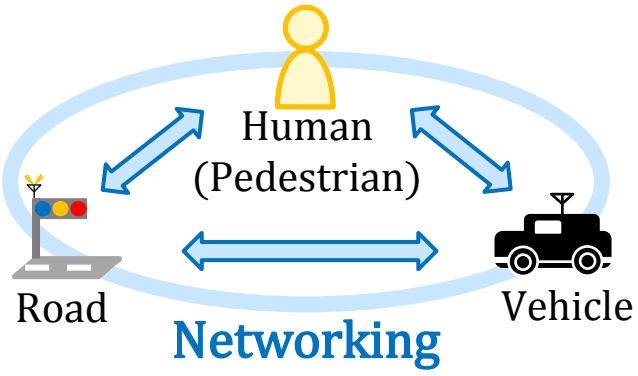
Weighted Cooperative Sensing Based on Spectrum Database for Cognitive Vehicular Networks

Yuya Ohue, Masayuki Kitamura, Kei Inage, Koji Ishibashi, Takeo Fujii
AWCC (Advanced Wireless Communication research Center)
The University of Electro-Communications, Tokyo, Japan

Application of CR to WVN

Wireless Vehicular Networks (WVN)

- Prospective entertainment service
  - More spectrum resources are necessary
- Spectrum resource is scarcity
  - Diversification of wireless communication

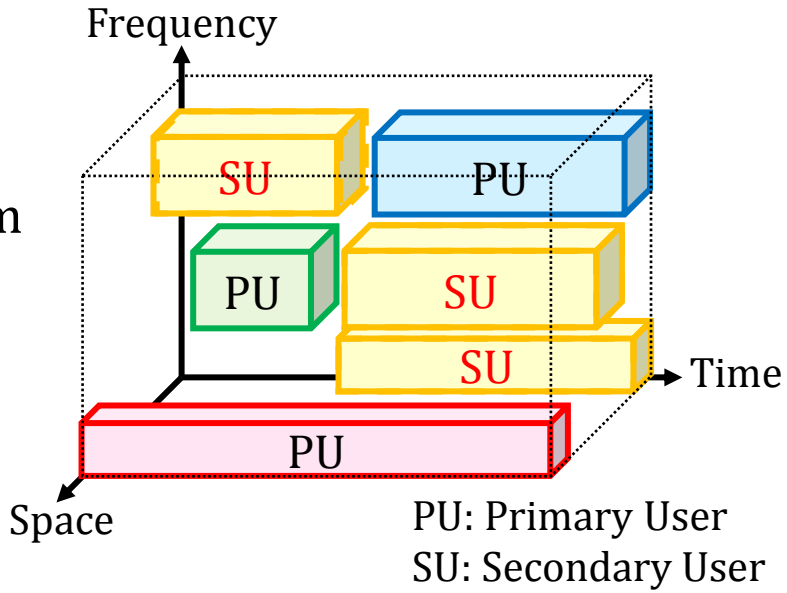


Apply CR to WVN

Cognitive Radio (CR)

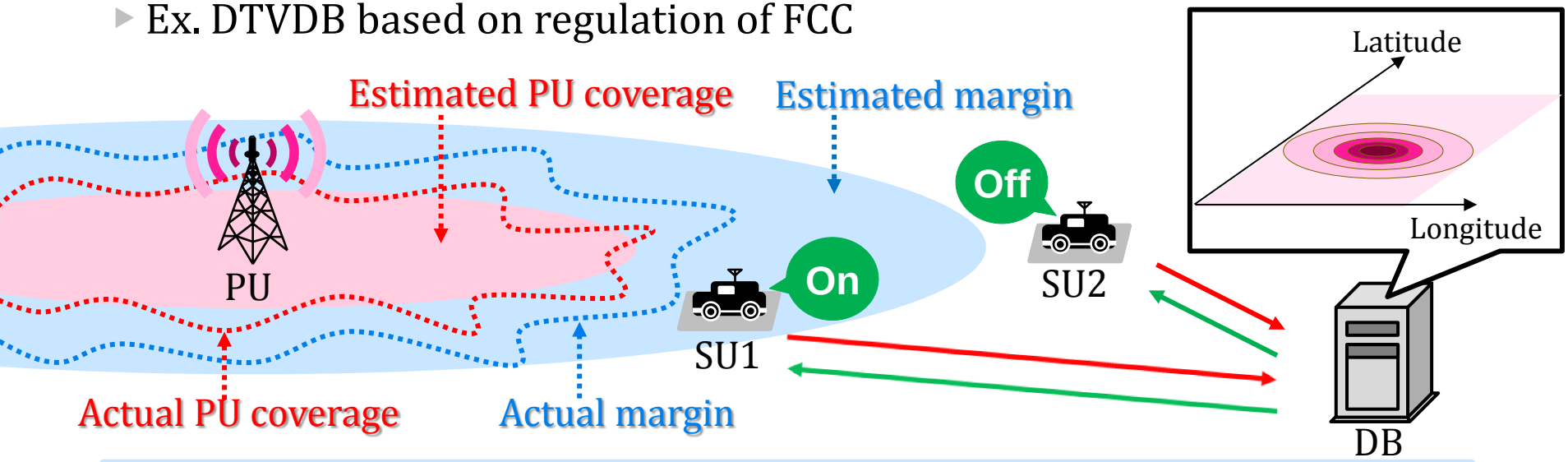
- Sharing the spectrum in White Space
  - Enable wireless system to utilize spectrum resource with high efficiency

Radio environment recognition is important
- Database (DB) approach
- Spectrum sensing approach



PU protection based on DB approach

- DB provides available channel information to SU
  - SU accesses to DB and obtains spectrum information of its own local position
- Conventional DB construction
  - PU coverage and protection margin are estimated by propagation model
    - Ex. DTVDB based on regulation of FCC



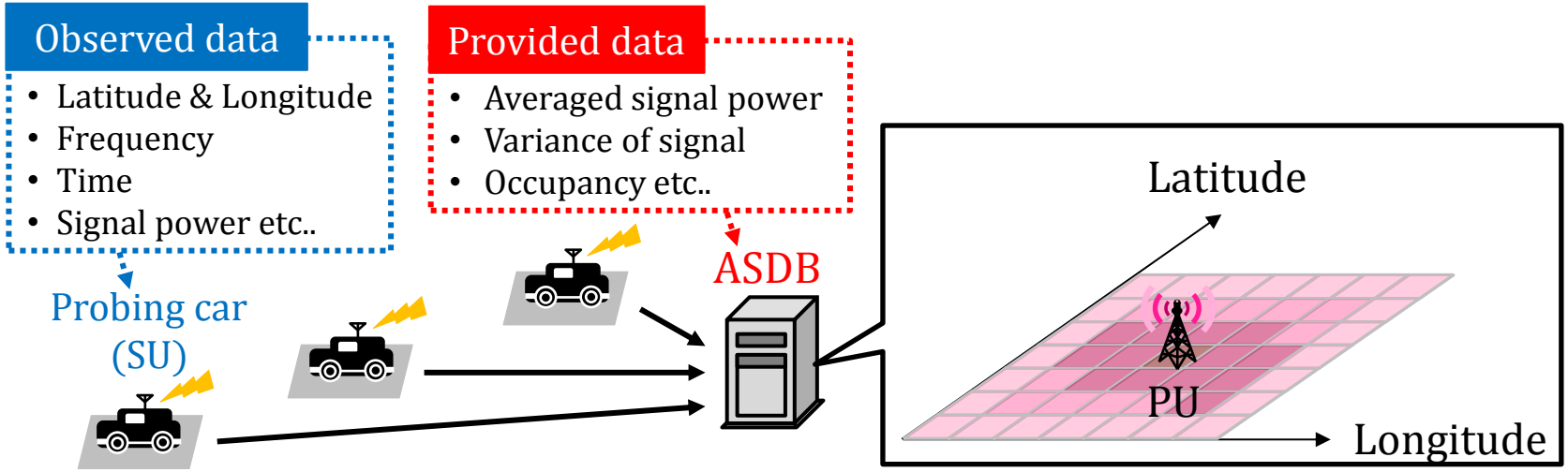
Estimated by propagation model
- Actual radio propagation cannot be modeled by simple equation
- Too large margin reduces opportunity of spectrum sharing

