oCPS

Intelligent Transportation Systems
V2V communications

Johan Lukkien
Multiple network technologies

C2C-CC (Car2Car Communication Consortium initiated by six European car manufacturers) architecture (~2010)

IEEE 802.11p
IEEE 802.11a/b/g
Other wireless technology (full coverage)
Remember: conceptual view

- Example data flows:
  - (1) gather detailed driving data to determine
    - local weather
    - road condition
  - (2) accident prevention by direct intervention
  - (3),(4) informing driver about upcoming road conditions

Example data flows:

- (1) gather detailed driving data to determine
  - local weather
  - road condition

- (2) accident prevention by direct intervention

- (3),(4) informing driver about upcoming road conditions
V2V: goals and characteristics

• Goals
  • Safety
  • Comfort
  • Traffic efficiency

• Main characteristics
  • Very high mobility of network nodes
  • Fully distributed system
  • IEEE 802.11p (CSMA/CA) as underlying technology

• Safety applications have strict requirements on (communication-)
  • Reliability
  • Delay
<table>
<thead>
<tr>
<th>Scenario and warning type</th>
<th>Scenario example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rear end collision scenarios</strong></td>
<td></td>
</tr>
<tr>
<td>Forward collision warning</td>
<td>Approaching a vehicle that is decelerating or stopped.</td>
</tr>
<tr>
<td>Emergency electronic brake light warning</td>
<td>Approaching a vehicle stopped in roadway but not visible due to obstructions.</td>
</tr>
<tr>
<td><strong>Lane change scenarios</strong></td>
<td></td>
</tr>
<tr>
<td>Blind spot warning</td>
<td>Beginning lane departure that could encroach on the travel lane of another vehicle traveling in the same direction; can detect vehicles not yet in blind spot.</td>
</tr>
<tr>
<td>Do not pass warning</td>
<td>Encroaching onto the travel lane of another vehicle traveling in opposite direction; can detect moving vehicles not yet in blind spot.</td>
</tr>
<tr>
<td><strong>Intersection scenario</strong></td>
<td></td>
</tr>
<tr>
<td>Blind intersection warning</td>
<td>Encroaching onto the travel lane of another vehicle with whom driver is crossing paths at a blind intersection or an intersection without a traffic signal.</td>
</tr>
</tbody>
</table>

Source: GAO analysis of Crash Avoidance Metrics Partnership information.

from: Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications, NHTSA, August 2014
ADAS

- Equipped with a user interface these applications end up as *Advanced Driver Assistance Systems (ADAS)*
  - e.g. a vibrating seat or other warning

  5 steps to full automation

- Currently under R&D:
  - Collaborative Adaptive Cruise Control
    - 2 or more vehicles in a platoon
  - multiple CACC: merging

Johan J. Lukkien, j.j.lukkien@tue.nl
TU/e Informatica, System Architecture and Networking

6-Sep-16
C’est le Rush
https://www.youtube.com/watch?v=Johmxw3cspA
How does this work?

• It is *cooperative*, *dynamic* and *ad-hoc*

• Two different approaches, same network technology (IEEE 802.11p)
  
  
  – **EU**: ETSI TC ITS standards, using Geo-networking

• Essentially: vehicles emit *periodically* or *event-driven* status information
  
  – called *Basic Safety Messages* (BSM, US)
  
  – and *Cooperative Awareness Messages* (CAM, EU)
IEEE 802.11p

- part of the full IEEE 802.11 (2800 page) specification: enhancements for use in Vehicles
- channels in the 5.9 GHz range (~300m in free field, max 1000)
- connect without BSS (stations with access point): no association, authentication
  - just direct, ad-hoc messaging when in range
- deal with high relative speeds of terminals
  - throughput 3-27Mbit/s per channel, typically 6Mbit/s per channel
- support prioritizing of traffic: EDCA (from 802.11e)
- UTC-based timing reference for synchronizing time accurately
(partial) Communication Stack: EU and US

Rate-adaptation Based Congestion Control for Vehicle Safety Communications, PhD thesis Tessa Tielert
ETSI GeoNetworking

- ETSI GN
  - Intended to work on different access technologies
- ITS-G5: implementation on IEEE 802.11p
  - three frequency classes
    * A:safety
    * B: non-safety
    * D: future
  - control and service channels
    * common control channel: primary channel for unsolicited traffic
  - protocols for channel switching
ETSI GeoNetworking

- ETSI GN provides ad-hoc local connectivity
  - Addressing: 48bit interface address extended with station information
  - use of a *location table* about neighbors
    - updated by info from incoming messages
  - GN routers, role of some stations
  - Services, e.g:
    - SHB: single hop broadcast (repeated)
    - unicast
    - geobroadcast: limit physical extent and limited number of hops
  - BTP: add multiplexing to the GN services
ETSI GN: Internet connectivity

