Continental
The Future in Motion

Vehicular Communications for Smart Mobility

Industry Perspectives and Research Notes

ITN 5VC

5G/6G School
Technische Universität Ilmenau
October 4th – 7th, 2022
Integrated Telematics for Next Generation 5G Vehicular Communications (ITN-5VC)

Dr. David González G.
Continental AG

Content of the Presentation

Part I

Continental AG

Solutions for Safe, Connected, and Sustainable Smart Mobility

Part II

V2X for Automotive

5G, Use Cases, Examples, and Radio Access Planning and Optimization

Part III

Final Remarks

Views on 6G and Collaboration with Academia

Part I
Continental AG

Quick Introduction

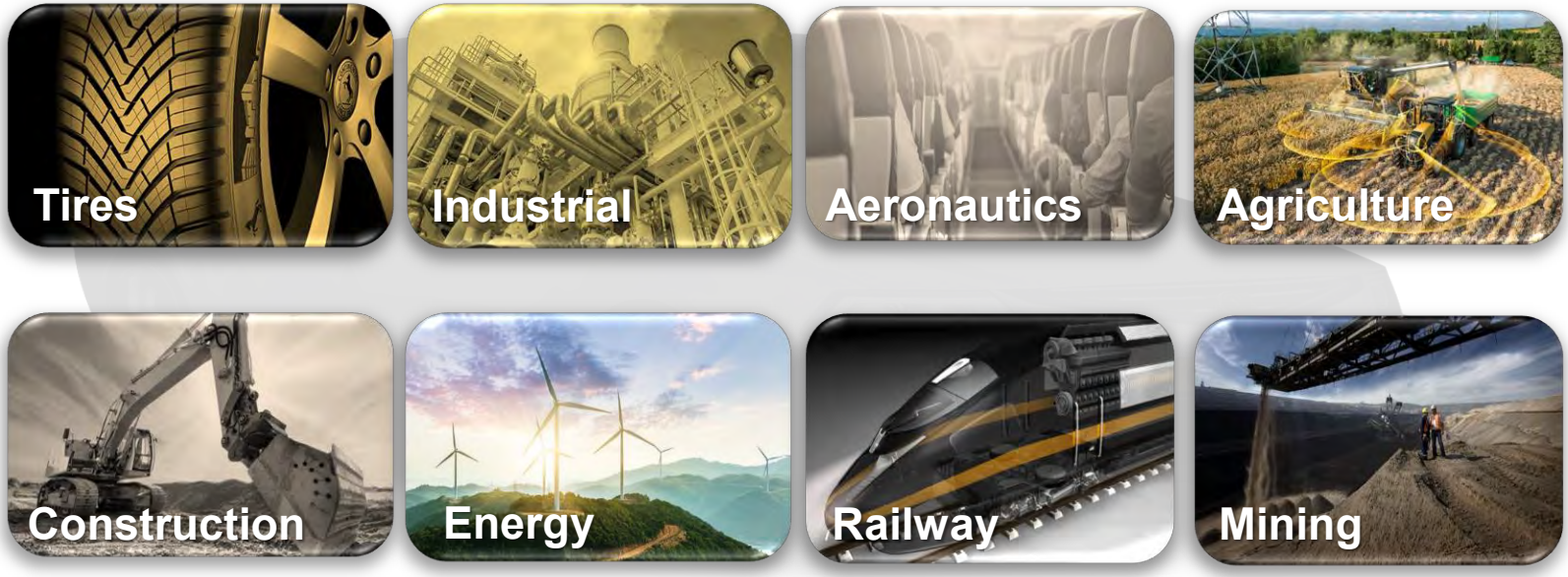
About Continental

150+ years of Innovation

- Founded in **1871** in Germany.
- In 2021, Continental generated sales of **€33.8 billion** and currently employs around **190,000** people in **58 countries and markets**.

About Continental

Serving Many Industry Sectors



More Info:
www.continental-industry.com

About Continental

Serving Many Industry Sectors

Automotive

Vehicular Communications
for Smart Mobility

Tires

ContiTech

About Continental

Today's focus

Automotive

Vehicular Communications
for Smart Mobility

- **Safety and Motion**

- **Architecture & Networking**

- **User Experience**

- **Smart Mobility**

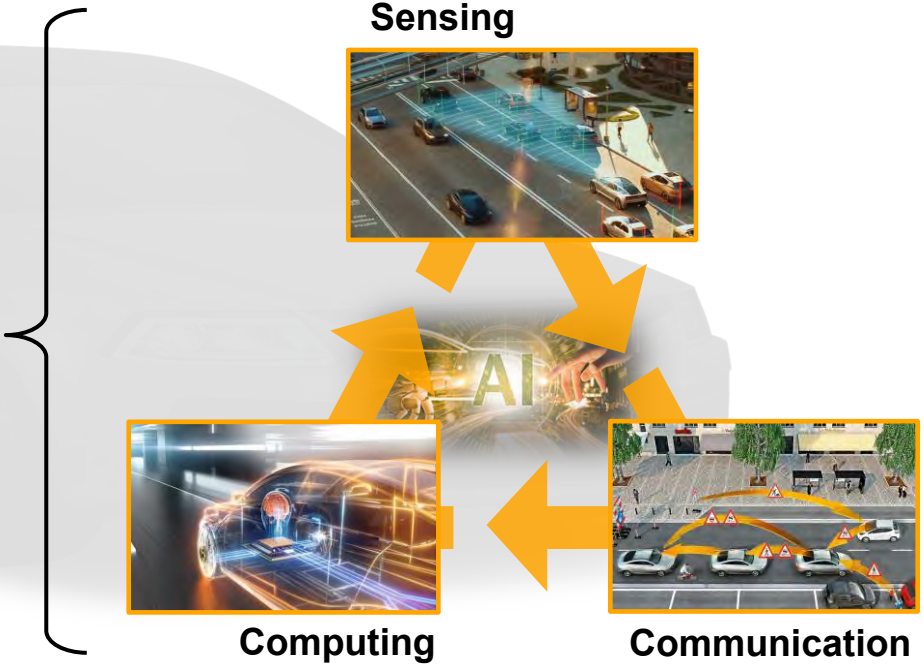
- **Autonomous Mobility**

About Continental

Today's focus

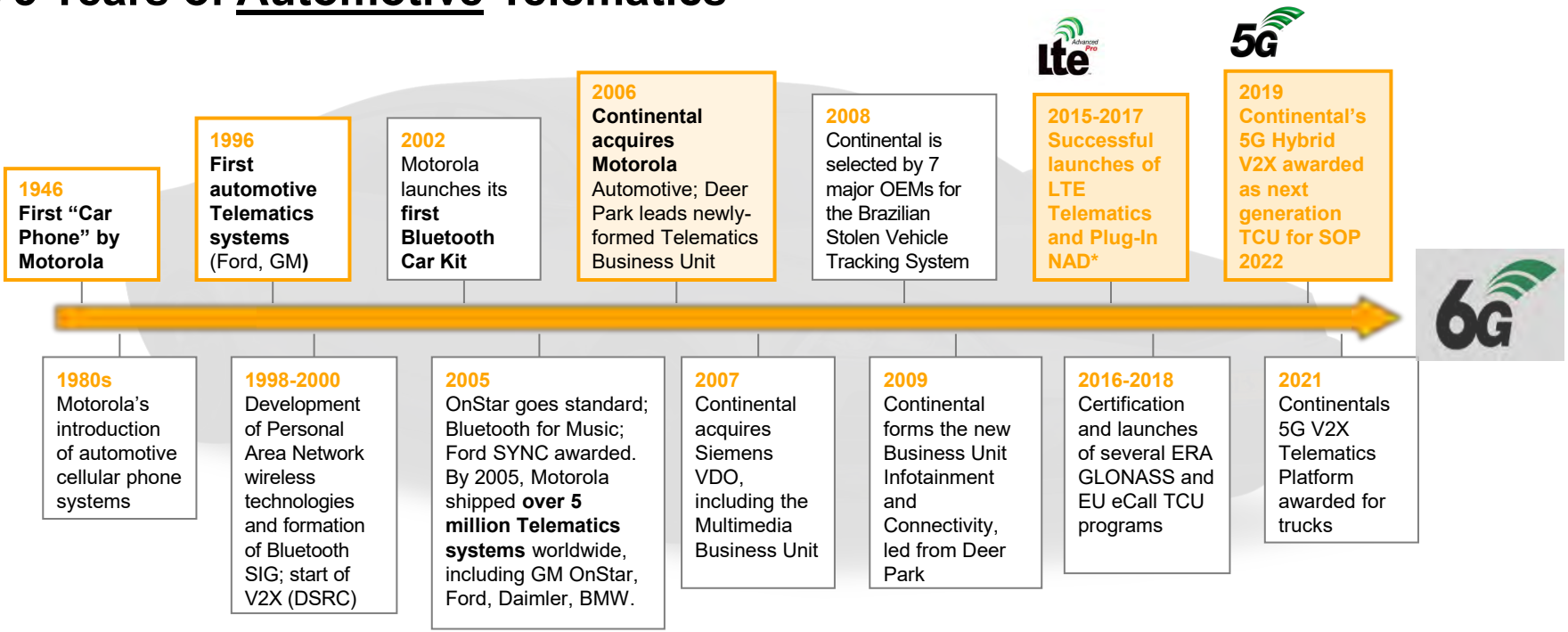
Automotive

Vehicular Communications
for Smart Mobility



About Continental

75 Years of Automotive Telematics



Sensing and Perception

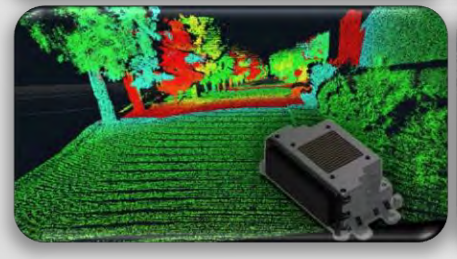
Enabling Autonomous Mobility and Safety

HRL131 Long Range LiDAR

Ultrasonic Sensor

Surround View System – SVS220

Advanced Radar Sensor - ARS540



Sensing and Perception

Enabling Autonomous Mobility and Safety

Automotive Radar

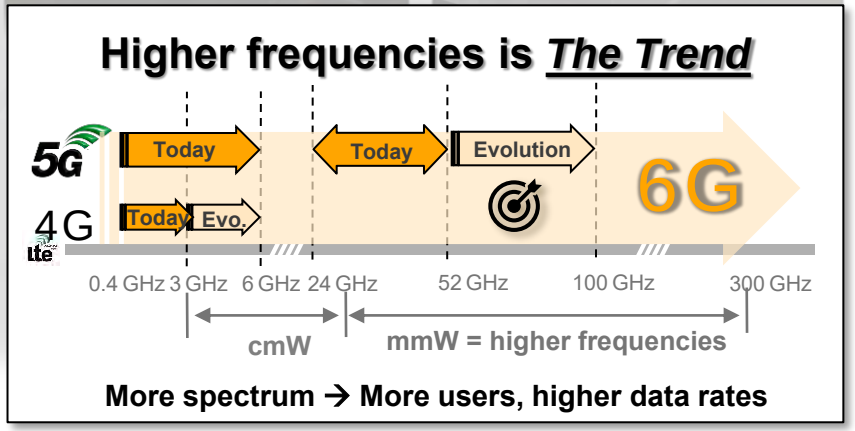
Applications:

- ☑ Collision Warning
- ☑ Adaptive Cruise Control
- ☑ Parking Aid
- ☑ Blind Spot Detection
- ☑ Lane Change Assistance, etc.

Importance:

- ☑ Safety
- ☑ mmW-based

- ☑ Convergence with Communications (!).



Sensing and Perception

Enabling Autonomous Mobility and Safety

Long Range Radar

Short Range Radar

Standardization // Frequency harmonization

- ☑ 24 GHz (ISM, UWB)
- ☑ 76-77 GHz: long-range
- ☑ 77-81 GHz: short-range

} 76-81 GHz

Regulations

- ☑ Electromagnetic compatibility (!)

Advances

- ☑ Semiconductors
- ☑ Packing and Assembly of ICs

Sensing and Perception

Enabling Autonomous Mobility and Safety

Antenna Technology

- ☑ Waveguide
- ☑ Planar microstrip

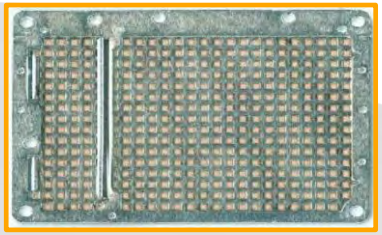
Beamforming

- ☑ Fixed beam (e.g., 3 beams)
- ☑ Mechanical scanning
- ☑ Digital beam forming

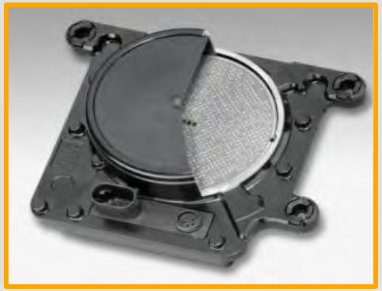
Range-Doppler Processing

- ☑ FMCW
- ☑ Pulse compression (Chirp)
- ☑ PMCW
- ☑ Digital (e.g., OFDM)

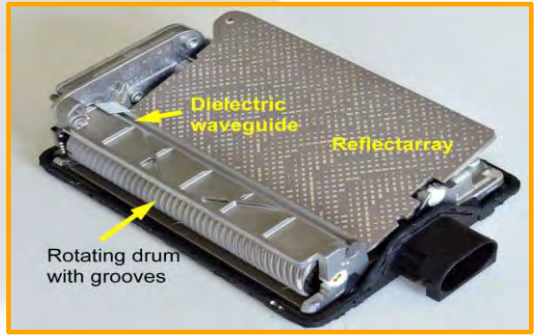
Waveguide



Planar patch



ARS200



ARS 300 antenna

Sensing and Perception

Enabling Autonomous Mobility and Safety

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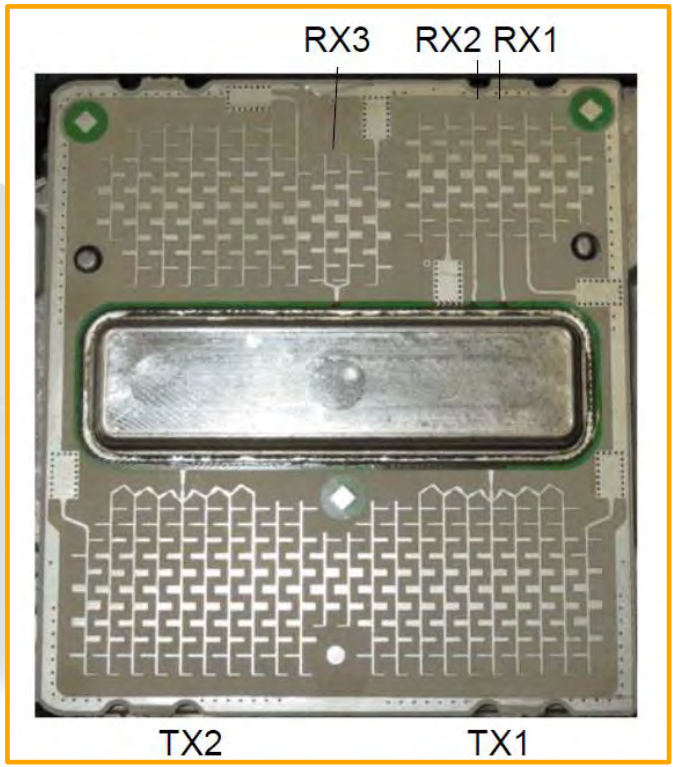

Sensing and Perception

Enabling Autonomous Mobility and Safety

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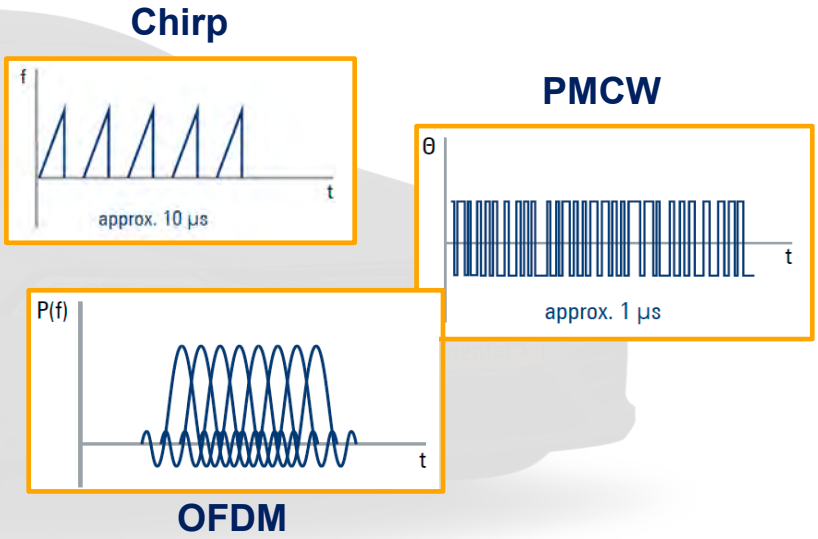


Sensing and Perception

Enabling Autonomous Mobility and Safety

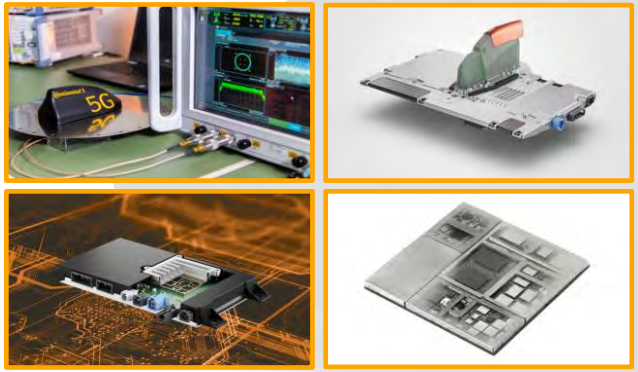
Opportunities:

- ☑ Interference
- ☑ Convergence with Communications
- ☑ Super-resolution
- ☑ Multi-purpose signaling

Communications

Enabling Vehicle Connectivity & Networking

Intelligent Antenna Modules (IAM)



Telematic Control Units (TCU)

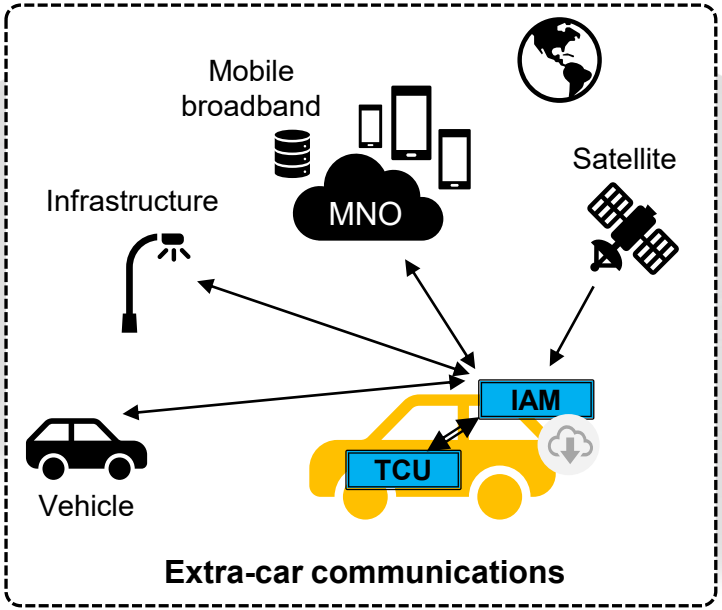
Network Access Devices (NAD)

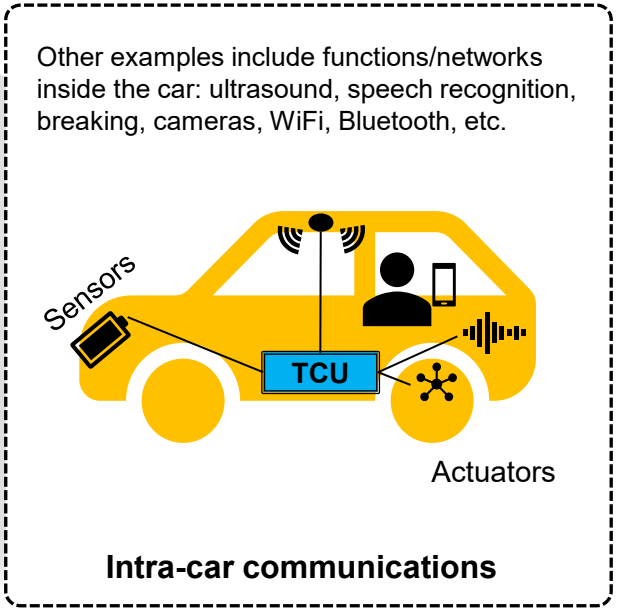
Communications

Enabling Vehicle Connectivity & Networking

Vehicles Connectivity: Intra- and extra-car communication.

Data: Car-centric and User-centric.



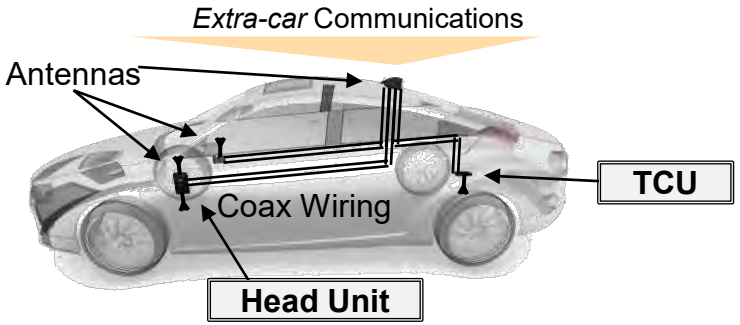


TCU: Telematic Control Unit, **IAM**: Intelligent Antenna Module, **MNO**: Mobile Network Operator.

