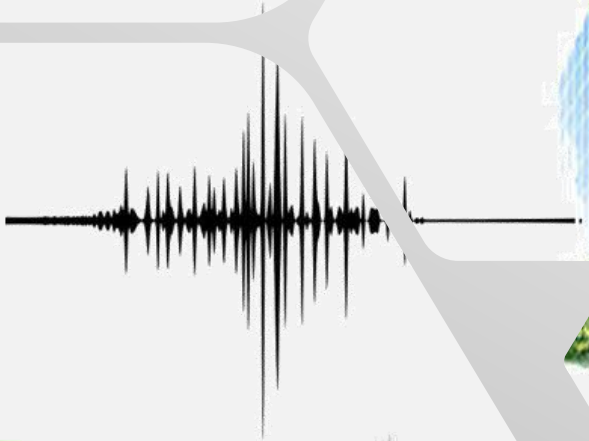


Heterogenous Sensor Networks

Vibration-based SHM

Guided Wave-NDT

Integrated Cyber-Physical Systems for Damage Detection and Diagnosis in SHM applications

Federica Zonzini

1st yearly assessment
October 22nd 2019
Bologna

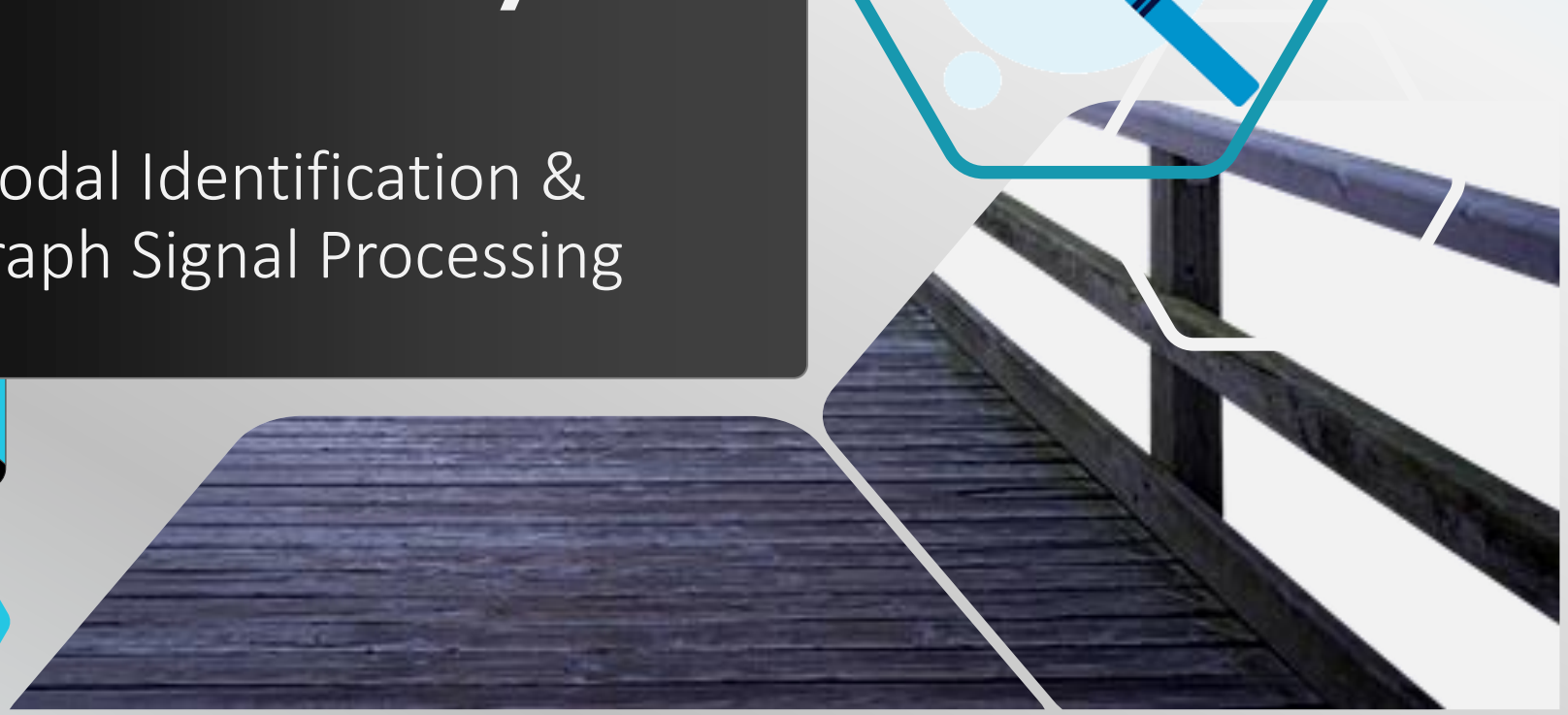
SEHM²

ALMA MATER STUDIORUM UNIVERSITÀ

Structural and Environmental Health Monitoring and Management

Operational Modal Analysis

Modal Identification & Graph Signal Processing



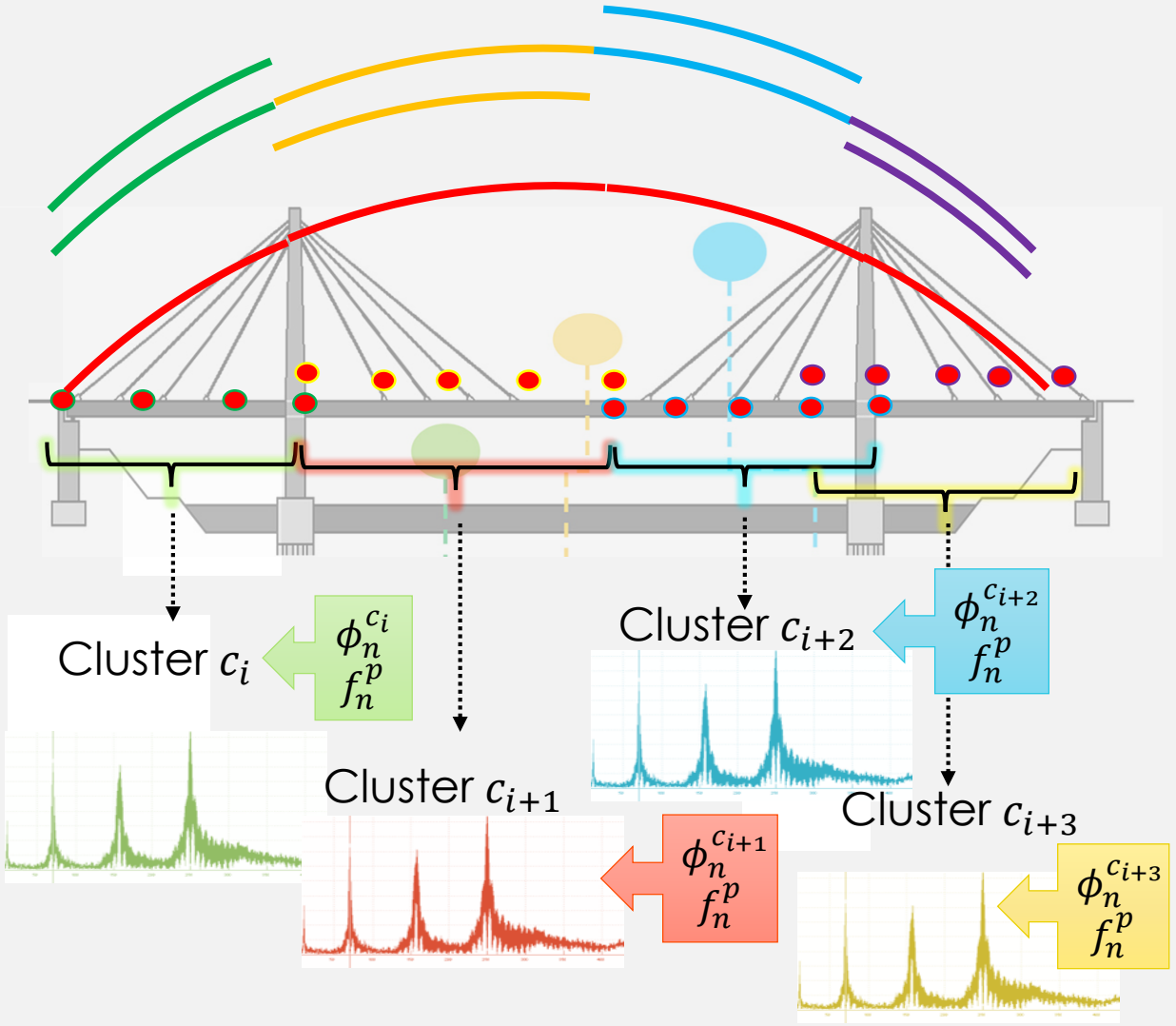
Cluster-based SHM of large structures

OMA

GW

HM

n modal shapes @ p sampling positions → N_c clusters



Cluster Head

