Data Dissemination in Ad Hoc Networks Based on Inter-Vehicle Communication

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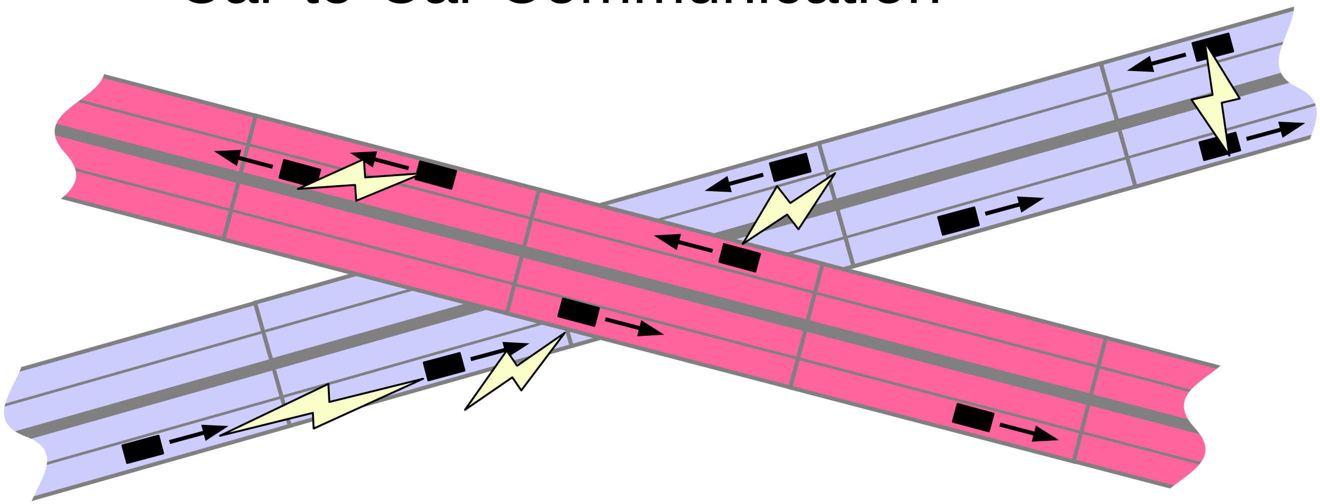
COST 289 Spectrum and Power Efficient Broadband Communications

Overview

- Vehicular Ad Hoc Networks (VANETs)
  - Advantages and Challenges
  - Standards and Applications
- Information Dissemination in VANETs
  - Segment-Oriented Data Abstraction and Dissemination
  - Adaptive Broadcast Mechanisms
- Example Application: Self-Organizing Traffic Information System
  - Simulation and Performance Evaluation
  - Prototype Implementation
- Context-Aware Packet Scheduling
  - Future Research

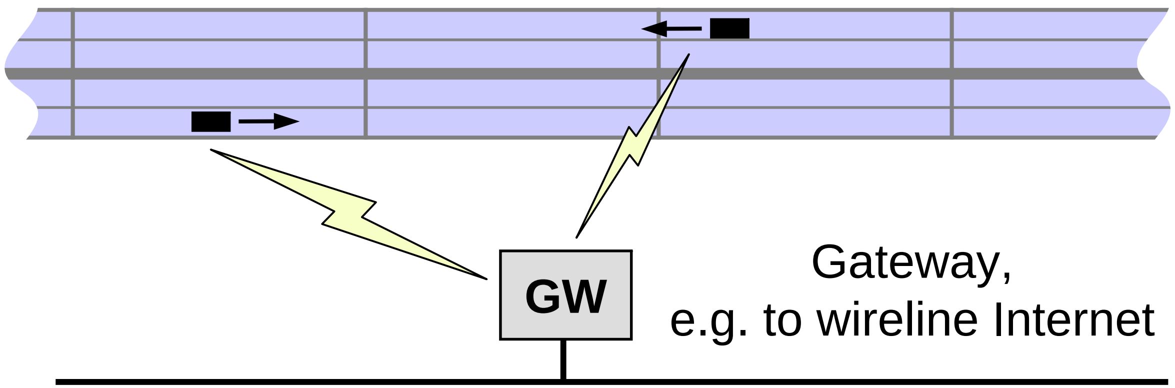
VANETs: Car-to-Car and Car-to-Roadside Communication

- Car-to-Car Communication



- Self-organizing network formed by the individual cars (Vehicular Ad Hoc Network)
- Direct communication without base stations

- Car-to-Roadside Communication



Gateway,
e.g. to wireline Internet

- Vehicle communicates with gateway at roadside (e.g. at gas station)
- Gateway provides access to conventional networks

Vehicular Ad Hoc Networks (VANETs)

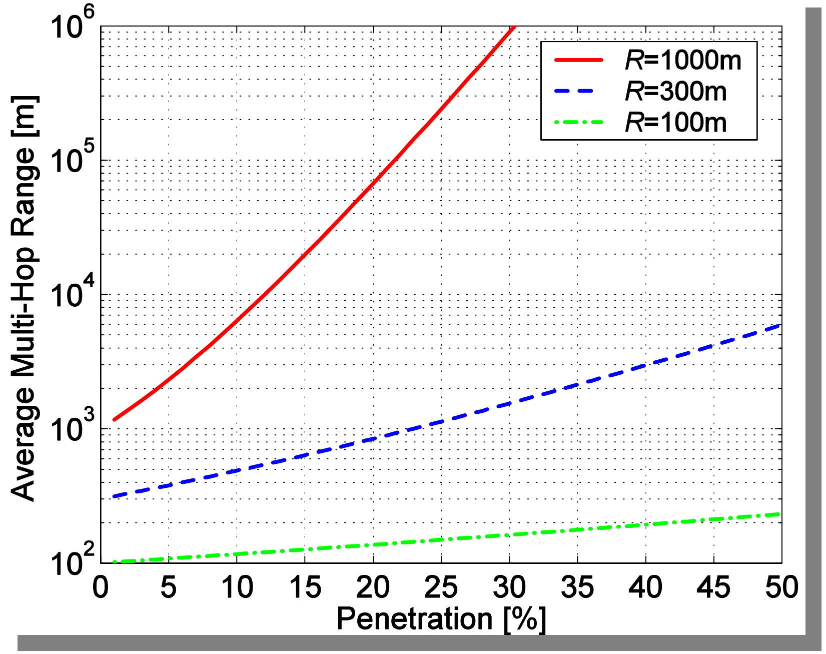
Key advantages:

- **Direct communication**
  - Low delay – even emergency notifications can be disseminated
  - Availability independent of communication infrastructure
- **No service fees**
  - Service provided by vehicles themselves, no service charges

Challenges:

- **Market introduction**
  - During market introduction, only very low number of vehicles equipped – usual multi-hop communication not suitable
- **Scalability**
  - Highly dynamic environment, node densities can change within seconds
  - New protocols required: Mainly broadcast (not unicast), end2end congestion control?

