Connected Vehicles

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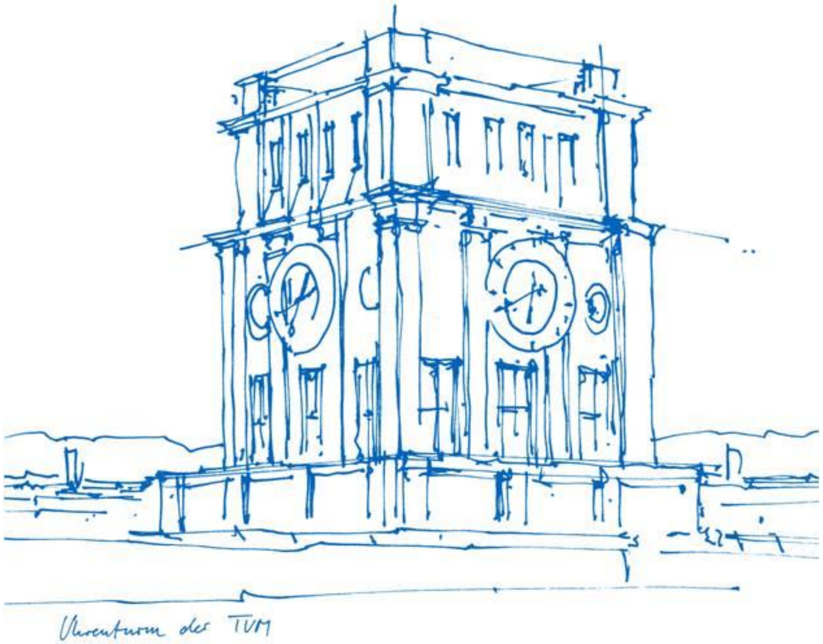
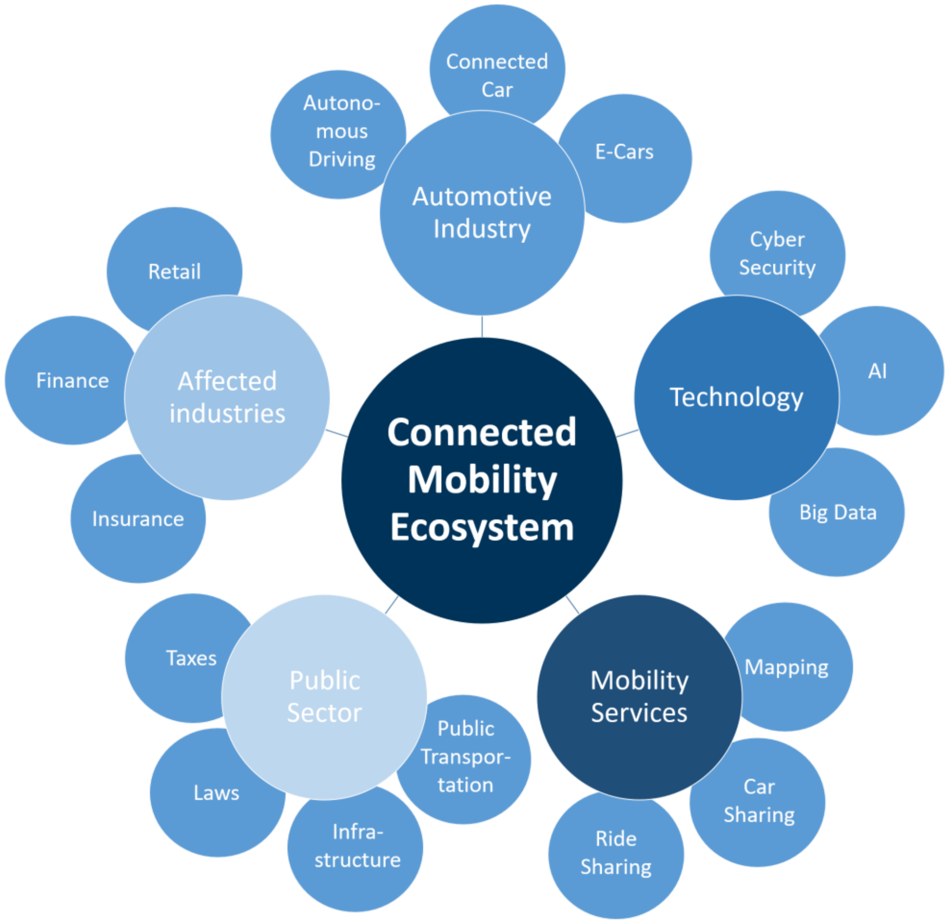


Outline

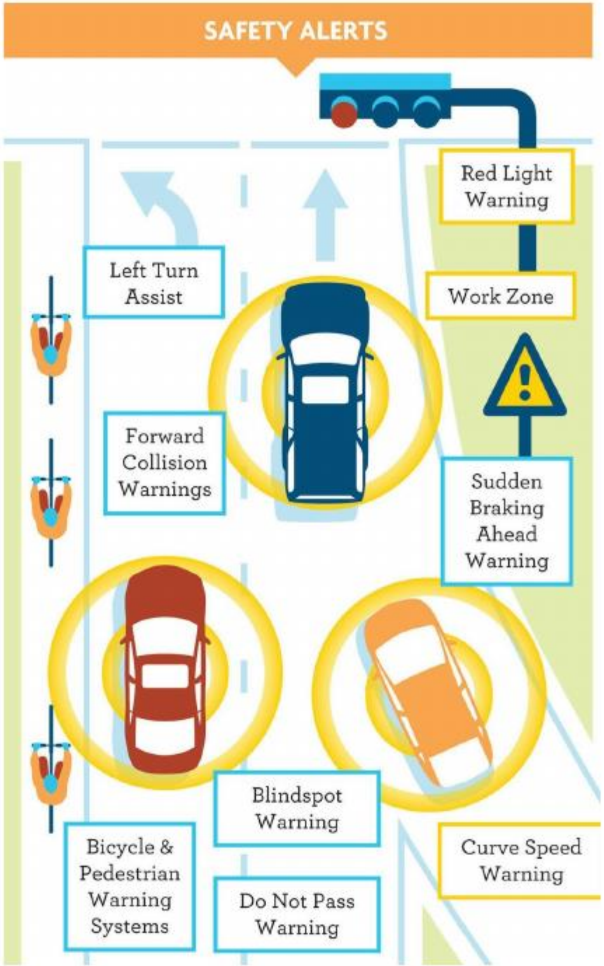
Connected Cars vs. Connected Mobility



Connected Cars in the context of connected mobility [15]

Why Connect Vehicles?

1. Crash Elimination
   - Monitor the environment and warn or react to hazards
2. Reduced Need for New Infrastructure
   - Improved management of traffic flows, smaller safety distances
3. Travel Time Dependability
   - Precise prediction of travel times and congestions
4. Improved Energy Efficiency
   - Predictive driving saves fuel, cooperative routing can use the existing infrastructure more efficiently
5. New Models for Vehicle Ownership
   - “Smart” vehicles are easier to share; self-driving cars will completely alter our understanding of mobility
6. New Business Models and Scenarios
   - Data from vehicles and services for them are a wide open playing field.



