Distance Based Decision Fusion in a Distributed Wireless Sensor Network

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Introduction

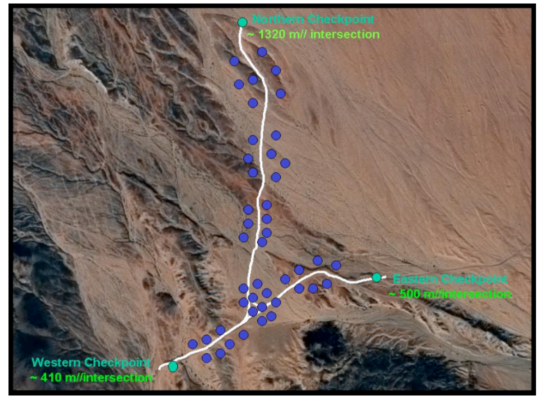
- Increasingly feasible miniature ad-hoc sensor network integration.
- Conventional centralized information and data fusion are unsuited because of amount of data.
- Distance-based fusion algorithm will select sensors that give reliable results to participate.

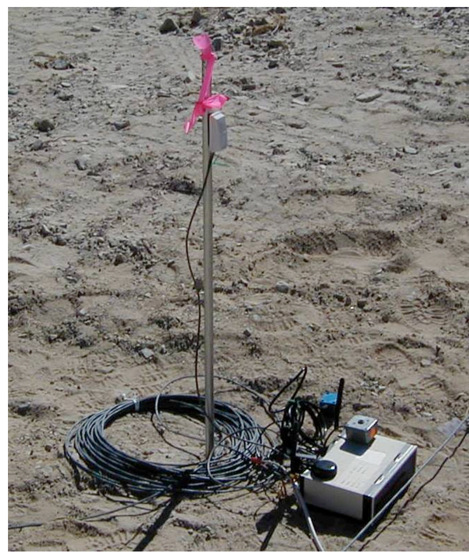
Wireless Sensor Nodes and Network

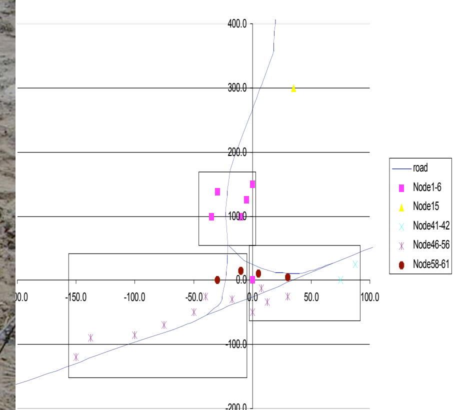
- Sensor node: computer, battery, sensors, transceivers.
- Deployment of sensor nodes outdoors.
- Regions: geographical clusters, each with a manager node.
- Objective: detect vehicles as they pass region, identify vehicle type, estimate location (EBL).

Sensor Network Signal Processing Tasks

- CFAR Target Detection
- Target Classification
- Target Localization
- Target Tracking





