Joint Utilization of Temporal and Spatial Diversity for Vehicular Spectrum Sensing

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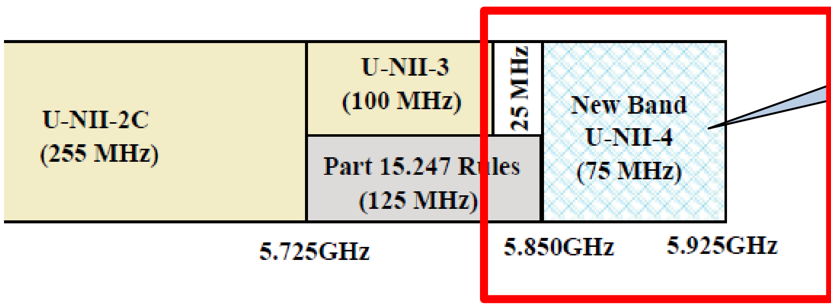
Outline

- Motivation
- System model
  - Mobility model
  - Propagation model
  - Scheduling algorithm
  - Local detection and fusion rules
- Results
  - Diversity
  - Fusion
  - Time versus space
- Future work and conclusion

Why cognitive vehicular networks?

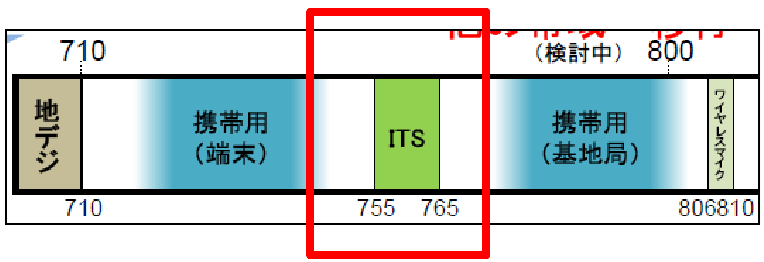
- Latest development with spectrum for vehicular applications
  - The US: Recent initiative from FCC to expand unlicensed bands for WiFi
    - Some left for vehicular networks?
    - Coexistence of DSRC and WiFi?



Currently assigned 75 MHz to DSRC

http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-13-22A1.pdf

  - Japan: Only 10 MHz at 760 MHz for V2V

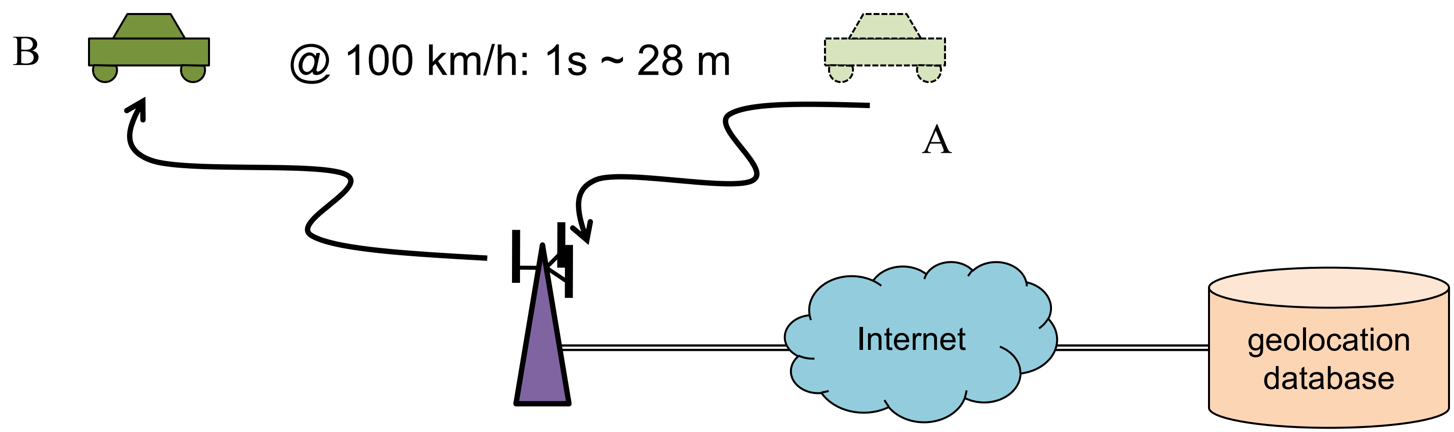


http://www.soumu.go.jp/main_content/000134495.pdf

  - Europe: 30 MHz at 5.9 GHz

Why sensing?

- Previously we pointed out some problems with the database lookup
  - Example: Latency in DB access