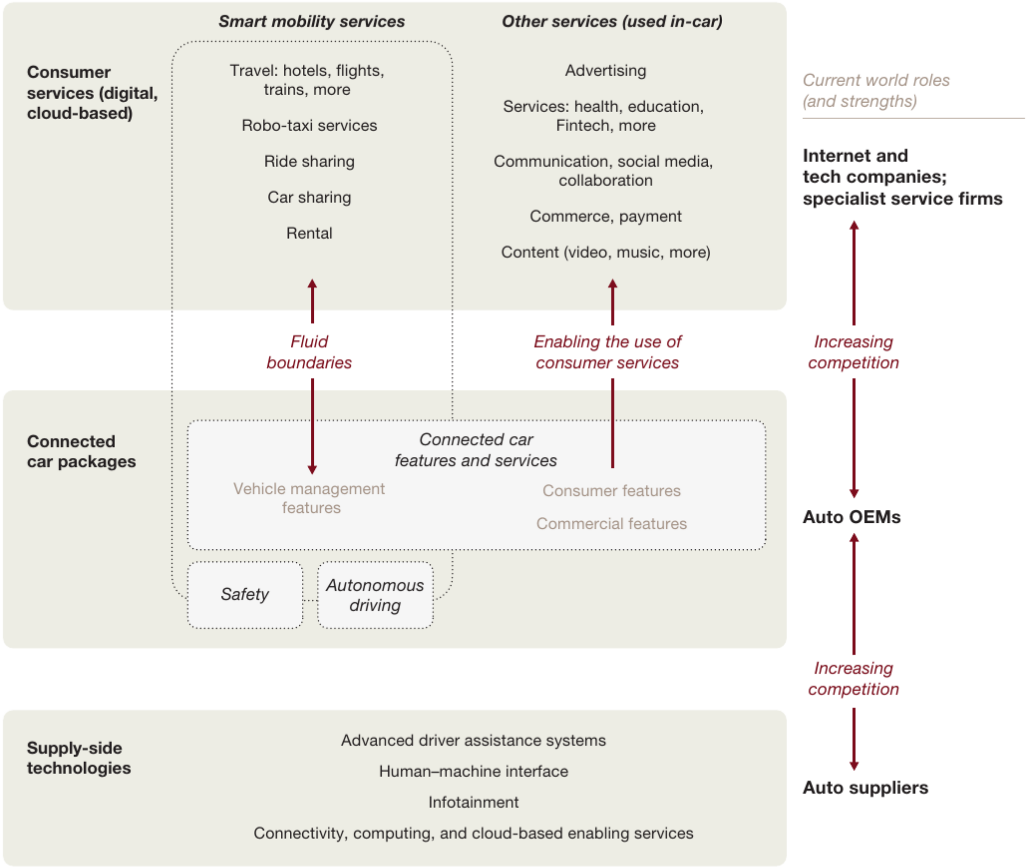
Safety Features of Connected Cars [1]

(source: [4],[10])

Novel Services

1. Traffic Safety
2. Infotainment
3. Traffic Efficiency
4. Cost Efficiency
5. Convenience, Interaction and others

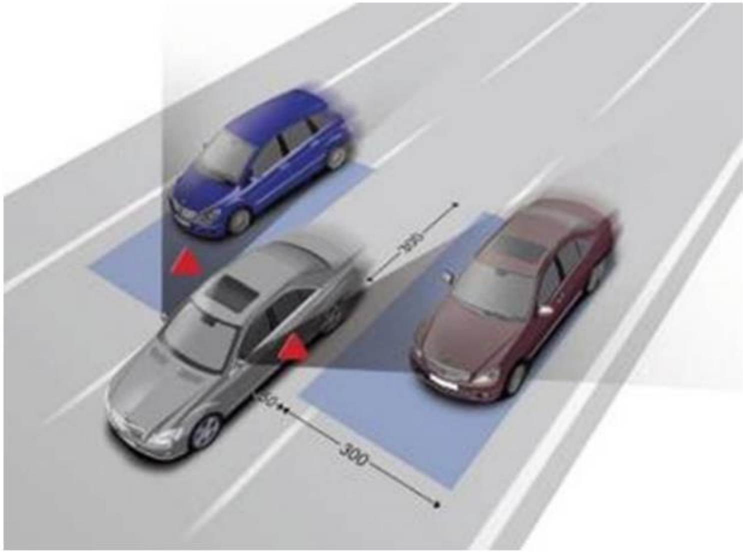
(source: [5])



Connected car technologies and services [11]

Novel Services

1. Traffic Safety
   - Accident avoidance and assistance
   - Look into the future – Providentia project
   - Remote maintenance, roadside and stolen vehicle assistance
2. Infotainment
3. Traffic Efficiency
4. Cost Efficiency
5. Convenience, Interaction and others

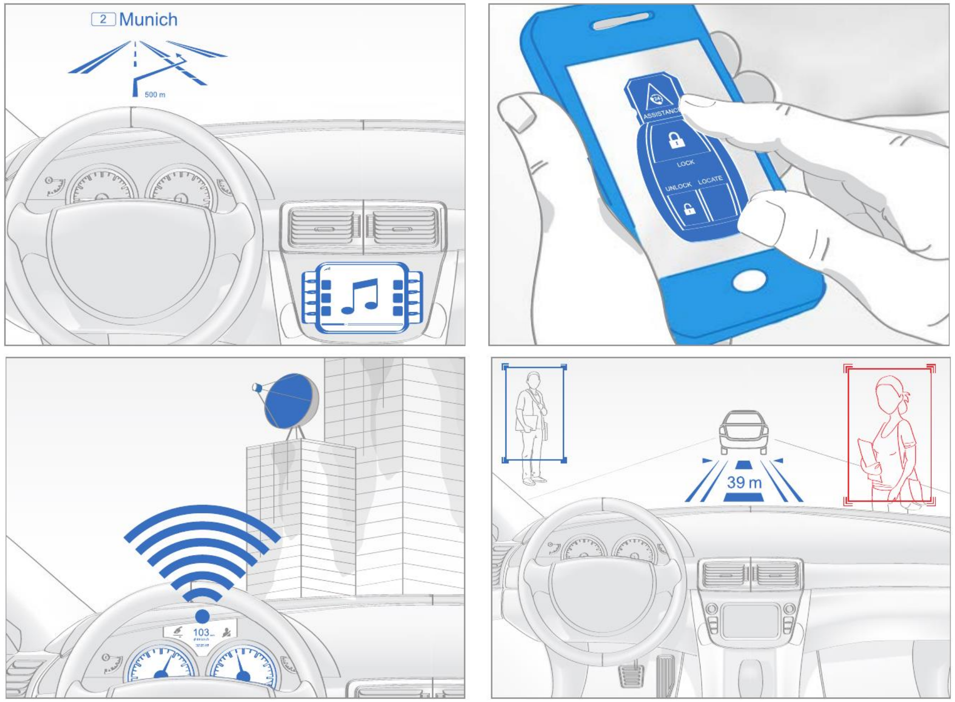


Blind spot warning [14]

Novel Services

1. Traffic Safety
2. Infotainment
   - Music Streaming
   - Video Streaming, games and Internet browsing
   - In-car Wi-Fi networks
   - Social networks
3. Traffic Efficiency
4. Cost Efficiency
5. Convenience, Interaction and others

(source: [5])

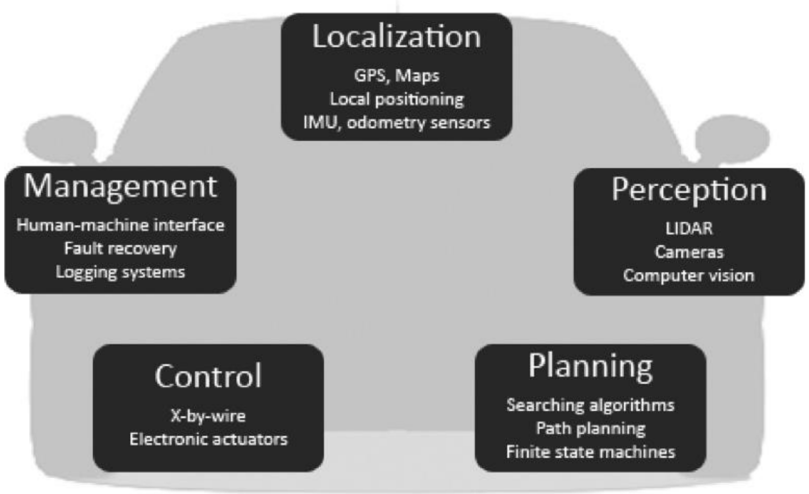


Connected services for the connected car [12]