Local Modal Shapes $\phi_n^{c_i}$

Spatially dependent information

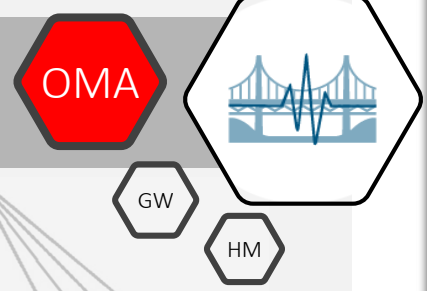
Modal shapes merging

Global Modal Shapes ϕ_n

Spatially independent parameter

Natural frequencies f_n

A Graph Signal Processing Perspective

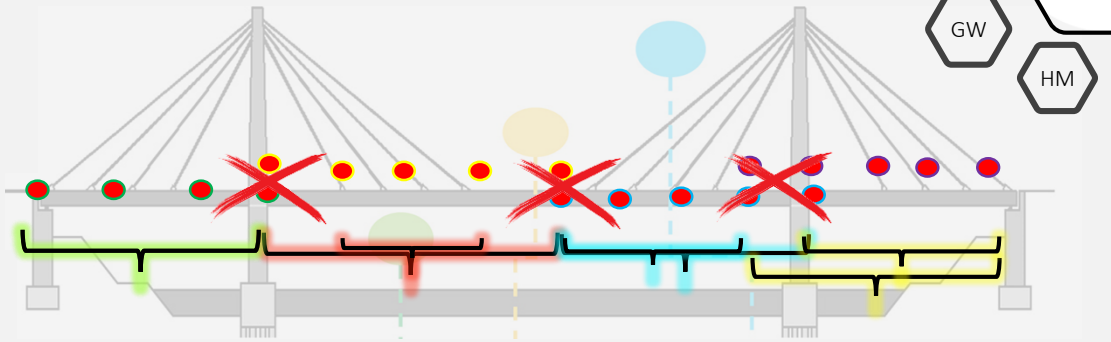


Overlapping solutions

Least-squares minimization

Limitations

- Electrical
- Computational
- Physical
- Technological

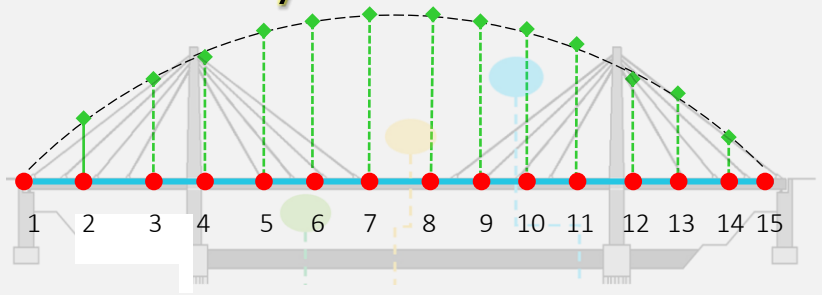


Non-Overlapping solution

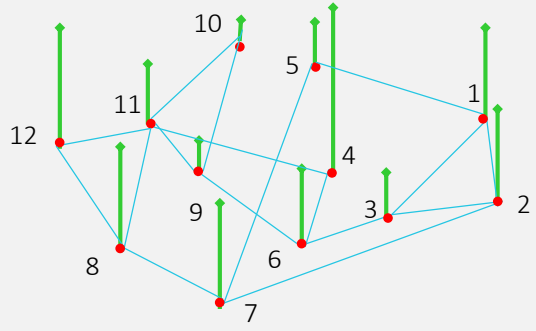
Graph Signal Processing

Smooth changes between connected nodes

↳ Higher versatility @ Same spatial accuracy



OMA domain		Graph Domain