- Forwarded to IPv6 gateway by GN protocols
- Adaptation layer provides transparency
- IPv6 of lower importance than safety applications

(draft) Vehicle to Internet communications using the ETSI ITS GeoNetworking protocol
Victor Sandonis, Ignacio Soto, Maria Calderon, Manuel Urueña

Johan J. Lukkien, j.j.lukkien@tue.nl
TU/e Informatica, System Architecture and Networking
ETSI GN: safety messages

- **CAM**: cooperative awareness messages
  - use the SHB protocol
  - repeated broadcast vehicle state in one-hop neighborhood

- **DENM**: decentralized environment notification messages
  - use the geocast protocol
  - inform about hazards and road conditions
US: WAVE/DSRC

- IEEE 1609 standardizes Wireless Access in Vehicular Environments over Dedicated Short Range Communication
  - 1609.1: resource management
  - 1609.2: security services
  - 1609.3: networking services (a.o. wave short message protocol)
    - broadcasting of basic safety messages
    - define channel number and power per message
  - 1609.4; multi-channel operation

- SAE J2735
  - defines the message content of WSMP
Some application examples
(US WAVE BSM ~SAE J2735)

<table>
<thead>
<tr>
<th>Apps.</th>
<th>Comm.type</th>
<th>Freq.</th>
<th>Latency</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane Change Warning</td>
<td>V2V, periodic, P2M</td>
<td>10Hz</td>
<td>100ms</td>
<td>150m</td>
</tr>
<tr>
<td>Collision Warning</td>
<td>V2V, periodic, P2M</td>
<td>10Hz</td>
<td>100ms</td>
<td>150m</td>
</tr>
<tr>
<td>Emergency Brake Lights</td>
<td>V2V, event-driven, P2M</td>
<td>10Hz</td>
<td>100ms</td>
<td>300m</td>
</tr>
<tr>
<td>Pre-Crash Sensing</td>
<td>V2V, event-driven, P2P</td>
<td>50Hz</td>
<td>20ms</td>
<td>50m</td>
</tr>
<tr>
<td>Stop Sign Assists</td>
<td>I2V and V2I, periodic</td>
<td>10Hz</td>
<td>100ms</td>
<td>250m</td>
</tr>
<tr>
<td>Left Turn Assistance</td>
<td>I2V and V2I, periodic, P2M</td>
<td>10Hz</td>
<td>100ms</td>
<td>300m</td>
</tr>
<tr>
<td>Traffic Signal Violation</td>
<td>I2V, periodic, P2M</td>
<td>10Hz</td>
<td>100ms</td>
<td>250m</td>
</tr>
<tr>
<td>Curve Speed Warning</td>
<td>I2V, periodic, P2M</td>
<td>1Hz</td>
<td>1s</td>
<td>200m</td>
</tr>
</tbody>
</table>

Eight high priority vehicle safety applications as chosen by NHTSA and VSCC.

VSCC – Vehicle Safety Communication Consortium of CAMP (Crash Avoidance Metrics Partnership)

V2V = Vehicle to Vehicle
P2M = Point to Multipoint
I2V = Infrastructure to Vehicle
Combining with Internet

Internet Apps
- TCP/UDP
- IPv6

WAVE Apps
- 1609.x
  - (1,2,3)

LLC/MAC (IEEE 802.11p with CSMA/CA)

PHY (IEEE 802.11p)

WAVE (Wireless Access in Vehicular Environment) standards:
IEEE 802.11p standard and 1609.x standards
Discussion
a CPS communication system

• What is the influence of the ‘physical’ on the ‘cyber’?
• Which layers are involved?
• Is there further opportunity for optimization?
  – what should be optimized then, what are metrics?
• Which transparencies are maintained and where is the layering broken?

• Examine your own projects. What (wireless) communication concerns do you see?
Modeling, Simulation, Testing

• What do we want to know / show / prove of this system?
  
  – functional properties and consistency of the specification
    • are the use cases addressed?