Advanced Spectrum Database (ASDB)

■ ASDB stores statistical data based on actual observed data [1]

» Probing cars observe radio environment and report results to ASDB

➡ Statistical data is connected with location information



[1]M. Kitamura, Y. Ohue, K. Inage, and T. Fujii, "Development of measurement based spectrum database for efficient spectrum sharing," *SDR-WInnComm 2014*, Mar. 2014.

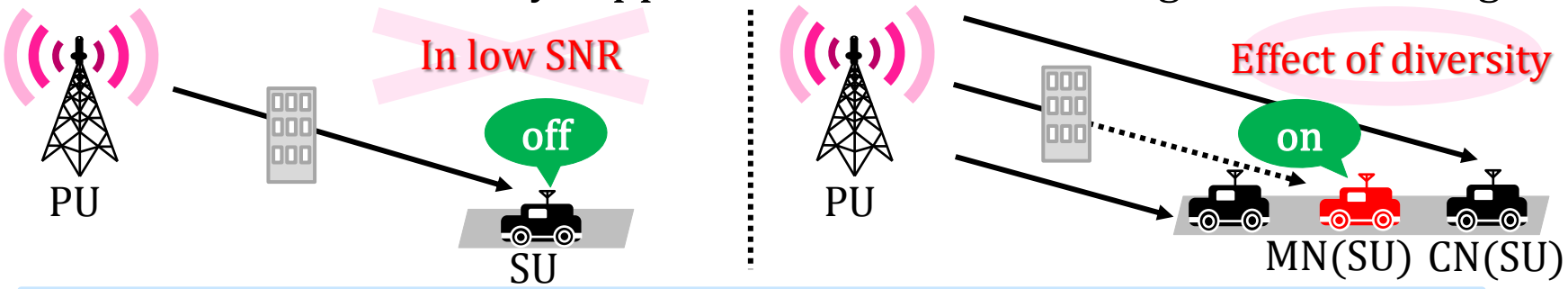
- Advantage: Statistical radio environment can be recognized
- Disadvantage: PU communication status is hard to recognize in real time

PU protection based on spectrum sensing

- SU observes radio environment and decides the status of PU
  - » Energy Detection (ED)
    - Simple structure ➡ Comparing received signal power with threshold
    - Individual ED ➡ Fading and shadowing affect sensing performance

Solution

- Cooperative sensing based on multiple nodes
  - » Master Node (MN) integrates observed data from Cooperative Nodes(CNs)
    - Effectiveness of diversity suppresses influence of fading and shadowing



- Advantage: PU communication status can be recognized in real time
- Disadvantage: Statistical radio environment is hard to recognize

Weighted cooperative sensing based on ASDB

Comparison between ASDB and cooperative sensing

	Instantaneous	Statistical
ASDB	–	✔
Cooperative sensing	✔	–

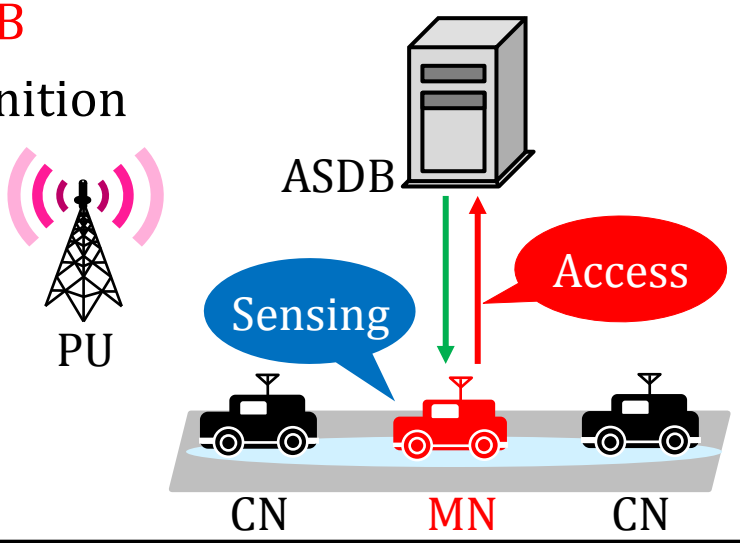
Point of this study

Hybrid technique based on spectrum sensing and ASDB

» Weighted cooperative sensing based on ASDB

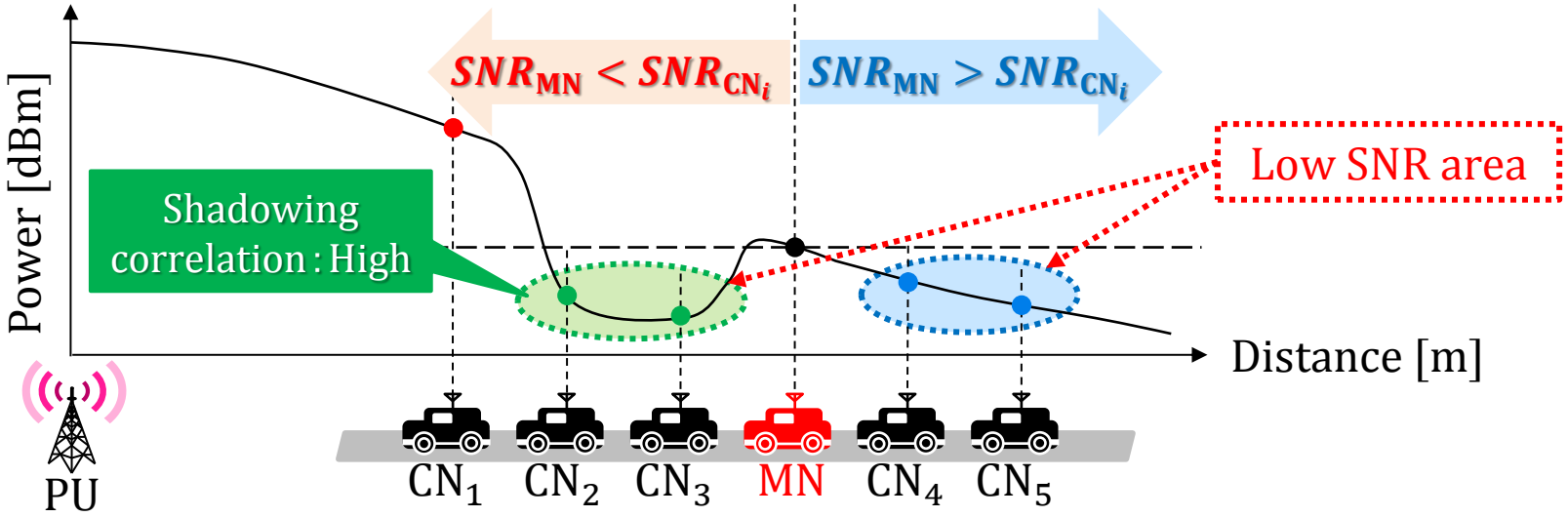
▸ Performing exact radio environment recognition

