Panel

Challenges on Mobility-based Technologies

Topics: Mobility, Speed, Security & Privacy, Precision..

Chair

Eugen Borcoci, University POLITEHNICA Bucharest, Romania

Panelists

Yingxuan Zhu, Futurewei, USA
Hocine Imine, COSYS-PICSL, University Gustave Eiffel, IFSTTAR,Marne-la-Vallée, France
Dirceu Cavendish, Kyushu Institute of Technology, USA/Japan
Mohamed-Slim Alouini, King Abdullah University of Science and Technology(KAUST), Saudi Arabia
Eugen Borcoci, University POLITEHNICA Bucharest, Romania
Takeshi Ikenaga, Kyushu Institute of Technology, Japan

Panel:
Challenges on Mobility-based Technologies
(mobility, speed, privacy and precision, …)

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Panellist Position

Federated Learning on Mobile Devices for Privacy Preservation

Yingxuan Zhu, Futurewei, USA Yingxuan.zhu@Futurewei.com

- Federated learning
- Data sharing without compromising privacy
- Challenges in mobile devices
- A framework for power management of mobile devices
- Non-IID data collaboration in federated learning

Panel

Challenges on Mobility-based Technologies

(IoT and Privacy)

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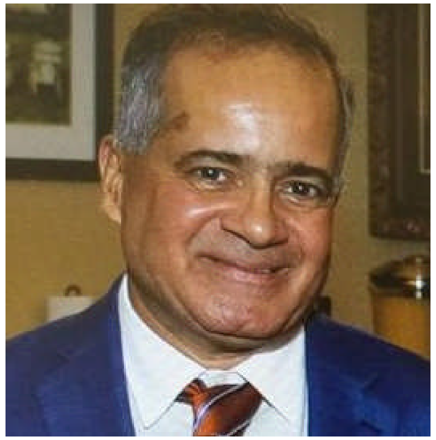
Panellist Position



IoT and Privacy

Dirceu Cavendish, Kyushu Institute of Technology USA/Japan cavendish@ndrc.kyutech.ac.jp

- 5G networking
- IoT Systems Architecture
- Privacy Technologies
- Privacy Challenges

→ Deep personal data mining is coming

→ Privacy regulations is ever more paramount

→ Data crime forensics will become a large business

Panel:
Challenges on Mobility-based Technologies
(mobility, speed, privacy and precision, …)

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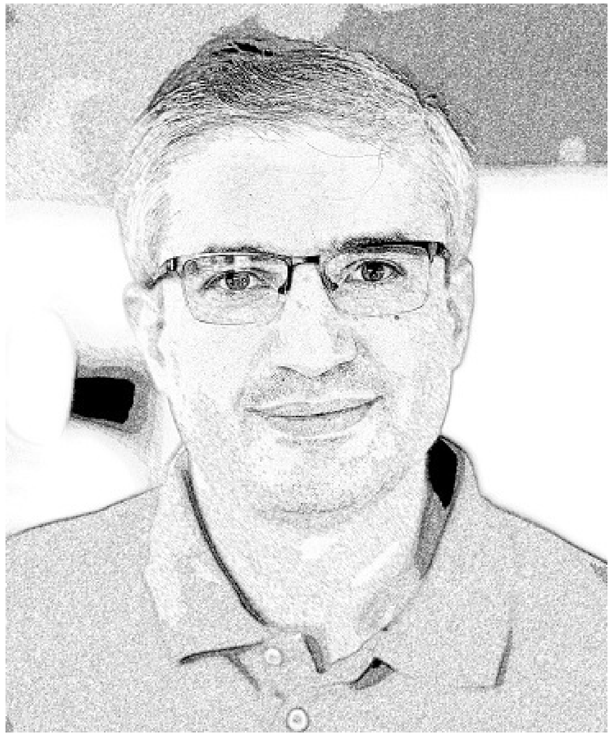
Panellist Position



The Blind Spots of 5G

Mohamed-Slim Alouini, KAUST, Saudi Arabia, slim.alouini@kaust.edu.sa

- Digital divide
- More energy consumption
- Electromagnetic field (EMF) exposure concerns
- Fragile equipment

Beyond 5G networks should

→ bridge the digital divide

→ Aims to be more energy efficient

→ Be designed in an EMF-aware fashion

→ Be more robust & resilient

Panel:
Challenges on Mobility-based Technologies
(mobility, speed, privacy and precision, …)

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Panellist Position

Mobility in IoT: connectivity solutions

Eugen Borcoci, University POLITEHNICA Bucharest, Romania eugen.borcoci@elcom.pub.ro

- Mobility capabilities needed in IoT apps – which domain?
- Smart Mobile IoT (M-IoT) - use cases – examples
- M-IoT applications classification in terms of mobility
- Low mobility
- High mobility
- Connectivity solutions

IARIA

LEPSiS

Laboratory for road Operations, Perception, Simulators and Simulations

Simulators to study the Effects of Road Surface Characteristics on Users' Behavior

***Hocine Imine**, University Gustave Eiffel, hocine.imine@univ-eiffel.fr*

- Intelligent Transportation Systems,
- Simulators and Vehicles modelling,
- non linear observation,
- nonlinear control and stability.

Université Gustave Eiffel

Panel:
Challenges on Mobility-based Technologies
(Multi-path Transport Protocol and QoS)

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Panellist Position

Multi-path Transport Protocol and QoS

Takeshi Ikenaga, Kyushu Institute of Technology, Japan ike@ecs.kyutech.ac.jp

- Mobile Networking
- Network Interfaces in Mobile Devices/Terminals
- Multi-path Transport Protocol
- QoS Management for Real-time Application

→ Evolution of mobile networks will cause frequent handovers

→ Demand for high quality real-time communication in the mobile environment will further expand

→ Developments of multi-interface and multi-path technologies are key to the future of mobile communications

Federated Learning on Mobile Devices for Privacy Preservation

Yingxuan Zhu, Jian Li

Email: Yingxuan.zhu@Futurewei.com, jian.li@Futurewei.com
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Privacy Preservation

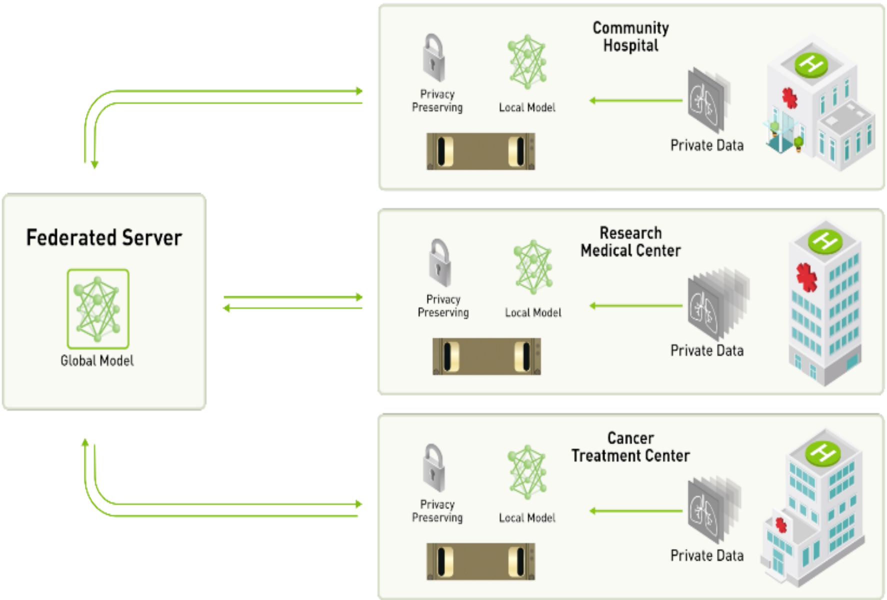
- **Server and Agents (or Clients) Scenarios**
  - Smart home hub and personal devices;
  - Transportation center and smart cars;
  - Hospital Server and medical devices with storage;
  - Collaboration between colleagues;
  - Government Server and computers in schools.
- **To preserve privacy, in the process, data of an Agent will never be sent to server or shared with other Agents.**

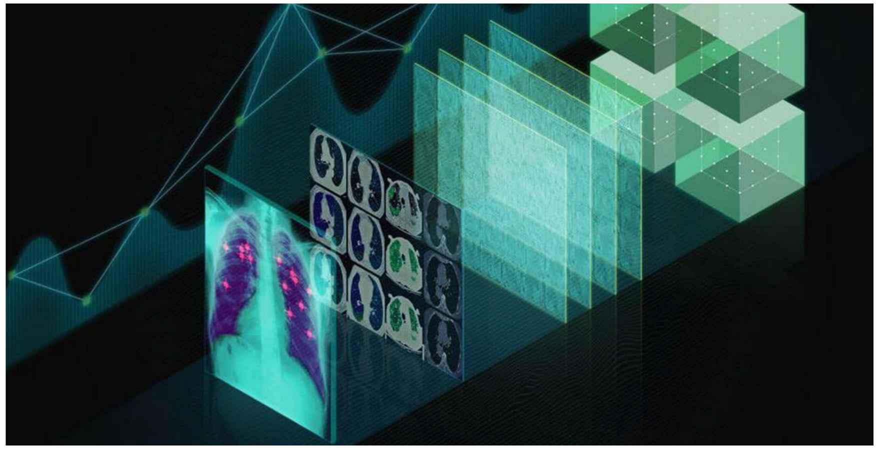
Federated Learning

Federated Learning is to train a shared model in multiple devices while leaving the training data in each device.

Characteristics:

- Multi-party learning: processes of learning and computing are decentralized, and take place in more than one devices; these devices are called the Agents.
- Federated: at least one device, called the Server, integrates the outputs from individual devices. The Server can be any individual device.
- Data stay in the Agents, and privacy preserving is the goal.