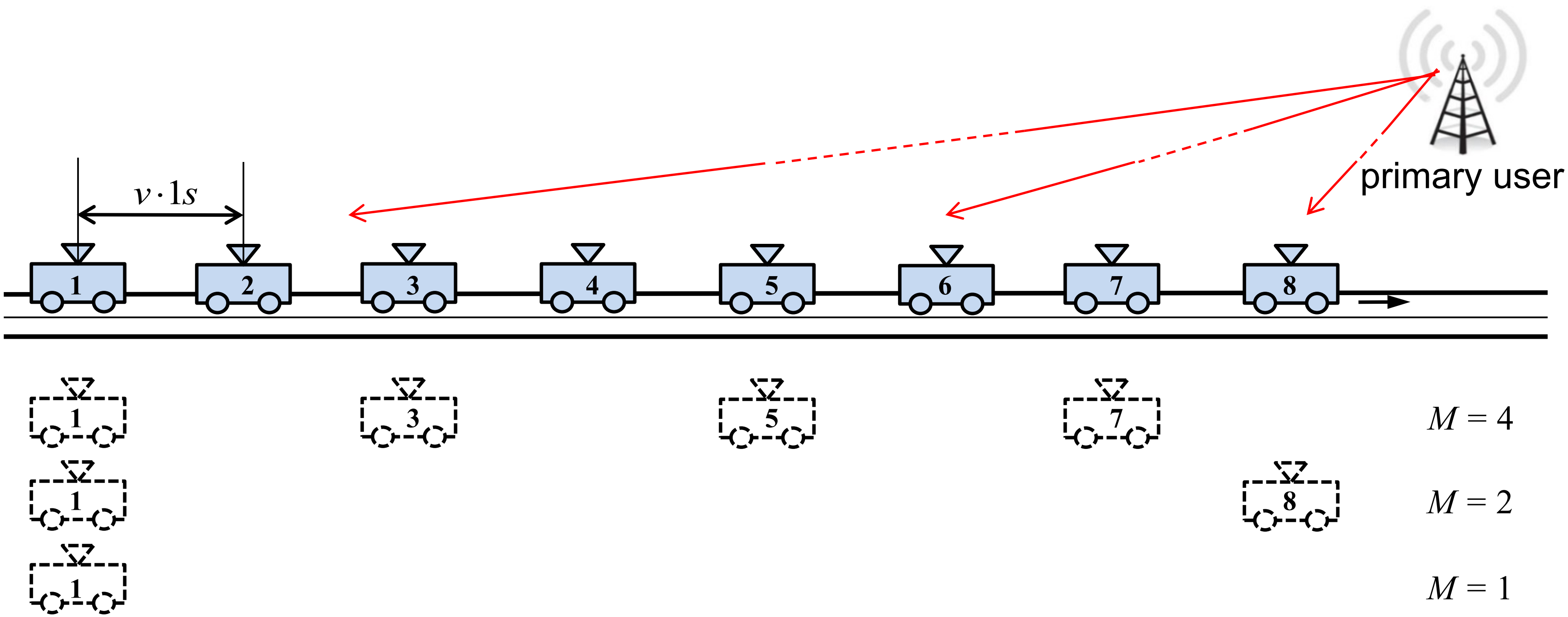


- Mobility creates diversity

mobility → diversity → lower outage probability → better sensing

Mobility model

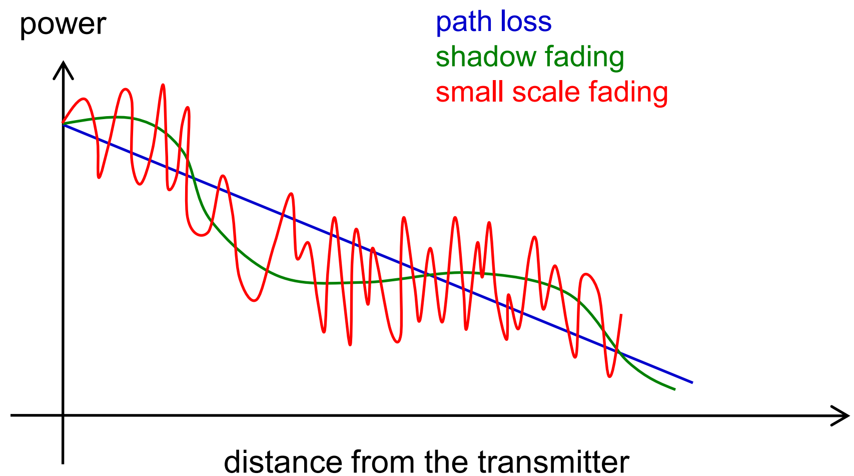
- Linear formation of M = 1,2,4 or 8 vehicles travels straight with speed v
  - rural environment 100 km/h
  - urban environment 50 km/h
- Cars are separated by distance passed in a second $v \cdot$ 1s



Conventional channel modeling approach

1. Average fluctuations in an area “a few wavelengths” in diameter
   - Mean power practically constant

2. Decouple channel variations into
   1. Large scale fading
      - Median path loss:
        steady attenuation with log of distance
      - Log-normal “shadowing”:
        “slow” random variations of power
   2. Small scale fading
      - Fluctuations due to change in phase
        of impinging waves



3. Assume <u>independence</u> between the large and the small scale fading
   - We assume distant primary user and neglect ~~path loss~~

Channel model

- PU signal: Constant amplitude A
  - Similar to ATSC DC pilot tone in baseband

- Small scale fading $h_s(t;\tau)$: GSM ver. 05.05
  - urban: 6-tap Rayleigh with Jakes Doppler spectra
  - rural: 4-tap Rice with Jakes spectra and K-factor 1

- Passing through the time varying filter

$$y(t) = \left[A * h_s(t;\tau)\right] \cdot h_l$$

shadowing

$$10\log_{10}(h_l) \sim \mathcal{N}(0, \sigma^2)$$

urban: σ = 10 dB
rural: σ = 3 dB

- Downsampling to 100 kHz and adding thermal noise + 5 dB noise figure
  - Common trick to lower the noise floor

$$r(t) = y(t) + n(t)$$

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Correlation taxonomy

- Shadow fading
  - decorrelation distance and time
    - 10 m urban, 100 m rural
  - correlation coefficient [Gudmundson '91]