Quasi-sinusoidal regime Smooth modal curves	→	Intrinsically smooth behavior
$V = \{p_0, \dots, p_{p-1}\}$ sampling positions	→	$V = \{v_0, \dots, v_{p-1}\}$ vertices
Modal coordinates	→	Graph signal
Spatial connectivity wrt Sampling disjunction	→	Graph connectivity
Spatial distance	→	Edge weight w_{mn}



GW-based Communication System

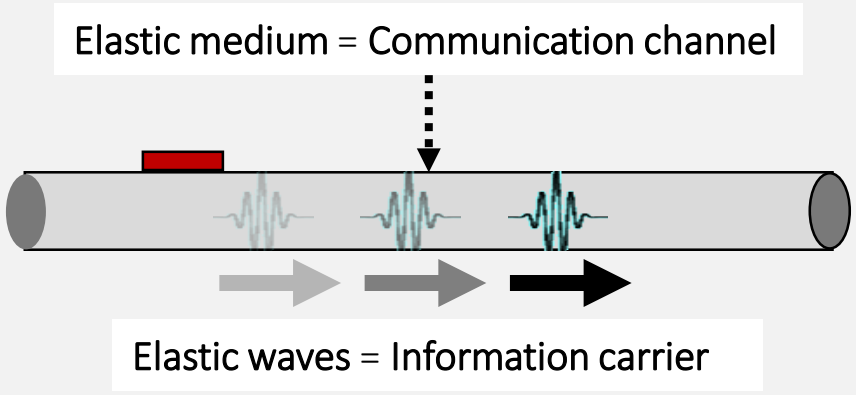
Inspection

Communication

Autonomous GW-based smart SHM system

GW-PROBE

- **Long distances** covered with **minimal** energy **dissipation**
- **Double sensitivity**: inner flaws (e.g. delaminations) and surface defects (e.g. cracks)
- **Punctual inspection** of **wide** areas