1 https://ai.googleblog.com/2017/04/federated-learning-collaborative.html
2 Qiang Yang, et al. Federated machine learning: Concept and applications. ACM Trans. Intell. Syst. Technol. 2019
3 https://blogs.nvidia.com/blog/2019/10/13/what-is-federated-learning/

Related Topics

- **Multi-party Computation (MPC)**

"A subfield of cryptography with the goal of creating methods for parties to jointly compute a function over their inputs while keeping those inputs private."[1] Note that MPC does not encourage interaction and it learns more from its protocol than from interaction.

- **Split learning**

Split learning trains deep neural networks over several data repositories without revealing actual raw data. This method reduces computational requirements on individual data sources, and decreases number of labeled samples required for training.

- **Differential privacy**

"A system for publicly sharing information about a dataset by describing the patterns of groups within the dataset while withholding information about individuals in the dataset." [2]

1. https://en.wikipedia.org/wiki/Secure_multi-party_computation
2. https://en.wikipedia.org/wiki/Differential_privacy

Evaluation Methods

- Computation cost

Computation cost was evaluated by the big-O[1]. Computation cost of a federated learning method can be evaluated by comparing the overall time used in achieving the same outcome by federated learning method and non-federated machine learning method. However, the overall computation time depends on the performance of each device in the federated learning system.

- Communication cost

The bandwidth spent in communication between Server and Agents.

- Privacy preserving

Privacy preservation can be evaluated by data leakage. There are different ways to measure data leakage, such as using KL Divergence between input and intermediate representation.[2]

- Accuracy

1. Keith Bonawitz, et al., Practical secure aggregation for privacy-preserving machine learning, ACM SIGSAC 2017.
2. Praneeth Vepakomma, et al., Reducing leakage in distributed deep learning for sensitive health data. ICLR 2019.

A Challenge in Federated Learning

- Each agent is different, which means data are diversified
- Take time to converge
- Don't handle outliers

- Because the total error is calculated by integrated parameters, so integrated parameters are usually sent back to each Agent during backpropagation, without considering difference between Agents.

Assume that a Server sends a training model to K Agents. Agent k has n_k training samples, and $n = \sum_{k=1}^{K} n_k$ is the total number of samples. Generally, the overall training objective is to minimize a lost function

$$\mathcal{L} = \arg\min_{W} \mathcal{F}(W).$$

where $\mathcal{F}$ is an objective function, or cost function, and W represents the parameters that minimize the cost function.

In current methods, at iteration t, $W^{(t)}$ is the weighted average of weights from each Agent:

$$W^{(t)} = \sum_{k=1}^{K} \frac{n_k}{n} w_k^{(t)}.$$

After the server compares results to target values, it back-propagates the difference equally to each Agent, even though each Agent contributes differently to final errors in Server.

Objective of our method: Reduce the effect of diversification in data without jeopardizing privacy, i.e., pass integrated parameters while maintain individual differences.

https://proandroiddev.com/federated-learning-e79e054c33ef

Thank you!

Internet 2020 Panel

Challenges on Mobility-based Technologies

IoT and Privacy

Dirceu Cavendish, Kyushu Institute of Technology, Japan

Network Design Research Center

5G Networking

5G Salient Characteristics

- Flexible and efficient spectrum usage (including millimeter wave)
- Efficient data transport: control/emergency/low latency
- New IoT use cases
  - Automotive: connected and ADAS cars
  - Healthcare: smart medical devices
  - Smart homes: surveillance, home automation

IoT systems architectures

- Small edge devices (sensor, appliance, combination)
- Cloud intelligent services
- Smartphone command and control

IoT Systems

Architecture

- Small edge device: sensor, actuator
- Cloud infrastructure
  - Data gathering and analysis
  - System security
- Command and control device: smartphone

Services Verticals

- Home management
- Transportation: Vehicle driving assistance, traffic control
- Healthcare: data analysis, therapy delivery
- Manufacturing industry

Privacy technologies

Data encryption at rest and in transit

- Strong requirements for Healthcare (HIPAA)
- Non-existent regulations for other vertical IoT markets

Authentication and Authorization

- Multifactor authentication
- Oauth2.0: explicit resource authorizations via security tokens
- Hardware Security Module (HSM): management of security credentials

Privacy challenges

Unreadable/unenforceable EULAs
- Cumbersome End-User License Agreements
- Click through services

Controlled data sharing
- Health personal data sharing with medical personnel only
- Vehicle data gathering for assisted driving, not insurance companies
- Massive data gathering (medical, transportation)

Third party data gathering
- Social networks gathering on non-users
- Surveillance systems: photos, geolocation, etc.
- Financial institutions: credit card activities, trading data.
- Wide scale shopping behavior: grocery stores (reward programs), wholesale stores, gas stations.

Technology failures
- IoT device hacking: cheap HW, small SW footprint
- Cloud system miss-management
- Cryptographic material leaks

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King Abdullah University of Science and Technology

