Technische Universität Braunschweig

Opportunistic Vehicular Networking

Lars Wolf
(and my (former) students Michael Doering, Sven Lahde, Tobias Pögel, …)
Email: wolf@ibr.cs.tu-bs.de
http://www.ibr.cs.tu-bs.de

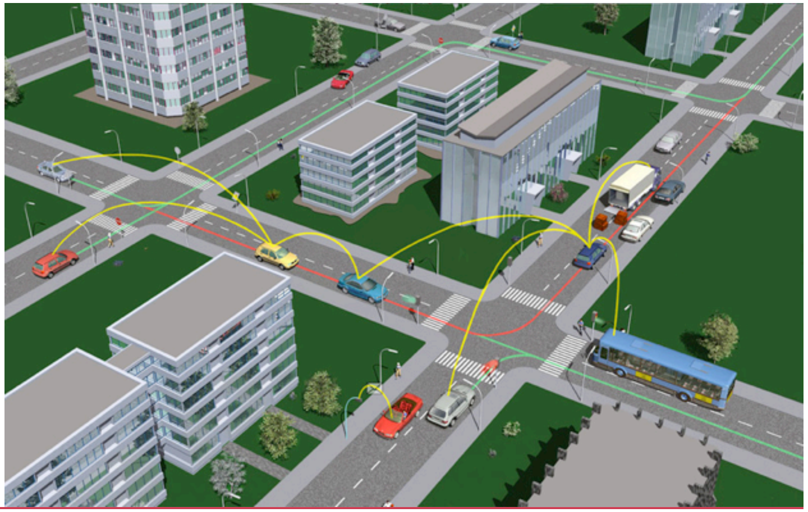
Vehicular Networking

Communication between vehicles and …

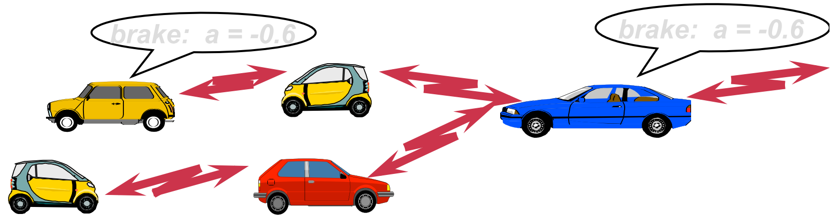
- vehicles → vehicle-vehicle communication (V2V)
- other road users like pedestrians, cyclists, …
- sensors of traffic / road infrastructure (V2I)
- other sensors in the surrounding area
- vehicle-anything communication (V2X)

- also called Car2Car, Car2…

→ Major topic in automotive industry

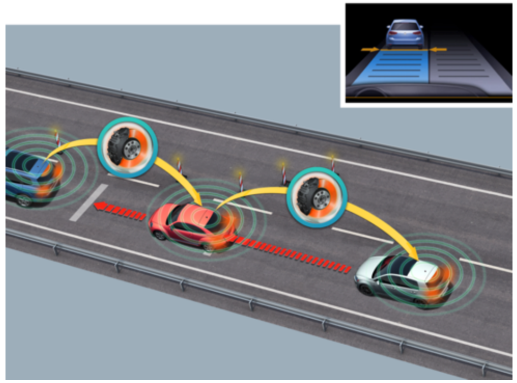


Vehicular Networking: Objectives

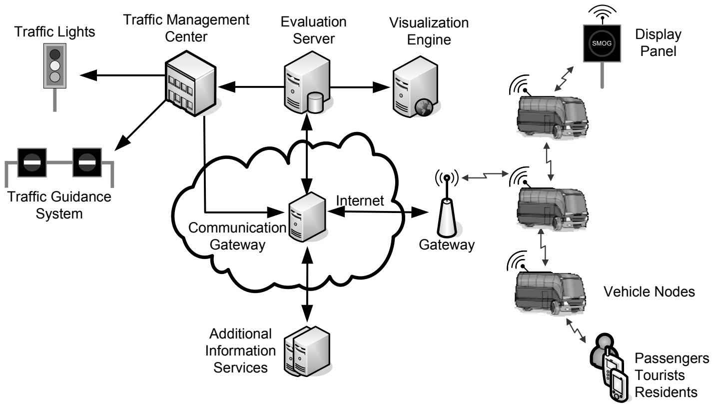


Many application areas, e.g.,

- traffic safety
- optimization of traffic flow, …
- but taking it further also for
  - marketing / advertisements, infotainment, …
  - collection and distribution of (sensor) data



