Industrial Internet of Things (IIoT): An Integrated Design of Secure Communications, Caching, Computing, and Control(SC^4)

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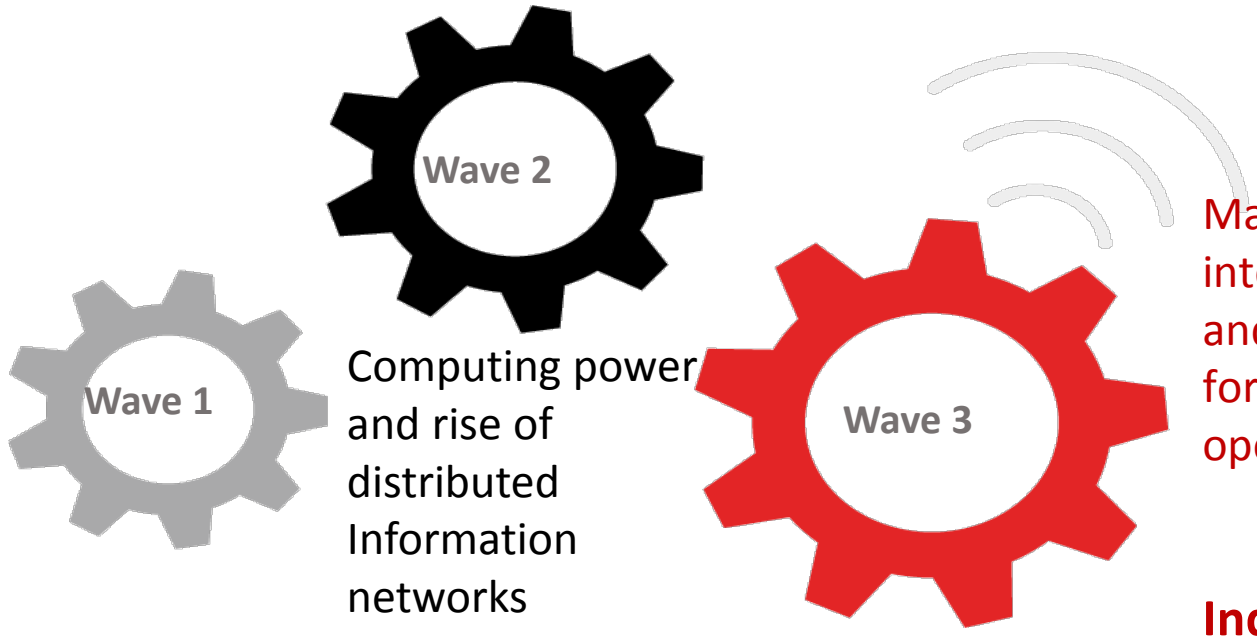
The Industrial Internet of Things (IIoT)

- An internet of ***things, machines, computers*** & ***people***, enabling ***intelligent*** industrial operations using ***advanced data analytics*** for ***transformational*** business outcomes.