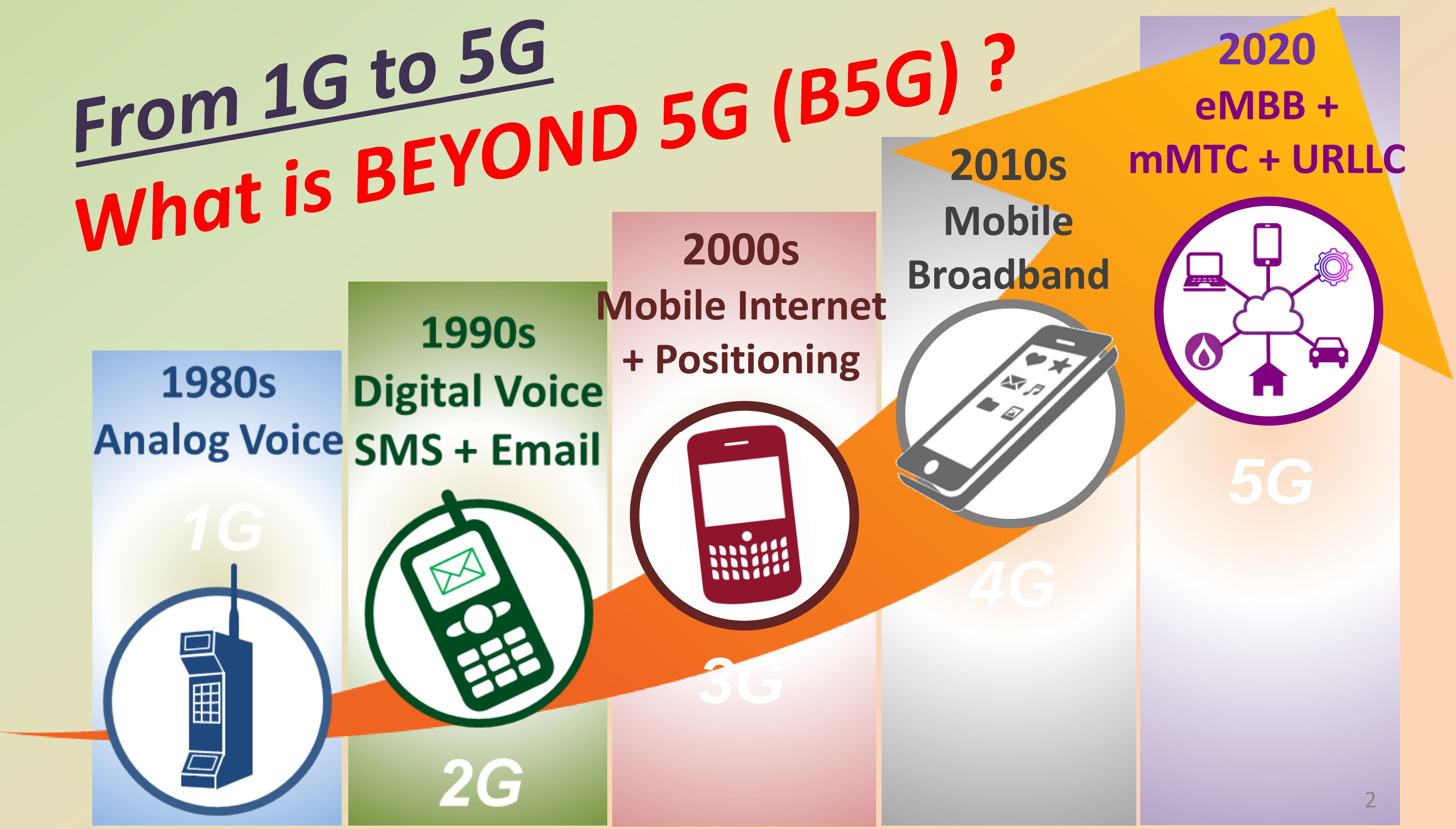
The Blind Spots of 5G

Panel 3 - InfoWare 2020
Oct 18-22, 2020, Porto, Portugal



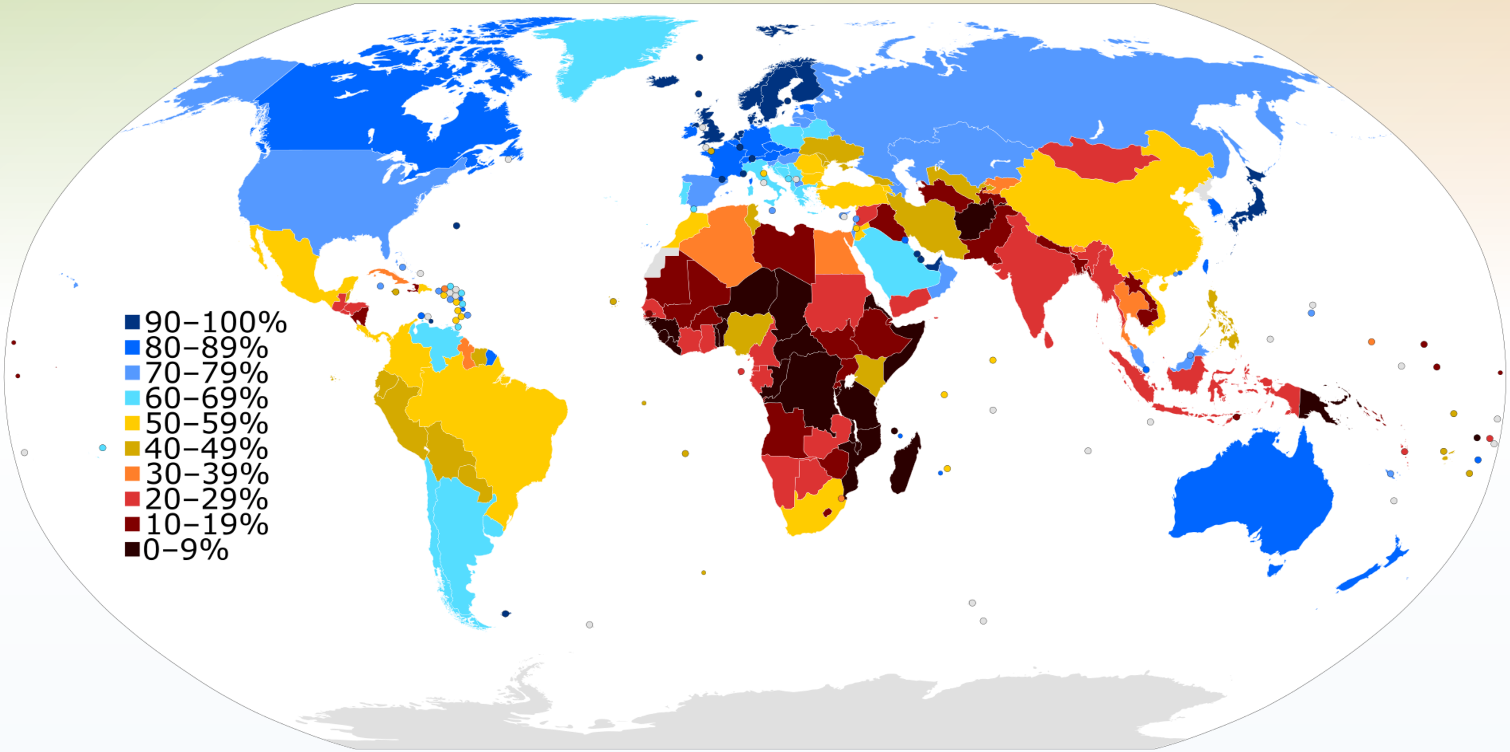
Mohamed-Slim Alouini
Communication Theory Lab. @ KAUST
http://ctl.kaust.edu.sa

Evolution of Generations



Digital Divide

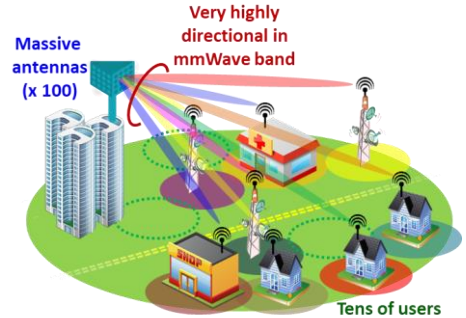
- **Billions of people around the world are still without internet access.**



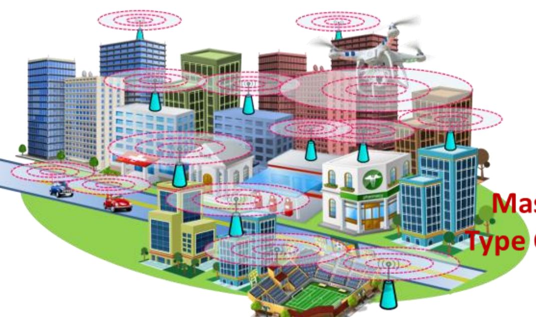
Source: [International Telecommunications Union]

E. Yaacoub and M.-S. Alouini, "A Key 6G Challenge and Opportunity - Connecting the Base of the Pyramid: A Survey on Rural Connectivity," Proceedings of IEEE, April 2020.

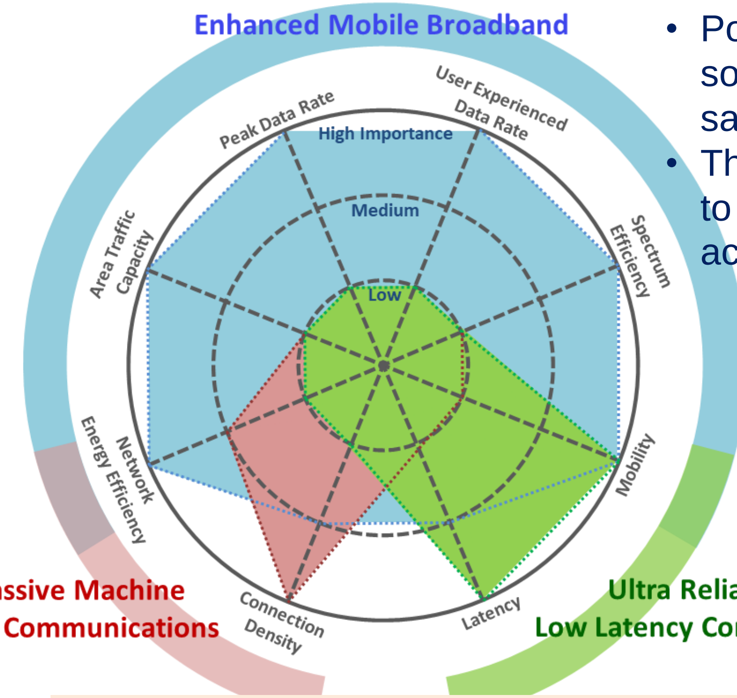
Power Consumption Concern



- Massive antenna arrays and beamforming
- mmWave band

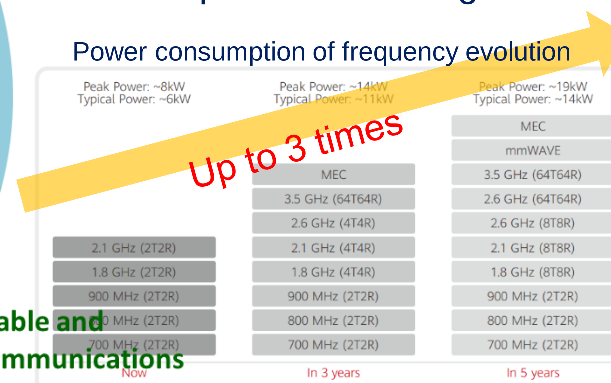


- Densification of 5G sites
- Massive connection of IoT devices



- Power consumption of 5G equipment in some bands is up 3 times of 4G with the same configuration.
- The number of sites is expected to be 2 to 3 times that of the 4G era in order to achieve 4G equivalent coverage.

Power consumption of frequency evolution

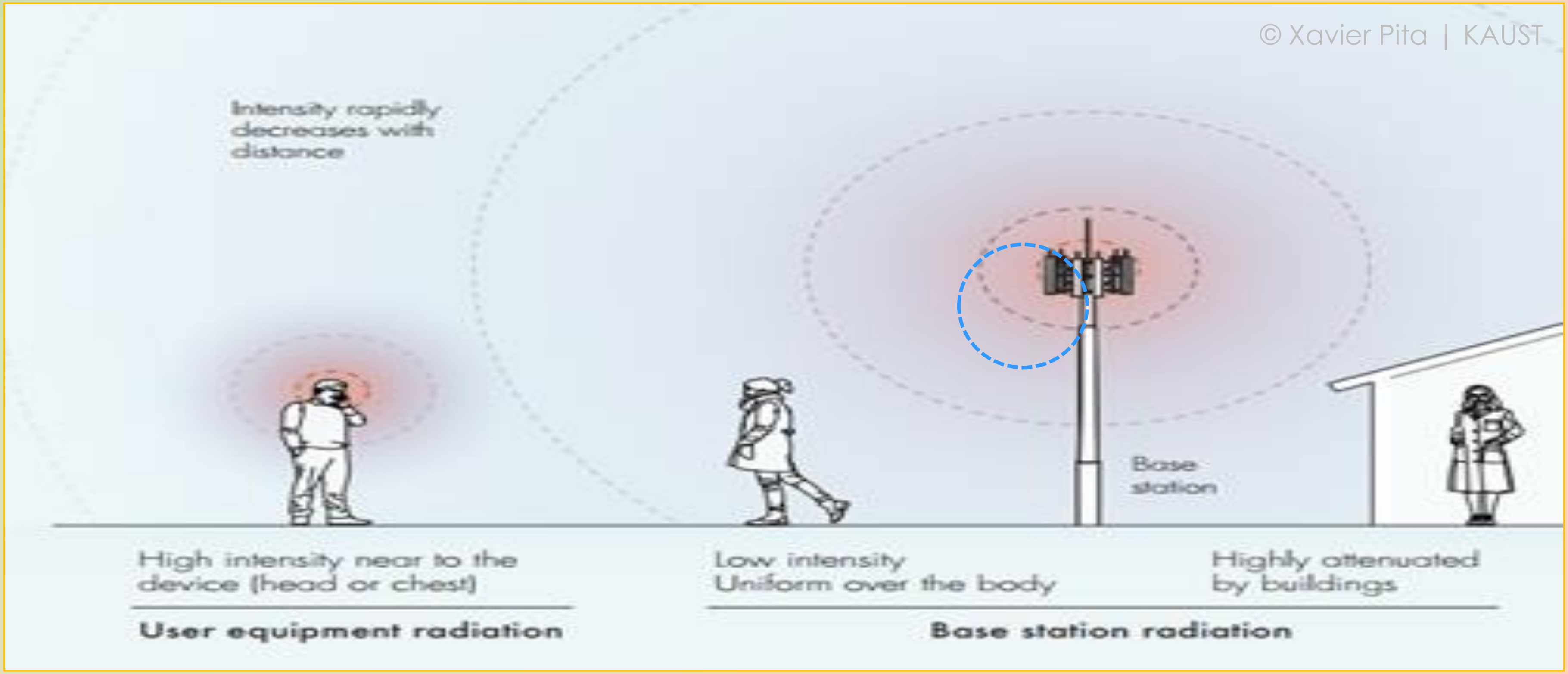


Huawei White Paper, "5G telecom power target network," *5th Global ICT Energy Efficiency Summit*, https://carrier.huawei.com/~/media/CNBGV2/download/products/network-energy/5G-Telecom-Energy-Target-Network-White-Paper.pdf