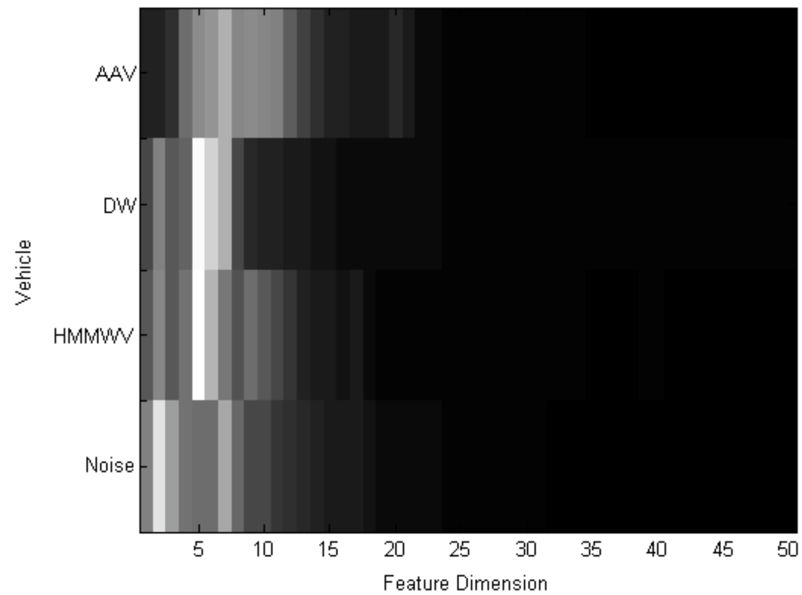


Sensor Network Signal Processing Tasks

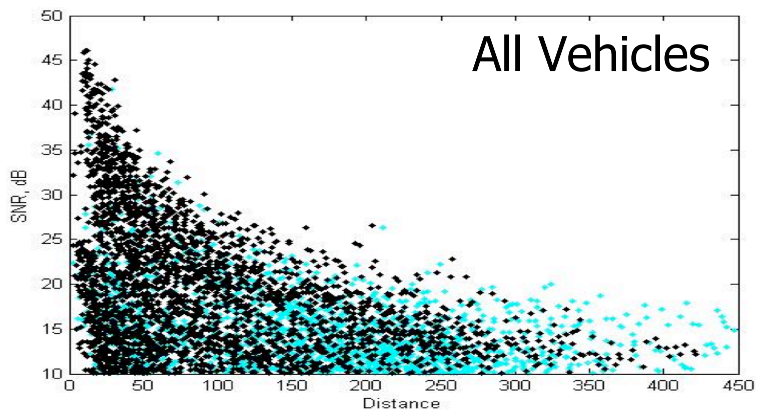
- Maximum Likelihood

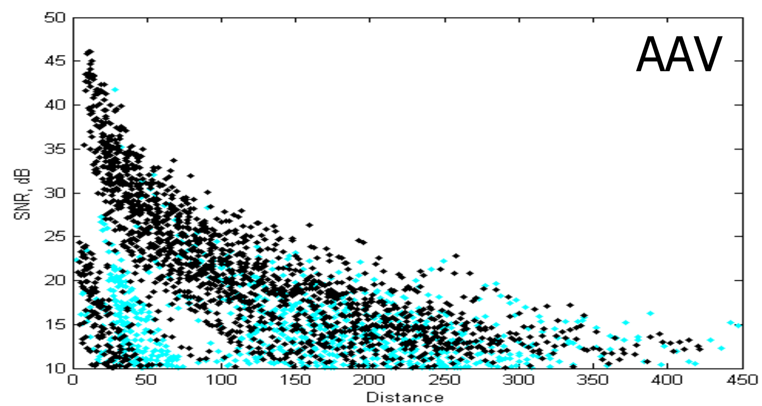
$$P(x \mid k) \sim \exp\left\{ -\frac{1}{2}(x - x_k)^T \Sigma_k^{-1}(x - x_k) \right\}$$

- 50-dim spectral feature:
  - Sampling frequency 4960 Hz
  - 512-point FFT, resolution ~9 Hz
  - Average first 100 points by pairs, describes ~900 Hz
- Signal + noise classification rate depends on SNR.
- SNR proportional to vehicle-node distance.