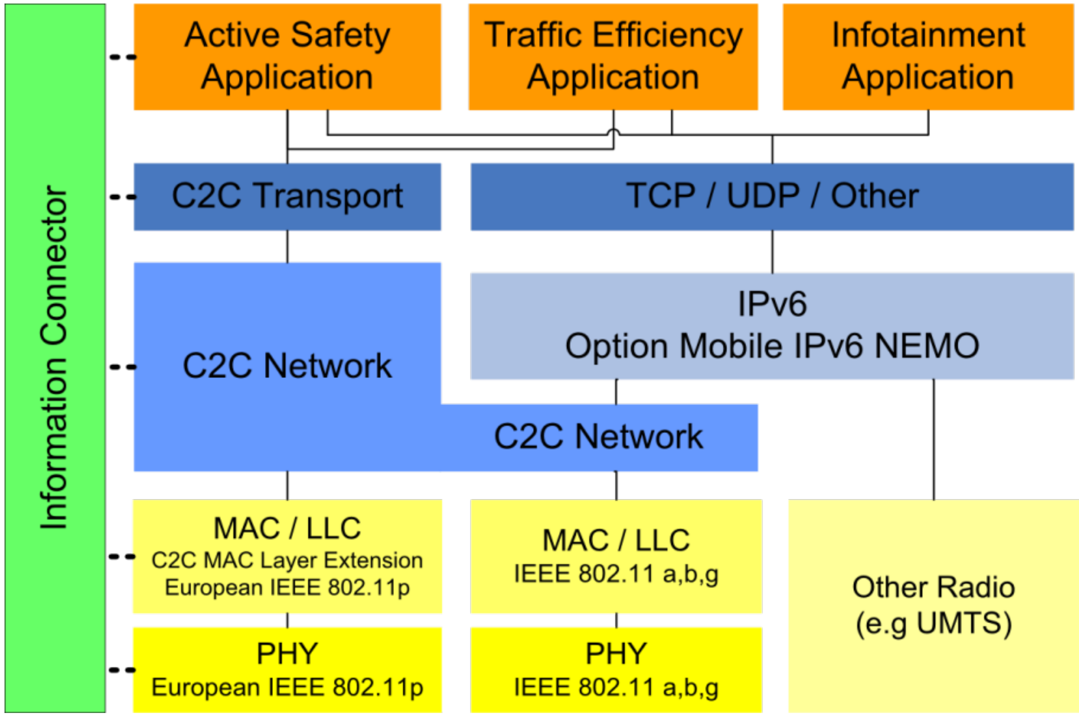
Source: Volkswagen AG, Wolfsburg



V2V: Base Communication

Communication standards, e.g., specified by ETSI and C2C-CC (Car-2Car Communication Consortium) (in Europe, but similar approaches in other parts of the world)

Base architecture according to C2C-CC manifesto



V2V: Base Communication (2)

Based on variant of WLAN-technology

- connectivity can be short-lived and occassionally break
- communication range relatively short

Broadcast-like message distribution

- CAM: Cooperative-Awareness Message
- DENM: Decentralized Environmental Notification Message

Major issue: **penetration rate**

- number of V2X-capabable vehicles / devices
- likely to increase (slowly) over years

→ Other ideas to support variety of applications would be useful

Opportunistic Communication

Many vehicles will have several network technologies, e.g.

- V2X based on IEEE 802.11p and other IEEE 802.11 technologies
- 2/3/4/5 G (cellular) network links

Select and use currently "best suited" communication technology

- different locations have different network charact. & availabilities
- changing user requirements and wishes
- disruptions & delays are possible