Wireless systems
No RF modules/cables

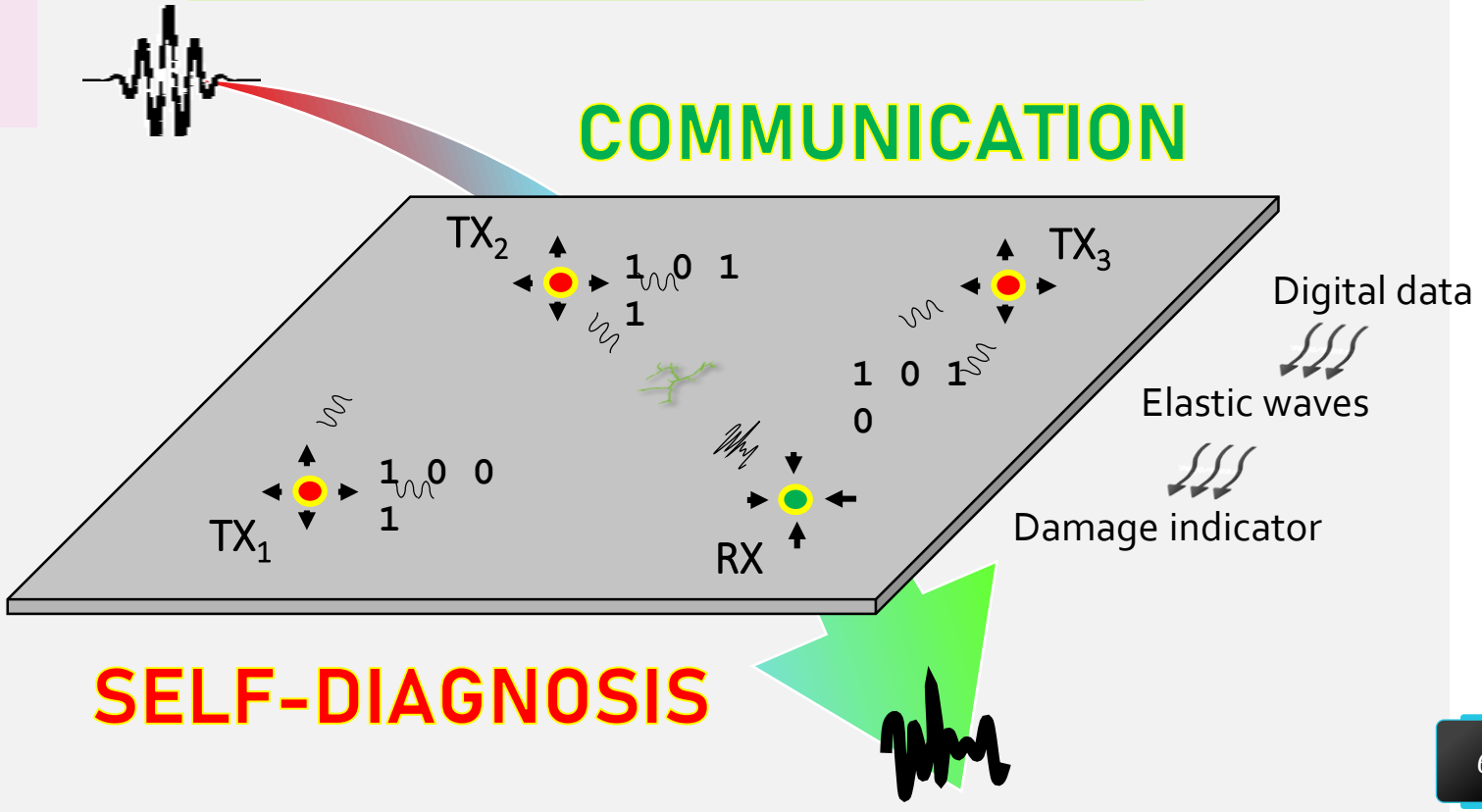
CDMA-MODULATION

Direct Spread Spectrum techniques:

- Higher bit-rate
- Highly orthogonal chipping sequences: lower interferences among users

