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

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

**Gateway (GW)** e.g. to wireline Internet
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](chart.png)
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 \( \approx 1 \) 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 \( \approx 1 \) 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
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
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!
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:

```
Vehicle A

Vehicle B

Vehicle C

D(B,C) < D_{TX}
```

Vehicle driving ahead encounters a vehicle on opposite lane.

Segment oriented data is updated in the respective knowledge bases.
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:

![Diagram](image)

Vehicles are not within respective transmission range for a while:

**No communication is possible.**
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:

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.
Example Application: **Self-Organizing Traffic Information System (SOTIS)**

- **Conventional TIS:** Centralized structure

- **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**

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Start Interactive Demo...
## Simulation Parameters

<table>
<thead>
<tr>
<th>SOTIS Parameters:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Penetration</strong></td>
<td>Varied in the range of 2 - 10%</td>
</tr>
<tr>
<td><strong>TTI Segment Length</strong></td>
<td>500 m (fixed)</td>
</tr>
<tr>
<td><strong>Inter-Transmission Int.</strong></td>
<td>0.5 s</td>
</tr>
<tr>
<td><strong>Knowledge Base</strong></td>
<td>TTI (avg. speed) of 100 km per road</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radio interface and propagation:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rate</strong></td>
<td>1 Mbit/s</td>
</tr>
<tr>
<td><strong>MAC</strong></td>
<td>IEEE 802.11 (broadcast → no RTS/CTS)</td>
</tr>
<tr>
<td><strong>Propagation</strong></td>
<td>Free-space</td>
</tr>
<tr>
<td><strong>Transmission Range</strong></td>
<td>1000 m (corresponds to range of FN air-interface)</td>
</tr>
</tbody>
</table>

| 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 |

<table>
<thead>
<tr>
<th>Types of Vehicles</th>
<th>2 (15% slow, 85% regul.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Desired Velocity</strong></td>
<td>142 km/h for regular</td>
</tr>
<tr>
<td></td>
<td>108 km/h for slow</td>
</tr>
<tr>
<td><strong>Avg. Velocity</strong></td>
<td>95.8 km/h (high density)</td>
</tr>
<tr>
<td></td>
<td>101.3 km/h (med. density)</td>
</tr>
<tr>
<td></td>
<td>106.4 km/h (low density)</td>
</tr>
<tr>
<td><strong>Traffic Sim. Cell Size</strong></td>
<td>7.5 m</td>
</tr>
</tbody>
</table>
• 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

rapid dissemination of information in self-organizing system
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 $D_{TX}$ is varied

Simulation A:
2x2 lane highway
Medium traffic density

* Source: ddg Gesellschaft für Verkehrsdaten mbH, DEKRA Benchmark
Adaptive Broadcast

- **Example:**
  
  - **Strictly periodic** broadcast of information:
    
    1. Task:
       - Information for road segments change
       - Updated values have to be distributed
    
    2. Objective:
       - Provide information as accurate as possible without minimal data rate (efficient utilization of available bandwidth)

    - **Adaptive inter-transmission interval:**
      
      Same bandwidth, but improved distribution of new TTI

  - Same location ≠ same info on environment
### 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:

<table>
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<tr>
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<th>Value</th>
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<tr>
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#### Traffic Simulation:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOTIS Penetration</strong></td>
<td>10%</td>
</tr>
<tr>
<td><strong>TTI Segment</strong></td>
<td>500 m</td>
</tr>
<tr>
<td><strong>Default interval</strong></td>
<td>$t_{\text{def}}$ 5 s</td>
</tr>
<tr>
<td><strong>Vehicles</strong></td>
<td>$\approx 2700$</td>
</tr>
<tr>
<td><strong>Avg. Headway</strong></td>
<td>3 s</td>
</tr>
<tr>
<td><strong>Road Length</strong></td>
<td>68 km</td>
</tr>
<tr>
<td><strong>Velocities: Fast/Slow Lane</strong> (initial. vel, norm. distributed)</td>
<td></td>
</tr>
<tr>
<td>$\mu$</td>
<td>140 km/h, 90 km/h</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>35 km/h, 25 km/h</td>
</tr>
</tbody>
</table>
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

SOTIS

Knowledge Base
Stores available information, recently received sensor data

Area Map
Road matching, segmentation, etc.
Map IF

SOTIS Core
Information processing, generating own data packets
KB IF

Display Adaptor
Visualization of Information

SOTIS

Sensor Adaptor
Sensing of data

Position Adaptor
Provides current location of vehicle

Comm. Adaptor
Sending/receiving

FN NaviServer
GPS

FN Router
IEEE 802.11

CAN Bus Interface
In-Car Network / Socket IF

RS232/USB

Positioner IF

Sensor IF

Communication IF

Standalone View

FN ShowRoom GUI

FN Demonstrator GUI
Demonstrator: SOTIS Application
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 $i$th vehicle is activated ($i=1\ldots4$).
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 $u(E, D_k)$
    Utility of sending the packet in the current context, function of environment variables $E$, and packet descriptors $D$
  - Update function $c(E, D_k)$
    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 $\hat{\mu}_{ub}$ and number of nodes in range $N$ in local area
- **Fairness**: Each node $i$ sends with instantaneous rate $r_i$

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

where $ub_i$ is

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

$K_i$: 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


Data Dissemination and Self-Organizing Traffic Info System

