Enabling Smart Cities for Sustainable and Eco-Friendly Smart World

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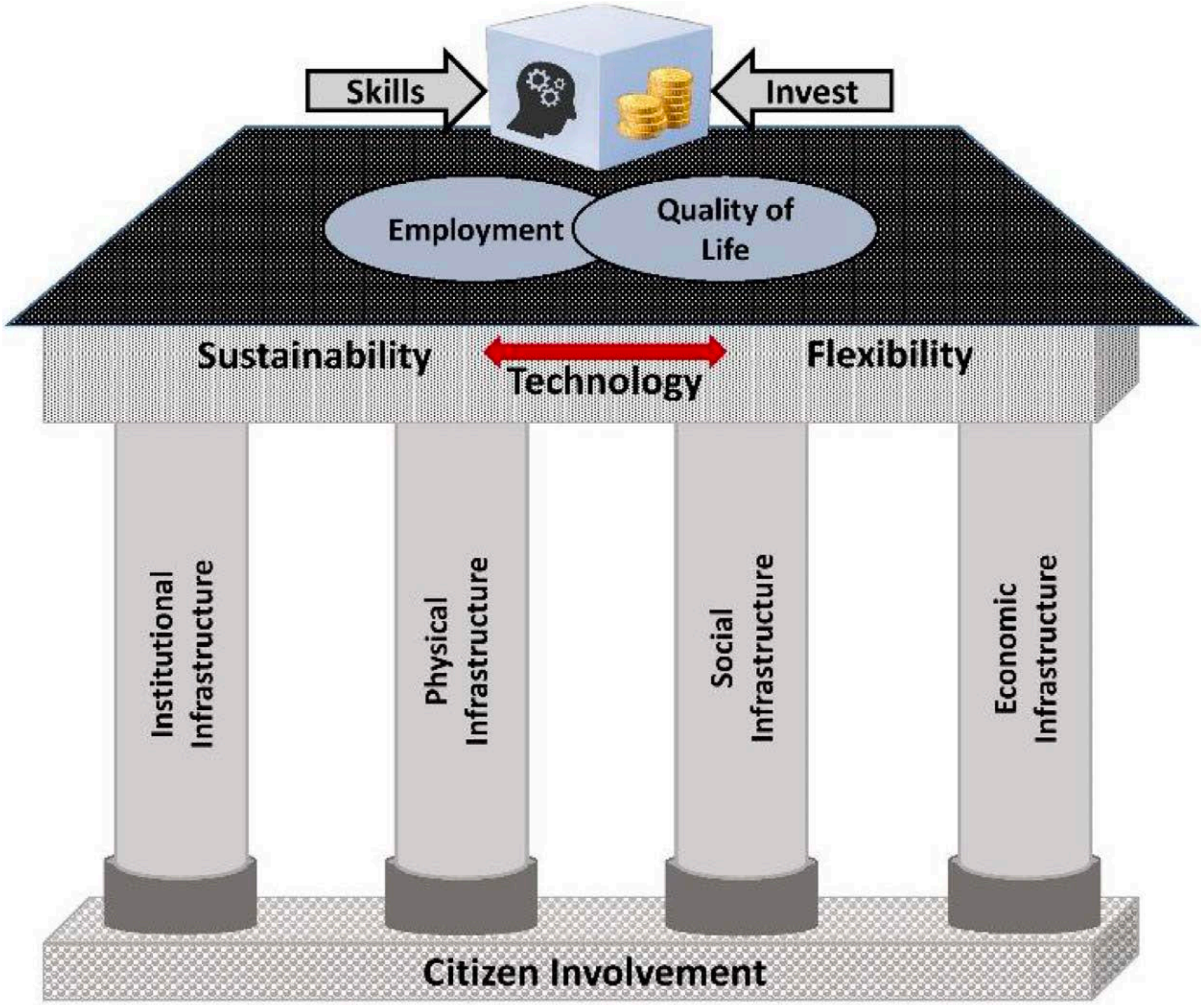
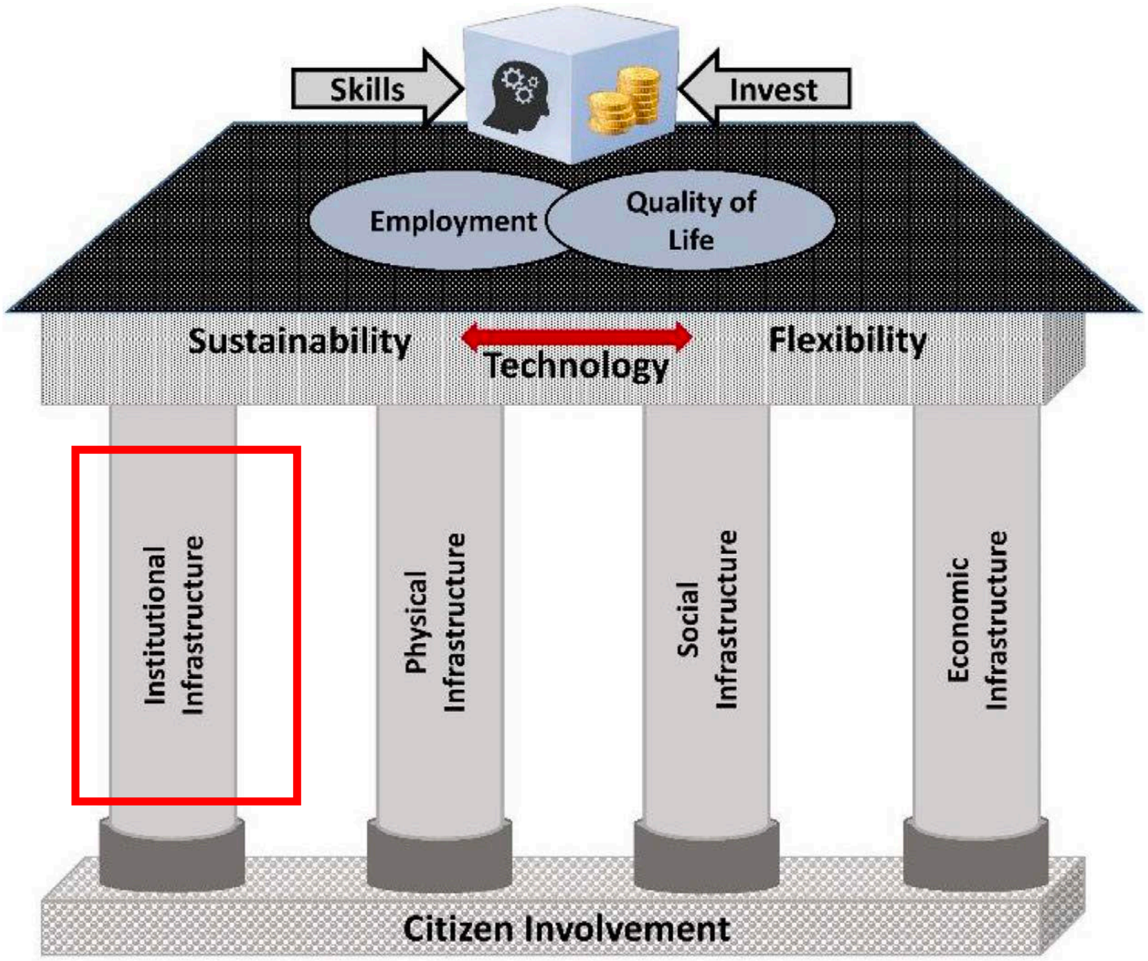
SMART CITY COSTITUTIVE PILLARS

According to European Union, the constitutive pillars of a Smart City involve the **institutional, physical, social and economic** infrastructures.



SMART CITY COSTITUTIVE PILLARS: ISTUTUTIONAL INFRASTUCTURE

SMART GOVERNANCE



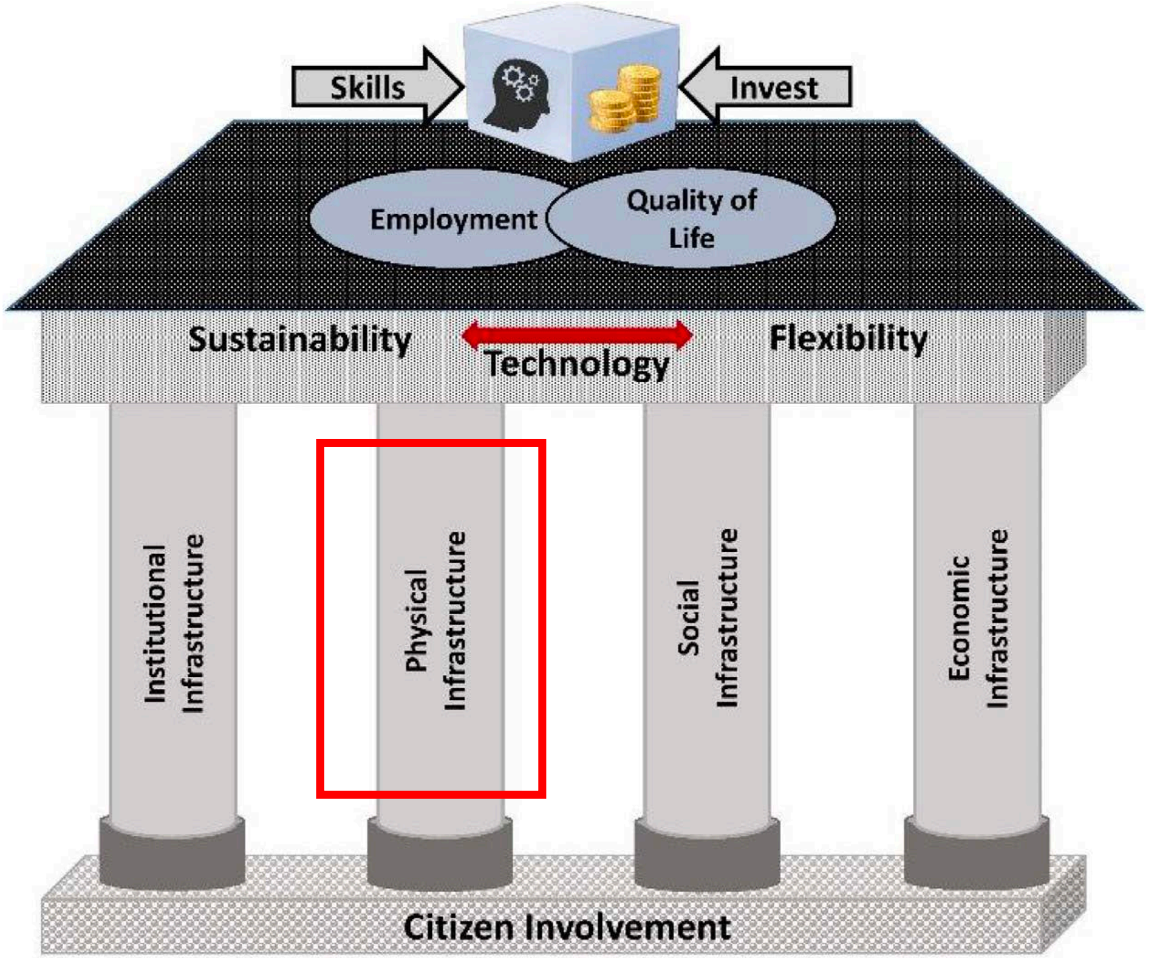
- Istitutional infrastructure involves the **governance of a smart city**, which has a remarkable role in **coordinating among citizens and administrative bodies**.

- The institutional infrastructure liaise with regional governments and central government to maximize the benefits of smart city.

- The institutional infrastructure of a smart city **integrates public, private, civil, and national organizations in order to provide interoperation between different services**.

This consolidation of **different administration bodies serves citizens more reliably, efficiently, and effectively**.

SMART CITY COSTITUTIVE PILLARS: PHYSICAL INFRASTRUCTURE



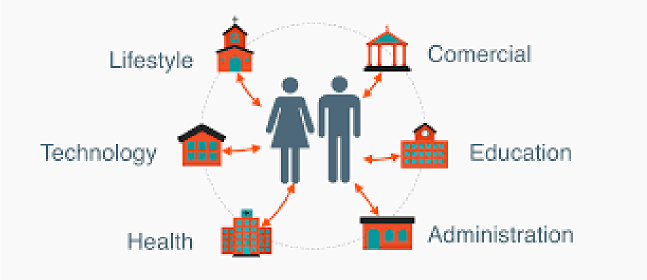
Physical infrastructure pillar aims at ensuring **sustainability of resources to continue city operations** at present and future.

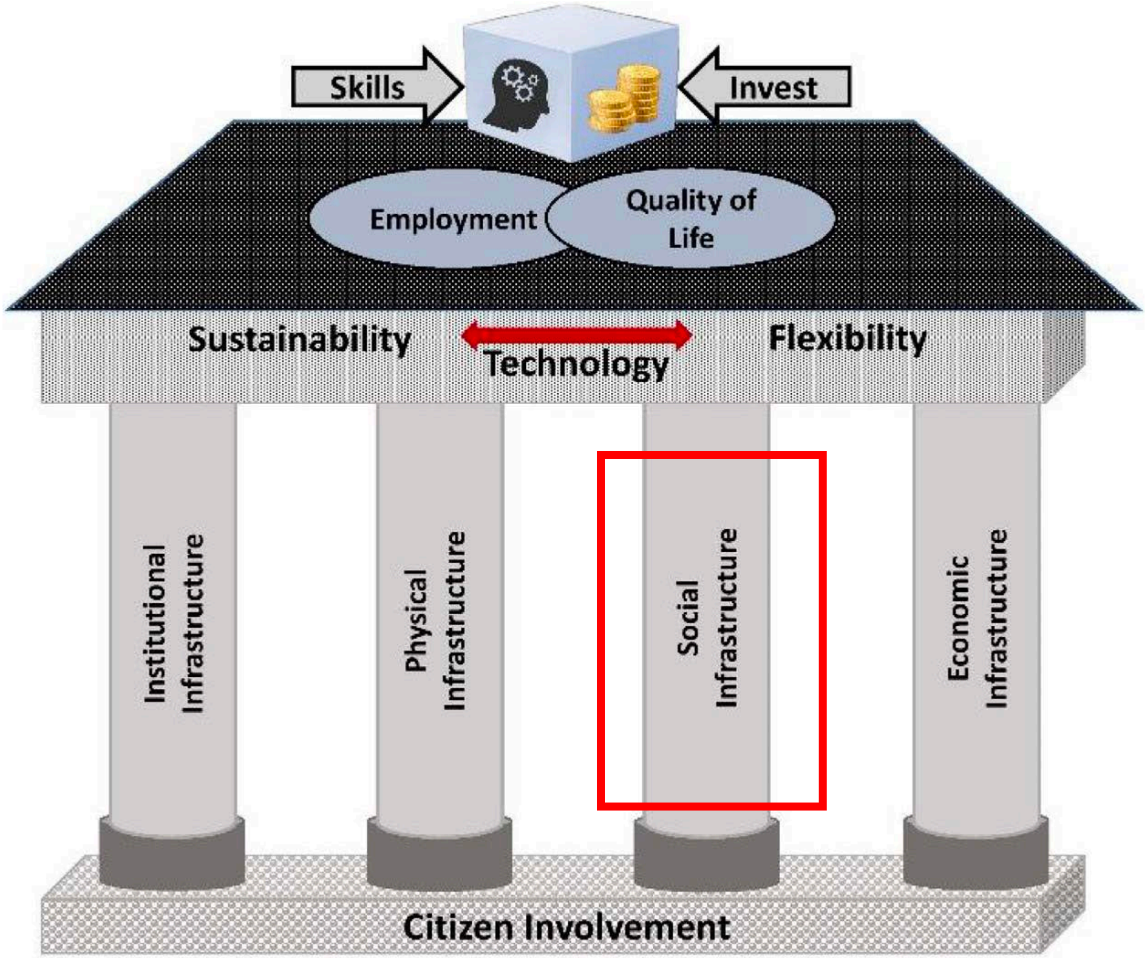
Physical infrastructure involves:

- ICT infrastructure
- Buildings
- Urban planning
- Renovation of buildings and services
- Energy solutions

The focus is to **preserve natural resources of the cities** such as waterways, green spaces and sewers, while increasing the **overall sustainability**.