Multiple TXs/inspectors

COMMUNICATION



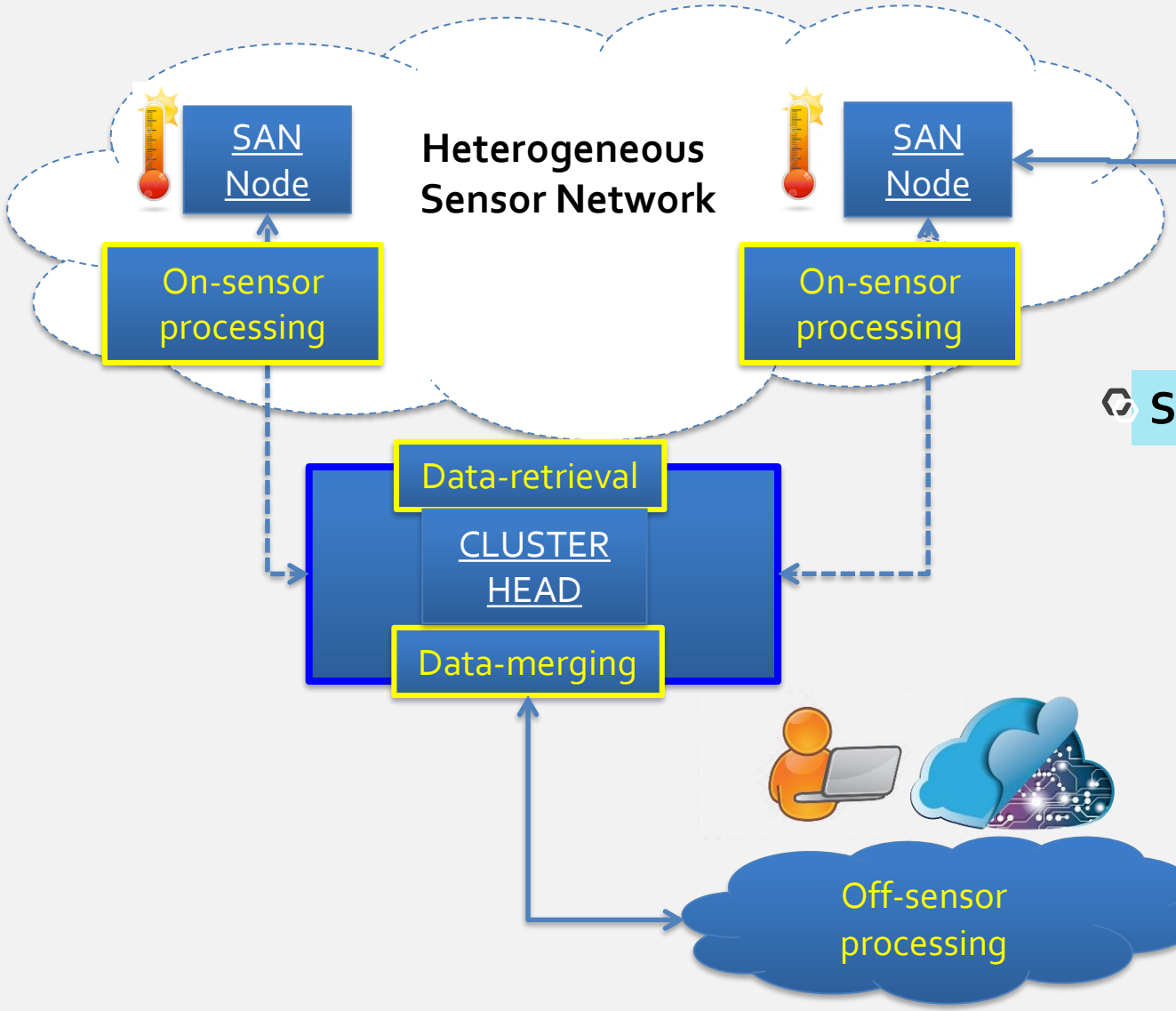
SELF-DIAGNOSIS

Heterogenous Sensor Networks

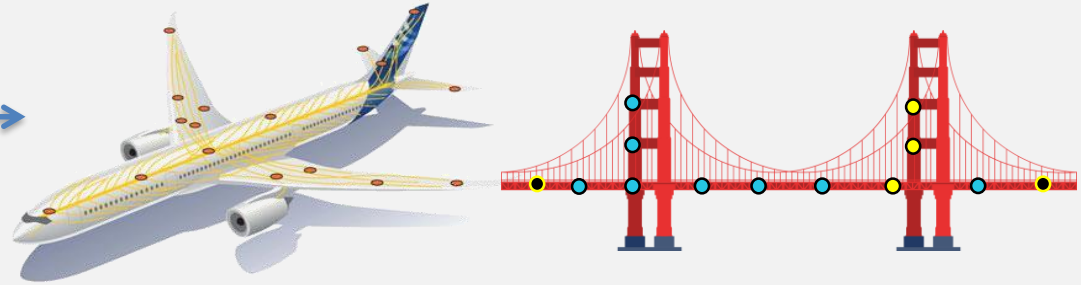
Multi-type data measurements

Common damage assessment

Towards Mesoscale Monitoring: An Heterogenous Approach



Sensorized structures (PTZs, MEMS, …)