$$D_l = v \cdot T_l$$

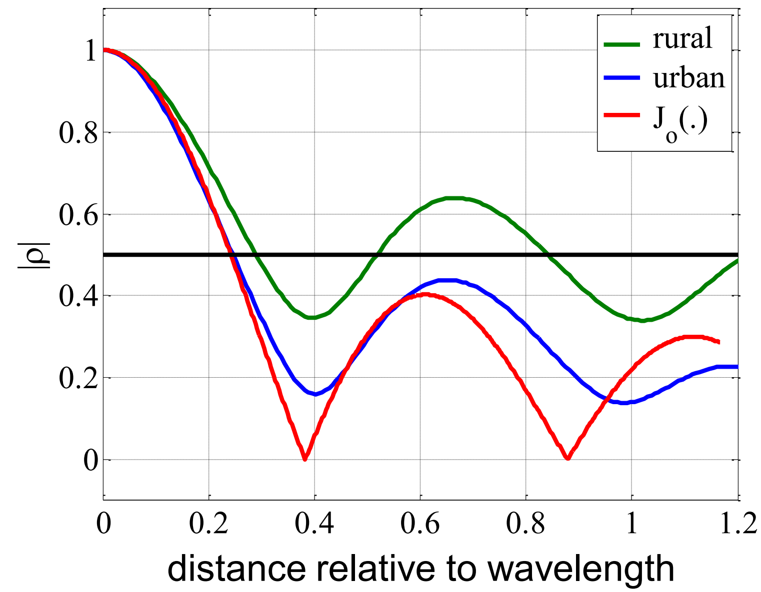
$$\rho = \exp\left(-\ln 2 \cdot \frac{d}{D_l}\right)$$

$$d \geq D_l : \quad \rho \leq 0.5$$

- Small scale fading
  - coherence distance and time

$$D_s = v \cdot T_s$$

  - correlation coefficient



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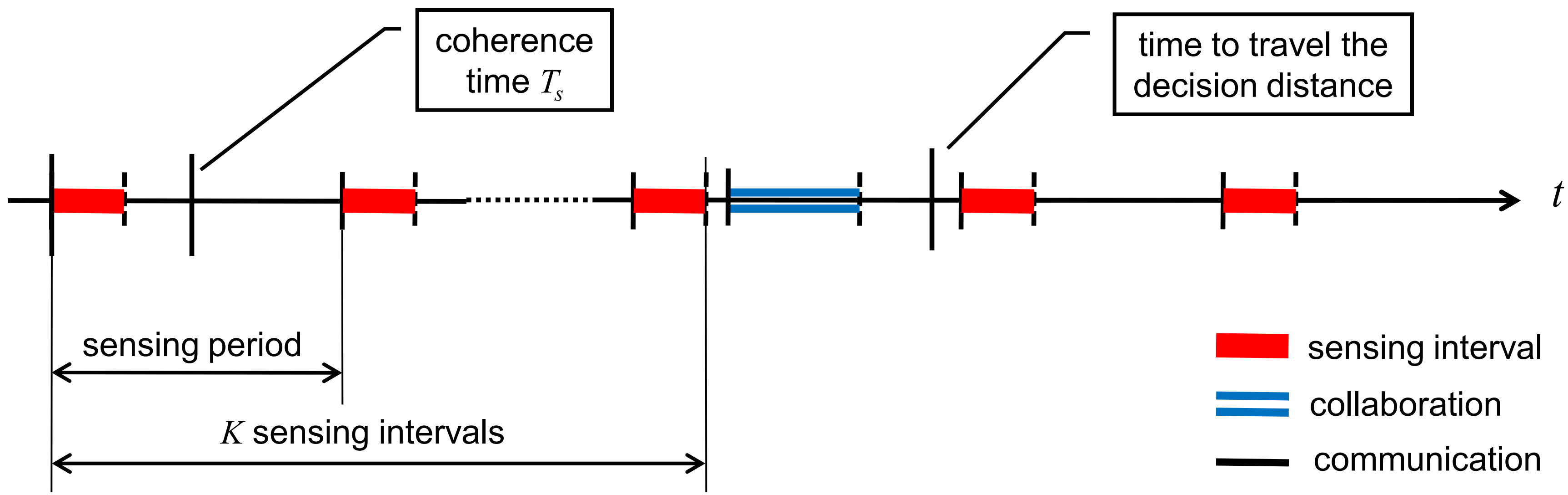
Regulatory domain requirements for primary detection

- With respect to time
  - "Perform sensing every x seconds"
  - FCC: Perform sensing at least once every 60 seconds
  - Not convenient for high speed mobile devices

- With respect to space
  - "Perform sensing if you move by more than y meters"
  - FCC: Check spectrum occupancy every 100 meters
  - Convenient for highly mobile secondary devices since <u>independent of speed</u>
  - We call it "Decision distance"
    - 10 m urban
    - 100 m rural

