5G Vertical Summit 2018

5G/B5G Technologies for Smart Factory

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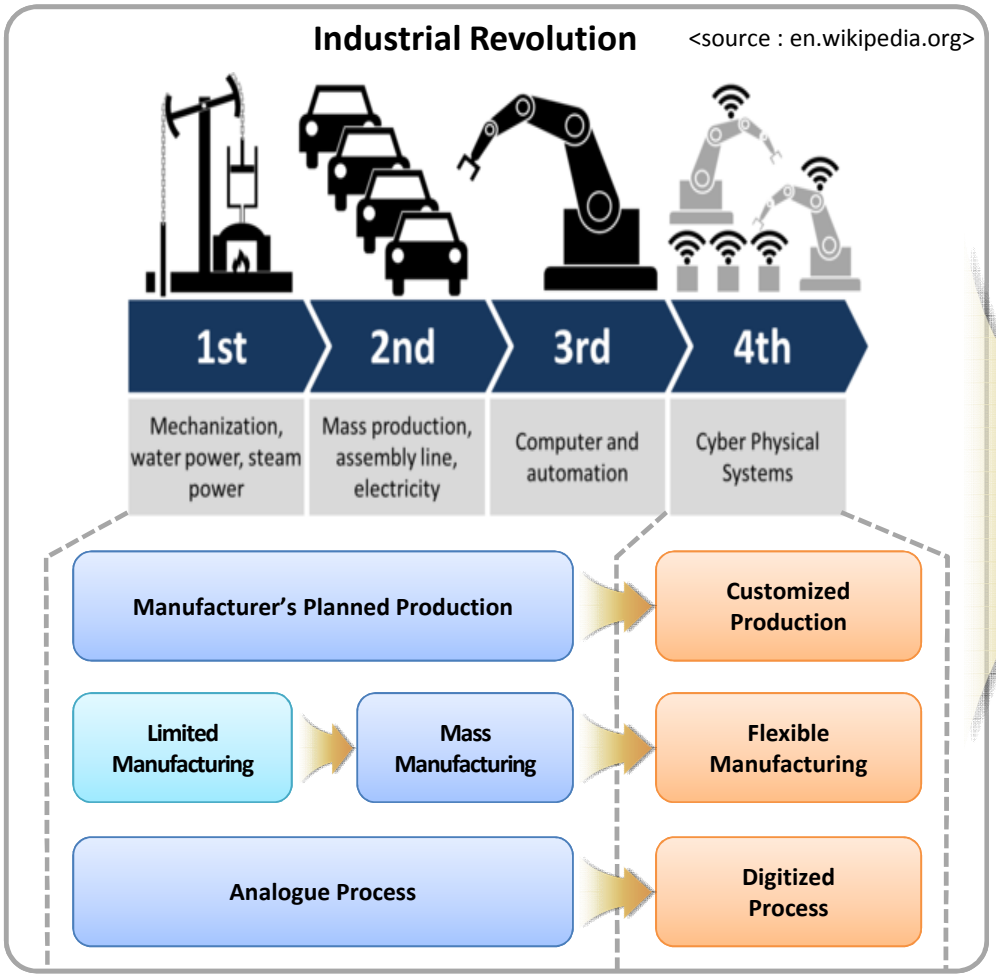
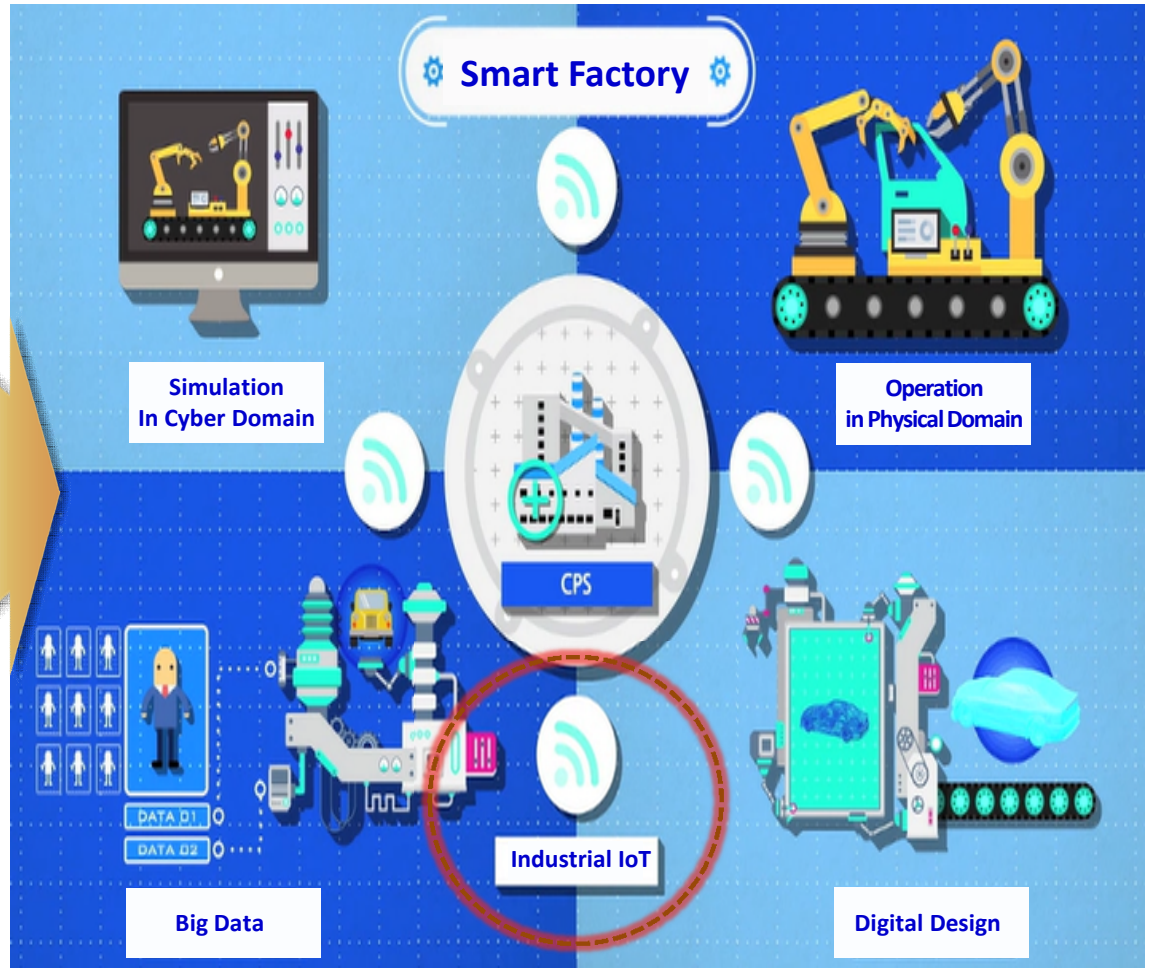
Overview - Industrial IoT for Smart Factory