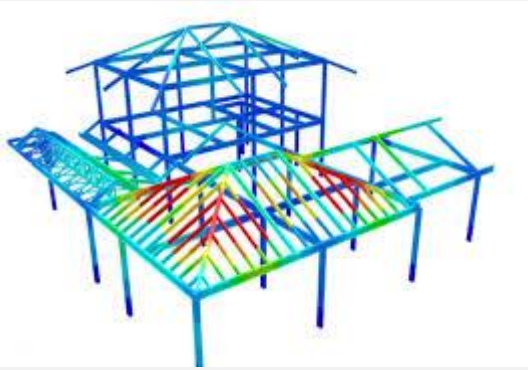
- **Scalability**
- **Cost-effectiveness**
- **Versatility**

- Simultaneous **multi-type technologies** (inertial, strain, displacement, voltage, etc)
- **Full-band analysis**: richer spectral content
- Microscopic vs Macroscopic behavior **OMA vs GWs/AEs**

Future Works

Modal Identification

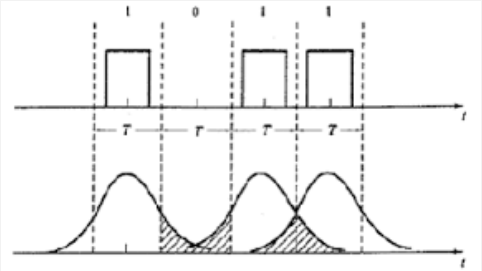
- Edge computing:
  - Hardware implementation of OMA algorithms on customized MEMS sensor nodes
  - Compressive Sensing (CS) techniques for WSN



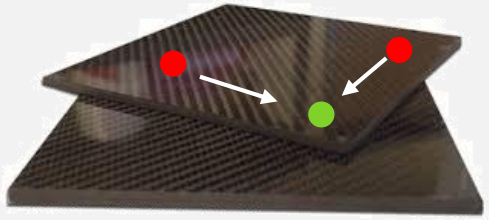
- GSP:
  - 3D frame monitoring
  - Complete extraction of OMA parameters in graph domain
- GSP and CS

GW-base Communication Systems

- Data Characterization:
  - Inter Symbol Interference
    - RMS delay spread
    - Power Delay Profile
  - Packet length and format

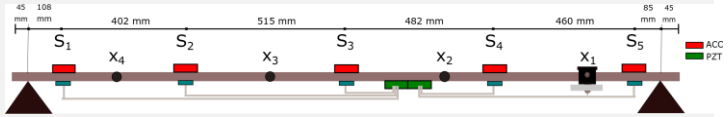


- Extended experimental campaign on more complex scenarios and/or multiple active TXs



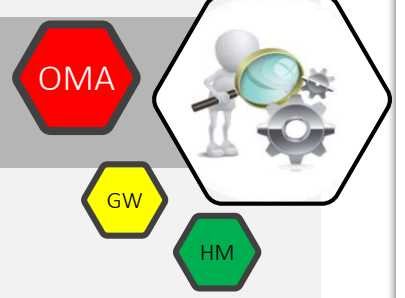
Heterogeneous Sensor Networks

- Sensor calibration
- Full modal parameters extraction from PZT devices
- Data merging:
  - Linear + rotational data
  - Unconventional PZT-only modal analysis vs classical inertial OMA