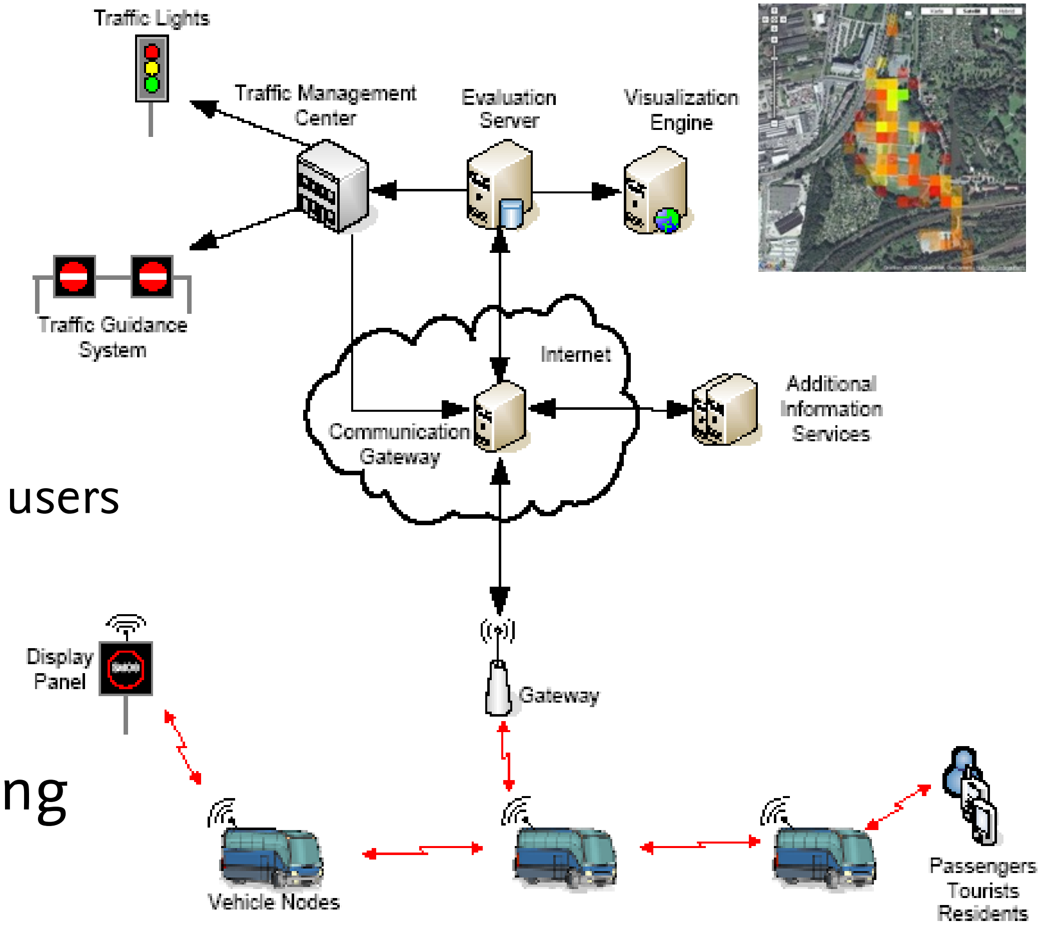
Research questions such as

- Which network should be used?
- Can mobility of nodes (vehicles) be used?

Opportunistic Vehicular Networks: Supporting Smart City Scenarios

Vehicles such as buses may

- collect data from
  - own sensors
  - sensors installed in the city
- distribute data to
  - central systems
  - decentralized components and users



Application areas, e.g.,

- many low-cost sensors for environmental monitoring
- or smart city in general

Disruption & Delay Tolerant Network (DTN) – Challenged Networks

Several origins, e.g., Inter-Planetary Networks

Useful for cases of sporadic communication

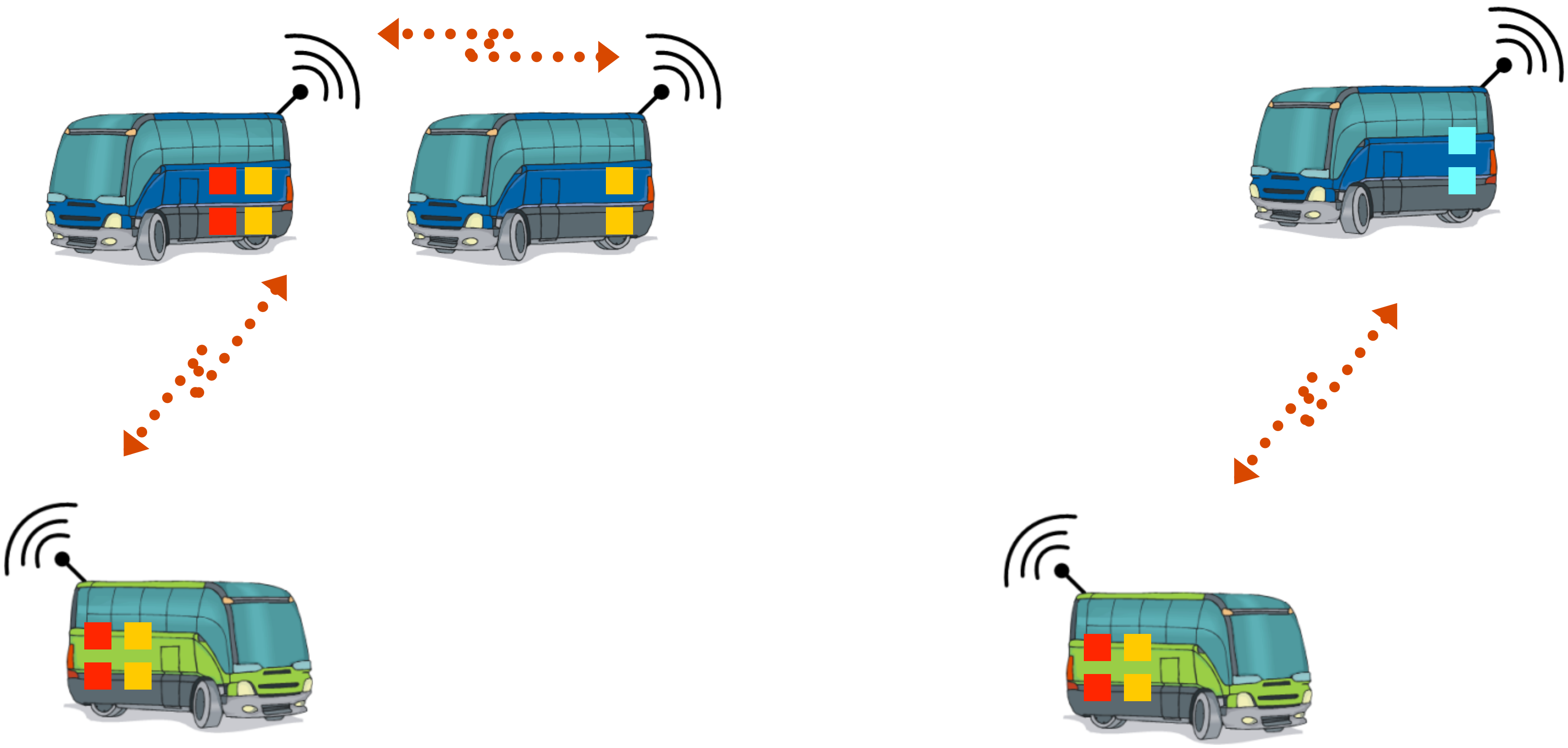
- no (complete) end-to-end communication
- incomplete network coverage

