Vehicular *ad hoc* networks – challenges, opportunities and standardization

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Vehicular *ad hoc* networks

• **Opportunities**
  – Communications between vehicles and infrastructure enables new applications such as road traffic safety and road traffic efficiency

• **Challenges**
  – High mobility and challenging operating environments (e.g., carrier frequency of 5.9 GHz)

• **Requirements**
  – High packet reception probability (reliability) and low delay
  – Security and privacy

Common set of standards is needed!
Terminology

• Vehicular *ad hoc* networks is a small subset of the Intelligent Transport Systems (ITS) domain
  – ITS incorporates everything from helping disabled people in public transport by using technology to scheduling flights at an airport
  – Special case of mobile *ad hoc* networks (MANET)
• Cooperative ITS (coined in Europe) is when vehicles collaborate to increase traffic safety/efficiency through *ad hoc* wireless communications or e.g., 3G
• Dedicated short-range communications (DSRC)
  – In Europe and Japan electronic toll collection (ETC) systems
  – Australia and US refer to 802.11p technology for direct communication between vehicles
Cooperative ITS

• Current active safety systems
  – Radars (24 GHz and 77 Ghz), laser radars and cameras

• Increase ’horizon of awareness’ beyond line-of-sight (LOS) technologies

• Wireless communication between vehicles can potentially decrease the number of accidents
  – Road traffic safety
  – Road traffic efficiency
Cooperative ITS cont’

• Can be realized through different wireless access technologies
  – IEEE 802.11p, 3G, Mobile WiMAX

• Focus here is on road traffic safety using ad hoc networking through IEEE 802.11p
Background

  Cooperative autonomous driving → Cooperative driver assistance

1999 – FCC in US allotted 75 MHz to ITS at 5.9 GHz

You tube clips shown at presentation

• Autonomous Driving/Highways (interesting at 14.28)
  – World Fair “Futurama” in New York, 1939
  – [http://www.youtube.com/watch?v=tAz4R6F0aaY](http://www.youtube.com/watch?v=tAz4R6F0aaY)

• PATH project realizing 8 car platoon in 1997
  – [http://www.path.berkeley.edu/nahsc/](http://www.path.berkeley.edu/nahsc/)
Platooning – CACC

- Cruise control (CC)
  - Manually braking

- Adaptive cruise control (ACC)
  - Adapt speed to the vehicle in front
  - Automatic braking

- Cooperative Cruise Control (CACC)
  - Including communication between vehicles
GCDC

- Grand Cooperative Driving Challenge (GCDC)
- May 2011
- Participants from Sweden: Halmstad University, Chalmers and KTH
- Cooperative ACC
- [http://www.youtube.com/watch?v=0JNqHhSxlng&feature=relmfu](http://www.youtube.com/watch?v=0JNqHhSxlng&feature=relmfu)
ITS development

Source: http://www.ertico.com/ and Hermann Maier
Traffic Safety Applications

• Emergency vehicle approaching
• Slow vehicle
• Stationary vehicle
• Emergency electronic brake lights
• Wrong way driving
• Adverse weather conditions
• Traffic condition
• Road work
• Etc.
Two types of messages

• Time-triggered position messages
  – Beacons, ”hello” messages, ”Here I am”
  – Europe: Cooperative Awareness Message (CAM)
  – US: Basic Safety Message (BSM) type 1

• Event-driven hazard warnings
  – Transmitted when a dangerous situation is detected by a vehicle to warn fellow road users
  – Europe: Decentralized Notification Message (DENM)
  – US: BSM type 2 (BSM2)
Communication Requirements

• The wireless communications protocols available today enables either reliable communications with low error rate or time-critical communications with real-time constraints – but not integrated high levels of both:
  – Voice has real-time requirements but is relatively error tolerant.
  – E-mailing requires reliable communications but is delay tolerant.
  – Control traffic on a fieldbus has requirements on both reliability and real-time but the fieldbus is wired and centralized.
  – Cellular networks carrying data traffic provides reasonable guarantees on real-time and reliability, but coverage is needed, and the cellular structure introduces increased delay.
Real-Time Communication

- Traffic safety applications have concurrent requirements on *delay* and *reliability*
- Packets have a deadline to meet
- Time-triggered position messages
  - 2-10 Hz, 300-800 byte
- Event-driven hazard warnings
  - Packet size and periodicity depend on traffic safety application
What is a VANET?

