Vehicular Network Simulator and Testbed Based on Mobile Channel

Fuqiang LIU
Prof., Vice Dean
School of Electronics and Information Engineering
Tongji University
fuqiangliu@163.com
Lab website: http://wm.tongji.edu.cn
• About us
• Contents
  – **Motivation**
  – **Research Topics**
    – ♦ Resource Assignment
      ♦ Mobility Management
      ♦ Channel Modeling
  – **Simulation and Test Platform**
    ♦ Heterogeneous Vehicular Network Simulation Platform
    ♦ Mobile Wireless Access Demonstration Platform
  – **Some Challenges**
● 1907 Tongji was founded by Erich Paulun, a German doctor in Shanghai. **Tongji** Means: cooperating by riding the same boat. “同济”意蕴“同舟共济”

● Profile: 24 Colleges; 54,750 Students; 7,593 Staff (include 13 academicians); Research funding Rank No.5-8 in China, 2008 about ¥ 1.4billion;
Tongji University’s Campuses

- Anting auto town;
- Auto Electronics

Shanghai

Siping Campus

Anting Campus
Research Platforms in Tongji (Siping campus)

• City Construction and Safety National Laboratory (城市建设与防灾国家实验室)
  – Civil engineering
  – Architecture and Urban planning,
  – Environment
  – Medical, etc.

• Current Important Projects:
  – 上海世博会总规划（planning of Shanghai EXPO 2010）
  – 上海世博会交通系统（ITS in Shanghai for EXPO）
  – 崇明生态岛（Chongming ecotypic-island）重大专项
Research Platforms in Tongji (Jiading campus)

- National Engineering Center of Advanced Ground Transportation (先进地面交通国家工程中心)
  - Automotive engineering
  - Transportation engineering
  - Electronics and information engineering
  - Mechanic engineering, etc.

Current Important Projects:
- Hybrid power Auto: National 863 key project
- Maglev train: Shanghai Maglev Demonstration
- Express railway: Beijing-Shanghai, etc.
Auto Electronics Research Platforms and partners

• In 2007, General Motors Corporation, EDS, SUN, UGS “Promoting Education Partnership program” center, over 470 million US dollars
• Embedded System and Computing-service Lab under the support of Ministry of Education, (Microsoft-Tongji Windows Mobile and Embedded R&D Center (6th Lab))
• National Linux, IC Design Base, Mentor Graphics- Tongji University System on Chip (SoC) hardware simulation and verification Joint Lab. Mentor Graphics donated 30 full IC design software valued 180 million dollars
• Infineon-Tongji University Automotive Electronics Lab
• Volkswagen (China) Research Center
• Tongji University- Freescale Automotive Electronics Joint Lab
• Tongji University- Siemens VDO joint Lab
• Tongji University- ThyssenKrupp Automotive Technology Joint Lab
• Renesas and Toyota, joint test in DSRC
• SAIC(Shanghai Automotive Industrial Corporation Group), Chery, Geely,
Other cooperative partners include:

- MOST and Ministry of Railway
- China South Locomotive & Rolling Stock Corporation Limited (“CSR”)
- Shanghai Shentong Metro Co., Ltd. Shanghai Maglev Transportation Development Co. Ltd.
Financial support under “985” research platform from Tongji University. There are 8 staff and 70 Ph.D./Master students

Three Research Directions:
- Cellular communications: 4G/LTE, QoS on MAC, Resource management and Networking;
- Vehicular communications: WAVE/DSRC/IEEE802.11p, V2V/V2I communication, Multi-channel Protocol and Mobility management
- Channel measurement and analysis for cellular and vehicular communications

International Cooperation:
- USA: Columbia University, University of Michigan, UTC, Microsoft, Cisco, etc.
- Finland: Helsinki University of Technology, Elektrobit, etc.
- France: ENST, INT, etc.
- Japan: National Informatics Institute, Toyota, Renesas, etc.

Domestic Cooperation:
- SHRCWC, Huawei, SAIC, Southeast University, Tsinghua University, etc.

Publication & Invention Patents:
- BW&M Lab has applied or gained 13 national patents, published more than 120 papers, 50 of which are searched by SCI, EI, ISTP, including IEEE Transactions on Wireless Communications, IEEE Transactions on Signal Processing, IEICE Transactions on Information and Systems, International Journal of Modern Physics, Journal on Communication IEEE International, Conference on Communications (ICC), IEEE Wireless Communications & Networking conference (WCNC), International Conference on Mobile Computing and Networking (MobiCom).
Related Research Projects in BW&M Lab