  – extra-functional properties of the specification
    • these are not always made explicit, e.g. performance
    • these are not directly following from design choices
    • these rely on a wide range of assumptions about
      – the environment of the system
      – the properties of subsystems

  – properties of the implementation
    • adherence to the specification
    • validation of the results above
    • … does it work?
Choose at least 2 out of 3

- Real world
- Model world
- Experiment
- Simulation
- Analytical description

The issue you want to shed light on.
Concerns of safety

• What is the combined behavior of application components distributed over several vehicles?
  – agreements on and effects of actuations?
  – which situational information needs to be taken into account?
    • road condition, #passengers in other car, #vehicles in certain range, …. ?
  – development and acceptance procedures for applications
    • https://blogs.nvidia.com/blog/2016/05/06/self-driving-cars-3/
    • https://www.youtube.com/watch?v=qhUvQiKec2U

• Communication from perspective of a given vehicle
  – do I know who is in my neighborhood?
    • how long does it take to know this?
  – are my messages received by vehicles in my neighborhood?
  – do I receive the messages of vehicles in my neighborhood?
  – how does this scale in function of vehicle density? of …?
Case study: scalability of periodic broadcast

• When the number of vehicles increases, collisions will increase as well
• Nodes will suffer losses through Near Neighbor and Hidden Node effects

• Questions:
  – what are effects on reliability, delay and fairness?
    • fairness: all vehicles taking the same loss?
  – what is the impact of HN, NN?
  – what is the impact of the *phase*, and of changes therein?
  – what are relevant metrics?

From: *Model, Analysis, and Improvements for Inter-Vehicle Communication Using One-Hop Periodic Broadcasting Based on the 802.11p Protocol*, T.Batsuuri, R.J.Bril, J.J.Lukkien
Periodic Broadcast in IEEE 802.11p

\[ a_i^{(k)} \overset{\text{def}}{=} \phi_i + k \cdot T_i \]

\( k : k^{th} \text{ message} \)
\( \phi_i = \text{initial phase (or offset) with respect to a common zero} \)
\( T_i : \text{period} \)

- **Defer**: waiting until channel is free; **Bf**: backoff; **AIFS**: see EDCA
- For broadcast, randomization in back-off process is limited
- Point-to-point techniques for solving hidden node problems do not work
  - MAC layer acknowledgement
  - RTS/CTS
Collisions

(a) CSMA/CA

(b) NN collision

(c) HN collision

$AIFS \times m_i \times m_j \times m_p$

$\rightarrow$ Sending message of $i$

$\rightarrow$ Receiving message of $i$

$\rightarrow$ Collision

$\rightarrow$ Ready to transmit (RTT)

$\rightarrow$ Deferring (Df)

$\rightarrow$ Backoff (Bf)

$\rightarrow$ Remaining Bf
How to setup the simulation?

- Two ‘independent’ parts:
  - Simulate vehicles, and vehicle movement
  - Simulate communication
    - how detailed should this be?

- Vehicle movement
  - idealized, parameterized
  - or real-world traces?
Simulation setup

Scenario: Every vehicle periodically broadcasts messages at 10Hz frequency within its communication range.

<table>
<thead>
<tr>
<th>Simulator</th>
<th>VNS &amp; NS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet size (bytes)</td>
<td>555</td>
</tr>
<tr>
<td>Channel rate</td>
<td>6Mbps</td>
</tr>
<tr>
<td>Communication Range(CR, m)</td>
<td>300</td>
</tr>
<tr>
<td>A slot time(us)</td>
<td>13</td>
</tr>
<tr>
<td>SIFS(us)</td>
<td>32</td>
</tr>
<tr>
<td>AIFS(us)</td>
<td>SIFS + 6*slots</td>
</tr>
<tr>
<td>CW(us)</td>
<td>7*slots</td>
</tr>
</tbody>
</table>
Highway model

Total path length is 3000m.
The inter-vehicle distance is changed to have different densities.
Assumptions

- All vehicles have the **same fixed period** for broadcasting.
- All vehicles broadcast messages of the **same fixed size**.
- For each vehicle, the **phase is determined randomly**.

**Definition**: we say that there is a link from vehicle A to vehicle B iff B can receive messages from A (i.e., B is in the communication range of A).

**Channel model**:
- Two-Ray Ground
- Communication range is effectively a sphere

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna gain</td>
<td>0 dB</td>
</tr>
<tr>
<td>Antenna height</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Noise floor ($nF$)</td>
<td>$-99$ dB</td>
</tr>
<tr>
<td>Power sense threshold ($PsTh$)</td>
<td>$-92$ dB</td>
</tr>
<tr>
<td>Carrier sense threshold ($CsTh$)</td>
<td>$-85$ dB</td>
</tr>
<tr>
<td>SINR threshold ($SrTh$)</td>
<td>8 dB</td>
</tr>
</tbody>
</table>
Metrics

• **Successful Message Ratio (SMR)** – the fraction of vehicles in Communication Range that receive a broadcast message.
  – Example: if a network has vehicles with 10 neighbors on average and on average 7 receive the message then SMR=70%
  – SMR is also defined per vehicle and per message