• Vehicular *ad hoc* networks
• Dezentralized network topology
  – No access point or base station
  – Peer-to-peer communication
• Self-organization
• Can contain roadside units (RSU)
Characteristics of VANETs

- Share a common communication channel
- Broadcast communication
  - Traditional Automatic Repeat reQuest (ARQ) are not possible
- The multipath environment where the radiowaves propagate
  - 5.9 GHz has been chosen for VANETs
- The number of participating nodes in a VANET cannot be restricted or foreseen
Frequency bands for cooperative ITS

• North America
  – 5.850-5.925 GHz Intelligent Transportation Systems Radio Service
    • 75 MHz
  – 7x10 MHz channels
    • 1 control channel and 6 service channels

• Europe
  – 5.875-5.925 GHz (30 MHz + 20 MHz)
    • Road traffic safety
      – 1x10 MHz control channel and 2x10 MHz service channels
    • Traffic efficiency
      – 2x10 MHz service channels
**Why 5.9 GHz?**

- US wanted to have an Electronic Toll Collection (ETC) that could function all over the US
  - Before every state had its own solution...
- Europe and Japan have had its ETC system at 5.8 GHz for many years
- Hard to find harmonized frequencies at lower frequency bands
IEEE WAVE/802.11p

- Safety applications
  - Safety application sublayer
  - Message sublayer
  - WSMP
  - 1609.2 Security

- Non-Safety applications
  - Application
  - Transport (TCP/UDP)
  - Network (IPv6)
  - IETF RFC 793/768
  - IETF RFC 2460

- Standards
  - SAE J2735
  - IEEE 1609.3
  - IEEE 802.2
  - IEEE 1609.4
  - IEEE 802.11p

WAVE = Wireless Access in Vehicular Environment
IEEE 802.11p

• An amendment to the WiFi standard IEEE 802.11
• Ratified in July, 2010
• No access point functionality
  – No authentication or association procedures
• Medium access control (MAC)
  – Carrier sense multiple access with collision avoidance (CSMA/CA)
  – Support for Quality of Service (802.11e)
IEEE 802.11p

- Physical layer of 802.11p
- Derived from the 802.11a
  - Defines 3 different channel widths: 5, 10, and 20 MHz
- Orthogonal Frequency Division Multiplexing (OFDM)
  - 48 data carriers and 4 pilots
  - Subcarrier spacing of 156.25 kHz
  - Symbol interval 8 μs (GI of 1.6 μs)
- 8 different transfer rates
  - 3, 4.5, 6, 9, 12, 18, 24, 27 Mbps
  - BPSK, QPSK, 16-QAM, 64-QAM
IEEE WAVE/802.11p

• 1609.3 WSMP
  – WAVE short message protocol (WSMP)
  – Developed to avoid excessive overhead
  – WAVE Short Messages (WSM)
  – WAVE Service Advertisements (WSA)
• SAE J2735 DSRC message set dictionary
  – 15 message types
  – Basic Safety Message (BSM)
    • ~300B, 10Hz
    • Conveys state information about the sending vehicle
    • Periodic ”Here I am” messages
• 1609.2 Security
IEEE WAVE/802.11p

- 1609.4 Multichannel operation
  - One Control channel (CCH)
  - Six Service channels (SCH)
Frequency bands in Europe

ETSi ES 202 663 (V1.1.0): “Intelligent Transport Systems (ITS); European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band”
ETSI TC ITS protocol stack

- Adds a facilities layer in-between transport and applications
- The access technologies do not only focus on *ad hoc* networking
ETSI – Access technologies

• Profile standard of IEEE 802.11p
  – Termed **ITS G5**
  – MAC and PHY
  – ES 202 663
  – Adapting 802.11p to the European spectrum

• Requirement on Decentralized Congestion Control (DCC)
  – TS 102 687
Motivations for DCC

- Adapt the transmit power through transmit power control (TPC) algorithms
- Adapt the packet generation in each node through transmit rate control (TRC)
- The number of nodes in a VANET cannot be restricted
- CSMA as MAC method will have trouble when the number of nodes increases within radio range
  - Unbounded channel access delay (nodes will not be able to transmit packets)
  - Affects the performance of the road traffic safety applications
DCC

• DCC influences three parts of the protocol stack
  – Access technologies
  – Network & Transport
  – Facilities
• Management plane plays a central role
• Cross-layer problem
ETSI – Network and transport

Applications

Facilities

Network & Transport

Access Technologies

Transport

Basic Transport Protocol

Transmission Control Protocol

User Datagram Protocol

Network

Geonetworking

Internet Protocol (IPv4, IPv6)
ETSI – Network and Transport

• Geonetworking
  – Media-independent functionality
    • TS 102 636-4-1
    • Does not rely on a specific access technology
  – Media-dependent functionality
    • TS 102 636-4-2
    • Supporting the DCC part

• Basic Transport Protocol (BTP)
  – TS 102 636-5-1
  – Connection-less (best effort delivery)
  – Low overhead
ETSI – Facilities

Application support
- E.g. Station positioning, Service management, Message management, Mobile station dynamics, LDM management, Security access

Information support
- E.g. LDM database, Data presentation, Location referencing, Station type/capabilities

Communication support
- E.g. Addressing mode, Mobility management, GEONET support, Session support
ETSI – Facilities cont’d

• Two central message types
  • Cooperative Awareness Messages (CAM)
    – TS 102 637-2
    – Periodic time-triggered position messages
    – ”Here I am”
    – 1-10 Hz, packet length including security up to 800 bytes
  • Decentralized Environmental Notification Messages (DENM)
    – TS 102 637-3
    – Event-driven hazard warnings
Local Dynamic Map (LDM)

- The LDM is a database storing and maintaining data
- TR 102 863
- Dynamic data received from other ITS stations through CAM and DENM
- Applications retrieve relevant data from the LDM
ETSI – Applications

• Basic set of applications
• TR 102 638
• Road safety (driving assistance)
  – Emergency vehicle, slow vehicle, wrong way driving, traffic condition, roadwork, etc.
• Traffic efficiency
  – Speed limits notification, enhanced route guidance
Ongoing activities within ETSI

• Revision of CAM and DENM specifications
• Channel specification of the ITS band at 5 GHz
  – How to use the different available frequency channels for cooperative ITS
  – TS 102 724
• Minimum set of standards to be finished mid 2012 to ensure interoperability
My Research: MAC in VANETs

• Problem: CSMA as MAC method is not scalable
  – Recall that the number of nodes in a VANET cannot be restricted or foreseen

• Solution: Self-organizing Time Division Multiple Access (STDMA)!