Communications

Enabling Vehicle Connectivity & Networking

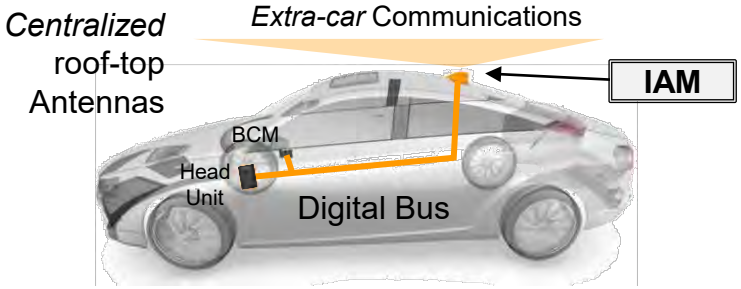
Antenna Modules



Classical Architecture

Benefits:

- ☑ Avoids expensive and heavy coaxial cables
- ☑ Saves space and weight
- ☑ Performance up due to less signal losses
- ☑ Higher flexibility with all wireless service in one unit

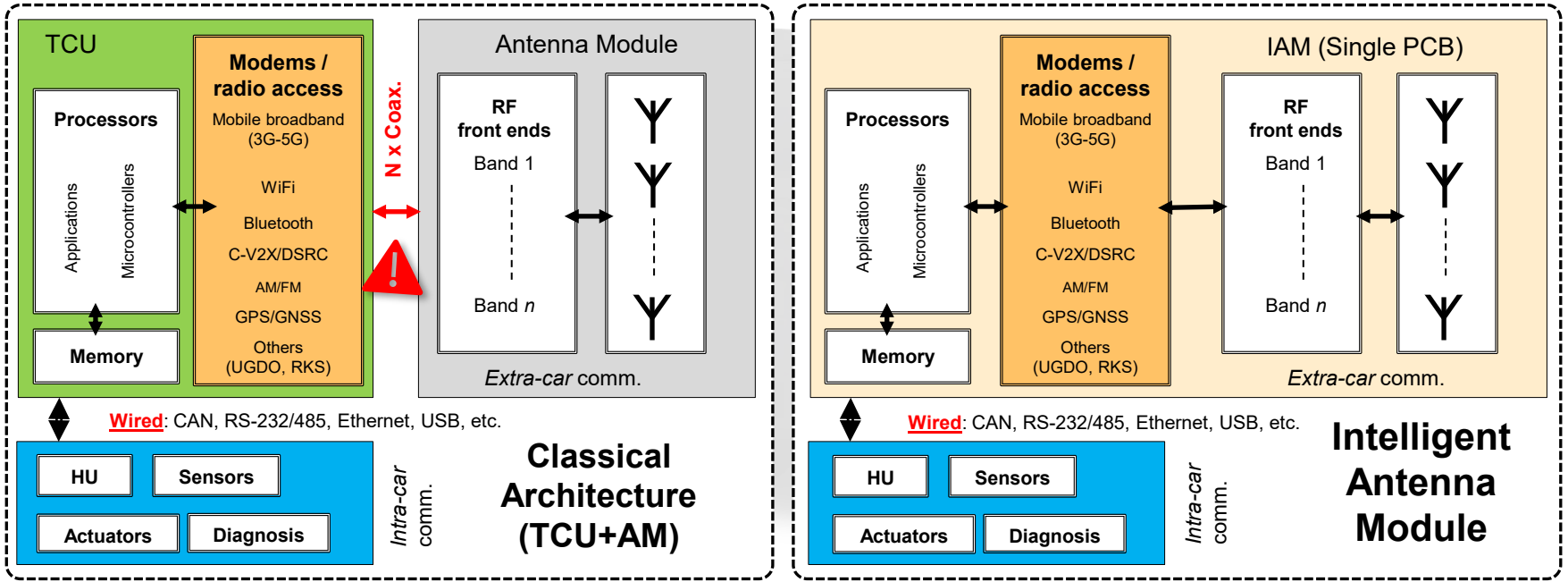


Intelligent Antenna Architecture

Communications

Enabling Vehicle Connectivity & Networking

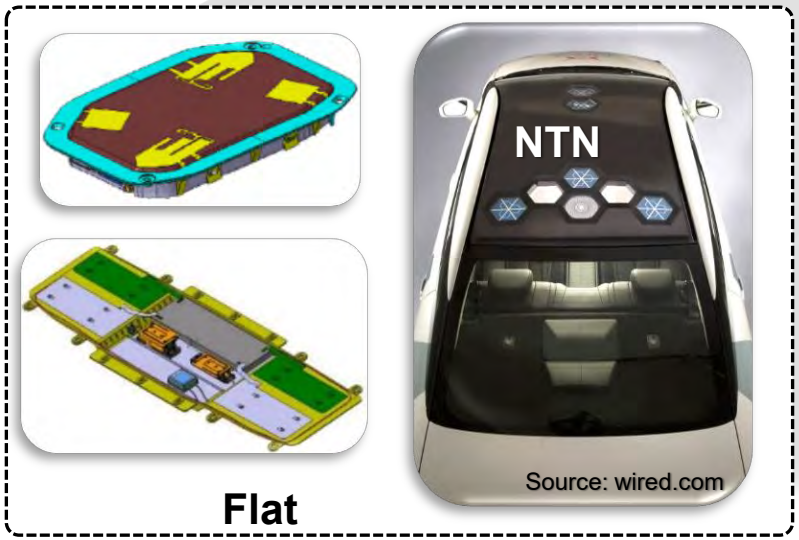
Architectures

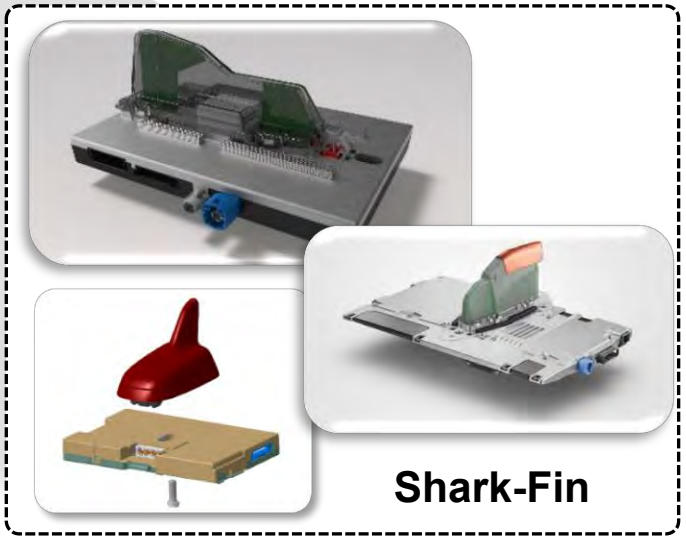


Communications

Enabling Vehicle Connectivity & Networking

Intelligent Antenna Module – Mechanical Integration Concepts

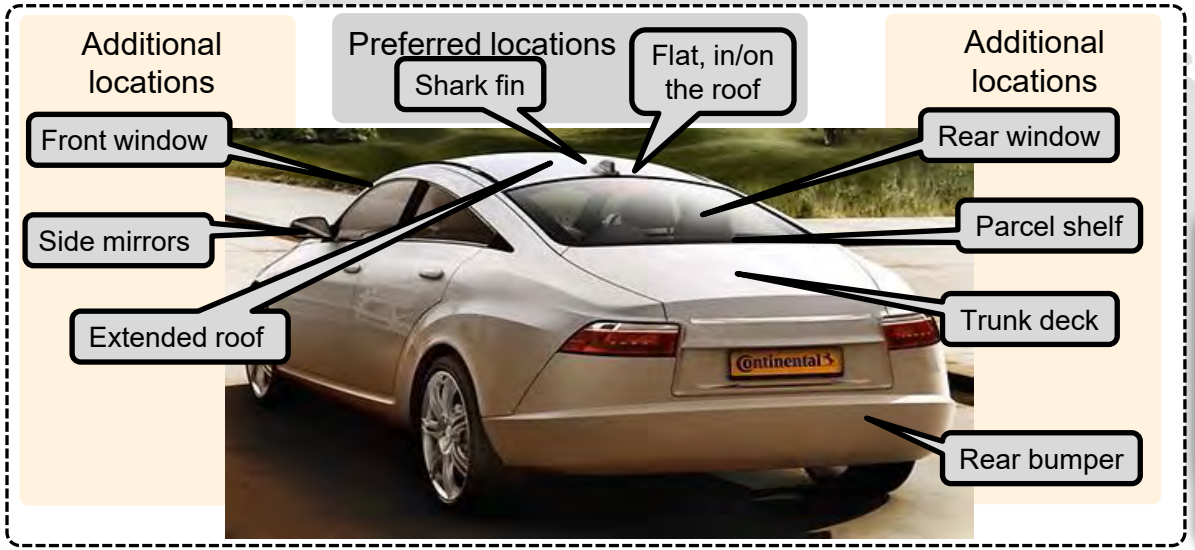




Communications

Enabling Vehicle Connectivity & Networking

Intelligent Antenna Module – Location and radiation patterns are key !!

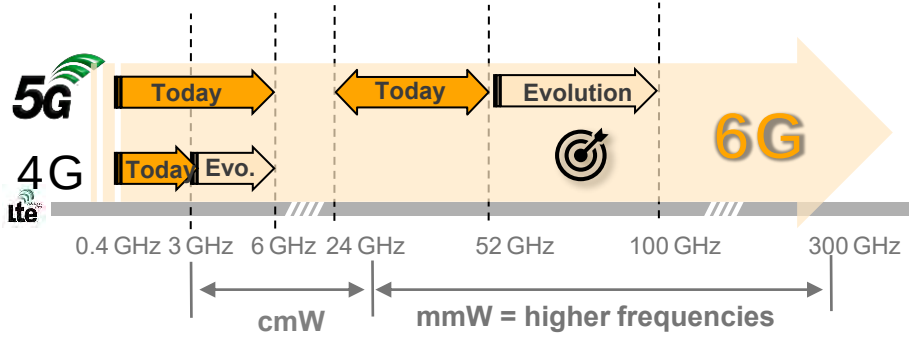


Communications

Enabling Vehicle Connectivity & Networking

Intelligent Antenna Module - mmW and Beyond

Higher frequencies is *The Trend*



More spectrum → More users, higher data rates

Bands	Frequency	Duplex
n1, n2, n3, n5, n7, n8, n20, n28, n38, n41, n50, n51, n66, n70, n71, n74, n75-84.	**FR1** < 6 GHz	FDD, TDD, SDL, SUL.
n257, n258, n259.	**FR2** 24.25 - 52.6 GHz	TDD
FR2+ 57 - 71 GHz		

Notes on RF exposure above 6 GHz

Regulations → reduced power levels (exposure limits) in FR2 w.r.t. FR1.

International Commission on Non-Ionizing Radiation (ICNIRP)

RF exposure standards: IEEE C95.1-2005, C95.1-2010a → inconsistencies

Carefull revision is needed → negative impact on coverage (FR2).

Communications

Enabling Vehicle Connectivity & Networking

NAD Solutions:
4G (LTE) to 5G (NR)

EDISON LTE CAT 3
MDM9x15 2x2 DL-MIMO
Quad GSM/EDGE
DC-HSPA+
42Mb DL/5.76Mb UL
CDMA 1xRTT/EvDO
TD&FD-LTE
100Mb DL/50Mb UL

1st Gen 9x15 LTE NAD
35 x 40mm

BELL LTE CAT 4
MDM9628 2x2 DL-MIMO
Quad GSM/EDGE
TDS-CDMA
DC-HSPA+
42Mb DL/5.76 Mb UL
TD&FD-LTE
150Mb DL/50Mb UL

2nd Gen 9628 LTE NAD
35 x 35mm

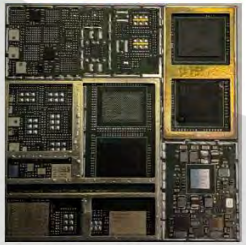
WATSON LTE-A CAT 11
MDM9x50 2x2 DL-MIMO
Quad GSM/EDGE
TDS-CDMA
DC-HSPA+
42MbDL/5.76Mb UL
TD&FD-LTE
600Mb DL/75Mb UL

3rd Gen 9250 LTE-A Pro NAD
40 x 40mm

FERMI LTE-A Pro CAT9
Cat19 optional
SA415 2x2 DL-MIMO
4x4 DL-MIMO optional
DC-HSPA+
42MbDL/5.76Mb UL
450Mb DL/75Mb UL
1.6Gpbs DL optional
Integrated Rel 14 C-V2X

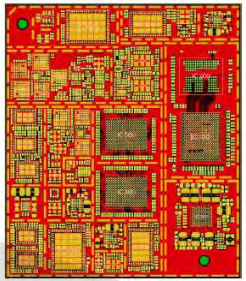
4th Gen SA415 LTE-A Pro
NAD with C-V2X
38 x 40mm

FERMI 5G NR
SA and non-SA w/EN-DC
SA515 4x4 DL-MIMO
Sub-6GHz 5G + refarmed 4G
5G 2x2 UL-MIMO optional
LTE-A Pro CAT 19
2CC intraband ULCA opt.
1.6Gb DL/200Mb UL on LTE
Integrated Rel 15 2Tx C-V2X



1st Gen SA515 5G
NAD with C-V2X
52 x 52mm

FERMI 5G NR w/ DSDA 4G CAT6
Same as **FERMI 5G-NR PLUS:**
Dual SIM Dual Active support with
SIM2 2G,4G 300Mb DL/50Mb UL



1st Gen SA515 5G DSDA
NAD with C-V2X
60 x 52mm

FERMI LTE CAT 4
SA415 2x2 DL-MIMO
Quad GSM/EDGE
DC-HSPA+
42Mb DL/5.76 Mb UL
TD&FD-LTE
150Mb DL/50Mb UL

4G Cat 4 Low Cost LTE NAD with C-V2X
38 x 40mm

5G

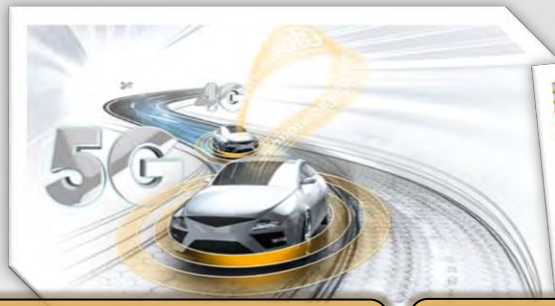
Release15
and Beyond

Smart Mobility

Always On – Securely Connected

› **Enabling Technologies**

› Wireless Communications Technologies → (Wireless) Connectivity



Automotive contribution to Standardization of Mobile Broadband

Research and Innovation

Smart Mobility

Always On – Securely Connected

› **Enabling Technologies**

› Wireless Communications Technologies → **(Wireless) Connectivity**

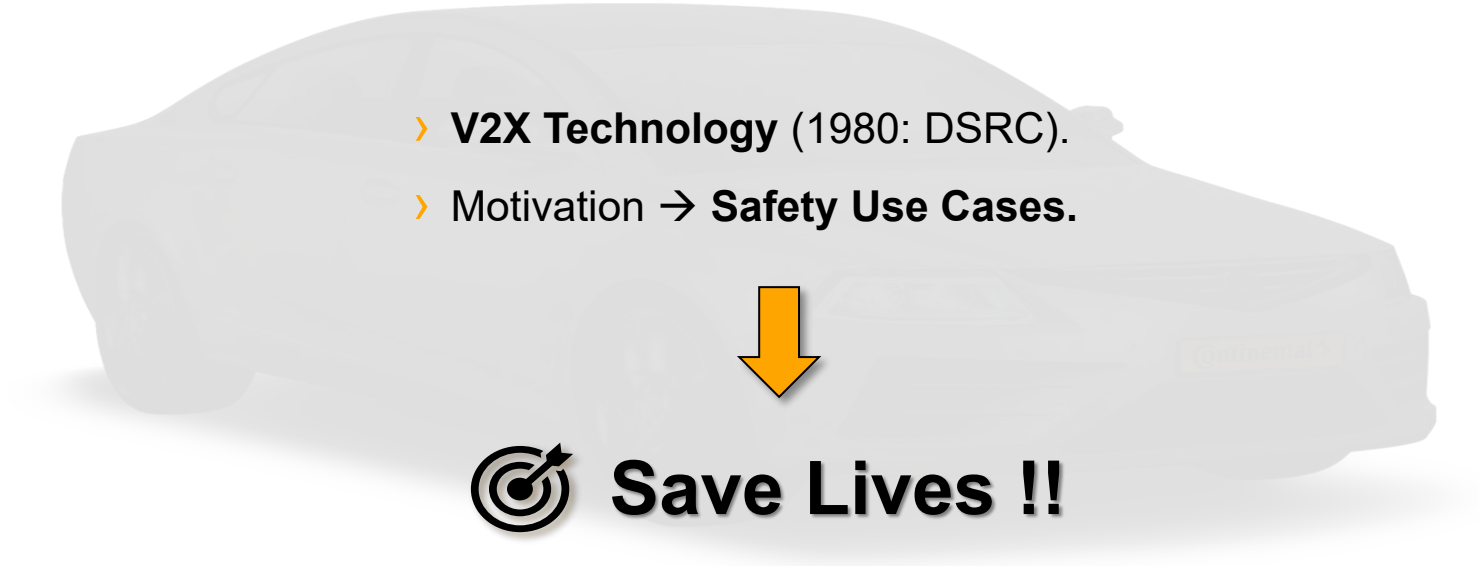
2020 technical fields in view of patent applications*

1. Medical
2. **Digital Communications**
3. Computer Technology
4. Electric Machinery, apparatus, energy
5. **Transportation**

*Source:
European Patent Office

Smart Mobility

First of all, it's about Safety

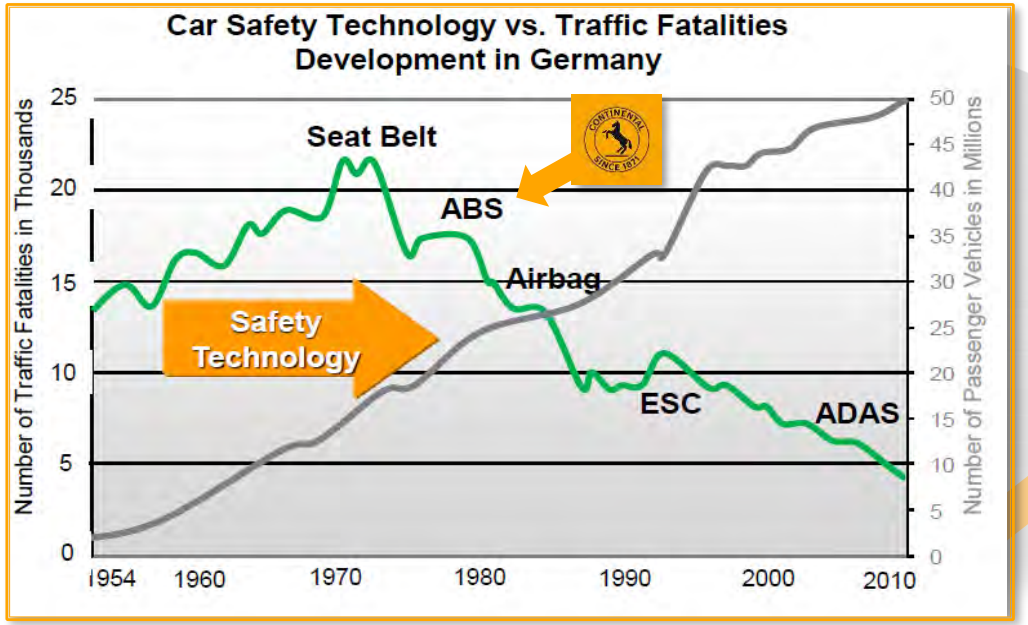


- **V2X Technology** (1980: DSRC).
- Motivation → **Safety Use Cases.**

Save Lives !!

Smart Mobility

First of all, it's about Safety



V2X:
Technology
for Safety

Cellular-V2X

LTE Advanced Pro

5G

3GPP A GLOBAL INITIATIVE

→ 2022

… and several other technologies
are being developed for that !!

ADAS: **Advanced Driver Assistance Systems**

Smart Mobility

First of all, it's about Safety

Automotive Culture: *Done is not better than Perfect.*

Safety First !!

Connectivity

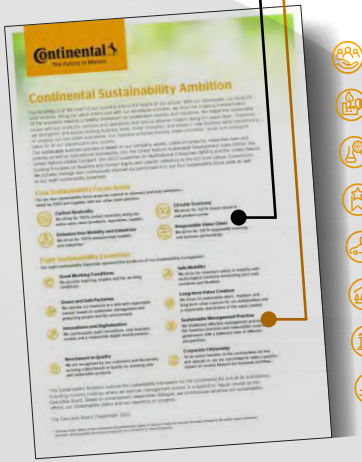
Smart Mobility

It's about Sustainability

Our Key Ambitions

By 2050 at the latest, we and our value chain partners are striving for:

- **100%** **Carbon neutrality** along our entire value chain
- **100%** **Emission-free mobility and industry**
- **100%** **Circular economy**
- **100%** **Responsible value chain**



+ 8 Essentials

- Good working conditions
- Green and safe factories
- Innovations and digitalization
- Benchmark in quality
- Safe mobility
- Long-term value creation
- Sustainable management practices
- Corporate citizenship

Foster innovation and phase in new business

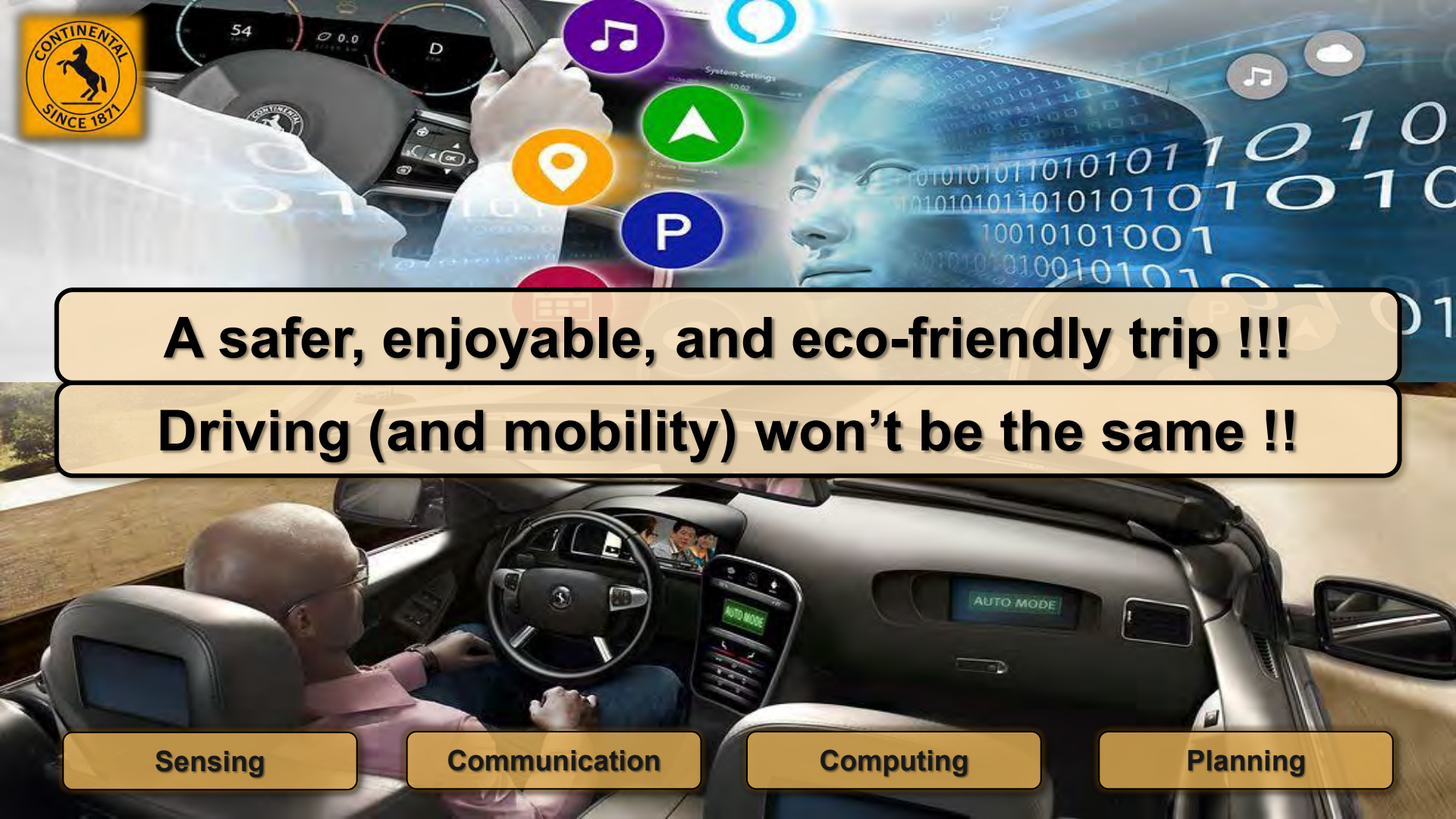
Transform or phase out non-viable business