SMART CITY COSTITUTIVE PILLARS: SOCIAL INFRASTUCTURE





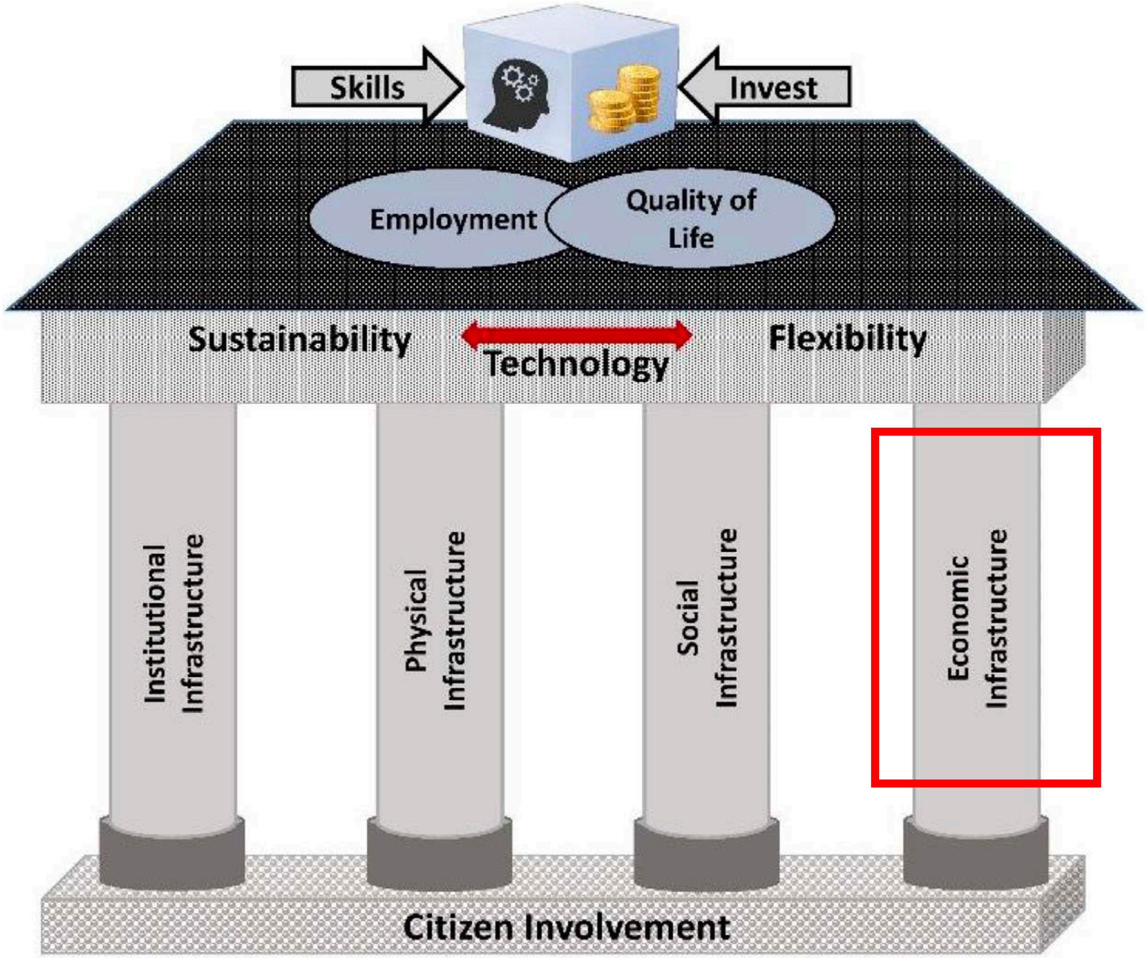
Social infrastructure pillar consists of:

- Intellectual capital;
- Human capital;
- Quality of Life.

Even though the smart cities are well organized, **they exploit advanced technologies with sophisticated devices**. It follows that the sustainability is not guaranteed **without social awareness**.

The objective is to **increase citizen awareness, responsibility, and commitment**, which are crucial to popularize the smart city concept. In doing so, citizens are involved into the evolution and the sustainability of a smart city.

SMART CITY COSTITUTIVE PILLARS:
ECONOMIC INFRASTUCTURE



Smart economy is identified as the **capability to flourish a smart city in terms of unceasing / steady economic** and job growth.

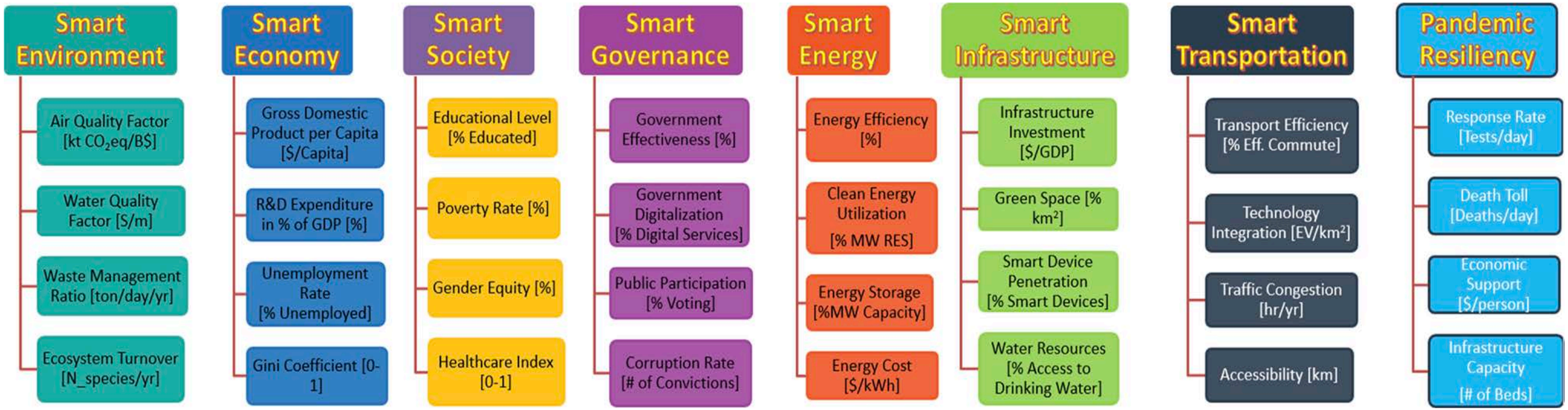
To Increase the city productivity by leveraging the best practices and applications of e-commerce and e-business.
To exploit the ICT to achieve better results in terms of reliability and **performance of the economic management**.

SMARTNESS LEVEL

However, a smart city **is not limited to a mere integration of ICT.**

Technical literature introduces a **Smart City Index (SCI)**[1], which is a **composite indicator ranging from 1 to 5**, to evaluate the smartness level of a city. **Cities can increase their smart city index by integrating and adopting smart city initiatives throughout the different domains**

SCI aggregates various domains along with their indicators to get its final value:



- Smart Environment
  - Air Quality Factor [kt CO_2eq/B$]
  - Water Quality Factor [S/m]
  - Waste Management Ratio [ton/day/yr]
  - Ecosystem Turnover [N_species/yr]
- Smart Economy
  - Gross Domestic Product per Capita [$/Capita]
  - R&D Expenditure in % of GDP [%]
  - Unemployment Rate [% Unemployed]
  - Gini Coefficient [0-1]
- Smart Society
  - Educational Level [% Educated]
  - Poverty Rate [%]
  - Gender Equity [%]
  - Healthcare Index [0-1]
- Smart Governance
  - Government Effectiveness [%]
  - Government Digitalization [% Digital Services]
  - Public Participation [% Voting]
  - Corruption Rate [# of Convictions]
- Smart Energy
  - Energy Efficiency [%]
  - Clean Energy Utilization [% MW RES]
  - Energy Storage [%MW Capacity]
  - Energy Cost [$/kWh]
- Smart Infrastructure
  - Infrastructure Investment [$/GDP]
  - Green Space [% km²]
  - Smart Device Penetration [% Smart Devices]
  - Water Resources [% Access to Drinking Water]
- Smart Transportation
  - Transport Efficiency [% Eff. Commute]
  - Technology Integration [EV/km²]
  - Traffic Congestion [hr/yr]
  - Accessibility [km]
- Pandemic Resiliency
  - Response Rate [Tests/day]
  - Death Toll [Deaths/day]
  - Economic Support [$/person]
  - Infrastructure Capacity [# of Beds]

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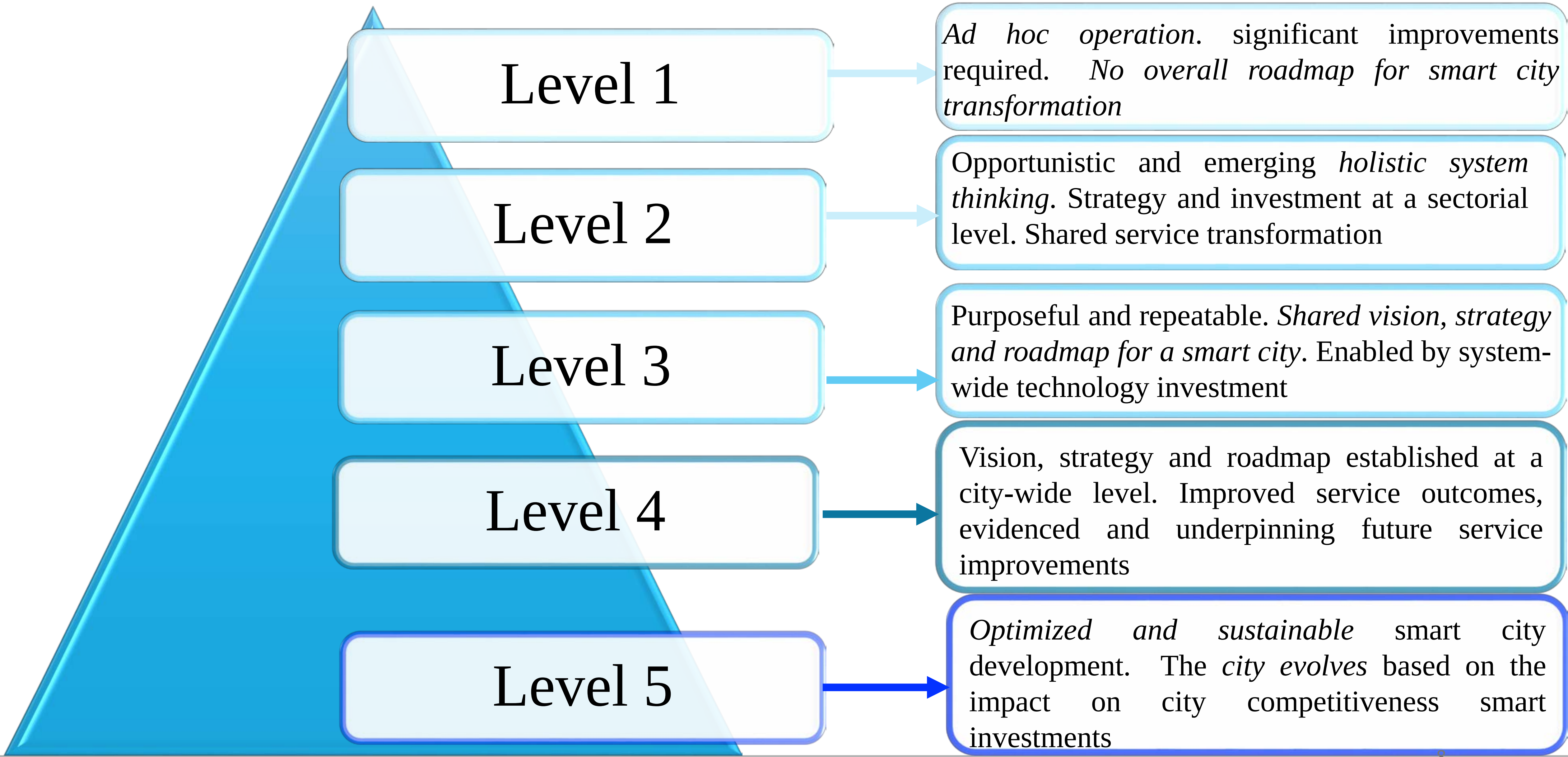
[1] Abu-Rayash, A., & Dincer, I. (2021). Development of integrated sustainability performance indicators for better management of smart cities. *Sustainable Cities and Society*, *67*, 102704.