• Method: Simulation and Analytical modelling (on-going)
Introduction

• Studied two different MAC protocols through simulation
  – CSMA of IEEE 802.11p
  – STDMA from AIS
• VANET setting (no central coordinator)
• The focus of our research is on road traffic safety applications
  – Requirements on low delay and high reliability concurrently
• Broadcast communications

Medium access control (MAC) is responsible for scheduling transmissions and minimize interference.
CSMA of IEEE 802.11p

• Carrier sense multiple access with collision avoidance (CSMA/CA)
• Senses the channel before transmitting
  – Listening period
• Backoff procedure invoked if channel sensed busy
  – Only invoked once due to broadcast communication
• Problems: Cannot handle overloaded situations!
  – Scalability problems lead to unbounded channel access delay, unpredictable and unfair behaviour
CSMA drawbacks

• Unpredictable channel access delay
  – Periodic messages need to be sent within its time period
  – The random backoff may cause a delay longer than the time period
  – Causes packet drops at sending node

• Collisions
  – The random backoff time chosen are discrete and thus nodes may choose the same
    • For example in 802.11e highest priority – {0 µs, 13 µs, 26 µs, 39 µs}
  – Two concurrently transmitting nodes may be located very close together

CSMA is not predictable nor scalable.
STDMA – a potential remedy?

- Self-organizing time division multiple access (STDMA)
- Already in commercial use
  - Automatic Identification System (AIS)
  - VDL mode 4
- Specially designed for position messages, e.g., CAM
- Divides the channel into slots and further into frames
  - One transmission fits into one slot
- Predictable channel access delay regardless of the number of competing nodes
- In overloaded situation “collisions” are scheduled to minimize interference
- Needs synchronization between nodes
- Fixed packet length

STDMA is predictable and scalable.
STDMA of AIS

• Self-organizing time division multiple access
• Divides the channel into slots and further into frames
  – One transmission fits into one slot
• Nodes are always granted channel access regardless of the number of nodes in the system
• More nodes than slots:
  – The nodes selects a slot for transmission at the same time as the node situated furthest away from itself
  – Channel access is always GUARANTEED!
  – Can handle overloaded situations!
• Needs synchronization, position information and support fixed packet sizes
Simulator

- Highway scenario
  - 12 lanes (6 lanes in each direction)
- Vehicle appear Poisson distributed with 1/3 Hz
- Gaussian distributed speed
  - Mean values 23 m/s, 30 m/s, and 37 m/s (70-140 km/h)
- Broadcast position messages (CAM)
  - 2 Hz 800 byte (12.8 kbps)
  - 10 Hz 300 byte (24 kbps)
  - 6 Mbps
- Nakagami $m$ channel model
Results – High vehicle density

2 Hz/800B, 20 dBm

2 Hz/800B, 25 dBm

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$R &lt; 100$ m</th>
<th>$R &lt; 200$ m</th>
<th>$R &lt; 300$ m</th>
<th>$R &lt; 400$ m</th>
<th>$R &lt; 500$ m</th>
<th>$R &lt; 600$ m</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal vehicle density</td>
<td>~15</td>
<td>~30</td>
<td>~45</td>
<td>~60</td>
<td>~75</td>
<td>~90</td>
<td>6-lane highway and an inter-arrival time of vehicles of 3 s using Poisson.</td>
</tr>
<tr>
<td>High vehicle density</td>
<td>~52</td>
<td>~104</td>
<td>~156</td>
<td>~208</td>
<td>~264</td>
<td>~316</td>
<td>12-lane highway and an inter-arrival time of vehicles of 1 s using Poisson.</td>
</tr>
</tbody>
</table>
Conclusions research

• STDMA has a higher reliability
  – Due to the synchronized transmissions
• CSMA has on average a lower delay when the network is not saturated
  – Low delay is beneficial but it is more important to have a finite delay in road traffic safety applications
• In STDMA nodes are never denied channel access
• CSMA is not predictable when the number of nodes increases
Wrap up

The performance of the vehicular ad hoc network (VANET) is very much dependent on the number of ITS equipped vehicles within radio range!
Wrap up

• Traffic safety applications
  – Concurrent requirements on reliability and delay
  – Can be classified as real-time communication systems

• VANETs
  – Common ’control’ channel
  – Broadcast preferred communication mode
  – 5.9 GHz poor ability to diffract around corners
  – Self-organizing algorithms
Thank you!

Questions?

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