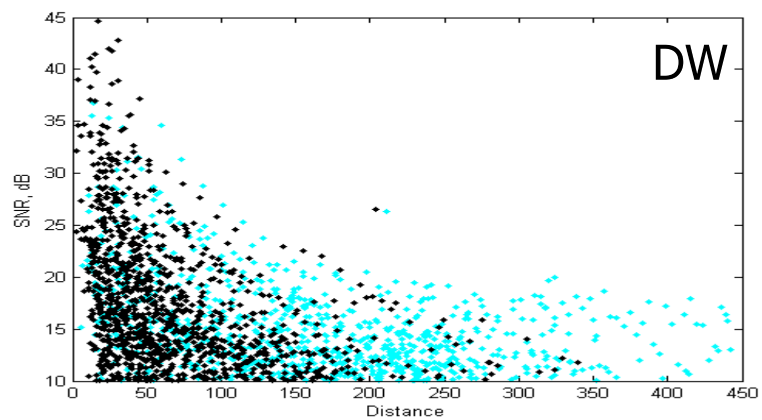


Classification Success

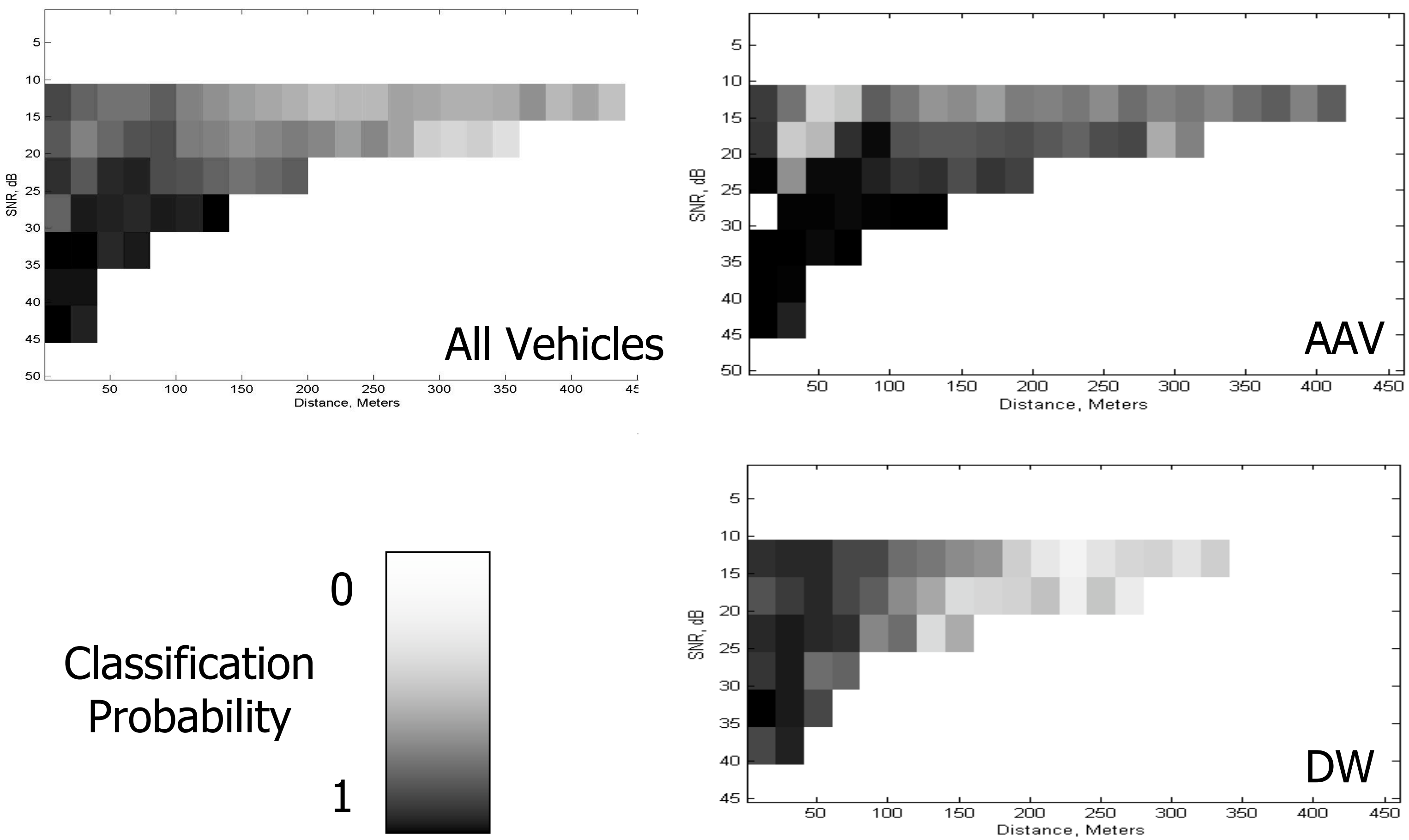




- Correct
- Incorrect



Classification Rate Distribution



Distance Based Decision Fusion

- Current system architecture allows localization prior to classification.
- Accurate localization allows for estimation of sensor-vehicle distance, estimation of probability of correct classification based on distance.
- Data fusion: function of marginal results from each node.
- Some events may be rejected by fusion algorithm.
- Measurements: classification and acceptance rates.

Decision Fusion

- $x(i)$ is the feature vector for ith sensor, C_k is the kth vehicle class, we must establish a function

$$P(x \in C_k \mid x(1), \ldots, x(N)) \triangleq P(x \in C_k \mid \underline{x})$$
$$\approx f(g(P(x \in C_k \mid x(i))), 1 \le i \le N)$$

- $g(z_k)$ is the maximum function:

$$g(z_k) = \begin{cases} 1 & z_k > z_j, k \neq j \\ 0 & \text{otherwise} \end{cases}$$

- This is called Decision Fusion

Distance Based Decision Fusion

- Multiplicative form: for statistically independent feature vectors *x(i)*, *x(j)*.

$$\hat{P}(x \in C_k \mid \underline{x}) = \prod_{i=1}^{N} P(x \in C_k \mid x(i))^{w_i}$$

  Not realistic for sensor network.

- Additive form: weighted sum of marginal posterior probabilities.

$$\hat{P}(x \in C_k \mid \underline{x}) = \sum_{i=1}^{N} w_i g_i(P(x \in C_k \mid x(i)))$$

- If $w_i=1$ for all i, simple voting.