Store-Carry-Forward principle

- collect and store information → bundles
- physical data transport via nodes (e.g., vehicles)
- forwarding of bundles when contact with other vehicles exist

→ Smart city scenarios: public transportation vehicles, e.g., buses

Bundle exchange



DTN Properties

Cost-efficient alternative (or extension) to cellular networks

- no complete coverage needed

Useful for various types of applications

- e.g., data collection, data distribution
- in „start phase“ of V2V

Interesting for VANETs (Vehicular Ad-hoc NETworks)

- Exploitation of inherent mobility of vehicles

But: limited usability for time-critical data

Bus-based Opportunistic Networks

Understanding mobility characteristics of buses is essential

- for design and evaluation of ad-hoc and delay tolerant communication networks in public transport

Mobility models or synthetic traces lack important details

→ Trace-based realistic movement patterns needed

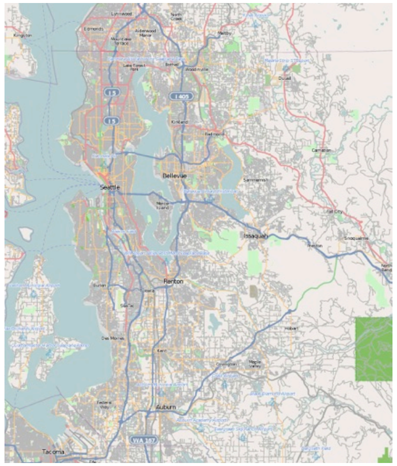
Look at two large-scale bus movement traces

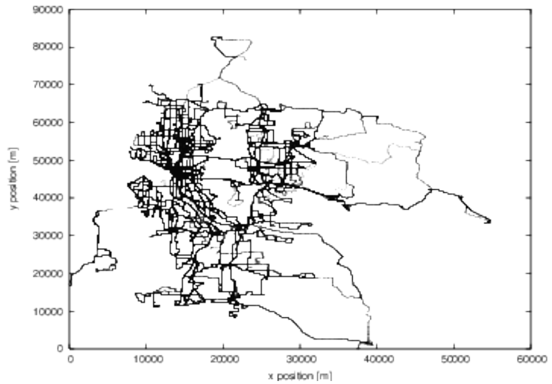
- Seattle: > 1000 buses
- Chicago: > 1600 buses

Seattle Trace

Basic characteristics

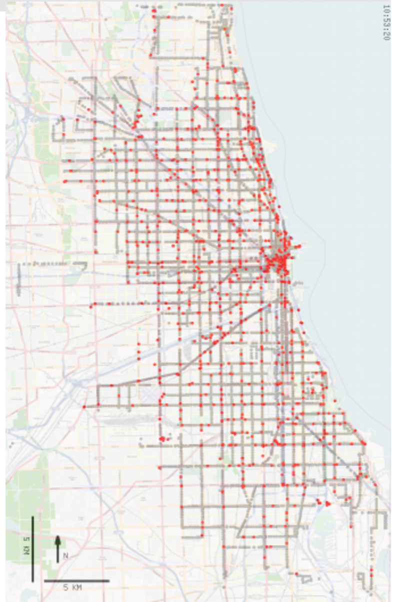
- ≈ 1200 buses, 240 lines of King County bus sys. (Seattle area)
- positions calculated by on-board Automatic Vehicle Location (AVL)
- no use of GPS
  - But combination of signpost transmitters, odometry and mapmatching (can provide accuracy of 1-20m, potentially better than GPS)
- can track vehicles on fixed routes only, no off-route vehicles





10000 consecutive position updates from Seattle trace; each dot represents one data point