Novel Services

1. Traffic Safety
2. Infotainment
3. Traffic Efficiency
   - Navigation, online route planning, street view
   - Traffic, weather and road condition monitoring
   - **Assisted driving and autonomous vehicles**
4. Cost Efficiency
5. Convenience, Interaction and others

(source: [5])

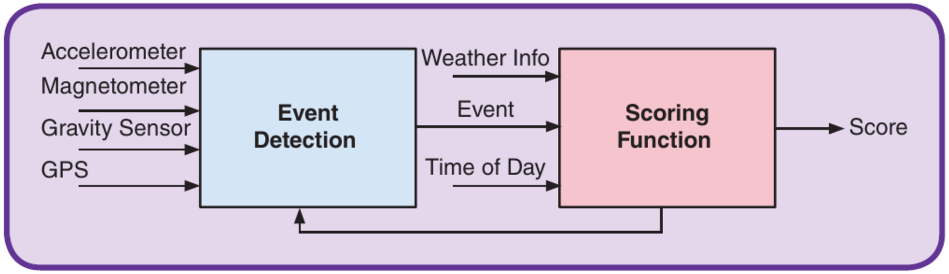


Functionalities for an autonomous vehicle [5]

Novel Services

1. Traffic Safety
2. Infotainment
3. Traffic Efficiency
4. Cost Efficiency
   - **Driver behavior profiling for insurance**
   - Algorithm-based vehicle pricing
   - Energy optimization
   - Contextual advertisement
   - Vehicle testing
5. Convenience, Interaction and others

(source: [5])

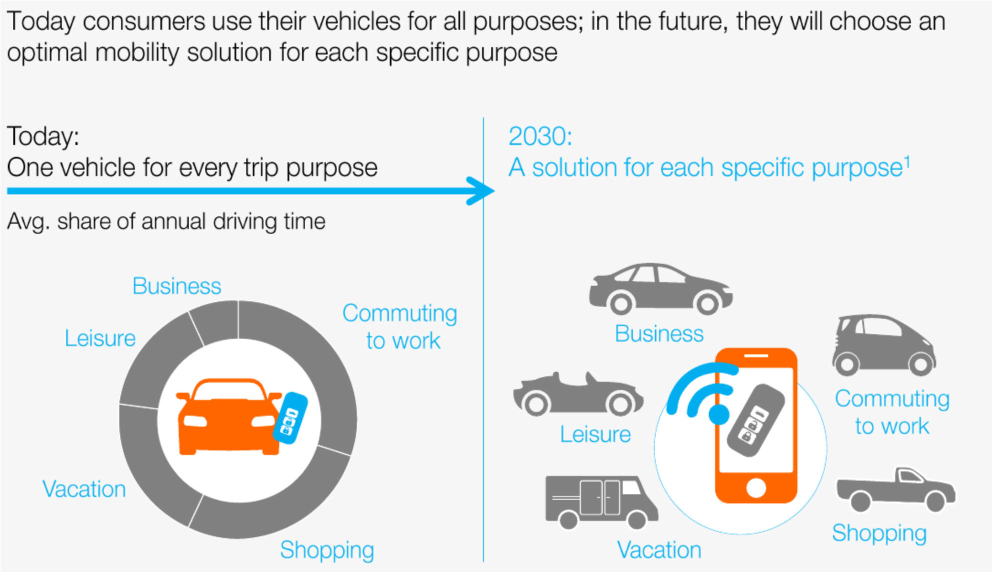


Event detection and scoring [13]

Novel Services

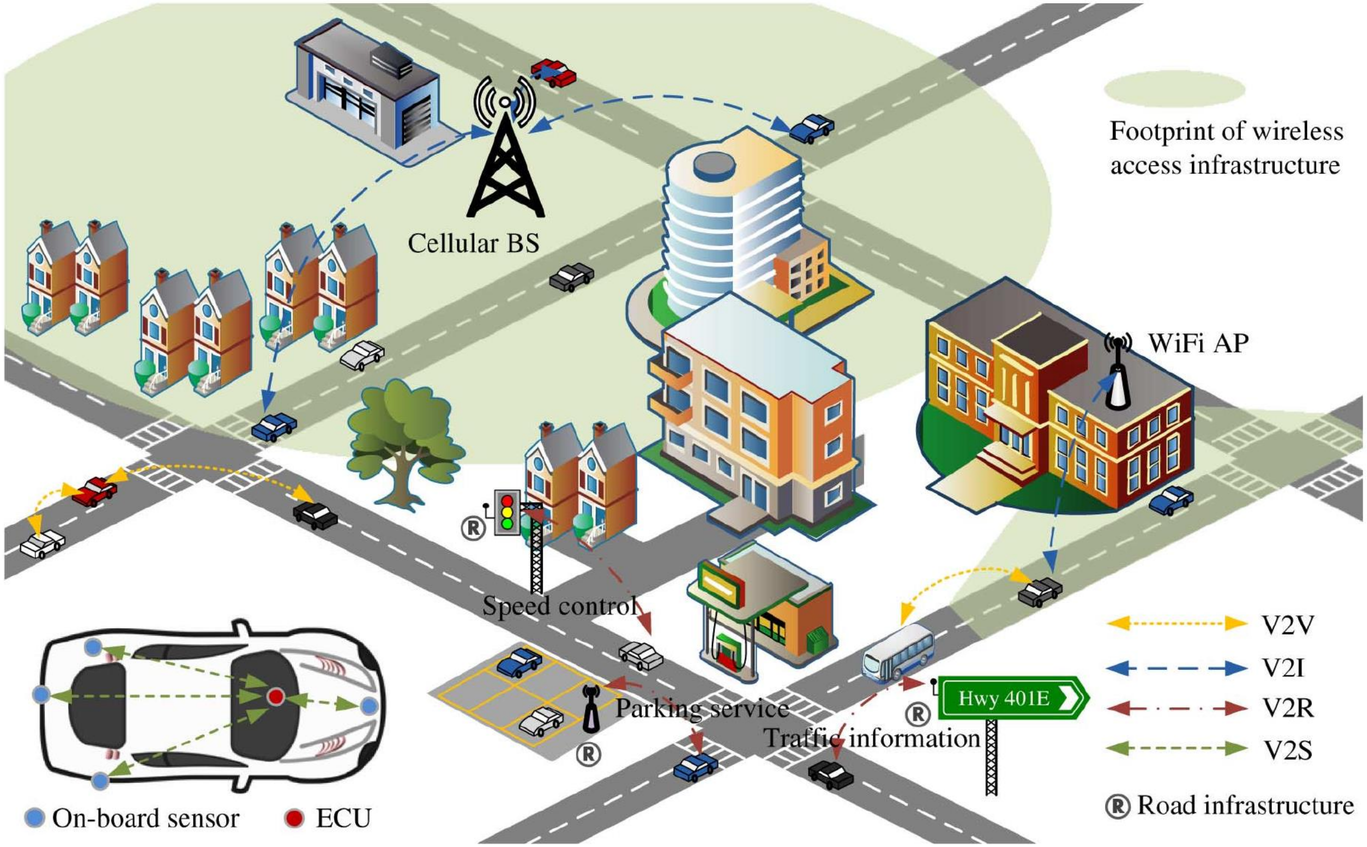
1. Traffic Safety
2. Infotainment
3. Traffic Efficiency
4. Cost Efficiency
5. Convenience, Interaction and others
   - Smart-home integration
   - Integration with wearable devices
   - **Car sharing**
   - Hand-free controls
   - Driver profiles