Machines and factories that power economics of scale and scope

Industrial Revolution

Computing power and rise of distributed Information networks

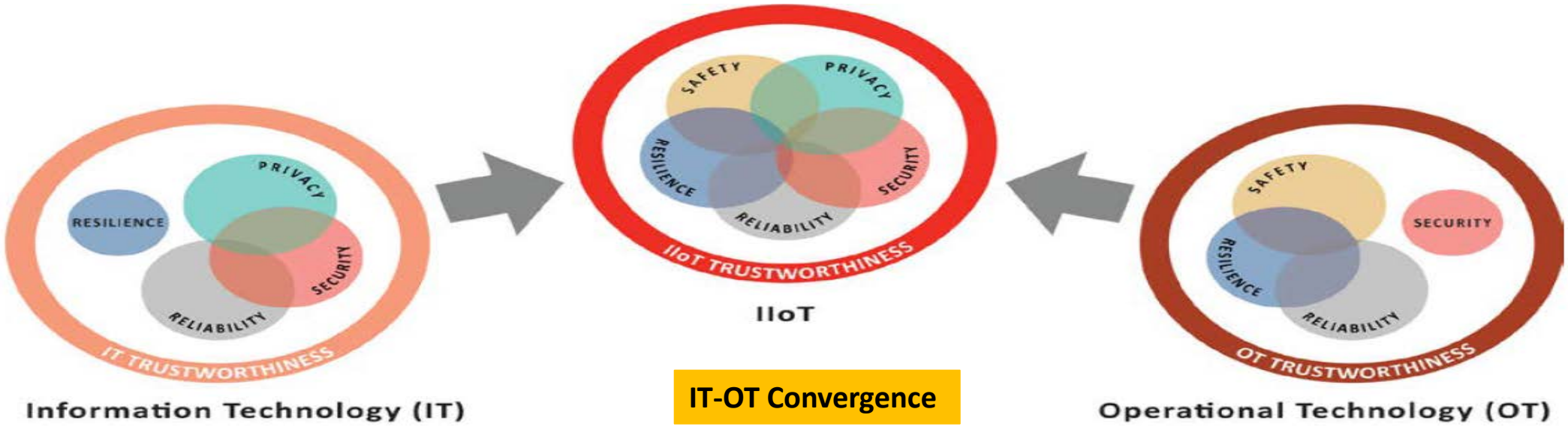
Internet Revolution

Machine-based analytics, integrating with physics-based and deep domain expertise, for automated and predictive operations