C. –L. I, S. Han, and S. Bian, "Energy-efficient 5G for a Greener Future ," Nature Electronics, April 2020.

EMF Radiation Concern

- Concern on electromagnetic field exposure
  - Potential health risks associated with the extra RF emissions from 5G base stations



L. Chiaraviglio, A. Elzanaty, and M.-S. Alouini, "Health Risks Associated with 5G Exposure: A View from the Communications Engineering Perspective ", Under Review. June 2020, Available on Arxiv: https://arxiv.org/pdf/2006.00944.pdf

Damage and Failures due to Disasters

- Telecommunication networks are not resilient and can be seriously damaged after:
  - Natural catastrophes such as s such as earthquakes, tsunamis, floods, and storms
  - Man-made disasters such terrorist attacks or nuclear explosions/nuclear radiation

K. Ali, H. X. Nguyen, Q. –T. Vien, and P. Shah, Disaster Management Communication Networks: Challenges and Architecture Design "2015 IEEE International Conference on Pervasive

Sustainability Development Goals

- In 2016, the United Nations released 17 Sustainability Development Goals (SDGs) for the 2030 Agenda

SDGs & B5G Networks

- SDGs are expected to drive the evolution of B5G networks.
- Hence B5G should target:
  - Digital Inclusion
  - Improved Energy Efficiency
  - No Bad Effects on Environment & Human Health
  - More Security and Privacy
  - Resilience, Robustness, and Dependability

S. Dang, O. Amin, B. Shihada, & M. –S. Alouini, "What Should 6G Be?", Nature Electronics, January 2020

Nikola Tesla
(10 July 1856 – 7 January 1943)

“When wireless is perfectly applied, the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole. We shall be able to communicate with one another instantly, irrespective of distance.”

Nikola Tesla (1925)

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Thank You

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Panel

Challenges on Mobility-based Technologies

Topics: Mobility, Speed, Security & Privacy, Precision..

Mobility in Internet of Things: connectivity solutions

Eugen Borcoci
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Mobility in IoT: connectivity solutions

- **Eugen Borcoci** : professor
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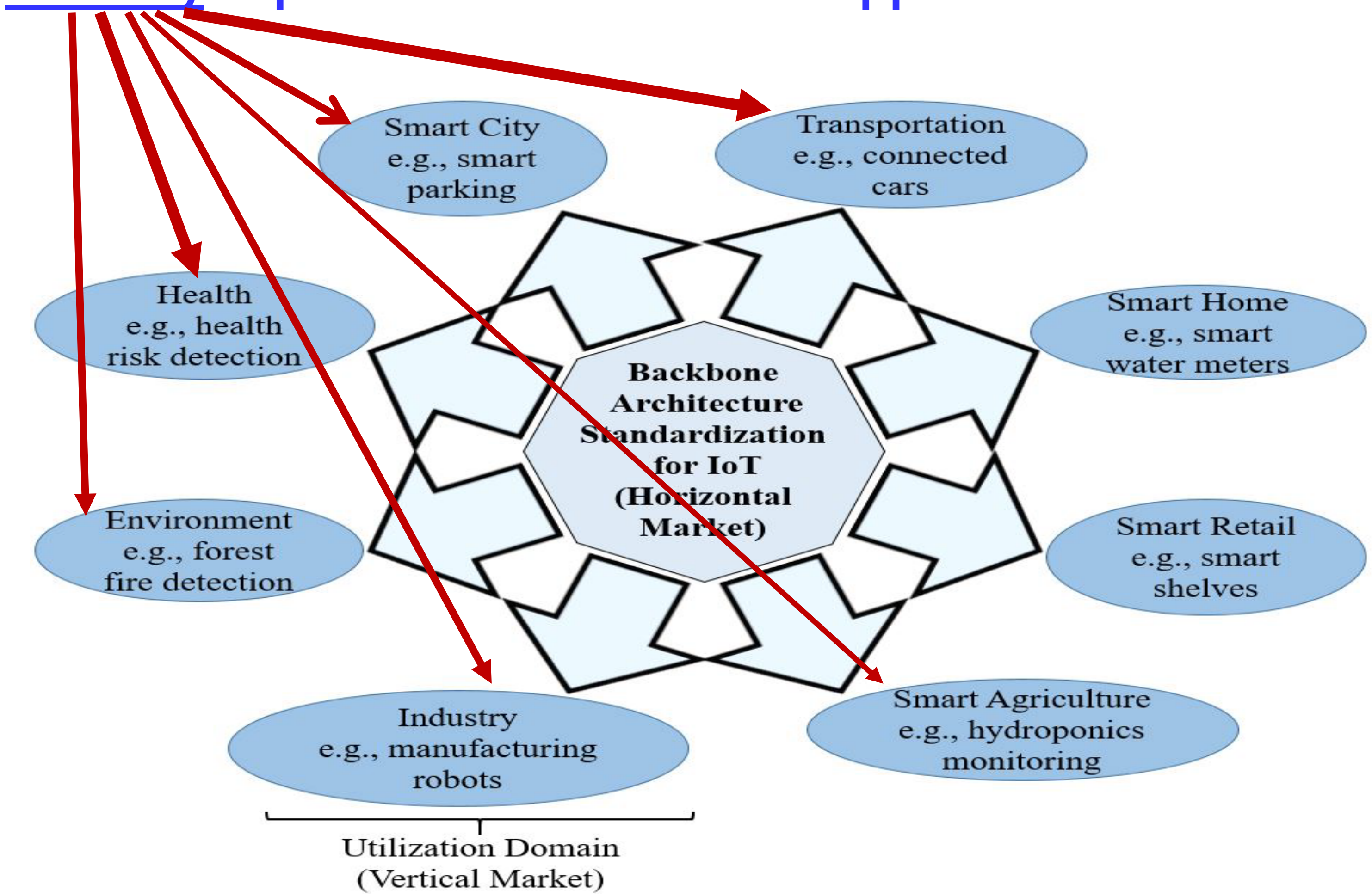
  - Address: 1-3, Iuliu Maniu Ave., 061071 Bucharest - 6, ROMANIA
  - E- mail address :eugen.borcoci@elcom.pub.ro

- Expertise: teaching and research activities in specific domains of telecommunications and computer networks architectures, technologies and services, like:
  - network architectures and services, management/control/data plane, communication protocols, 3G/4G, quality of services assurance over multiple domains networks, multicast and multimedia services over IP networks and heterogeneous access.
- Recent research interest and activities: new technologies like Software Defined Networking (SDN), Network Function Virtualization (NFV), Cloud/fog/edge computing, 4G/5G networking and slicing, vehicular communications.
- Publications: 6 books, 4 textbooks and over 200 scientific or technical papers and scientific reports.
- UPB team leader in many national and int'l European research projects.

Mobility in IoT: connectivity solutions

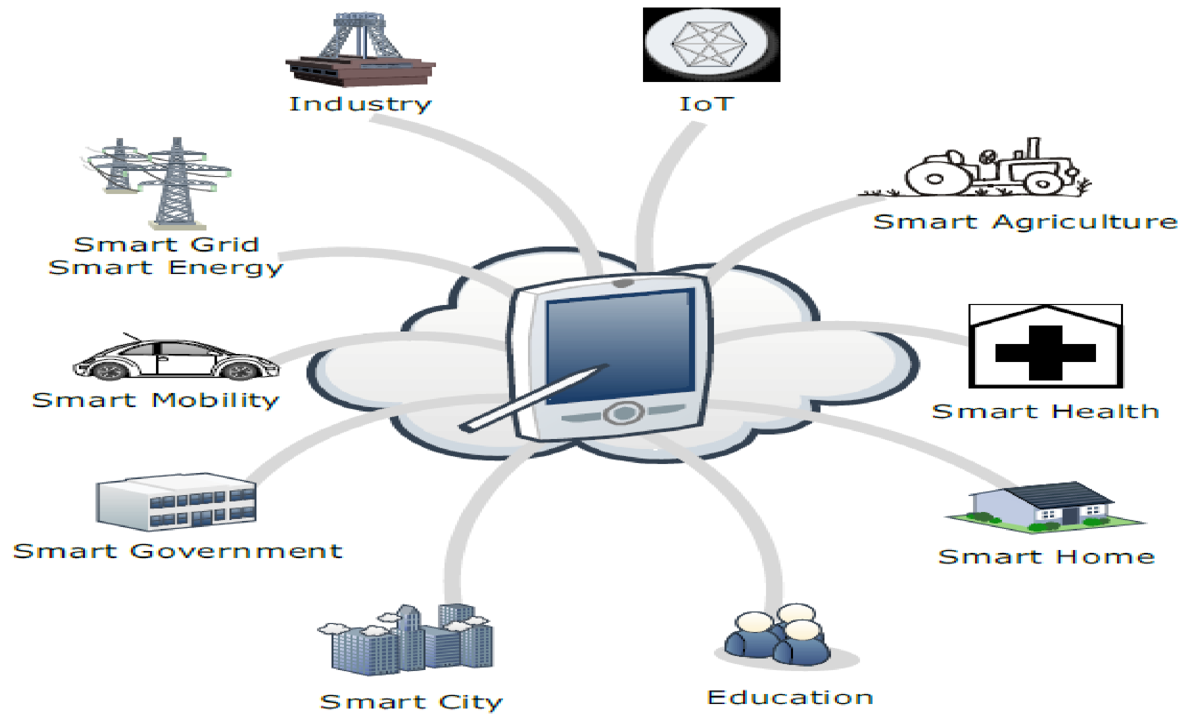
- **Mobility capabilities needed in IoT apps – which domain?**



Adapted from source: J.Ding, M.Nemati, C.Ranaweera, and J.Choi, "IoT Connectivity Technologies and Applications:A Survey" arXiv:2002.12646v1 [eess.SP] 28 Feb 2020.