(source: [5])



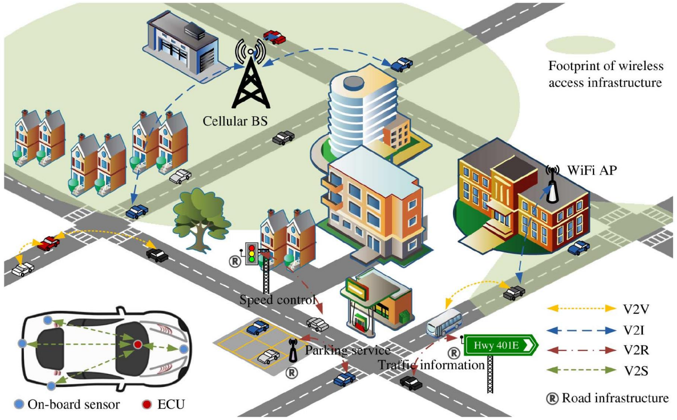
Multi-modal traffic [12]

The Ecosystem



Connected Vehicle eco-system [2]

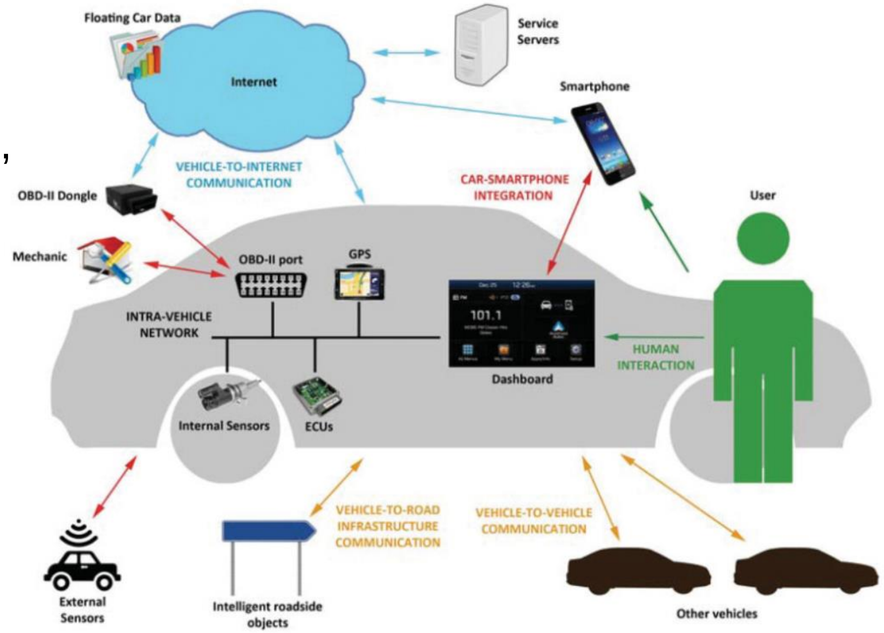
The Ecosystem



1. **V2S**: Vehicle to Sensors on board
   - Collect the data from sensors at central control units
   - CAN Bus, ZigBee, RFID, 60GHz Millimeter Wave
2. **V2V**: Vehicle to Vehicle communication
   - Peer-to-peer communication between cars
   - Accident avoidence, route optimization, social interaction
   - Vehicular Ad-hoc Network (VANET); 802.11p WAVE
3. **V2I**: Vehicle to Internet communication
   - Access to services and multimedia information
   - Cellular infrastructure (3G/4G/5G)
4. **V2R**: Vehicle to Roadside Infrastructure
   - Information exchange between vehicles and intelligent road infrastructure
   - Dedicated Short-Range Communications (DSRC); 802.11p WAVE

Defining “Connected Car”

A connected car is a vehicle
— capable of **accessing the Internet** at anytime, using either a built-in device or brought-in user devices;
— equipped with a set of modern applications and dynamic contextual functionalities, offering **advanced infotainment** features to the driver and passengers;
— capable of i**nteracting with other smart devices**
on the road or in mechanical shops, leveraging vehicle-to-road infrastructure communication technologies;
—capable of **interacting with other vehicles**, leveraging vehicle-to-vehicle communication technologies. [5]

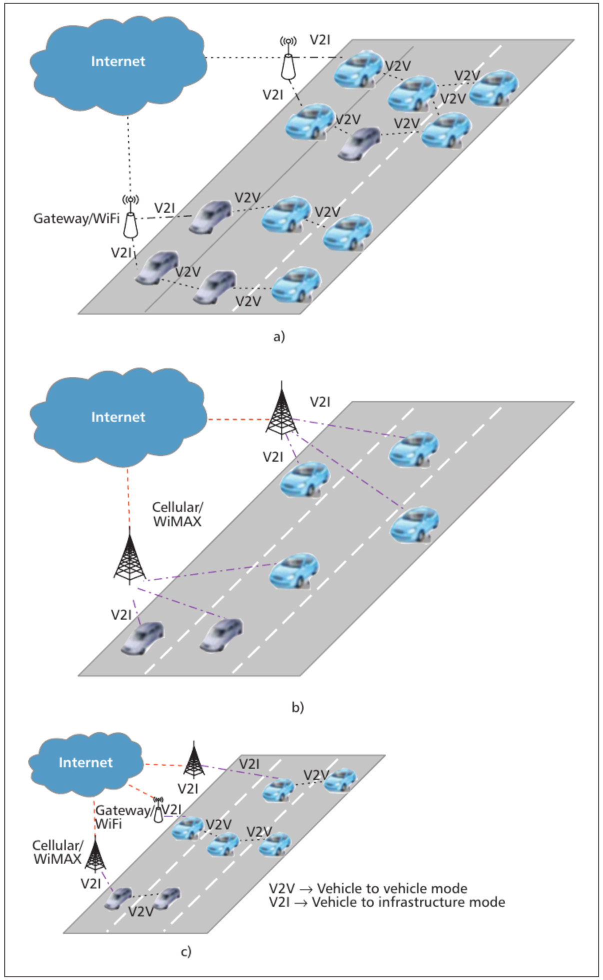


Connected Car System [5]

Communication Patterns

1. Communication technologies:
   - Dedicated short range communication (DSRC)
   - Wireless access for vehicular environments (WAVE)
   - Cellular network
   - WiMAX
   - 802.11p

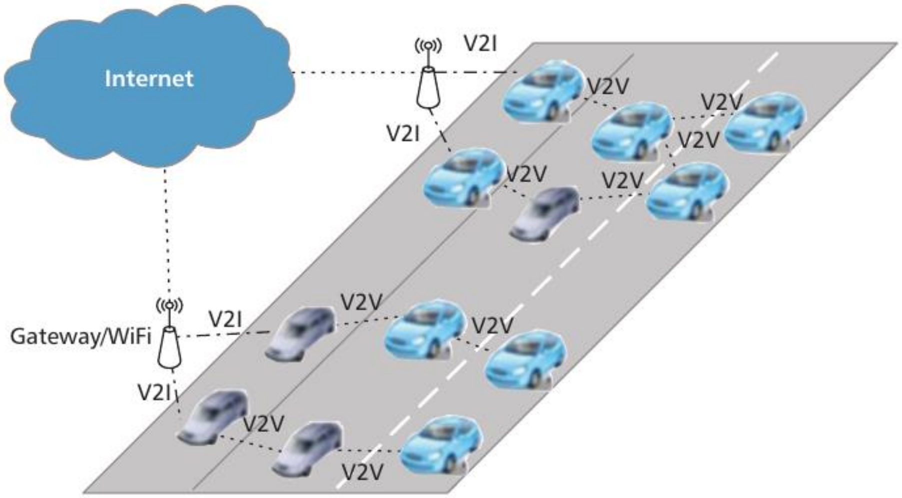
2. Enable different architectures



Communication Architectures [3]