Industrial Internet Revolution

Source: IIC

IIoT for IT-OT Convergence



source: IIC

Communication network
- Heterogeneity
- Massive data

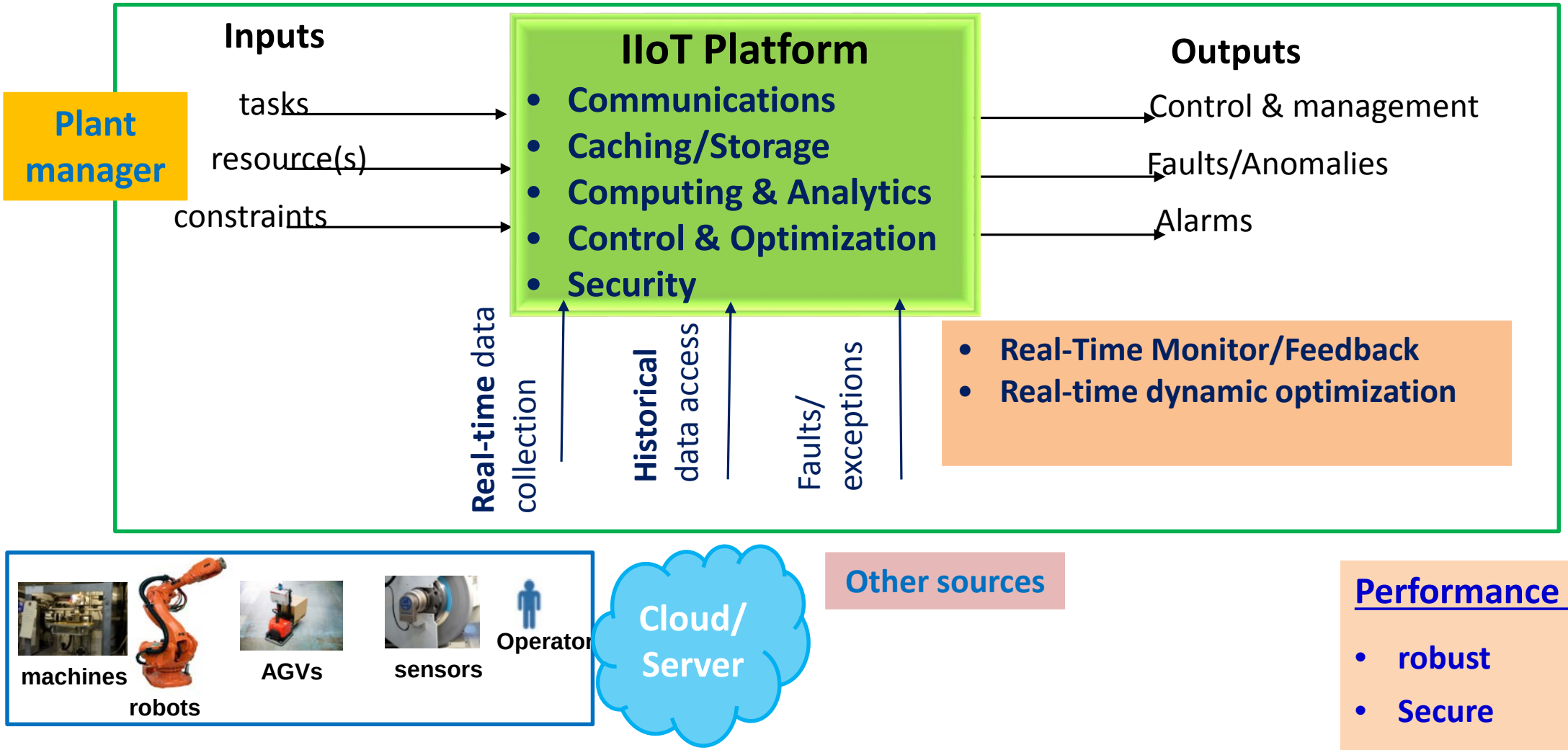
Data Intelligence

Control network
- Time/mission-critical
- Highly reliability

Security

SC4

An IIoT Architectural View



Integrated design of SC⁴

Performance Metrics

- robust
- Secure
- responsive
- efficient
- agile

Wide Applications and Realms of Transformation

Broad applicability in multiple industry sectors

Operation Efficiency | Process Optimization | Performance Management


Shop Floor Smartification


Decentralized production steering


Predictive Maintenance


Mobile & Real-Time performance tracking


Immersive Training


High resolution supply-chain


Digital plant logistics


Automated replenishment


Cloud-based Analytics


E-Performance Boards


Workforce Tracking


Integrated product development


Automated inspection

Data-driven quality control


Digital factory design

Opportunities in the IIoT

Savings and growth opportunities across every industry

1% savings from efficient Industrial Internet solutions could save billions in operational costs

$30B
fuel cost saving in aviation industry

$66B
fuel cost saving in gas powered fleets

$63B
productivity improvement in healthcare

$90B
reduction in Cap X in oil & gas exploration and development

$27B
productivity improvement in rail industry





** Projected savings are based on 1% efficiencies/savings*

Source: Industrial Internet: Pushing the Boundaries (2012, Evans & Annuziata)