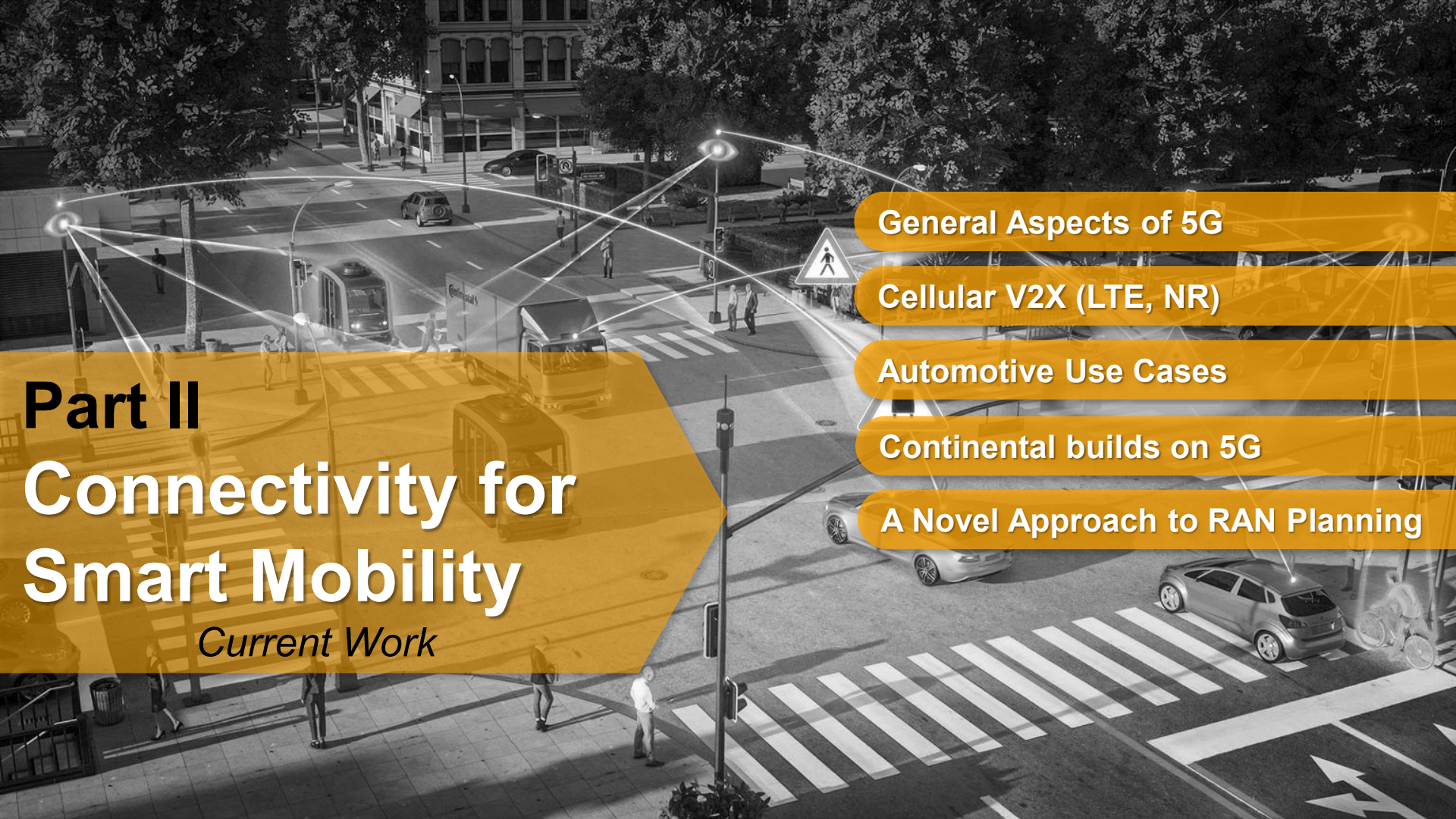
Sustainable business practices

Smart Mobility

It’s about Sustainability

Our Ambitions for a Sustainable Future


CONTINENTAL
SINCE 1871
A safer, enjoyable, and eco-friendly trip !!!
Driving (and mobility) won't be the same !!
AUTO MODE
Sensing
Communication
Computing
Planning



Part II
Connectivity for Smart Mobility

Current Work

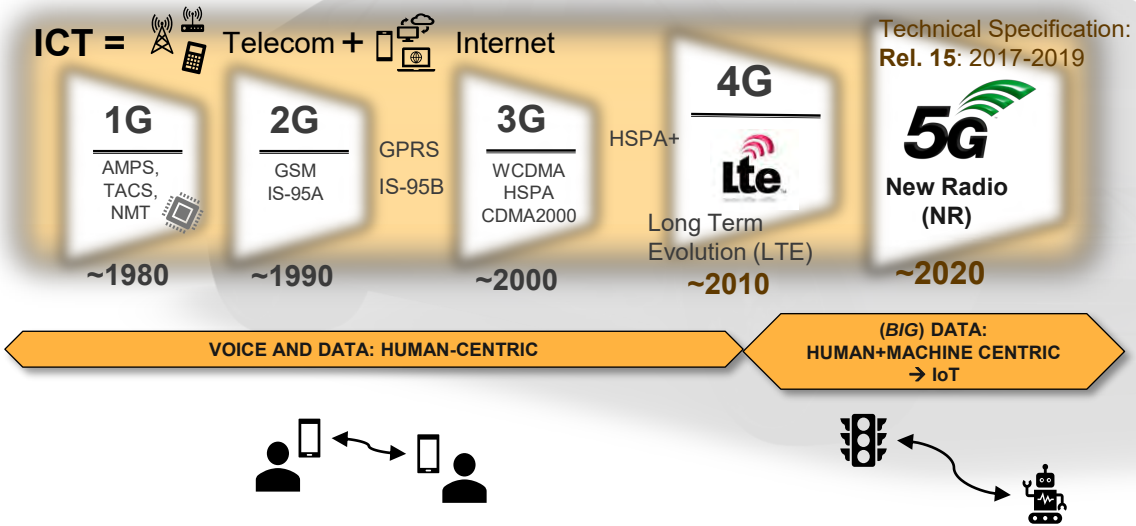
- General Aspects of 5G
- Cellular V2X (LTE, NR)
- Automotive Use Cases
- Continental builds on 5G
- A Novel Approach to RAN Planning

General Aspects of 5G

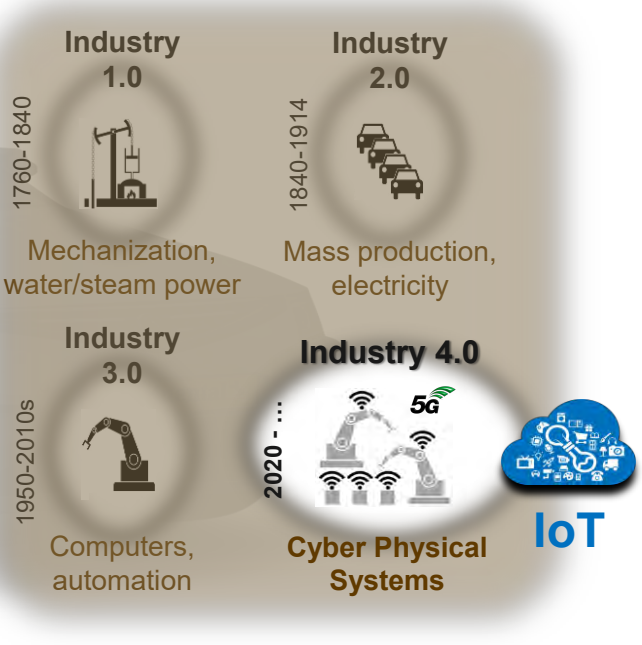
Mobile Communications

Evolution of Mobile Communications

ICT: **I**nformation & **C**ommunications **T**echnologies

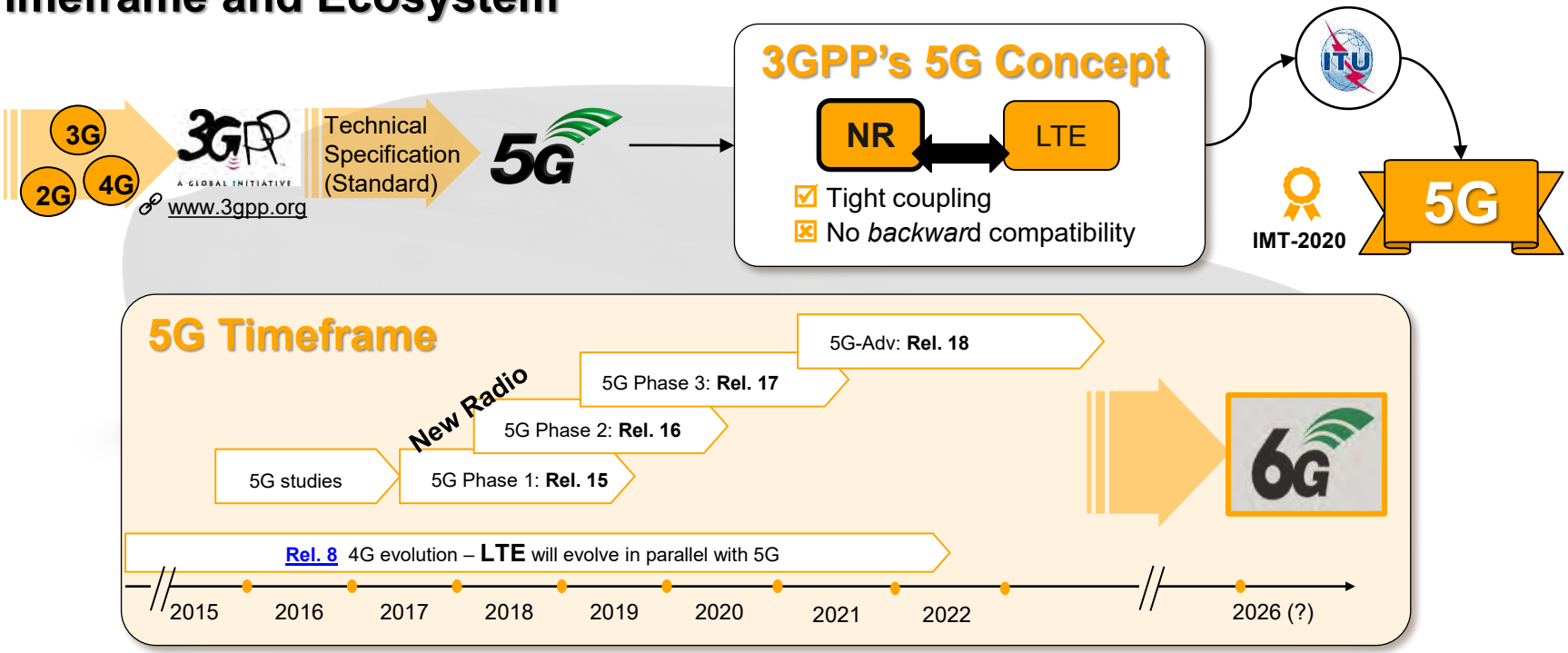


Industrial Evolution



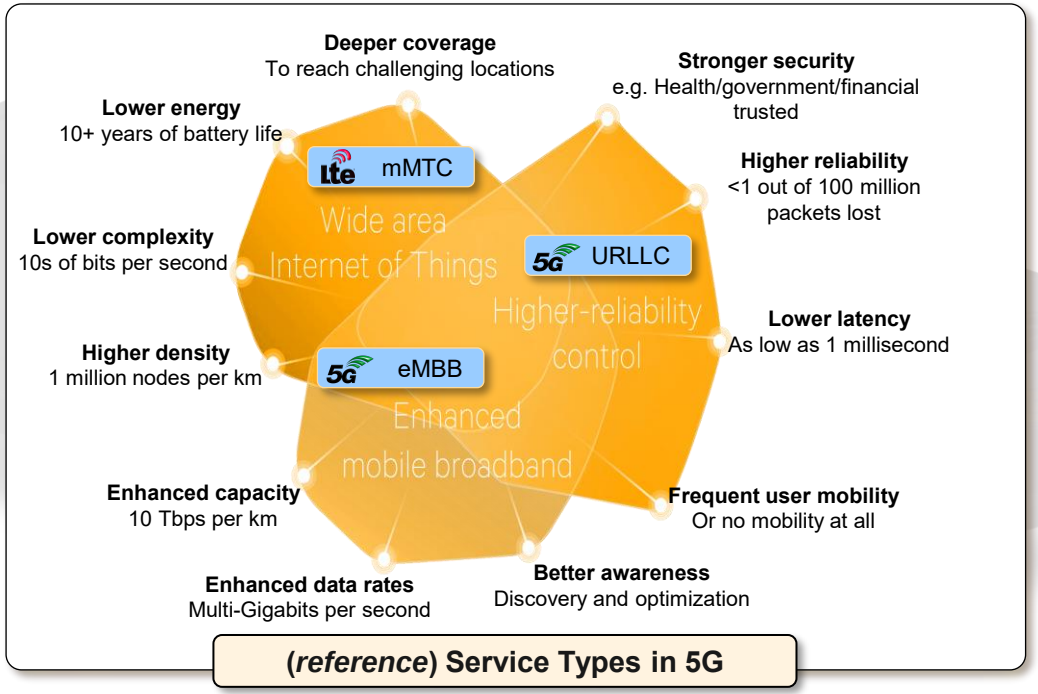
General Aspects of 5G

Timeframe and Ecosystem



General Aspects of 5G

Reference Service Types and Requirements



General Aspects of 5G

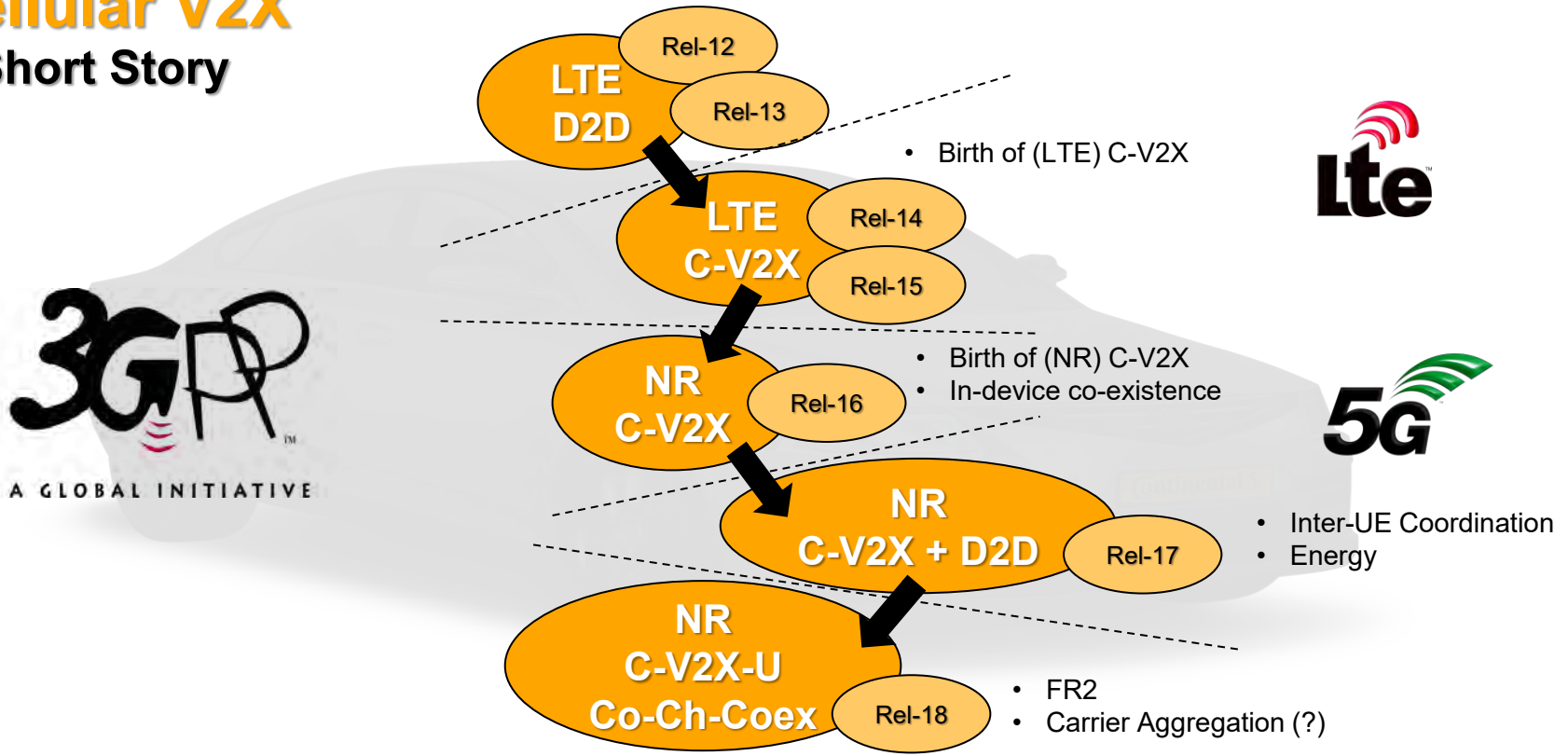
5G support for Advanced Automotive Use Cases

Opportunities:

- ☑ Mobility in FR2
- ☑ AI-powered RAN
- ☑ Non-Terrestrial Networks
- ☑ Positioning (many use cases and techniques)