Communication Patterns

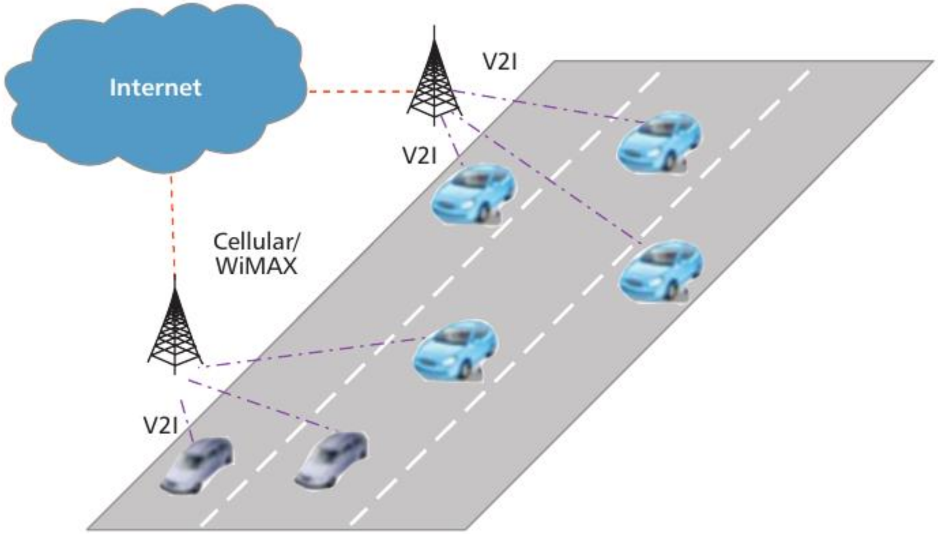
1. With only DSRC:
    - Infrastructure-free mode (V2V)
    - Infrastructure mode (V2I)
    - Mixed mode (V2V and V2I)



Communication Architectures [3]

Communication Patterns

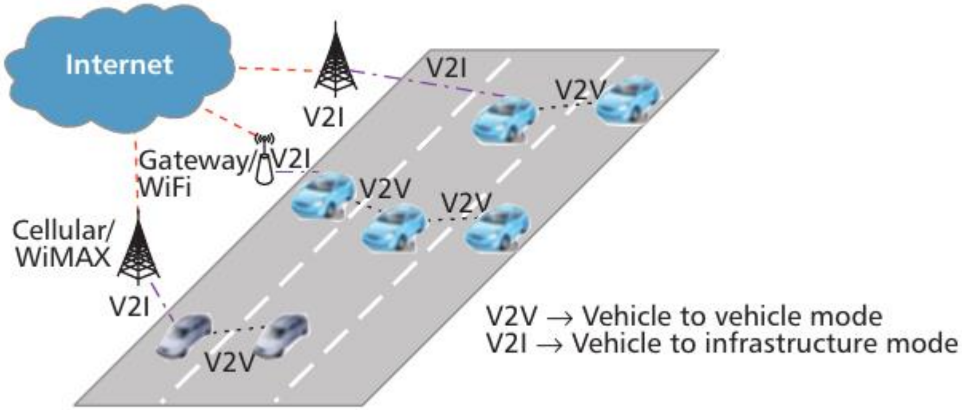
2. With broadband (LTE, WiMAX):
   - Cars can communicate directly via the Internet



Communication Architectures [3]

Communication Patterns

3. With DSRC and broadband:
   - Mixed access possible



Communication Architectures [3]

Platforms

	Producer	Open Source	Based on	Features
QNX Car Platform	Blackberry	No	QNX Neutrino OS	Multiprocessor support; ISO 26262 ASIL D certification; real-time features; microkernel RTOS; advanced graphic features; power and thermal management features.
Windows Embedded Automotive	Microsot	No	Windows Embedded Compact 7	Support for multi-core IA, ARM v7 and SH4 architectures; phone support with Bluetooth; UI framework extensible via Silverlight; speech engine support.
GENIVI	GENIVI Alliance	Partially	Linux	Focus on open-source distribution and platform standardization; d-bus optimization; audio management; graphical management; automotive diagnostics.
Tizen IVI	Linux Foundation	Yes	Linux	HTML5 and JavaScript development platform; multi-user architecture and login management; multi-seat support; single sign on framework; DLNA; speech framework.
Android	Used by Renault for R-Link	Partially	Linux	Huge app library; advanced GUI; compatibility with the vast majority of smartphones.
Automotive Grade Linux	Linux Foundation	Yes	Linux (Tizen IVI)	Focus on reference distributions or IVI, ITS and other areas; processor-independent; support for multiple hardware architectures; mobile device integration and bluetooth support.

Popular platforms for embedded applications [5]

Smartphone integration

	Producer	Based on	Features
MirrorLink	Car Connectivity Consortium	OS-agnostic	Easy-to-use in-dash control over compatible smartphones (limited compatibility); compatible applications: audiobooks reader, navigator, location sharing system, real time news about road problems, radio and music.
AppLink	Ford	QNX (originally Windows)	Connection to smartphone application through voice commands, internet radio streaming, social media; app-link compatible mobile application available for Android and iPhone (need support by the particular smartphone).
Apple CarPlay	Apple	QNX and other IVI platforms, as a VM	SIRI integration, navigation, smartphone control, music control, iMessage voice control and response, third party application support.
Android Auto	Open Automotive Alliance	QNX and other IVI platforms, as a VM	User interface similar to the corresponding android smartphone one; integration with Google Now, navigation, music control, phone calls, SMS management, web search, car hardware support and monitoring, third party app support.

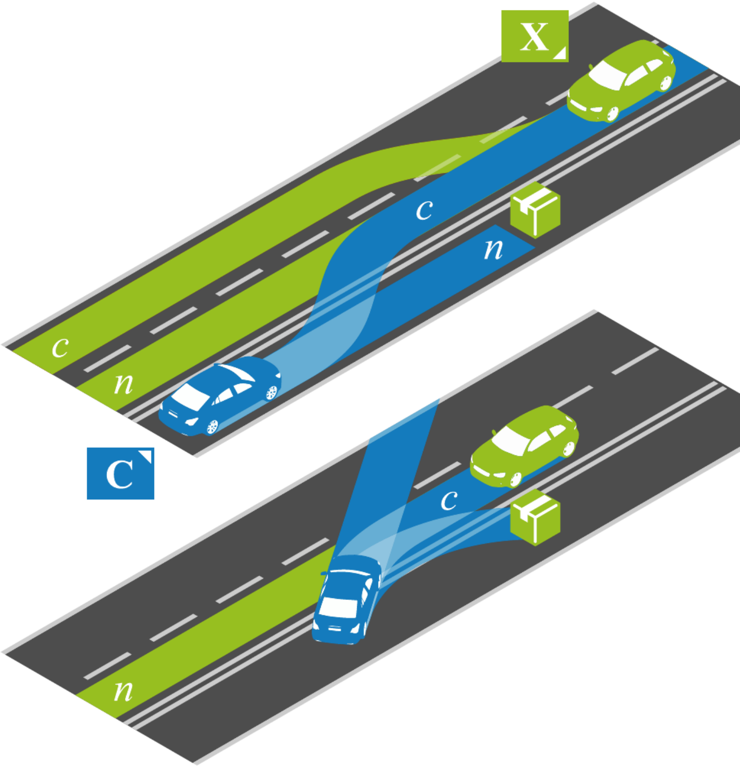
Popular smartphone link solutions [5]

