Resilient-by-Design: A Resilience Framework for Future Wireless Networks

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OULU and The University of Oulu

Natural Sciences and Mathematics

Biosciences

Medicine and Health

Economics and Business Administration

Engineering and Architecture

Information and Communication Technologies

Education and Psychology

Humanities

14 200
Students

4 100
Staff

1958
Established

Research strengths

- ICT& Digitalization
- Health & Wellbeing
- Materials & Space

CAPITAL OF NORTHERN SCANDINAVIA

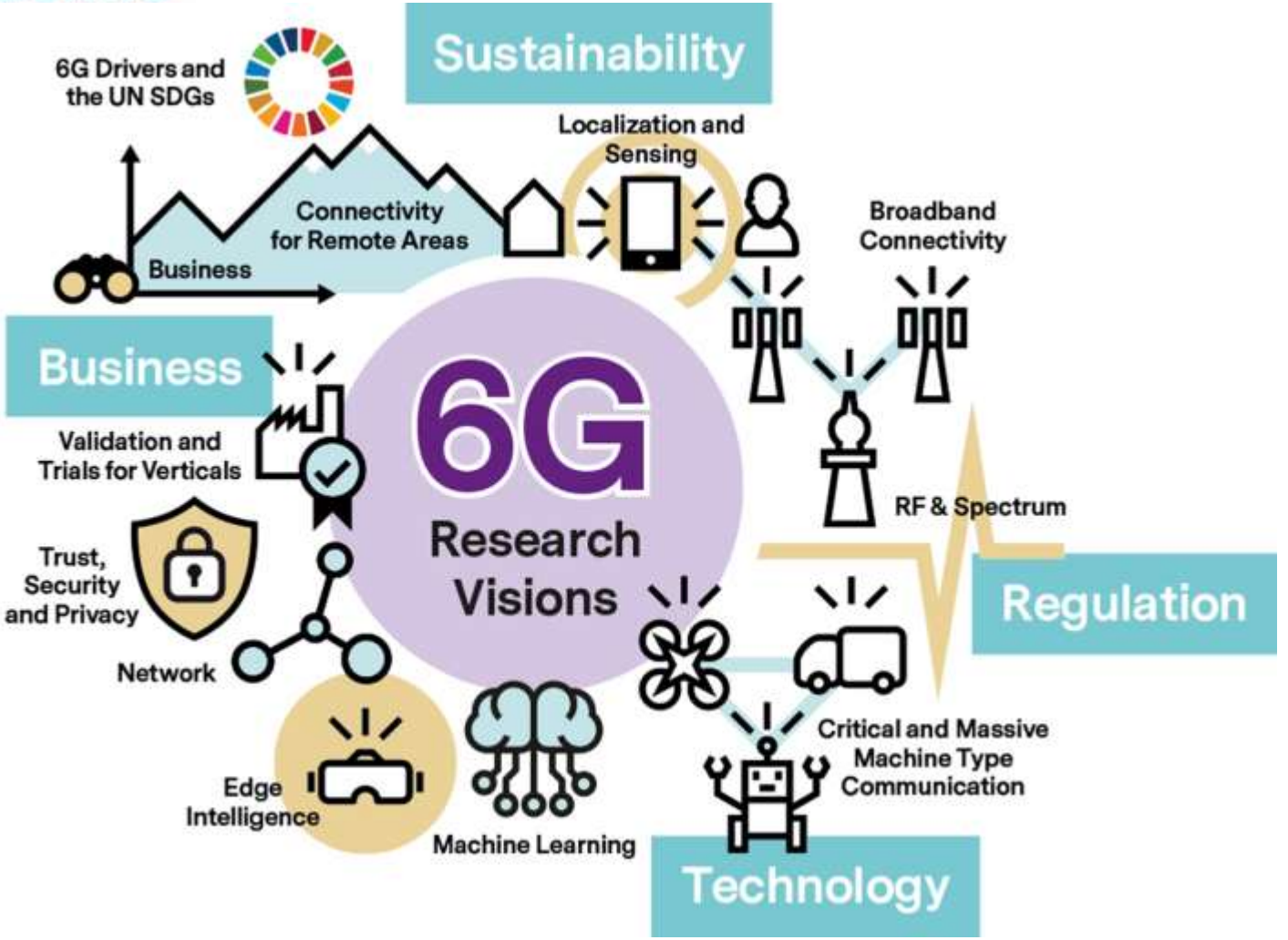
Ranked 30th in the world for Telecommunications Engineering (2024)