Chicago Trace



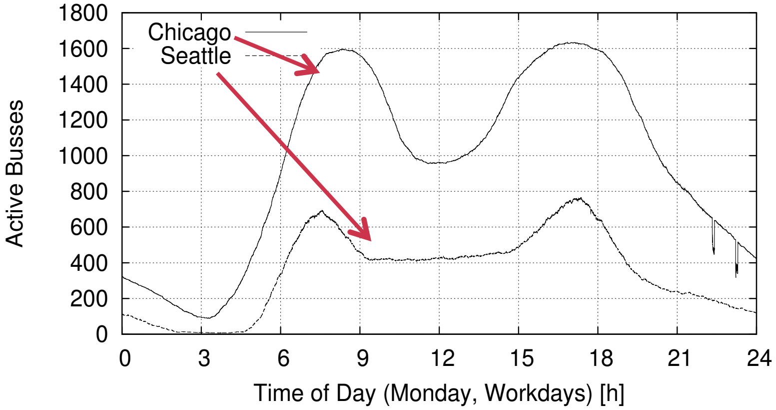
Basic characteristics

- >1600 buses, 150 lines and > 11000 bus stops
- AVL sends position updates to central server
  - positions based on GPS (w/ backup odometry sys.)
- stored information, e.g.,
  - timestamped vehicle ident. and WGS-84 coord.
  - route and trip identifiers, direction and destination of the trip
- extensive meta-data such as
  - names and geo-locations of stops
  - definitions of routes & timetables (available via Google Transit)