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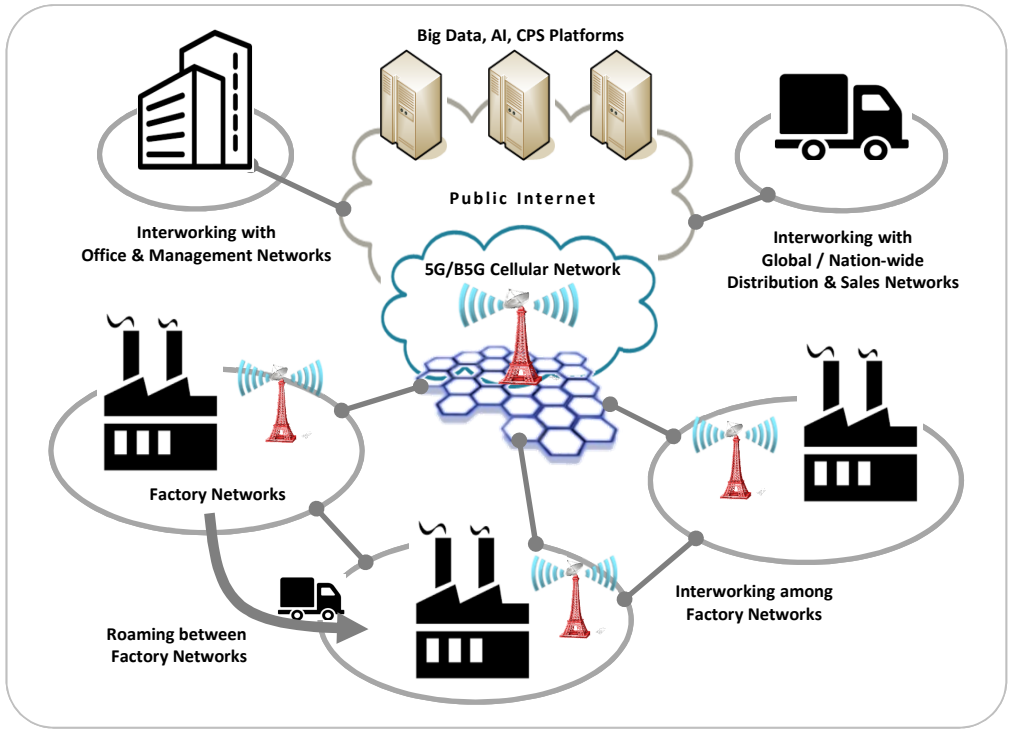
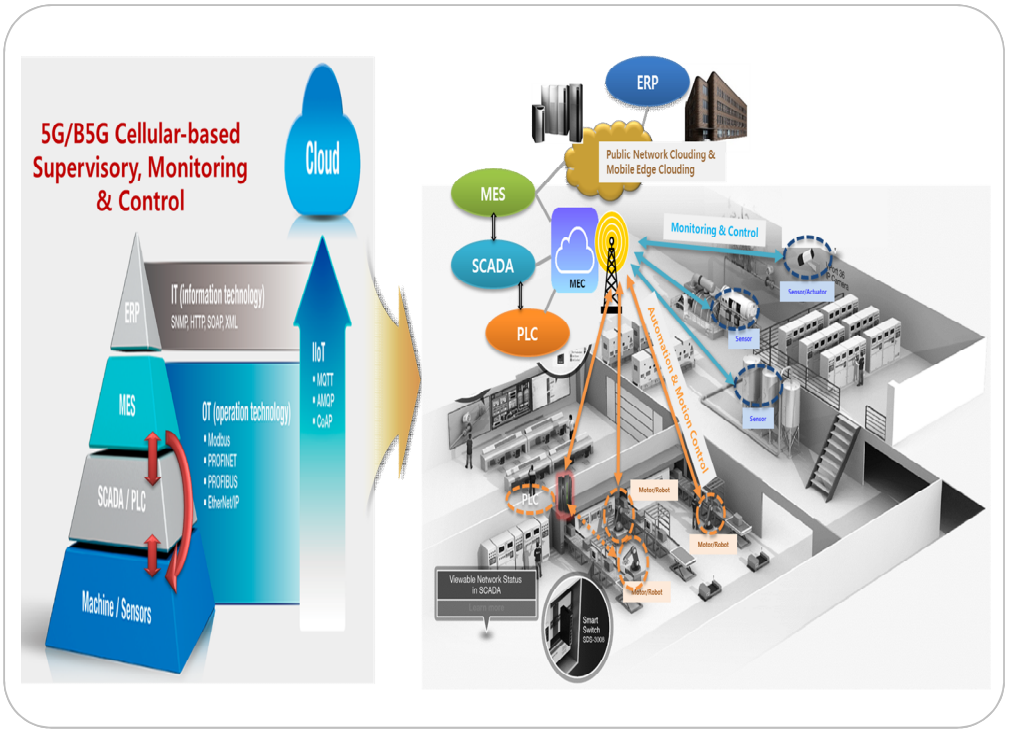
Overview – Cellular-based Industrial IoT