Maximum A Posterior Decision Fusion

- Weighting factor as function of distance and SNR, determined using CFAR and EBL information.
- We formulate a Maximum A Posterior (MAP) Probability Gating Network, using Bayesian estimation:

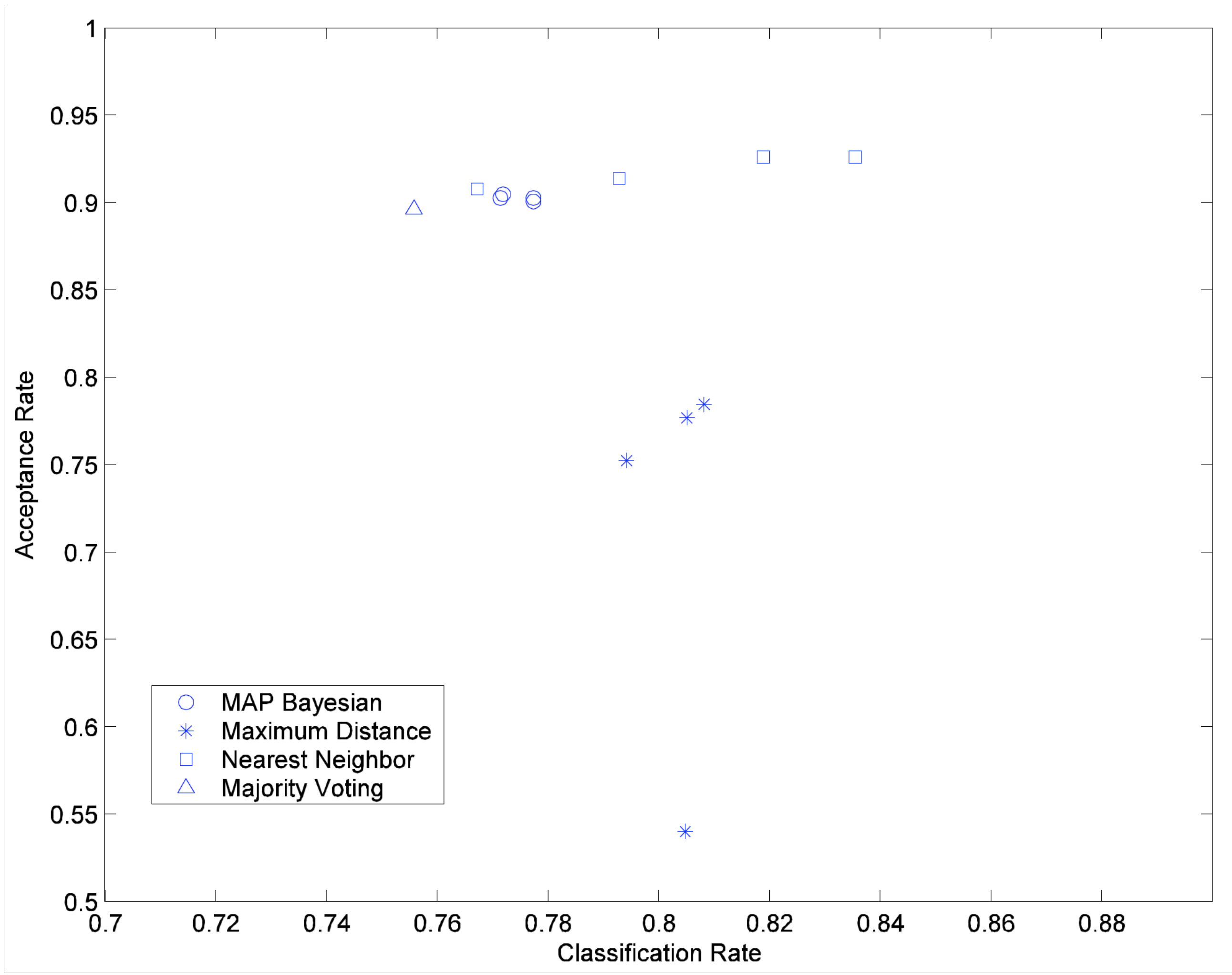
$$\hat{P}(x \in C_k) = P(x \in C_k \mid \underline{x}, d_i, s_i) \cdot P(\underline{x} \mid d_i, s_i) \cdot P(d_i, s_i)$$

- Probabilities from experiment data.

Maximum A Posterior Decision Fusion

- This amounts to assigning weights: $$w_i = P(\underline{x} \mid d_i, s_i) \cdot P(d_i, s_i)$$
- Other methods:
  - Distance gating: $$w_i = \begin{cases} 1 & d_i \le d_{max} \\ 0 & \text{otherwise} \end{cases}$$
  - Nearest Neighbor: $$w_i = \begin{cases} 1 & d_i \le d_j, \forall j \ne i \\ 0 & \text{otherwise} \end{cases}$$
  - Baseline: simple voting ($w_i = 1$ for all i)

Experiment Results



Results

- Closest node gives highest acceptance, classification rates for accurate localization estimates
- MAP Fusion has smaller dependence on localization error than other methods
- Both of these methods can reduce communication needed for decision

Further Work

- MAP Classifier allows for exclusion of those samples with low classification rates (i.e. only samples with $w_i > 0.5$ are allowed).
- This will allow for reduction of communication bandwidth used for classification fusion.
- This method can be applied to other signal processing tasks.