- Clustered architecture and related topology multi-type data measurement

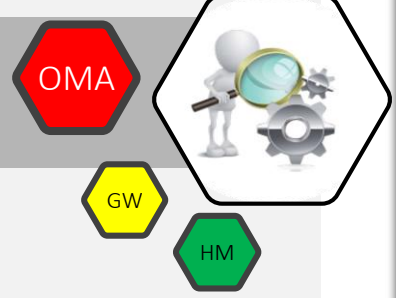
Disseminations I



Contribution to conference procedeedings and posters

- Zonzini Federica, Michelangelo Maria Malatesta, Aguzzi Cristiano, Testoni Nicola, Verardi Martina, and Scarponi Valentina. **A sensor network target on a novel identification of cracks**. In *FRUCT Oy*, Finland, ISSN 2305-7254, ISBN 978-952-68653-6-2, 602, 2018 [Poster]
- Alberto Girolami, Federica Zonzini, Luca De Marchi, Davide Brunelli, and Luca Benini. **Modal analysis of structures with low-cost embedded systems**. In *Proceedings - IEEE International Symposium on Circuits and Systems*, volume 2018-, pages 1-4. Institute of Electrical and Electronics Engineers Inc., 2018 [Conference proceedings]
- Federica Zonzini, Luca De Marchi, and Nicola Testoni. **A small footprint, low power, and light weight sensor node and dedicated processing for modal analysis**. In *Lecture Notes in Electrical Engineering*, volume 539, pages 361-370. Springer Verlag, 2019 [Conference proceedings]
- Testoni Nicola, Aguzzi Cristiano, Zonzini Federica, Luca De Marchi, Agugliaro Giuseppe, Tullio Salmon Cinotti, and Marzani Alessandro. **Reti di monitoraggio leggere basate su un nodo sensore multifunzione**. In *Sicurezza ed affidabilità delle attrezzature a pressione*. Atti di convegno, pages 1-10, 2018 [Conference proceedings]
- Federica Zonzini, Michelangelo Maria Malatesta, Denis Bogomolov, Nicola Testoni, Luca De Marchi, and Alessandro Marzani. **A spectral peak-picking method for on-board operational modal analysis of multi-type vibration-based SHM**. In *ANCRiSST 2019 Procedia*. Sapienza University of Rome, 2019 [Conference proceedings]

Disseminations II



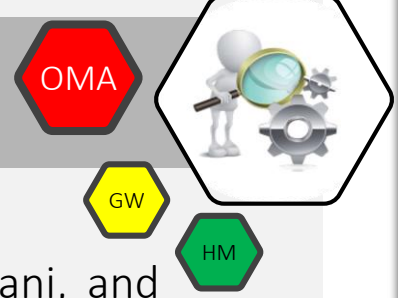
- Federica Zonzini, Michelangelo Maria Malatesta, Denis Bogomolov, Nicola Testoni, Luca De Marchi, and Alessandro Marzani. **Heterogeneous sensor-network for vibration-based SHM**. In *2019 IEEE International Symposium on Measurements & Networking (M&N)*, pages 1-5. IEEE, 2019 [Conference proceedings]

- Federica Zonzini, Alberto Girolami, Davide Brunelli, Nicola Testoni, Alessandro Marzani, Luca De Marchi. **A graph signal processing technique for vibration analysis with clustered sensor networks**. Proceedings of Applications in Electronics Pervading Industry, Environment and Society, September 11-13, Pisa. To be published in *Lecture Notes in Electrical Engineering*, 2019 [Conference proceedings]

- Federica Zonzini, Luca De Marchi, Nicola Testoni, Alessandro Marzani. **Direct Spread Spectrum Modulation and Dispersion Compensation for Guided Wave-based Communication Systems**. Proceedings of the IEEE 2019 International Ultrasonics Symposium, October 6-9, Glasgow. To be published in *Proceedings - IEEE International Ultrasonics Symposium*, 2019 [Conference proceedings]

- Michelangelo Maria Malatesta, Zonzini Federica, Denis Bogomolov, Mirco Tarozzi, Nicola Testoni, Giuseppe Agugliaro, Canio Mennuti, Alessandro Marzani, Luca De Marchi, Andrea Benedetti. **Monitoraggio di una trave di calcestruzzo armato con rete di sensori eterogenea miniaturizzata**. In *XVIII Conferenza Nazionale sulle Prove non Distruttive Monitoraggio Diagnostica, AIPnD, Biennale PND-MD*, Milano, 2019 [Conference proceedings]