- **International Key Project from MOST (With Cisco):** Research on City Transport Information Network Based on Next Generation Broadband Wireless Technology, 2005.10-2008.1
- **Sub-Project 973 Program from MOST (No.2004CB719802):** Research on Microwave negative refraction construction, 2004.10-2009.9
- **National Natural Science Foundation of China (60904068/F030209):** Different vehicular car-following modeling and simulation based on cooperative driving in a car-to-car wireless communication environment, 2010.1-2012.12
- **Science and Technology Breakthrough Major Project of Science and Technology Commission of Shanghai Municipality (STCSM) (No.07dz15006_2):** Broadband wireless network performance test and key technology research, 2007.7-2009.6
- **Science and Technology Breakthrough Major Project of Shanghai Science and Technology Committee (06dz15013):** Solution and Evaluation Testing of Multi-antenna Technology for Future Mobile Communication, 2006.10-2008.9
- **Basic Breakthrough Major Research Project of Shanghai Science and Technology Committee (08DJ1400301), 2008.6-2010.6
- **Huawei Project (YBWLY2009005):** Wireless Channel Measurement Data Analysis and Statistical Modeling, 2009.1-2010.6
- **Huawei Project (No.YBWLY2008053):** Key technology research on LTE Broadband wireless communication testing, 2008.07-2009.12
- **Cisco Project:** Service Access on Highway VANETs, one of three projects in Asia Universities
Contents

• Motivation

• Research Topics

  ♦ Resource Assignment
    - *Adaptive Multi-Channel Operation*

  ♦ Mobility Management
    - *Handover Management*
    - *Routing protocol*
    - *Mobility Model*

  ♦ Channel Modeling
    - *Propagation Characterization*
    - *Modeling Methods*
    - *Simulation process*
    - *Radio Channel Measurement and Analysis Platform*

• Simulation and Test Platform

  ♦ Heterogeneous Vehicular Network Simulation Platform
  ♦ Mobile Wireless Access Demonstration Platform

• Some Challenges
Motivation

- Safety and transport efficiency
  - In the world, 1.2 million people died from traffic accidents; 518 billion every year. (Data according to World Health Organization); In China: 2007 81k died, 380k are injured every year on the roads
  - Traffic jams generate a tremendous waste of time and of fuel
- Most of these problems can be solved by providing appropriate information to the driver or to the vehicle
Ongoing Works in the Lab

**Networks Convergence:**
BWA&DSRC
- Resource Assignment
- Mobility Management
- Cooperative Communication

**Channel Investigations:**
Measurements & Modeling
- Channel Characterization
- Channel Analysis and Modeling
- Mobile Channel Modeling

**Network Testing:**
Simulation & Test Platform
- Cellular Network Simulation
- Heterogeneous Simulation
- Mobile Access Demonstration

http://WM.tongji.edu.cn
Active Safety offers many new opportunities.

Passive Safety has become a commodity.
A Smart Vehicle

Event data recorder (EDR)
Forward radar
Positioning system
Communication facility
Rear radar
Display
Computing platform

Human-Machine Interface

- Communication: typically over the Vehicular ad hoc networks (VANET)
  Example of protocol: IEEE 802.11p (WAVE)
- Smart camera used in car
Vehicle Communication Networks

- Vehicle to Vehicle
- Vehicle to Roadside
- Vehicle to Internet

Introduction and Motivation
Motivation

◆ High-speed transportation tools

- The influence of multi-path effect and shadow effect are increased.
- The fading is aggravated.
- The influence of bit error rate caused by Doppler-effect can’t be ignored.

✧ So, many conclusions of land mobile communication are not applicable for high-speed railway mobile communication.
✧ It is important to research on characterizing the propagation channel in high-speed environments

Open Issues:
- To characterize the time-variant channels for high-speed railway
- To conduct the real channel measurements and analysis
- To estimate the channel parameters using high-resolution algorithm
- To construct channel models for high-speed railway environments
Contents

• Motivation
• Research Topics
• ♦ Resource Assignment
   - Adaptive Multi-Channel Operation
♦ Mobility Management
   - Handover Management
   - Routing protocol
   - Mobility Model
♦ Channel Modeling
   - Propagation Characterization
   - Modeling Methods
   - Simulation process
• Simulation and Test Platform
  ♦ Heterogeneous Vehicular Network Simulation Platform
  ♦ Mobile Wireless Access Demonstration Platform
  ♦ Radio Channel Measurement and Analysis Platform
• Some Challenges
1) Adaptive Multi-channel Operation(1)

♦ DSRC: Dedicate short rang communications:

Adaptive broadcasting mechanism: A Distributed Multi-channel MAC: implementing adaptive broadcasting mechanism bounded transmissions for safety applications

Architecture
A Centralized Multi-channel Coordination MAC Protocol achieves high throughput for non-safety applications, while maintaining adequate and timely safety awareness.
2) GHO with Channel Re-allocation(1)

GHO: Group HandOver

The MS in the MRS can’t feel the handover process, and if the resource is not enough, nrtPS connections in this MRS releases some channels for rtPS handover.
GHO with Channel Re-allocation(2)

♦ Improved Markov chain model is used to conduct a performance analysis of both SHO and GHO with preemptive sub-channel borrowing.
Vertical Handover Management Based on IEEE802.21

- Design VHDCs and JRRMs, which are located in the access networks, to realize VHD and JRRM function.