Some Use Cases

Digital Manufacturing

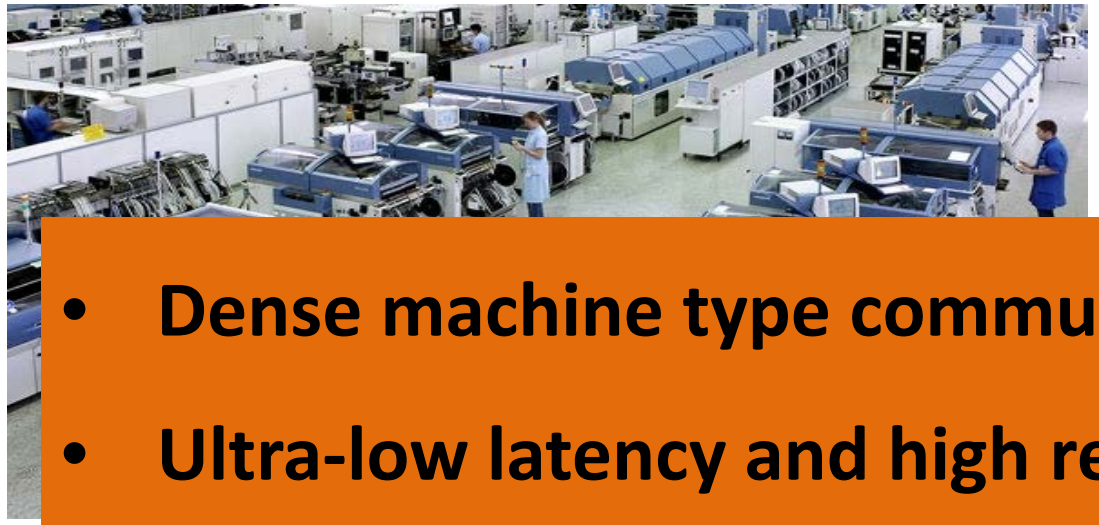
Chemical, Energy, Oil & Gas

Warehouse & Logistics

Robotics & Automation

Some Use Cases

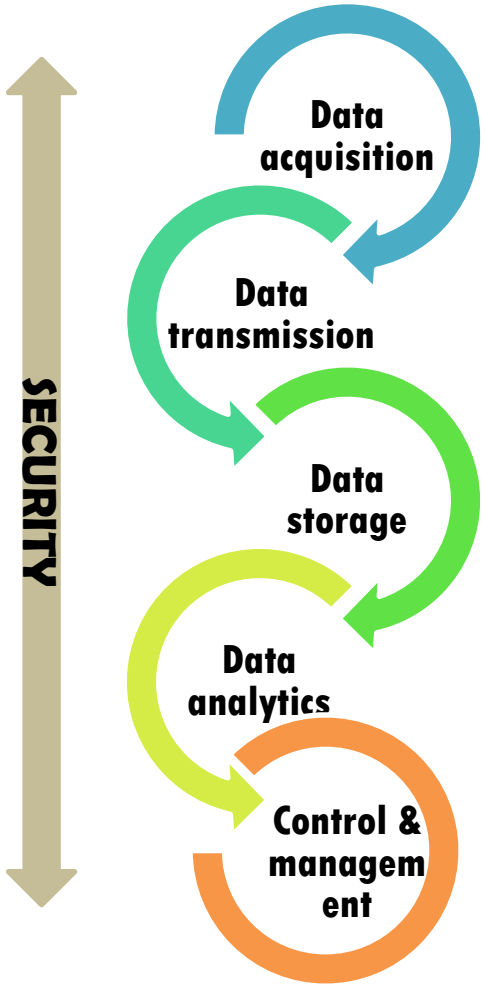
Digital Manufacturing



Chemical, Energy, Oil & Gas

- Dense machine type communications (MTC)
- Ultra-low latency and high reliability MTC
- (Nearly) Real-time action: edge computing
- Distributed/Centralized Data storage & information retrieval

IIoT Design Challenges



- Heterogeneity
- Massive data

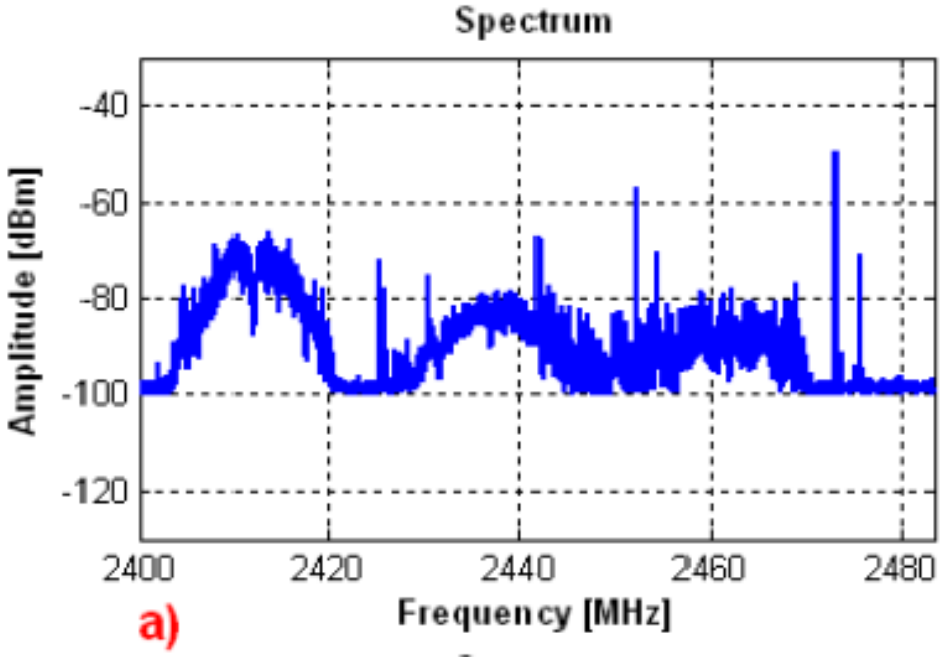
- High Availability
- High Reliability
- Low Latency