Mobility in IoT: connectivity solutions

- **Smart Mobile IoT (M-IoT) - use cases – examples**
  - The smart M-IoT - incorporate a large set of services for (smart): industry, healthcare, monitoring, home, city, agriculture, environment, public safety communications, transportation, navigation, education and others.



Source: V.Sharma, et al., "Security, Privacy and Trust for Smart Mobile-Internet of Things (M-IoT): A Survey", arXiv:1903.05362v3 [cs.NI] 9 Aug 2020

Mobility in IoT: connectivity solutions

▪ Smart Mobile IoT (M-IoT)

▪**M-IoT advantages**:

- Easy way for users and organizations to accommodate and host services through intelligent architecture
- Cost- effective solutions of smart M-IoT networks and applications (e.g. Personal applications, private networks and clouds)
- Information management, processing, and validation and data flow management across a wide range of networks
- Support for H2D and D2D communication with low overheads and low-complexity
- Support for real-world apps such as driverless cars, urban-surveillance, smart retailing, industrial Internet,provisioning of app. base for AR/VR services
- Contextual network through intelligent and rapid data acquisition and processing.
- Low-frequent maintenance remote control operation
- Self-configuring capacity and support for a large set of devices through a common interface
- Support for crowd-sourcing and edge-computing models
- Capable to form on-demand network in case of public safety contexts
- Industrial automation and personalized control formations

Mobility in IoT: connectivity solutions

- **M-IoT applications classification in terms of mobility:**
  - **low and high mobility**

  - **Low mobility** – they can easily rely on existing connectivity technologies
    - Example: smart agricultural sensors: machine-oriented, low data rate, delay-tolerant, long-range, low power, non-critical, and low mobility
  - **High mobility**
    - Examples: vehicles, trains and airplanes
    - Requirements related to
      - enhanced connectivity for in-vehicle/on-board apps
      - access to the Internet
      - enhanced navigation through instant and real-time information
      - autonomous driving and vehicle diagnostics

Mobility in IoT: connectivity solutions

- **High mobility** (cont'd)
- (challenging issues)
  - the speed can be up to hundreds km/h
  - need: handover, redirection, and cell reselection in connected states
  - increases the Doppler effect
  - can jeopardize the reliability of the connectivity technologies

- **Which connectivity technology ?**

  - **low mobility** applications
    - They can use general connectivity solutions designed for IoT, e.g. : LPWAN (e.g., LoRa/LoRaWAN and NB-IoT)

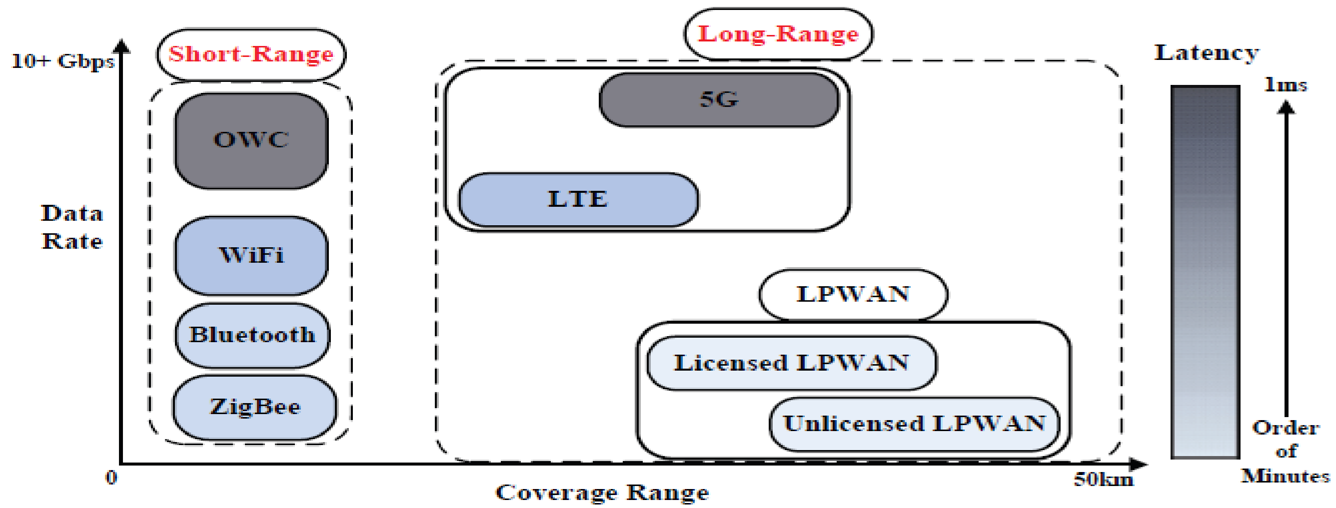
  - **high mobility** applications
    - generally utilize cellular connectivity technologies (4G, 5G)
    - challenges: require significant improvements to overcome high mobility issues for future high mobility applications

Mobility in IoT: connectivity solutions

- **Connectivity technologies for low and high mobility- examples**

IoT Mobility type	Apps. examples	Suitable connectivity technology
High	Autonomous vehicles	LTE/LTE-A (LTE-M , NB-IoT) 5G
Low	Cycling, Pedestrian mobility	LPWAN, Bluetooth/BLE, ZigBee

- **IoT connectivity technologies (**in terms of data rate, coverage, and latency)



Source: J.Ding, M.Nemati, C.Ranaweera, and J.Choi, "IoT Connectivity Technologies and Applications:A Survey" arXiv:2002.12646v1 [eess.SP] 28 Feb 2020.

Conclusions

- **M-IoT aplications-** significant development in near future
- Large range of connectivity solutions
- **Selection of a connectivity solution -** depending on requirements such as
  - specific use cases
  - geographic coverage range: short, medium, large
  - low mobility versus high mobility
  - data rate
  - response time needed
  - reliability
  - degree of security
  - cost and complexity

References

1. J.Ding, M.Nemati, C.Ranaweera, and J.Choi, "IoT Connectivity Technologies and Applications:A Survey" arXiv:2002.12646v1 [eess.SP] 28 Feb 2020.
2. V.Sharma, et al., "Security, Privacy and Trust for Smart Mobile-Internet of Things (M-IoT): A Survey", arXiv:1903.05362v3 [cs.NI] 9 Aug 2020
3. ITU-T, S.Tabanne, "Internet of Things: A technical overview of the ecosystem", “Developing the ICT ecosystem to harness Internet-of-Things (IoT)”, 28-30 June 2017, Mauritius
4. ITU-T S.Tabanne, “IoT systems overview”, 30 Sept.-03 Oct. 2019, Bangkok, Thailand, https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2019/ITU-ASP-CoE-Training-on-/IoT%20systems%20overview.pdf
5. 5G Americas white Paper, “5G A future of IoT”, July 2019, https://www.5gamericas.org/5g-the-future-of-iot /

Acronyms

AR	Augmented Reality
6LoWPAN	IPv6 over Low Power Wireless Personal Area Networks
D2D	Device to Device
H2D	Human to Device
IoT	Internet of Things
LoRaWAN	Long Range Wide Area Network
LPWAN	Low power WAN
LTE-A	Long-Term Evolution Advanced
LTE	Long-Term Evolution
M-Iot	(Smart) Mobile IoT
NB-IoT	Narrow Band IoT
OWC	Optical Wireless Communications
VR	Virtual Reality
WAN	Wide Area Network
WPAN	Wireless Personal Area Network

Simulators to study the Effects of Road Surface Characteristics on Users' Behavior

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Perceptions, Interactions, Behaviors & Simulations **Lab** for road and street users

University Gustave Eiffel, France

VEHICULAR 2020, The Ninth International Conference on Advances in Vehicular Systems, Technologies and Applications

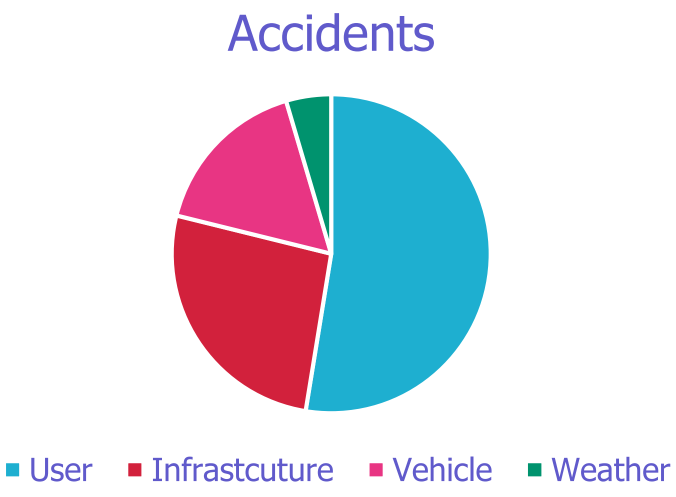
Université Gustave Eiffel

Contexte

More than 1.3 million people dying on the world's roads every year, and as many as 50 million others are being injured. Studying road-user behavior through simulations is a promising tool to address challenges, such as learning to drive, awareness of risks, road safety.
The aim is to consider the driver as a control system in order to obtain the necessary actions to ensure the vehicle's path. This will undoubtedly help to better understand driver behavior and improve the quality of the vehicle modelling and its simulation.