Analytical Result: Avg. Multi-hop Range



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IVC: Standards and Applications

Standards for PHY and MAC:

- Dedicated Short Range Communication (900 MHz band)
- Dedicated Short Range Communication (5.9 GHz, 802.11a R/A)
  - Based on IEEE 802.11a WLAN, tx range ≈1 km
  - Supported by > 40 of the largest automotive and electronics manufacturers
- UTRA TDD Ad Hoc (BMBF project *FleetNet*, developed by TUHH, Siemens, IANT Uni Hannover)
  - Based on Cellular UMTS standard, tx range ≈1 km
- Extended Self-Organizing Time Division Multiple Access (E-SOTDMA) (TUHH)
  - Based on SOTDMA (standardized by ITU-T for maritime AIS)

Applications:

- DSRC consortium proposes more than 200 applications for IVC
- Comfort applications
  - Improve passenger comfort and traffic efficiency
  - E.g.: traffic/weather information systems, gas/restaurant location and price information, Internet access
- Safety applications
  - Increase passenger safety
  - E.g.: emergency warning system, lane changing assistant, road condition warning

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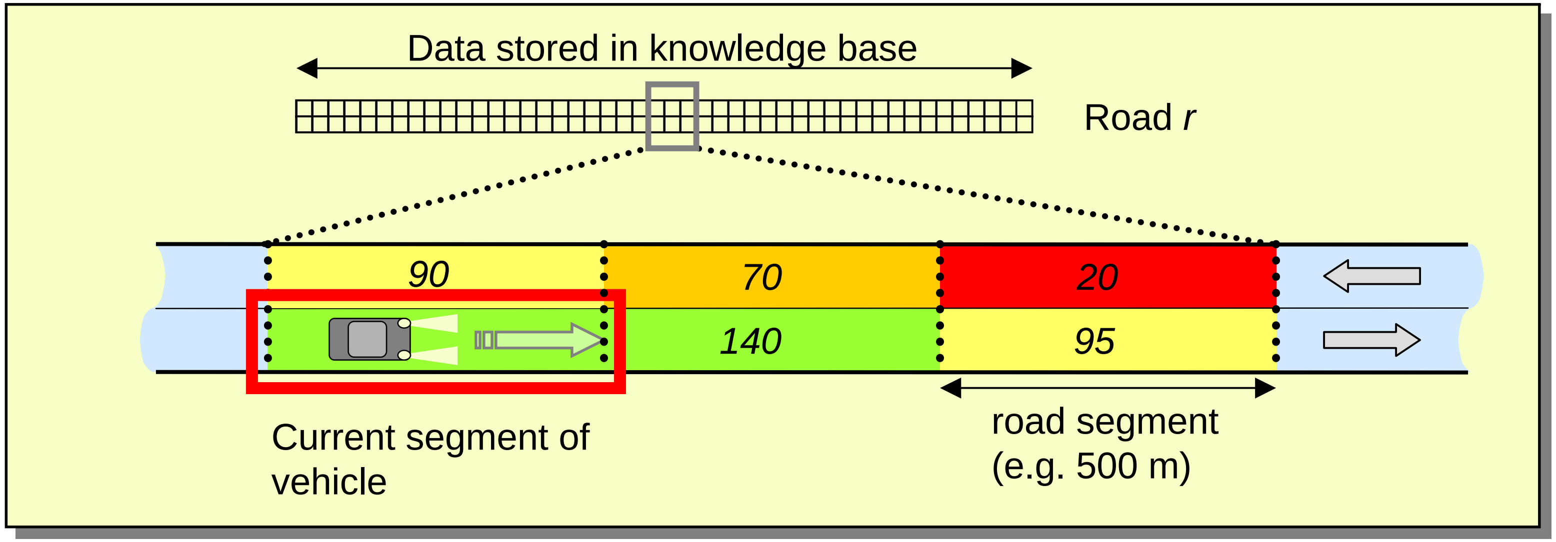
Segment-Oriented Data Abstraction



- Roads have **unique IDs,** are composed of **roads segments of a specific length**
- **Each vehicle collects info** (average speed, road conditions, weather, etc.)
- Two data values per road segment
  - Information value (e.g. average velocity)
  - Time stamp (time of measurement/age)
- Data values are stored in a local in-vehicle knowledge base
- **Data abstraction** on per-segment basis

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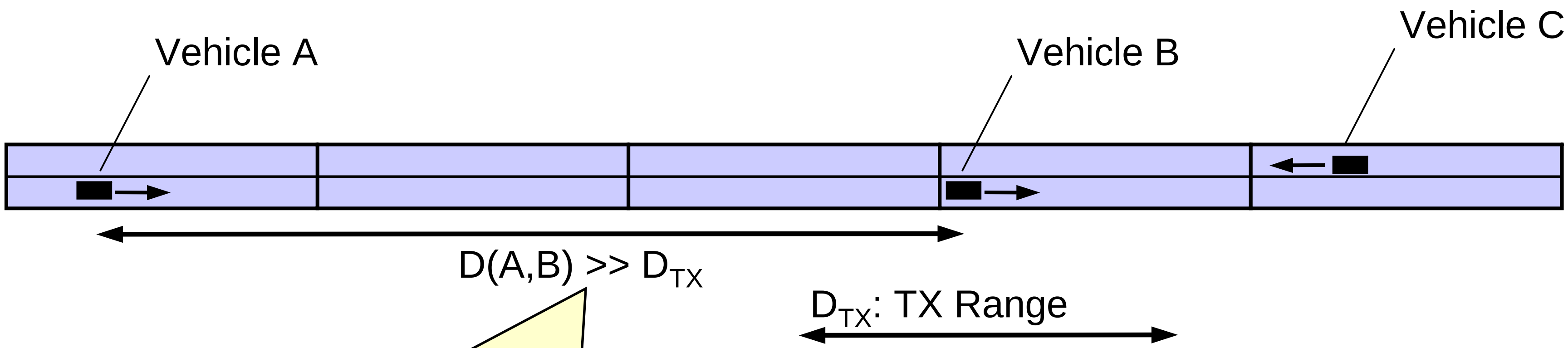
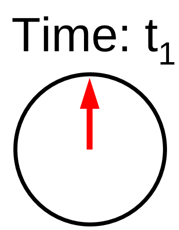
Segment-Oriented Data Dissemination

- Information disseminated on **per-segment** basis
- Application-layer **store-and-forward** approach
- Each car **repeatedly broadcasts** all available information
- Exploit **typical movement pattern** in vehicular scenarios:



Typical situation in case of low market penetration / low traffic density:

Vehicles A and B cannot communicate via (single or multihop!) communication!