6G Flagship

The world's first and largest academic research program on 6G

Strategic Research Areas (SRAs)

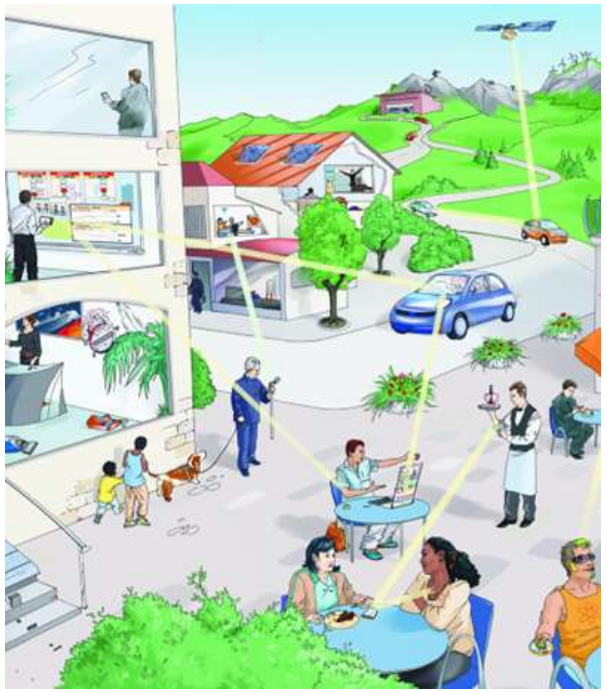
- Wireless connectivity solutions
- Device and circuit technologies
- Distributed intelligent wireless computing
- Sustainable human-centric services and applications



https://www.6gflagship.com/

Visions from 4G to 6G and Beyond….?

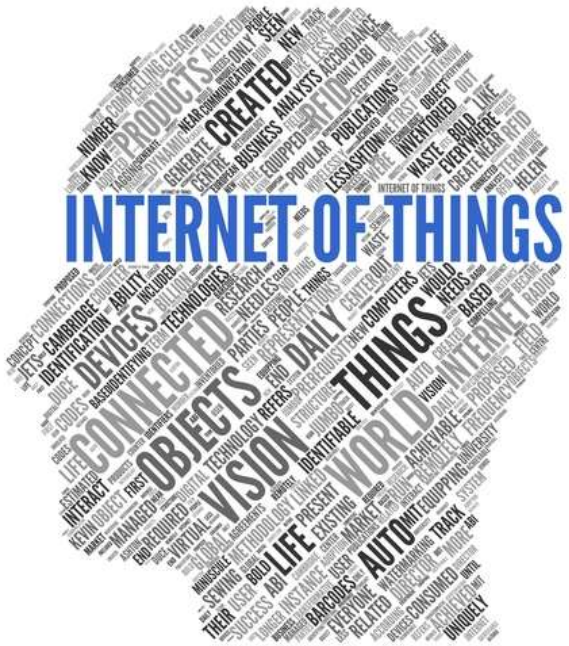
4G



ABC (Always Best Connected)

Vision from 2003

5G



Next 50 billion connected things

2013 vision

6G

6G metaverse and digital twins

2023

Beyond 6G

Resilient, sustainable and AI driven society?

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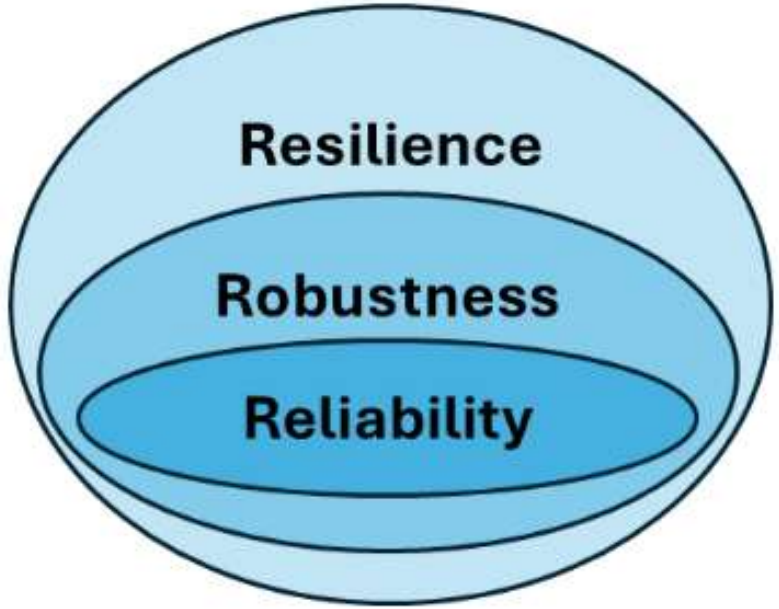
Resilience – What and Why?