→ essential for development and evaluation of routing algorithms

Characteristics

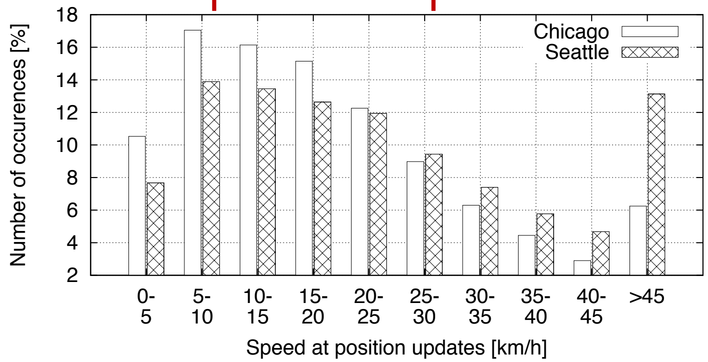
Active buses on Mondays



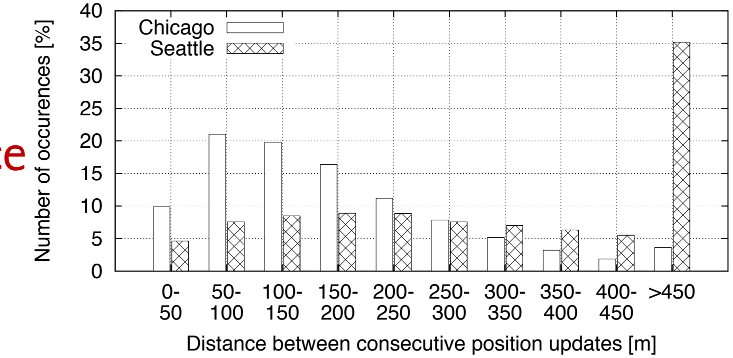
Chicago trace contains more details

Characteristics at position updates

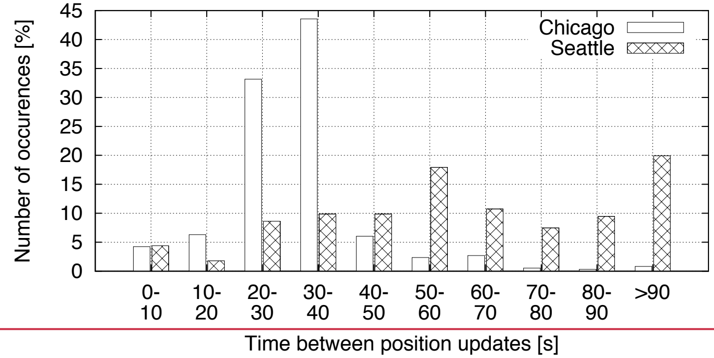
speed



distance



time

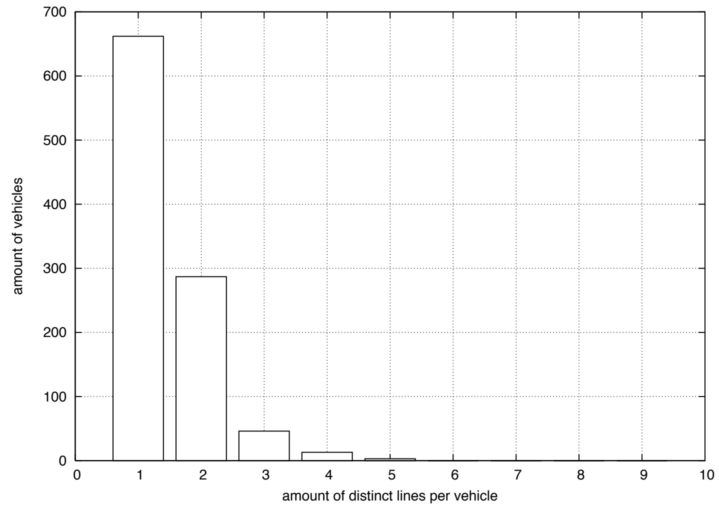


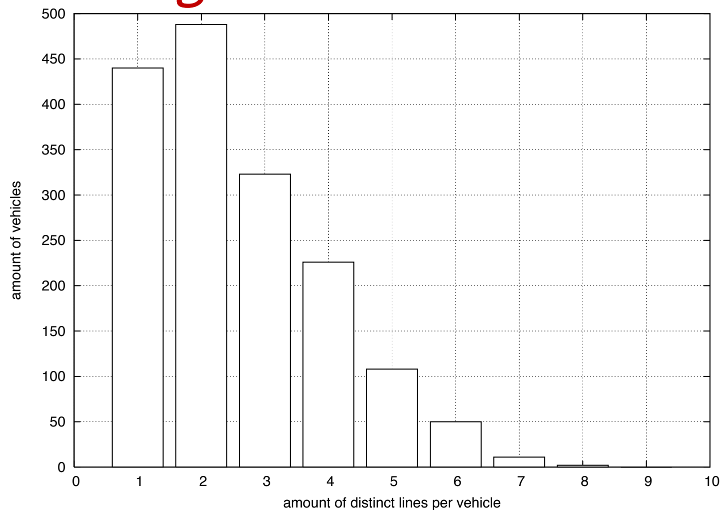
Characteristics: Bus to Line Assignment

Seattle

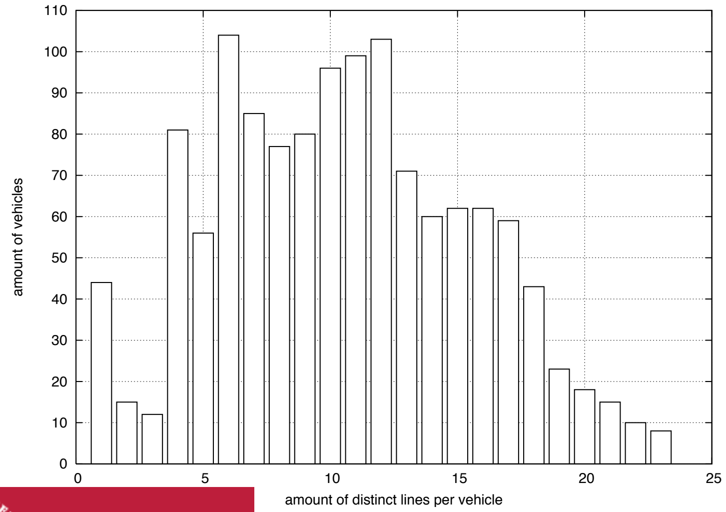
Chicago

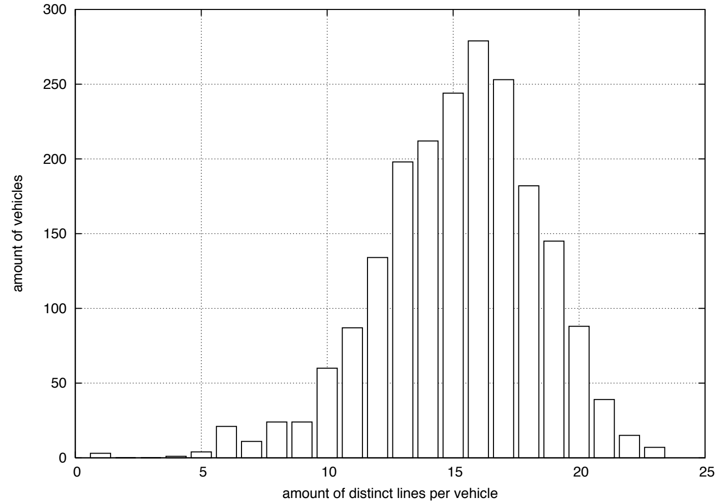
Monday morning 7h-12h





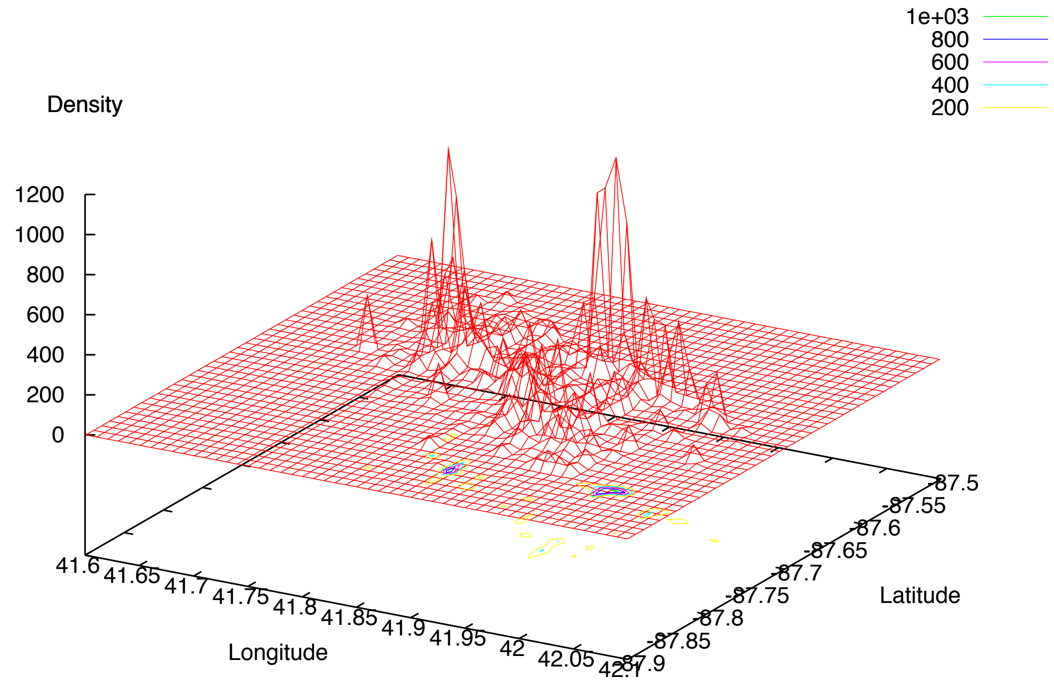
Whole duration of trace (16 resp. 18 days)





Characteristics: Density of Position Updates for Chicago Trace

Density of position updates
(≅ vehicle density) for a
5 hour time window
(Monday morning 7h-12h)