Some data

– 92 % caused by driver (speed, presence of alcohol, fatigue ,..)
– 46% related to Infrastructure
– 29% related to Vehicle
– 8% related to divers causes (Weather, Warning,..)



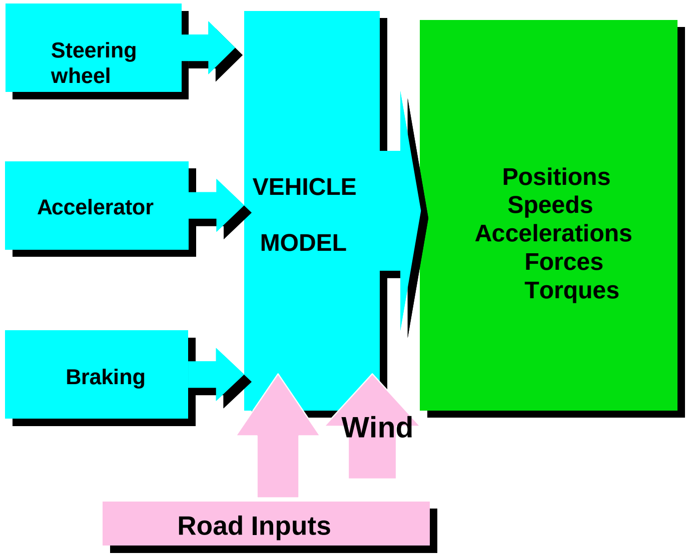
Different types of accidents:

- Lane departure (Transverse instability)
- Rollover (Roll instability)
- Jackknifing, implied especially in Heavy vehicle accidents (Yaw instability)

Université Gustave Eiffel

Road characteristics

Geometric and surface characteristics of the road have a direct effect on the forces generated in the tire contact footprint, under the action of applied commands.

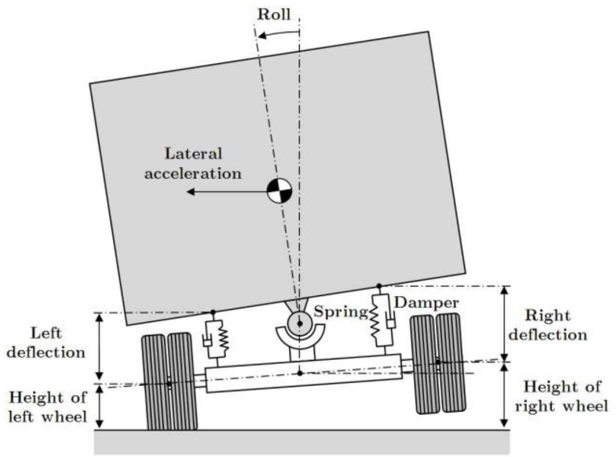


Vehicle/Infrastructure interaction

- Road Profile ➔ Vertical deformation of the road
- Road adhesion ➔ Skid resistance is a friction to prevent a tire from sliding along the pavement surface
- Longitudinal and lateral slope
- Radius of curvature

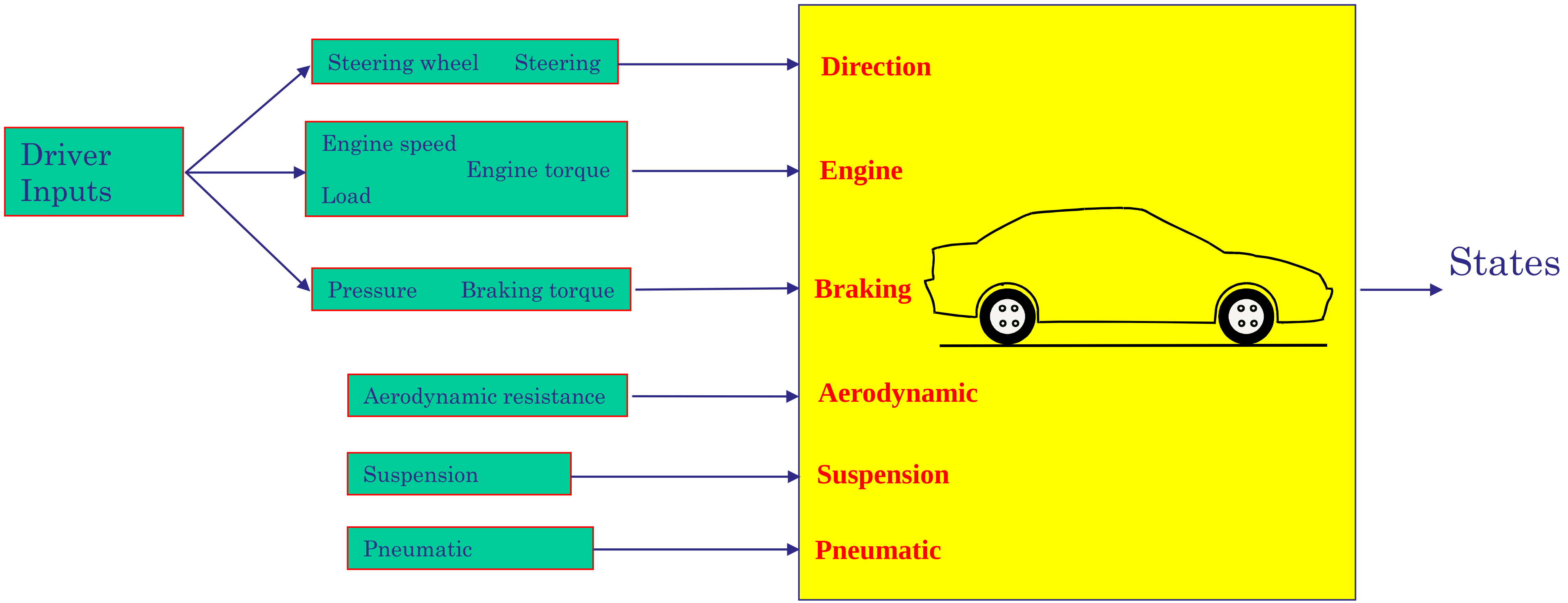
Road profile and Road adhesion in vehicle dynamics

– Road Profile ➔ can cause rollover and control loss of the vehicle



– Road adhesion ➔ sliding and control loss, lane departure of the vehicle

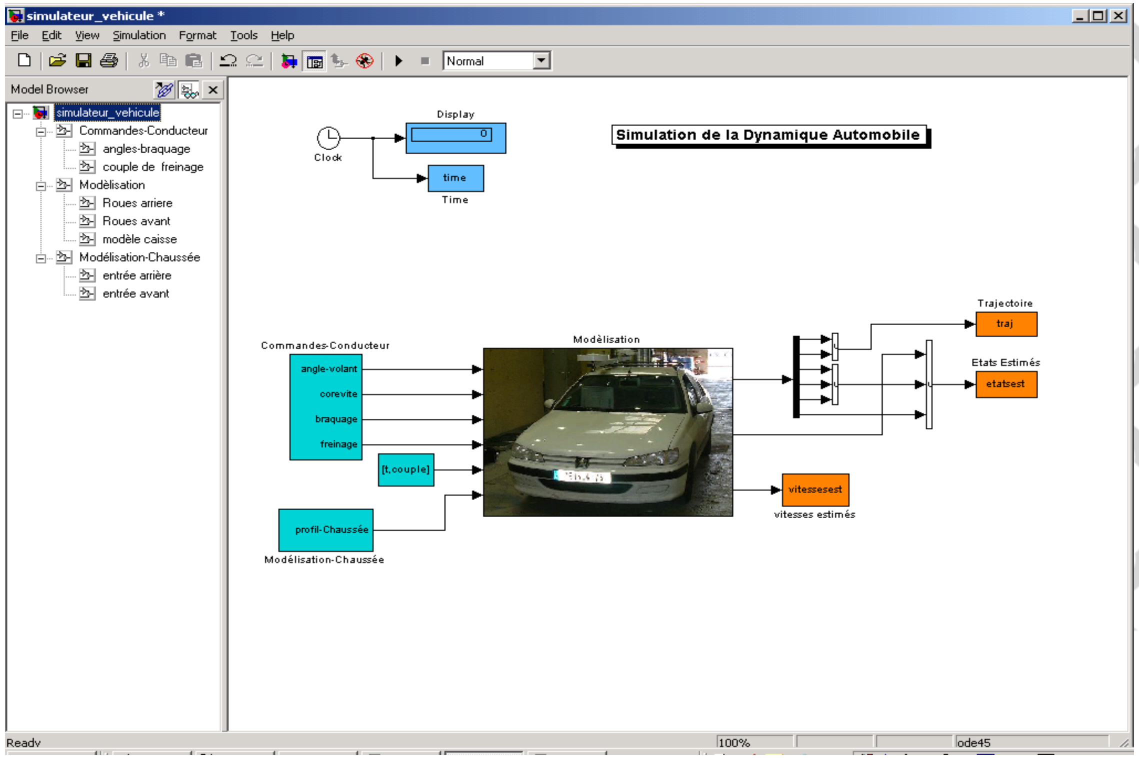
Vehicle modelling and road interaction



Vehicle model is developed taking into account road characteristics (Road profile, road adhesion, slops, radius of curvature)

Vehicle Model simulation

Before to design and develop simulators in order to conduct and study the behavior of drivers and vulnerable users (cyclists, pedestrians) in different situations, the developed vehicle model should be simulated and its outputs (positions, speeds,..) analysed.