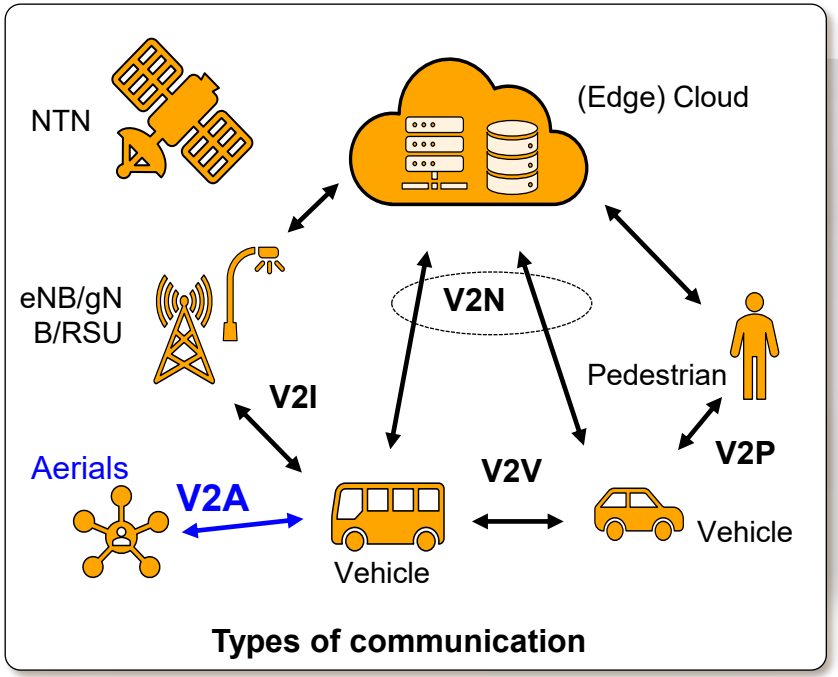
Cellular V2X

A Short Story

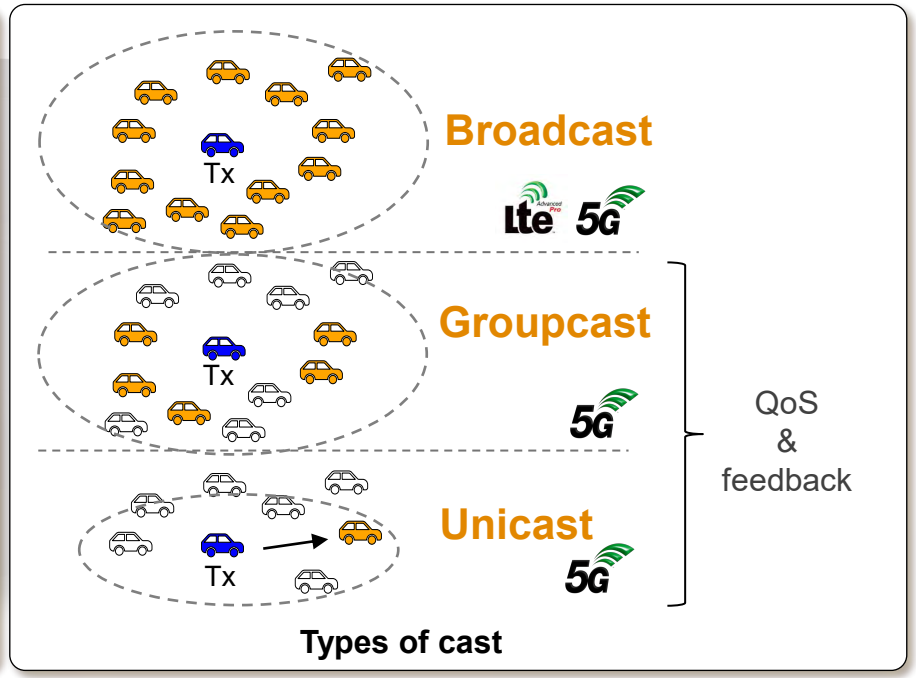


Cellular V2X

Essentials



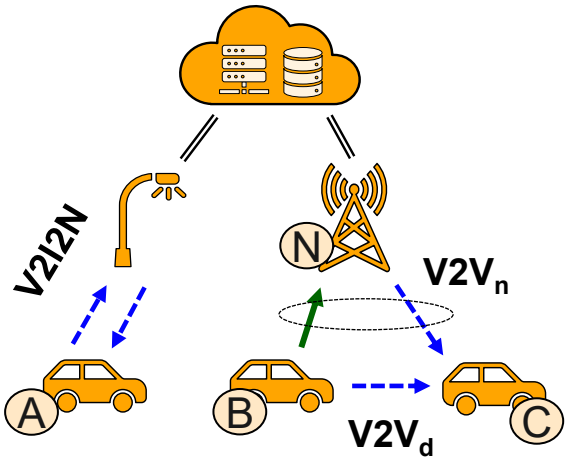
Types of communication



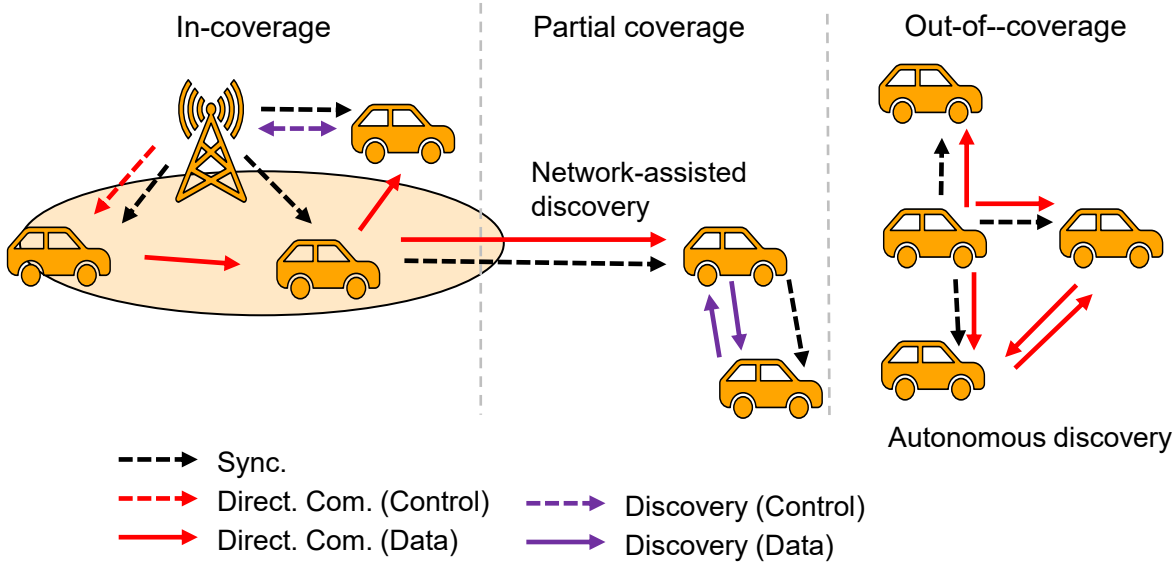
Types of cast

Cellular V2X
Essentials

Direct and Network-based communication

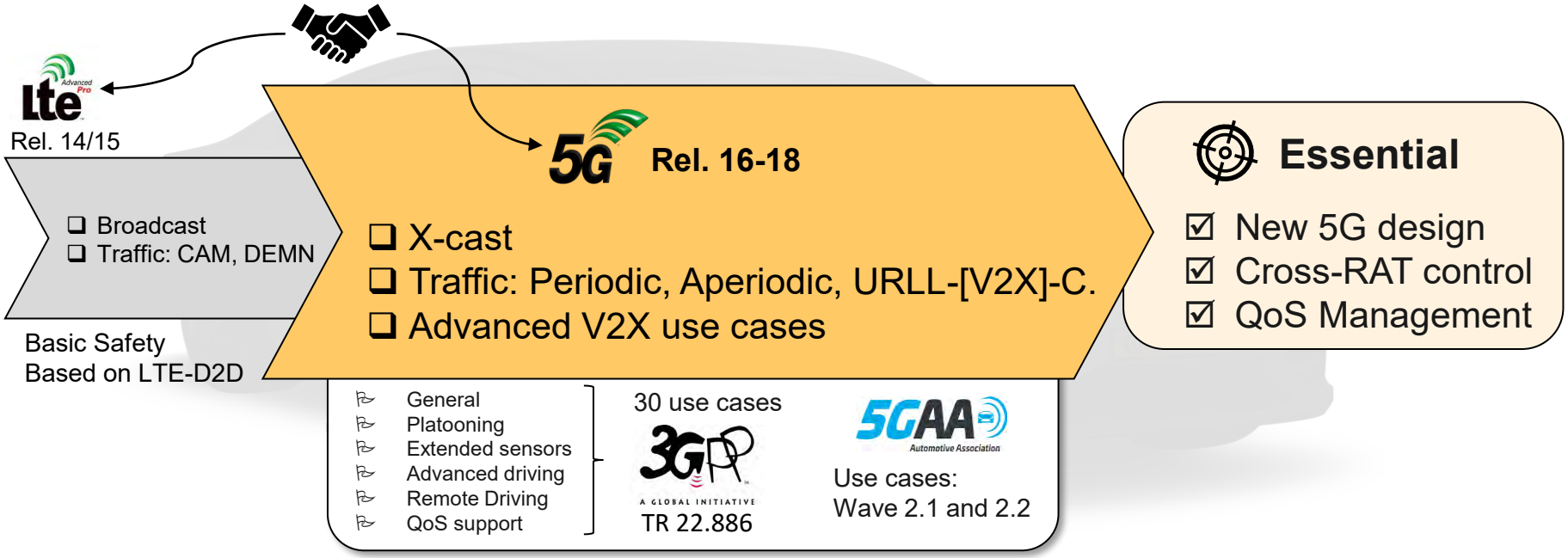


Different coverage scenarios, sync. Options, and resource allocation modes



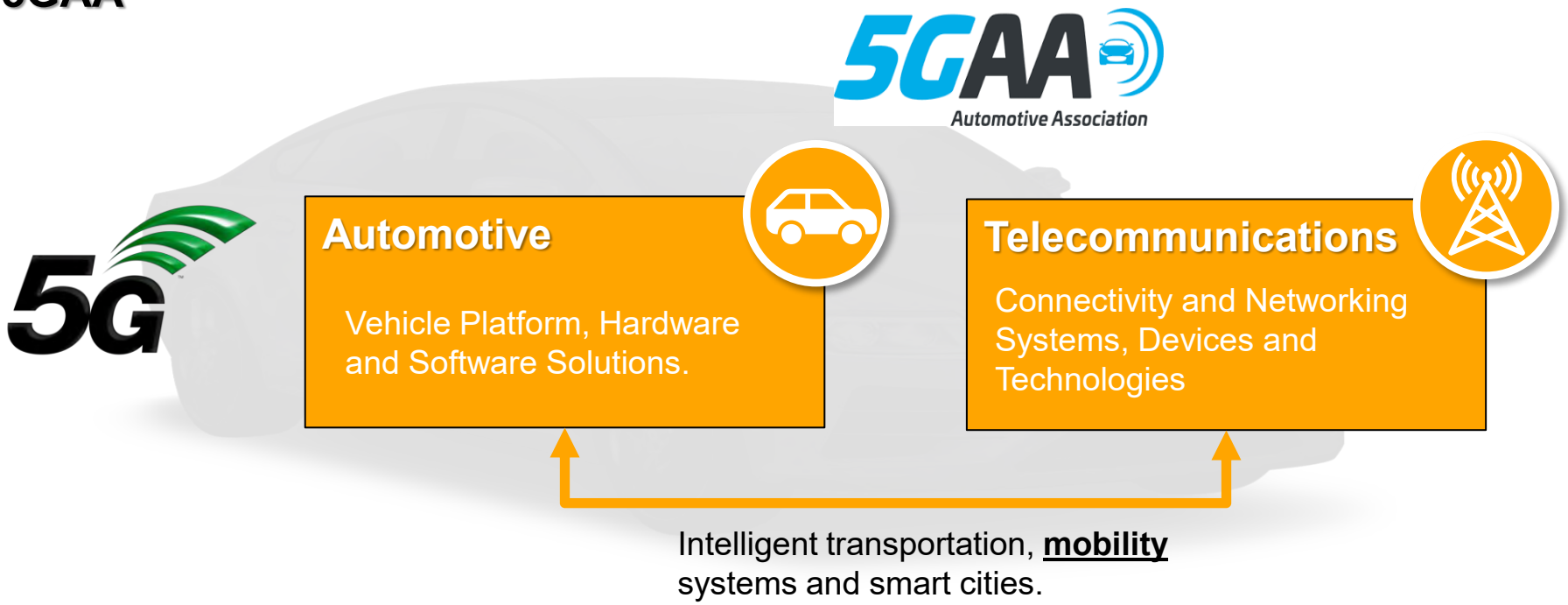
Automotive Use Cases

Requirements from the Automotive Sector



Automotive Use Cases

5GAA



Automotive Use Cases

5GAA – WG1: Use Cases and Technical Requirements

- Classification (category):
  - Safety
    - ✓ Emergency Braking, Collision warning, or Lane change
  - vehicle operations management
    - ✓ Sensors monitoring, software updates, remote support
  - convenience
    - ✓ Infotainment, and autonomous smart parking
  - autonomous driving
    - ✓ Tele-operation, and handling of dynamic maps
  - Platooning
    - ✓ Collect and establish a platoon, determine position in platoon, dissolve a platoon, leave a platoon
  - traffic efficiency and environmental friendliness,
    - ✓ Traffic jam information, Routing advise e.g., Smart routing.
  - society and community.
    - ✓ Vulnerable Road User (VRU) protection, traffic light priority

Automotive Use Cases

5GAA – WG1: Use Cases and Technical Requirements

› Definitions

Road Environment	**typical places** where vehicle traffic and C-V2X use cases occur
Use Case	**high level procedures** of executing an application in a particular situation with a specific purpose.
Use Case Scenario	specific use case scenarios can be derived for different situations that may imply in **different specific requirements**

› Service Level Requirements { range, information requested/generated, service level latency, service level reliability, velocity, vehicle density, positioning, and need for interoperability, regulatory efforts, and/or, standardization.

Automotive Use Cases

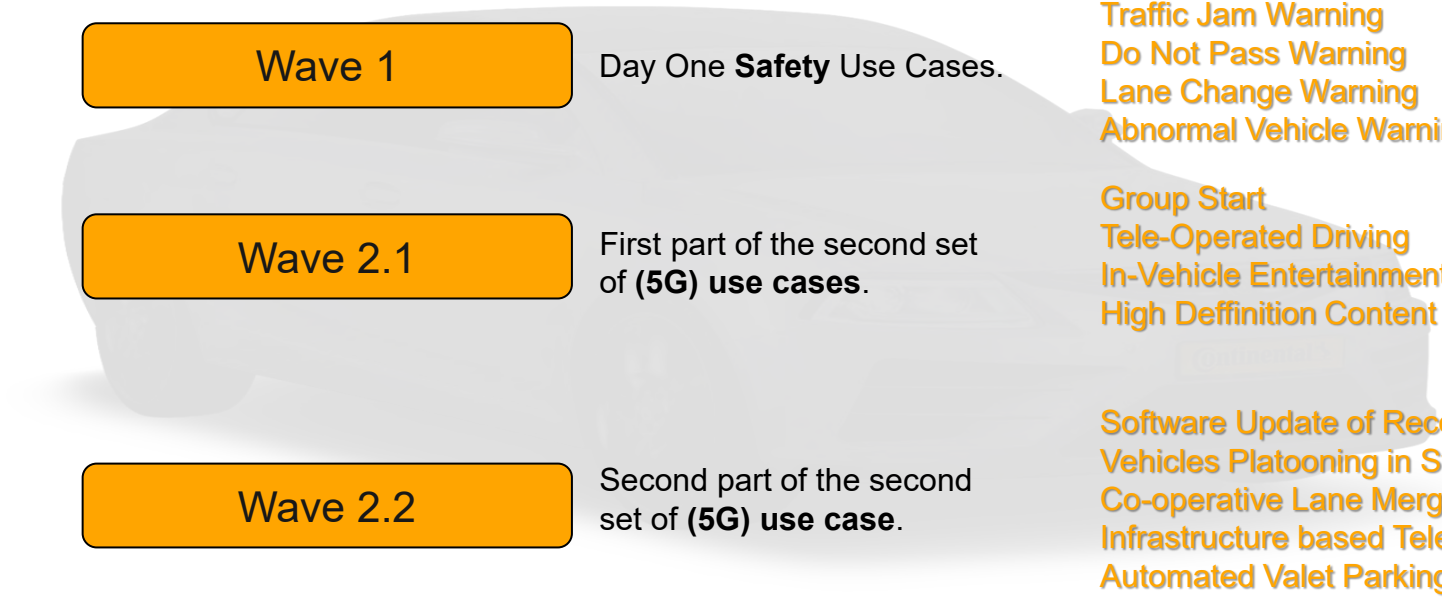
5GAA – WG1: Use Cases and Technical Requirements

› Templates for Use Case Descriptions

Name	Actors	Constraints
Use Case Scenario	Vehicle Roles	Illustrations
Category	Road & Roadside Infrastructure Roles	
Road Environment	Goal	Pre-Conditions
Short Description	Needs	Main Event Flow

Automotive Use Cases

5GAA – WG1: Use Cases and Technical Requirements



Wave 1 — Day One **Safety** Use Cases.

- Traffic Jam Warning
- Do Not Pass Warning
- Lane Change Warning
- Abnormal Vehicle Warning

Wave 2.1 — First part of the second set of **(5G) use cases**.

- Group Start
- Tele-Operated Driving
- In-Vehicle Entertainment
- High Deffinition Content Delivery

Wave 2.2 — Second part of the second set of **(5G) use case**.

- Software Update of Reconfigurable Radio
- Vehicles Platooning in Steady State
- Co-operative Lane Merge
- Infrastructure based Tele-Operated Driving
- Automated Valet Parking (Wake Up)

Automotive Use Cases

5GAA

- **Roadmap** for mass Deployment of C-V2X use cases.
- **Trends**: Predictive QoS, DAS, MEC (multi-MNO), Safety Treatment, etc.
- **Other Working Groups**:
  - System Architecture and Solution Development,
  - Evaluation, Testbeds and Pilots,
  - Standards and Spectrum,
  - Business Models and Go-To-Market Strategies,
  - Regulatory and Public Affairs,
  - Security and Privacy.

More Info:
https://5gaa.org/

Automotive Use Cases

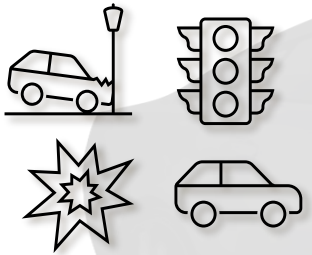
Continental's view

Future of Mobility with C-V2X technology at **IAA Mobility Conference 2021**. Munich Sept. 2021.

Thinknet 6G Summit 2021: *6G Use Cases from the Automotive and Mobility Sector.* Munich Nov. 2021.

Continental Builts on 5G

Some Examples of Intelligent Transport Services



Collision Warning

- Efficient, reliable, and real-time distribution of data among road users, smart infrastructure, and applications.
- Edge-Cloud of different Mobile Network Operators.

From: 01:13

Continental Builts on 5G

Some Examples of Intelligent Transport Services

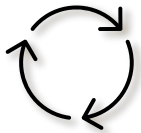
Continental Automotive - Digital Guardian Angel (continental-automotive.com)

Continental Builts on 5G

Some Examples of Intelligent Transport Services

Vulnerable Road Users

- Cell load and vehicle mobility impact end-2-end latency.
- MEC system optimisations and 5G radio will reduce latency further.



See

AI and video camera in vehicle

Analyse & Predict

AI in network edge cloud

Alert and brake

Vehicle

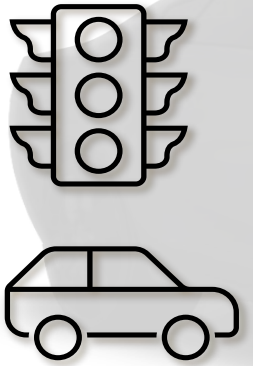
Continental Builts on 5G

Some Examples of Intelligent Transport Services

Connected Mobility – Digitaler Fußgängerschutzschild

Continental Builts on 5G

Some Examples of Intelligent Transport Services



Intelligent Traffic Light Assist

Continental Builts on 5G

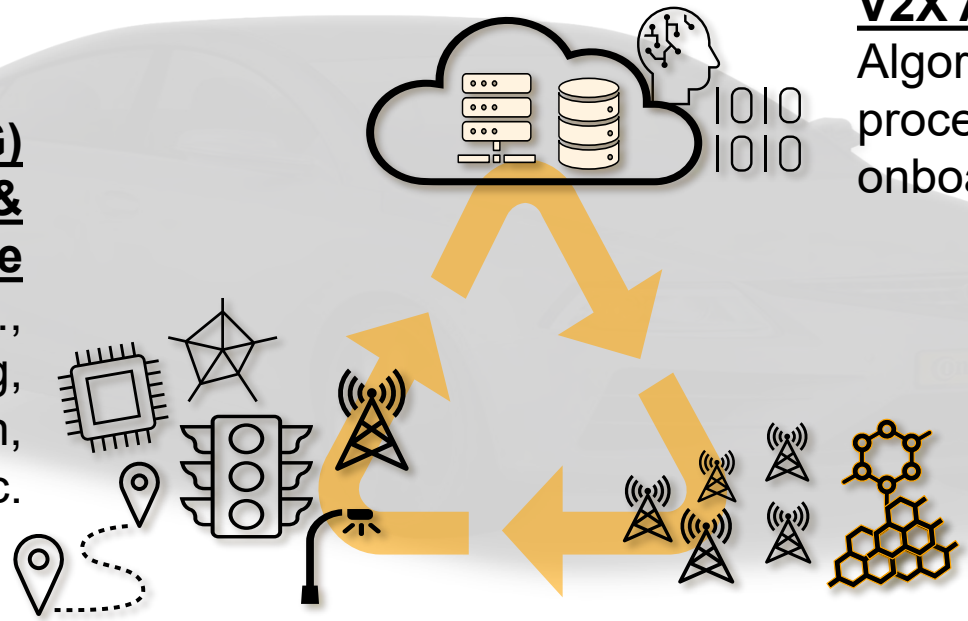
Some Examples of Intelligent Transport Services

Continental: Intelligent Traffic Light Assist

Continental Builts on 5G

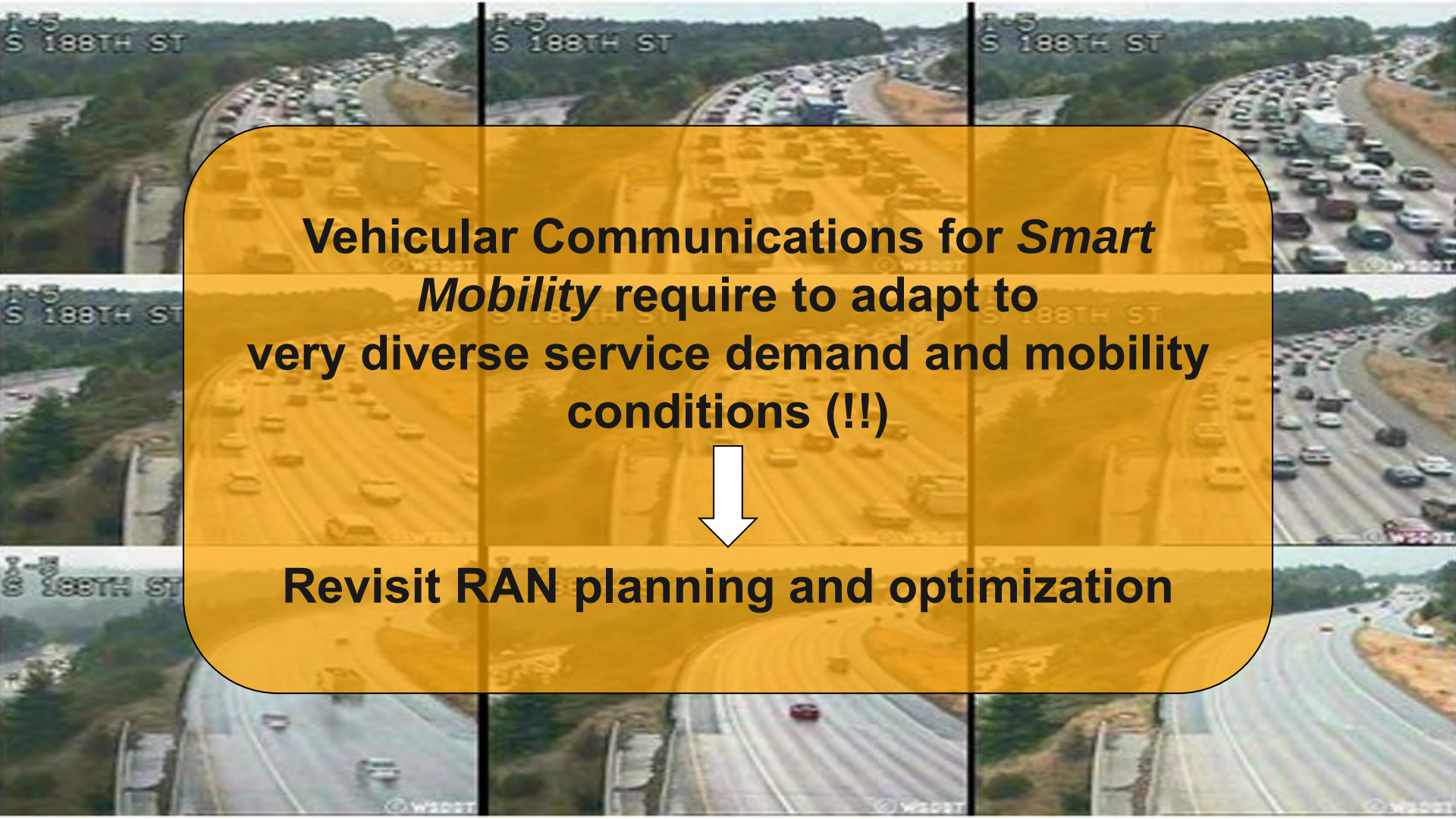
Some Examples of Intelligent Transport Services

(4G/5G) Infrastructure & Hardware
Connectivity (e.g., PHY), sensing, prediction, positioning, etc.



V2X Applications
Algorithms, data fusion, processing (e.g., MEC, onboard), AI, etc.

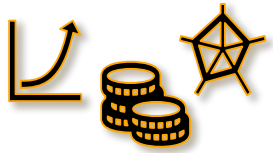
RAN Planning
System-centric techniques, optimization.


Vehicular Communications for *Smart Mobility* require to adapt to very diverse service demand and mobility conditions (!!)
Revisit RAN planning and optimization

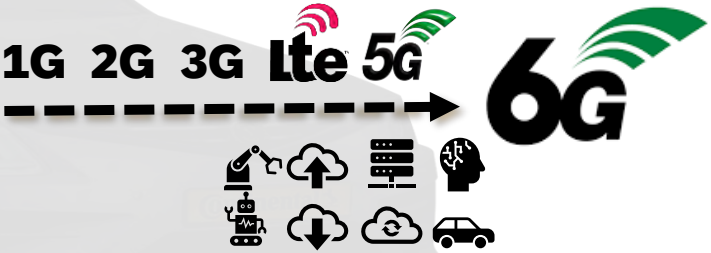
A Novel Approach to RAN Planning

Essentials of Network Planning, and *all that*

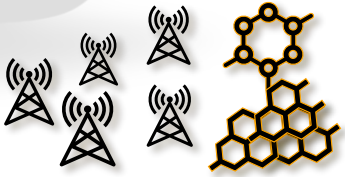
- **Mobile broadband**: exponential growth, quality expectations, cost, etc.



- **Mobile broadband <u>evolution</u>**: complexity.



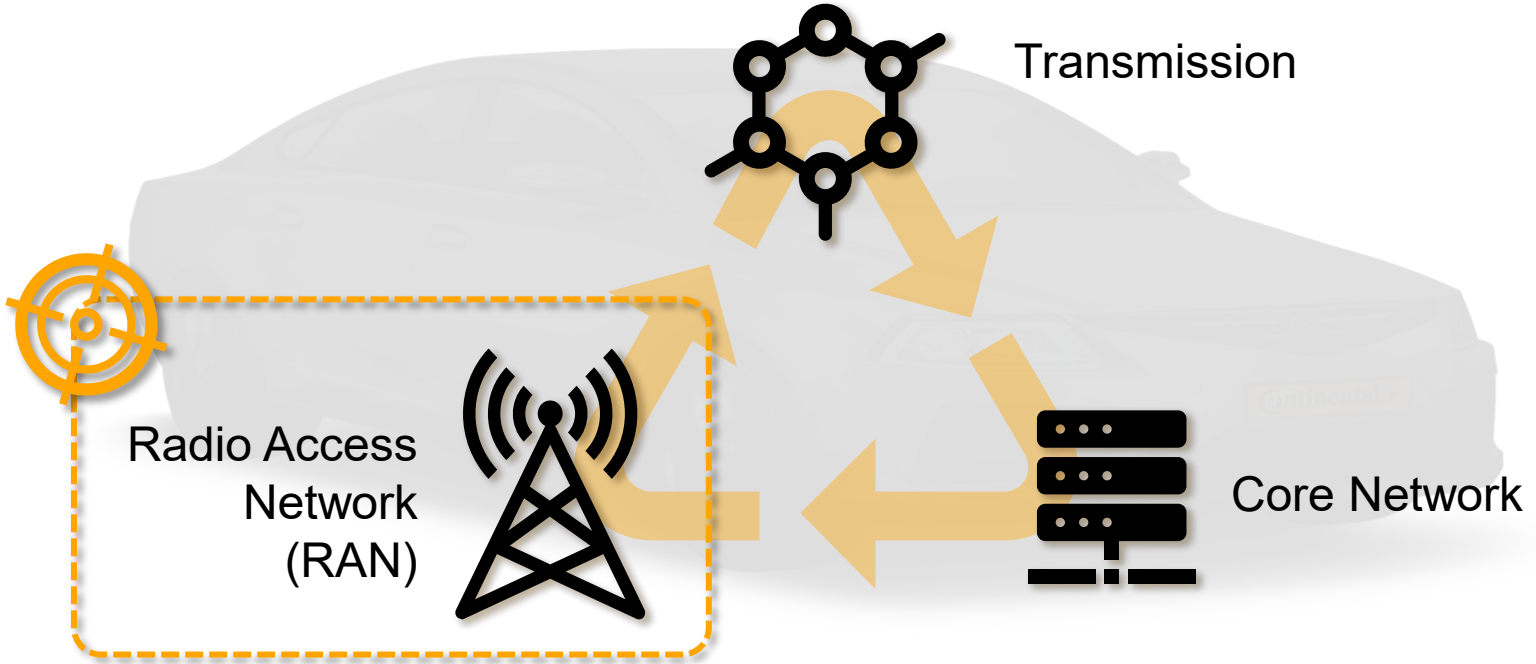
- **Network Planning and Optimization**: also complex ...