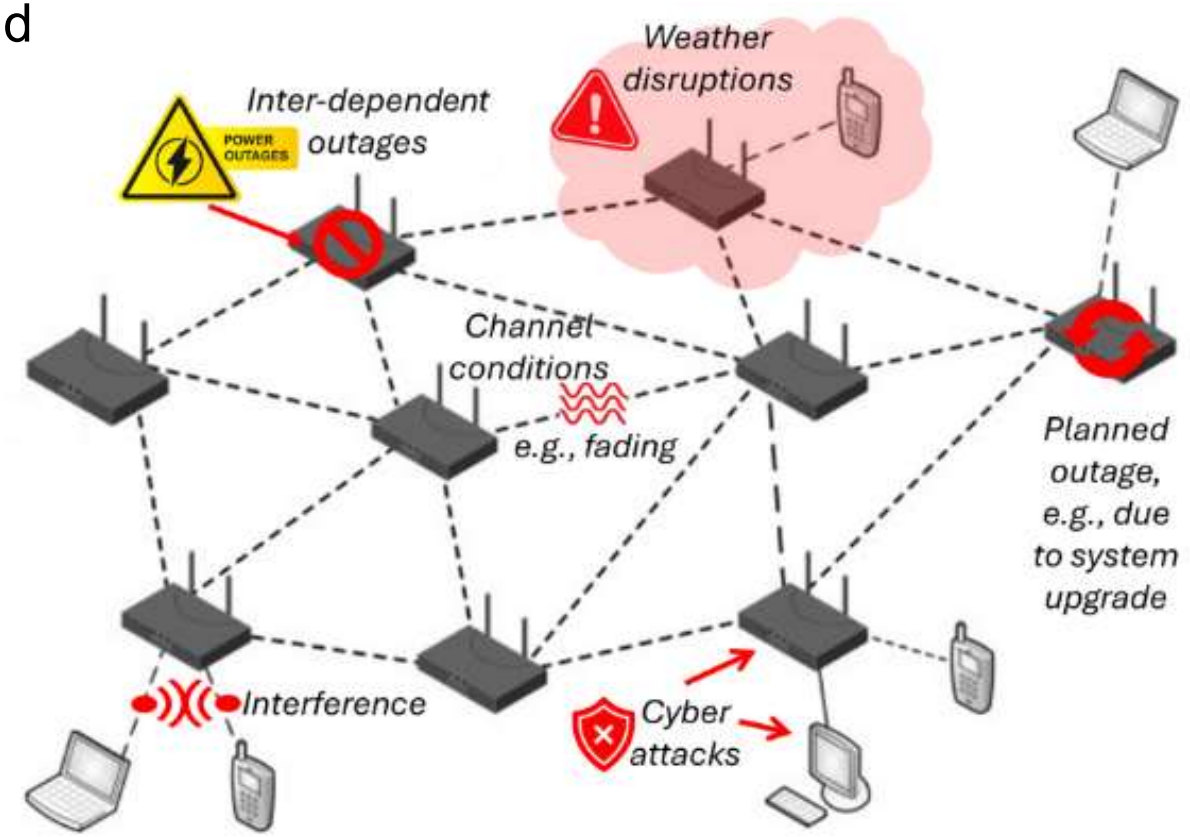
Resilience is the ability of a network or a system to continue operating correctly during and after a natural or man-made disturbance

- Resilience includes two aspects: *maintaining QoS in the face of disruptions* and the *quality of remediation* or recovery from a failure
- Resilience is sometimes (mistakenly) used synonymously with reliability and robustness
  - **Reliability** is the ability to perform as required for a given time interval, under given conditions
  - **Robustness** is defined as the ability to continue operation in the face of *known* challenges



Why is resilience gaining importance?