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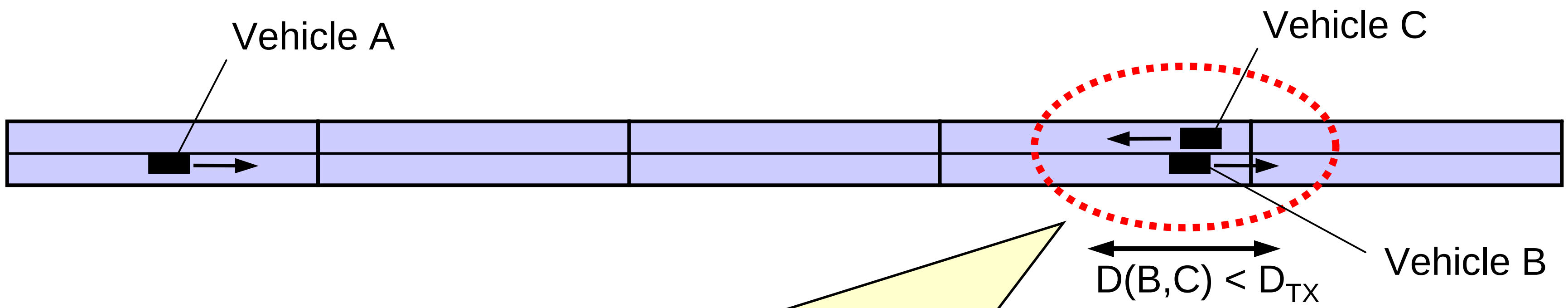
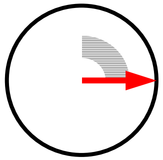


Vehicle driving ahead encounters a vehicle on opposite lane.

Segment oriented data is updated in the respective knowledge bases.

Time: t_2



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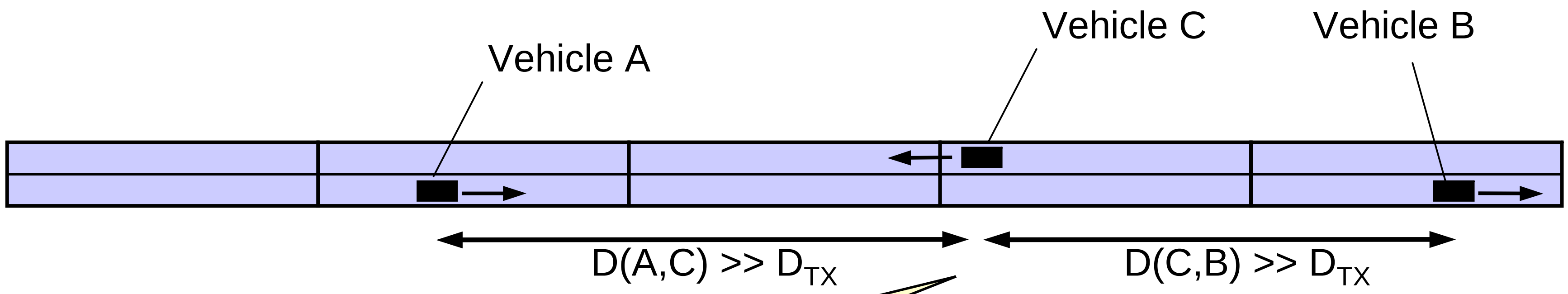
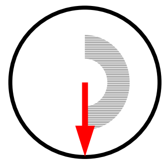


Vehicles are not within respective transmission range for a while:

No communication is possible.

Time: t_3



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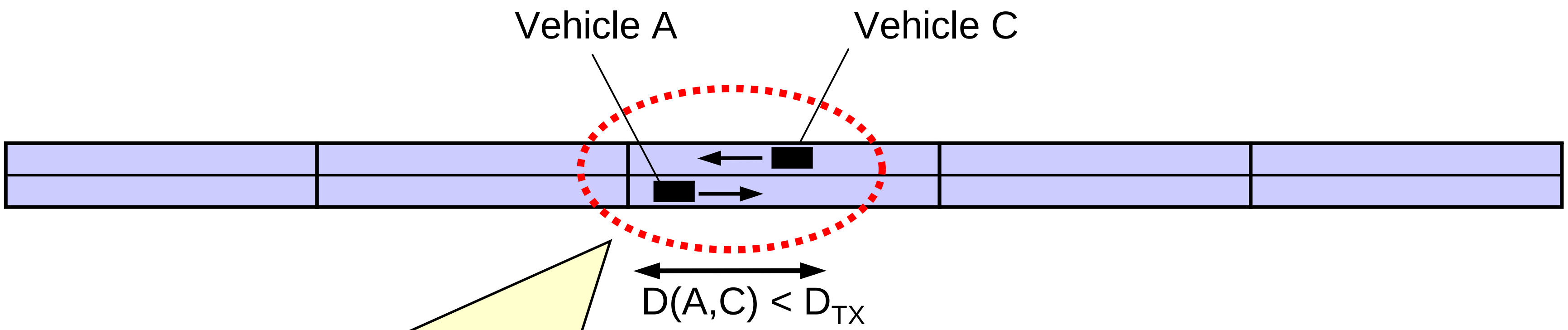
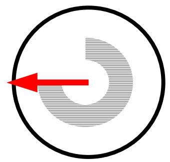


Due to the specific movement pattern and a store-and-forward approach, cars can obtain information from vehicles far ahead even in low density situations.

Time: t_4



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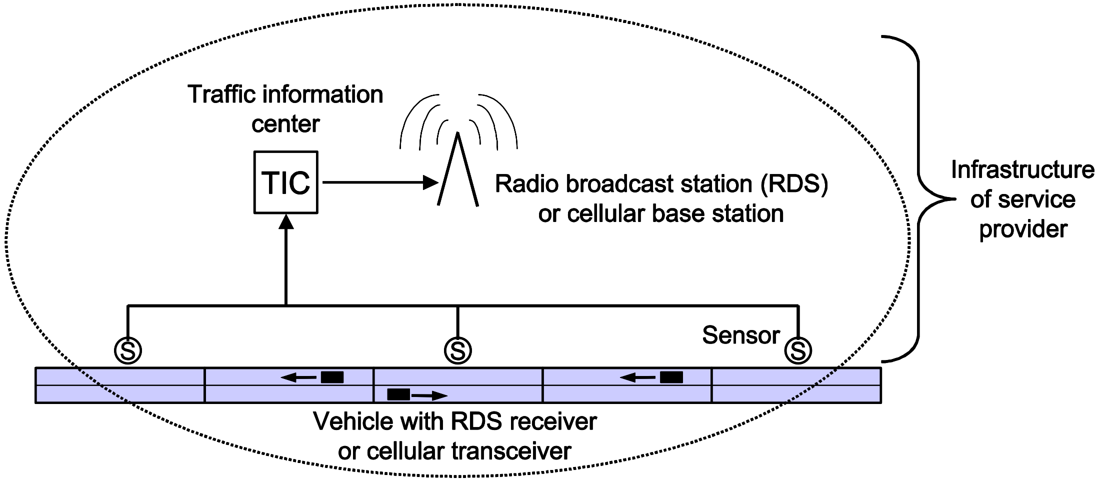
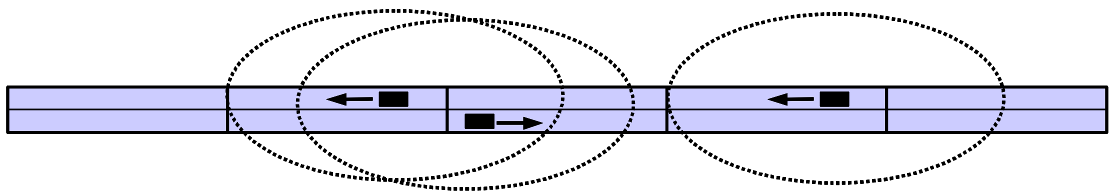