**VHDC**: Vertical Handover Controller  
**JRRM**: Joint Radio Resource Management

<table>
<thead>
<tr>
<th>VHDC</th>
<th>JRRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIHF</td>
<td></td>
</tr>
<tr>
<td>Link layer</td>
<td></td>
</tr>
<tr>
<td>Physical layer</td>
<td></td>
</tr>
</tbody>
</table>

**MN protocol stack**
- 802.11, 3GPP-LTE
- Application layer
- MIHF
- 802.11 MAC | 3GPP-LTE MAC
- 802.11 Physical layer | 3GPP-LTE Physical layer

**AP/BS protocol stack**
- Link layer
- Physical layer

**System Diagram**
- WLAN
- Cellular
- MN
- VHDC & JRRM
- VHDC & JRRM

http://WM.tongji.edu.cn
3）Connectivity Estimation Forwarding Routing protocol

♦ Nodes with stable link state and less distance from the destination will be chosen as the next hop in the routing selection process.

♦ Nodes’ position and movement information is used to estimate the link lifetime of the connected neighbors in this routing protocol.
4）Realistic Mobility Model

- By utilizing real map data (such as the map of Tongji Jiading campus) and traffic simulator, we build realistic mobility model, including the information of both road and the vehicle movements.

Traffic flow characteristics
- Vehicles speed range
- Lanes number
- Vehicles density
- Lane changing features
- Traffic regulation
Analytical Model

, it is very important to know how to construct a complete and close-to-reality analytical model. Our purpose is to bring the real field environment into the laboratory, and to set up an excellent system-level analytical platform. The figure presents detailed elements for the analytical model, which includes various responses from the channels, the antenna array and the system itself.
Time-Variant Channel Analysis

- Multipath parameter variation under indoor dynamic environment.
  - High-resolution analysis in Time/Space/Frequency domain.
  - Propagation path life and evolving path trajectories.
  - Coherence of environments.
  - Dynamics of channel responses.
Mobile Channel Modeling

Figure. Power spectra of the simulated channel for Scenario ii. (a): Power delay spectrum; (b) Power Doppler frequency spectrum; (c) Occurrence frequency of Doppler frequency per path; (d) Delay-Doppler frequency power spectrum.
Keyhole/Relay Propagation Channels

♦ A generic model to characterize the propagation channel in a keyhole environment.

♦ Application Scenarios

Outdoor to indoor
Relay topology
Multi-access
Keyhole Model Evaluation

♦ Similar DoA-delay constellations are observed for all path groups.

\[ P(\Omega_{\text{Tx}}, \Omega_{\text{Rx}}; \Omega_{\text{Tx}} = \Omega'_{\text{Tx}}) \propto P_{\text{Rx}}(\Omega_{\text{Rx}}) \]
Proposed Improvements for MIMO Channel Simulation

♦ The possible improvements for the channel simulation especially in generating the multipath parameters, which will be able to provide more efficient and accurate MIMO channel matrix for better link-level simulation.

- Automatic classification of propagation environment
  - System calibration, System responses, Phase variation (noise), Clock synchronization, Modeling of calibration errors.
  - Mobility model estimated from real measurement data

- Accurate prediction involving ele-mag. modeling
  - Hybrid construction of power profile
  - Involve environments into fading prediction, detailed “local” power distribution

- Multi-dimensional power spectrum of propagation channel
  - Generate random samples obeying correlation and spectral density
  - Apply continuous multi-variate pdf (not unif.) to generate random-phase-shift of sub-path

- MIMO Channel Matrix

To generate environment parameters and system parameters

To generate path loss and shadow fading

To generate multipath parameters
Radio Channel Measurement and Analysis Platform

- Electronically beam-scanning
- Distributed pan-tilt control
- Virtual antenna array
- Scanning measurement
- Real-time data collection
- GPS & Rubidium sync

Simulation and Test Platform
Radio Channel Measurement and Analysis Platform

Simulation and Test Platform
Some Simulated Results of High-Speed Channels

The simulation results of Rice channel can be gotten using two colored Gaussian random process.