- **Resilient by design**[1] has been designated as one of the common design principles for 6G and beyond
- Why?
  - Systems becoming more complex
  - Increasing unpredictability:
    - Adverse weather, geo-political tensions, advance security threats (e.g., AI induced)
  - Technological interdependence
  - Shifting Paradigm from Prevention to Adaptation
    - Absorb unexpected shocks, adapt to changing conditions, recover quickly from disruptions



[1] https://www.oulu.fi/en/news/joint-statement-endorsing-principles-for-6g-secure-open-and-resilient-design

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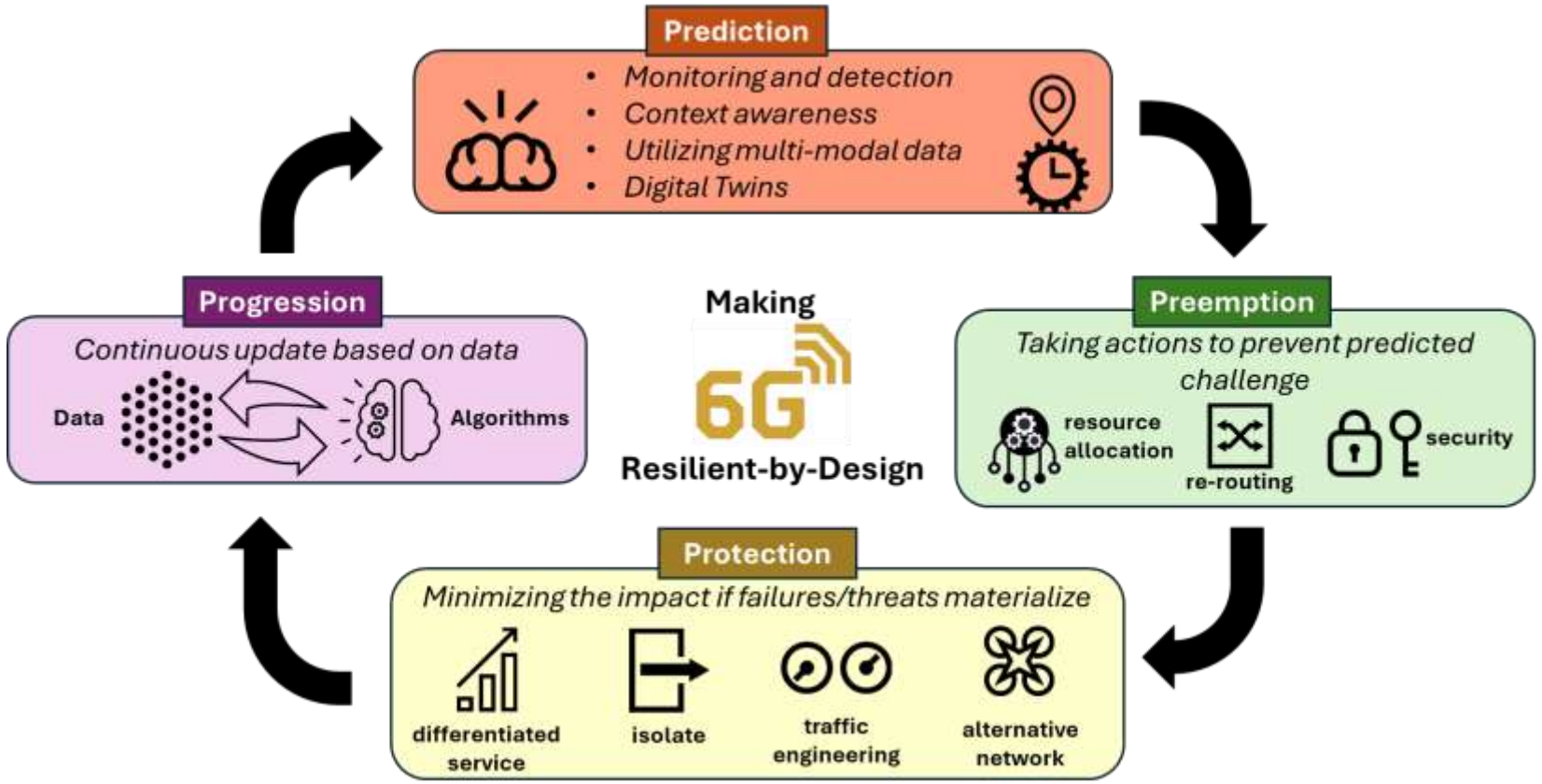
Resilience – How?