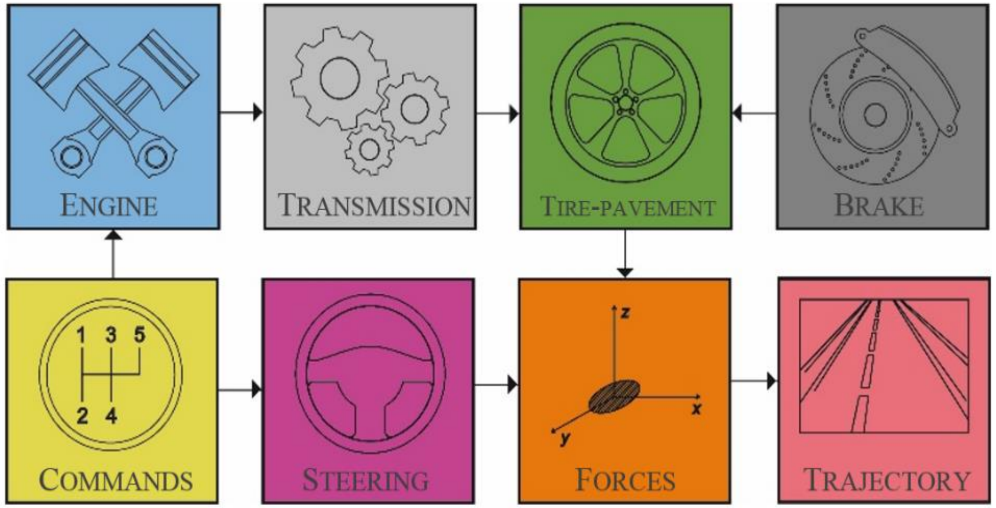
PICS-L lab at Université Gustave Eiffel designs and develops simulators in order to better understand the users’ immersion in a virtual reality environment.

Université Gustave Eiffel

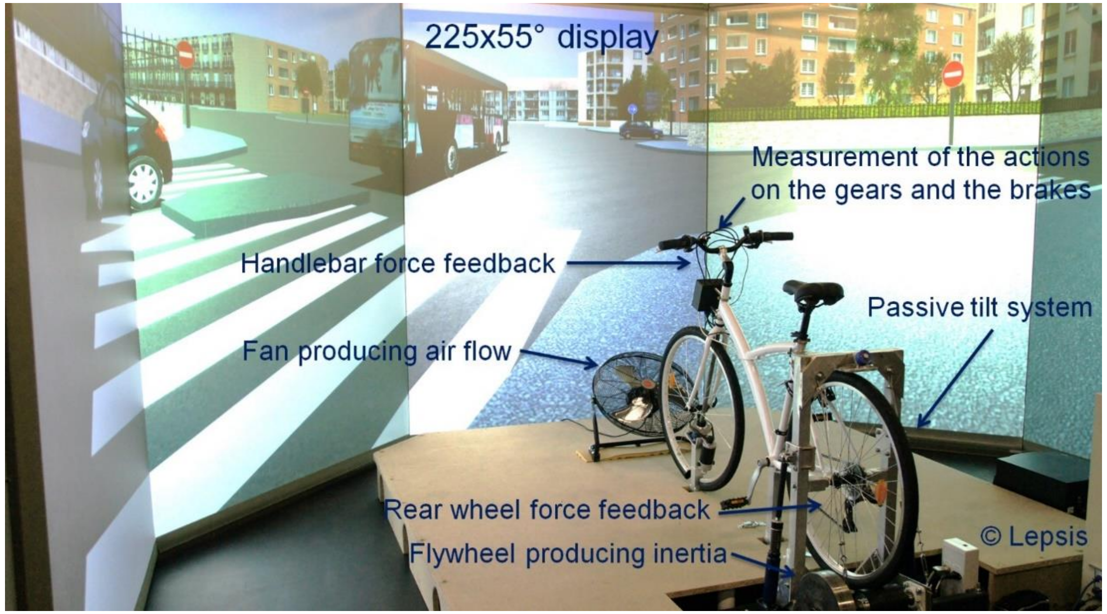
Car Simulator

PICS-L Lab driving simulator is designed with a 2 DOF motion cueing platform to study the yaw motion vehicle control and simulator sickness in the virtual environment.

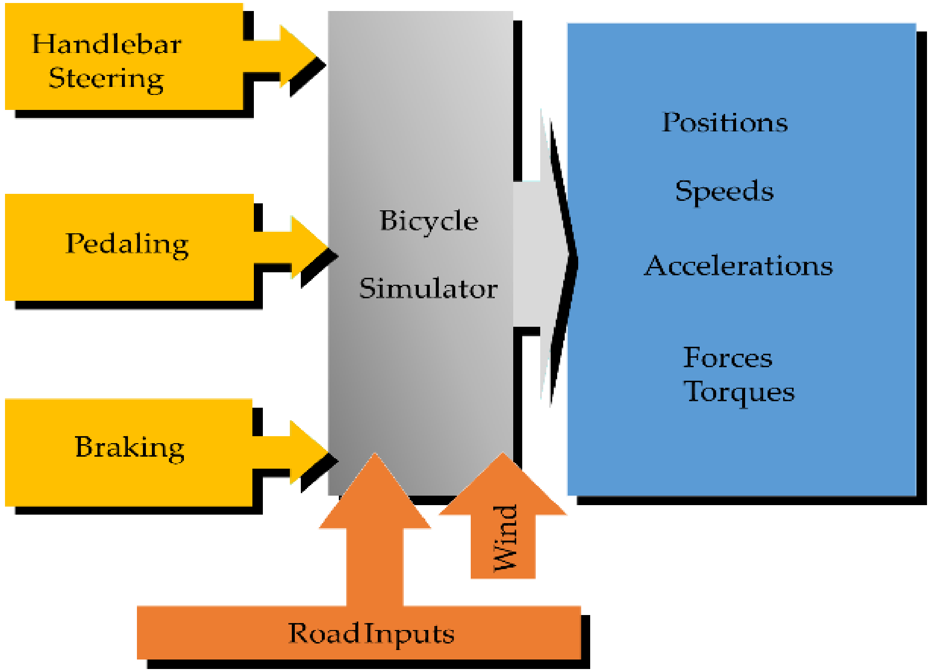
Different parts of simulator



Bicycle simulator



Inputs/Outputs of the bicycle simulator

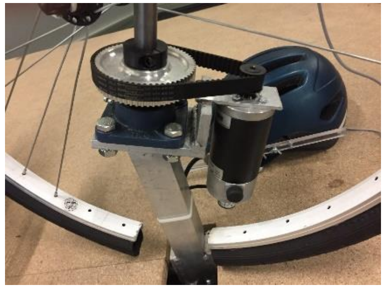


Caro, S., Chaurand, N., Dang, N.T., & Vienne, F. (2013). Conception d'un simulateur de vélo pour l'étude du comportement des cyclistes. Journées Transports & Déplacements du Réseau Scientifique et Technique du MEDDE. Bron, France, Juin 19-21.

Real tests with instrumented vehicles

By conducting comparative studies between a driving simulator and a real driving on track or road, the aim is to verify the reliability of the simulator, as well as to compare the behavior of the driver in both systems, simulator and vehicle. The tests results from the simulator are compared to the results obtained by an instrumented vehicle equipped with accelerometers, Gyrometers, GPS and mobile eye tracking in order to:

- analyse the road characteristics and their influence on safety.



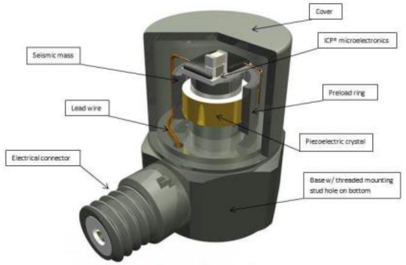
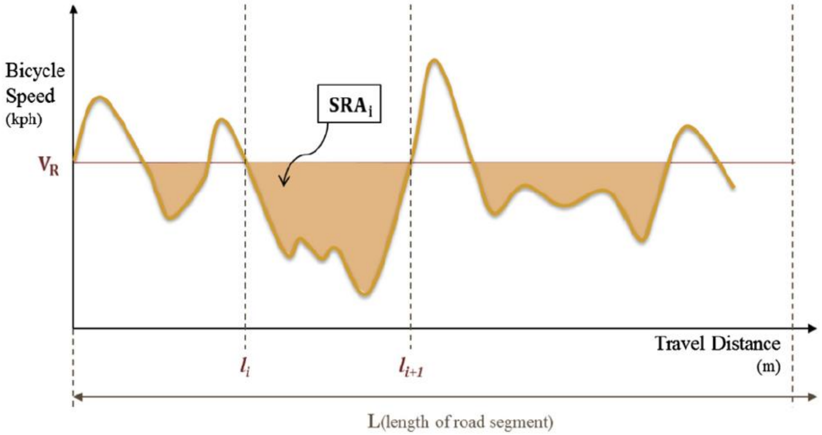


Figure 1: Typical ICP® Accelerometer

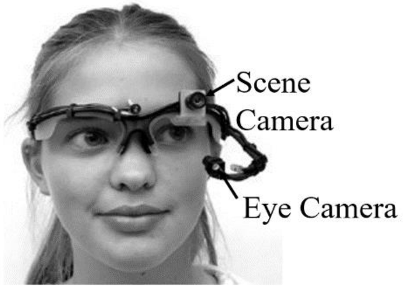
- define drivers and trajectories classes.



