Case Study of AGV in Industry 4.0 Environments – An Evaluation of Wireless Communication Protocols

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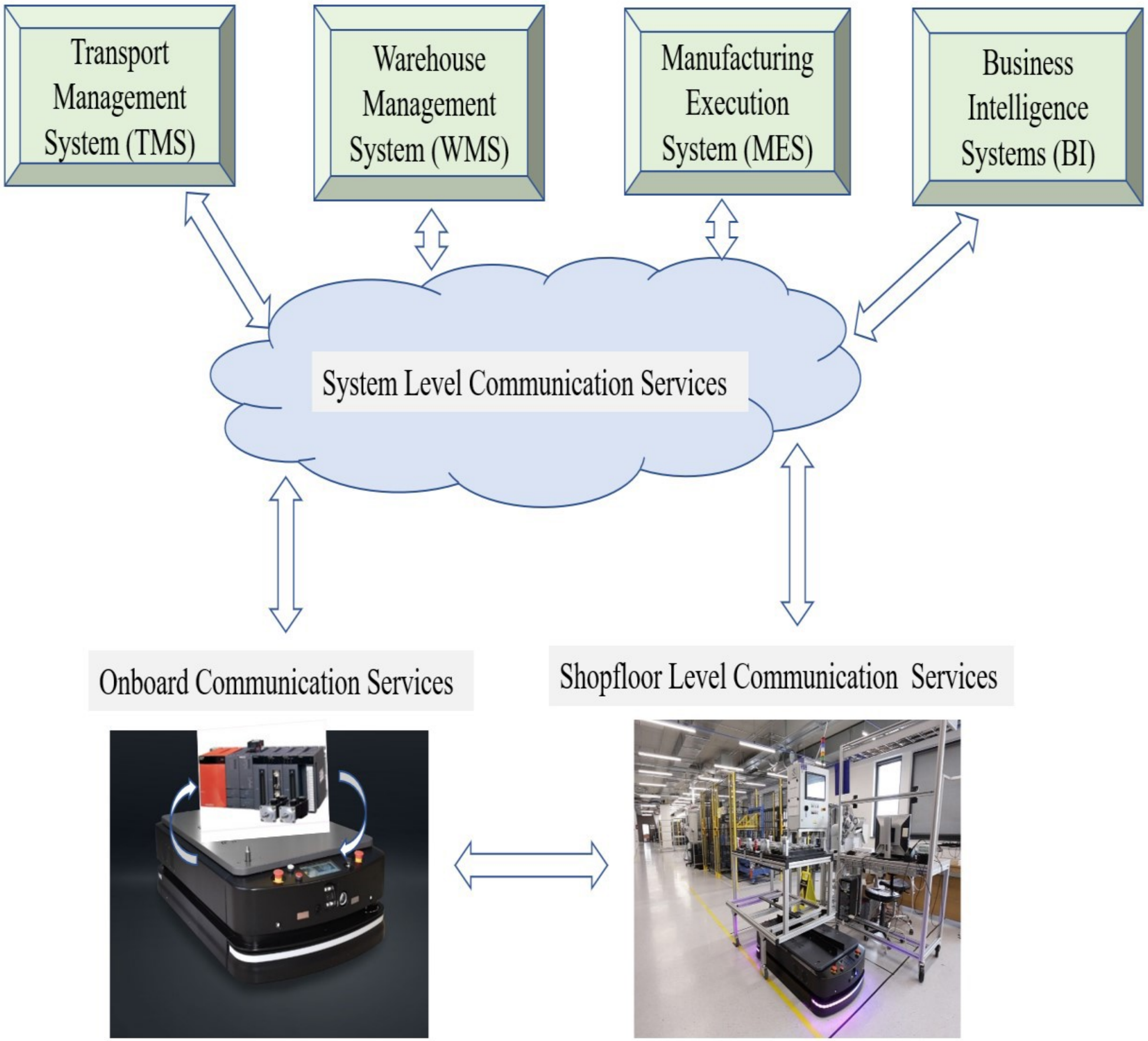
Contribution

- **A case study of AGVs in an industrial environment**.
  - Communication services are described
    - **Wireless** communication with the other part of the production area
    - Wired interconnections between the AGV and an onboard collaborative robot.

- The second part of the contribution is to **assess various protocols for wireless communication**.