Case Study: Cooperative Driving

1. Cars can communicate and coordinate their behavior to avoid obstacles.

2. Obvious target for cyber-attacks, e.g.
   - Attacking the CAN bus, sensors or communication units
   - Manipulate roadside infrastructure or online databases
   - They will usually be hardened

3. It is also possible to attack the V2V communication!
   - Since everyone is supposed to participate, hard to harden
   - No central form of trust



Cooperative driving [7]

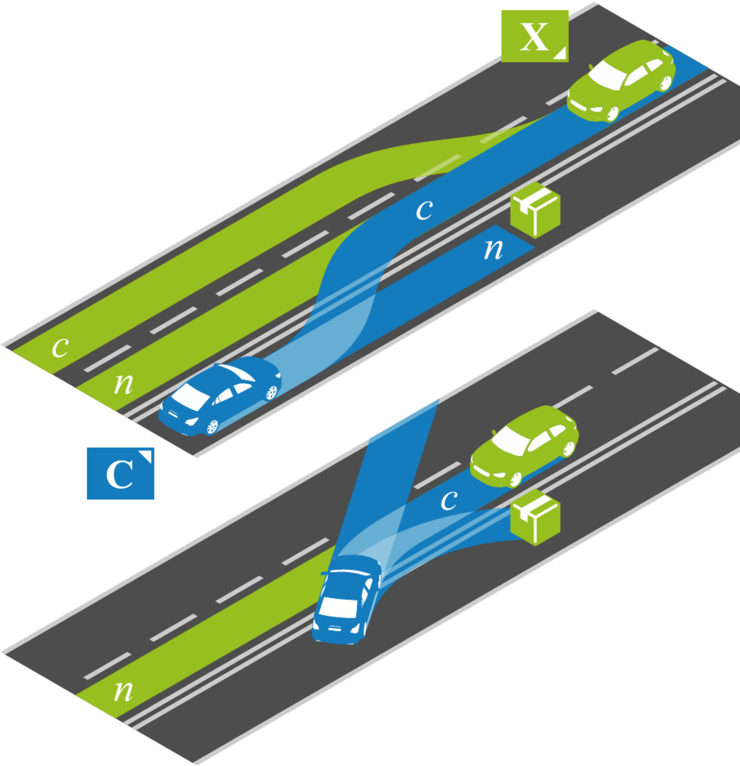
Case Study: Cooperative Driving

1. The blue car is a “smart” car

2. The green car is either “smart” (upper part), or “dumb” lower figure

3. The “smart” case, both cars can communicate and find the best course of action:
   - Green changes to lane the leftmost lane
   - Blue changes to the middle lane, avoiding the obstacle

4. In the “dumb” case, without any communication:
   - The blue car can break and hit the obstacle at a reduced speed
   - The green car continues on the “middle” lane



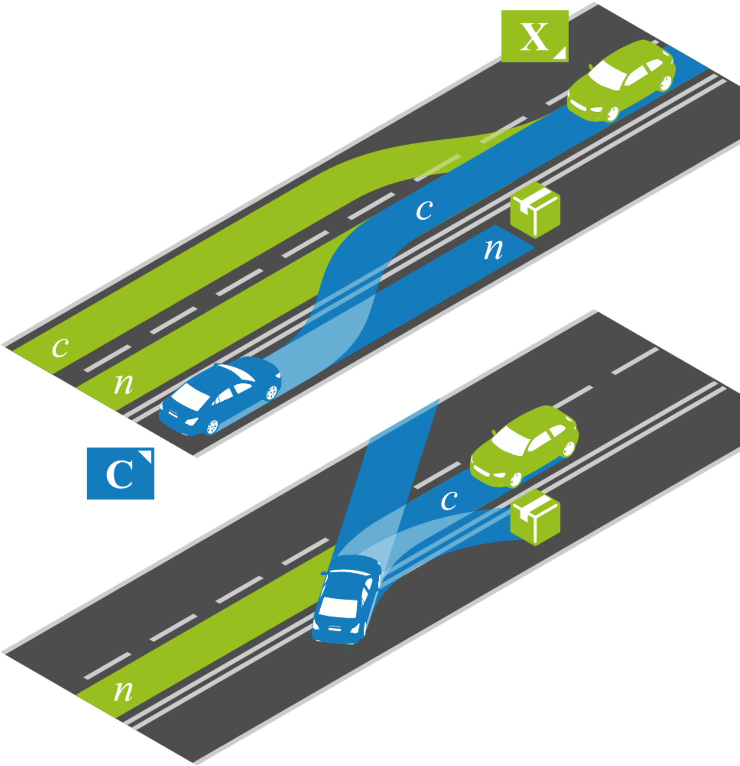
Cooperative driving [7]

Case Study: Cooperative Driving

1. Attack Goal: Convince the blue car, that the green one is smart.

2. This is depicted in the lower part of the figure:
   - The blue car assumes that the green car will change lanes
   - The green car, oblivious of the blue car, will fail to do so
   - The result is a high-speed crash

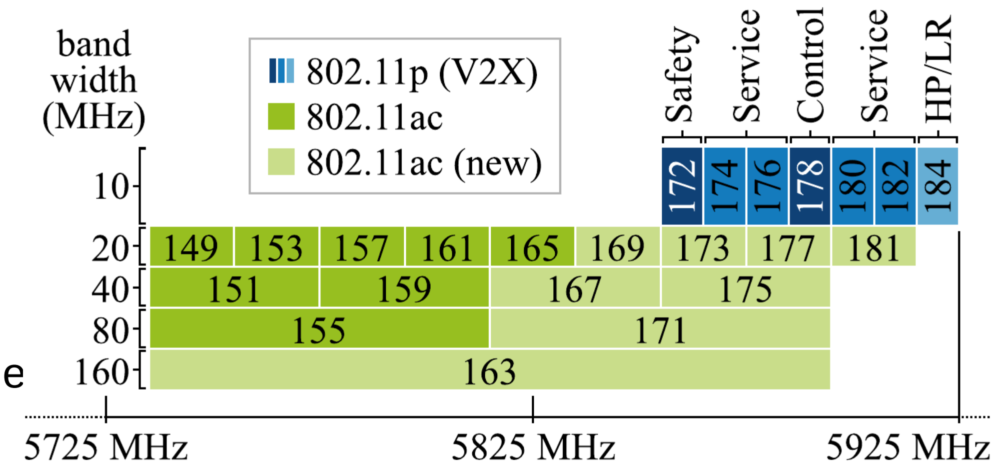
3. Attack Vectors:
   - The software of the cars
   - The hardware of the cars
   - Any infrastructure
   - The communication between cars
   - [note: relevant attack surface for non-connected cars as well!]



Cooperative driving [7]

Case Study: Cooperative Driving

1. Premise:
   - The V2X communication (802.11p) wireless spectrum overlaps with the new 802.11ac Wifi spectrum
   - Mobilephones will support the new Wifi spectrum; their antennae can be used to also transmit V2X data
   - Compromising a large set of smartphone e.g., with a worm, can cause them to interfere with V2X communication.