Speed Profile

Université Gustave Eiffel

Simulate the perception/action driver's loop



Mobile Eye-tracking

Expected results

- One of the results of this research is to establish recommendations to improve users safety. The experimental data will be studied and analyzed, and database will then be constructed, and its simulated version created.
- It's also interesting to reproduce in simulation these experiments in different locations and countries in order to test the algorithms developed on the simulator and on the road. These algorithms analyze the trajectories of drivers and classify them according to the risk level of the vehicle, in two categories: safe or risky.

Conclusion

Simulators can be used to improve the safety and stability of vehicles, but also to :

- ✓ simulate the driver's perception in vehicle control tasks.
- ✓ simulate real road characteristics and study their influence on the safety.
- ✓ test new models of vehicles, taking into account the road characteristics.
- ✓ define drivers and trajectories classes.

Simulators to study the Effects of Road Surface Characteristics on Users' Behavior

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Perceptions, Interactions, Behaviors & Simulations **Lab** for road and street users

University Gustave Eiffel, France

VEHICULAR 2020, The Ninth International Conference on Advances in Vehicular Systems, Technologies and Applications

Université Gustave Eiffel

九州工業大学
Kyushu Institute of Technology

Panel:
Challenges on Mobility-based Technologies

Multi-path Transport Protocol and QoS

Takeshi Ikenaga, Dirceu Cavendish
Kyushu Institute of Technology, Japan

IARIA Internet2020/InfoWare2020

IoTRC Kyushu Institute of Technology

Mobile Networking

- High speed and broadband wireless access
  - 5G (- 20Gb/s) , Wi-Fi 6 (- 9.6Gb/s)
- Utilizing higher frequency bands
  - 5G New Radio (3GHz – 5GHz , 24GHz – 40GHz) , Wi-Fi (- 6GHz)
- Small Cell
  - Around 50 – 100m radius coverage by single base station
  - Many small cells to cover a wide area / Hybrid (macro and small)

- Importance of handover management
  - Handovers occur frequently
  - Increasing real-time and time-sensitive applications

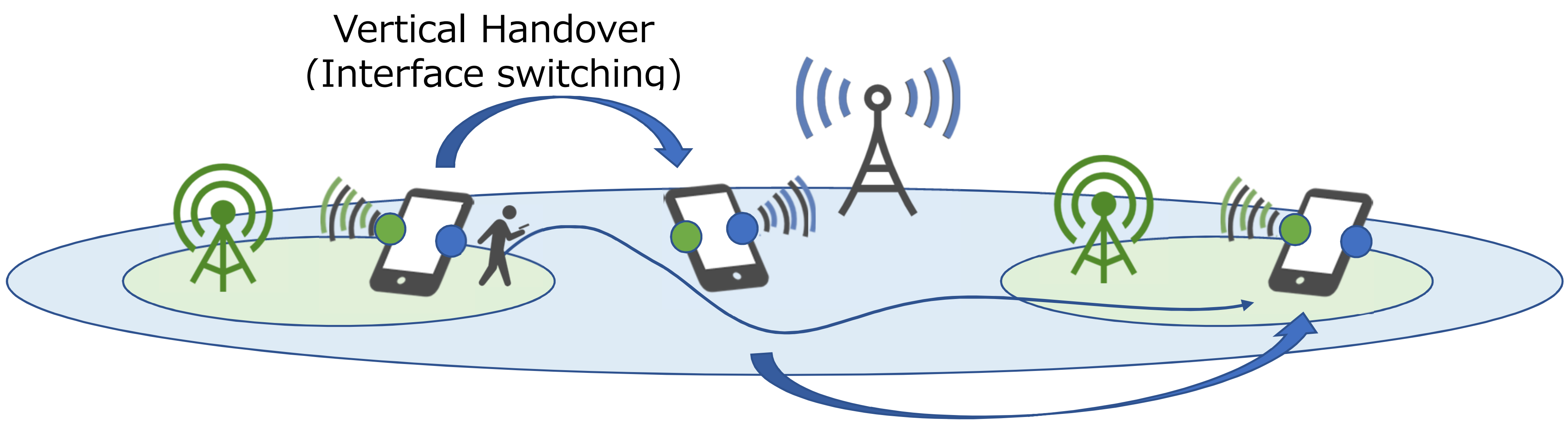
  ↓

  - Provides seamless communication to the applications

Mobile Device/Terminal Features

Smartphone/Tablet

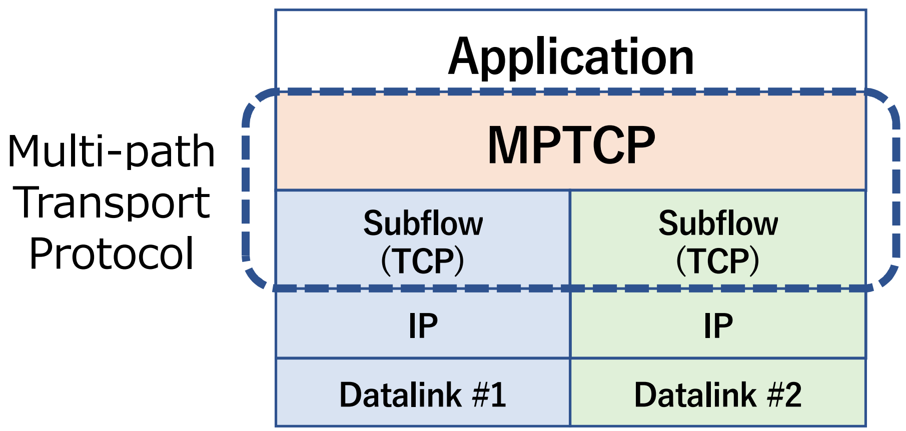
- Multiple high speed wireless communication interfaces for the Internet access
  - Cellular : 4G/LTE, 5G (sub-6 and millimeter wave)
  - Wireless LAN : IEEE 802.11a/b/g/n/ac/ax
- Switching between multiple interfaces dynamically

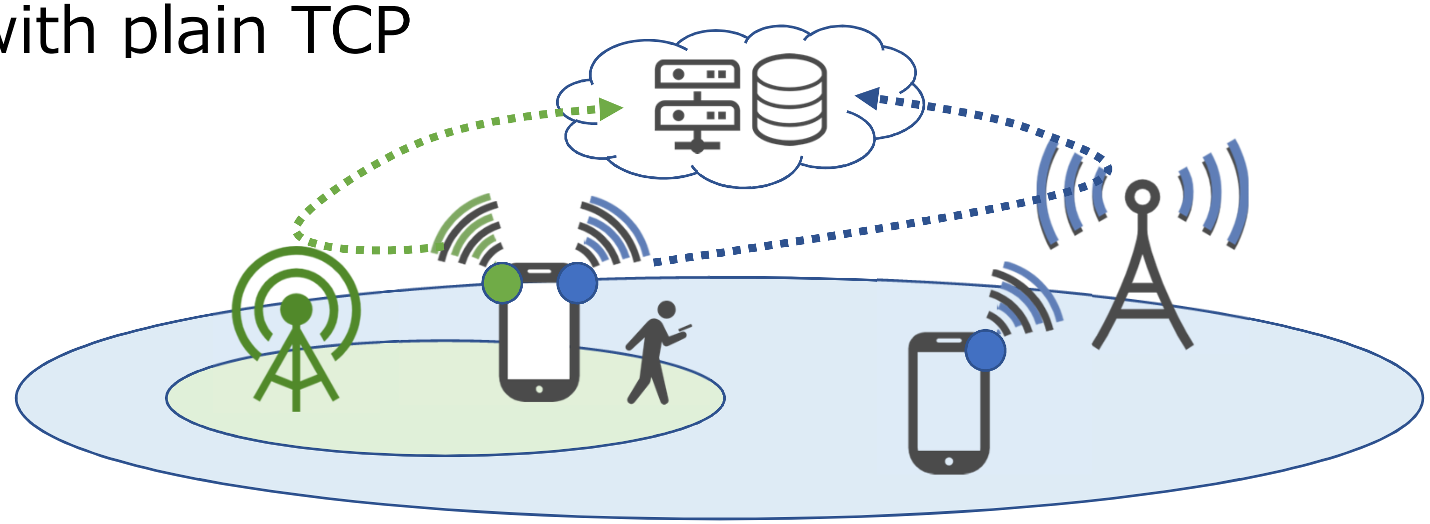


Multi-path Transport Protocol

... Frequent handovers in a mobile environment

- Using multiple interfaces **simultaneously**
  - Usability : hiding interface switching for user/applications
  - Reliability : redundancy through heterogeneous link multiplexing
  - High throughput performance : utilize all available resources
- Multipath TCP (MPTCP)
  - Provides efficient resource multiplexing
  - Backward compatible with plain TCP





QoS Management for Real-time Application

Communication Quality of Services

- Issues in using multiple links simultaneously
  - Head-of-Line blocking
    - Difference in performance/quality between links
    - Frequent handovers
  - Coexistence of real-time applications with other applications
    - Priority control, Fairness

- Efficient congestion control and scheduling algorithms are needed

> **Evolution of mobile networks will cause frequent handovers**
> **Demand for high quality real-time communication will further expand**
> **Optimizing the use of multiple interface resources is the primary challenge**