- High accuracy
- Low Latency

- **Severe interference**
- **High background noise** in industrial environment

- **Local data**
- **Real-time data**
- **Imbalanced data**

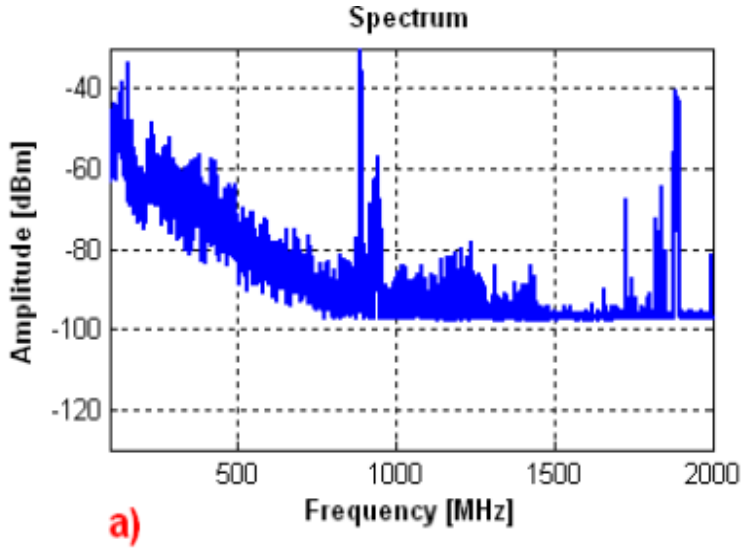
Inter-network Interference



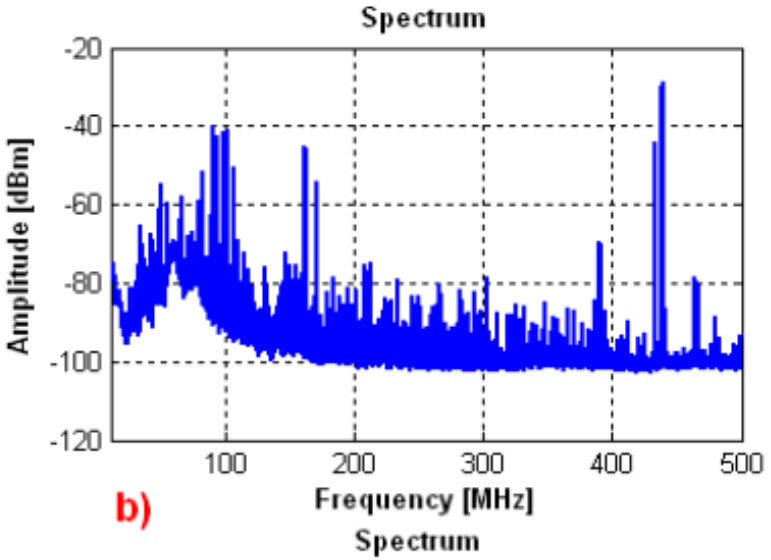
WLAN experience interference from bluetooth in open-air storage at steel mill

Per Ängskog, Carl Karlsson, Javier Ferrer Coll, José Chilo, Peter Stenumgaard, "Sources of Disturbances on Wireless Communication in Industrial and Factory Environments", 2010 Asia-Pacific International Symposium on Electromagnetic Compatibility, April 12 - 16, 2010, Beijing, China.

EMI



Paper mill, large machinery converts large tree timber into small pieces
Measurement taken over 6 hours in vicinity of initial process in the paper mill



Paper mill, measurement close to a crane that moves back and forth
Measurement taken over 6 hours in vicinity of initial process in the paper mill

Per Ängskog, Carl Karlsson, Javier Ferrer Coll, José Chilo, Peter Stenumgaard, "Sources of Disturbances on Wireless Communication in Industrial and Factory Environments", 2010 Asia-Pacific International Symposium on Electromagnetic Compatibility, April 12 - 16, 2010, Beijing, China.

Ultra-Low Latency High Reliability: Real-time Classes and Their Requirements

Types of application	Real-time requirements		Real-time class
	Latency	Jitter	
Monitoring and diagnostics (PLC to PLC)	10–100 ms	–	1
Process control (PLC to distributed IOs)	1–10 ms	≤1 ms	2
Motion control	<1 ms	≤1 μs	3

End-to-end network latency

Network synchronization → Time sensitive network

Ultra-Low Latency High Reliability: 3GPP

Use Case	Latency	Reliability	Synchronization	jitter
Motion Control	1ms	at least 99.9999%, ideally even 99.999999%	±500ns or below	< 50% cycle time
Mobile Robots	1ms			
Control to control comm.	4ms			

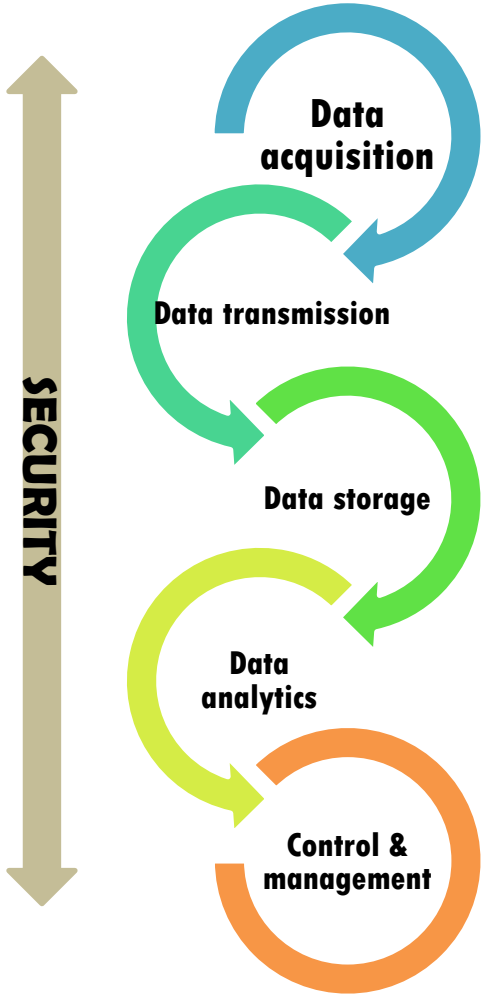
3GPP TR22.804, R15

End-to-end network latency

Network synchronization → Time sensitive network

APPROACHES & (INTERIM) SOLUTIONS

Cognitive Communications, Edge-Cloud Collaborative Analytics



- Heterogeneity
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- High Availability
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- High accuracy
- Low Latency