Improvement of recognition performance
- PU protection accuracy
- Spectrum sharing opportunity



Utilization of weighting factor in WVN

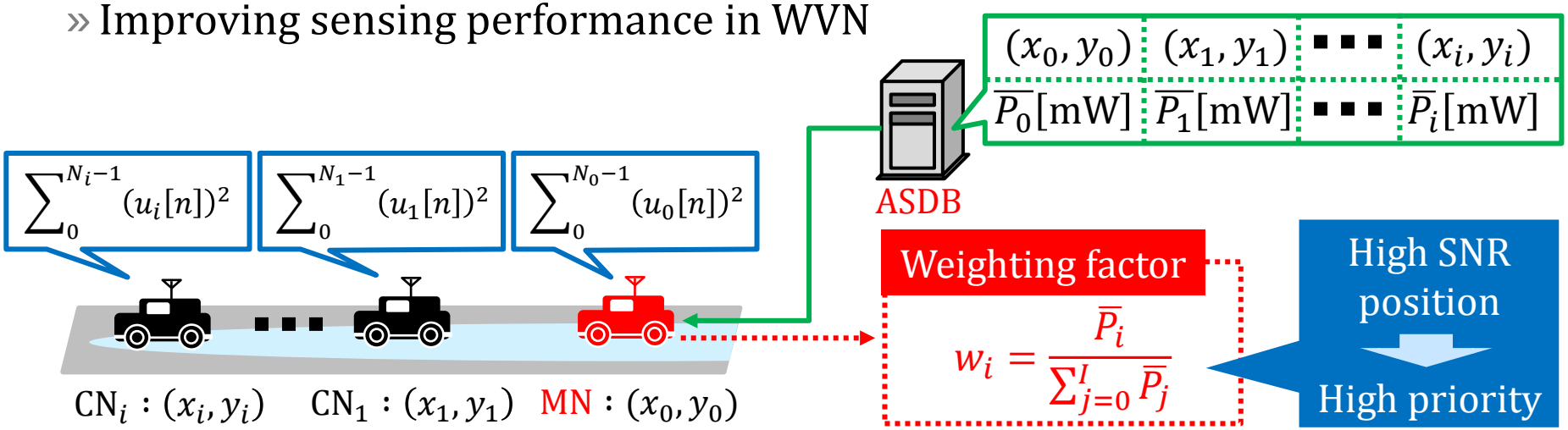
- Distribution of CNs are different from the previous works in WVN
  - » Sensing nodes=Vehicles: Placed on the road in high mobility
  - » Influence of buildings and geometry are strong
  - » Applying weighting factor is effective
    - ▸ Practical process does not exist



Weighting factor based on ASDB
- ASDB has been stored statistical information based on actual observation
- MN obtains averaged PU signal power from ASDB as weighting factor

Proposed weighted cooperative sensing

- Weighting factor is generated by averaged received power $\overline{P_i}$
  - » At each location where signal is observed
  - » Improving sensing performance in WVN



Test statistic

$$T(u) = \sum_{i=0}^{I}\sum_{n=0}^{N_i-1} w_i \cdot (u_i[n])^2$$

Threshold

※Distribution of AWGN : $N\left(\sum_{i=0}^{I} N_i w_i \sigma_w^2, \sum_{i=0}^{I} N_i w_i \sigma_w^4\right)$

$$\gamma = \sqrt{\sum_{i=0}^{I} N_i w_i \sigma_w^4}\, Q^{-1}(P_{\mathrm{FA}}) + \sum_{i=0}^{I} N_i w_i \sigma_w^2$$

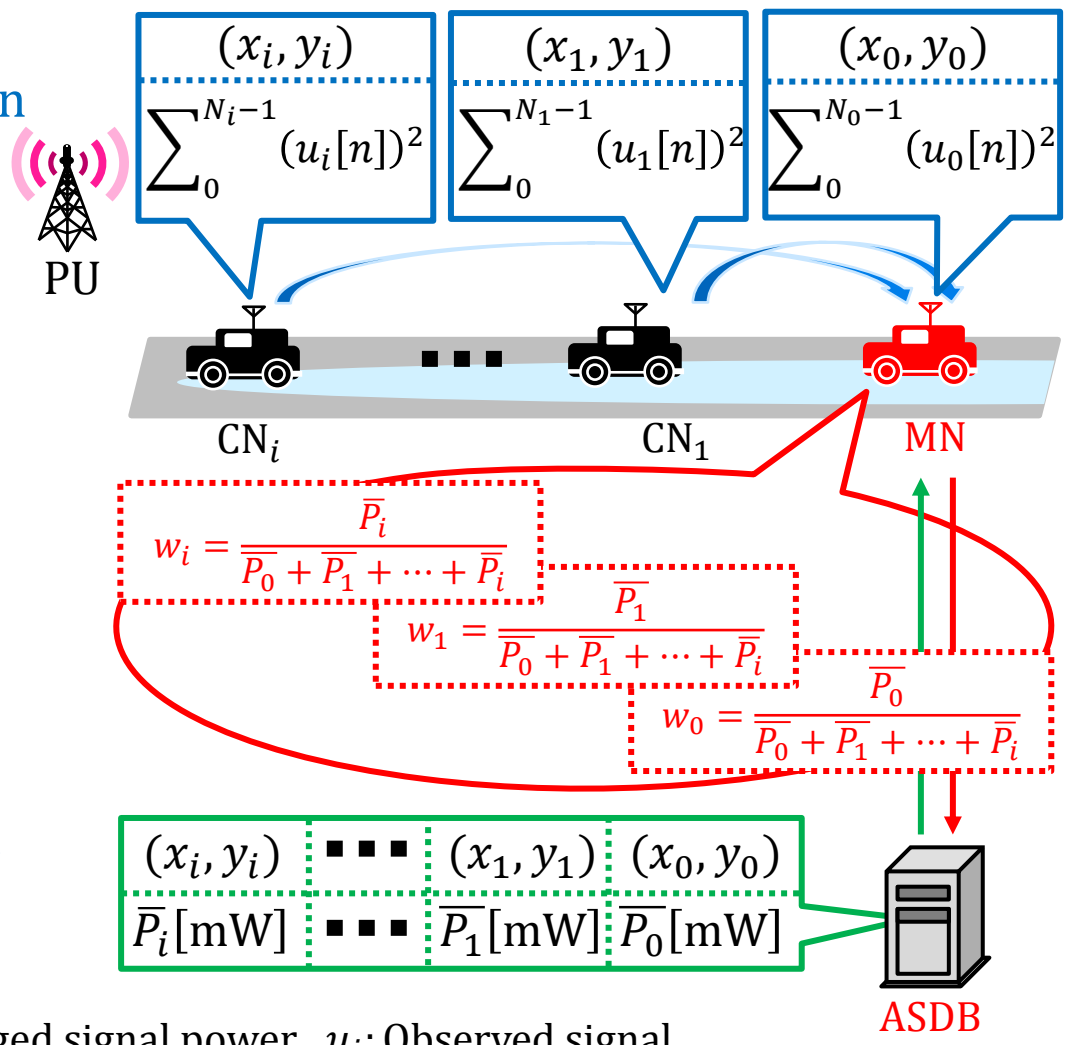
$i(=0,1,\ldots,I)$: The index of node P_i: Averaged signal power u_i: Observed signal