5G/B5G-based Industrial Network Infra



5G/B5G-based Factory Automation Network

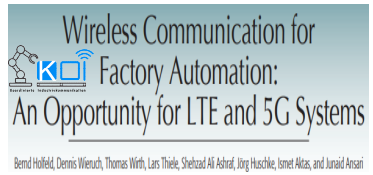


Unified 5G/B5G-based Industrial IoT Networks for Smart Factory

Trends – General

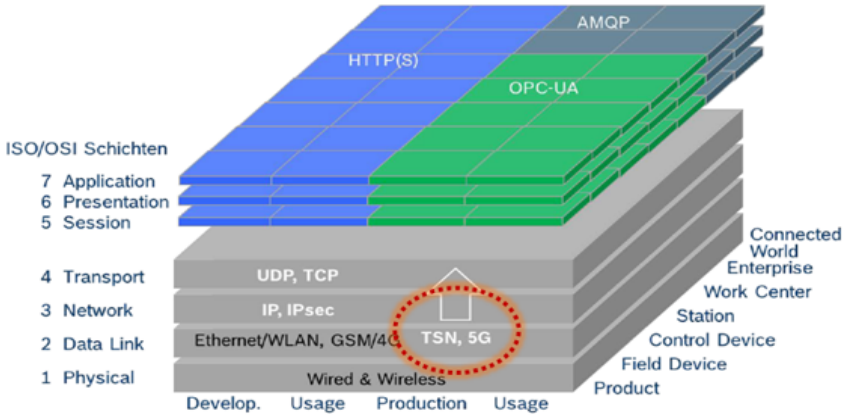
White Papers

- White Papers on 5G-based Industrial Automation published by major cellular companies since 2015



Industry 4.0

- 5G in RAMI 4.0 (Reference Architecture Model for Industrie 4.0)



Horizon 2020 5GPPP Phase 2

- Smart Factory related Projects

Trends – Business

[2017.09.] 5G-based Cloud Robotics

[2018.02.] Industrial IoT Innovation Lab

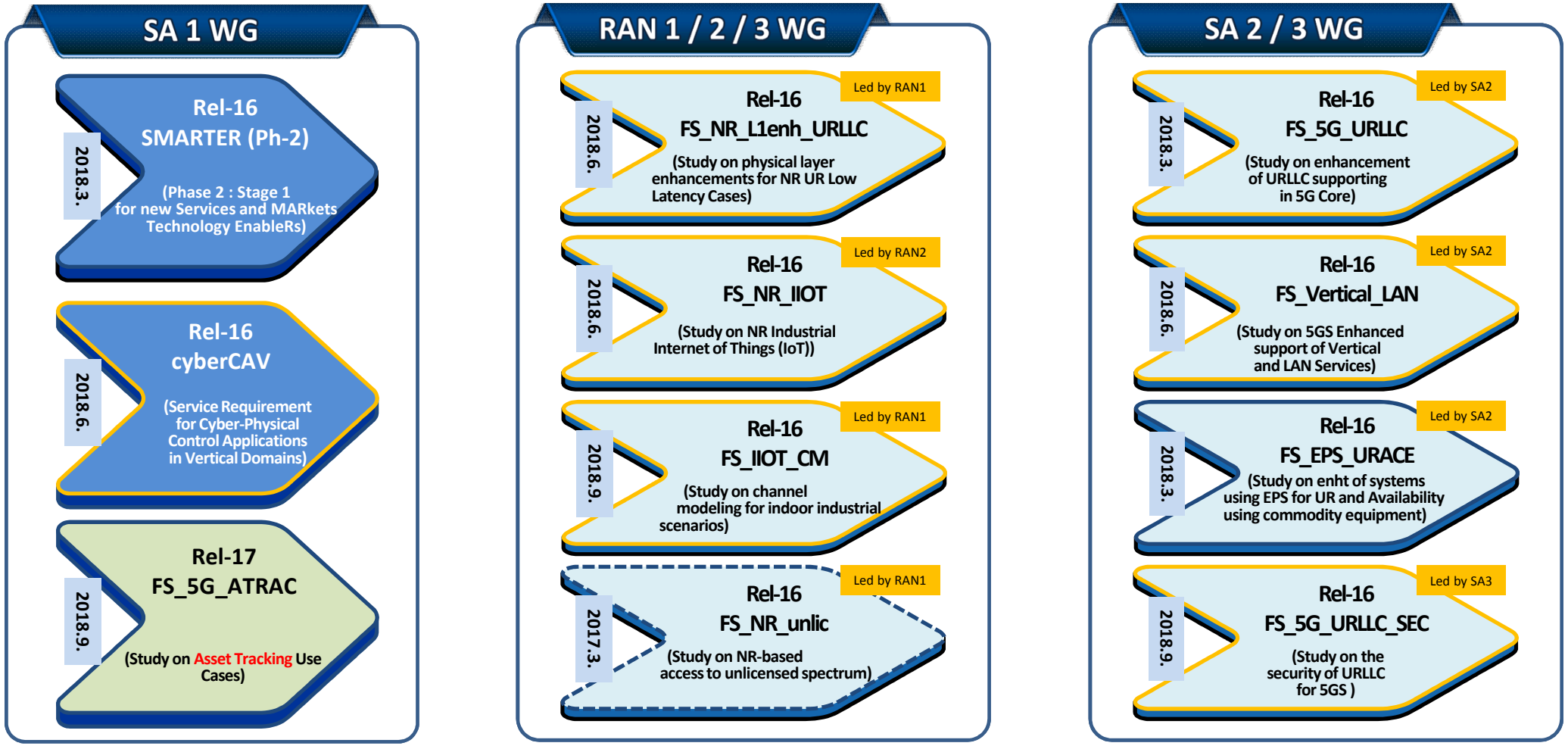
[2018.03.] 5G-Industry Project led by SKT