- Communication requirements are based on the production scenarios conducted by **Aiut Ltd..**
    - **both a manufacturer of AGVs and**
    - **an integrator of the industrial IT systems that use these devices**



Case study – Communication requirements

- Onboard communication
  - Onboard safety
  - Natural navigation, docking
  - Acquiring the measurement and processing data from the end-point devices
  - 5 main communication groups:
    - Drive group ;
    - Safety group ;
    - End-point devices ;
    - Cobot-related equipment ;
    - Human-Machine Interface

CobotAGV:
Autonomous Guided Vehicles (AGV) equipped with collaborative robots (Cobot)

Case study – Communication requirements

- Shopfloor communication
  - Safety on the shopfloor (e.g., safety button on AGV or production station)
  - Between AGV and production stations to perform the production process
    - exchange of docking-process signals, statuses, permissions to work, etc.

Case study – Communication requirements

- System-level communication
  - Manufacturing Execution System (MES), Warehouse Management System (WMS), Transport Management System (TMS), and Business Intelligence systems (BI)
    - Transportation orders
    - Controlling the traffic of a fleet of AGVs
      - Real-time problems, e.g., dead-lock management
    - Event-based information:
      - E.g., notification about AGV arrivals and status of execution orders.

Wireless communication protocols, requirements

- Real-time and reliability is necessary for the safety-related shopfloor-level communication
- Continuous communication is needed between the TMS and AGVs when a real-time problem for a fleet of AGVs must be solved.
- Reliable communication between AGV and MES/TMS

- In addition, security, reduced energy consumption, a low roaming delay, low jitter, and low cost of equipment.

Wireless communication protocols

- Wireless communication is affected by:

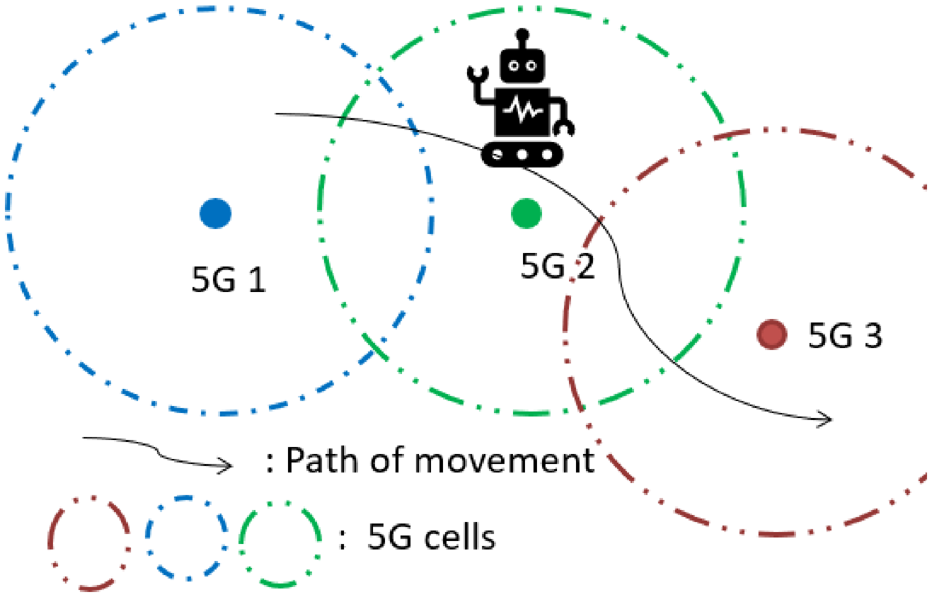
- Interference
- Reflection
- Diffraction
- Attenuation
- …

- The link quality is nondeterministic

- **Experimental tests should be conducted to assess the suitability before deciding on wireless technology**.