SMARTNESS LEVEL (2)



Level 1

Ad hoc operation. significant improvements required. *No overall roadmap for smart city transformation*

Level 2

Opportunistic and emerging *holistic system thinking*. Strategy and investment at a sectorial level. Shared service transformation

Level 3

Purposeful and repeatable. *Shared vision, strategy and roadmap for a smart city*. Enabled by system-wide technology investment

Level 4

Vision, strategy and roadmap established at a city-wide level. Improved service outcomes, evidenced and underpinning future service improvements

Level 5

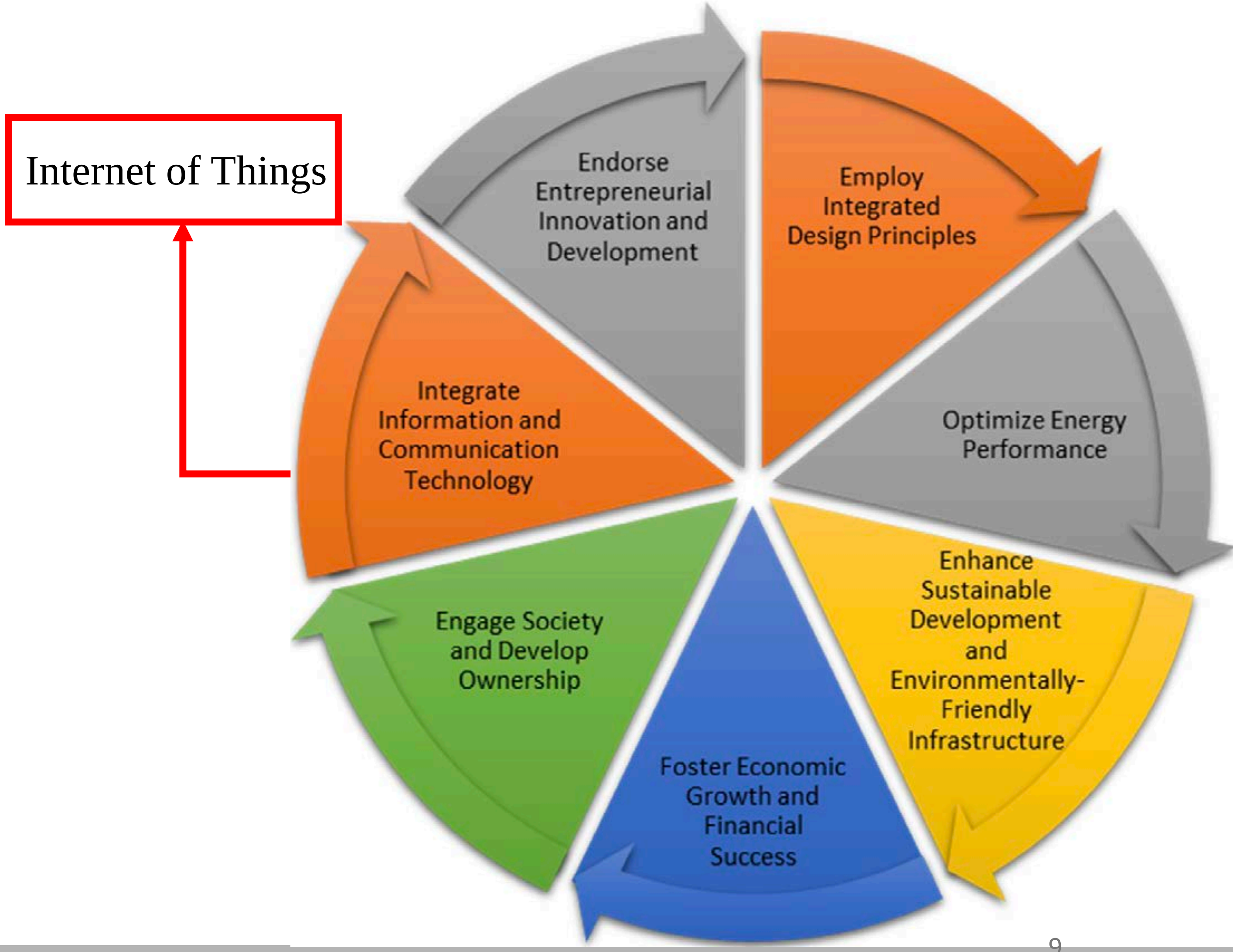
Optimized and sustainable smart city development. The *city evolves* based on the impact on city competitiveness smart investments

SMART CITY: GUIDING PRINCIPLES

Smart city concept is a dynamic concept and not a stagnant one. Its evolution is based on the practices of quality management, where **process and services are constantly assessed for improvement and positive feedback**.

“*Anytime, anywhere, anymedia*” has been for a long time the vision pushing forward the advances in **IoT.** In this context, wireless technologies have played a key role and today the ratio between radios and humans is nearing the 1 to 1 value.

The world become a small village where *things* are connected each other and with the rest of the world via **global communication protocols**.



Internet of Things

Endorse Entrepreneurial Innovation and Development

Employ Integrated Design Principles

Optimize Energy Performance

Enhance Sustainable Development and Environmentally-Friendly Infrastructure

Foster Economic Growth and Financial Success

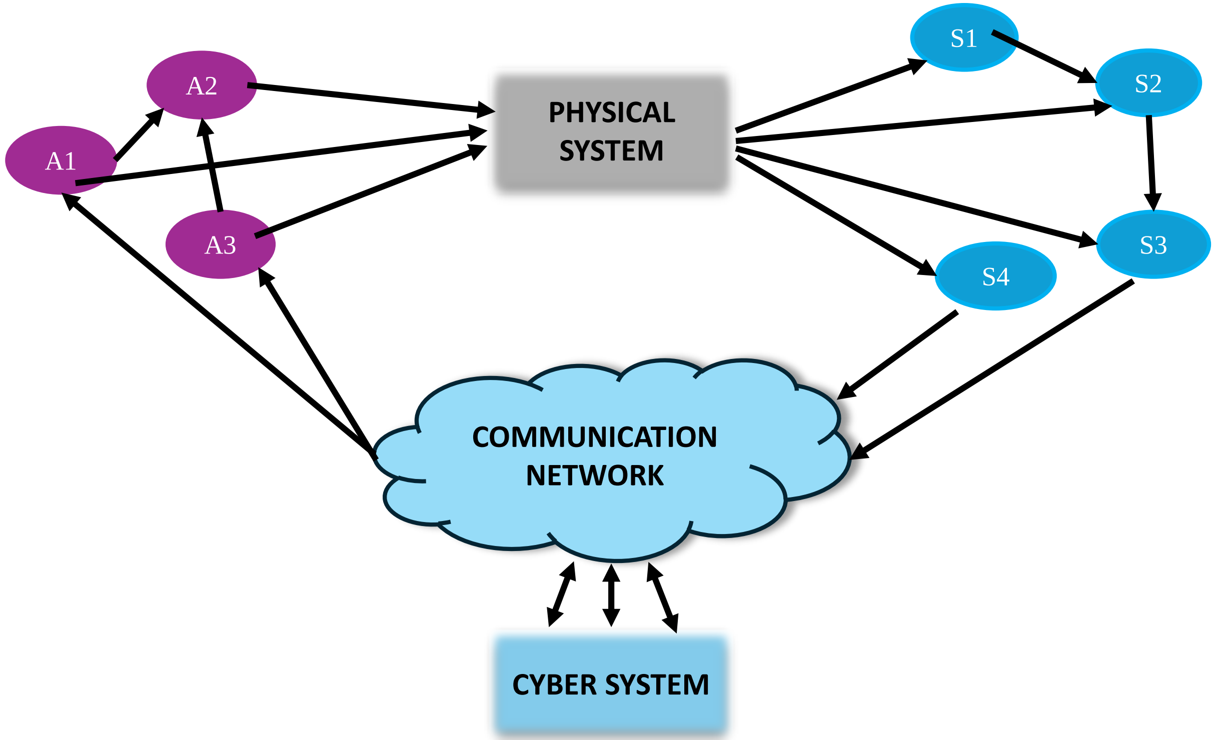
Engage Society and Develop Ownership

Integrate Information and Communication Technology

WHAT DO THE *'THINGS'* INCLUDE?

The *things* include **both communication devices and physical objects** (*e.g.*, cars, computer, home appliances, etc..).

The basic idea of IoT is that **everything** (e.g., from small rooms to large buildings, from everyday appliances to sophisticated embedded systems, from man-made artifacts to natural objects) **around us could be connected, sensed, cooperatively operated** over the Internet.



SMART CITY AS CYBER-PHYSICAL SYSTEM

Bringing together the physical realm with the cyber one consisting of a **wide umbrella** of novel computing technologies, the vision of a smart city as a ***Cyber-Physical System*** (CPS) in a networked perspective is enabled, where the **communication infrastructure is the core for a smart handling of all the involved “*Things*”**

Cyber-Physical Systems Actions

- Sensors detect and capture the events →
- Actuators are used to affect the physical ojbects →
- Inter communication among other CPS →
- Evaluation and saving of global data and information →
- Human Machine Interface

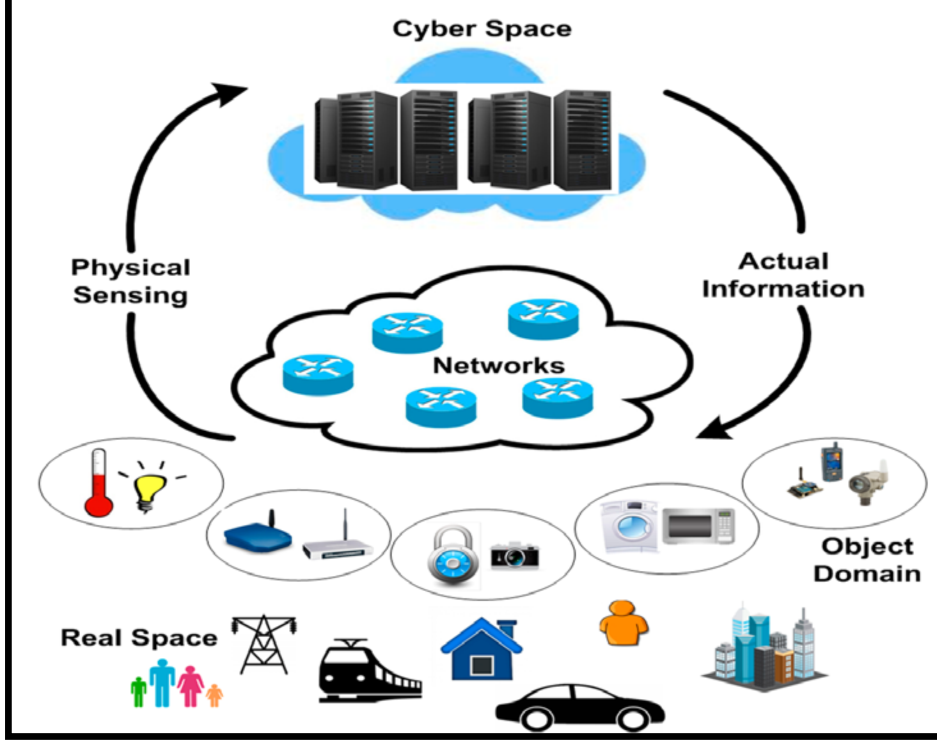
Cyber-Physical Systems Awareness Properties

- Self Healing
- Self Adaption
- Self Discovery
- Self Energy Supply
- Self Optimization

A SERVICE-ORIENTED CYBER-PHYSICAL SMART CITY

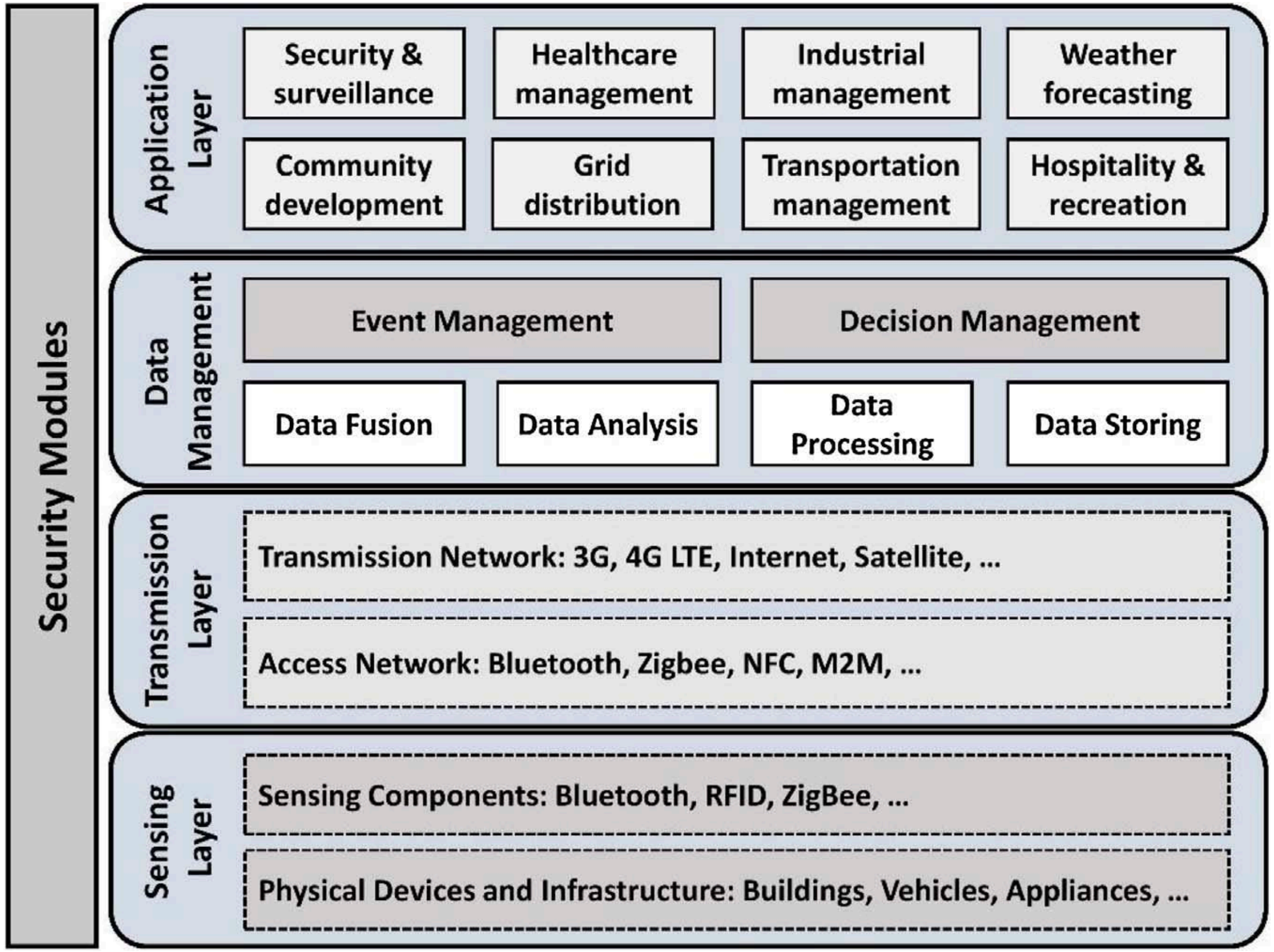
By integrating ICTs, infrastructures, intelligent devices, the Smart City final aim is addressing all urban citizens needs by **providing more efficient services and solutions with respect to the ones available into a ’regular’ city**, thus enabling a **service-oriented** vision.

Smart Solutions to urban citizens complex problems



SERVICE-ORIENTED SMART CITY ARCHITECTURE

The architecture of a **service-oriented smart city** is typically **a bottom-up architecture** consisting of four layers: 1) *sensing layer; 2) transmission layer; 3) data management; 4) application layer*.