… but important !!

A Novel Approach to RAN Planning

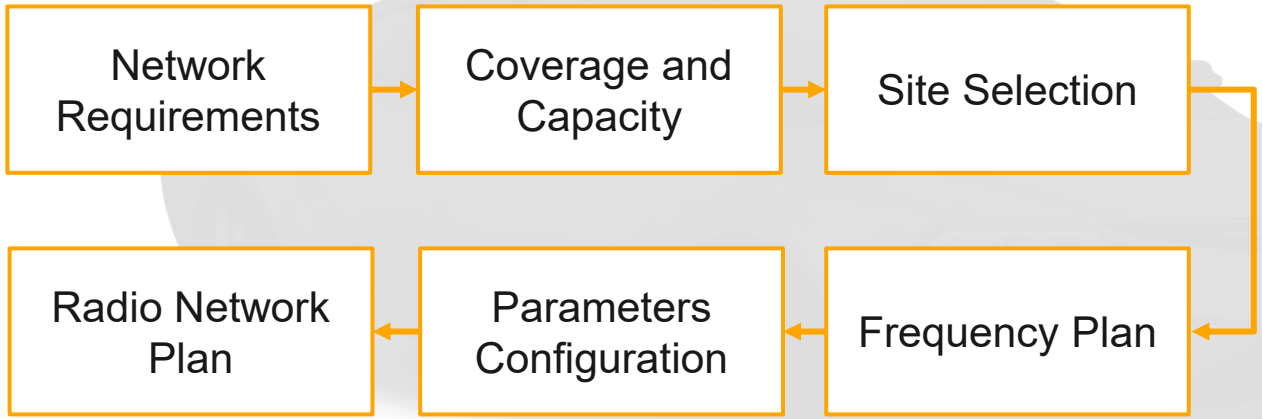
Essentials of Network Planning, and *all that*

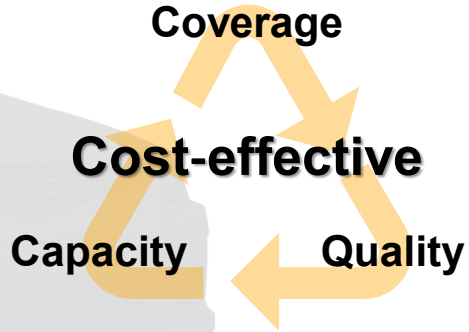


A Novel Approach to RAN Planning

Essentials of Network Planning, and *all that*

Conventional Radio Network Planning



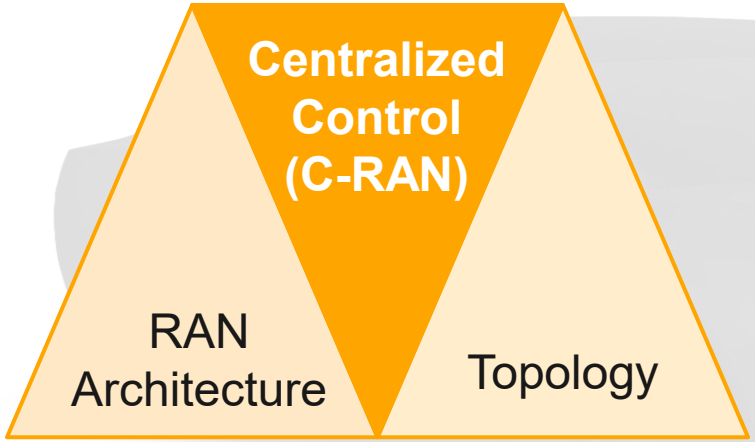


Specific aspects applies to each Radio Access Technology (RAT)

A Novel Approach to RAN Planning

Essentials of Network Planning, and *all that*

C-RAN: Cloud Radio Access Network



✓ Spectral efficiency and cost saving

✓ Flexibility (!!)

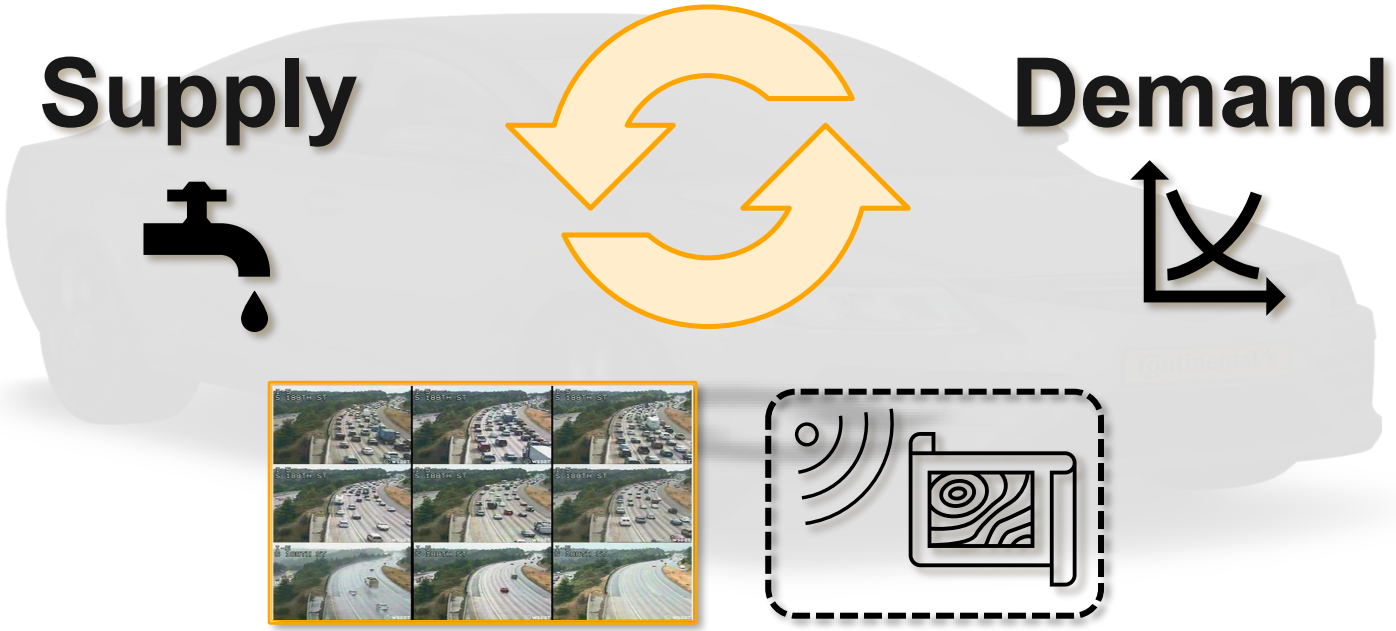
✗ Transmission Infrastructure
- o distance / latency
- o bandwidth
- o redundancy

Optimization: cost vs. performance

→ **Multiple (conflicting) Criteria**

A Novel Approach to RAN Planning

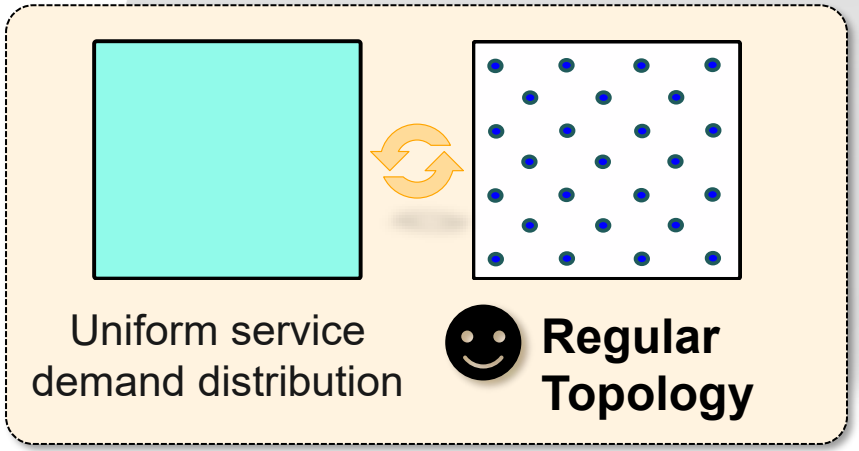
Essentials of Network Planning, and *all that*

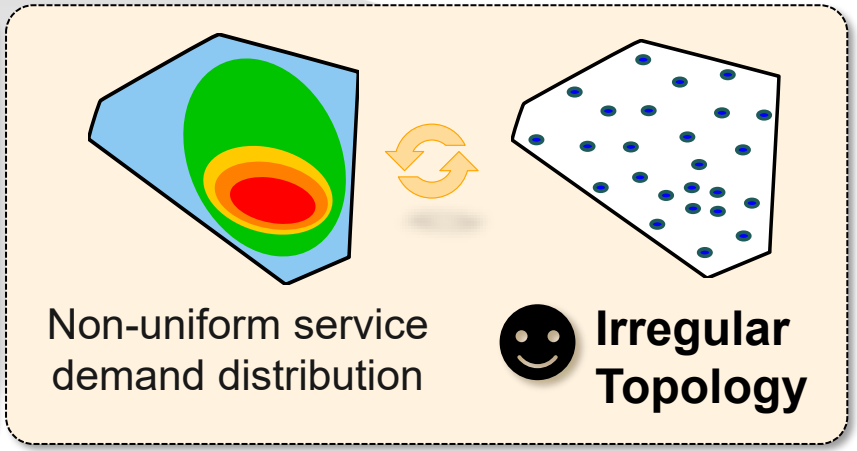


A Novel Approach to RAN Planning

Transformations and Spatial Mappings – why?

RAN planning/optimization is a *spatio-temporal* problem …





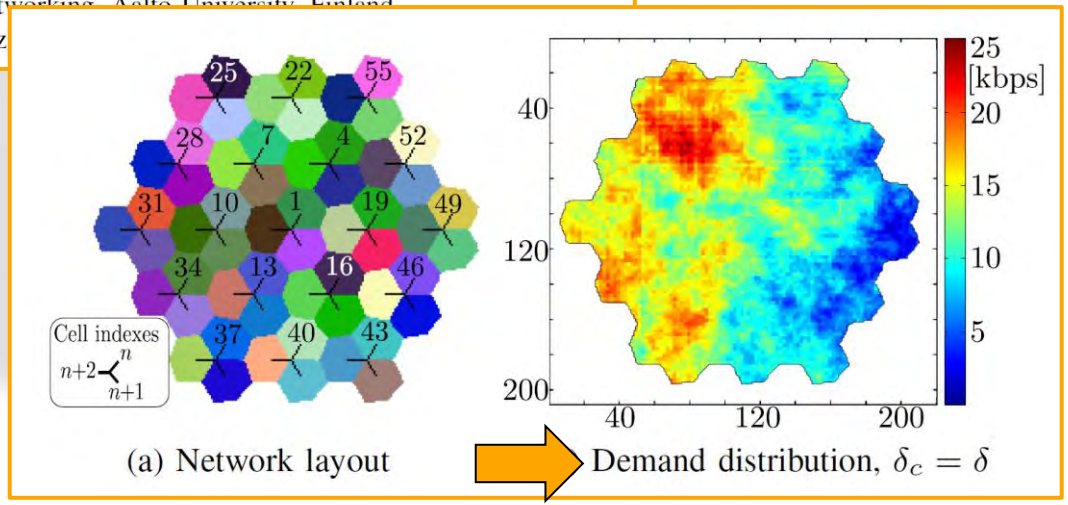
A Novel Approach to RAN Planning

Transformations and Spatial Mappings – initial observations

Topology and Irregularity in Cellular Networks

2015

David González G and Jyri Hämäläinen
Department of Communications and Networking, Aalto University, Finland
Emails: {david.gonzalezgonzalez



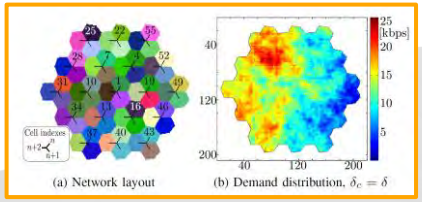
(a) Network layout

Demand distribution, $\delta_c = \delta$

Supply – Demand
"*Compatibility*"

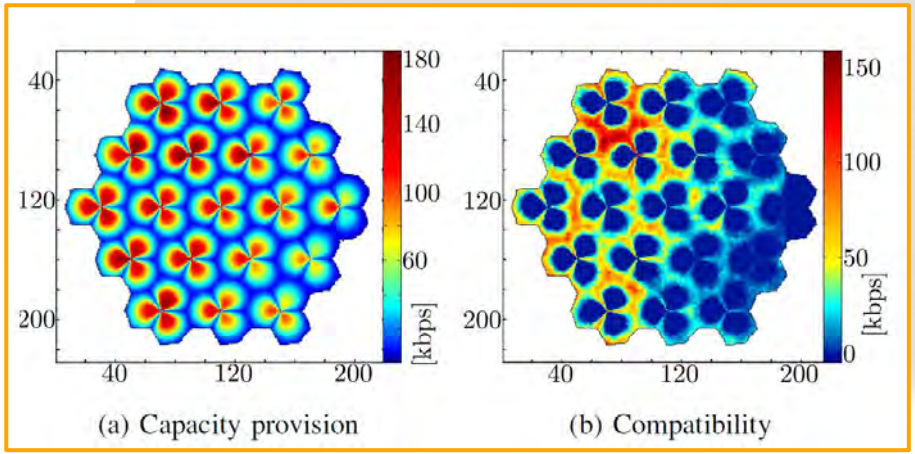
A Novel Approach to RAN Planning

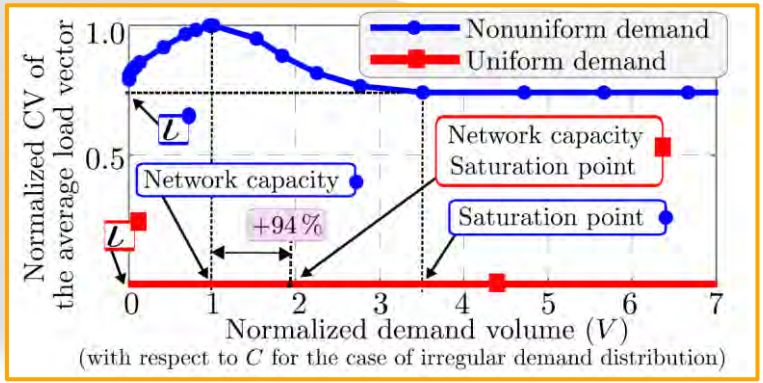
Transformations and Spatial Mappings – initial observations



System-centric analysis

planning and optimizing





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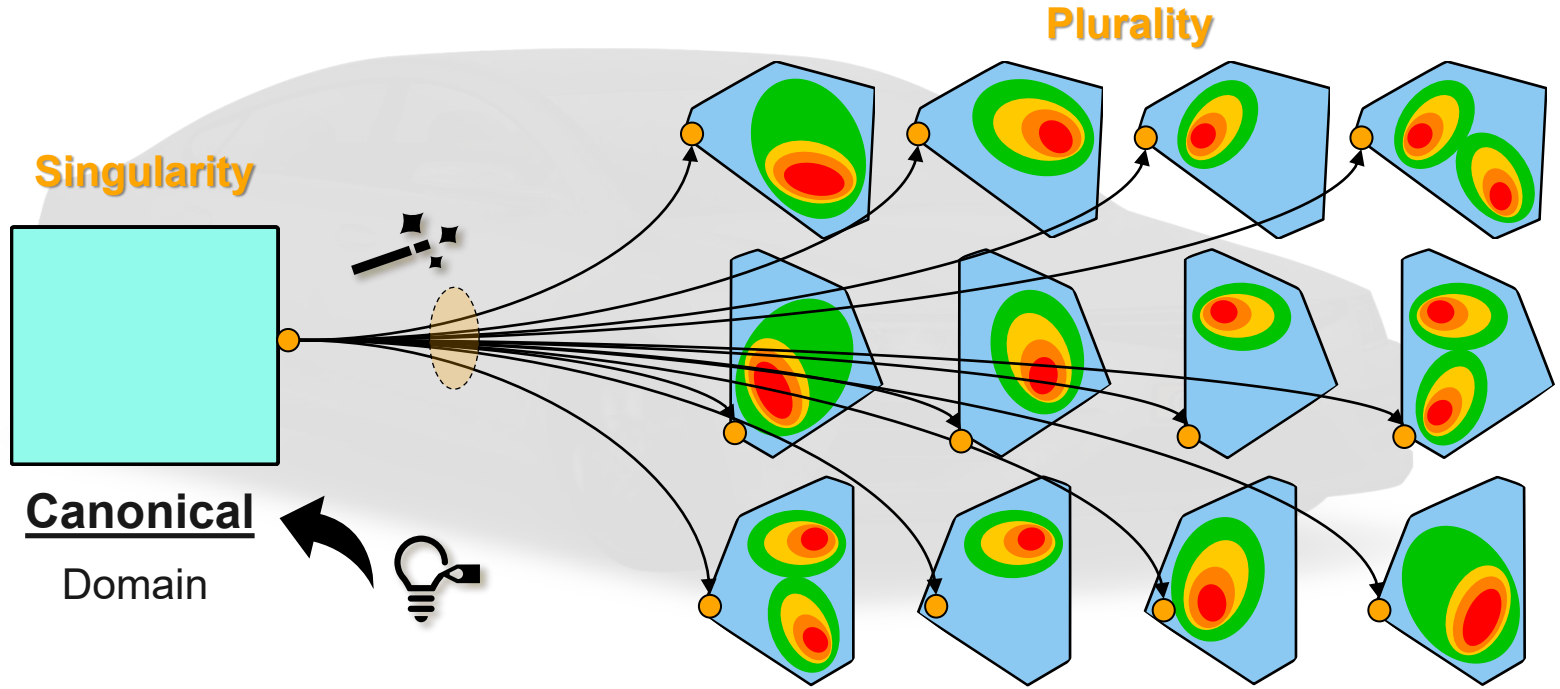
Transformations and Spatial Mappings – the idea



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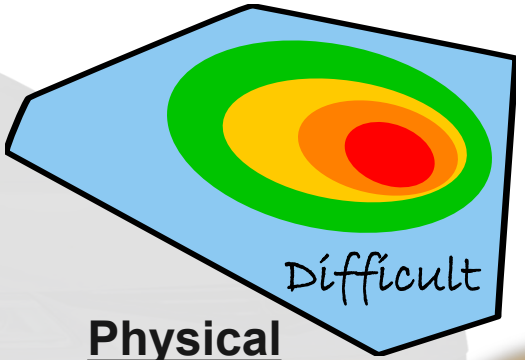
Spatial Mappings – Why? What Type of Correspondence?

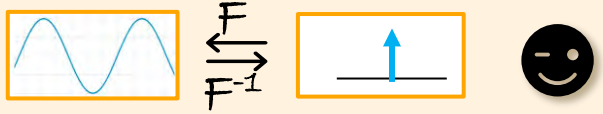


Canonical
Domain

Physical
Domain

The Reality

People like transformations !!



✕ Polynomials
Image Processing

A Novel Approach to RAN Planning

Spatial Mappings: Introducing novel tools

2016

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS

Looking at Cellular Networks Through Canonical Domains and Conformal Mapping

David González G. and Jyri Hämäläinen

2018

IEEE/ACM TRANSACTIONS ON NETWORKING, VOL. 26, NO. 1, FEBRUARY 2018

Spatial Mappings for Planning and Optimization of Cellular Networks

David González G., *Member, IEEE*, Harri Hakula, Antti Rasila, and Jyri Hämäläinen, *Member, IEEE*

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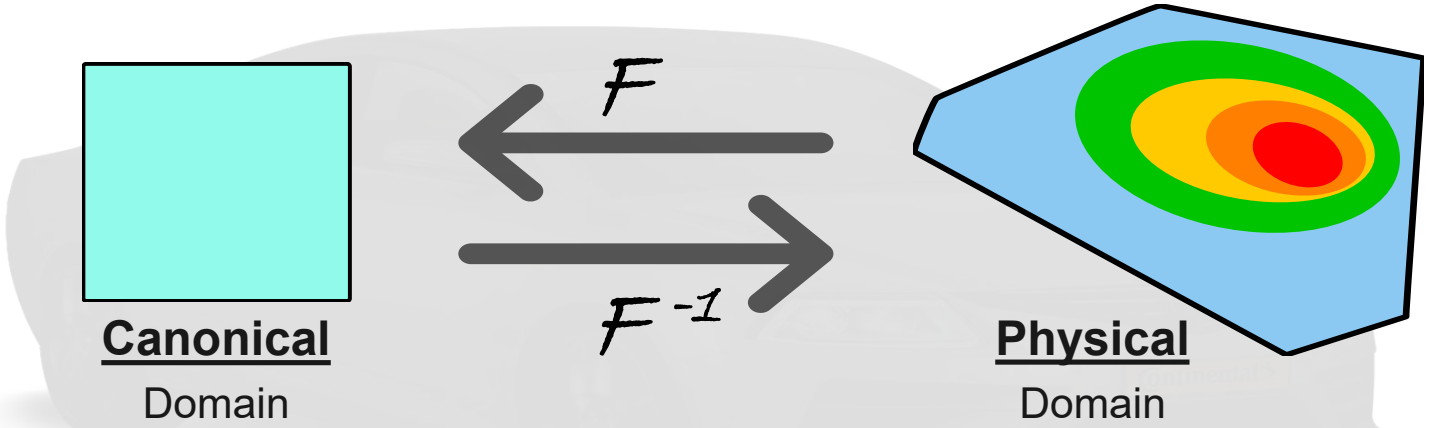
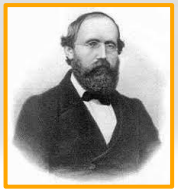
Spatial Mappings: Why Conformal Mapping?



➡ Existence of F



Bernhard Riemann

An important and profound result from **Complex Analysis**, the **Riemann's mapping theorem**, guarantees the existence of a conformal mapping between non-empty, open, and simply connected proper subsets of **C**.