Paradigm change

Best effort → Resilient by design



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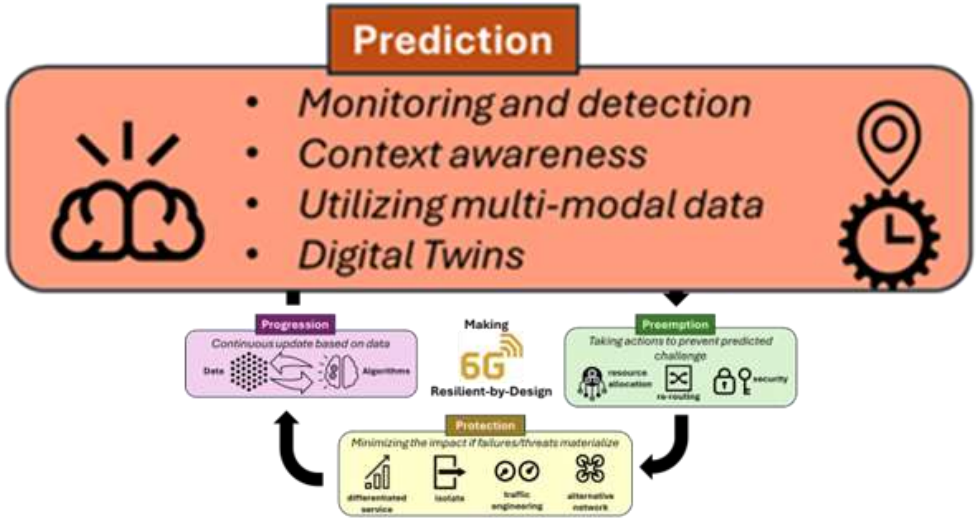
The Resilient-by-Design Framework: Prediction

Advanced monitoring and predictive capabilities to predict/detect faults:

- **Model-Based Approaches**
  - Bayesian framework for prediction
  - Context-awareness through multi-modal data
  - Security threat assessment and risk anticipation
- **Data-Driven AI Methods**
  - Machine learning techniques (SL, UL, RL)
  - time-series models (LSTM)
  - graph-based approaches
- **Advanced Techniques**
  - Digital twin integration



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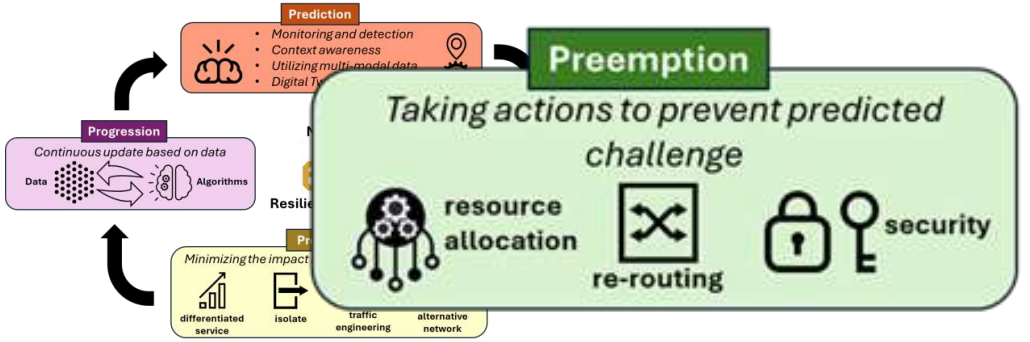
The Resilient-by-Design Framework: Preemption

Preemptive actions to address predicted faults

- **Resource Management Strategies**
  - Proactive resource allocation
  - Efficient traffic flow multiplexing
- **Network Routing Resilience**
  - Proactive rerouting for predicted node failures
- **Security Preemptive Measures**
  - Predictive analytics for threat mitigation
  - Zero Trust Architecture incorporating continuous authentication, and authorization for all devices