$n(=0,1,\ldots N_i-1)$: The index of sample σ_w: Standerd deviation of AWGN P_{FA}: False alarm rate

Procedure of proposed method

Decision procedure

1. Requesting CNs for cooperation
   - Observed information by CNs
     - » Location: (x_i, y_i)
     - » Signal power: $\sum_0^{N_i-1}(u_i[n])^2$
2. Requesting averaged power $\overline{P_i}$ from ASDB
   - MN obtains averaged power of each MN and CNs location
3. Generating weighting facter w_i
   - Operated by MN



$i(=0,1,\ldots,I)$: The index of node P_i: Averaged signal power u_i: Observed signal

$n(=0,1,\ldots N_i-1)$: The index of sample σ_w: Standerd deviation of AWGN P_{FA}: False alarm rate

Procedure of proposed method

Decision procedure

4. Calculating $T(u)$ and γ
   - Operated by MN
   - Multiply w_i by observed data

5. Deciding communication status of PU
   - $T(u) \underset{<}{\overset{\geq}{}} \gamma$: ON / OFF

Evaluate effectiveness of proposed method

Simulation & Emulation

Weighting factor

$$w_i = \frac{\overline{P_i}}{\sum_{j=0}^{I} \overline{P_j}}$$

Test statistic

$$T(u) = \sum_{i=0}^{I} \sum_{n=0}^{N_i - 1} w_i \cdot (u_i[n])^2$$

Threshold

$$\gamma = \sqrt{\sum_{i=0}^{I} N_i w_i \sigma_w^4 \, Q^{-1}(P_{\mathrm{FA}}) + \sum_{i=0}^{I} N_i w_i \sigma_w^2}$$

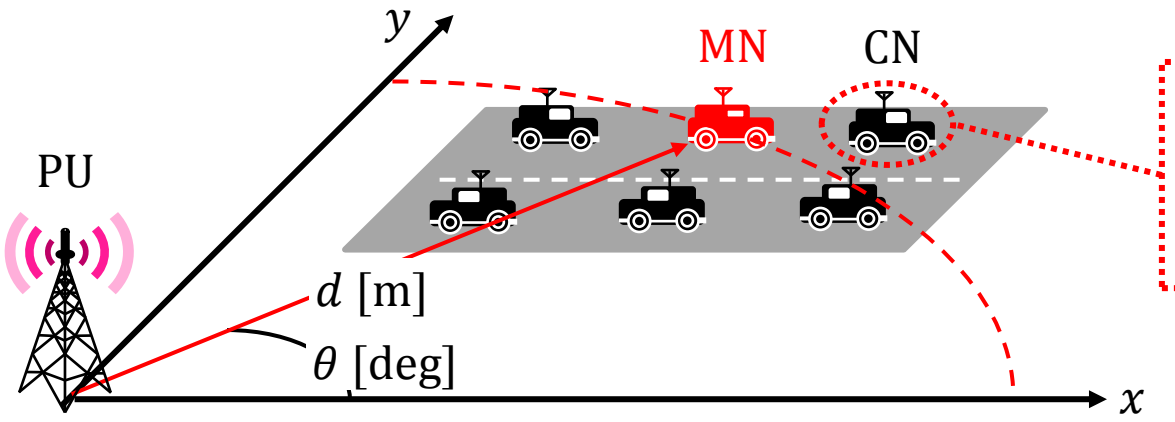
$i(=0,1,\ldots,I)$: The index of node P_i: Averaged signal power u_i: Observed signal

$n(=0,1,\ldots N_i - 1)$: The index of sample σ_w: Standerd deviation of AWGN P_{FA}: False alarm rate

Simulation specifications

- Evaluating sensing performance under $P_D = 0.9$
  - » Comparative approaches
    - Individual ED and Cooperative sensing
  - » Two types of simulations
    - Type1: Detection boundary
    - Type2: Improvement factor for SNR

Simulation model



- CNs are distributed following Poisson distribution
- About 20 cars are in the cooperative coverage

Simulation parameters

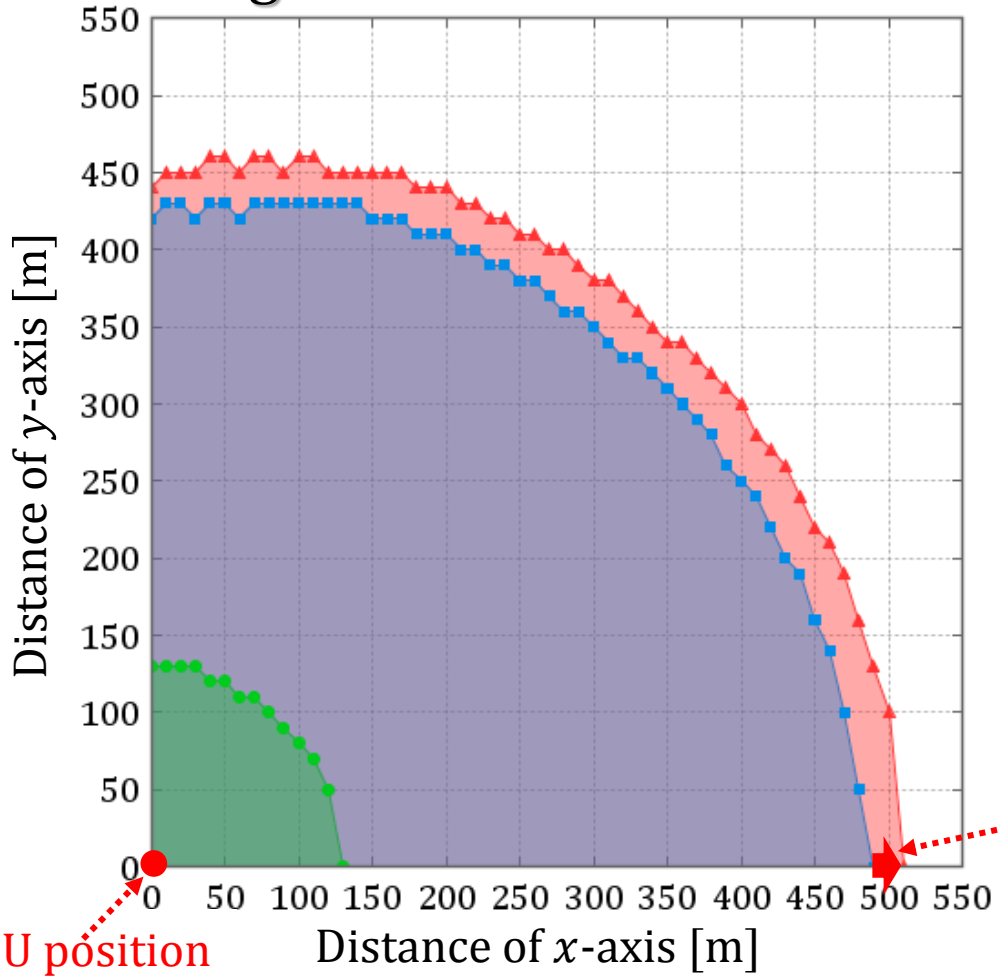
Channel model	Propagation loss Correlation shadowing Rayleigh fading
Carrier frequency of PU	653.142857[MHz]
Signal sample	128
Average noise power	-95[dBm]
False alarm rate	0.1
Propagation factor	4.0
Reference distance	50[m]
Standard division of shadowing	8[dB]
Correlation distance of shadowing	20[m]
Mode of Poisson distribution	1.0
Radius of cooperative coverage	150[m]
Antenna gain of SU and PU	2[dBi]
Velocity of vehicle	45[km/h]
Safe distance between vehicle	30[m]