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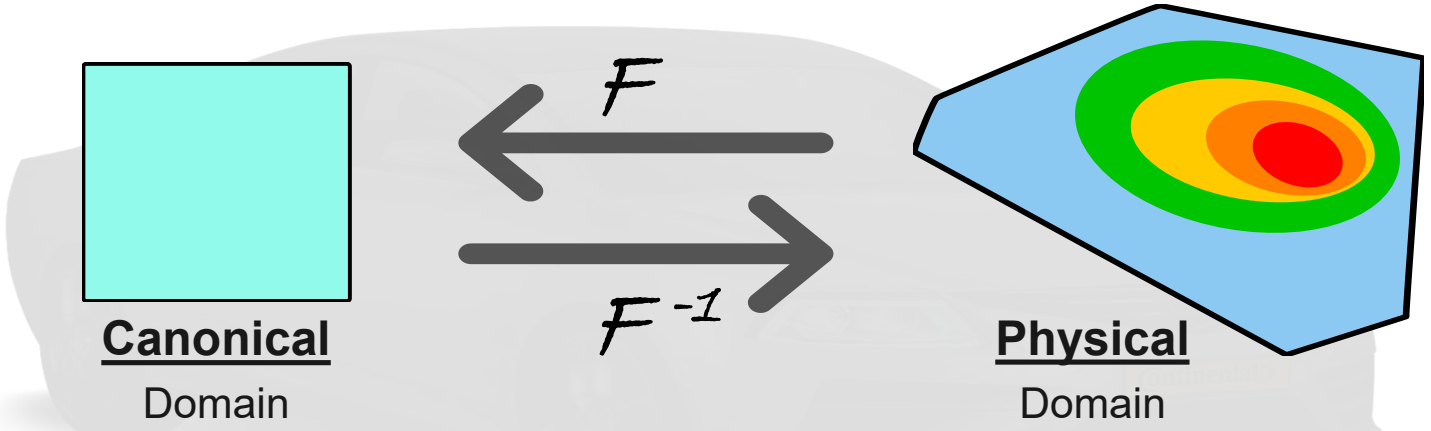
Spatial Mappings: Schwarz-Christoffel transformations



- Existence and calculation of F
- Existence and calculation of F^{-1}

E. Christoffel H. Schwarz

A well-studied family of conformal mappings, the **Schwarz-Christoffel transformations**, makes possible **finding and computing both mapping and inverse** by means of efficient numerical methods

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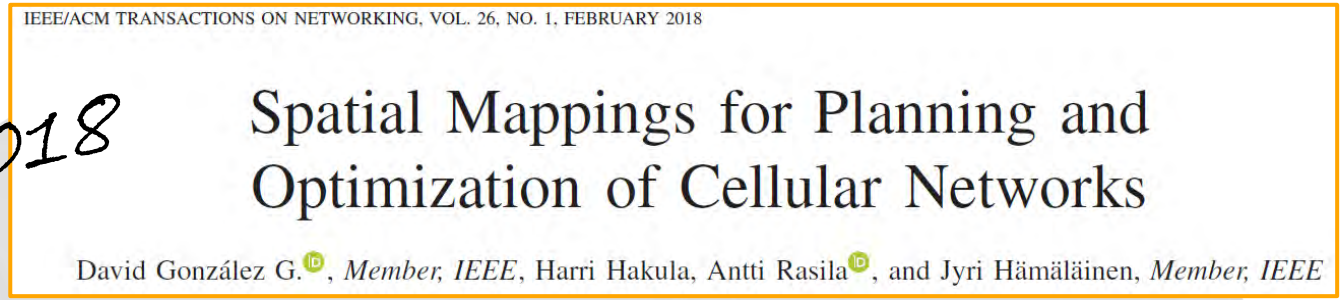
Spatial Mappings: Introducing novel tools



Contributions: novel supply-demand concepts based on

1. Conformal Mapping and power optimization
2. Centroidal Voronoi algorithms and power Voronoi diagrams

→ **RAN planning/optimization** (Irregularity minimization)

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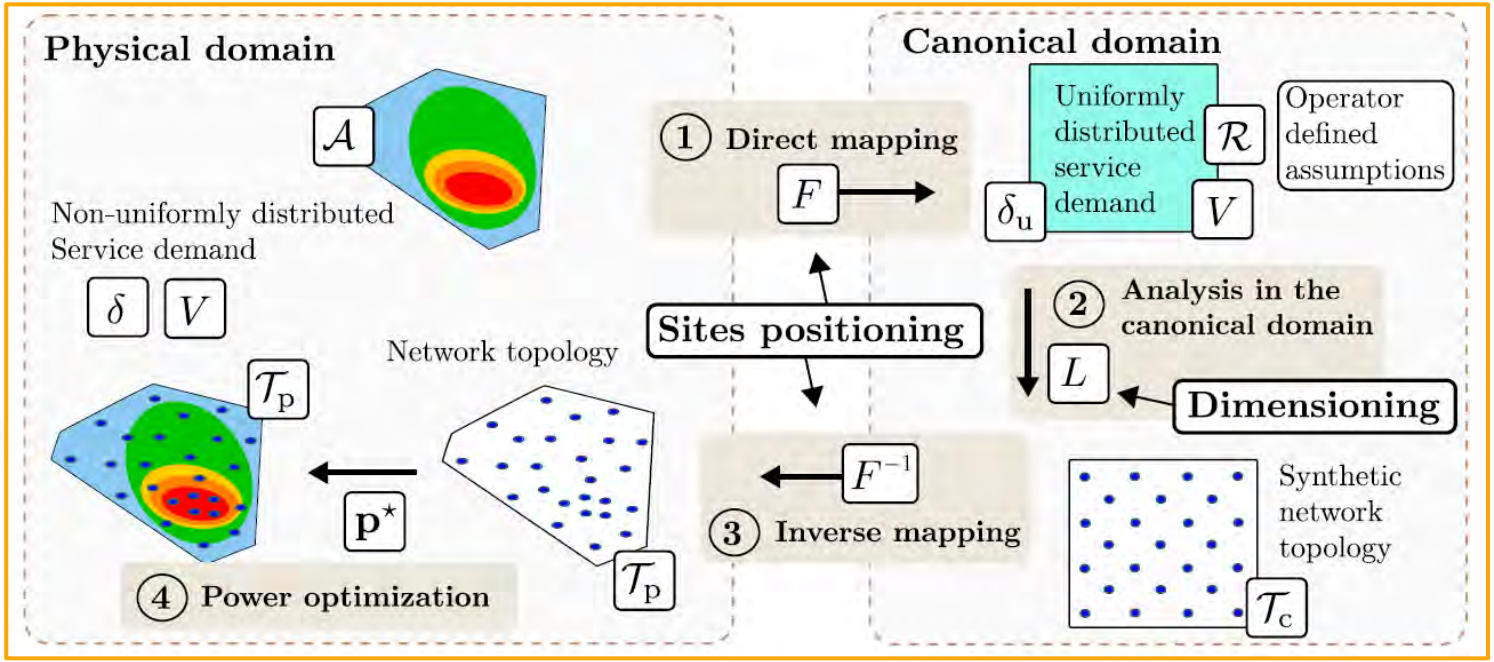
Spatial Mappings: Introducing novel tools

1 Conformal Mapping and power optimization



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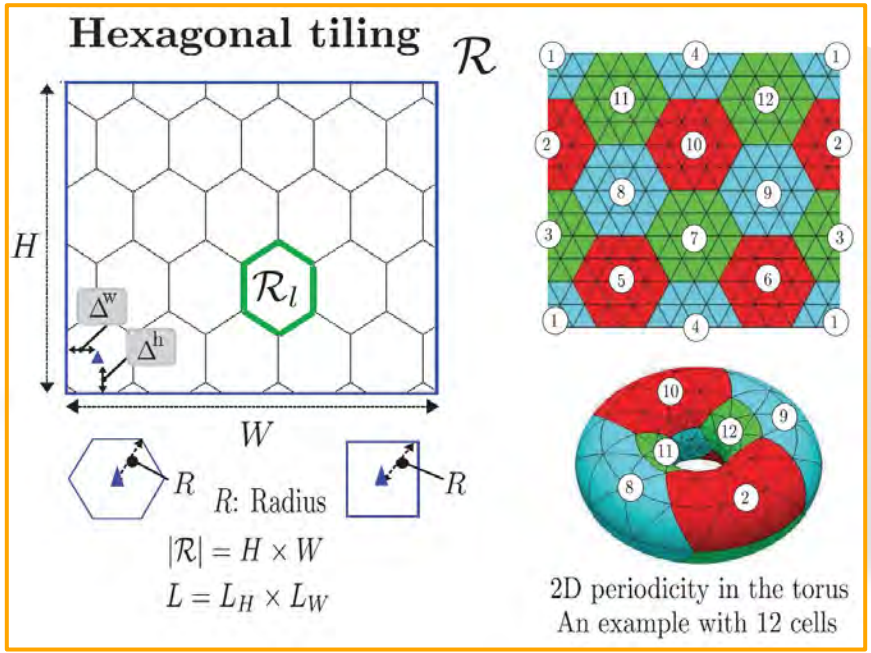
Spatial Mappings: Introducing novel tools

1 Conformal Mapping and power optimization



Analysis in the canonical domain.

Determine the number of cells (Capacity required for the service demand volume).

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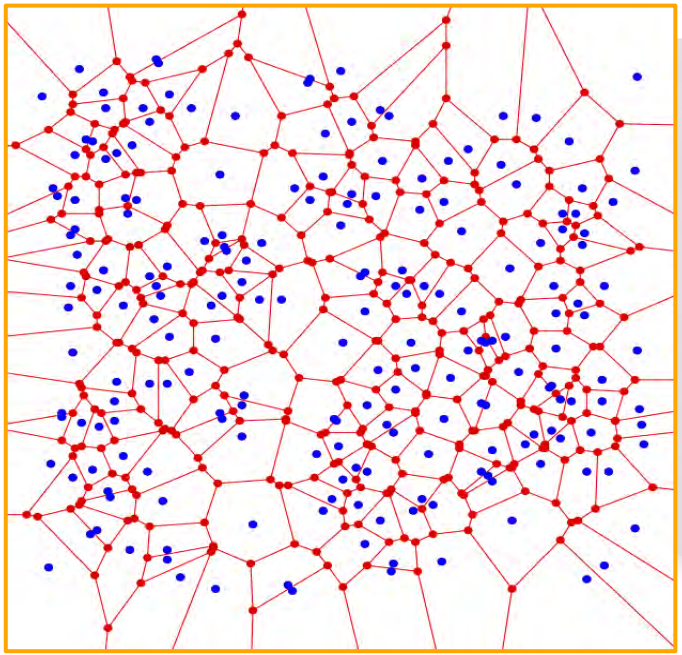
Spatial Mappings: Introducing novel tools



2 Centroidal Voronoi algorithms and power Voronoi diagrams

Voronoi diagrams

$$\mathcal{A}_l \triangleq \{\boldsymbol{a} \in \mathcal{A} | \|\boldsymbol{a} - \boldsymbol{a}_l\|_2 \leq \|\boldsymbol{a} - \boldsymbol{a}_k\|_2, \forall l \neq k\}$$

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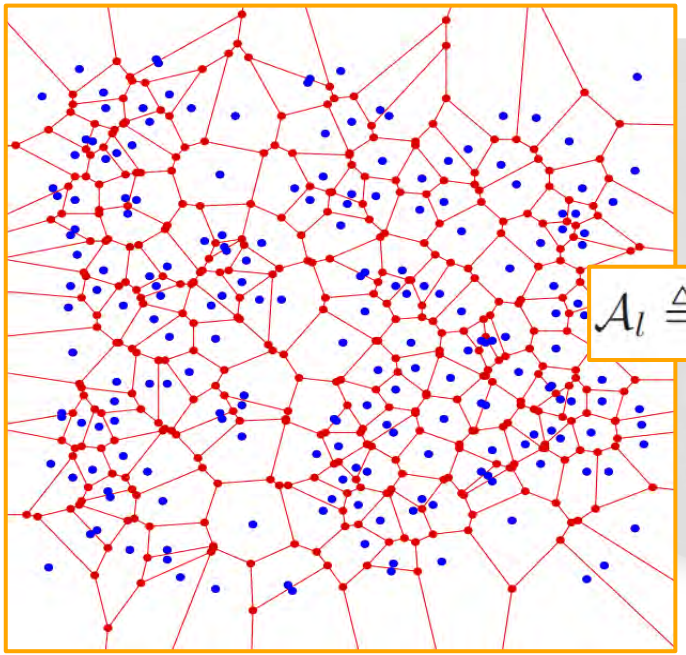
Spatial Mappings: Introducing novel tools



2

Centroidal Voronoi algorithms and power Voronoi diagrams

Power Voronoi diagrams

$$\mathcal{A}_l \triangleq \{\boldsymbol{a} \in \mathcal{A} | \|\boldsymbol{a}-\boldsymbol{a}_l\|_2 - w_l \leq \|\boldsymbol{a}-\boldsymbol{a}_k\|_2 - w_k, \forall l \neq k\}$$

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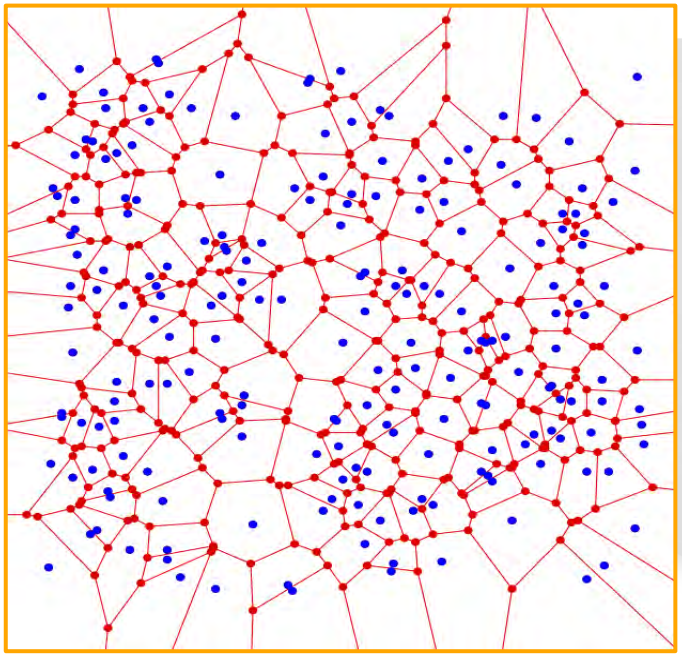
Spatial Mappings: Introducing novel tools



2

Centroidal Voronoi algorithms and power Voronoi diagrams

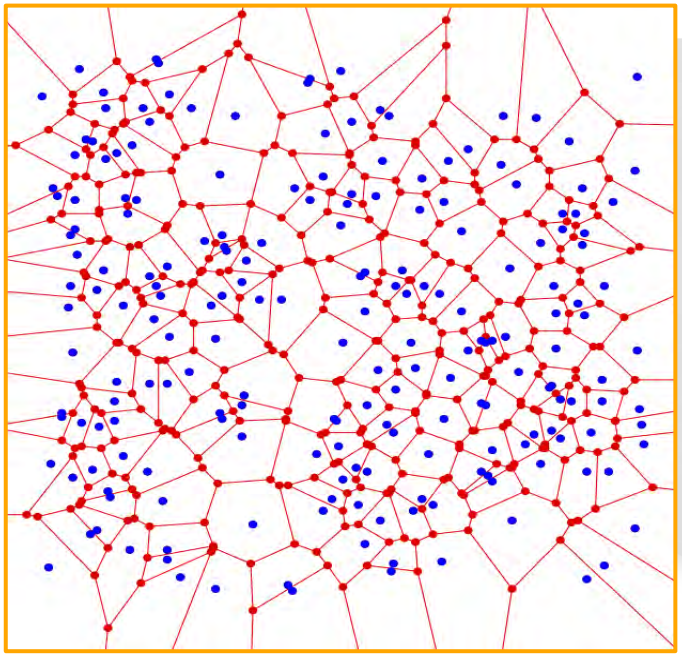
Mass centroid

$$\boldsymbol{c}_l \triangleq \frac{\int_{\mathcal{A}_l} \boldsymbol{a}\delta(\boldsymbol{a})d\boldsymbol{a}}{\int_{\mathcal{A}_l} \delta(\boldsymbol{a})d\boldsymbol{a}} \triangleq \left(\frac{\iint_{\mathcal{A}_l} x\delta(x,y)dxdy}{\iint_{\mathcal{A}_l} \delta(x,y)dxdy}, \frac{\iint_{\mathcal{A}_l} y\delta(x,y)dxdy}{\iint_{\mathcal{A}_l} \delta(x,y)dxdy} \right)$$

Requires a function defined over *A* → good !!

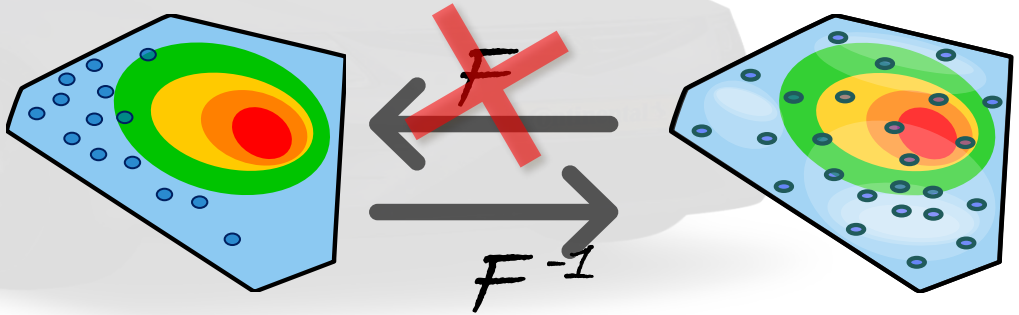
A Novel Approach to RAN Planning

Spatial Mappings: Introducing novel tools



2 Centroidal Voronoi algorithms and power Voronoi diagrams

No need to compute *F*

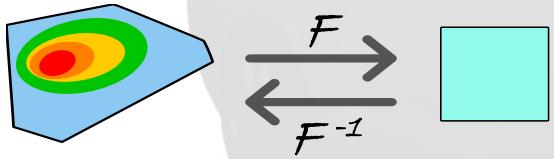


Suitable for new networking scenarios !!

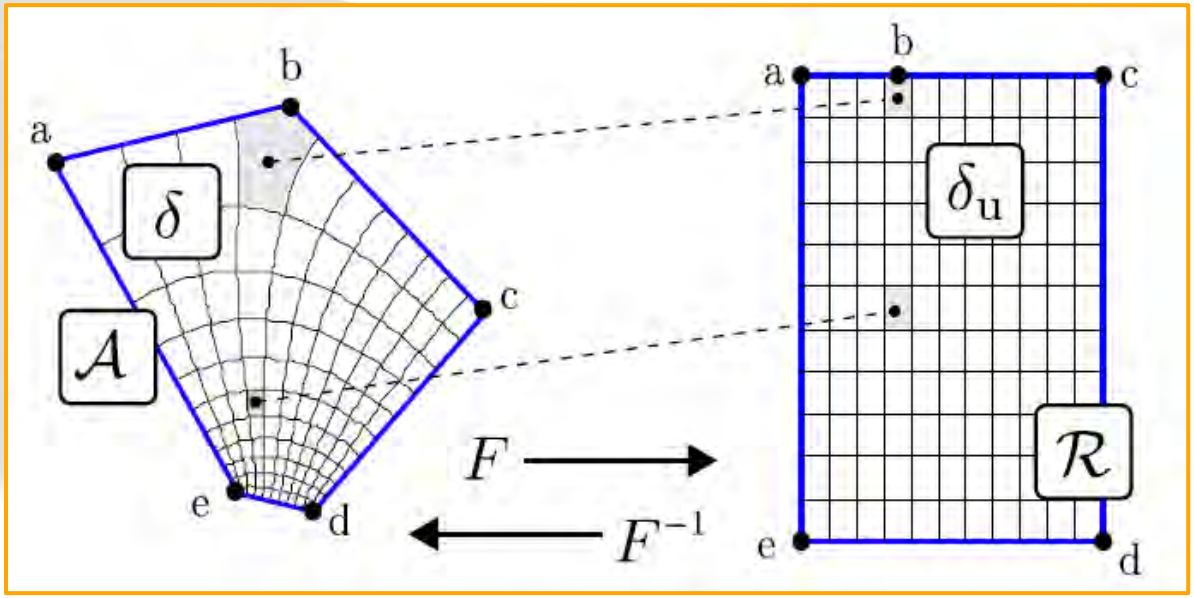
A Novel Approach to RAN Planning

Spatial Mappings: Engineering Solutions

1 Conformal Mapping and power optimization



Very difficult !!



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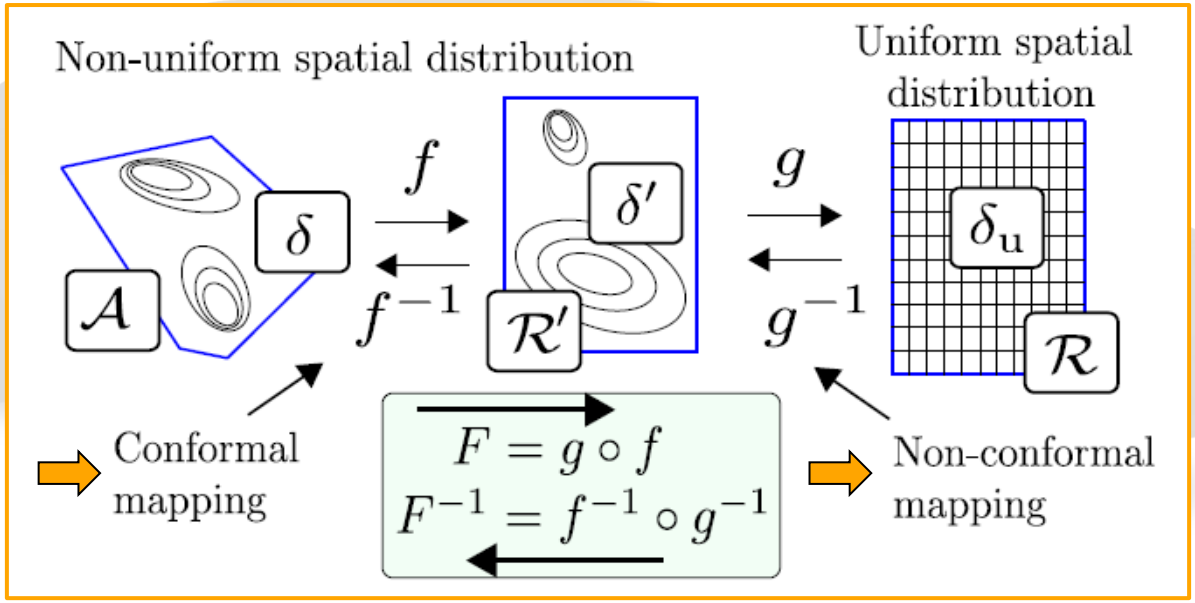
Spatial Mappings: Engineering Solutions

1 Conformal Mapping and power optimization



Feasible

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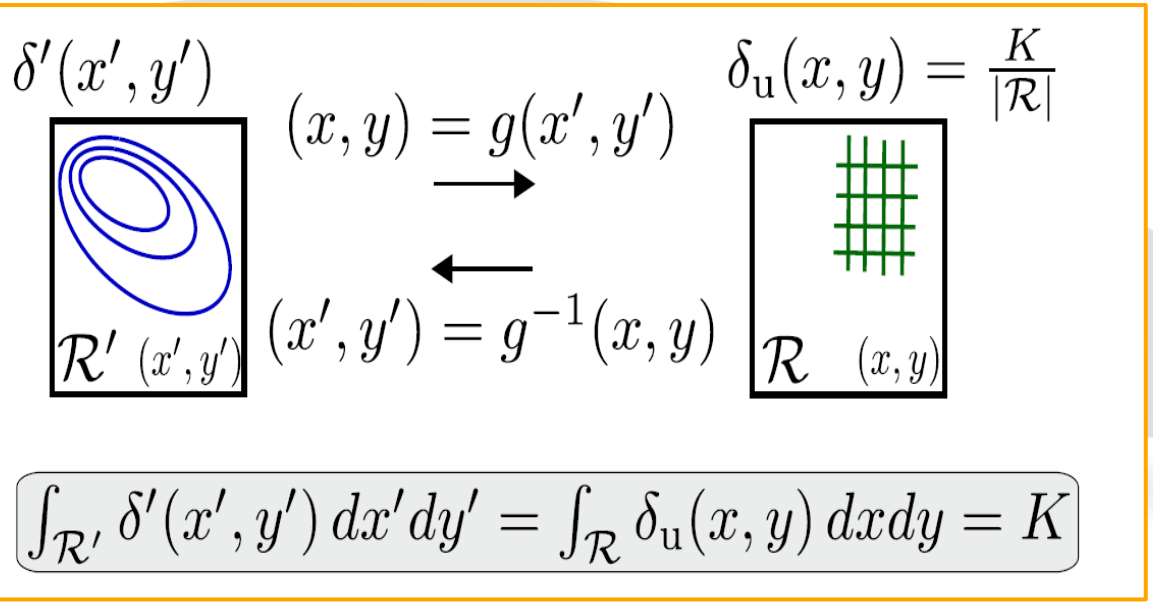
Spatial Mappings: Engineering Solutions

1 Conformal Mapping and power optimization

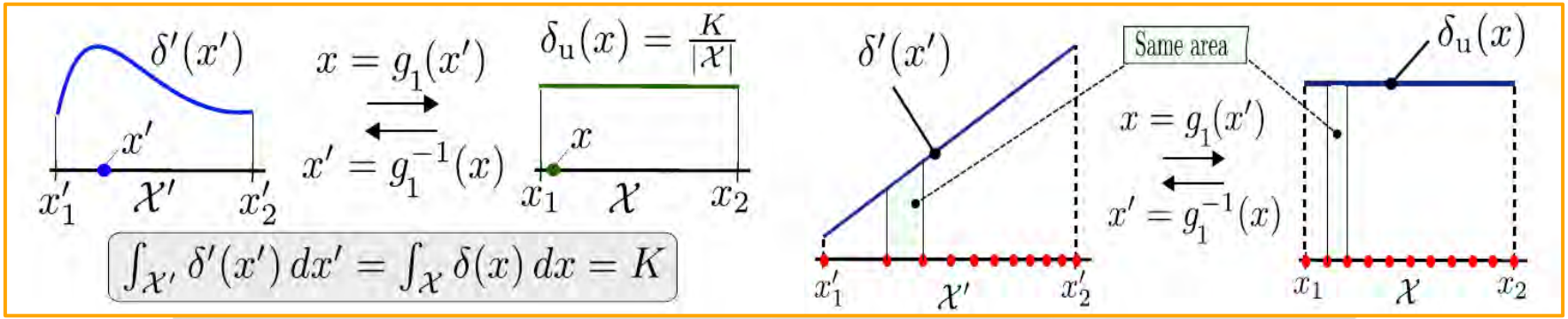


Service Demand Volume

A Novel Approach to RAN Planning

Spatial Mappings: Engineering Solutions

1 Conformal Mapping and power optimization



Non-conformal mapping: volume-preserving service demand re-distribution

(Illustration in 1D)

$$\int_{x'_1}^{x'} \delta'(x')dx' = \int_{x_1}^{x} \delta_u(x)dx = \frac{x - x_1}{x_2 - x_1}.$$

Solution in 1D: Trivial (closed-form in many *useful* cases).