Cognitive learning in gateway, network controller, and device

- To understand the traffic, network, device, and environment
- To decide who to use which protocol at what time, and in which channel/spectrum
- To detect anomaly and manage anomaly
- To detect faults and recover from faults

Edge-cloud collaborative data analytics

- Edge analytics for real-time decision making
- Cloud analytics for automatic feature engineering
- Edge-cloud interaction model for intelligent data and knowledge sharing

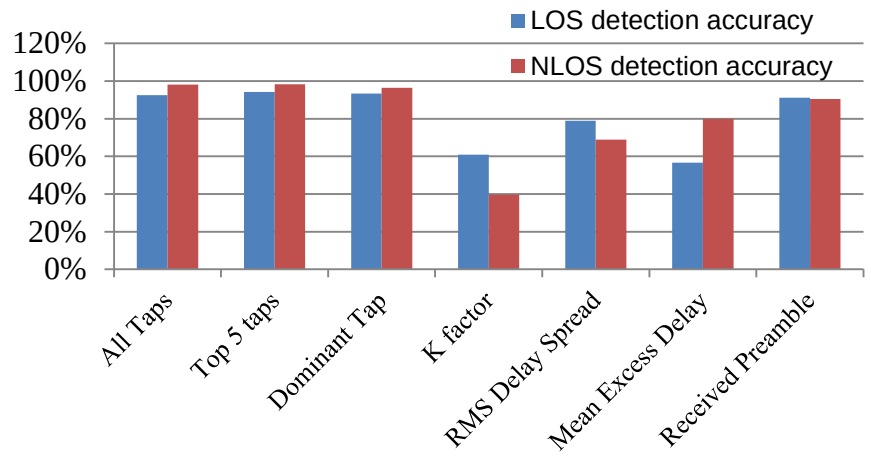
Design Example: Machine Learning-based Channel Classification

BACKGROUND / MOTIVATION

- **Channel classification** to identify Line of Sight (LOS)/Non-Line of Sight (NLOS) is important to guarantee the Quality of Service when adaptive Modulation and Coding Scheme (MCS) is used; especially for transmissions at 60GHz band.
- Current approach of channel classification using scalar metric thresholding is **limited** by the availability of good channel estimate, and its performance degrades when inaccurate channel estimate is used in the classification.
- This project proposes a novel **machine-learning based** channel classification scheme which is **robust** against the channel estimation error, with application in aircraft scenario.

RESULTS

- The **machine learning** approach achieves superior classification performance compared to other methods [1].

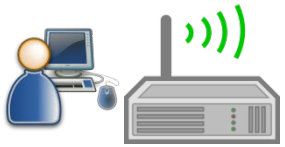


BENCHMARKING

	LOS	NLOS
K factor [2]	61%	40%
RMS Delay Spread [3]	79%	69%
Mean Excess Delay [3]	57%	80%
I^2R - CSI (All taps)	92%	98%
I^2R - CSI (Top 5 taps)	94%	98%
I^2R - Dominant Tap	93%	96%
I^2R - Received Preamble	**91%**	**90%**

[1] E. Kurniawan, L. Zhiwei, and S. Sun, "Machine Learning-based Channel Classification and Its Application to IEEE 802.11ad Communications," *IEEE Globecom 2017*, Singapore, Dec. 2017.
[2] F. Benedetto, G. Giunta, A. Toscano, and L. Vegni, "Dynamic LOS/NLOS Statistical Determination of Wireless Mobile Channels," *IEEE VTC 2007*, pp. 3071-3075, Dublin, Ireland, April 2007.
[3] I. Guvenc, C. C. Chong, and F. Watanabe, "NLOS Identification and Mitigation for UWB Localization Systems," *IEEE WCNC 2007*, pp. 1571-1576, Hong Kong, China, March 2007.