Security Modules

Application Layer
Security & surveillance
Healthcare management
Industrial management
Weather forecasting
Community development
Grid distribution
Transportation management
Hospitality & recreation

Data Management
Event Management
Decision Management
Data Fusion
Data Analysis
Data Processing
Data Storing

Transmission Layer
Transmission Network: 3G, 4G LTE, Internet, Satellite, ...
Access Network: Bluetooth, Zigbee, NFC, M2M, ...

Sensing Layer
Sensing Components: Bluetooth, RFID, ZigBee, ...
Physical Devices and Infrastructure: Buildings, Vehicles, Appliances, ...

The security modules are integrated to each layers since sensitive data protection is a key concern of any smart city.

- **Data collection from physical devices** is the main responsibility of **sensing layer**, which reside at the bottom of the architecture.

- By exploiting different communication technologies, **transmission layer carries data to the upper layers**.

- **Data management** layer processes and stores valuable information, which are useful for service provision offered to several **applications at the top layer**.

…NOT ONLY BENEFITS

Although the **IoT** became ubiquitous in everyone daily life, **the big data generated in the IoT requires vast storage capacity, cloud computing and large channel bandwidth for transmission**. Moreover, the processing of big data consumes high power.

Hence, IoT along with the exploitation of advanced ICTs contribute to both high **energy consumption and carbon emissions**

Up to the date, the ICT sector is responsible, e.g., for:

- $\mathbf{2.4\%-3\%}$ of global electricity consumption with a forecasted 20% increase annually
- $\mathbf{2\%\ -\ 2.5\%}$ of worldwide carbon emissions

Shuja, J., Ahmad, R. W., Gani, A., Abdalla Ahmed, A. I., Siddiqa, A., Nisar, K., ... & Zomaya, A. Y. (2017). Greening emerging IT technologies: techniques and practices. *Journal of Internet Services and Applications*, *8*, 1-11.

SUSTAINABLE SMART WORLD PARAGIGM

GREEN USAGE

Minimizing the power consumption by using devices in an environmentally sound manner.

GREEN DISPOSAL:

Reusing and recycling old computers and other electronic equipment

Smart & Sustainable World

GREEN DESIGN:

Designing energy efficient devices and equipment

GREEN MANUFACTURING:

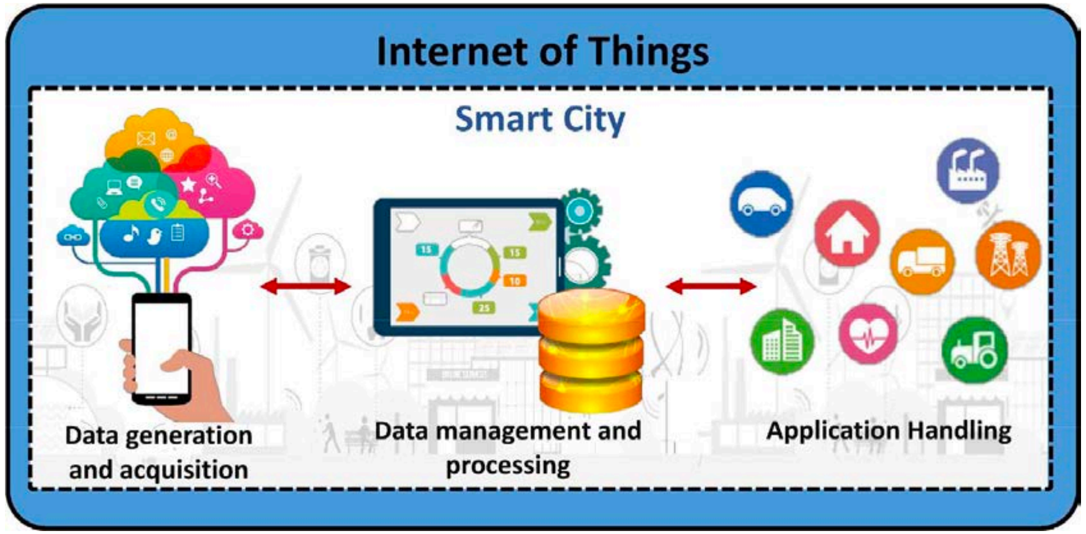
Producing electronic components and other associated subsystems with minimal or no impact on the environment

GREEN IoT

There is the need of **re-formulate IoT, or better the services achievable via IoT, in "sustainable" and "eco-friendly" manner**

This leads to the **new concept of** "**Green IoT**", which focuses on using IoT so to optimize:

- **Energy efficient use** of **devices, communication** resources and interconnections.
- **Carbon emission reduction** -including hazardous emissions, resources consumption and pollution- **while providing smart cities services**.



Smart Transportation

Smart Grids

SMART CITY APPLICATION HANDLING

Smart Transportation

Smart Grids

SMART TRANSPORTATION

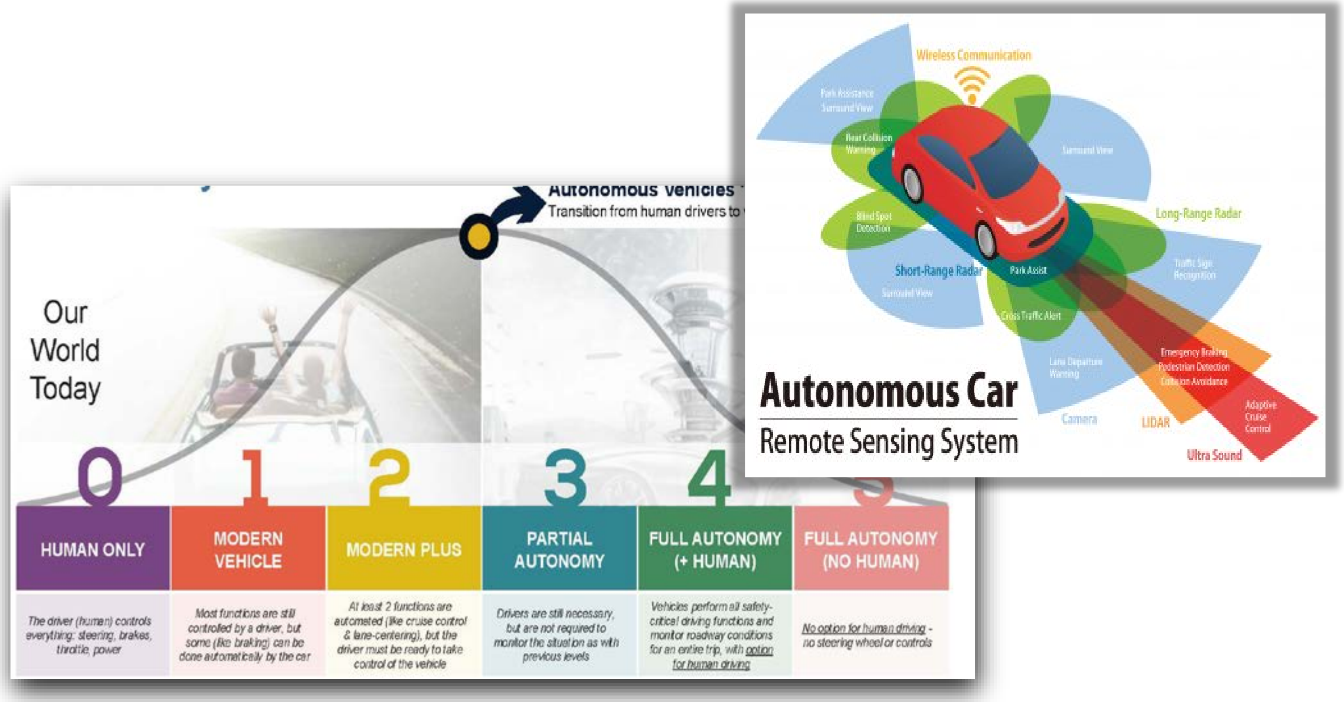
The concept of connecting everyday object has revolutionized the conventional transportation system, thus leading to **Intelligent Transportation Systems (ITS)** and **Internet of Vehicles (IoVs)** framework (leveraging Vehicular Ad hoc NETwork (VANET), Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, the road and its actors are components of a cyber-physical network)

Owing to real-time communication capabilities, transport systems became able to act timely and efficiently based on real-time data. Smart transportation systems convey information regarding congestion level of streets, alternative routes and alternative transportation mediums to passengers.

Mobility solutions enabled **by CCAM (Cooperative, Connected and Automated Mobility) aim adding social value to transport, e.g., increased safety, reduced traffic jam and environmental impacts**

CONNECTED COPERATIVE AUTOMATED VEHICLES

CAVs combine the digital world with automated technologies to **assist, or replace humans, in cars**.
Exploiting V2X information (Vehicle-to-Everything), they can take decisions or suggest to a driver behaviours, not only on the basis of data coming from on-board sensors and infrastructures, but also from the other nearby vehicles



0 HUMAN ONLY	1 MODERN VEHICLE	2 MODERN PLUS	3 PARTIAL AUTONOMY	4 FULL AUTONOMY (+ HUMAN)	5 FULL AUTONOMY (NO HUMAN)
The driver (human) controls everything: steering, brakes, throttle, power	Most functions are still controlled by a driver, but some (like braking) can be done automatically by the car	At least 2 functions are automated (like cruise control & lane-centering), but the driver must be ready to take control of the vehicle	Drivers are still necessary, but are not required to monitor the situation as with previous levels	Vehicles perform all safety-critical driving functions and monitor roadway conditions for an entire trip, with option for human driving	No option for human driving - no steering wheel or controls

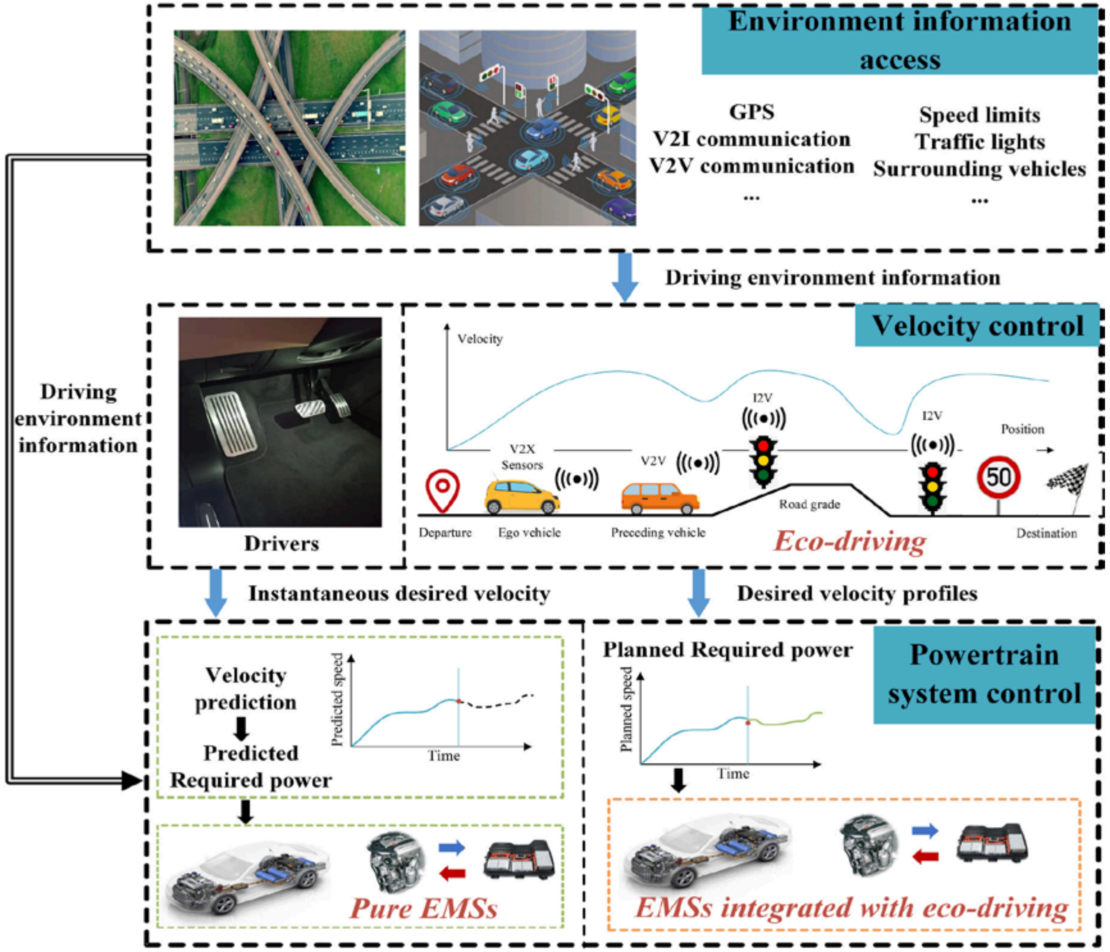
Communication networks:

1. *Wi-Fi networks*
2. *(IEEE 802.11p, IEEE 802.11d)*
3. *Mobile networks 4G/5G*

Leveraging V2X, connected vehicles can **share information with neighbours -** Position, speed, acceleration, time-stamp, id vehicle, heading – (*On-board sensors: IMU, GPS, proximity sensors, sensor-fusion modules based on nonlinear filters, ….*) and/or **receive a reference signal** coming from a leading vehicle or a **road infrastructure** (*acting as a virtual leader*)

ECO-DRIVING MOTION OF CAVS

CAVs have the ability to **optimally plan and execute driving operations** through the usage of the surrounding road traffic environment information as obtained from communication and detection technologies.



The primary aim of eco-driving control for CAVs is to achieve a **"social optimum" target improving the energy economy of a specific area**.

The structure of an energy-saving control system of CAVs consists of three layers:

1. Obtain environment information via V2X communication (deliver information to CAVs)
2. Control driving speed and generation of the desired velocity profile
3. Control the powertrain system, which outputs driving torque to fulfil the required power for the tracking of the desired driving speed

Li, J., Fotouhi, A., Liu, Y., Zhang, Y., & Chen, Z. (2024). Review on eco-driving control for connected and automated vehicles. *Renewable and Sustainable Energy Reviews*, *189*, 114025.