Designated frequency spectrum [7]

2. Bapp et al. [7] show that such an attack is feasible

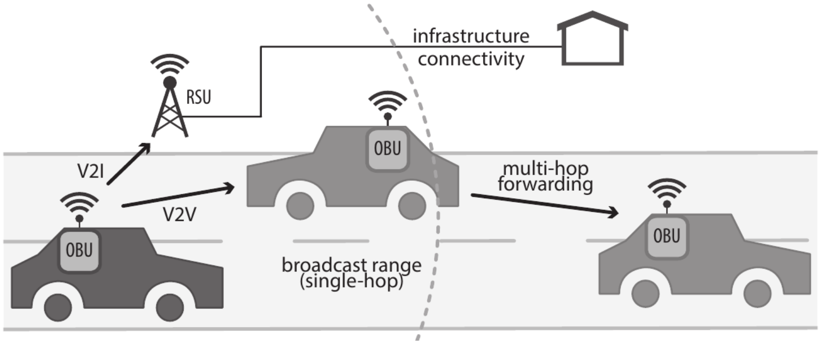
3. Potential countermeasure: Confirm messages via a second channel: e.g., by flickering the LEDs in the head- and taillights in a way that is invisible to humans

Case Study: Privacy for Connected Cars

1. If cars communicate with each other, this communication might be recorded and used to repeatedly identify cars.

2. If IDs are broadcast, identifying cars is a lot easier than the large scale tracking of license plates

3. Petit et al. show that, even with changing pseudonyms tracking stations at just two intersections are enough to track 40% of cars and when covering eight intersections 90% of cars can be identified.



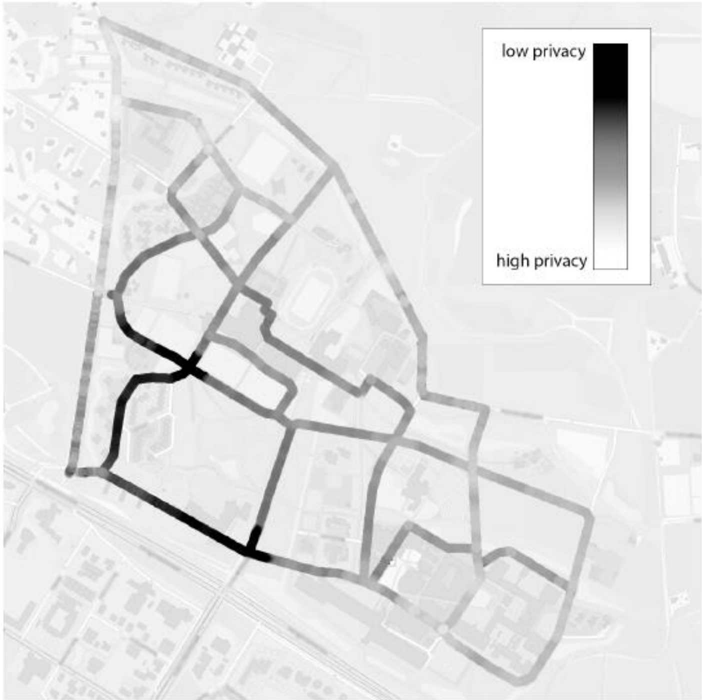
Connected Car communication [8]

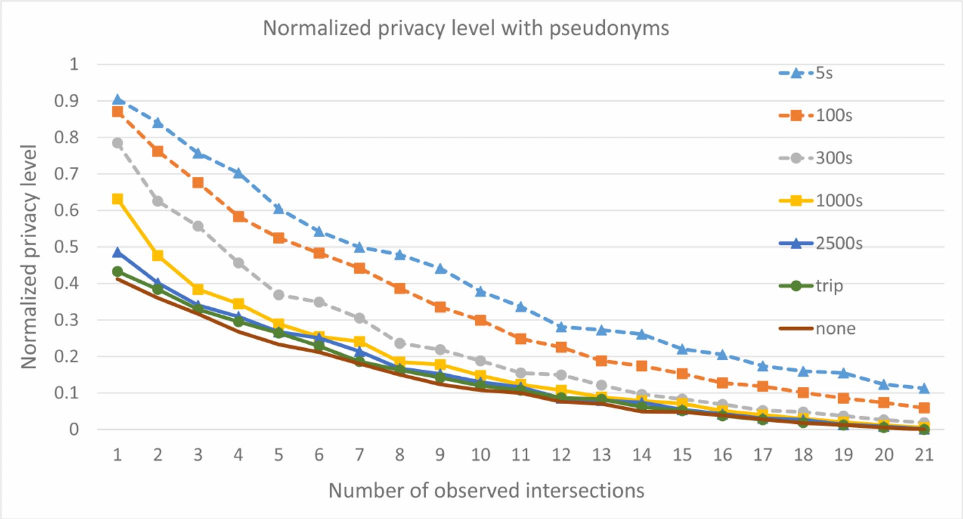
Case Study: Privacy for Connected Cars

1. [right:] Directly next to the intersections car privacy is very low [8]

2. [bottom:] Privacy decline over time, depending on the pseudonym change frequency [8]

3. Currently pseudonyms are not part of any standard!





Accountability as a Way Forward

1. The problems in the above case study is a result of the **interaction** between different systems.

2. How should we now design systems to identify these **unexpected** and **unwanted** events?

3. Real world example: Tesla autopilot crash [9]

A. CRASH INFORMATION

Location:	US-Alt 27, milepost 29, near Williston, Levy County, Florida
Vehicle #1:	2015 Tesla Model S 70D
Operator #1:	Private operator
Vehicle #2:	2014 Freightliner Cascadia truck tractor in combination with a 2003 Utility 3000R refrigerated semitrailer
Operator #2:	Okemah Express, LLC Palm Harbor, FL
Date:	May 7, 2016
Time:	4:36 PM EDT
Fatalities:	1
NTSB #:	**HWY16FH018**

Accountability as a Way Forward

1. Things will go wrong at the level of cars, infrastructure, services, communication: Safety, Security, Privacy, …

2. **Design time**: Problems can be avoided – but not all problems and interactions can be known (or predicted) a-priori

3. **Runtime:** We can detect (some) problems, and avoid or at least mitigate them

4. **Post mortem:** We need to nalyze the problem, attribute responsibility (or even liability!) and avoid similar problems in the future

Why do problems happen?

1. Hardware: **systematic** and **random** faults, they are usually well understood

2. Software: **only systematic** faults, usually not well understood because of the diversity of software
   - What are potential problems?
   - How to identify them? And what even is our specification?

3. Rules and decision-procedures are often not well understood (machine learning!)

4. Unexpected behavior of the environment (esp. cyber-physcial systems!)

5. More and more “open” systems that can be joined (often at runtime) by other systems

6. “Rich” interfaces have to be described and their compliance has to be checked and ensured

And now?

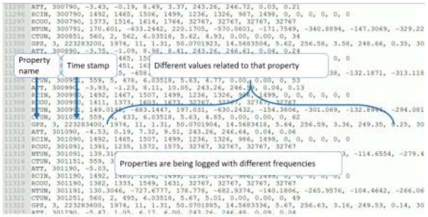
1. Things will go wrong.

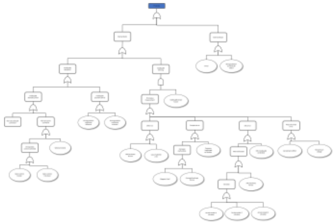
2. Accountability is the property of a system to aid answering questions about the Why and assign responsibility or even liability.

3. We need:
   - **Logs** to preserve evidence: What? When? In which granularity? How long to store them? How to ensure authenticity and integrity?

   - **Models** for causal analysis: When to mitigate problems and when to let them “happen”? How to deal with “known unkowns”? How can such models be improved with new knowledge?