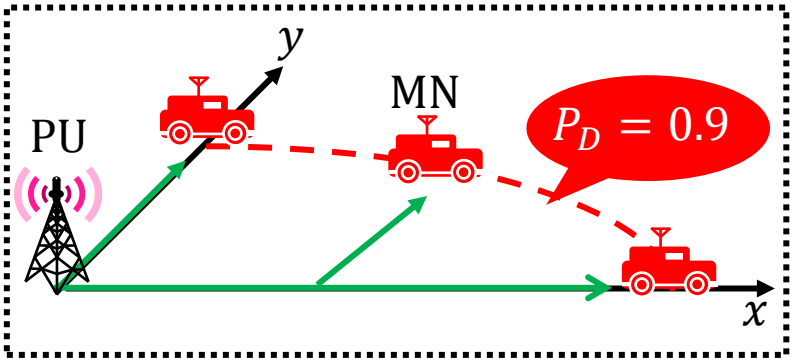
Detection boundary for achieving P_D=0.9

- Transmit power of PU is −10.0 dBm

※P_D : Probability of PU detection

- $\theta = 0$ deg: Extension 20 m





Individual sensing
Cooperative sensing
Weighted cooperative sensing

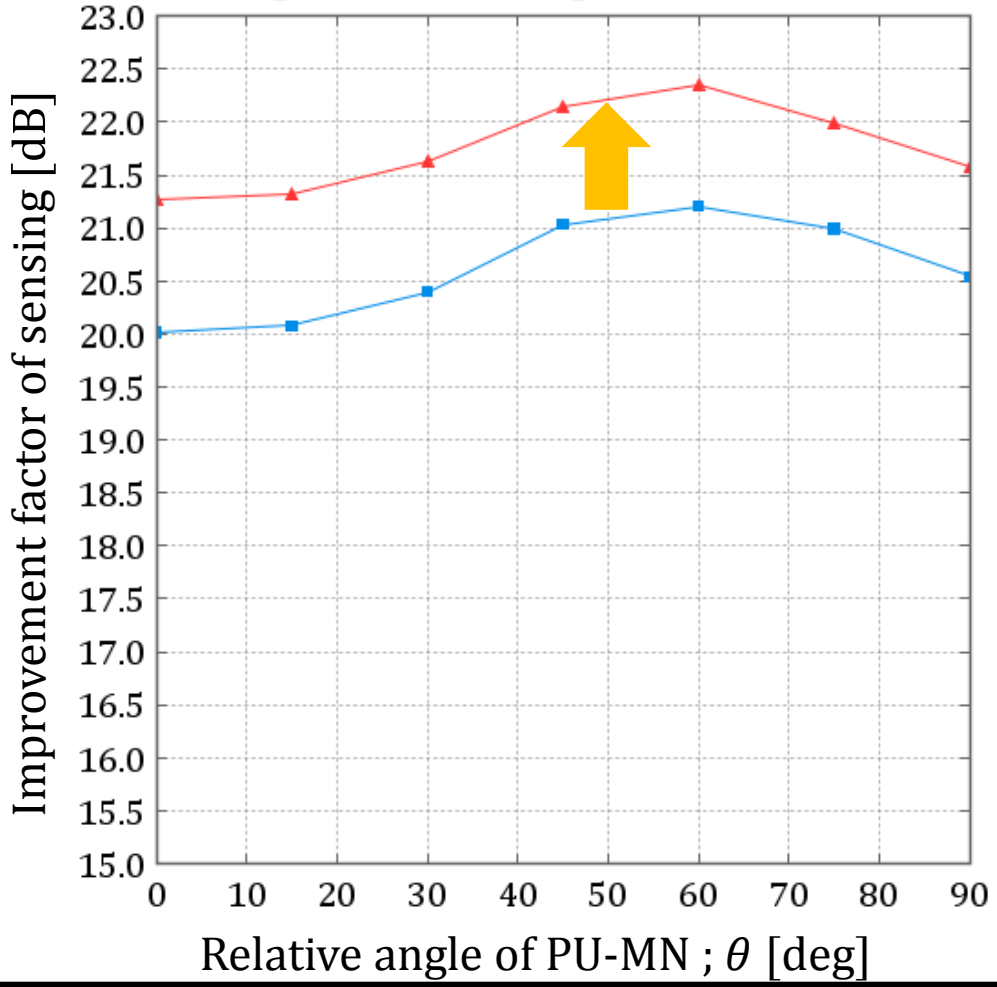
Extension !