[2018.04.] 5G Smart Factory Trial

[2018.04.] 5G-ACIA kick-off

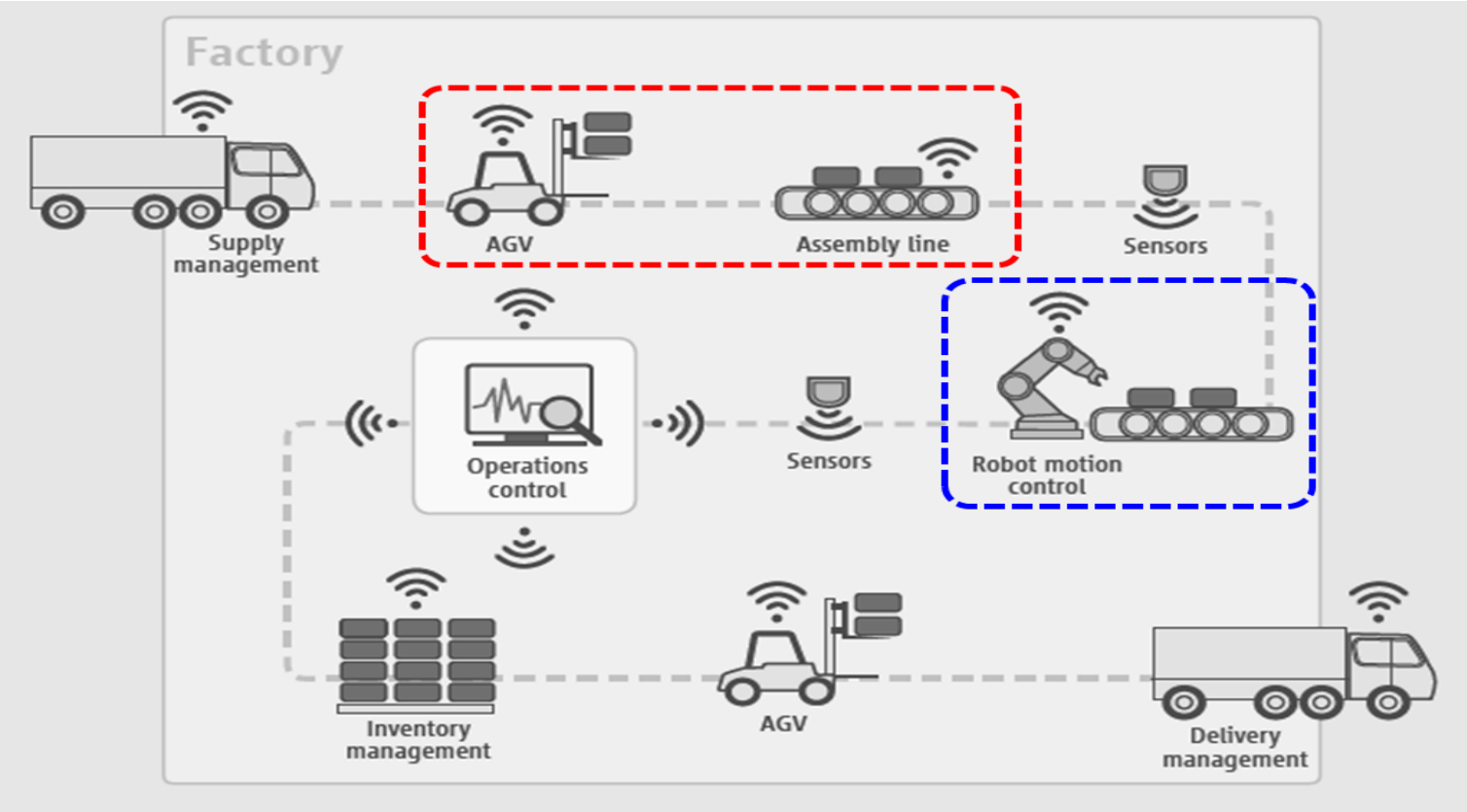
[2018.09.] 5G-based Smartt Factory TB

Trends – 3GPP Standardization



Use Cases

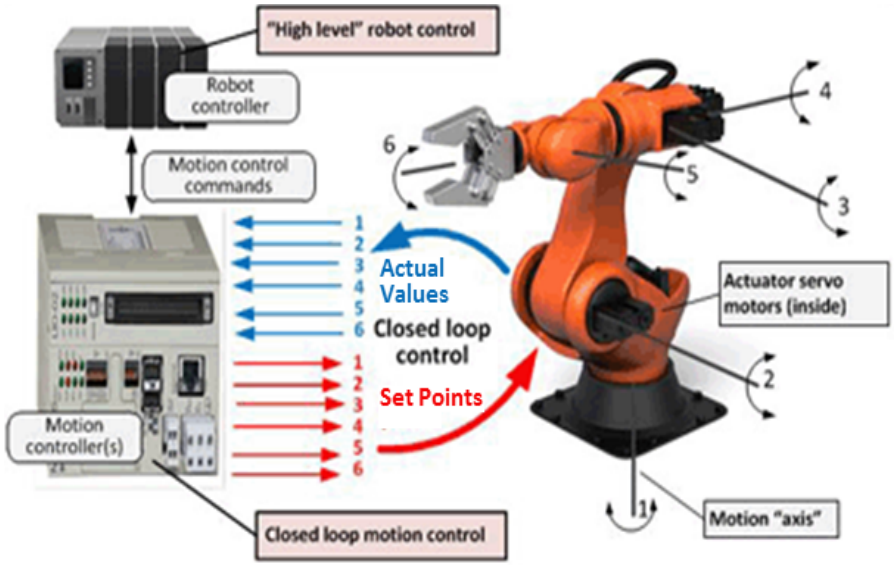
- **Key application**
  - Motion Control
  - Mobile Robot



(Example of process for Smart factory)

Use Cases

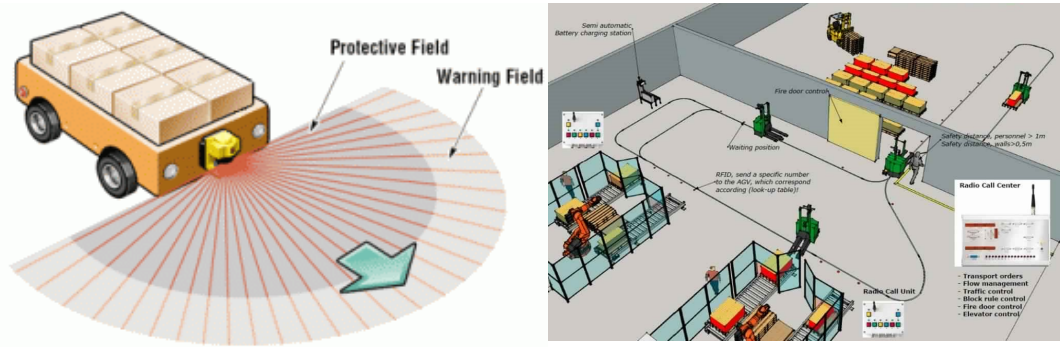
- **Motion Control**
  - Closed-loop control application
    - Machine tool, Packaging machine, Printing machine
  - Characteristics
    - Strict latency and reliability requirement
    - Private networking
    - Low mobility (Roaming and Handover)



(Robot motion control system with 6 motor drives)

Use Cases

- **Mobile Robot**
  - Programmable machine that performs various predefined process or control for autonomous operation