• **Conventional TIS:** Centralized structure



Vehicles with SOTIS system
(decentralized sensing, processing and distribution of traffic information)

• **SOTIS:** Decentralized distribution of Traffic and Travel Information (TTI) by self-organizing inter-vehicle communication

Advantages of SOTIS

- **No infrastructure required**
  → Available anywhere (cities and highways)
- **Low delay**
  Immediate notifications in case of dangers in the local area
- **High level of detail**
  Bandwidth only shared by cars in transmission range
- **Traffic analysis instantly available**
- **Functionality available if only a very low percentage of all cars is equipped**

Start Interactive Demo...

Simulation Parameters

SOTIS Parameters:

Penetration	Varied in the range of 2 - 10%
TTI Segment Length	500 m (fixed)
Inter-Transmission Int.	0.5 s
Knowledge Base	TTI (avg. speed) of 100 km per road

Radio interface and propagation:

Rate	1 Mbit/s
MAC	IEEE 802.11 (broadcast → no RTS/CTS)
Propagation	Free-space
Transmission Range	1000 m (corresponds to range of FN air-interface)

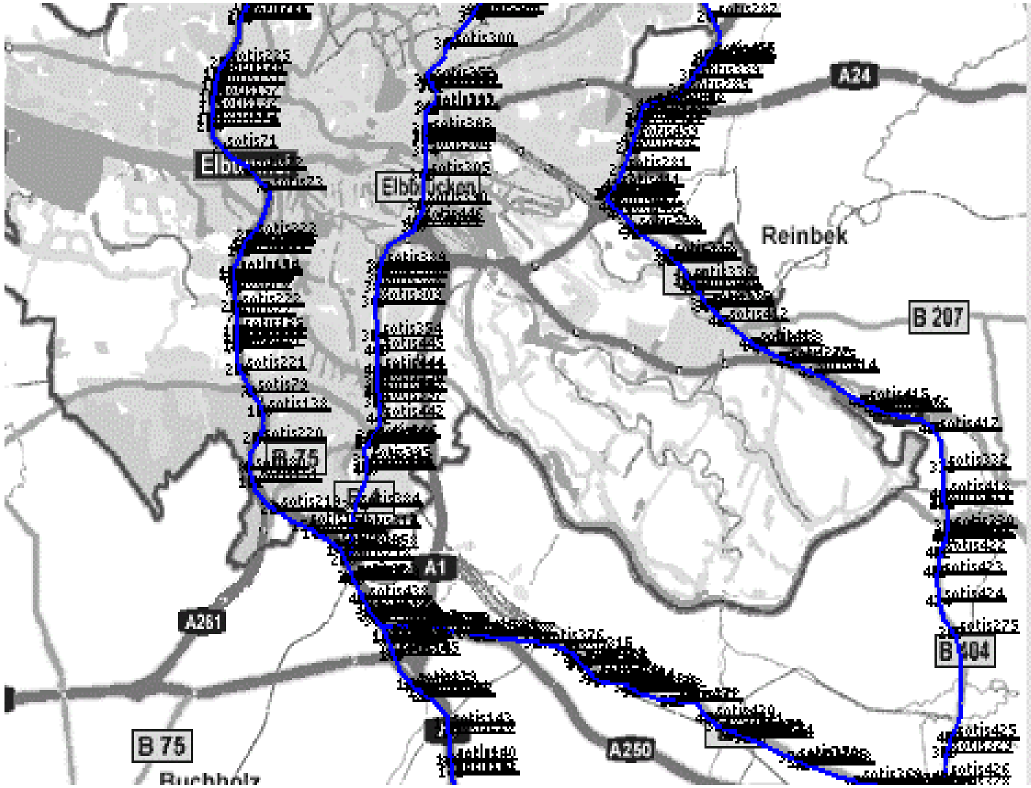
Traffic Density	≈14.5 cars/km/lane (high) ≈ 10.0 cars/km/lane (medium) ≈ 7.3 cars/km/lane (low)
Avg. Headway (exp. distributed)	2 s, 3 s, 4 s (high, medium, low density)
Road Length	140 km, 110 km
Lanes	2 per direction

Types of Vehicles	2 (15% slow, 85% regul.)
Desired Velocity	142 km/h for regular 108 km/h for slow
Avg. Velocity	95.8 km/h (high density) 101.3 km/h (med. density) 106.4 km/h (low density)
Traffic Sim. Cell Size	7.5 m

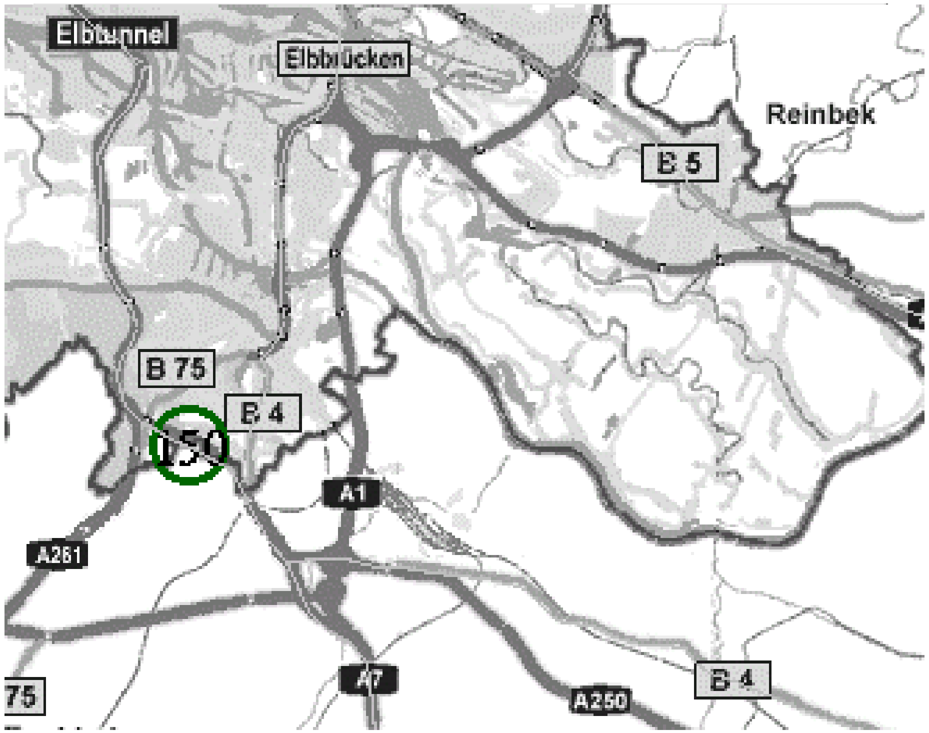
Simulating SOTIS

- Feasibility of the proposed approach demonstrated using simulations
- Example: two highways, medium traffic density, 5% of cars use SOTIS