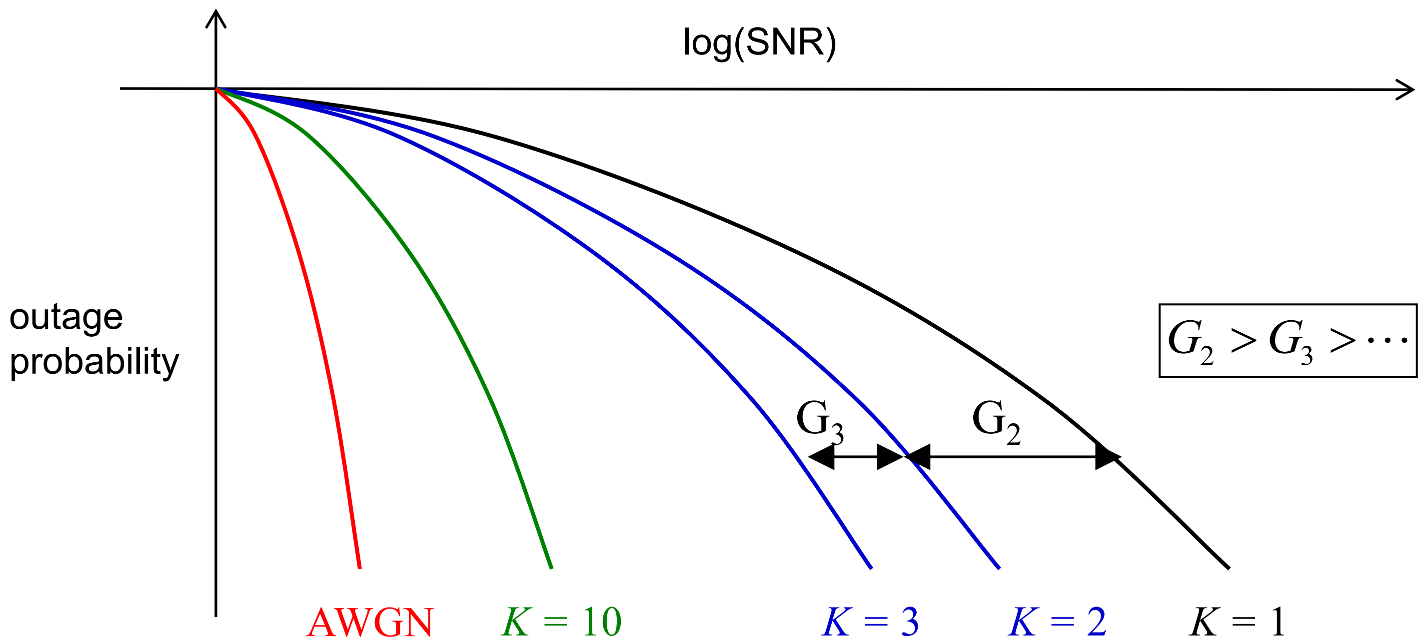
Scheduling of sensing

- Sensing interval is shorter than small scale fading coherence time T_s
  - Provides statistically invariant (good or bad) channel during sensing
- Sensing period (much) larger than the small scale fading coherence time
  - Repeating sensing K times results in quasi-independent local sensing outcomes



Basic idea: Better utilization of small scale diversity

- Diversity gain does not scale with the number of “diversity branches” K
- We increase number of branches exponentially to compensate
  - Easy to do with a moving car in time domain
  - Hard to put 10 antennas separated by a meter on a device



Energy detection

- Take KN samples of $r(t)$ to obtain a vector $\boldsymbol{R}$
  - scheduling: N samples in K successions
  - benchmark: KN samples in one run
- Compare average to the threshold η

$$\boldsymbol{R}'_m \boldsymbol{R}_m \underset{H_0}{\overset{H_1}{\underset{<}{\geq}}} KN\eta$$

- Decide

$$\begin{cases} H_1 : \text{Primary user present} \\ H_0 : \text{Channel is free} \end{cases}$$

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Fusion

- If M or K is changed N is also changed to make fair comparison
- Hard combining
  - Combine M local decisions by AND, OR, or simple majority rule
- Soft combining
  - EGC

$$\sum_{m=1}^{M} \boldsymbol{R}_{\boldsymbol{m}}' \boldsymbol{R}_{\boldsymbol{m}} \underset{H_0}{\overset{H_1}{\gtrless}} MKN\eta$$

  - MRC

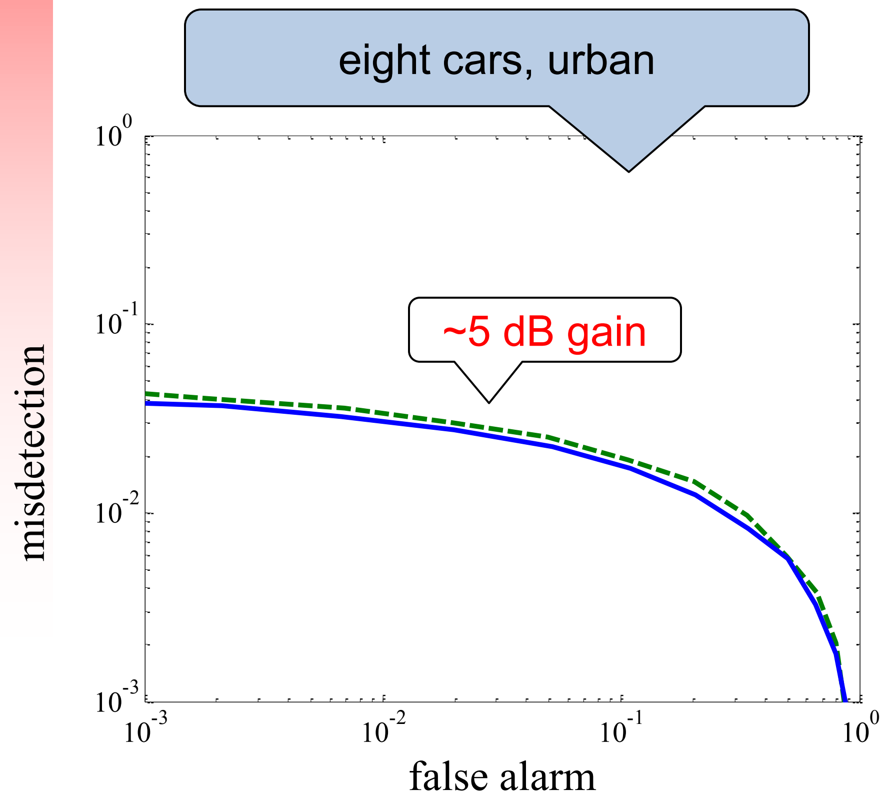
$$\sum_{m=1}^{M} a_m \boldsymbol{R}_{\boldsymbol{m}}' \boldsymbol{R}_{\boldsymbol{m}} \underset{H_0}{\overset{H_1}{\gtrless}} MKN\eta$$

