Outline

- Lund University and Department of EIT (overview)
- Overview of intelligent transportation systems
- Properties of propagation channels
  - Fundamentals
  - Radio channel research
  - V2V channels
- V2V channel measurements
  - Initial Lund’07 measurements
  - Follow up DRIVEWAY’09 measurements
  - Antenna placement and diversity measurements
- Channel characterization and modeling
- Summary & Discussion
A world-class university

- Founded in 1666
- 8 faculties
- 47,000 students
- Almost 3,000 research students
- 6,800 employees
- Around 650 professors
- 800 senior lecturers
- 1,200 lecturers and other research staff
- Turnover EUR 760 million – 1/3 education, 2/3 research

Department of EIT

- Research labs at EIT
  - Broadband Communication
  - Electronics
  - Communication
  - Network and Security
  - Signal Processing
  - Electromagnetic theory
- Information Theory
- Radio Systems
- Telecommunication Theory

- Radio Systems
  - Channel measurements and modeling
  - Algorithm development for digital transmitter/receiver
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Current road traffic related problems

Fact:
Land transportation systems have become crucial components of modern world.

Problems:
• According to world health organization report in 2004, 1.2 million people die in road accidents per year.
• 50% of these are vulnerable road users,
  • 23% motorcyclists,
  • 22% pedestrians,
  • 4% cyclists.
• By 2020, road crashes will be third leading cause of disability/death worldwide.
• The ever increasing number of vehicles demands efficient use of available roads.
Main communication paradigms, 
• Vehicle-to-Infrastructure (V2I) 
• Vehicle-to-Vehicle (V2V) 
Benefits, 
• Road traffic safety 
• Road traffic efficiency

In short...
It is the channel that determines the ultimate performance limits of any communication system.
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What is Channel?

• Usually channel model is made of three constituents
  – Path-loss determines the average (over local space and time) power received for a given TX-RX range
  – Shadowing is added to the path-loss to account for local large-scale effects (Obstruction, static multi-paths, etc.)
  – Fading represents the short-term variations of the received power and is caused by multipath propagation
Free-space loss

If we assume RX antenna to be isotropic:

\[ P_{RX} = \left( \frac{\lambda}{4\pi d} \right)^2 P_{TX} \]

Attenuation between two isotropic antennas in free space is (free-space loss):

\[ L_{\text{free}}(d) = \left( \frac{4\pi d}{\lambda} \right)^2 \]

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Free-space loss

Friis’ law

Received power, with antenna gains \( G_{TX} \) and \( G_{RX} \):

\[ P_{RX}(d) = \frac{G_{RX} G_{TX}}{L_{\text{free}}(d)} P_{TX} = P_{TX} \left( \frac{\lambda}{4\pi d} \right)^2 G_{RX} G_{TX} \]

\[ \boxed{\text{Valid in the far field only}} \]

\[ P_{RX,\text{db}}(d) = P_{TX,\text{db}} + G_{TX,\text{db}} - L_{\text{free,db}}(d) + G_{RX,\text{db}} \]

\[ = P_{TX,\text{db}} + G_{RX,\text{db}} - 10\log_{10} \left( \frac{4\pi d}{\lambda} \right)^2 + G_{RX,\text{db}} \]

In free space, the received power decays with distance at a rate \( = 20 \text{ dB/decade} \)
Free-space loss
What is far field?

The free-space loss calculations are only valid in the far field of the antennas.

Far-field conditions are assumed "far beyond" the Rayleigh distance (also known as Fraunhofer distance):

\[ d_R = \frac{2L_a^2}{\lambda} \]

where \( L_a \) is the largest dimension of the antenna.

Another rule of thumb is: "At least 10 wavelengths"

The reference distance \( d_0 \)

- For path-loss propagation models, a close-in distance \( d_0 \) is selected such that it lies in the far-field region.

\[ P_{RX}(d)dBm = 10\log \left[ \frac{P_{RX}(d_0)}{0.001W} \right] - 20\log \left( \frac{d}{d_0} \right) \quad d \geq d_R \]

- For practical systems in the 1-2 GHz region, \( d_0 \) is typically chosen to be 1 m in indoor environments, and 100 m or 1 km for outdoor environments.

- For distances \( d > d_{\text{break}} \), the above equation doesn’t hold anymore.
The WSSUS model
Assumptions

A very common wide-band channel model is the WSSUS-model. **Roughly speaking it means that the statistical properties remain the same over the considered time (or area)**

Recalling that the channel is composed of a number of different contributions (incoming waves), the following is assumed:

- The channel is Wide-Sense Stationary (WSS), meaning that the time correlation of the channel is invariant over time.

- The channel is built up by Uncorrelated Scatterers (US), meaning that contributions with different delays are uncorrelated.
What is large scale and small scale?

Large-scale fading
Basic principle
Small-scale fading, two waves: 
*location-dependent, time-varying fading*

- If no movement is involved, Rx sees different signal strength (*location-dependent fading*)
- If Rx moves, Rx experiences *time-varying fading* (small-scale fading, short-term fading)

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Radio channel research

Main objective is to understand the underlying mechanisms behind the propagation of a signal from transmitter to receiver in order to construct a mathematical model for controlled synthesis of channels.