    - Cooperative motion control (CMC), AGV (Automatic Guided Vehicle)
    - Operation based on instruction from guidance control
    - Transportation of product and material
  - Characteristics
    - Mobility within restricted area
    - Private networking



(Automated Guided Vehicles (AGV) operation scenario)

Requirements

- **KPI for Factory automation scenario**

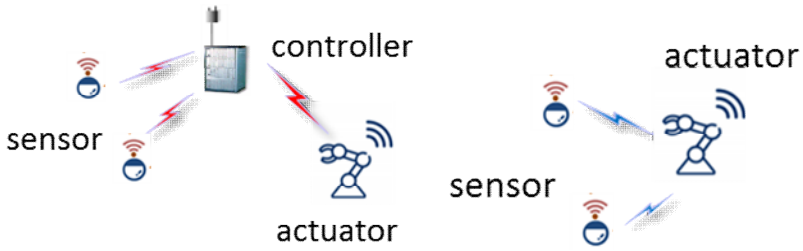
	Motion Control (Machine Tool)	Mobile Robot (Cooperative Robot)	Mobile Robot (AGV)
Latency (UL/DL) [ms]	< 0.25	< 0.5	10 ms
Cycle time [ms]	< 0.5	< 1	20 ms
Cyclic traffic jitter	< 50% of cycle time	< 50% of cycle time	-
Synchronicity [us]	< 1	< 1	< 10
Reliability (1–BLER)	$1 - 10^{-9}$	$1 - 10^{-9}$	$1 - 10^{-7}$