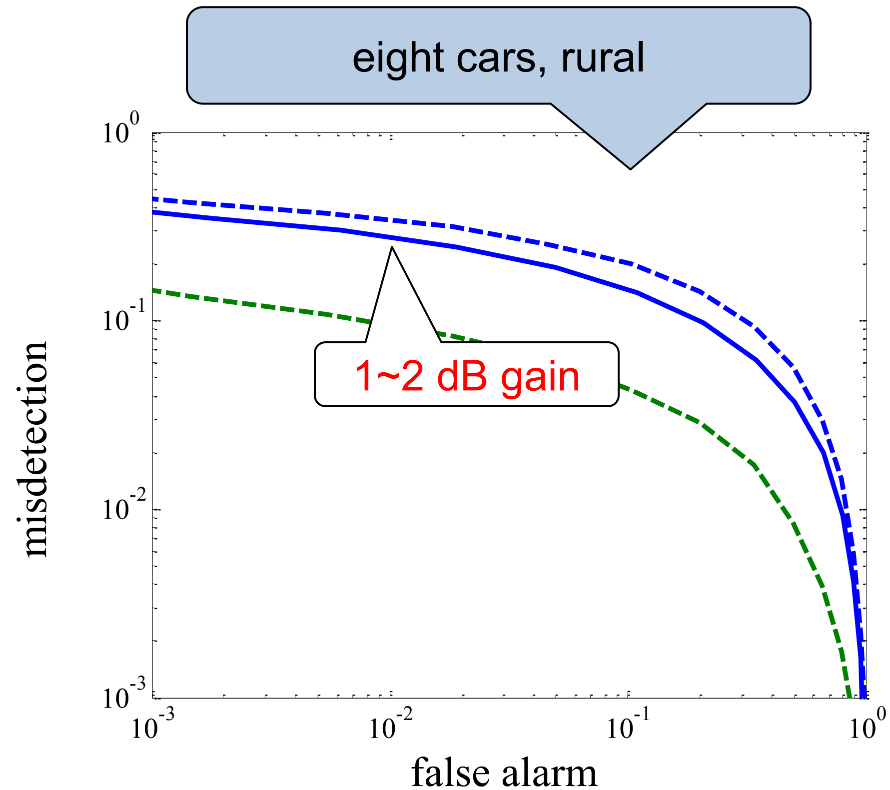
$$a_m = \frac{\boldsymbol{R}_{\boldsymbol{m}}' \boldsymbol{R}_{\boldsymbol{m}}}{\sum_{m=1}^{M} \boldsymbol{R}_{\boldsymbol{m}}' \boldsymbol{R}_{\boldsymbol{m}}}$$