- **Static Model**
  - Spectral-based, e.g., beamforming
  - Stochastic maximum likelihood
  - Deterministic maximum likelihood

- **Dynamic Model**
  - Kalman filters, e.g., EKF, UKF
  - Sequential Monte Carlo, e.g., Particle filter

- **Measurement based**
  - SAGE, RIMAX

- **3D ray-optical based**
  - Ray tracing

Cellular Channels vs. V2V Channels

**Base station**
- Elevated position
- Fewer scatters
- Static

**Mobile station**
- Close to ground
- Many scatterers in the surrounding
- Static or Dynamic

**Vehicle-to-vehicle**
- Both antennas are close to ground
- Many scatterers in the surrounding (moving/static)
- Highly dynamic
- Typically higher frequency compared to cellular systems.

The catch:
V2V channels are fundamentally different from cellular channels and are subject to faster fluctuations.
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Channel measurements

\[ s(t) \xrightarrow{H(t,\tau)} r(t) \]

• Principle of channel measurements
  – Transmit a known signal \( s(t) \)
  – Estimate the channel \( H(t, f) \) from the received signal \( r(t) \)

Commonly used channel measurement tools:
• Vector network analyzer
• Channel sounder
Channel Sounder

- Calibrated antenna elements for directional estimation

Measurement based channel modelling
V2V channel measurements objectives

- Obtain a **general understanding** of vehicle-to-vehicle propagation channels
  - Underlying mechanisms
  - System impact
  - Gain from multiple-antenna systems
  - Antenna/channel interaction
- Build **simulations models** for system evaluation
  - Vehicle-to-vehicle propagation channels are different from many other propagation channels

**Next step:**
**Preparation for measurements**

**Measurement campaign step by step**

1. **Antenna calibration**
2. **Channel sounder mounting**
3. **Conduction measurements**
Measurement campaign step by step

- Antenna calibration
- Channel sounder mounting
- Measurement-based Channel Characterization and Modelling of Vehicle-to-Vehicle Communications
  Taimoor.abbas@eit.lth.se

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Measurement campaign step by step

- **Antenna calibration**
- **Channel sounder mounting**
- **Conduction measurements**

Initial Lund’07 V2V channel measurements

- TX/RX mounted on small trucks
- 4x4 MIMO measurement campaign
- Measurements with cars in same and opposite lanes

Antenna elements
- Non-omni-directional antenna

Measurement-based Channel Characterization and Modelling of Vehicle-to-Vehicle Communications
Taimoor.abbas@eit.lth.se
Measured Traffic Scenarios

Highway Measurements:

- Two lane (each direction) highway
- Direction of travel was separated by 0.5m high wall
- TX/RX speed (80-90km/h)
- Many moving vehicles
- LOS and OLOS conditions
- Only convoy measurements

Urban Measurements Lund:

- Width 9-14 m
- Single lane
- Parked cars along street
- Some traffic

Urban Measurements Malmö:

- Width 14-40 m
- Two lanes and turn lanes
- Parked cars along street
- Busy traffic
Measured Traffic Scenarios

Rural Measurements:

• Single lane country road
• TX/RX speed (60-70km/h)
• No moving vehicles
• Always LOS conditions
• Measurements while driving in Convoy and in Opposite direction

Rural measurements can be treated as reference, where no or very few scatterers are around.

Conclusions from Initial ’07 Measurements

We found that:

• Vehicle-to-vehicle propagation channels are fundamentally different from cellular propagation channels
• Vehicle-to-vehicle propagation channels are non-stationary
• A geometric-stochastic propagation channel model is suitable

...but also concluded that:

• Measurements with trucks are practical, but will influence the measured channel (antenna height)
• Measurement conduct (cars in convoy or opposite directions on highways etc.) is commonly used, but not representative for many vehicle-to-vehicle applications (e.g., intersection collision avoidance)
DRIVEWAY’09 measurements partners

• Preparation time: 7 months
• Time for channel measurements: 5 days
• Time for antenna calibration: 8 days
• Total milage: 3800km
• Channel sounder IR: 120 GB
• Audio/Video documentation: 14GB
• Antenna calibration: 7GB
• .xls notes: 600kB
DRIVEWAY’09 measurements

Vehicle-to-vehicle measurements:

• Regular cars:
  standard hatchback style
• Realistic antenna design:
  4-element linear array of patch antennas integrated in rooftop radome
• Realistic antenna placement

Consequences:

• Shadowing by car roof inclination
• Shared space with other antennas (e.g., GPS)

Application specific measured scenarios

Identified scenarios where V2V communications will be (particularly) useful, e.g.,

– collision avoidance,
– emergency vehicle warning,
– hazardous location notification,
– wrong-way driving warning,
– co-operative merging assistance,
– slow vehicle warning,
– lane change assistance
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General Observations – Time/Delay

Time-delay characteristics:

- Rapidly varying channel
- Discrete components carry significant energy and change delay bin with time
- Diffuse components following LOS
Non Line-of-sight (NLOS) signal reception

- NLOS signal reception is enabled due to scattering of radio waves, e.g.,
  - single or multiple bounce reflections,
  - diffraction.