Improvement factor vs. relative angles

■ Distance from PU to MN is $d = 300$ m

※P_D : Probability of PU detection

■ $\theta = 0$ deg: 1.2dB improvement

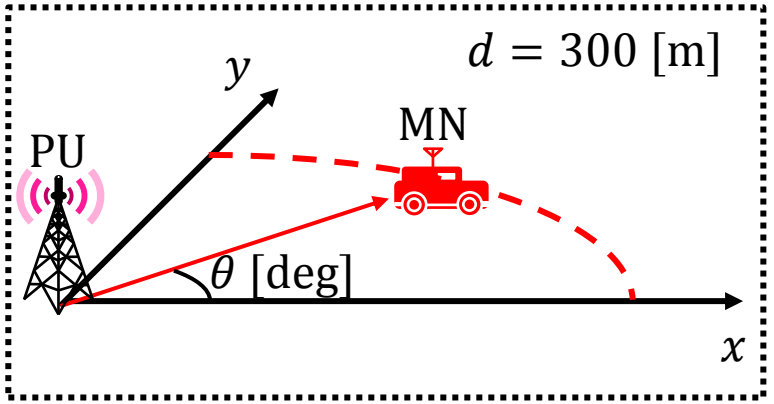


Improvement factor of sensing

- Under the $P_D = 0.9$
- Differences of SNR
- between individual ED and each cooperative method

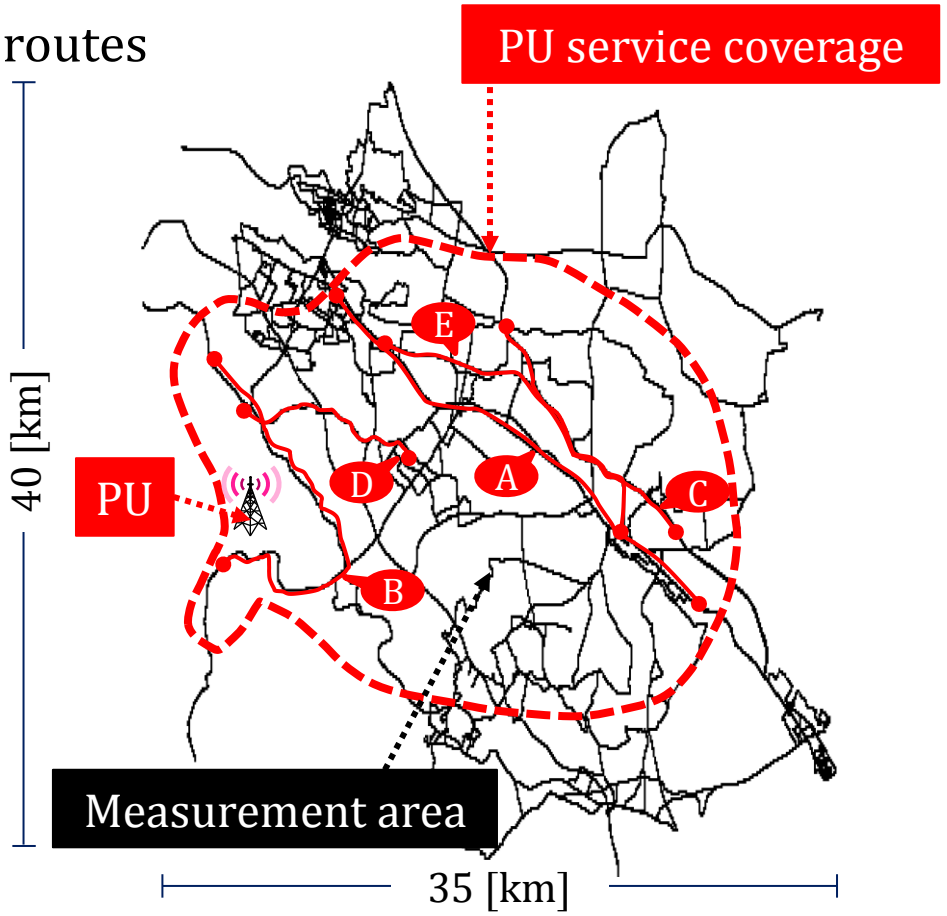
Cooperative sensing

Weighted cooperative sensing



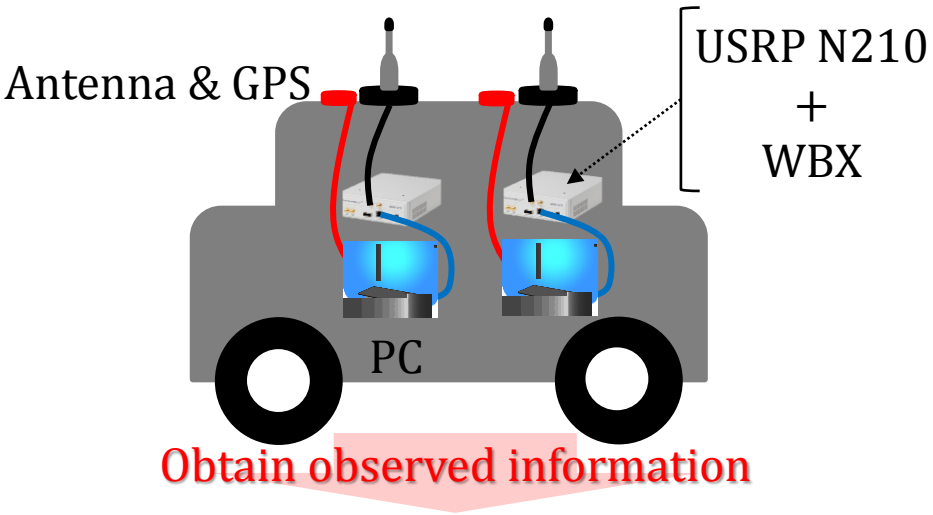
Experiment

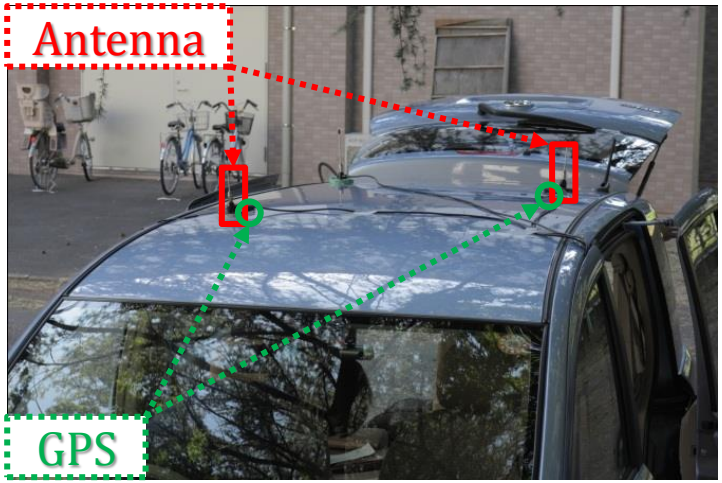
- Experimental measurement in Kumagaya city, Saitama, Japan
  - » Suppose Kumagaya relay station to be PU
  - » 5 probing cars make measurement for 8 h × 5 days
    - Organizing vehicle sequence in 5 routes



Experimental vehicle constitution

- All probing cars are configured equally
  - » Measurement device is USRPN210
  - » Antenna is monopole antenna





- Antenna
  - Received signal power
- GPS
  - Observing time
  - Observing position
    - Latitude & longitude