Design Example: Edge-Cloud Interactive Computing



light-weight edge analytics

Gateway

Cloud

machine learning on the fly

Edge Analytics

- Resource-aware algorithm design and model selection
- Real-time decision making with limited resources
- Local knowledge representation and model update at edge
- Knowledge integration, from edge to server
- Knowledge dispatching to edge
- Model update at edge

Selective data transmission from edge to cloud

Data Channel

Knowledge Channel

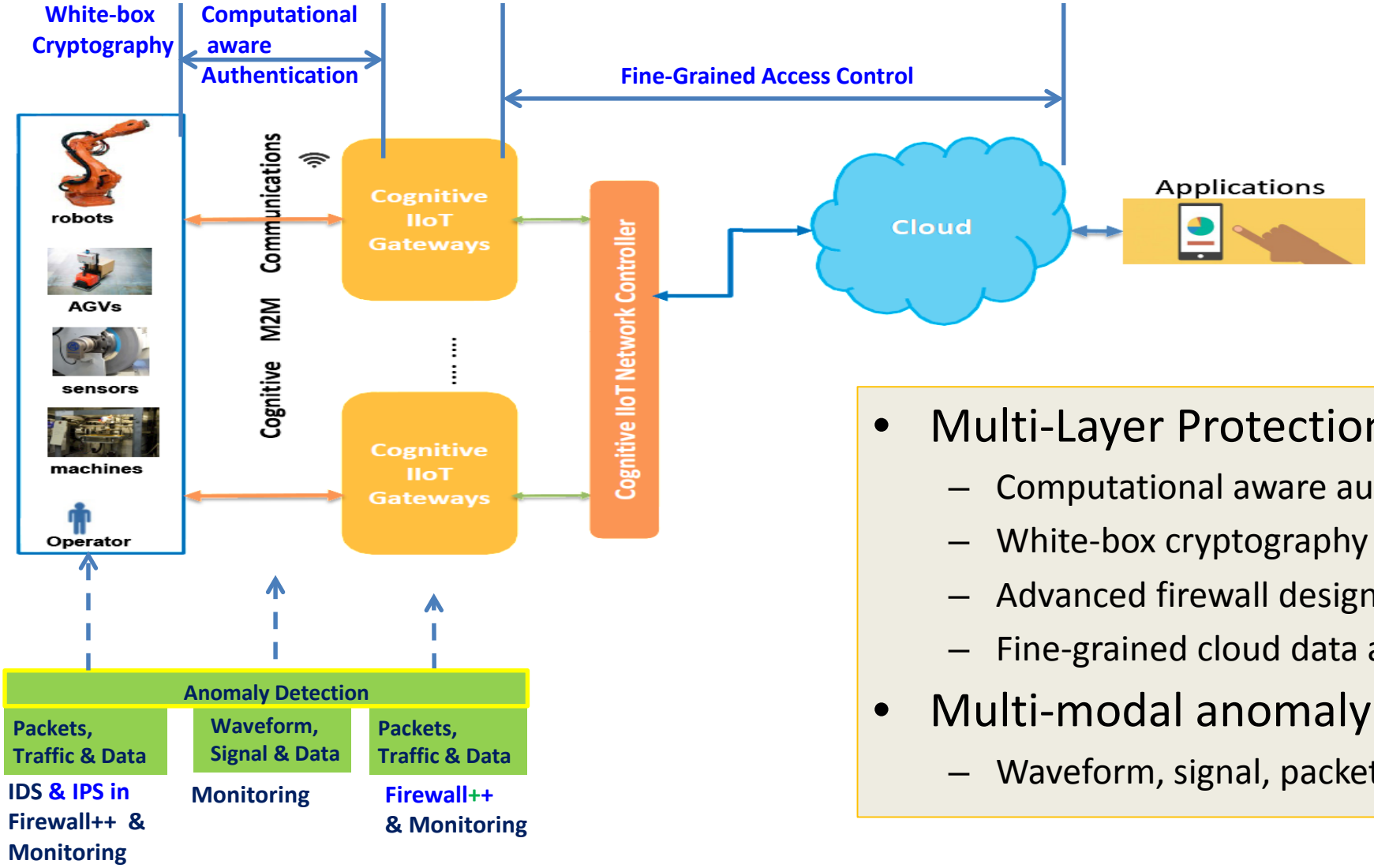
Knowledge transmission between edge and cloud

- Engineered features
- Model parameters
- Data summaries

Cloud Analytics

- Automatic feature engineering for on-the-fly predictive maintenance
- Deep learning to automate feature generation
- Semi-supervised learning to train model
- Boosted online learning to enhance model robustness
- Online learning to optimize complex performance metric that is suitable for imbalanced data