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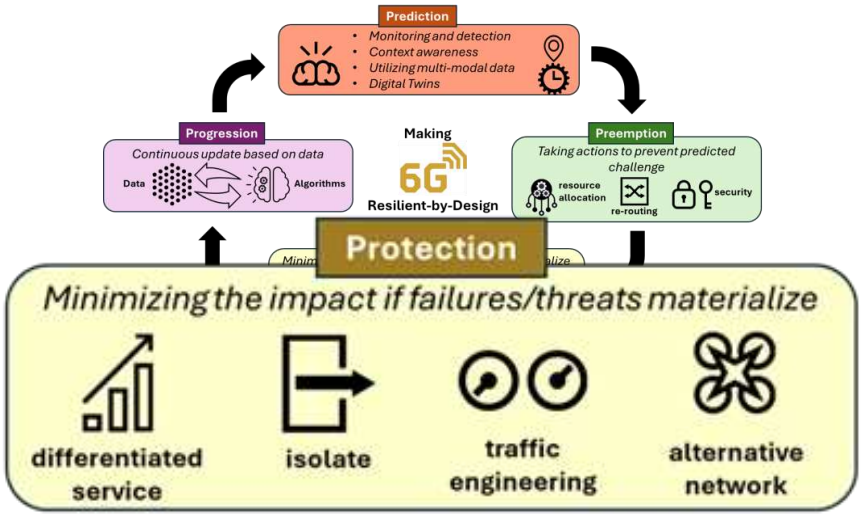
The Resilient-by-Design Framework: Protection

Strategies for protection and/or recovering from network disruptions

- **Isolation Mechanisms**
  - Network of networks architecture
- **Service Level Management for graceful degradation**
  - Dynamic operating modes to ensure service continuity under impaired conditions
- **Traffic Engineering Strategies**
  - Critical and delay-sensitive services to be prioritized
- **Novel Network Architectures**
  - Space, Air, and Ground Integrated Networks (SAGIN)



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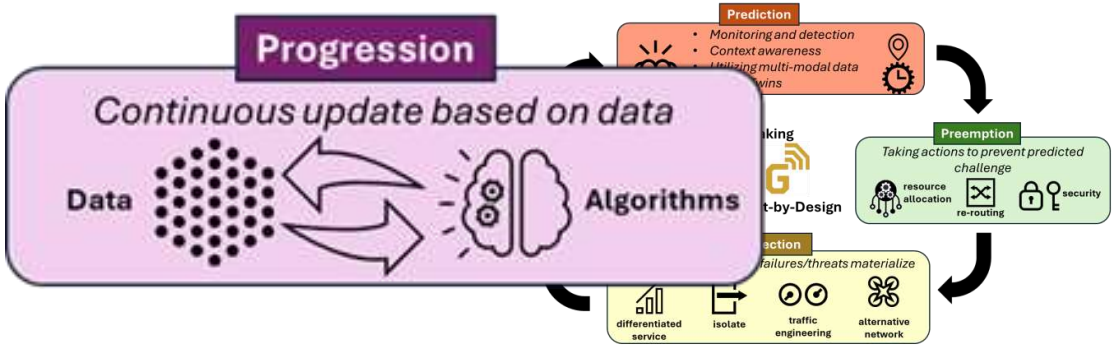
The Resilient-by-Design Framework: Progression

- Continuous learning cycle
- **Dynamic model updates**
  - Update model parameters
  - Adopt new tools
- **Data-driven refinement**
  - Integrate new observation data
  - Apply transfer learning techniques
- **Holistic performance assessment**
  - Continuous KPI tracking
  - Cost-performance trade-off analysis
  - Adaptive security frameworks involving joint security-QoS optimization



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Conclusions and The Way Forward

- Resilience will be a critical defining feature of future systems
- Network resilience aims to maintain acceptable service levels under unpredictable and challenging conditions
- Comprehensive resilience framework involves four key stages:
  - predicting disruptions,
  - making preemptive decisions,
  - protecting the network, and
  - continuously updating defense mechanisms
- Resilience is a cross-disciplinary topic that requires interdisciplinary collaboration

Read the new 6G Resilience White Paper from the University of Oulu's 6G Flagship program
https://oulurepo.oulu.fi/handle/10024/59226

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