Density can, e.g., be exploited for routing

- for example, density of different lines can be used to identify where there is large probability that vehicles of different lines encounter each other

What can this be used for?

E.g., to study routing algorithms

- How to forward data such that it arrives at destination?
- Which node / bus to send data to?

Routing in such networks is difficult

- Uncertainty about point in time and duration of next contact
- Will there ever be any contact with a specific peer?

DTN Routing in Public Transportation: Aims

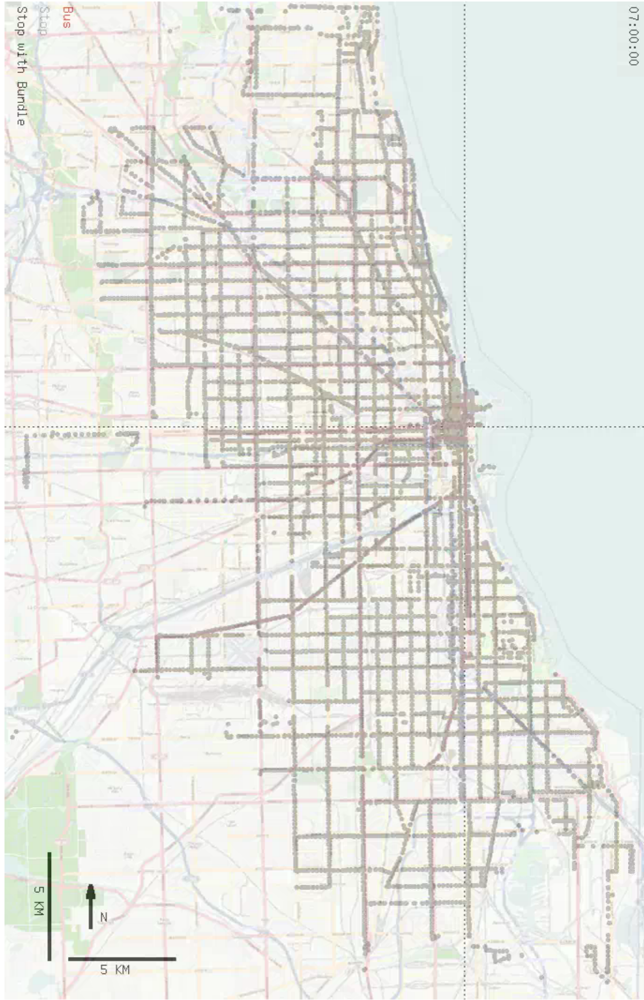
- Low latency
- High reliability
- Low resource needs

Routing in DTN

In general two classes of approaches

1. Duplicating approaches
    - generate copies of bundles
      and distribute them on different paths
    - fast spreading of bundles in network