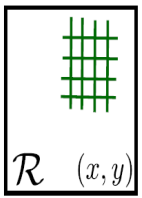
A Novel Approach to RAN Planning

Spatial Mappings: Engineering Solutions

1 Conformal Mapping and power optimization

$\delta'(x', y')$ $\quad (x, y) = g(x', y')$ $\quad \delta_{\mathrm{u}}(x, y) = \frac{K}{|\mathcal{R}|}$

$(x', y') = g^{-1}(x, y)$



$$\int_{\mathcal{R}'} \delta'(x', y')\, dx'dy' = \int_{\mathcal{R}} \delta_{\mathrm{u}}(x, y)\, dxdy = K$$

$$\delta'(x', y') = \delta'_{\mathrm{x}}(x')\delta'_{\mathrm{y}}(y') \Rightarrow \textbf{1D}$$

$$\delta'(x', y') \Rightarrow \textbf{Marginalization}$$

$$\delta'_{\mathrm{x}}(x') = \int \delta'(x', y')dy'.$$

$$\delta'_{\mathrm{y}}(y', x) = \frac{\delta'(x', y')}{\delta'_{\mathrm{x}}(x')} = \frac{\delta'(u(x), y')}{\delta'_{\mathrm{x}}(u(x))}.$$

Non-conformal mapping: volume-preserving service demand re-distribution

A Novel Approach to RAN Planning

Spatial Mappings: Cell Load-Coupling in OFDMA

1 Conformal Mapping and power optimization

Cell load: resource usage to satisfy a required service demand (<1).

$$\alpha_l = \frac{VR_{\min}\log(2)}{B}\int_{\mathcal{A}_l}\frac{\delta_a}{\log\left(1+\gamma_a(\boldsymbol{\alpha},\boldsymbol{p})\right)}da.$$

The load of each cell is *coupled* to the load of other cells

$$\gamma_a(\boldsymbol{\alpha},\mathbf{p}) = \frac{p_{\hat{l}}G_{\hat{l},a}}{\sum_{l=1,l\neq\hat{l}}^{L} p_l G_{l,a}\alpha_l},$$

Interference generated by each cell is proportional to it load.

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 11, NO. 6, JUNE 2012

Analysis of Cell Load Coupling for LTE Network Planning and Optimization

Iana Siomina and Di Yuan, *Member, IEEE*

$$\boldsymbol{\alpha} = \boldsymbol{f}(\boldsymbol{\alpha},\mathbf{p}).$$

Existence and uniqueness of $\boldsymbol{\alpha}$ is shown for a given $\boldsymbol{p}$.

OFDMA:Orthogonal Frequency Division Multiple Access

A Novel Approach to RAN Planning

Spatial Mappings: Power Optimization

1 Conformal Mapping and power optimization

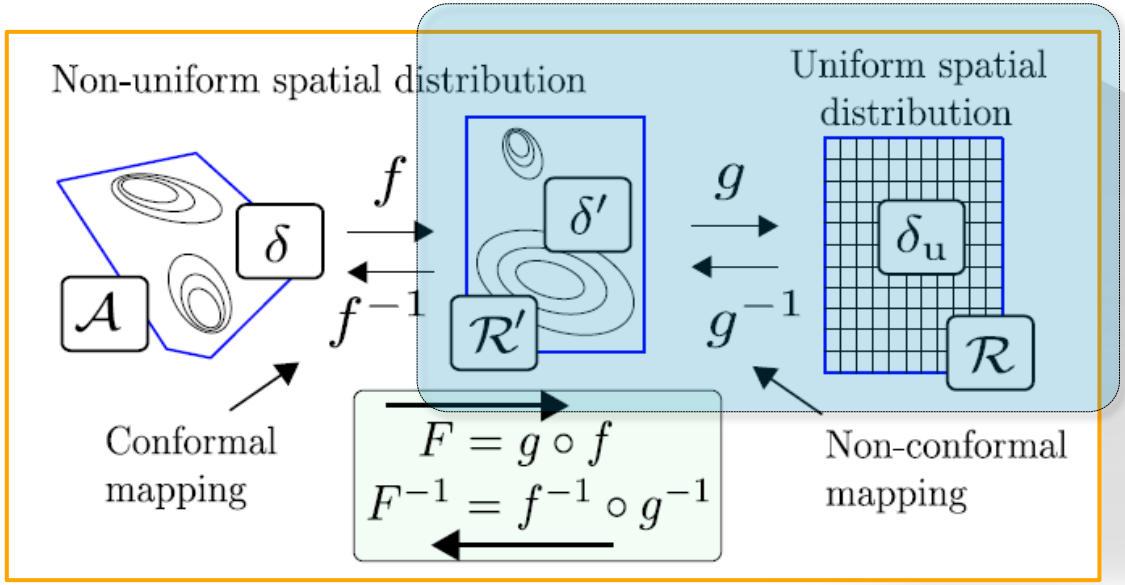
$$\begin{aligned} &\underset{\mathbf{p}}{\text{minimize}}\ \mathrm{Var}\{\boldsymbol{\alpha}\}, \\ &\text{subject to}: \boldsymbol{\alpha} = \boldsymbol{f}(\boldsymbol{\alpha}, \mathbf{p}), \\ &\qquad\qquad \mathbf{p} \in \mathbb{R}_{+}^{L}. \end{aligned}$$

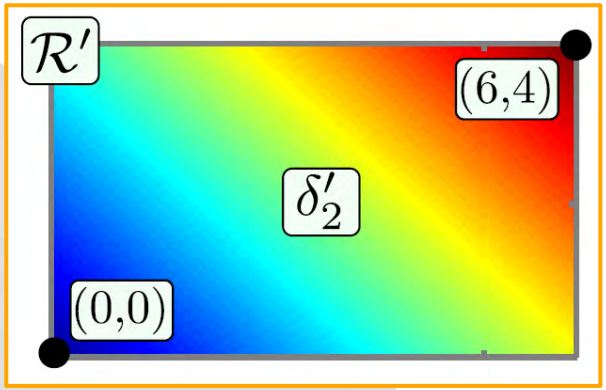
- ☑ Uniform load pattern is unique.
- ☑ Spare capacity is maximized.

A Novel Approach to RAN Planning

Spatial Mappings: Some Results

1 Conformal Mapping and power optimization



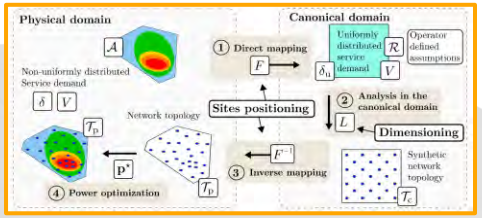


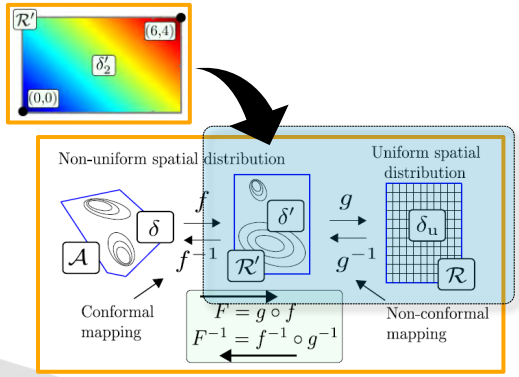
$$\delta'_2(x', y') = x' + y'$$

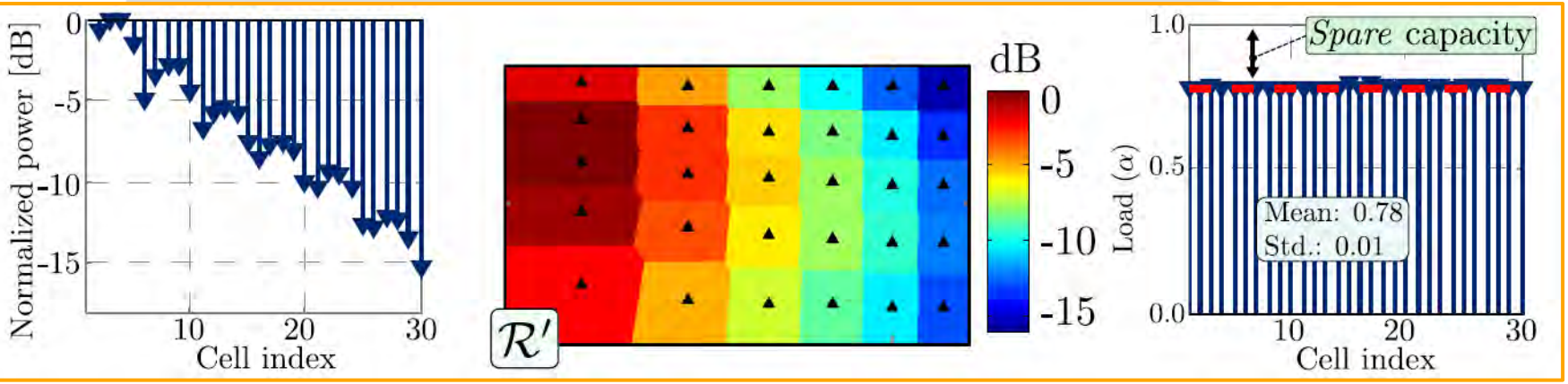
A Novel Approach to RAN Planning

Spatial Mappings: Some Results

1 Conformal Mapping and power optimization







A Novel Approach to RAN Planning 2

Spatial Mappings: Some Results

Centroidal Voronoi algorithms and power Voronoi diagrams

Algorithm 1 Network Planning Based on Centroidal and Power Voronoi Diagrams

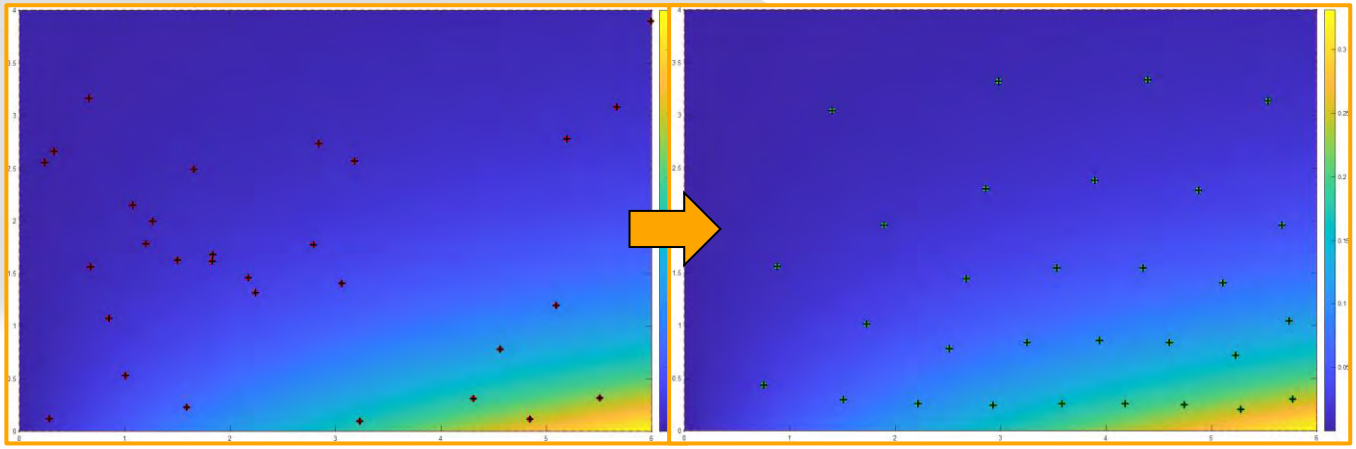
Inputs : Random network topology: $\mathcal{L}^{\mathrm{R}} = \{a_1^{\mathrm{R}}, a_2^{\mathrm{R}}, \cdots, a_L^{\mathrm{R}}\} \subset \mathcal{A}$, spatial service demand distribution: δ, algorithm parameters: $N \in \mathbb{N}$, $\Delta < 0$, $0 < \kappa < 1$, $T \in \mathbb{N}$, ϵ.

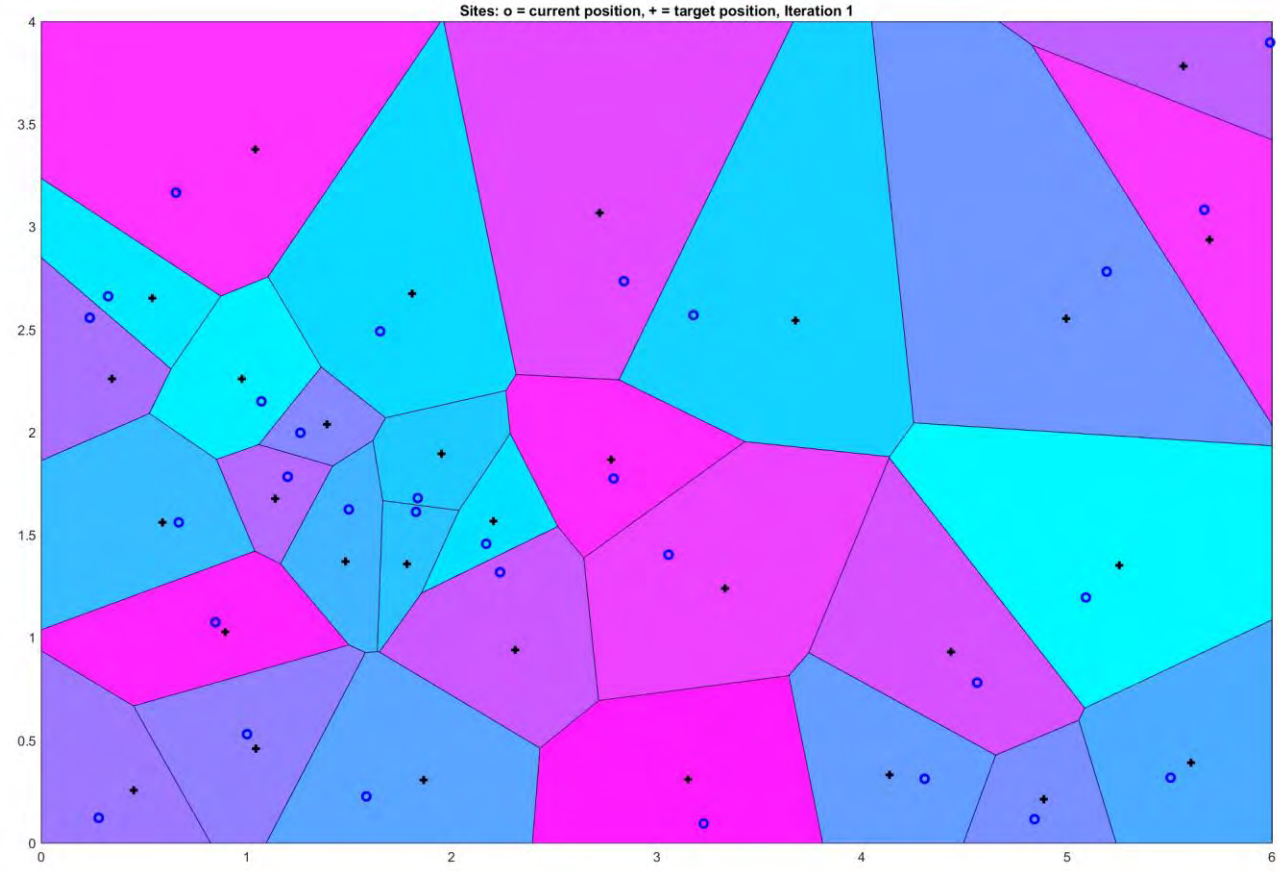
Output: Network topology compatible with δ: $\mathcal{T}_{\mathrm{p}}$.

$\mathcal{W} \leftarrow 0$; /* Initialization */
$i \leftarrow 1$;
$\mathcal{T}^0 \leftarrow$CVA($\mathcal{L}^{\mathrm{R}}$, δ, N); /* Baseline topology: std. centroidal Voronoi algorithm */
repeat
  $\mathcal{C}^{i-1} \leftarrow$MassCentroids($\mathcal{T}^{i-1}$, δ); /* Centroids */
  $\mathcal{L}^i \leftarrow \mathcal{C}^{i-1}$; /* Update generators */
  $\mathcal{T}^i \leftarrow$PowerVoronoiDiagram($\mathcal{L}^i$,$\mathcal{W}$); /* Power Voronoi diagram: see (8) */
  $\mathcal{V}^i \leftarrow$ServiceDemandShare($\mathcal{T}^i$,δ); /* Service demand share: see (10) */
  $j \leftarrow$MaxIndex($\mathcal{V}^i$); /* Index of the cell with the highest demand volume */
  $w_j \leftarrow w_j + \Delta$; /* Reduce weight cell j */
  if (mod(i,T)==0) **then**
    $\Delta \leftarrow \Delta \cdot \kappa$; /* Convergence: reduce Δ every T iterations */
  end
  $i \leftarrow i + 1$;
until $\epsilon \leq$CoefficientOfVariation($\mathcal{V}^i$);
return $\mathcal{T}_{\mathrm{p}} \leftarrow \mathcal{T}^i$; /* Return network topology */

RAN optimization on Centroidal and Power Voronoi Diagrams

$$\delta_1'(x', y') = x' e^{-y'}$$




Sites: o = current position, + = target position, Iteration 1
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6

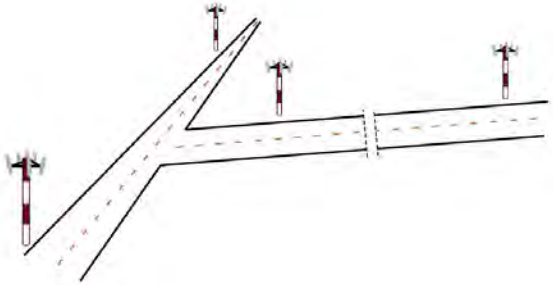
A Novel Approach to RAN Planning

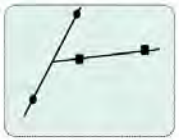
Spatial Mappings: Relevance to V2X

Canonical Domains for Cellular Networks: Analysis of the One-Dimensional Case

2016

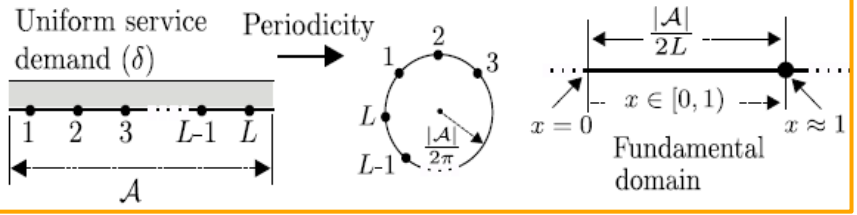
David González G. and Jyri Hämäläinen
School of Electrical Engineering, Aalto University, Finland
Emails: {david.gonzalezgonzalez, jyri.hamalainen}@aalto.fi





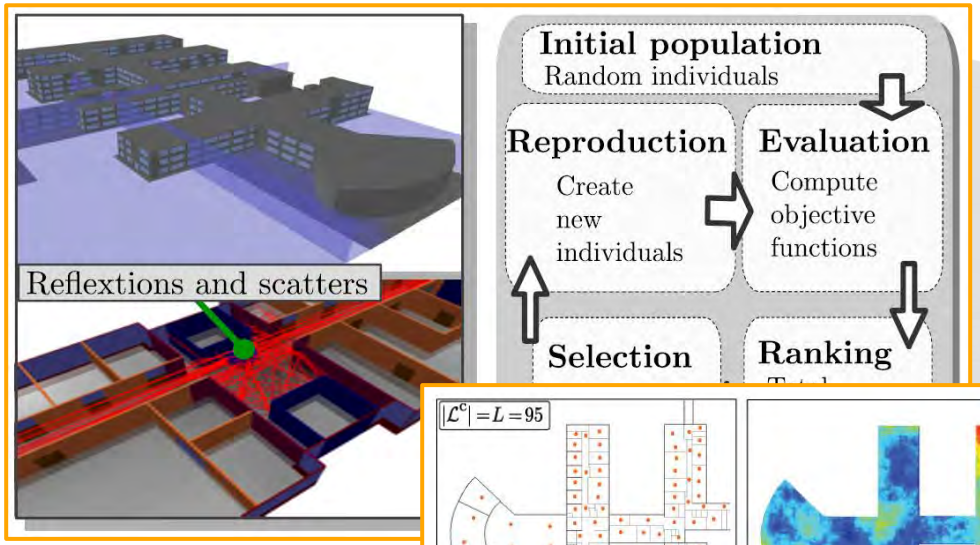
Network model

☑ Predictability



RAN Planning

Achieving a *good* Compromise



Usage of Metaheuristics

- ☑ Multi-objective optimization
  - o Interference coordination
  - o mmW Indoor planning
  - o Multi-RAT planning
  - o Cell-Switch Off
- ☑ for 6G !!

RAN Planning

Achieving a *good* Compromise

2012

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 12, NO. 5, MAY 2013

Optimization of Soft Frequency Reuse for Irregular LTE Macrocellular Networks

David González G, *Student Member, IEE*

2013

US009730153B2

(12) **United States Patent**
Gonzalez et al.

(10) **Patent No.: US 9,730,153 B2**

(54) **SYSTEM AND METHODS FOR MULTI-OBJECTIVE CELL SWITCH-OFF IN WIRELESS NETWORKS**

Related U.S. Application Data

(60) Provisional application No. 61/847,403, filed on Jul. 17, 2013.

