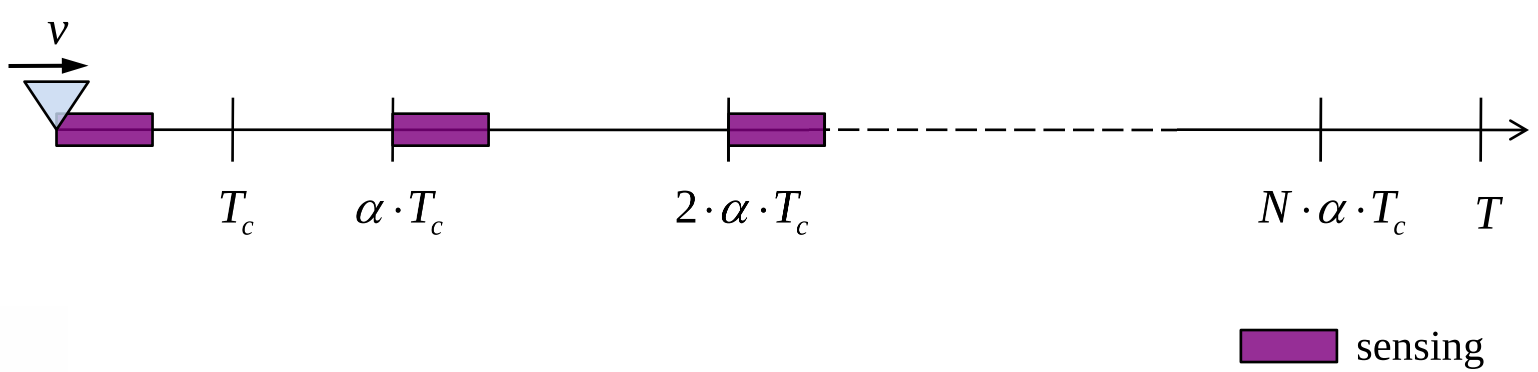
- Crude estimates for $D_c$ and $T_c$ can be a priori tabulated

[Gudmunson '91]
at 900 MHz

| environment | $D_c$ (m) |
|---|---|
| suburban | 300 |
| urban | 7 |

- Select $\alpha > 1$ to accommodate for inaccuracies

$$N = \left\lfloor \frac{T}{\alpha \cdot T_c} \right\rfloor = \left\lfloor \frac{D}{\alpha \cdot D_c} \right\rfloor$$



# Sensing and MAC sublayer design

- Activities controlled on the MAC layer
  - Scheduling of quiet periods for sensing
  - Selection of the sensing duration
  - Exchange of sensing related messages
    - including data fusion for cooperative sensing
  - Keeping track of unused available channels for backup
  - “Pushing” of spectrum availability information from the database to the terminals without sensing capability

- These tasks are difficult to coordinate in ad-hoc V2V networks
  - No base station to coordinate these activities as in centralized networks

# Regulatory domain issues

- Different bands might be available for white space utilization
- Different channel width inside the same bands
  - digital TV: 6, 7, or 8 MHz wide.
- Different licensed standards in the same band
  - digital TV example: ATCS, DVB, and ISDB–T
    - require different feature detection: pilot tone versus pilot symbols
- Different across regulatory domains
  - Example: in 802.22 geolocation accuracy for Canada is not specified
- The design of vehicular MAC can be standardized differently across regulatory domains
  - Example:
    - Japan: mix of TDMA for I2V and CSMA for V2V in 700 MHz band
    - The US: CSMA/CA based DSRC in 5.9 GHz band

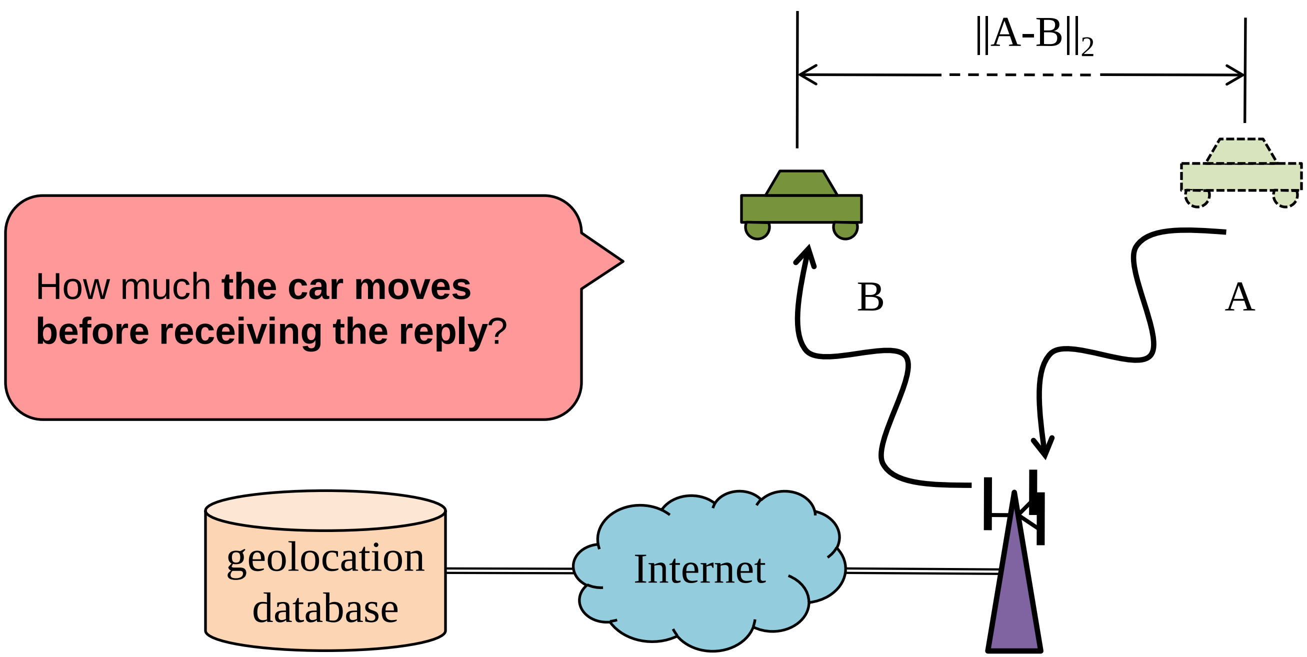
# Conclusion

- Protecting primary users in the mobile environment is challenging
- Spectrum scarcity imposes development of cognitive vehicular networks
- Neither spectrum sensing nor geolocation database lookup alone can provide sufficient protection for incumbent users
- Vehicular environment makes easier to utilize temporal diversity rather than spatial diversity to improve sensing performance
  - decentralized and volatile V2V network topology makes collaboration difficult
  - repetition of sensing is a more viable option
  - for efficient utilization of temporal diversity the scale of channel fluctuations should be taken into account
- Another challenge in ad-hoc V2V networks is synchronization of quiet periods for sensing

# Backup slides

# Database lookup issue 3:
## Access latency

- A car sends request to the database at position A
- Reply arrives when the car is at B
- How far they are apart?
  - at 100 km/h delay of 1 s corresponds to ~ 28 m
- Is the reply information valid at B?
  - the car must anticipate future positions and query in advance

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