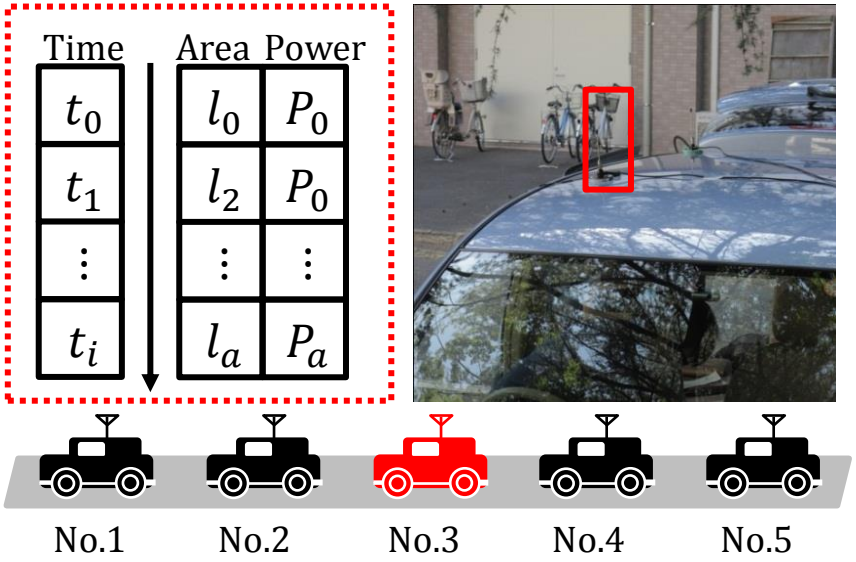
Frequency	473.142857[MHz]
Sampling rate	200 [kHz]
FFT size	2048
Antenna gain	2 [dBi]

Utilization of observed information

- Sensing data and ASDB are generated from measurement results
  - » Measurement point: 32342719 points
  - » Each measurement data is connected and saved into each mobile radio

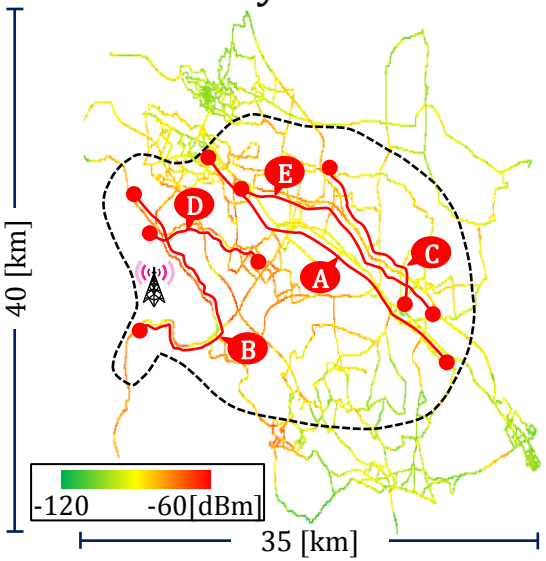
Instantaneous information for sensing

- Instantaneous data of observation
- Data with front antenna is used for emulation



Statistical information for ASDB

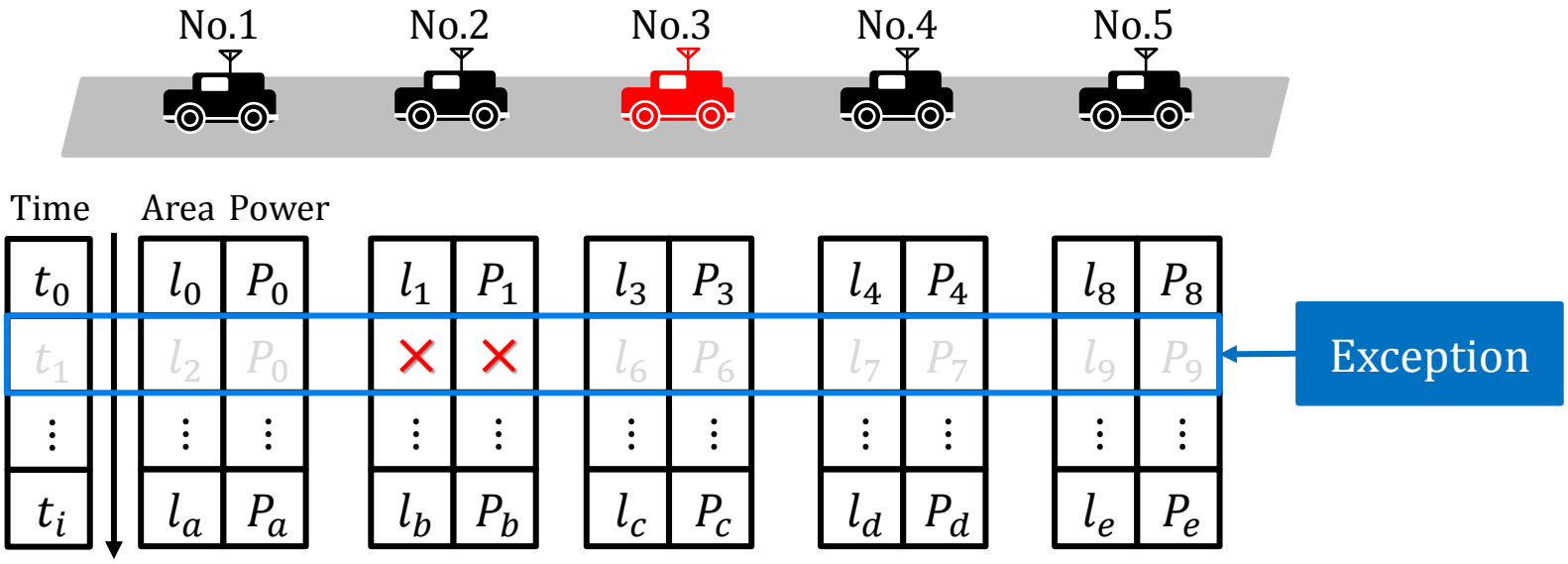
- Utilizing information of all mobile radio
- Averaged power is calculated by each area



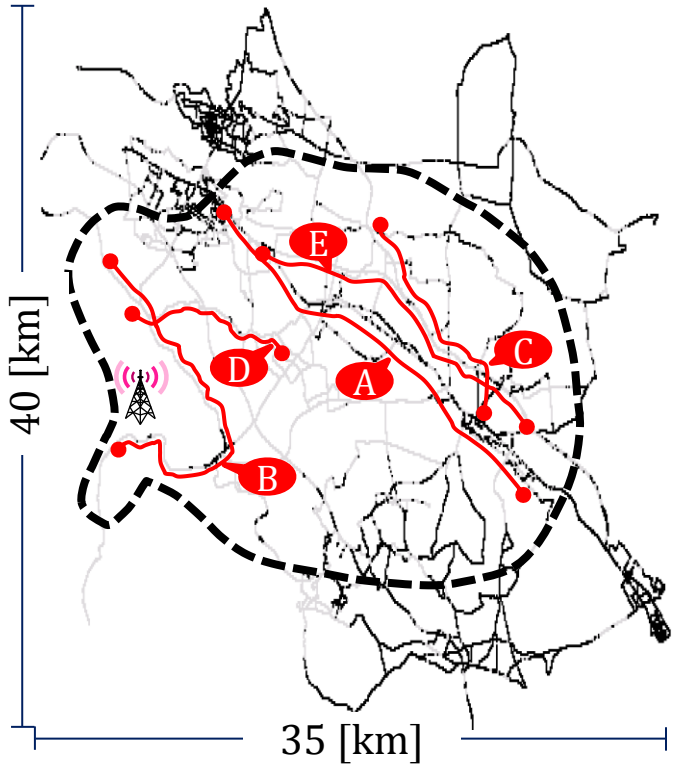
Comparison of detection performance
➡Individual ED, cooperative sensing and proposed sensing