Diversity gain

benchmark
scheduling

SNR (dB)	color
-10	
-5	





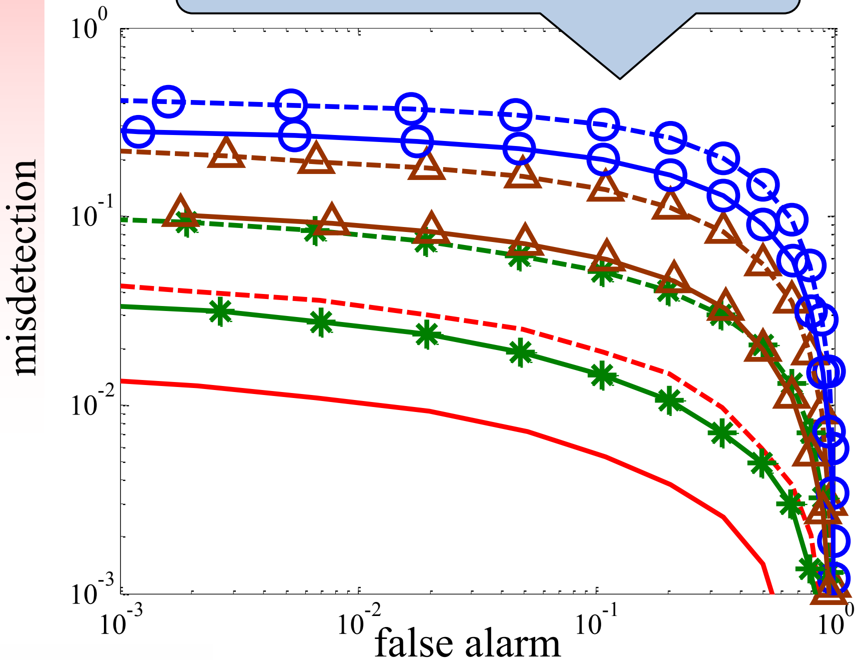
Collaboration and scheduling

# of cars	color
1	blue
2	dark red
4	green
8	red

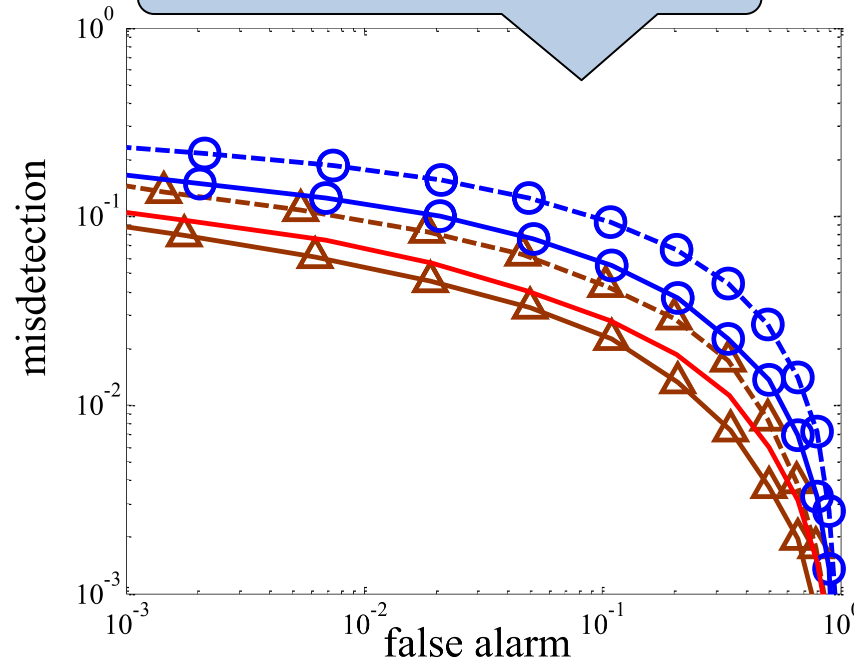
benchmark
scheduling

- For selected parameters
  - in urban environment:
    scheduling ~ doubling number of cars
  - in rural environment:
    above two cars no diversity gain due to correlation

urban, -5 dB, EGC



rural, -5 dB, EGC



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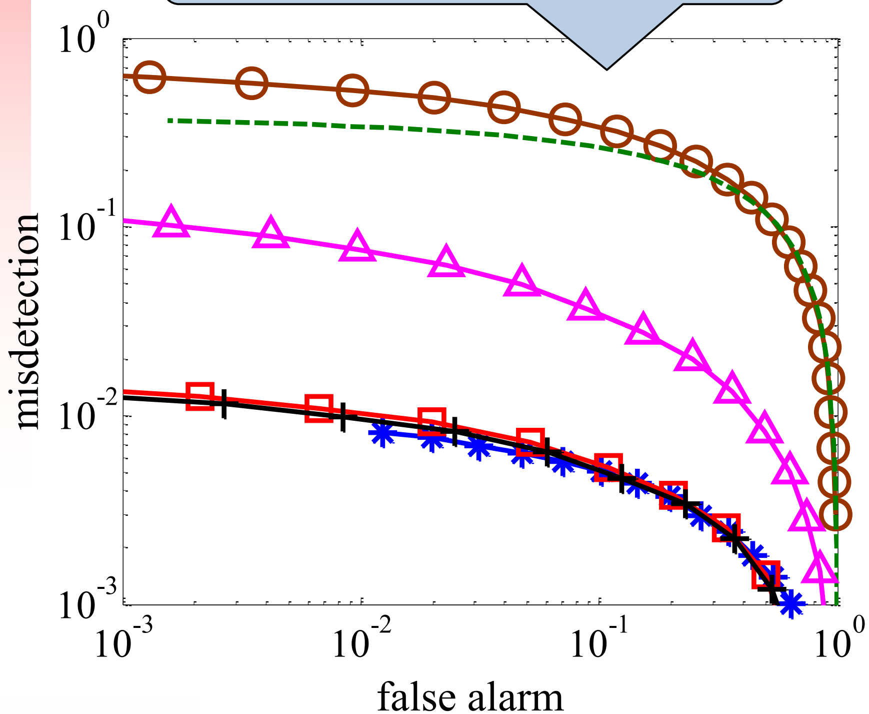
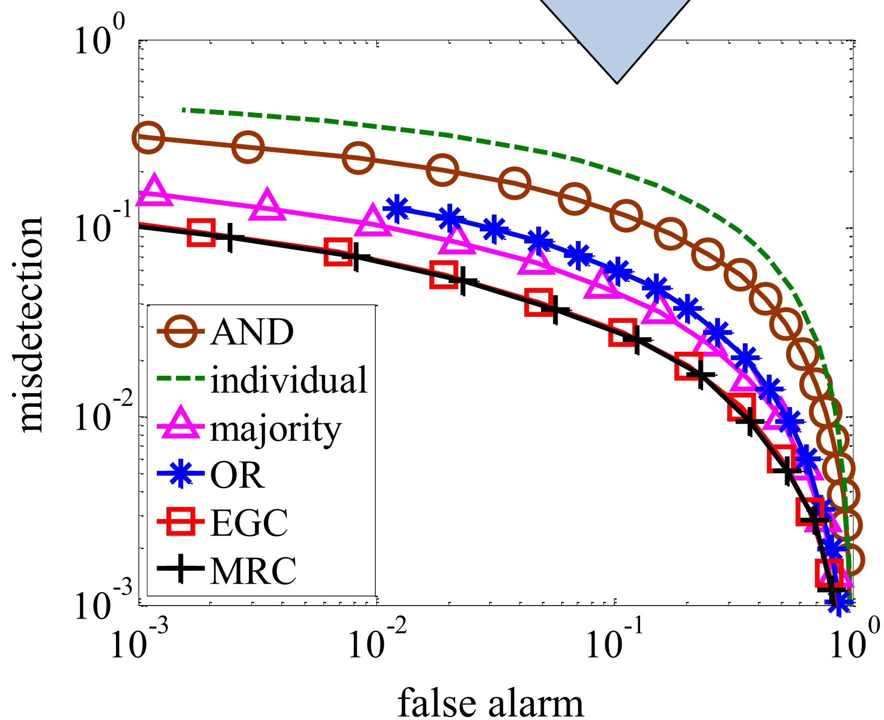
Performance of different fusion algorithms with scheduling