Fig.1 100km/h Amplitude of the Rice Process

Fig.2 100km/h Phase of the Rice Process

Fig.3 200km/h Amplitude of the Rice Process

Fig.4 200km/h Phase of the Rice Process
Some Simulated Results of High-Speed Channels

- **Fig. 5 300km/h Amplitude of the Rice Process**

- **Fig. 6 300km/h Phase of the Rice Process**

\[ \text{Rice process is that the signal amplitude changes rapidly in a short period. It is the flat fast fading of small-scale fading.} \]

\[ \text{With the increase in speed, the Doppler frequency shift is increasing. Then the Doppler expansion is increasing and the coherence time is reducing. At last, the rate of Rice fading is going up.} \]

\[ \text{When the frequency is constant, the reciprocal of average fade duration is proportional to the speed. It means that with the increase in speed, the average fade duration will decrease.} \]
Contents

• Motivation

• Research Topics
  • ♦ Resource Assignment
    - *Adaptive Multi-Channel Operation*
  ♦ Mobility Management
    - *Handover Management*
    - *Routing protocol*
    - *Mobility Model*
  ♦ Channel Modeling
    - *Propagation Characterization*
    - *Modeling Methods*
    - *Simulation process*
    - *Radio Channel Measurement and Analysis Platform*

• Simulation and Test Platform
  • ♦ Heterogeneous Vehicular Network Simulation Platform
  • ♦ Mobile Wireless Access Demonstration Platform

• Some Challenges
Heterogeneous Vehicular Network
Simulation Platform

Outlines

Architecture of Simulation Platform

Cellular+WAVE implementation

WAVE MAC implementation

Predication and position-based routing

UTC Second

Synchronization Interval (50ms)

CCH Interval (50ms)

SCH Interval (50ms)

Backoff slots

Guard Interval

Non-Safety App DATA

Backoff slots

SIFS

WSA: WAVE Service Advertisement

Higher Layer

Link Layer

Queue

MAC Layer

WAVE MAC

Physical Layer

WAVE PHY

Channel

Higher Layer

Link Layer

Queue

MAC Layer

Cellular MAC

Physical Layer

Cellular PHY

Channel

Node i

Node j

Vi

Vj

ΔVij

θ

x

y

θ = θi - θj

D0

l ⊥ Vi

Previous position

Current position

Wi = (yi-yi0)/(xi-xi0)×(xi0-x)+yi0

Queue

Cellular MAC

LL

Cellular PHY

Physical Layer

MAC Layer

Higher Layer

Cellular

Relay Station

Node i

Node j

0

Node i

Node j

E = (xj-xi)(yi-yj) + (yj-yi)(xi-xj)

LDE

Previous position

Current position

Simulation and Test Platform

http://WM.tongji.edu.cn
Heterogeneous Vehicular Network Simulation Platform

♦ DEMO:

✦ Group Handover

✦ Position-Based Routing
Mobile Wireless Access Demonstration Platform

Simulation and Test Platform
Mobile Wireless Access Demonstration Platform

♦ DEMO(Birdview):
Hardware-in-the-Loop Simulation Technology

♦ Simulation Platform Associated with Real Application Traffic Test

➤ Playing in local media server (Left)
➤ Playing in the receiver node with packet loss and delay (Right)
Future Wireless Network Simulation Platform

♦ DEMO:
♦ DEMO (in car)

♦ DEMO (video prewarning)
Contents

• Motivation

• Research Topics
  • ♦ Resource Assignment
    - Adaptive Multi-Channel Operation
  ♦ Mobility Management
    - Handover Management
    - Routing protocol
    - Mobility Model
  ♦ Channel Modeling
    - Propagation Characterization
    - Modeling Methods
    - Simulation process

• Simulation and Test Platform
  ♦ Heterogeneous Vehicular Network Simulation Platform
  ♦ Mobile Wireless Access Demonstration Platform
  ♦ Radio Channel Measurement and Analysis Platform

• Some Challenges
Some challenges

• Our research works:
  – Focus on the future vehicular network structure, convergence technology (Cellular & Vehicular).
  – To build simulation and hardware testbed for performance evaluation of vehicular networking.
  – To conduct V2V radio propagation channel measurement, high-resolution analysis and channel modeling.

• Some challenges:
  – LTE-Advanced challenge; Non-mainstream?
  – Who pushes WAVE technology to be used in Automobile? auto companies or mobile companies?
Heterogeneous Networks Convergence

LTE, 3G, WiMAX, WLAN, DSRC/WAVE, etc, differ in bandwidth, latency or cost.

WAVE: wireless Access in Vehicular Environment

DSRC: Dedicated Short Range Communication

RNC: Radio Network Controller
MME: Mobile Management Entity
3G-SGSN: Serving GPRS Support Node
S-CW: Serving Gateway
P-CW: PDN Gateway

Internet Core

MANET Gateway

802.11 Gateway

Single vertical handover
Group vertical handover

http://WM.tongji.edu.cn
DEC 21-22, 2009
Thanks for your attention!