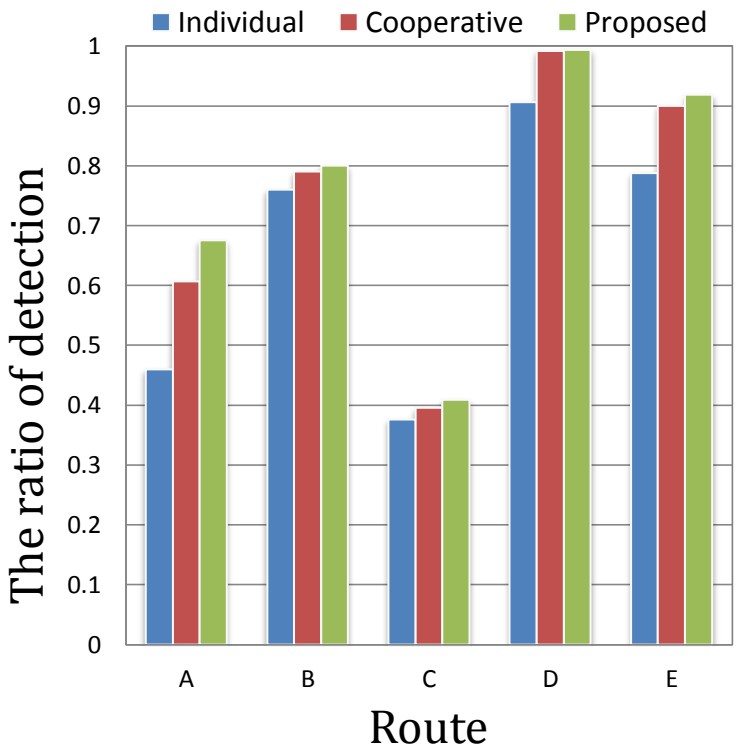
Emulation specifications

- Operating sensing decision in off line process
  - MN is No.3
  - Threshold is set by −95 dBm in all spectrum sensing methods
  - Loading sensing data in order of time scales
  - Only in the case that all cars have sensing data at the same time
    - The number of sensing trials is unified in each method



Ratio of detection number in PU coverage

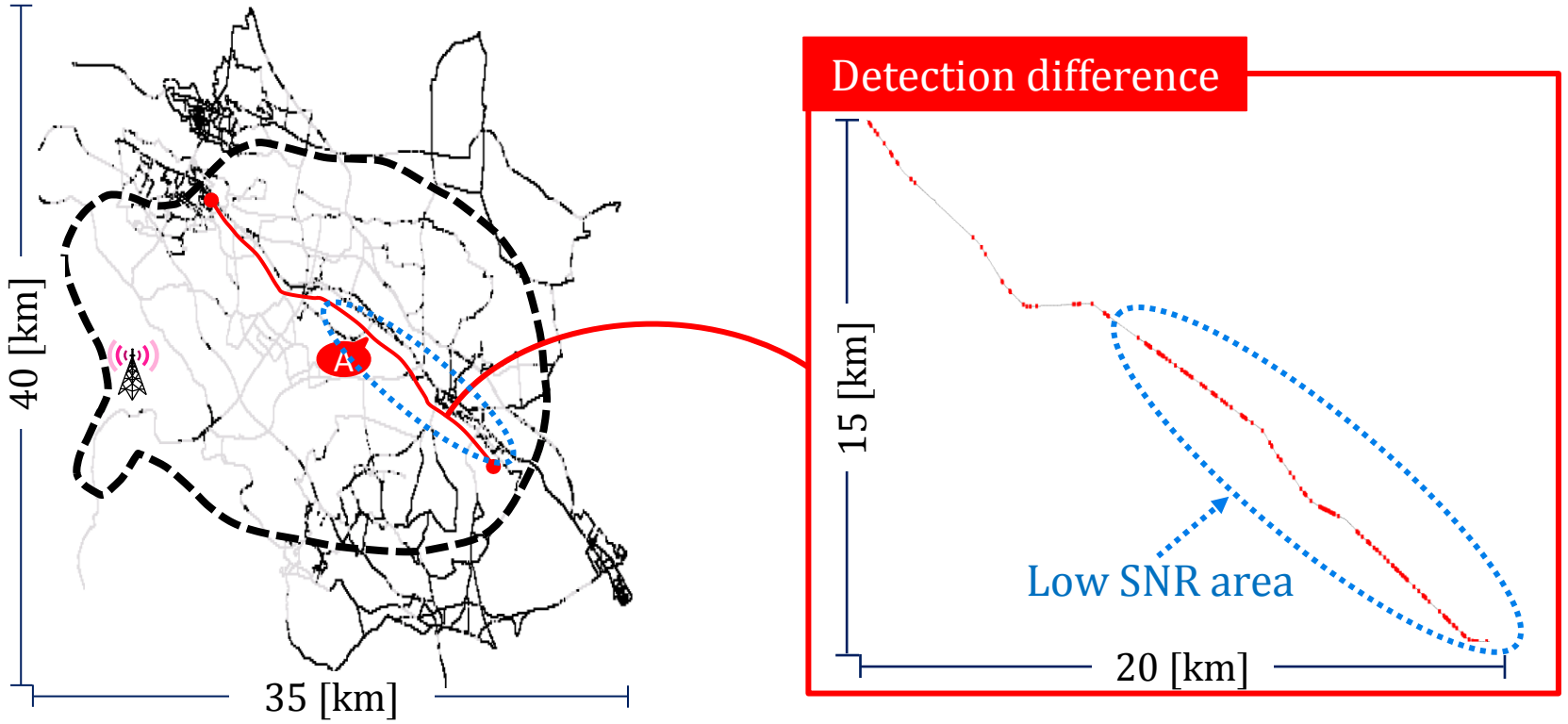




※Black mesh: Average received power is under γ

- Detection rate of proposed method is the highest
  - » Spectrum sharing in PU coverage ➡ Avoidance
    - ▸ The method with much detection rate ➡ Performance of PU protect is high

Detection differences in PU coverage



※Black mesh : Average received power is under γ

※Miss detection: not detect PU

■ Plot the difference of PU detection

- » Proposed method detects PU, but Cooperative sensing doesn't detect PU
- » Low SNR area is remarkable: in blue circle
  - ▸ Decrease the number of miss detection ➡ Reliable sensing method

Conclusion

- Conventional technique for radio environment recognition

	instantaneous	statistical
ASDB	–	✔
Cooperative sensing	✔	–

- Proposed method
  - » Weighted cooperative sensing based on ASDB
    - Generating weighting factor using averaged PU signal power
    - Giving priority to data of high SNR area
      - » Improving performance of PU detection
- Evaluation
  - » Simulation result
    - Between 2 types of simulation, proposed method improves performance
  - » Emulation based on actual DTVB signal of Kumagaya relay station
    - Utilizing 5 probing cars and ASDB
    - Results show proposed method can reduce the number of miss detection in low SNR area

Thank you for your attention