Global Simulation View



View of Individual Car



(loop of 0- 60s of simulation time)

⇨ rapid dissemination of information in self-organizing system

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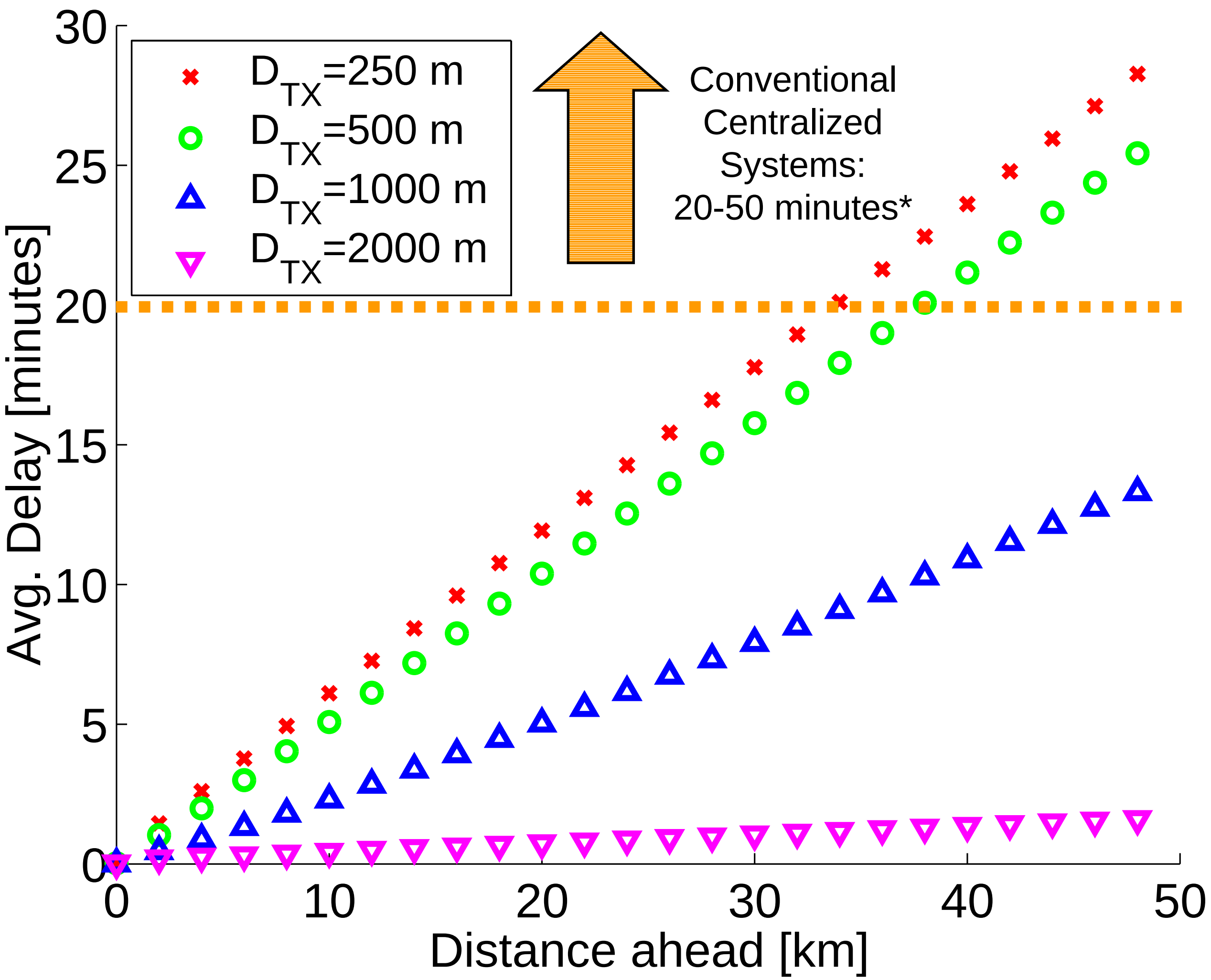
Example Simulation Result (5% equipped with IVC)



- Detailed simulations in extended version of *ns-2*
- Vehicular mobility model based on microscopic traffic simulation
- IEEE 802.11 MAC, transmission range $\boldsymbol{D_{TX}}$ is varied