TRAFFIC CONGESTION ISSUE

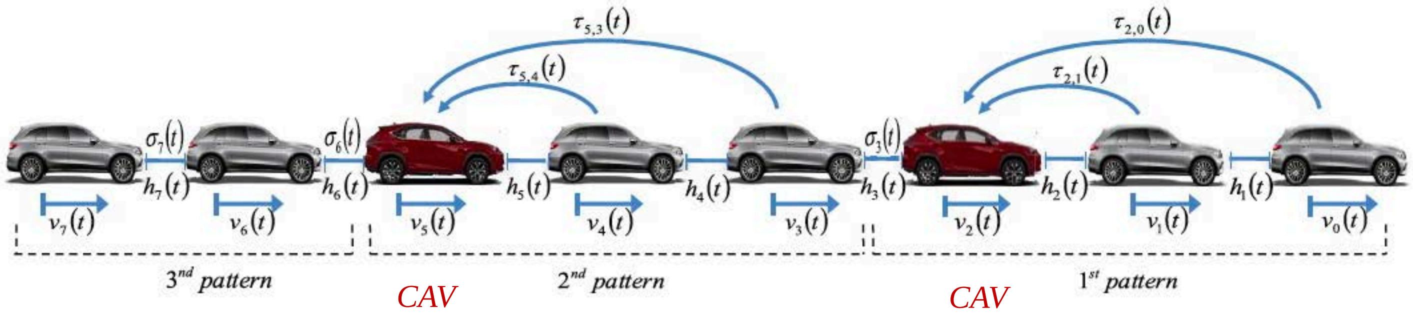
Chaotic traffic conditions result in congested roads, high pollution, lesser fuel economy and even wastage of time. Road **congestion is mainly due to rapid acceleration/deceleration of human-driven vehicles** resulting in **stop-and-go-effects**

Human driver behaviours that mostly increase these phenomena are the frequent lane changing (e.g. due to accidents and obstacles) or the habit of using mobile devices while driving, hence increasing the occurring of **sudden accelerating/ braking manoeuvres**

The IoV can enable **Cooperative-Intelligent Sustainable Transport Systems (C-ITS)** that can mitigate these phenomena (?)

CAVs IN MIXED TRAFFIC

Traffic jam can be mitigated (**reduction of stop-and-go effects**), when cooperative driving algorithms are active on a **subset of CAVs within the traffic flow**, **by exploiting the effects/information coming from all the connected ahead vehicles along the traffic chain**, without restricting the analysis to the presence of the only preceding vehicle (via sensing).



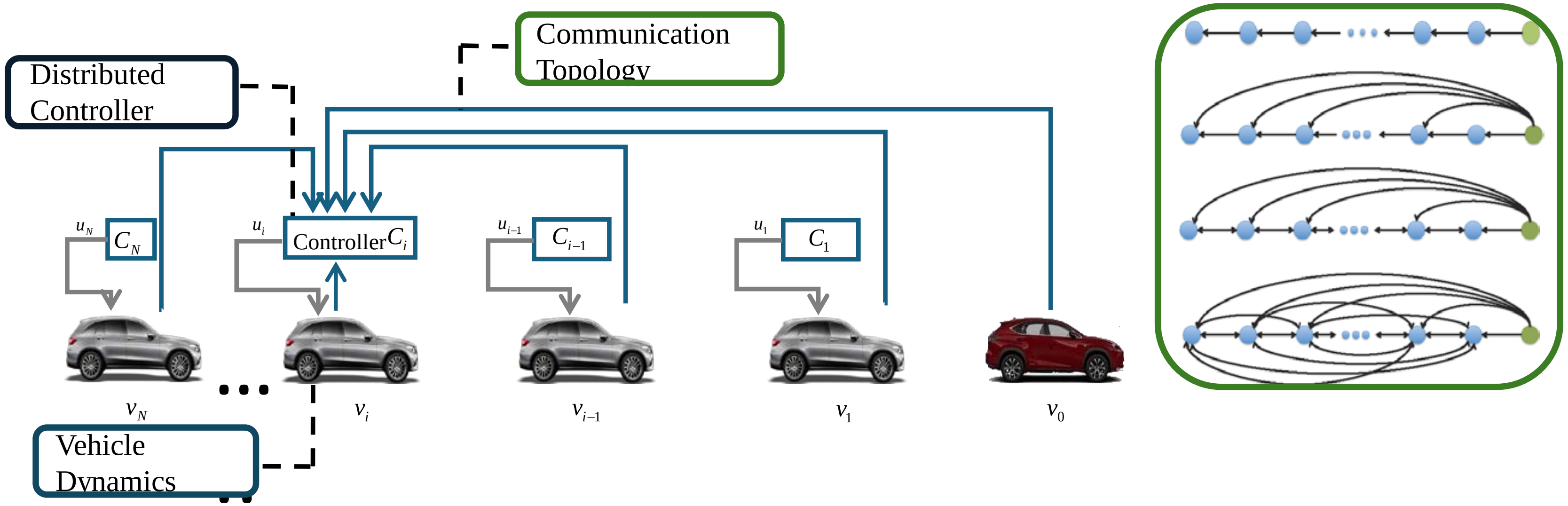
Eight Vehicles chain when a small disturbance acts on the head vehilce: all vehicles are human-driven; only vehicle 2 is autonomous; both vehicle 2 and vehicle 5 are autonomous

L. Zhang and G. Orosz, "Motif-Based Design for Connected Vehicle Systems in Presence of Heterogeneous Connectivity Structures and Time Delays," in IEEE Transactions on Intelligent Transportation Systems, vol. 17, no. 6, pp. 1638-1651, June 2016
Di Vaio, M., Fiengo, G., Petrillo, A., Salvi, A., Santini, S., & Tufo, M. (2019). Cooperative shock waves mitigation in mixed traffic flow environment. IEEE Transactions on Intelligent Transportation Systems, 20(12), 4339-4353.

SMART TRANSPORTATION: PLATOONING AND FLEETS

By leveraging V2V/V2I communications, ***platoon-based driving*** is one of the fundamental ITS strategies, where CAVs **cooperatively travel as a fleet by maintaining safe inter-vehicular spacing, while tracking a reference speed profile** (enhancing road efficiency, safety)

PLATOON-BASED DRIVING PATTERN OF A FLEET OF CAVS



CHALLENGES

- Since the communication topology is not a priori known (the active links depends on actual connectivity conditions), the **control protocol must be fully-distributed**

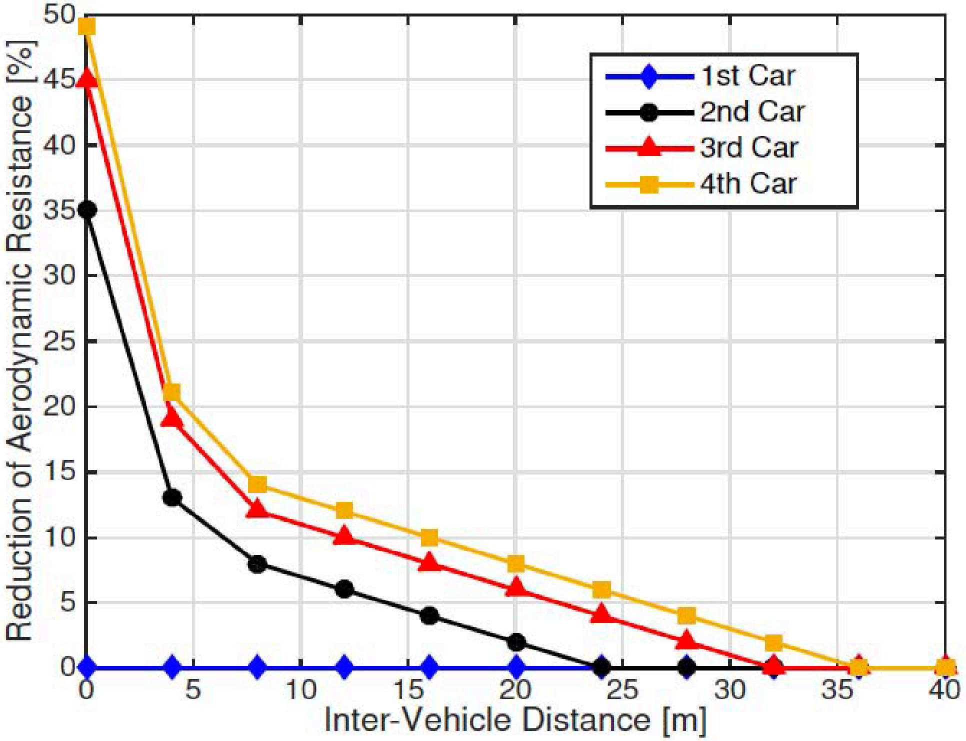
- Control actions have to be designed and implemented at **single car level without requiring any information about the global communication structure** (e.g., its Laplacian)

- Vehicles dynamics are heterogenous (e.g., mass, drivetrain mechanical efficiency, wheel radius, max. driving/braking torques) and nonlinear (e.g., due to the presence of the aerodynamic drug and friction effects)

- External disturbances could arise, (e.g. from variations in wind velocity and/or road slope)

ECO-FRIENDLY EFFECT OF PLATOONING

Experimental results have proved **a $6\% - 10\%$ fuel economy improvement in platooning application** due to the reduction of the aerodynamic resistance forces and the **minimization of unnecessary acceleration / deceleration manoeuvres**



The airdrag reduction factor relies on:

a) inter-vehicle distance between adjacent vehicles;
b) specific position of the vehicle within the platoon.

The first vehicle (leader) has zero reduction of airdrag resistance coefficient, while it increases as the positioning index of a vehicle within the platoon increases.
For all position $N \geq 4$ it assumes the same value as for the 4^{th} vehicle.

ELECTRIFICATION

Transportation electrification is indispensable for low carbon emissions in the transportation sector, and the recent line-up of **electric vehicles (EVs)** covers various vehicle usages, such as personal, business, commercial, and public.

However, **sustainability and environmental benefits are usually behind autonomy/consumption performance in the customers ranking**

This is is a crucial aspect to foster the transition to e-mobility

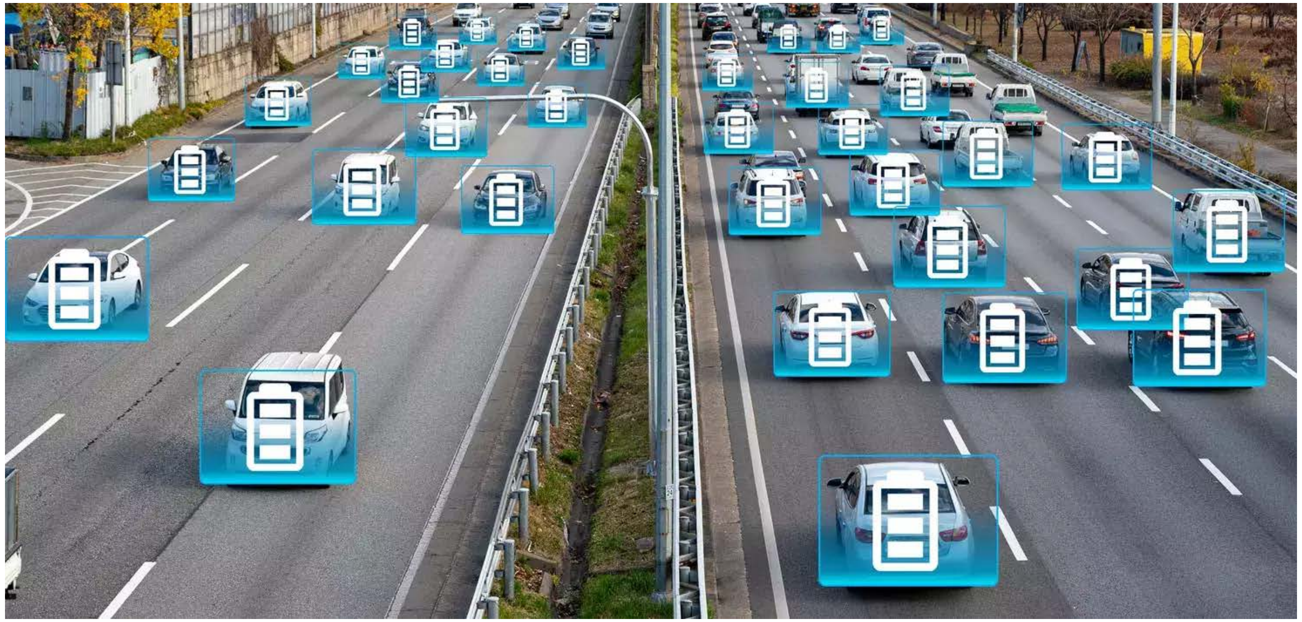
ELECTRIFICATION CHALLENGES

The challenges and difficulties faced in their adoption are:

- high cost of infrastructure
- scarcity of charging stations
- limited range or range anxiety
- battery performance

Potential solutions include:

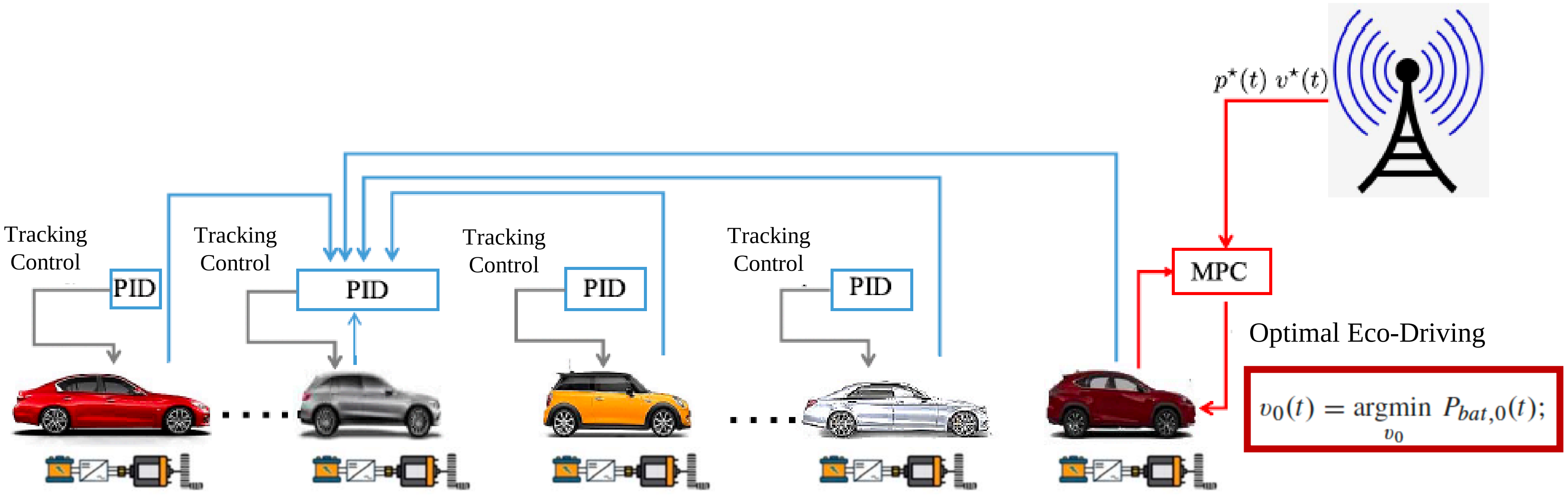
- enhancing the charging infrastructure
- increasing the number of charging stations
- using battery swapping techniques
- **battery-oriented eco-driving solutions**