- Factors that influence the NLOS-reception are:
  - Objects such as buildings, road-signs, light poles, parked and moving vehicles
  - Structure and material properties of these objects
  - Street width, distance of TX/RX vehicles from the intersection center
**Directional analysis**

A high-resolution algorithm (SAGE) is used for a refined identification of interacting objects in,

- LOS situations
- OLOS situations
- NLOS situations

The results show that:

1. Single and double bounce reflection processes are dominating in the absence of LOS.
2. Reflections from other vehicles are not “seen” as major contributors to the received signal power.
3. Large directional spread motivates use of multiple antennas to exploit diversity.

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**Merging lanes vs. urban intersections**

Received power is negligible in NLOS. Scatterers contributes only when there is LOS.
Relatively better NLOS reception than merging lane scenario due to multiple scatterers (mainly buildings at the corners).

Both scenarios are safety critical with NLOS propagation conditions. The merging lanes scenario has worse propagation conditions than the urban intersections due to open surroundings.

- Received power drops up to 20 dB depending upon the DOA and the differences in antenna gain of the RX elements.
- This motivates to use TX/RX antennas that have omni-directional pattern otherwise multiple antennas should be used.
Ray tracing

• Deterministic approach, can be very realistic
• Solve approximation to Maxwell’s equation, using high-frequency approximation

[Image of ray tracing scenario]

Validation of ray-tracing based model

**Goal:** Comparison of ray-tracing channel simulator and channel measurements

• 3D virtual scenario is created which includes buildings, traffic signs, lamp posts as well as parked cars along roadside.
• Only the direct path, specular reflections (1st and 2nd order) and non-specular reflections (1st order) are considered to characterize the channel.
• Measured polarimetric antenna patterns are used.
• GPS coordinates of TX/RX, logged during measurement, are used for simulation.
Validation of ray-tracing based model

- Very good agreement in LOS and near LOS regions.
- In NLOS, the ray tracing model underestimates the channel gain.
- Gap can be reduced by increasing the order of reflection.
- Contribution of third and higher-order specular and non-specular reflections is missing in the simulator.
Validation of NLOS path loss model

Reference non-line-of-sight path loss model

- Mangel et. al. in [1] has presented a NLOS path-loss model at 5.9 GHz named VirtualSource11p.
- The model is based on an extensive measurement campaign conducted in Munich, Germany.
- The NLOS path-loss model is claimed to be flexible and incorporated specific geometry aspects.
- Question: Is the model valid only in the intersections where the measurements were taken?

The results in this study suggest to introduce an intersection dependent gain parameter in the reference NLOS model to cope with varying scattering. But otherwise the proposed model seems to be accurate.

Measured channel gain for urban scenario

10 dB extra attenuation translates to a 3 time reduction of communication range, e.g. 100 m instead of 300 m.
Network simulations

Simulation scenario,

- 10 km long highway
- 4 lanes (2 on each side)
- 400 byte long CAM messages
- Channel access procedure is carrier sense multiple access (CSMA)
- Vehicle speeds independent Gaussian distributed with mean (23, 30) m/s per lane and standard deviation 1 m/s
- Vehicles Poisson distributed with inter-arrival rate of 1 s, 2 s, 3 s.
- Channel models comparison,
  - Nakagami dual slope
  - LOS/OLOS dual slope model

Two-ring model

- Reflects key properties:
  - Scattering occurs around TX and RX
  - Both TX and RX are moving
- Closed-form equations for Doppler spectra
Tap-delay line model

- Segmented time-invariant tapped delay line
  
  [Acosta and Ingram 2007]

- Time-varying tapped delay line
  
  [Matolak 2008]

Distributed antenna measurements

- Position of antenna is expected to have large impact
  - Both TX and RX antennas are at same height
  - Relatively close to ground level (1-2m above ground)
  - Shadowing effects are expected

- Measurements in the past have been conducted with same type of antenna arrangements
  - Usually roof mounted antenna
  - Single exception exists with antenna placed inside-windscreen
Impact of antenna placement

DIVERSITY’11 measurement setup

Antennas used are omni-directional.

- Leftside-mirror antenna location has strongest channel gain.
- Roof antenna location has strongest channel gain.

• Leftside-mirror antenna is sensitive to the alignment of cars.
Impact of antenna placement

Diversity arrangements with complementary antennas seems to be the preferred solution, e.g., roof or left-side-mirror together with the bumper antenna.

Selected publications

### Selected publications (cont.)


For details please visit: [Vehicle-to-vehicle channel modeling at EIT](#)
Conclusions

• V2V channels differ significantly from standard cellular channels
  – do not expect satisfactory performance for standard WLAN equipment

• For network simulations – include shadowing effects
  – buildings, vehicles,
  – long correlation time for shadowing from other vehicles

• For link simulations – include non-stationarities and consider the double selective channel
  – high Doppler spread – short correlation time
  – high excess delay – small coherence bandwidth

• Multiple antenna arrangements might be required to get reliable links
  – Rx diversity

• Many challenges and opportunities still remain

Thank you!

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