<u>Simulation A:</u>

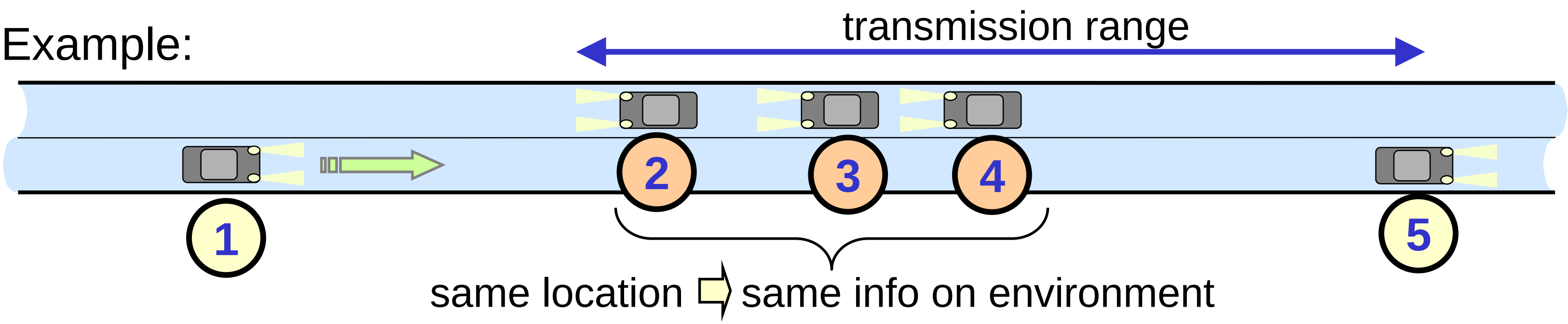
2x2 lane highway

Medium traffic density

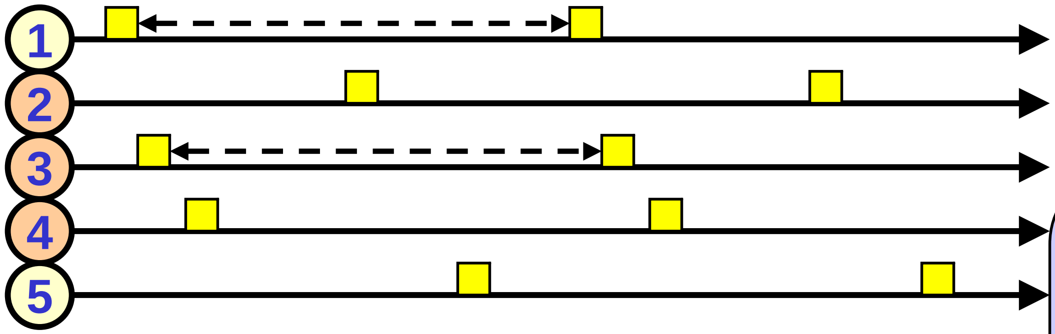
* <u>Source</u>: *ddg Gesellschaft für Verkehrsdaten mbH, DEKRA Benchmark*

Adaptive Broadcast

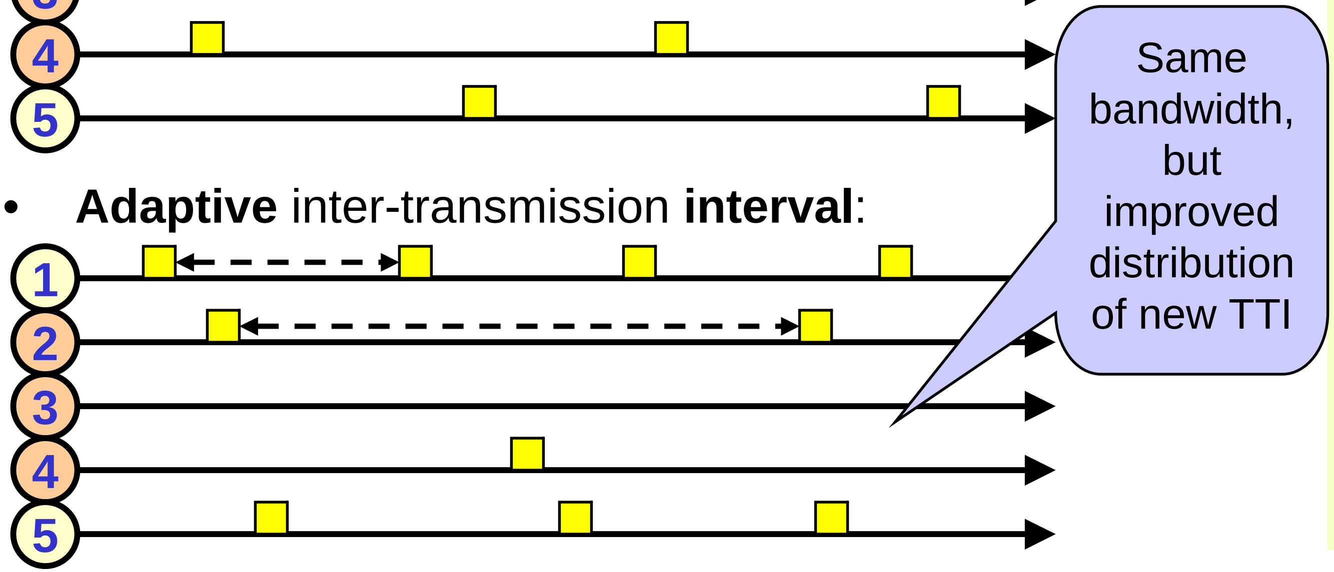
- Example:



- **Strictly periodic** broadcast of information:



- **Adaptive** inter-transmission **interval**:



Task

- Information for road segments change
- Updated values have to be distributed

Objective

- Provide information as accurate as possible without minimal data rate
  (efficient utilization of available bandwidth)

Simulation Parameters

Adaptive Broadcast:

- **Basic idea:** Reception of **similar data** causes **increase of inter-transmission interval**, **significantly differing data** causes **decrease of inter-transmission interval**
- Data for each segment: uniformly distributed random value (max. entropy), changed every 300s
- 5 different parameter sets for adapting the inter-transmission interval + strictly periodic reference system

Radio Interface:

Rate	1 Mbit/s
MAC	IEEE 802.11 (no RTS/CTS)
Propagation	Free-space
Transmission Range	1000 m (range of FN air-interface)

Traffic Simulation:

SOTIS Penetration	10%
TTI Segment	500 m
Default interval t_{def}	5 s

Vehicles	≈2700
Avg. Headway (exp. distributed)	3 s
Road Length	68 km

Velocities: Fast/Slow Lane (initial. vel, norm. distributed)	
μ	140 km/h, 90 km/h
σ	35 km/h, 25 km/h

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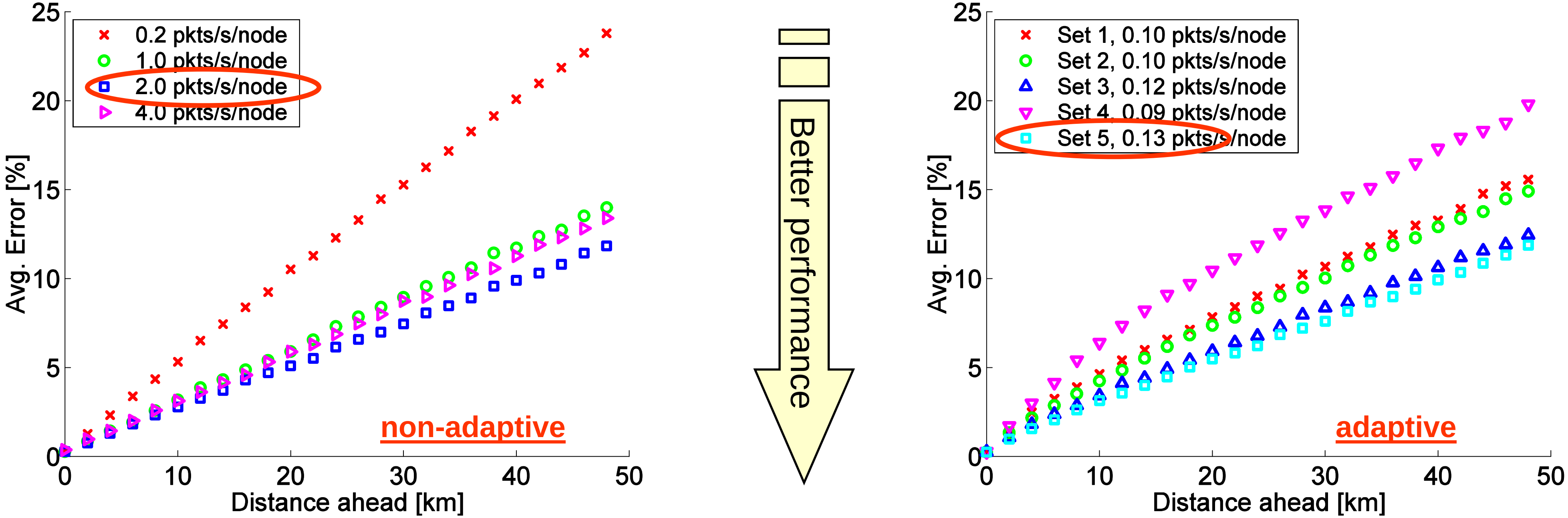
Simulation Result: Adaptive Broadcast