• **First Delay (FD)** – the longest interval in which no message is successfully delivered between two vehicles since they established a link (i.e. a delay to discover each other)

• **No Message Interval (NoM)** – the longest interval in which no message is successfully delivered in a link
Results: overall SMR vs. Vehicle Density (VD)

- minSMR: all phases equal
- maxSMR: optimal scheduling
- no HN: single broadcast domain
- significant losses at low densities

VD = 48

SMR ~ 78%
CDF of vehicles by its SMR

- CDF: Cumulative Distribution Function
  - $y\%$ vehicles have at most $x\%$ SMR
- Some vehicles have SMR of 15%, and some of 100%
  - unfair!
- Ideal case: all the same
First Delay (60 simulated seconds)

- Most vehicles see each other within 100ms
- Some vehicles never see each other

- 52644 links are established (~36000 links between vehicles traveling in opposite directions, ~17000 links for the same direction)
CDF of NoMessage Interval

- $y\%$ links have up to $x$ seconds NoM
- Most NoMs are short
- However, a positive number of NoMs is larger than 10s
Possible adjustments

\[ a_{i}^{(k)} \overset{\text{def}}{=} \phi_{i} + k \cdot T_{i} + \text{jitter} \]

\( k : k^{th} \text{ message} \)

\( \phi_{i} = \text{initial phase (or offset) with respect to a common zero} \)

\( T_{i} : \text{period} \)

- Elastic:
  - randomize the phase every \textit{er} (elastice rate) messages
    - appears to improve fairness

- Jitter:
  - give a jitter of \textit{AJ} msec (Activation Jitter) to the arrival moment
    - appears to improve long delays
• Strict periodic scheme

\[ a_i^{(k)} \overset{\text{def}}{=} \phi_i + k \cdot T_i \]

• Elastic scheme

\[
\begin{align*}
    a_i^{(k)} & \overset{\text{def}}{=} \begin{cases} 
    \phi_i & \text{if } k = 0 \\
    a_i^{(k-1)} + T_i & \text{if } k \mod er_i \neq 0 \\
    a_i^{(k-1)} + \text{rand}(2 \cdot T_i) & \text{if } k > 0, k \mod er_i = 0
    \end{cases}
\end{align*}
\]

er – elastic rate, \text{rand} – random function

• Jitter scheme

\[ a_i^{(k)} \overset{\text{def}}{=} \phi_i + k \cdot T_i + \text{rand}(AJ_i) \]

AJ – Activation Jitter (in units of message transmission time)
Two solutions into one: SMR

- Neither Jitter nor Elastic changes SMR!
- Combined: best results
- MD: multi-domain
- Choice of $er=6$, $AJ=20$ based on experimentation
Two solutions into one

- Neither Jitter nor Elastic changes SMR!
Two solutions into one

- Neither Jitter not Elastic changes SMR!
- Combined: best results
Literature

- Vehicle ad-hoc Network, Standards, Solutions, and Research, edited by Campolo, Molinaro, Scopigo, Springer
- Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications, NHTSA, August 2014
- Rate-Adaptation Based Congestion Control for Vehicle Safety Communications, PhD thesis Tessa Tielert
- Model, analysis, and improvements for inter-vehicle communication using one-hop periodic broadcasting based on the 802.11p protocol, Batsuuri, Lukkien, Bril, Wireless Sensor and Mobile Ad-hoc Networks
Concluding

• What further analysis is required?
  – to increase understanding of the communication system operation, in more circumstances, or in a more accurate model
    • will a real implementation exhibit the behavior of the previous slides
  – to understand application operation, quality

• What further physical aspects could be taken into account such that the system will behave better
  – need metrics that need to be improved

• There are strong concerns of privacy and security that may influence system design and operation significantly
Privacy, Safety, and Security

- **Privacy**: control over personal information

- **Safety**: freedom from danger or risk on injury resulting from recognized but potentially hazardous events

- **Security**: regulating access to (electronic) assets according to some policy
  - *policy*: allowed and disallowed actions
  - *security mechanisms*: can be regarded as enforcing the policy

- Privacy and safety restrictions result in *security policies*
  - *security for privacy and security for safety*

- In addition: security for protection of the business case
  - *security for the business case*, quite often an *availability concern*
Security to protect safety in BSM

- A vehicle could perform a (physical) action upon receiving certain messages. This response must be on good grounds, and safe.
  - **authentication**: does this message really come from
    - that particular car?
    - the car left behind me?
  - **authorization**: what is allowed
    - by this party?
    - by this message?
  - **integrity**: was this message not tampered with?

- Further concerns regarding safety:
  - are messages really delivered (and not lost or jammed)?
  - **functional safety**
    - maintain safe and responsive behavior while executing normal functions