Road traffic **IoV information** combined with **accurate predictive models** of the CAEV, **including the battery system dynamics**, enables controlling the car kinematic in real-time so preserve energy consumption and, hence, its battery autonomy

The **optimization of the speed profile is so performed on-line, taking into account in real-time battery system**/regenerative braking performance during **acceleration/deceleration** phases

TOWARDS BATTERY ORIENTED ECO-DRIVING CONTROL

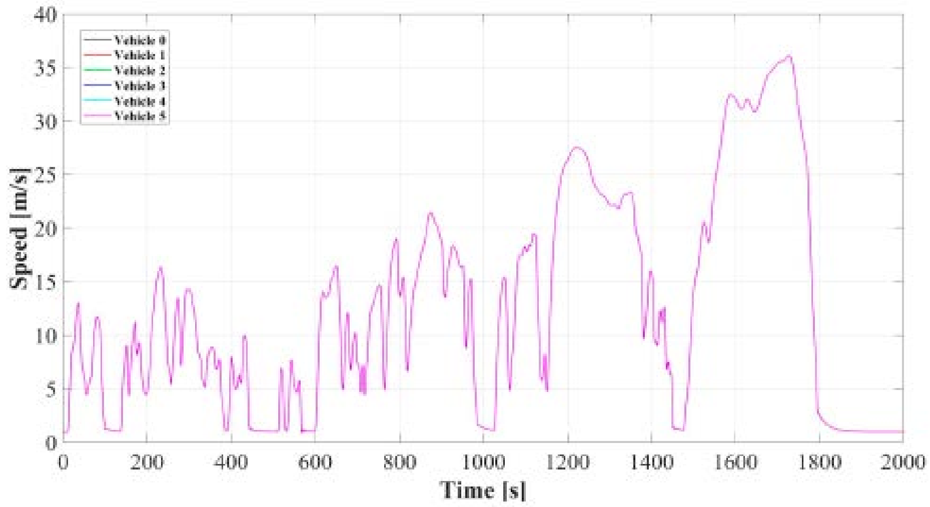


$$v_0(t) = \underset{v_0}{\operatorname{argmin}}\ P_{bat,0}(t);$$

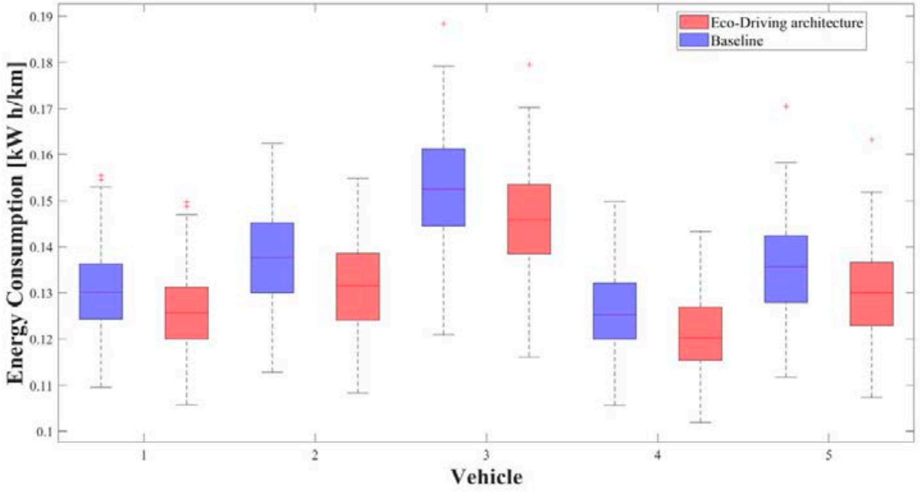
- Exploiting a predictive strategy driving the leader motion in order to compute the optimal ecological trajectory to be imposed
- Leveraging distributed model-based control which drives the follower vehicles motion for achieving a precise leader-tracking with a desired transient behaviour as required for the accurate implementation of the energy-saving control

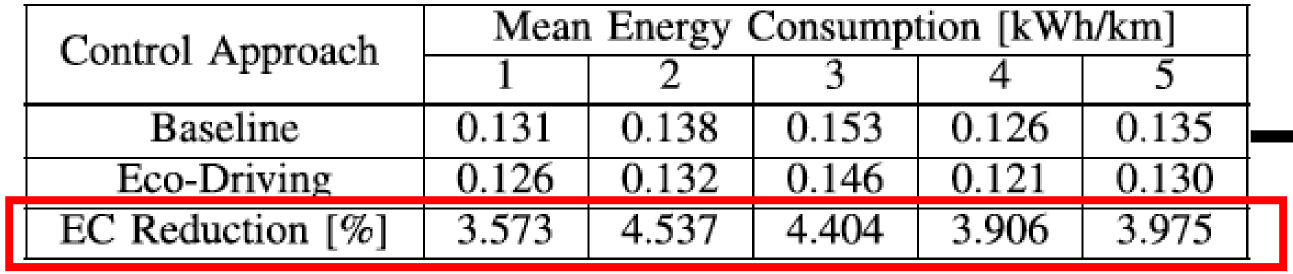
Coppola, A., Lui, D. G., Petrillo, A., & Santini, S. (2022). Eco-driving control architecture for platoons of uncertain heterogeneous nonlinear connected autonomous electric vehicles. *IEEE Transactions on Intelligent Transportation Systems*, *23*(12), 24220-24234

TOWARDS BATTERY ORIENTED ECO-DRIVING CONTROL (2)



WLTP cycle





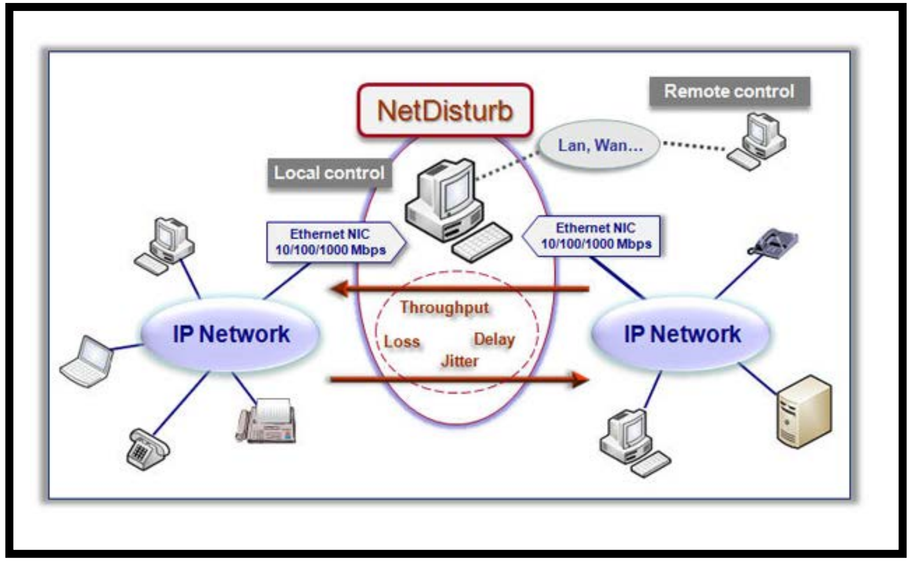
Control Approach	Mean Energy Consumption [kWh/km]				
	1	2	3	4	5
Baseline	0.131	0.138	0.153	0.126	0.135
Eco-Driving	0.126	0.132	0.146	0.121	0.130
EC Reduction [%]	3.573	4.537	4.404	3.906	3.975

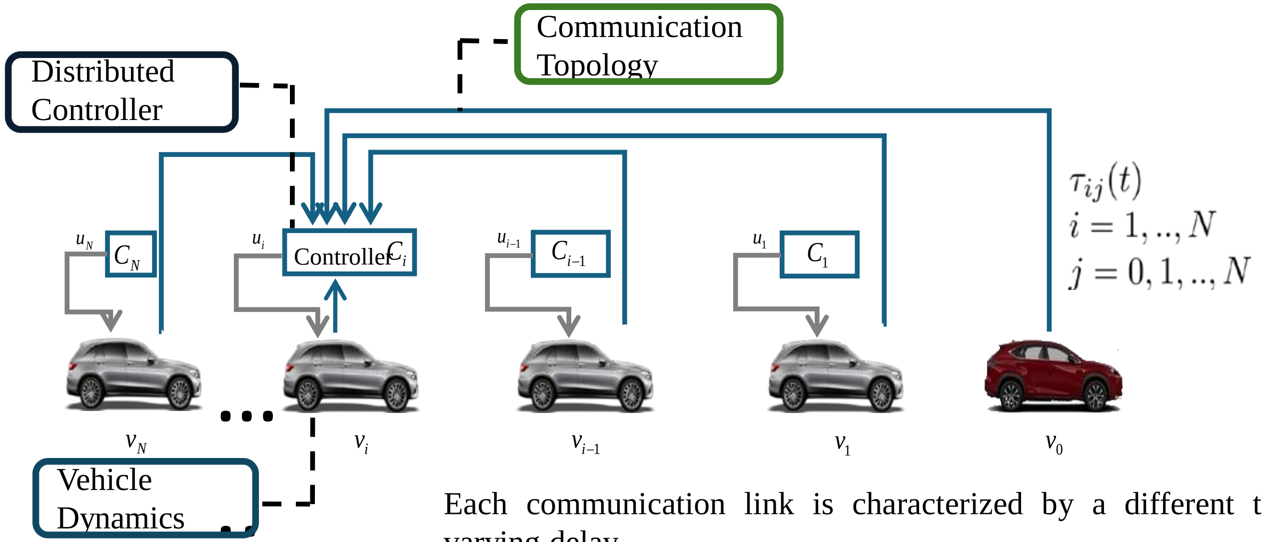
For the comparison, baseline control approach does not involve the energy-saving nonlinear MPC

Coppola, A., Lui, D. G., Petrillo, A., & Santini, S. (2022). Eco-driving control architecture for platoons of uncertain heterogeneous nonlinear connected autonomous electric vehicles. *IEEE Transactions on Intelligent Transportation Systems*, *23*(12), 24220-24234

IoV : Communication Issues

Cooperative control strategies are traditionally designed under the implicit restrictive assumption of perfect communication environments and unlimited bandwidth.





Each communication link is characterized by a different time-varying delay

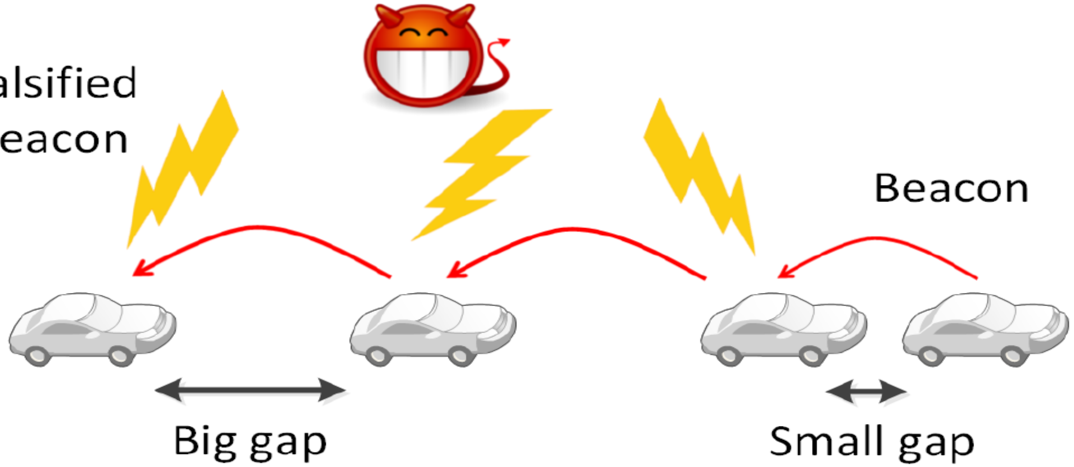
During normal operating conditions, wireless communication networks introduce unavoidable **communication impairments** due to the current status of each of the communications links (e.g., bounded communication delays and packet losses).

It follows that it is crucial to deploy cooperative control algorithms **resilient and robust to networked-induced phenomena** from the very beginning of their design phase (**Time-delayed Control Solution**)

$$u_i = -\sum_{j=0}^{N} \alpha_{ij} k_{ij}^{\top}(t) \begin{bmatrix} r_i(t-\tau_{ij}(t)) - r_j(t-\tau_{ij}(t)) - d_{ij} \\ v_i(t-\tau_{ij}(t)) - v_j(t-\tau_{ij}(t)) \\ a_i(t-\tau_{ij}(t)) - a_j(t-\tau_{ij}(t)) \end{bmatrix}$$

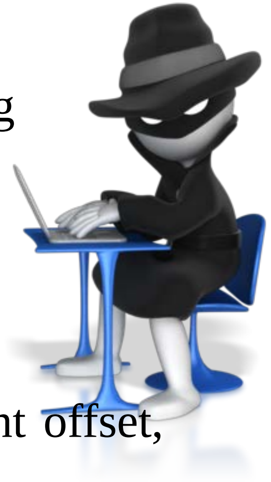
THRETS

- Besides communication issues arising in normal operating conditions, wireless communication networks may suffer different **security threats**.
- In collaborative driving applications, the sudden appearance of a **malicious attack** on the communication network is crucial since it mainly compromises:
  a. the correctness of data traffic flow;
  b. the application safety.



Traditional security methods in the technical literature on communication networks (wireless or not) include encryption/decryption methods, authentication tools, and digital signatures.

SECURITY IN VEHICULAR NETWORK



Vehicular networks suffering from security threats can compromise the correct functioning of cooperative driving application and its safety.