Disseminations III

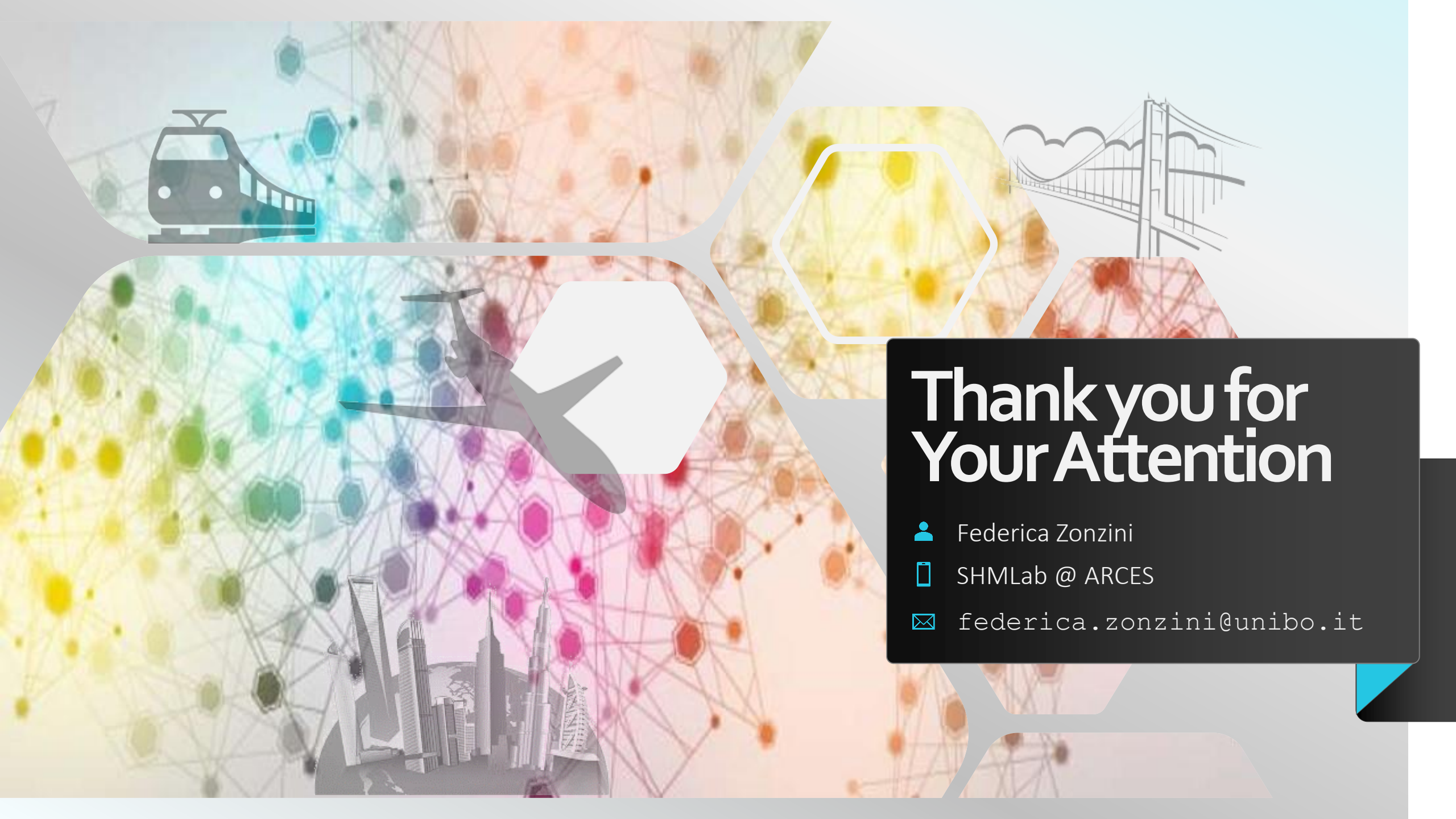


Scientific articles

- Nicola Testoni, Cristiano Aguzzi, Valentina Arditi, Federica Zonzini, Luca De Marchi, Alessandro Marzani, and Tullio Salmon Cinotti. **A sensor network with embedded data processing and data-to-cloud capabilities for vibration-based real-time SHM**. *JOURNAL OF SENSORS*, 2018:1-12, 2018
- Testoni Nicola, Zonzini Federica, Marzani Alessandro, Scarponi Vantina, and Luca De Marchi. **A tilt sensor node embedding a data-fusion algorithm for vibration-based SHM**. *ELECTRONICS*, 8:1-14, 2019
- Christian Kexel, Nicola Testoni, Federica Zonzini, Jochen Moll, Luca De Marchi. **Low-power MIMO guided-wave communication**. Submitted to *Mechanical Systems and Signal Processing*, 2019
- Federica Zonzini, Alberto Girolami, Luca De Marchi, Davide Brunelli, Alessandro Marzani. **Cluster-based Vibration Analysis of Structures with Graph Signal Processing**. Submitted to *IEEE Transactions in Industrial Electronics*, 2019
- Federica Zonzini, Michelangelo Maria Malatesta, Denis Bogomolov, Nicola Testoni, Luca De Marchi, and Alessandro Marzani. ***Vibration-based SHM with up-scalable and low-cost Sensor Networks***. Submitted to *IEEE Transactions on Instrumentation and Measurement*, Special Section of IEEE M&N 2019 Conference, 2019

Awards

Best Paper Young Author Award "Nicola Pitrone", *2019 IEEE International Symposium on Measurements & Networking (M&N), July 08-10, Catania 2019*



Thank you for Your Attention

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