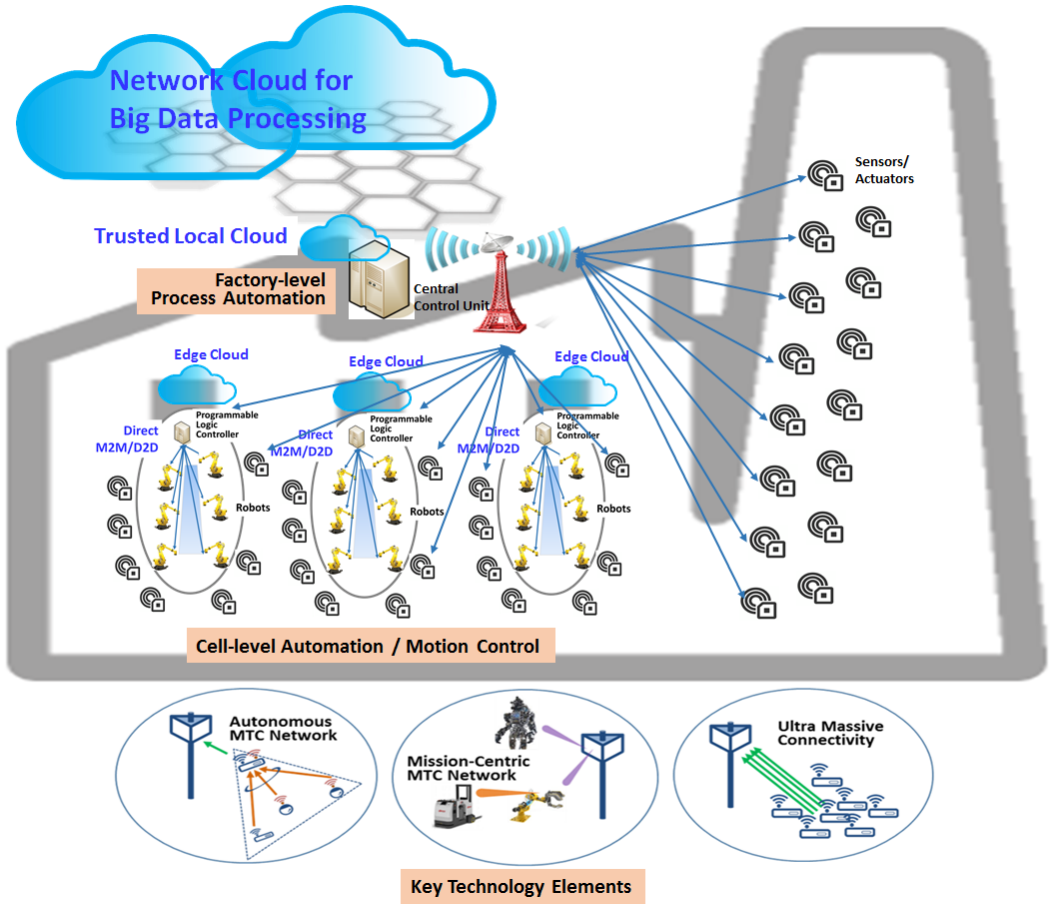
* **Cycle time** : The entire transaction time from the transmission of a command (set points) by the controller to the reception of a response (actual values) by the controller. It includes all lower layer processes and latencies on the air interface as well the application-layer processing time on the sensor/actuator.
* **Cyclic traffic jitter** : The maximum deviation of a time parameter relative to a reference or target value. In the factory automation, it means the variation of round-trip delay of cycle traffic under assumption of tight synchronization.
* **Synchronicity** : The maximum allowed time offset within the fully synchronized system between mobile device (controller, sensors, actuators) clocks. All mobile devices inside a local network or a certain group shall be synchronised at the application level within the specified accuracy.

Deployments

- **Two-tier radio access network architecture**
  - Large-area master/slave networking
  - Local-area M2M networking
  - Time Sensitive Network (TSN)

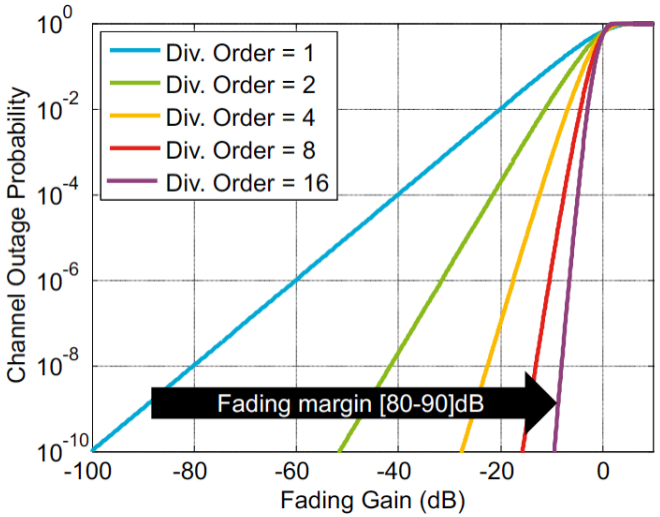
- **Traffic for Industrial IoT**
  - Sensor Traffics (including Video)
  - Actuators
  - Controller



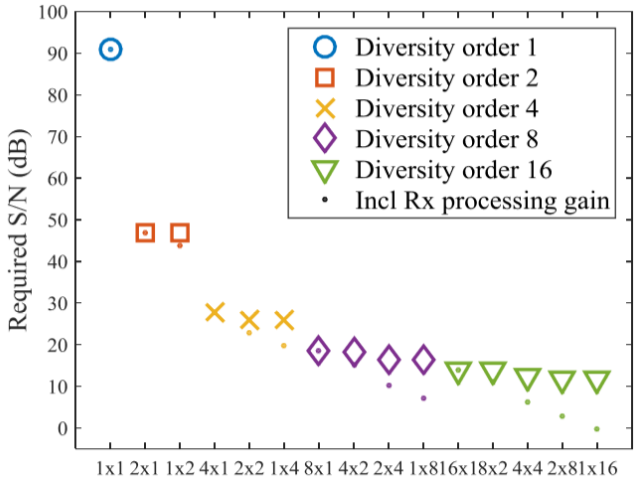


Technical issues - Reliability

- **Diversity**
  - Frequency and space diversity for Robust channel gain
  - Multi Rx antennas for Receiver processing gain
  - Time diversity may not be suitable due to the latency constraint*