Some security vulnerabilities:

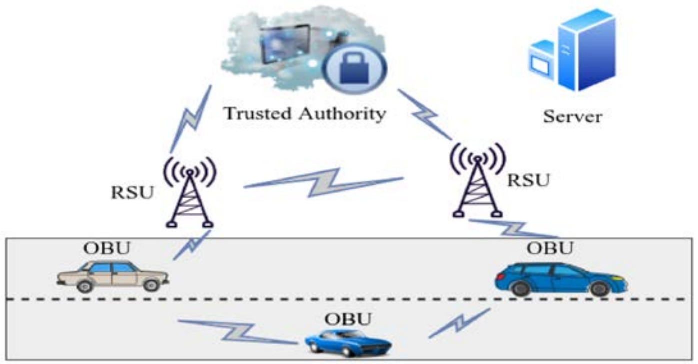
1. **Spoofing:** an internal adversary takes the control of one vehicle within the fleet and imposes a constant offset, e.g., to its current acceleration value from a given time instant
2. **Message Falsification:** an adversary starts listening the messages wirelessly sent on networks and, after receiving each beacon, it tries to manipulate and to falsify the content of positions messages in order to rebroadcast them
3. **Denial-of-Service (DoS):** an adversary overloads and overwhelms the communication capacity of one specific vehicle within the platoon in order to make them unable to exchange the necessary information for cooperative driving.
4. **Burst Transmission:** an internal adversary, tries to manipulate all the data traffic flow in order to disperse some beacons with a randomly loss rate

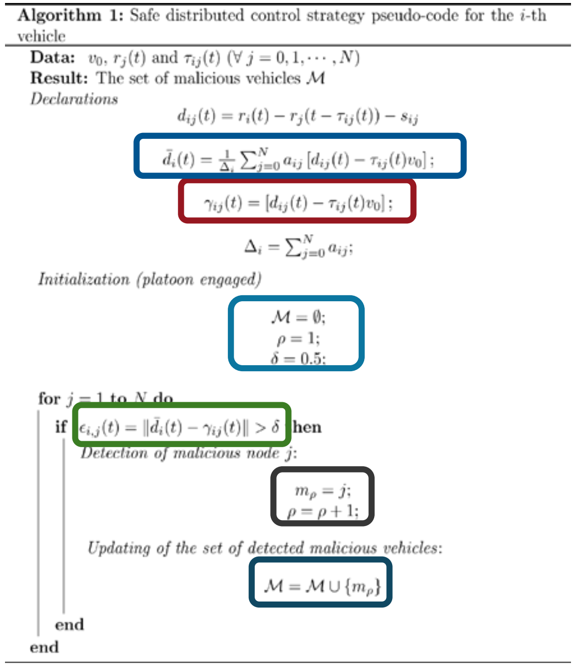
RESILIENT COOPERATIVE CONTROL STRATEGY

To counteract cyber attacks, it is possible to exploit the cooperation features of control strategies, as well as their ability to cope with time-delays

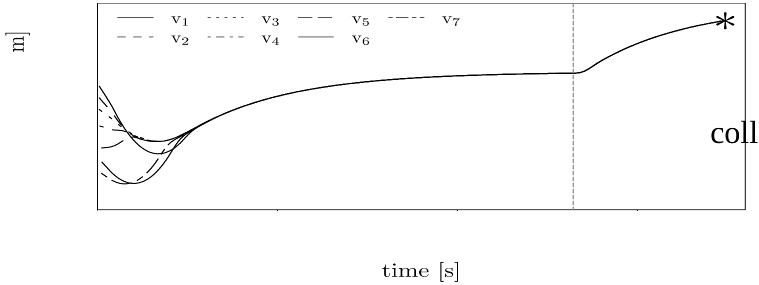
1. embedding **collaborative mechanisms** within the control strategies to detect and react to Spoofing and Message Falsification with the aim of **discarding compromised information (cooperative constructing a belief about the information and isolating the malicious vehicle**)

2. **reacting to hard communication time-varying delay** for counteracting **DoS and Burst** and hence for somehow compensating the lack of information during the attacks.

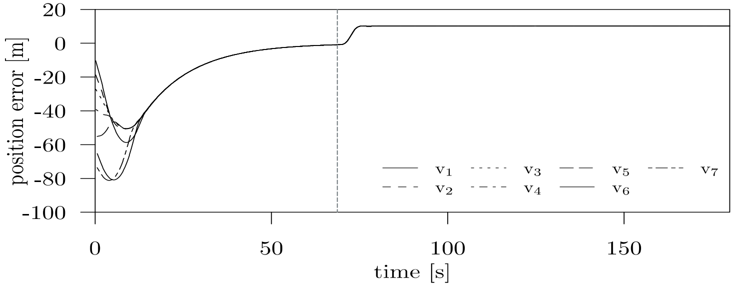




```
Algorithm 1: Safe distributed control strategy pseudo-code for the i-th vehicle
Data: $v_0$, $r_j(t)$ and $\tau_{ij}(t)$ ($\forall\, j = 0, 1, \cdots, N$)
Result: The set of malicious vehicles $\mathcal{M}$
Declarations
    $d_{ij}(t) = r_i(t) - r_j(t - \tau_{ij}(t)) - s_{ij}$
    $\bar{d}_i(t) = \frac{1}{\Delta_i} \sum_{j=0}^{N} a_{ij} \left[ d_{ij}(t) - \tau_{ij}(t) v_0 \right];$
    $\gamma_{ij}(t) = \left[ d_{ij}(t) - \tau_{ij}(t) v_0 \right];$
    $\Delta_i = \sum_{j=0}^{N} a_{ij};$
Initialization (platoon engaged)
    $\mathcal{M} = \emptyset;$
    $\rho = 1;$
    $\delta = 0.5;$
for $j = 1$ to $N$ do
    if $\epsilon_{i,j}(t) = \|\bar{d}_i(t) - \gamma_{ij}(t)\| > \delta$ hen
        Detection of malicious node $j$:
            $m_\rho = j;$
            $\rho = \rho + 1;$
        Updating of the set of detected malicious vehicles:
            $\mathcal{M} = \mathcal{M} \cup \{m_\rho\}$
    end
end
```



collision (star symbol)



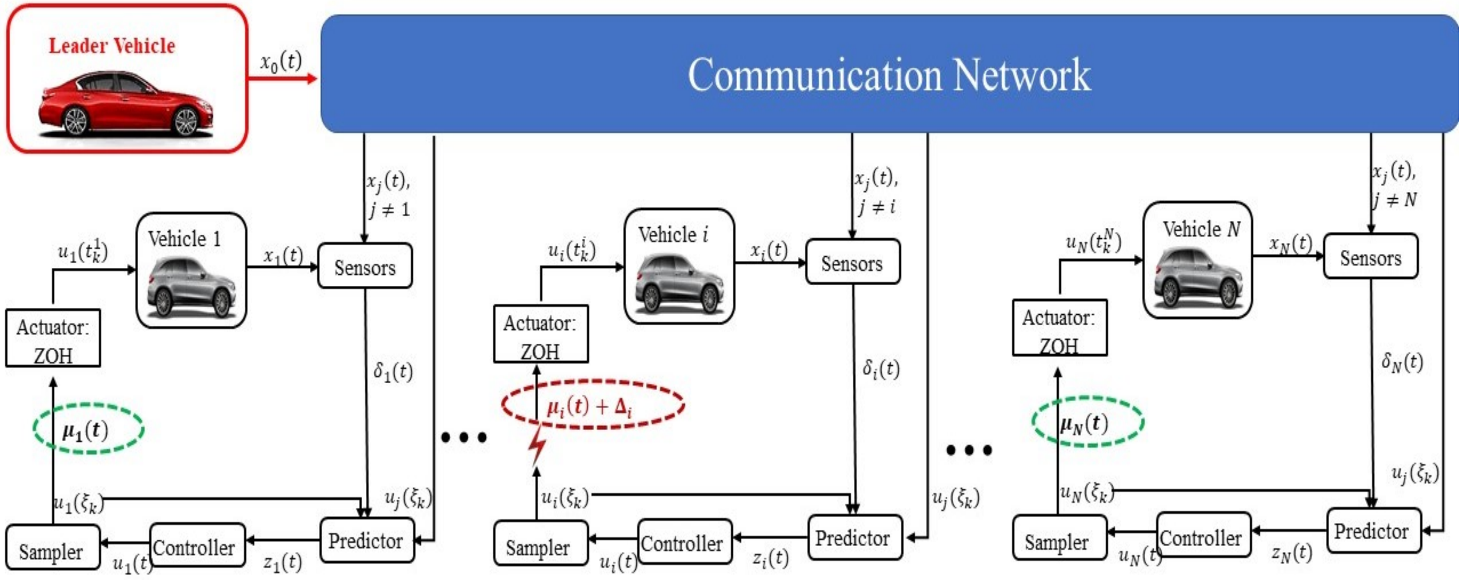
Spoofing (+3.5 [m/s^2] for all vehicles)

Petrillo, A., Pescape, A., & Santini, S. (2020). A secure adaptive control for cooperative driving of autonomzous connected vehicles in the presence of heterogeneous communication delays and cyberattacks. *IEEE transactions on cybernetics*, *51*(3), 1134-1149.

RESILIENCE VIA PREDICTOR BASED FEEDBACK CONTROL

To counteract destabilizing effect of DoS attacks and communication time-delays, which can be modelled as **large delays**, another solution could be the introduction of predictor-based feedback controller.

The idea is to **predict the future velocity and distances of vehicles based on the last available data packets. Such prediction can be done based on the history of GPS position and velocity** contained by basic safety messages (BSM).



Digital implementation of the distributed controller for network workload mitigation

$$t_k^i = \xi_k + D_i, \rightsquigarrow \textit{control updating instant}$$

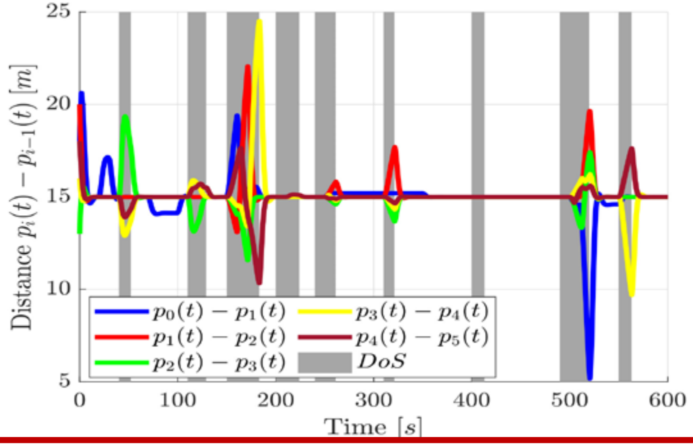
$$D_i = \mu^\star + \Delta_i \ \rightsquigarrow \textit{large delay}$$

The predictors may improve **stability under intermittent communication and ensure robustness against the variations of time delay due to packet losses, while sampled-data implementation ensures communication resources saving objective**

Caiazzo, B., Lui, D. G., Mungiello, A., Petrillo, A., & Santini, S. (2023, September). On the resilience of autonomous connected vehicles platoon under DoS attacks: a predictor-based sampled data control. In *2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC)* (pp. 4907-4912). IEEE

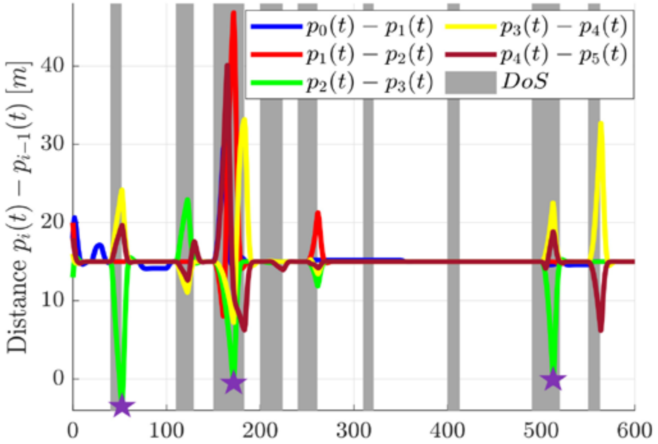
RESILIENCE VIA PREDICTOR BASED FEEDBACK CONTROL

- DoS attacks + communication time-delays: predictor-based feedback control mitigation



- DoS attacks + communication time-delays: without predictor-based mechanism

The predictor-free controller is not able to counteract the involved large input delays, even causing collisions during DoS attacks occurrence (star symbols).



Sampling period $h = 0.01$ and large delay value $D = 16$ $[s]$

Caiazzo, B., Lui, D. G., Mungiello, A., Petrillo, A., & Santini, S. (2023, September). On the resilience of autonomous connected vehicles platoon under DoS attacks: a predictor-based sampled data control. In *2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC)* (pp. 4907-4912). IEEE

SMART CITY APPLICATION HANDLING

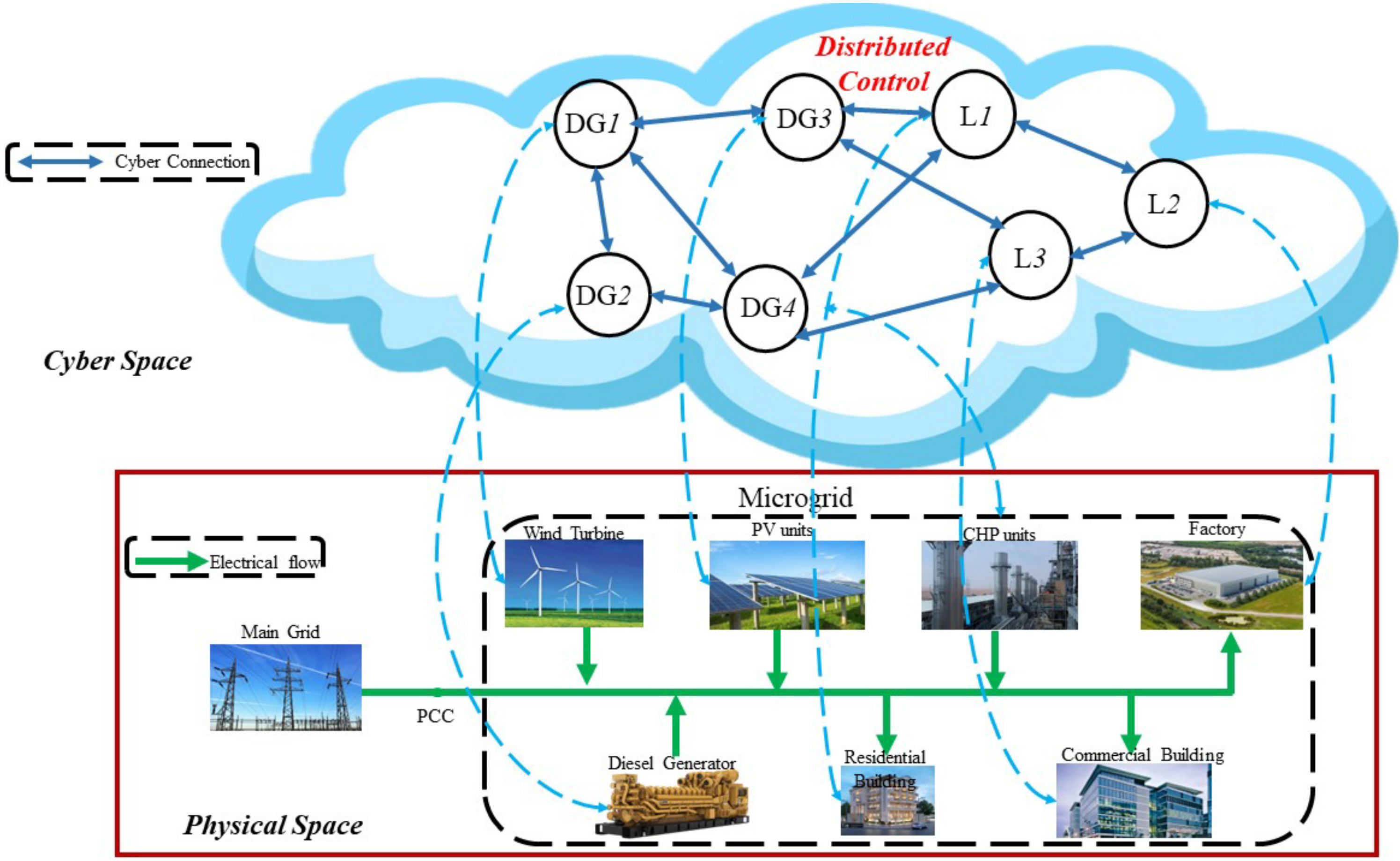
Smart Transportation

Smart Grids

SMART GRIDS: ENERGY TRANSITION (1/2)

Recent advances in ICTs, along with the deployment of small-scale **distributed generation sources**, led to the current *energy transition*, mainly devoted to decarbonisation of energy sector and net zero greenhouse gas emissions.