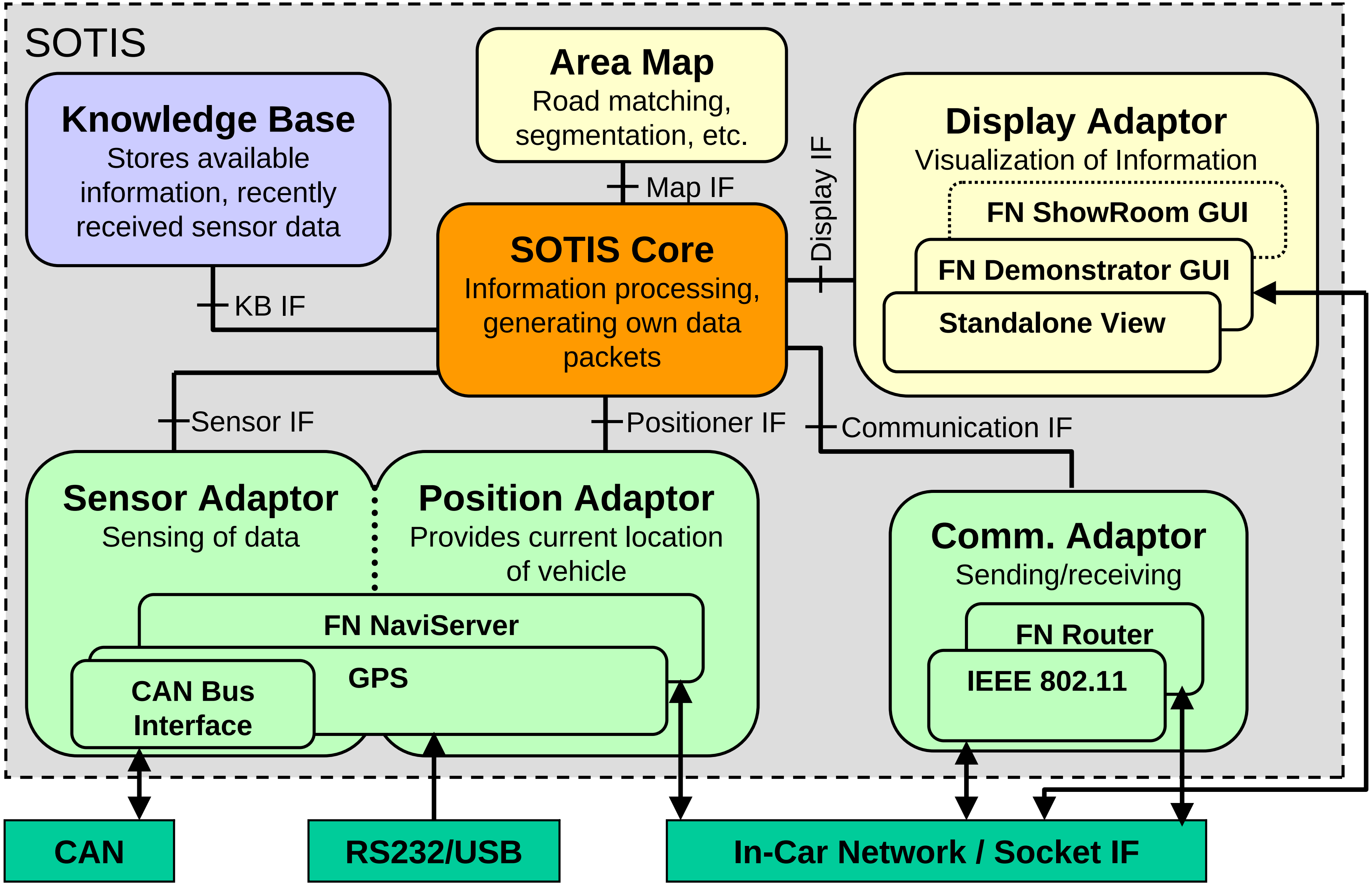
Performance Criterion: Average error of information about a road segment available in vehicle.



Result

- Performance of adaptive scheme with average rate of 0.13 pkts/s/node comparable to non-adaptive scheme with 2.0 pkts/s/node
- In average, adaptive scheme requires less than 10% of rate of the non adaptive scheme to achieve the same performance