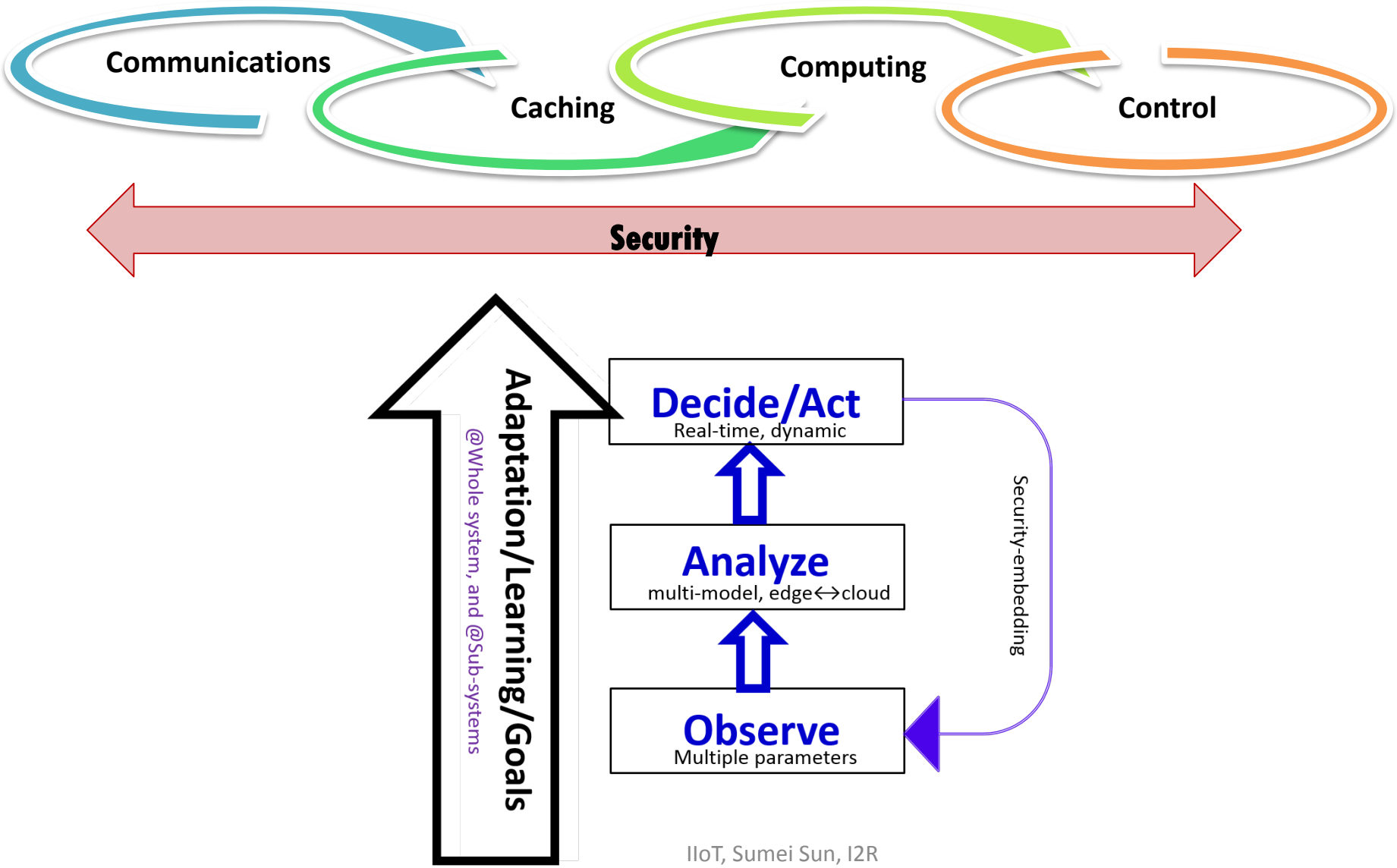
End-to-End Security



- Multi-Layer Protection
  - Computational aware authentication
  - White-box cryptography
  - Advanced firewall design
  - Fine-grained cloud data access control
- Multi-modal anomaly detection
  - Waveform, signal, packets, traffic, data

[1] S. Sun, Y. Wu, B. S. Lim, and H. D. Nguyen, "A High Bit-Rate Shared Key Generator with Time-Frequency Features of Wireless Channels," *IEEE Globecom 2017,* Singapore, Dec. 2017.

Cognitive IIoT with Autonomous Continuous Learning & Intelligent Adaptation



Thank you!