(Fading gain for various antenna diversity orders*)

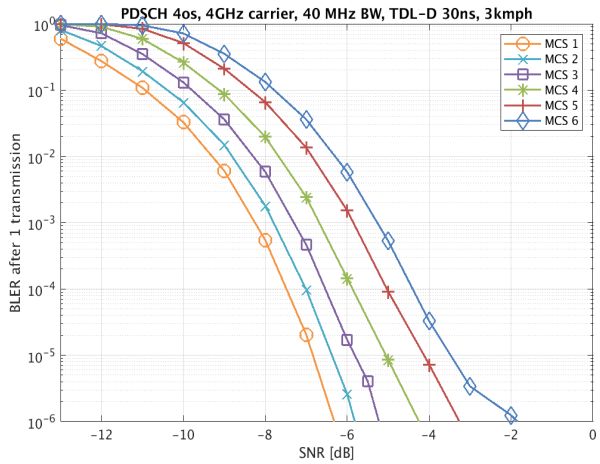


(Required SNR margin to combat fading dips)

(*Radio Access for Ultra-Reliable and Low-Latency 5G Communications, IEEE ICC 2015)

Technical issue – Reliability

- **Channel Coding**
  - Performance limitation in 5G NR
    - Error floor for LDPC codes at certain code rates and block lengths*
    - List decoder complexity in short block lengths and low code rate**
  - More robust coding scheme
    - Performance guarantee at short block lengths less than a few hundreds of bits
    - Coding schemes with large Hamming distance without error floor at the target BLER (e.g. 10^{-9})
    - Combination of error detection and correction codes for high coding gain



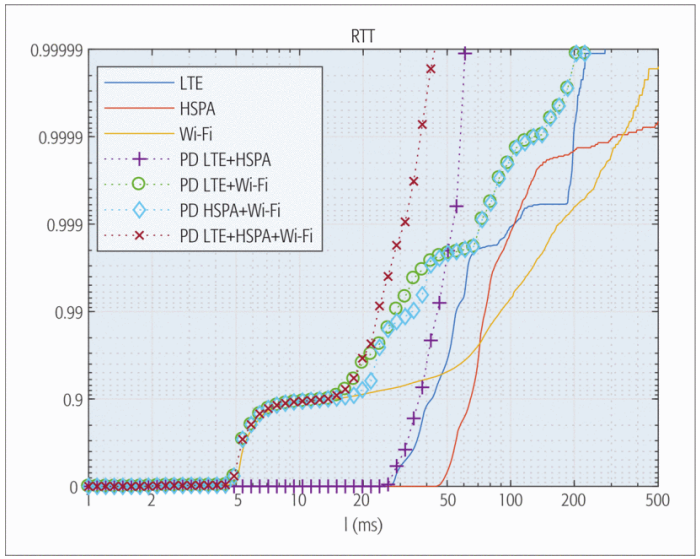
(Error floor in LDPC in Factory automation scenario*)

*R1-1812166, "Evaluation of URLLC Factory Automation Scenario," 3GPP TSG-RAN WG1 Meeting #95
** Short block-length codes for Ultra-Reliable Low Latency Communications," IEEE Communications Magazine, 2018

Technical issue - Reliability

- **Link adaptation**
  - Reliability control under varying interference
    - Conservative link adaptation assuming the worst case interference
  - Dealing with variation of wireless channel gain
    - Stabilization utilizing large-scale (wideband, long-term) diversity
    - Selection and further adaptation on a small-scale

- **Topology**
  - Short association distance
    - Overall SINR improvement with network densification
  - Multiple associations
    - Multiple connectivity with TRP cooperation

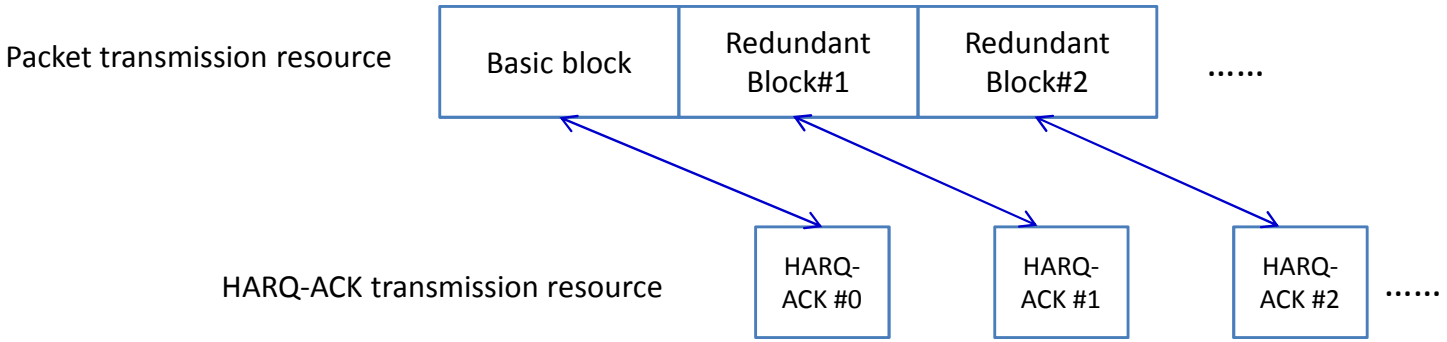


(Achievable reliability for different round-trip latencies of packet duplication)*