   - **Algorithms** to reason about the models and the actual evidence.






```
Inadequate_control_law_exo= false
Wind_exo= false
voltage_sensor_error_exo= true
Broken_propeller_exo= false
Broken_ESC_exo= false
Being_pushed_pulled_by_an_object_exo= false
Broken_Engine_exo= false
battery_voltage_drop_exo= true
```

A learning system

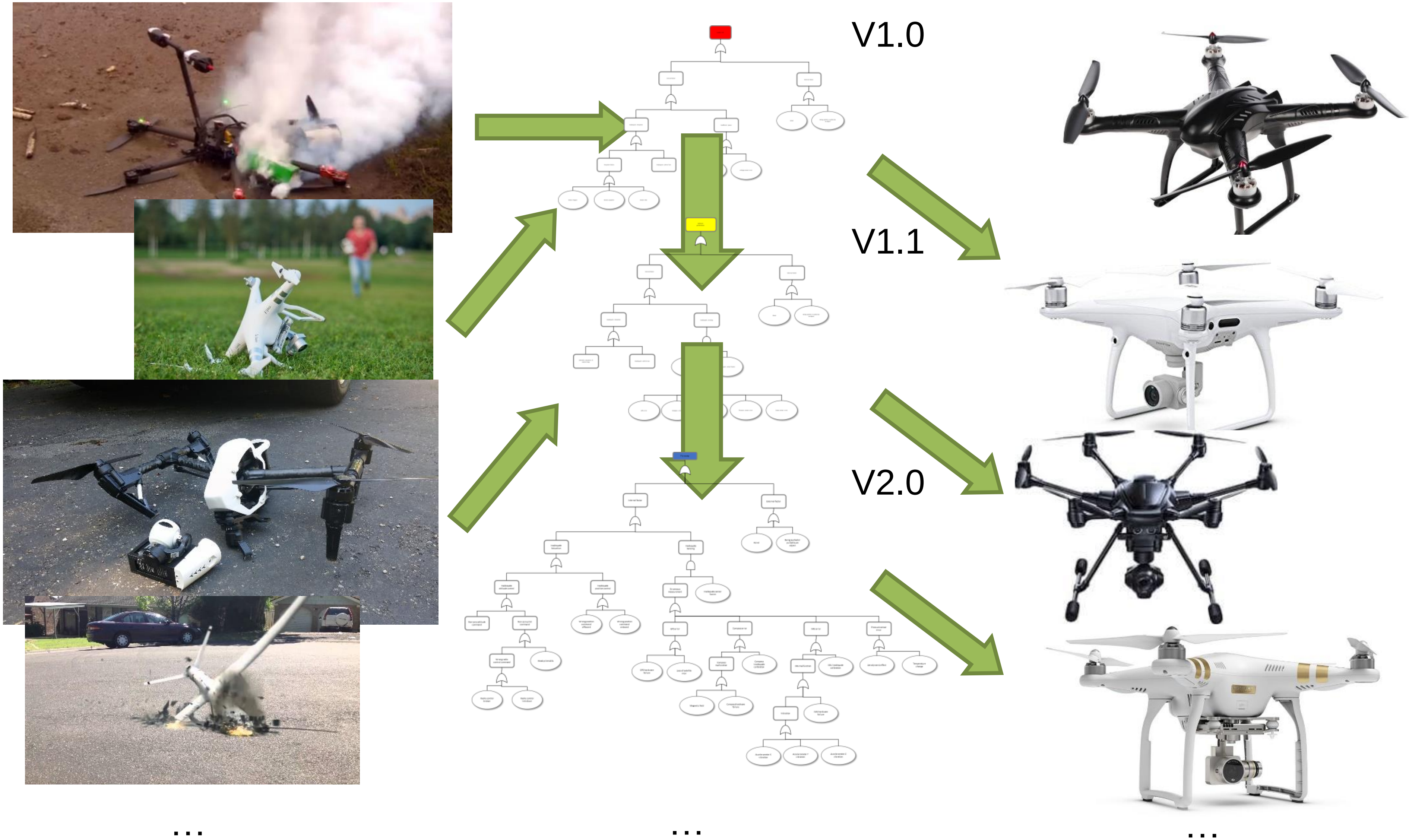
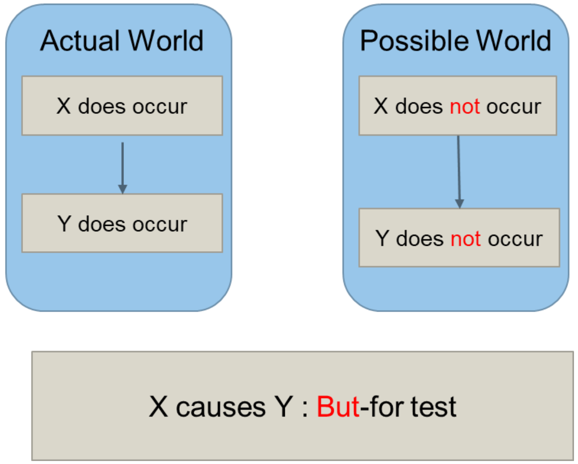
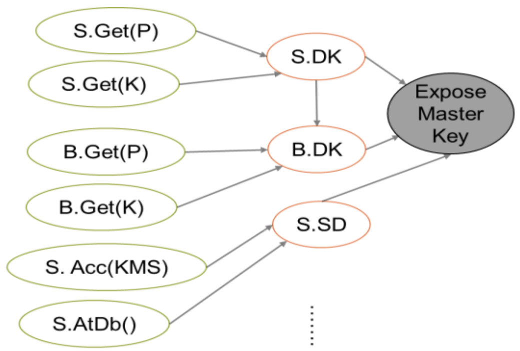


Image source: Google search „drone crash“

Causal Analysis





Signature: S=(U,V,**R**)

- U: Set of exogenous variables
- V: Set of endogenous variables
- **R**: Associates with each variable a set of possible values

Causal Model: M=(S,**F**)

- **F**: Associates a function F_X with each $X \in V$
  In words: „ F_X tells us the value of X given the values of all other variables in $U \cup V$"

$\vec{X} = \vec{x}$ is an actual cause of φ in $(M, \vec{u})$ if the following three conditions hold:

- AC1: $(M, \vec{u}) \models \vec{X} = \vec{x}$ and $(M, \vec{u}) \models \varphi$
- AC2 (a^m): There is a set $\vec{W}$ of variables in V and a setting $\vec{x}'$ of the variables in $\vec{X}$ such that if $(M, \vec{u}) \models \vec{W} = \vec{w}$, then $(M, \vec{u}) \models [\vec{X} \leftarrow \vec{x}', \vec{W} \leftarrow \vec{w}]\neg\varphi$
- AC3: $\vec{X}$ is minimal; no subset of $\vec{X}$ satisfies conditions AC1 and AC2.

Future Challenges

1. Technical
   - Recording, filtering, fusing, transmitting, storing, analyzing, processing, interpreting mobility data – in-network or outside
   - Software architecture, security, safety, privacy, software updates, …
   - Unified frameworks for mobility applications
   - Quality of Service for information (e.g., prioritize emergency communication)
   - Network topologies for fast moving and position changing systems
   - Energy efficient algorithms and devices
   - Accountability, also for ML approaches
2. Conceptual
   - Interoperability of devices
   - Modeling and testing connected vehicles (!)
   - Managing the mobility and movement of vehicles and people
3. Societal
   - Infrastructure Construction
   - Laws and Regulation; liability; data quality
   - Data ownership and protection laws
   - Counteracting the tendency of “platforms” to beget monopolies (Winner takes all)
4. Business

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