Microgrids (MGs) represent the conceptualization of this transition, where the **combination of physical plants with bi-directional measurement and control loops** entails the vision of MGs as ***Cyber-Physical Energy Systems*** (**CPES**) in a ***Networked Control System*** (**NCS**) perspective.



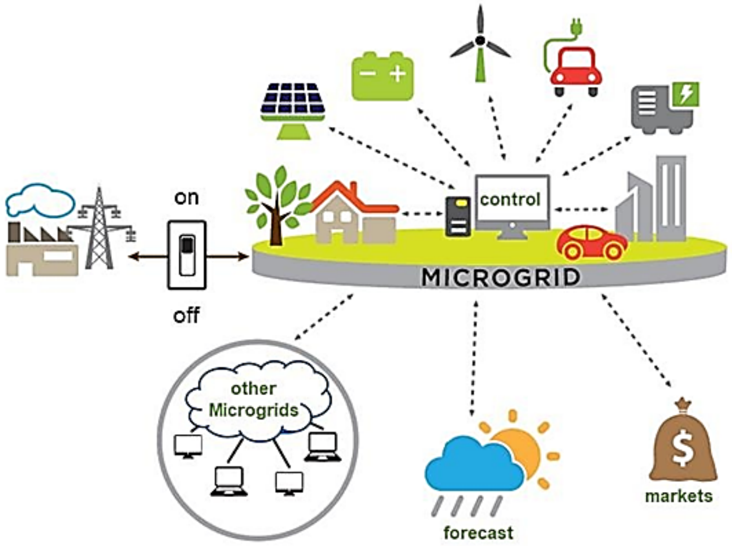
A set of spatially distributed intelligent systems, i.e., the electronically **interfaced Distributed Energy Resources** (DERs), where the communication among sensors, actuators and controllers occurs through a **shared band limited digital communication network**

SMART GRIDS: ENERGY TRANSITION (2/2)

A MG is a cluster of **interconnected DGs, loads and energy storage units** which are collectively managed in order to increase the hosting capacity of DGs and to improve the energy security and reliability, while offering flexibility services to the grid.

MGs are able to work in a double operating mode:

- **Islanded mode**, i.e., the MG works autonomously and possible mismatches between the generated power and loads may result in voltage/frequency instability;
- **Grid-connected**, i.e., its dynamics is dominated by the main grid.



In Islanded operation the MG **control becomes crucial for a reliable power delivery and to preserve synchronization, voltage stability and load sharing**

SMART GRIDS: CYBER-PHYSICAL ENERGY SYSTEMS

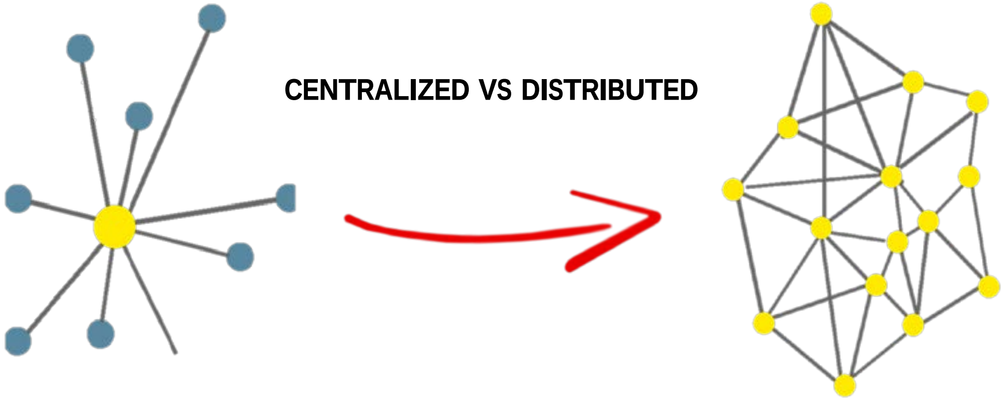
Earlier approaches for voltage/frequency stability of islanded Microgrids are **centralized**:

- Unaffordable complexity;
- Hardware redundancy;
- Data storage resources scalability issues;
- Sensitivity to single-point failures.

☹

↓

This issue is solved by moving towards **distributed control** strategy for frequency and voltage stability of islanded MG. Each MG component is represented as a dynamical system which, **sharing information with the neighboring agents, aims at achieving a common coordinated behaviour at the global level in terms of voltage/frequency set-points**



SMART GRIDS: COMMUNICATION-BURDEN PROBLEM

- The hypothesis of a continuous interaction among distributed generation units may incur **heavy burden on the communication network** and it could be also unrealistic in some practical application, especially when the communication bandwidth and channels are limited

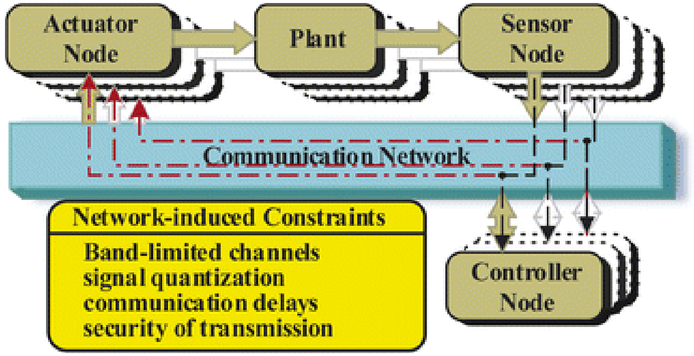
- A stressed communication network will cause **frequent packet dropouts and increased delays**

- The communication **network workload** strongly increases when the **number of distributed generation units** to be controlled become larger

- The need of **reducing the communication network workload is crucial** (**Green IoT**) in electric power systems due to the presence of electronically interfaced power converter.

COMMUNICATION RESOURCES SAVING-ORIENTED CONTROL ARCHITECTURE

- No-Continuous updates of the controllers with communication resources assumed to be limited.
- Power electronic converter are not stressed;
- Green usage of smart device
- Easier implementation in digital control platform.



TOWARDS DISTRIBUTED APERIODIC CONTROL FOR VOLTAGE REGULATION

Objective → Move towards a distributed aperiodic control for voltage regulation in islanded Microgrids with the aim of **reducing the number of controllers updates, thus minimizing the amount of communication network workload** from controller-to-actuators, while preserving voltage synchronization to the reference value.

EVENT-TRIGGERED CONTROL

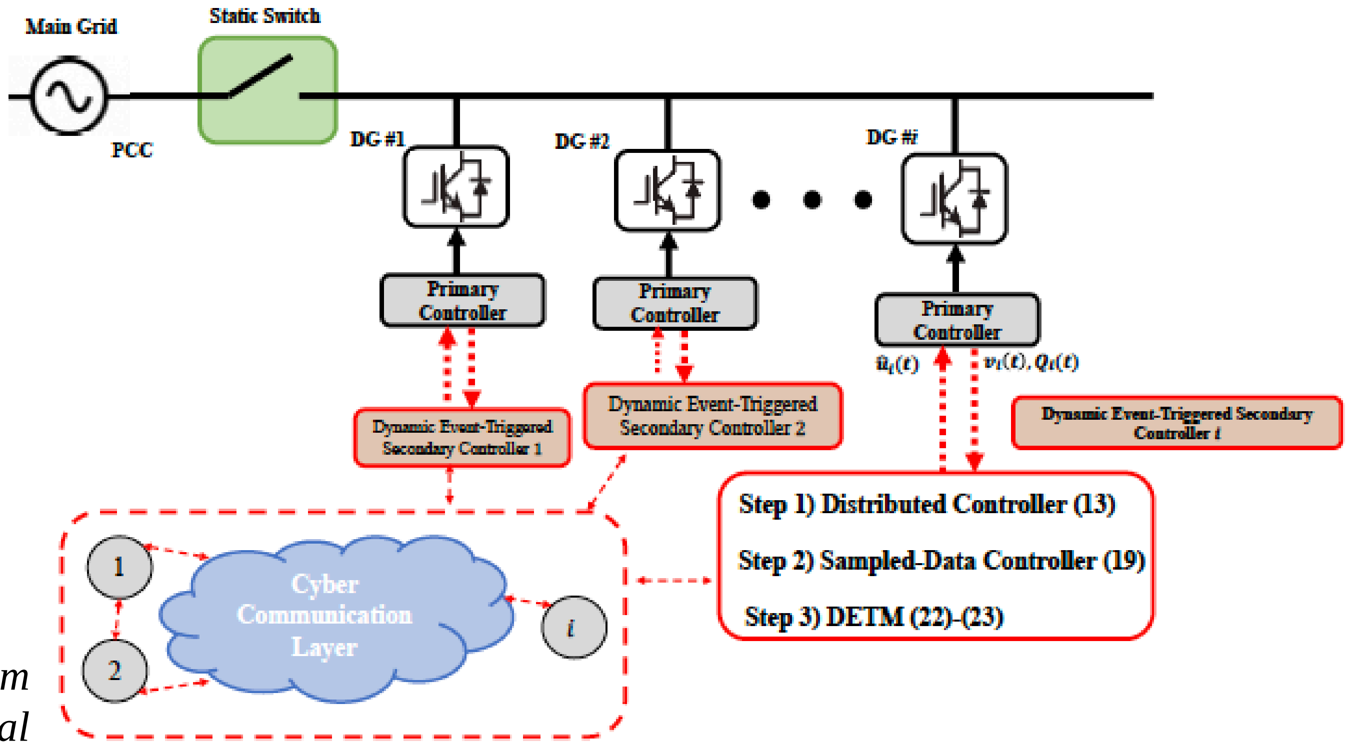
as a suitable solution to avoid costly communication and reduce higher workload

Static triggering rules

fixed and constant threshold

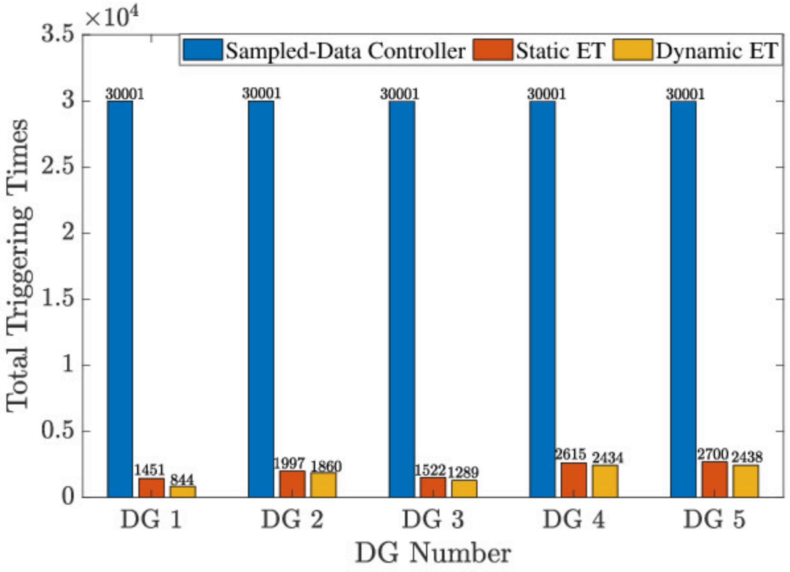
Dynamic triggering rules

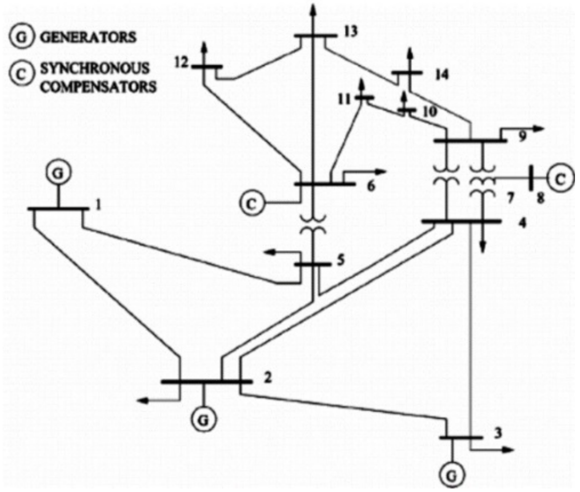
Dynamic adjustable mechanism provided by an additional auxiliary variable, which allows ***achieving larger minimal-inter-events times***



Andreotti, A., Caiazzo, B., Fridman, E., Petrillo, A., & Santini, S. (2024). Distributed Dynamic Event-Triggered Control for Voltage Recovery in Islanded Microgrids by Using Artificial Delays. ***IEEE Transactions on Cybernetics***

TOWARDS DISTRIBUTED APERIODIC CONTROL FOR VOLTAGE REGULATION (2)





IEEE 14-bus test system, with 5 distributed generation units.

Controller	DG1	DG2	DG3	DG4	DG5	Total
Sampled Data Controller	-97.18	-93,8	-95.7	-91.89	-91.87	-94.1
Static ETM	-41.83	-6.87	-15.31	-6.92	-9.70	-13.81

Comparison with conventional Static Event-Triggered Strategy and Sampled-Data Controller (Without ET mechanism)

The **reduction of the burden** with respect to Sampled-Data controller and Static ET mechanism are about **94.1%** and **13.81%**, respectively.

Andreotti, A., Caiazzo, B., Fridman, E., Petrillo, A., & Santini, S. (2024). Distributed Dynamic Event-Triggered Control for Voltage Recovery in Islanded Microgrids by Using Artificial Delays. ***IEEE Transactions on Cybernetics*.**

CHALLENGES & CONCLUDING REMARKS

- **Cost-effective solutions** design and implementation
- **Preserving security and privacy** in connected environment.
- **Greening**: ensure energy efficient communication between IoT nodes and provide energy efficient IoT services
- **Large Scale Test Benches** in Fully Interactive Virtual Smart City

THANKS FOR ATTENTION!

Questions?

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