Demonstrator



Demonstrator: SOTIS Application

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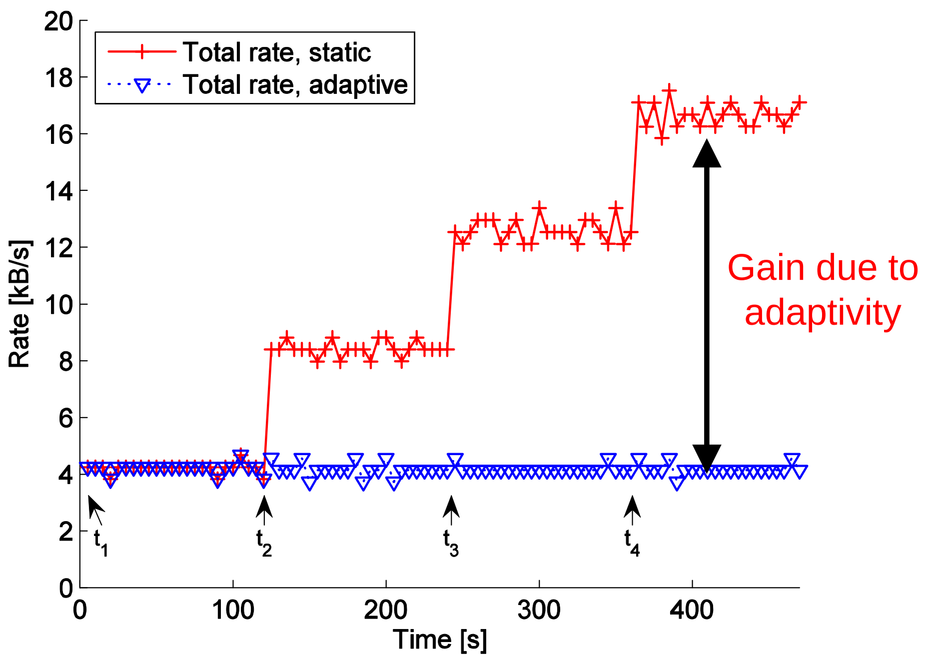
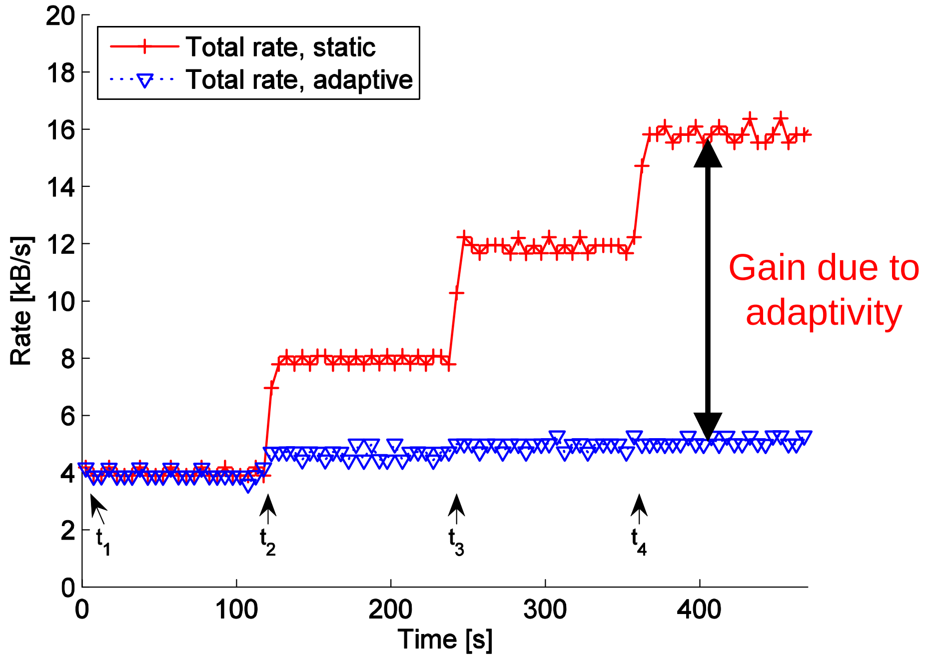
Adaptive Broadcast: Simulation vs. Prototype Results

Simple Dynamic Scenario:

4 vehicles located all within transmission range of each other (total connectivity). At time t=0, no vehicle is active. At time t_i the ith vehicle is activated (i=1…4).



Simulation



Measurement

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Research Challenges: Context-Aware Scheduling

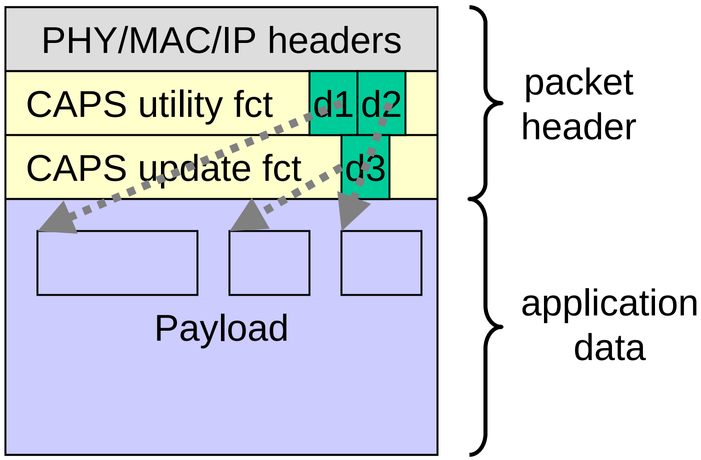
- Conventional approaches for congestion control cannot be used:
  - Large amounts of broadcast data ⇒ conventional end2end approach infeasible
  - Single application does not see all packets/total load ⇒ investigated heuristic adaptive broadcast technique at app. layer is not optimal if multiple apps used
  - Data sent by applications needs to be adapted on a lower layer (network layer)

- Packet scheduling: Even with standard WLAN, 3.8 MByte per encounter of 2 vehicles (rel. vel. 180 km/h) can be transferred
  - E.g. whole 282 000 km of highway + country roads in Germany @ 5 byte per segment of 500 m could be transmitted
  - Which application data to transmit? Which order? Who should transmit?

- Proposed Solution: Context-aware scheduling at network/MAC layer
  - Rate of individual applications and packet order adapted to context of vehicle
  - Optimization criterion: total utility achieved

Outline: Context-Aware Packet Scheduling (1/2)

- Distributed scheduling located between network and MAC layer
- Maintains a set of environment variables **E** (shared+app. specific)
  $\Rightarrow$ Representation of current context of mobile node
- Applications insert utility function and update function in header
  - *Generalized utility function* $\mathbf{u}\left(\mathbf{E}, \mathbf{D}_k\right)$
    Utility of sending the packet in the current context, function of environment variables **E**, and packet descriptors **D**
  - *Update function* $\mathbf{c}\left(\mathbf{E}, \mathbf{D}_k\right)$
    New values of **E** if packet is sent or received, function of **E** and **D**
  - *Descriptors **D***
    References ("pointers") to parts of the payload



Outline: Context-Aware Packet Scheduling (2/2)

- Node maintains estimate of average utility per byte $\widehat{\mu}_{ub}$ and number of nodes in range *N* in local area
- Fairness: Each node *i* sends with instantaneous rate r_i

$$r_i = \frac{ub_i}{N\widehat{\mu}_{ub}}$$

where ub_i is

$$ub_i = \max_{k \in [0, K_i]} \frac{\mathbf{u}(\mathbf{E}, \mathbf{D}_k)}{s_k}$$

K_i: total number of packets at node *I*

s_k: size of packet *k*

⇒ Decentralized scheduling on network layer based on application layer utility (i.e. same benefits as heuristic adaptive broadcast approach)

⇒ Open issues:

- ⇒ Required computational power to evaluate utility functions in realtime?
- ⇒ Optimal application dependent utility functions?

Conclusions

- Broadband IVC improves passenger safety and comfort
- Due to specific movement pattern, vehicular ad hoc communication is **feasible** even if only a **low ratio** of all vehicles is **equipped**
  - Broadcast + store-and-forward based data dissemination
  - Dissemination range of >50km possible even if only 2-5% equipped
- **Adaptive broadcast** and scheduling schemes can **significantly reduce** the **required bandwidth** (e.g. use only 10% of the bandwidth compared to non-adaptive system in simulated typical road scenarios)
- New approaches for decentralized scheduling are required
  - Congestion control for broadcast data
  - Taking context-dependent importance into account

References:

UTRA TDD Ad Hoc and Decentralized Synchronization

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Data Dissemination and Self-Organizing Traffic Info System

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