* Wireless Access for Ultra-Reliable Low-Latency Communication: Principles and Building Blocks, IEEE Network, 2018

Technical issue – Reliability

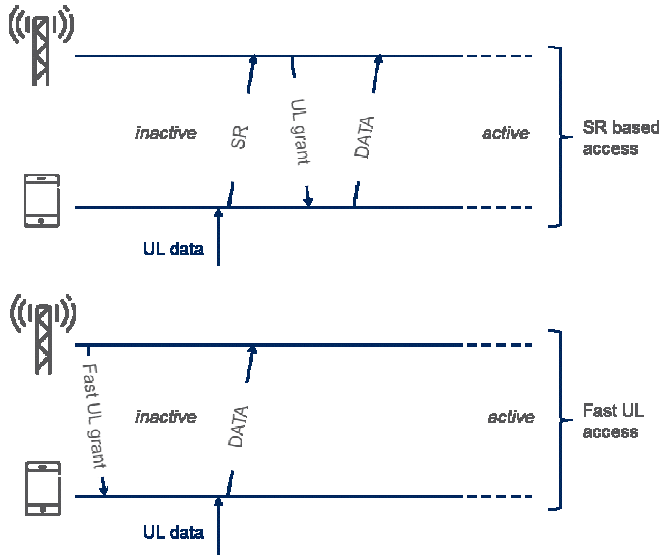
- **Retransmission**
  - Conventional Hybrid Automatic Retransmission reQuest (HARQ) with latency improvement
    - Fast retransmission of redundancy versions based on fast HARQ-ACK response
    - Potential reliability issue with control signaling such as grant and HARQ-ACK
    - Limitation in time and energy use due to the time-discontinuous transmission
  - New Retransmission Mechanism
    - Automatic time-continuous retransmission for full time and energy use
    - Tx termination upon reception of ACK
    - Block-wise self-decodable structure to facilitate early decoding and early Tx termination



Technical issue – Massive Connectivity

- **Multiple Access**
  - Conventional procedure for packet transmission
    - Resource assignment and grant by scheduler
    - Signaling overhead and long latency of control information for short data transmission
  - Grant-free autonomous Transmission
    - Regular or event-driven fast transmission using pre-configured parameters
    - Pre-configured semi-persistent resources for predictable traffic pattern
    - Interference-robust multiple access
      - Partially overlapping CDM with orthogonal + non-orthogonal spreading
      - Successive interference cancellation on receiver

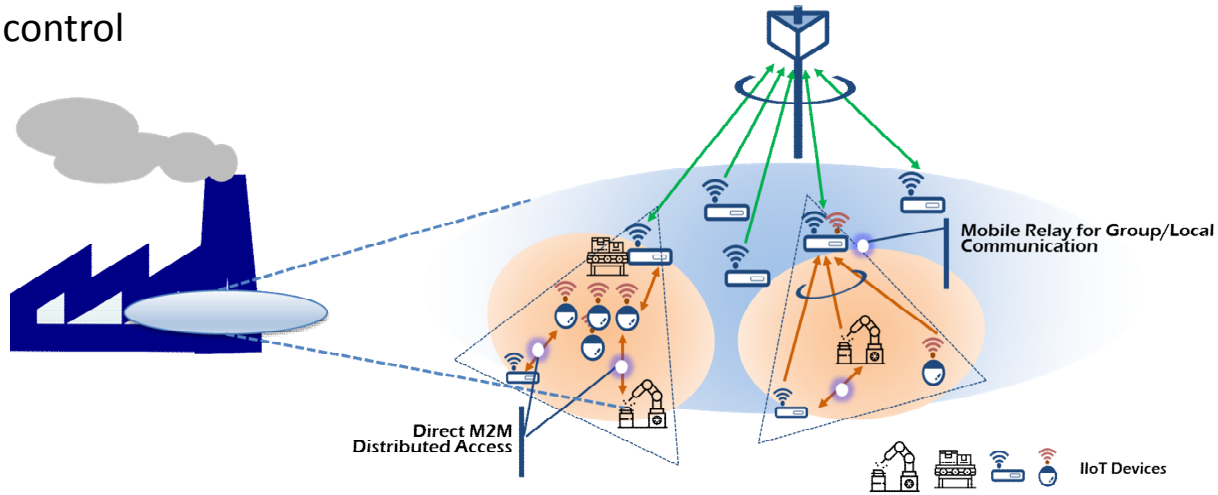
* CDM: Code Division Multiplexing



(Example of fast UL transmission: 3GPP Rel-14, Ericsson)

Technical issue – Massive Connectivity

- **Direct M2M**
  - Benefits form shorter link distance and fewer hops
    - Direct source-to-destination transmission for short range
    - Relaying for long range, i.e., via a base station or mater node
  - Separate spectrum for different link types
    - Low delay, Inter-link interference control



Conclusion

- **5G may not be efficient or not be able to meet the requirements**
  - Wireless Industrial IoT replaces the conventional cable connection with wireless connection
  - May need further enhancement to meet requirement for factory automation
  - The radio access technology ingredients such as synchronization, multiple access, channel coding, diversity, direct M2M need to be revisited.

- **New wireless communication technology for factory automation**
  - Integration and simultaneous support of massive MTC and enhanced URLLC would be a key feature
  - Factory automation puts forth very stringent requirements going beyond 5G-URLLC/mMTC
    - Extremely high reliability (up to 1-BLER 10^{-9}) & low latency (< 1 ms)
    - Massive connectivity (> 1 device/m^2)

Thank You !!!

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