RAN Planning

Achieving a *good* Compromise

Indoor Planning Optimization of Ultra-dense Cellular Networks at High Carrier Frequencies

2015

Saray Renilla Lamas, David González G and Jyri Hämäläinen
Department of Communications and Networking, Aalto University, Finland.
Emails: {saray.renillalamas, da

Indoor Planning and Optimization of LTE-U Radio Access over WiFi

2016

Omar Sandoval[1], David González G.[1], Jyri Hämäläinen[1], Sangjo Yoo[2]
[1] School of Electrical Engineering, Aalto University, Finland
{omar.sandovalmendoza, david.gonzalezgonzalez, jyri.hamalainen}@aalto.fi
[2] Gwangju Institute of Science and Technology (GIST), Republic of Korea, asapyoo@gist.ac.kr

A Novel Approach to RAN Planning

Spatial Mappings: Challenges for Beyond 5G

- ☑ New types of links
- ☑ Many *planning-breaking* features
- ☑ Inter-RAT resource allocation
- ☑ 3D
- ☑ Data and AI/ML oriented

- ☑ Vehicular Networks
- ☑ 6G will provide *opportunities* (e.g., OTFS)

A Novel Approach to RAN Planning

Spatial Mappings: Modern Tools and Trends

- ☑ Modeling (graph, connectivity, spanning trees)
- ☑ Network Science
- ☑ Self-Similarity, Fractality, and Chaos
- ☑ Optimization and Stochastic Geometry
- ☑ Service-based network dimensioning
- ☑ IoT
- ☑ Uncertainty Quantification

- ☑ Others

Part III
Final Remarks

Views on 6G

Views on 6G for Automotive

Collaboration with Academia

Views on 6G for Automotive

Mobile Edge Computing

Views on 6G for Automotive

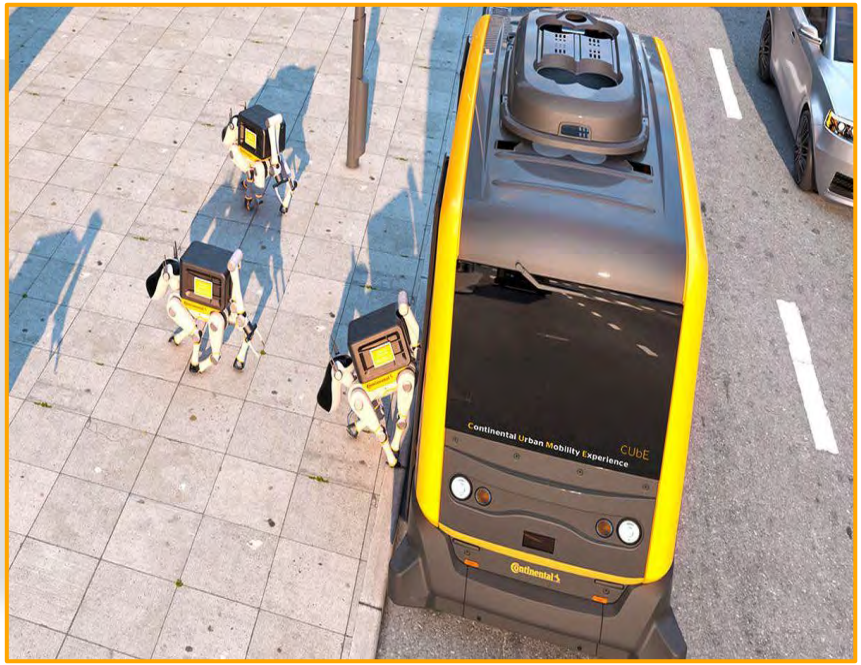
Integration of Terrestrial and Non-Terrestrial Access

Views on 6G for Automotive

Reliability in High Mobility Scenarios

Views on 6G for Automotive

Internet of Things

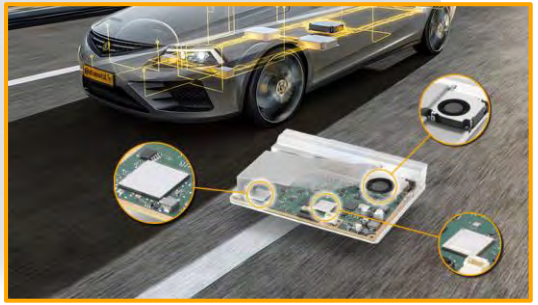


Views on 6G for Automotive

Intra-Vehicle Communications

Views on 6G for Automotive

Software-Defined Vehicles



Views on 6G for Automotive

Cyber Security in Post-Quantum Times

2018

VEHICULAR NETWORKING

POST-QUANTUM ERA IN V2X SECURITY: CONVERGENCE OF ORCHESTRATION AND PARALLEL COMPUTATION

Engin Zeydan, Yekta Turk, Berkin Aksoy, and Yaman Yagiz Tasbag

2019

SECURE WIRELESS COMMUNICATIONS FOR VEHICLE-TO-EVERYTHING

Physical-Layer Security and Privacy for Vehicle-to-Everything

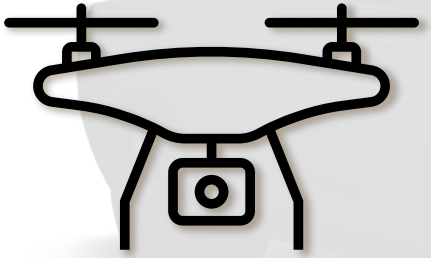
Basem M. ElHalawany, Ahmad A.Aziz El-Banna, and Kaishun Wu

2019

SECURE WIRELESS COMMUNICATIONS FOR VEHICLE-TO-EVERYTHING

Views on 6G for Automotive

Drones and Aerials



2019

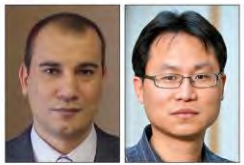
SECURE WIRELESS COMMUNICATIONS FOR VEHICLE-TO-EVERYTHING

Unmanned Aerial Vehicle Meets Vehicle-to-Everything in Secure Communications

Bodong Shang, Lingjia Liu, Junchao Ma, and Pingzhi Fan

2019

DRONES IN THE ERA OF V2X COMMUNICATIONS

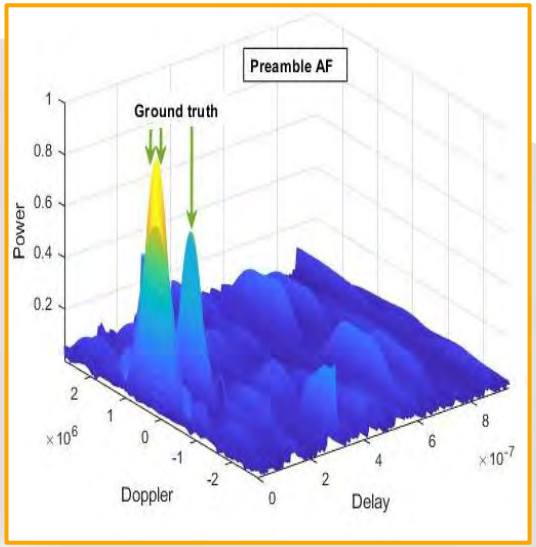


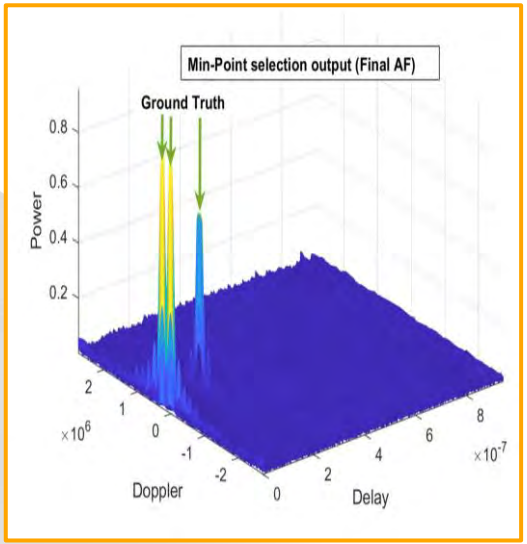
Anwer Al-Dulaimi

Xiaodong Lin

Views on 6G for Automotive

Integrated/Joint Sensing/Radar and Communication

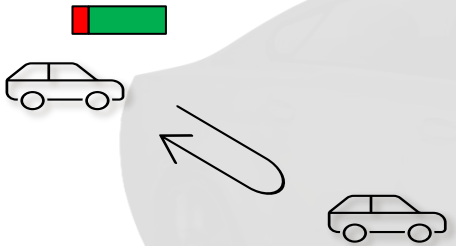




Resolving multiple targets

Views on 6G for Automotive

Integrated/Joint Sensing/Radar and Communication



- ☑ Data and Preambles
- ☑ Single-carrier + Multi-carriers
- ☑ (auto+cross)correlation properties

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
01 September 2022 (01.09.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/180220 A1

(51) International Patent Classification:
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G01S 7/00 (2006.01) *G01S 13/931* (2020.01)

(21) International Application Number:
PCT/EP2022/054810

(22) International Filing Date:
25 February 2022 (25.02.2022)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
21159355.3 25 February 2021 (25.02.2021) EP

(71) Applicants: **CONTINENTAL AUTOMOTIVE GMBH** [DE/DE]; Vahrenwalder Straße 9, 30165 Hannover (DE). **NANYANG TECHNOLOGICAL UNIVERSITY** [SG/SG]; 50 Nanyang Avenue, Singapore 639798 (SG).

(72) Inventors: **GONZALEZ, David, Gonzalez**; c/o Continental Teves AG & Co. OHG, Intellectual Property, Guerickestr. 7, 60488 Frankfurt am Main (DE). **JAGANNATH, Rakshith**; c/o Nanyang Technological University, 50 Nanyang Avenue, 639798 Singapore (SG). **GUAN, Yong, Liang**; c/o Nanyang Technological University, 50 Nanyang Avenue, 639798 Singapore (SG).

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,

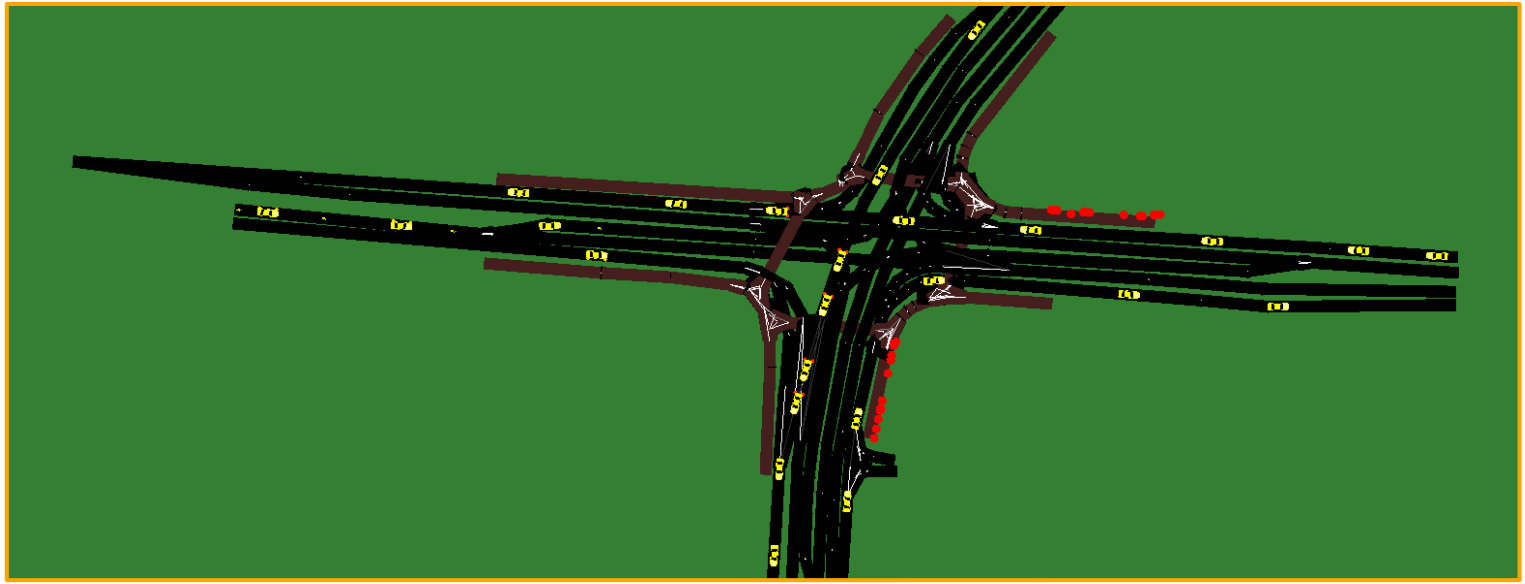
(54) Title: A NOVEL METHOD FOR RADAR SENSING USING COMMUNICATION SIGNALS WITH SINGLE CARRIER PREAMBLE AND MULTI-CARRIER DATA

Views on 6G for Automotive

Smart Infrastructure and Advanced and Accurate Modeling

Views on 6G for Automotive

Simulations



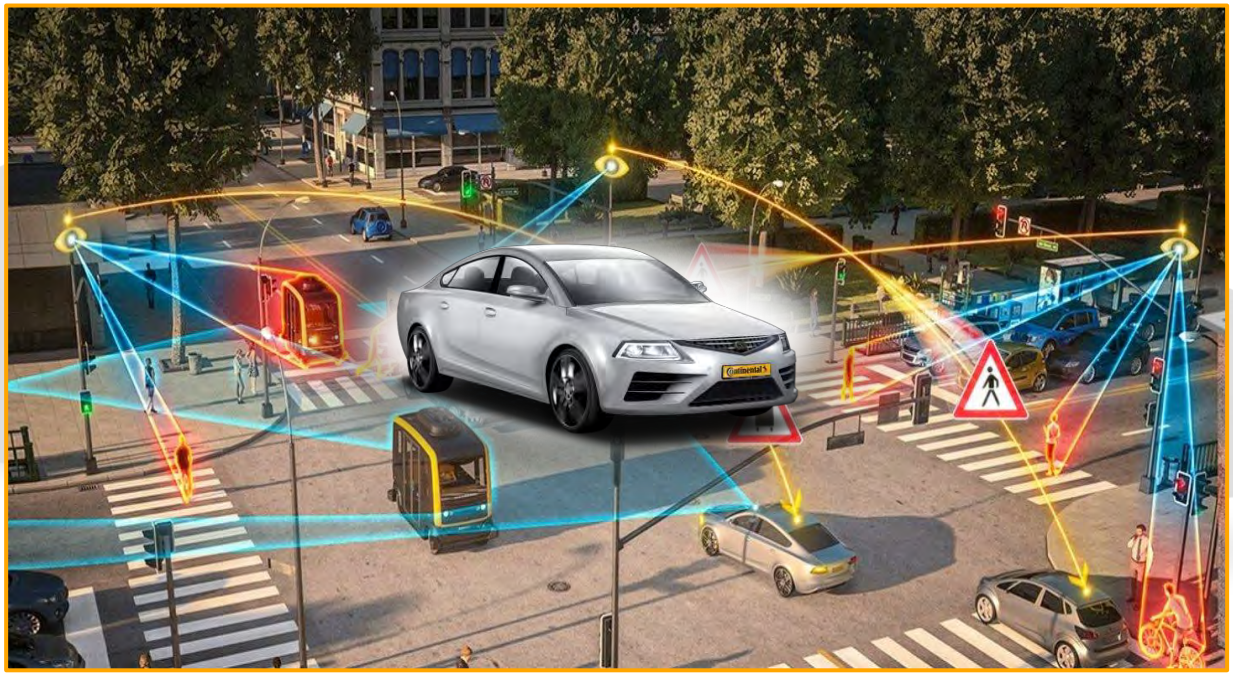
Views on 6G for Automotive

Open RAN

- ☑ white-box hardware
- ☑ open source software
- ☑ efficiency, intelligence and versatility
- ☑ interoperability and standardization

Views on 6G for Automotive

More Distributed and Vehicle-Centric Networking



Views on 6G for Automotive

Others

2017

ENABLING MOBILE AND WIRELESS TECHNOLOGIES FOR SMART CITIES

Vehicular Social Networks: Enabling Smart Mobility

Zhaolong Ning, Feng Xia, Noor Ullah, Xiangjie Kong, and Xiping Hu

2022

5G-NR Latency Field Performance for Immersive Live Video

Jin Yang
Verizon Communications
jin.yang@verizon.com

Andreas Andersson
Ericsson
andreas.b.andersson@ericsson.com

Susan Sanders
Verizon Communications
susan.sanders@verizon.com

2021

Robust, Resilient and Reliable Architecture for V2X Communications

Muhammad Awais Khan, Saptarshi Ghosh, Sherif Adeshina Busari, *Member, IEEE*, Kazi Mohammed Saidul Huq, *Senior Member, IEEE*, Tasos Dagiuklas, Shahid Mumtaz, *Senior Member, IEEE*, Mudde
and Jonathan Rodriguez, *Senior Member,*

2019

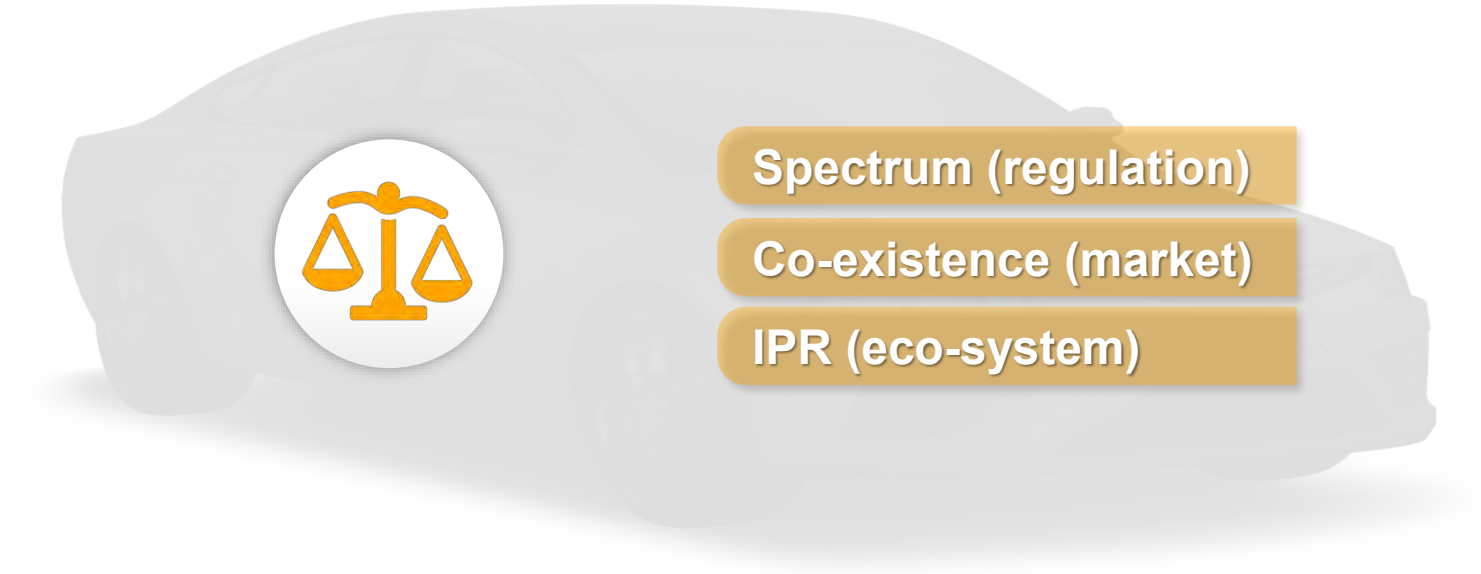
(19) Deutsches Patent- und Markenamt

(10) **DE 10 2019 213 878 B4** 2022.06.15

(54) Bezeichnung: **Verfahren zur Steuerung des Sendezugriffs auf ein Kommunikationsmedium und zur Ausführung des Verfahrens eingerichtete Vorrichtung**

Views on 6G for Automotive

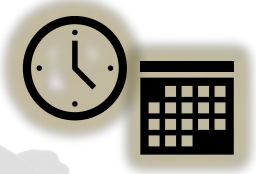
Last but not least … *what else we need ?*



Collaboration with Academia

A *must-have*

- Collaboration with Academia



- Success

- Expectations
  - Company
  - Professor
  - Student

Collaboration with Academia

Models and Alternatives

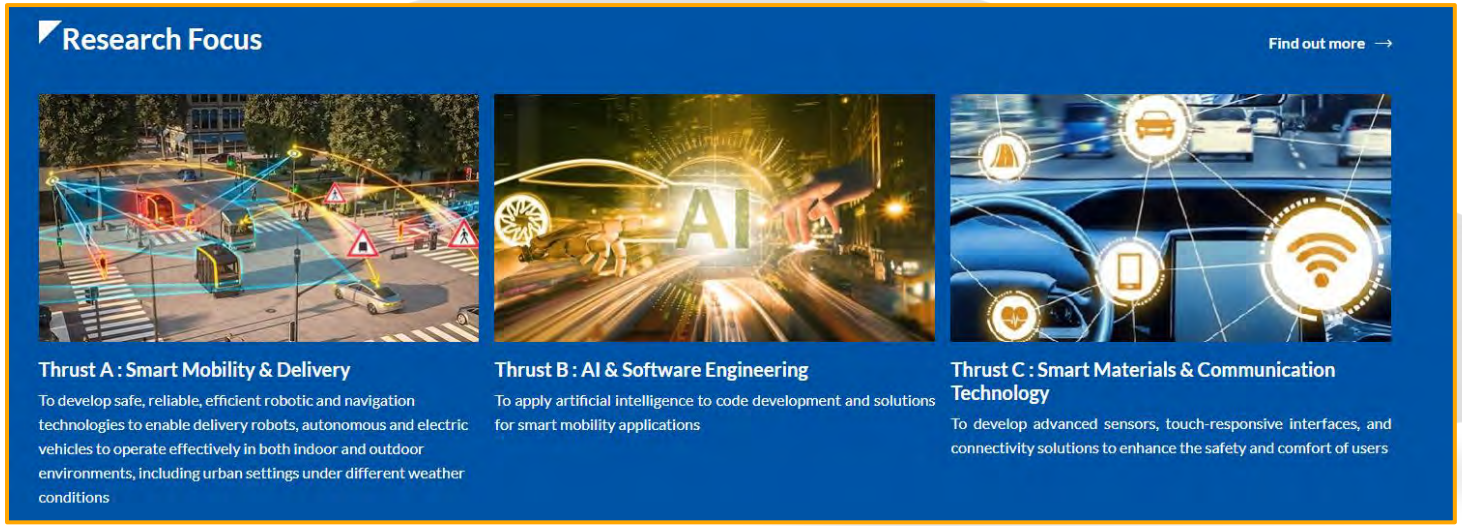
- Research: basic and/or applied
- Ideas for Projects
- Technology Performance Assessment
- Master and Ph.D. students
- Final Remarks




Collaboration with Academia

Examples

Continental – Nanyang Technological University (NTU)



https://www.ntu.edu.sg/continental-ntu

Collaboration with Academia

Examples

Robots to deliver food in Jurong East as part of trial involving new NTU laboratory

Collaboration with Academia

Examples

FUTURE 6G TECHNOLOGY: JACOBS UNIVERSITY BREMEN AND CONTINENTAL INTENSIFY COOPERATION

Researching future applications of 6G (from left to right): Hyeon-Seok Rou (PhD candidate), Giuseppe Thadeu Freitas de Abreu (professor of electrical engineering), Niclas Führling (student), David González (senior research engineer and project manager at Continental) and Hiroki Limori (PhD candidate). (Source: Jacobs University)

Thanks for your attention !!

david.gonzalez.gonzalez@continental.com