- Soft combining performs well in both environments
  - Equal average powers result in EGC being similar to MRC
  - In strong fading the sensor with the strongest signal is most likely accurate
    - OR rule performs similar to soft fusion

eight cars, urban, -5 dB

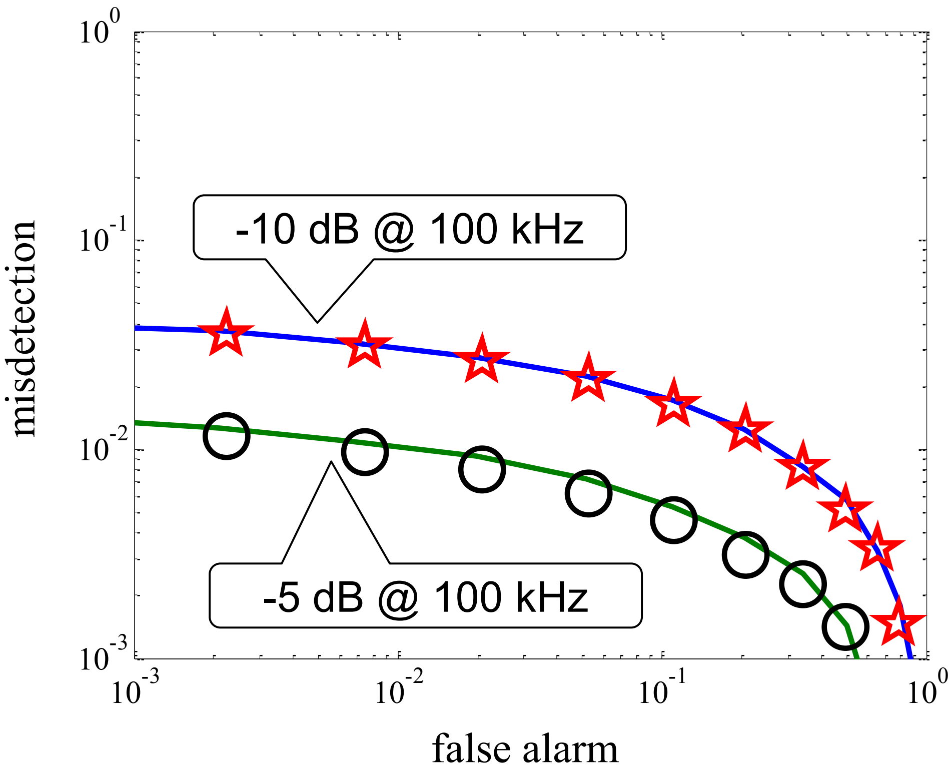


eight cars, rural, -5 dB
agrees with [Borota '11]

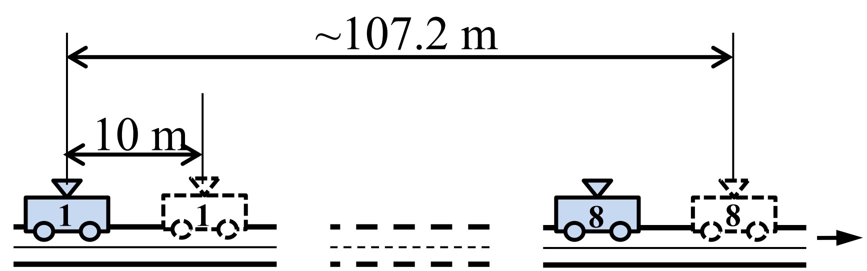


Space – time tradeoff

- A single sensor achieves the same performance as eight sensors when covering the same distance



urban environment	
-10 dB, 8 cars, 10 m	blue
-5 dB, 8 cars, 10 m	green
-10 dB, 1 car, 107 m	☆
-5 dB, 1 car 107 m	O