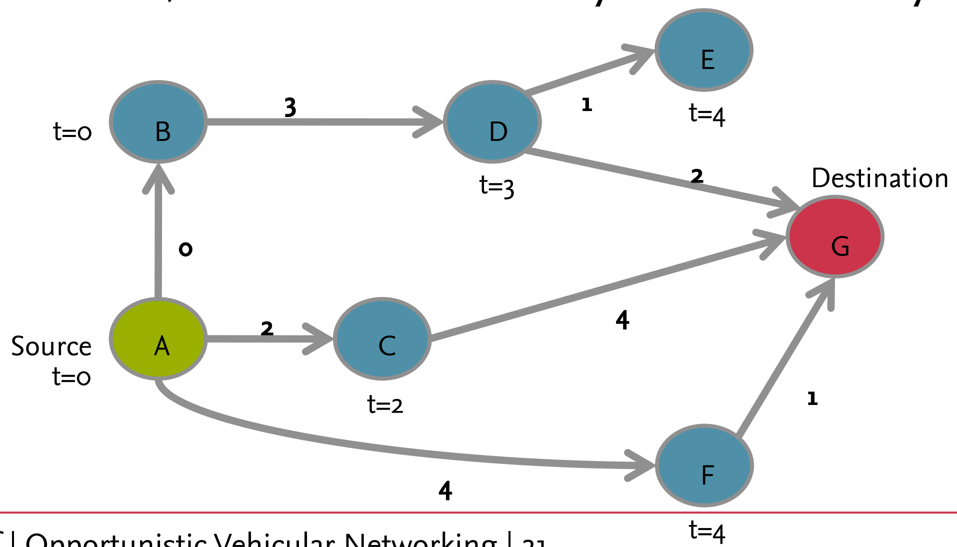
    → but severe resource load



Routing in DTN (2)

1. Duplicating approaches
2. Approaches reducing contact uncertainty
   - use contact prediction based on historic or other context data
     - public transport
     - trajectories of vehicles / data from navigation systems etc.
   - distribution of bundles better directed in network

   → lower resource load, but still uncertainty about delivery



Path 1: A → B → D → G
Duration = 5 minutes

Path 2: A → F → G
Duration = 5 minutes

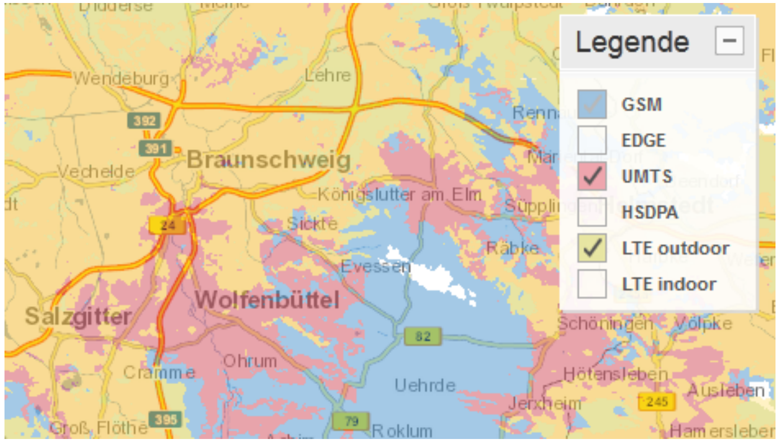
Path 3: A → C → G
Duration = 6 minutes

[Weights in minutes]

Connectivity Map to Improve (Backend) Communication

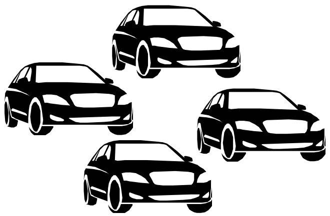
Improving Vehicle ↔ Backend communication using context data to predict network properties
→ ConnectivityMap

- (Cellular) networks for in-car online services
- High network dynamics result in frequent changes in communication properties
- Connectivity Map allows communication optimizations based on predictions



- Network Coverage (© Vodafone.de) -

Connectivity Map



1.) Vehicles collect network and measurement data

2.) Transfer data to a central server, analyze data and calculate predictions

3.) Distribute connectivity predictions and perform optimizations

Conclusions

Communication capabilities important for many mobility use cases

- to improve traffic safety, efficiency, ...
- also for autonomous cars → to allow them to cooperate

Integrated vehicular networking scenarios would be useful

- V2X using 802.11p, ... only wont be enough for many years
  - e.g., penetration rate is too low
  - integration with other participants (pedestrians, bicycles, ...) needed
- Additional use of other networks will be helpful
  - typically more for non-safety, non-time-critical applications

Server systems for management etc. needed as well

Conclusions (2)

Opportunistic vehicular networking could be base for even more large scale systems

- e.g., smart city with MANY sensor-actor / Internet of Things dev.

However, evaluation of algorithms not easy due to large scales

Security aspects must be taken into account in all places

Questions?