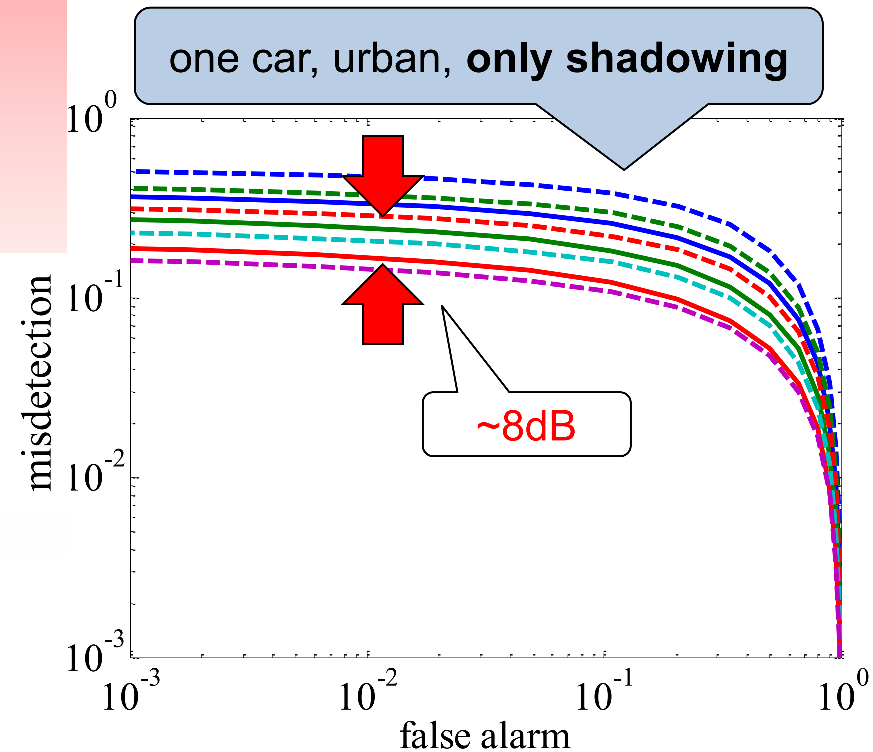


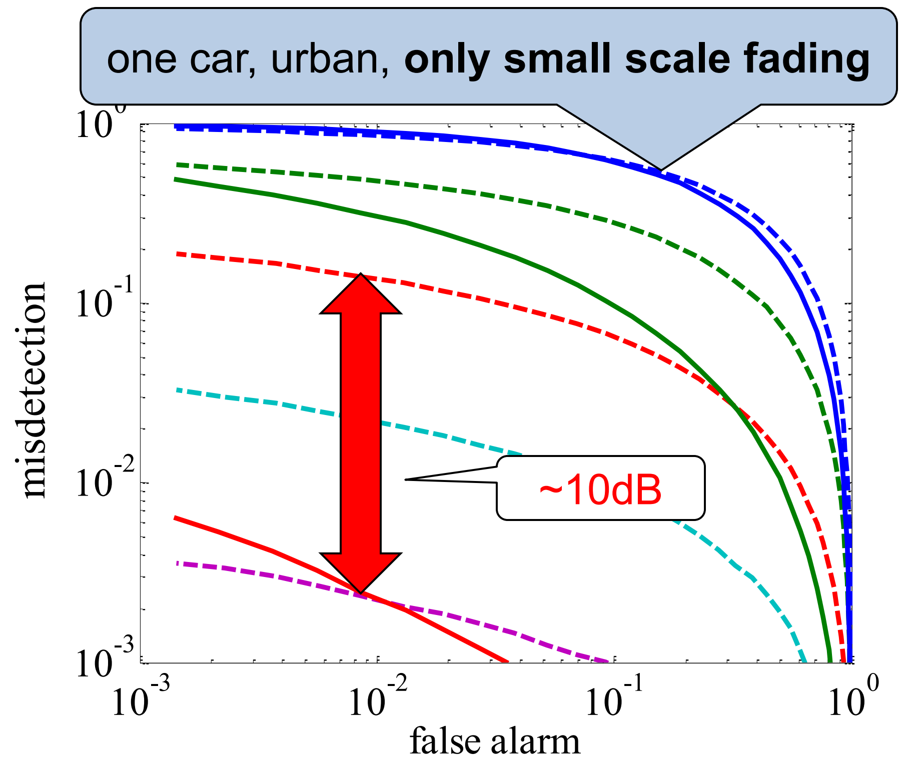
Future work

SNR (dB)	color
-10	
-5	
0	
5	
10	

benchmark	
scheduling	

- What creates diversity gain?
  - Small and/or large scale fading?
  - How much gain for different SNRs?





Conclusion

- Splitting sensing interval into a number of shorter intervals improves sensing performance through better utilization of diversity

- Soft fusion performs consistently good in rural and urban environment
  - For calibrated “equal” sensors EGC as good as MRC

- Due to speed cars can trade space for time to exploit diversity

- Whether to collaborate or not depends on the regulatory domain requirements
  - For decision distance < shadowing decorrelation distance
    collaboration must be used
  - For decision distance > shadowing decorrelation distance
    single sensor can achieve the same performance as collaborating sensors

Backup slides

Simulation parameters

<table>
<tr><th>Environment</th><th colspan="4">Rural</th><th colspan="6">Urban</th></tr>
<tr><td>Shadow fading</td><td colspan="4">mild</td><td colspan="6">severe</td></tr>
<tr><td>standard dev. σ</td><td colspan="4">3 dB</td><td colspan="6">10 dB</td></tr>
<tr><td>decorrelation dist. D_l</td><td colspan="4">100 m</td><td colspan="6">10 m</td></tr>
<tr><td>local area size (m)</td><td colspan="4">10 λ_c</td><td colspan="6">5 λ_c</td></tr>
<tr><td>Small scale fading</td><td colspan="4">LOS, GSM rural</td><td colspan="6">NLOS, GSM urban</td></tr>
<tr><td>tap delays (μs)</td><td>0</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0</td><td>0.2</td><td>0.6</td><td>1.6</td><td>2.4</td><td>5.0</td></tr>
<tr><td>relative powers (dB)</td><td>0</td><td>-2</td><td>-10</td><td>-20</td><td>-3</td><td>0</td><td>-2</td><td>-6</td><td>-8</td><td>-10</td></tr>
<tr><td>Rice K-factor</td><td colspan="4">1</td><td colspan="6">n/a</td></tr>
<tr><td rowspan="2">Doppler spectra</td><td colspan="4">LOS: Jakes+$\delta(0.7 f_{max})$</td><td colspan="6" rowspan="2">all taps: Jakes</td></tr>
<tr><td colspan="4">all other taps: Jakes</td></tr>
<tr><td>Sensor speed v</td><td colspan="4">100 km/h</td><td colspan="6">50 km/h</td></tr>
<tr><td>Carrier frequency f_c</td><td colspan="10">700 MHz</td></tr>
<tr><td>Sensing bandwidth</td><td colspan="10">100 kHz</td></tr>
<tr><td>Baseline sensing interval</td><td colspan="4">0.1 ms
(N = 10 samples)</td><td colspan="6">1 ms
(N = 100 samples)</td></tr>
<tr><td>Sensing period</td><td colspan="4">40 ms</td><td colspan="6">80 ms</td></tr>
<tr><td>Decision distance</td><td colspan="4">100 m or 10 m</td><td colspan="6">10 m or 107 m</td></tr>
<tr><td>SNR</td><td colspan="10">-10, -5, 0 dB</td></tr>
<tr><td>Sensor link budget</td><td colspan="10">-5 dB</td></tr>
</table>

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