Wireless communication protocols – 5G vs Wi-Fi6

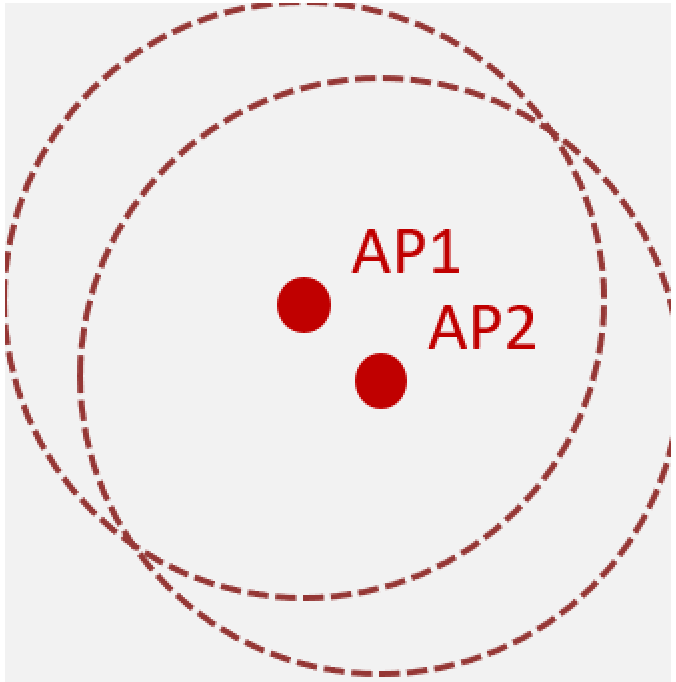
- Private 5G compared against Wi-Fi 6 for controlling **Autonomous Mobile Robots** (AMR) [*].
- AMR navigated within an industrial research lab and crossed several 5G cells.
  - The control-loop latency
    - Median was 11ms
    - And less than 25ms at the 99.9% percentile.
- Wi-Fi 6 and frequency planning were used,
  - The control-loop latency
    - Median was 5ms,
    - The value at the 99.9% percentile was 0.5s and the packet PER was about 0.4%.



[*]: I. Rodriguez et al., "An experimental framework for 5G wireless system integration into industry 4.0 applications," Energies, vol. 14, no. 15, p. 4444, 2021.

Wireless communication protocols – IEEE 802.11 (Wi-Fi)

- Using **redundancy** communication to achieve **reliability** [*],
- A dual-arm robot communicated with a mobile robot on an industrial shopfloor through **two Access Points** (AP) using IEEE 802.11.
- The APs that were used operated on nonoverlapping channels 1 and 11.
  - Each transmitted packet was duplicated and sent through each of the two APs.



- Improved end-to-end connectivity.
- In addition, the variability in latency was reduced, i.e.,
  - the percentage of packets delayed of more than 136ms was reduced
    - from 20% when only one AP was used
    - to 3.9% when two APs were used.

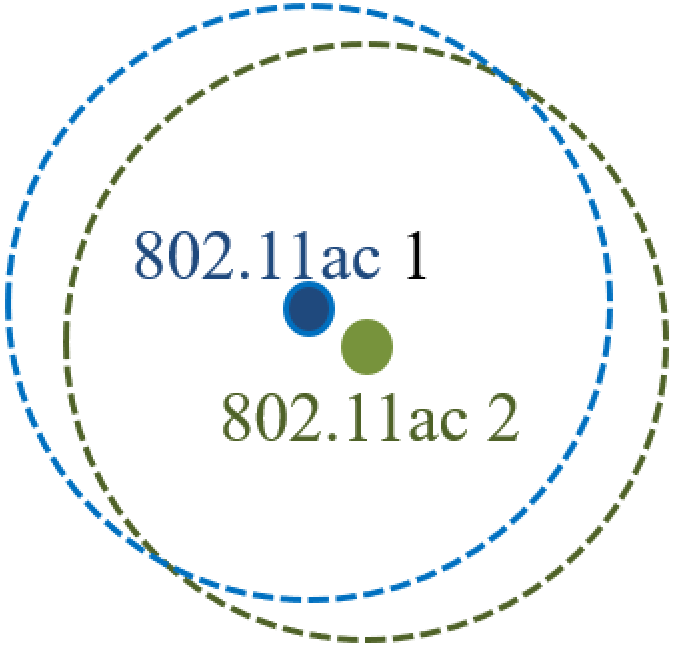
[*]: M. C. Lucas-Estañ, J. L. Maestre, B. Coll-Perales, J. Gozálvez, and I. Lluvia, "An experimental evaluation of redundancy in industrial wireless communications," in 2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA), vol. 1: IEEE, pp. 1075-1078., 2018

Wireless communication protocols

AGV equipped with two **IEEE 802.11ac** to **reduce disconnection time** and **improve reliability [*]**.

- The communication was switched to the second interface based on **RSSI**

- The PLR was reduced by 21%, and the delay time was reduced to less than 10ms.



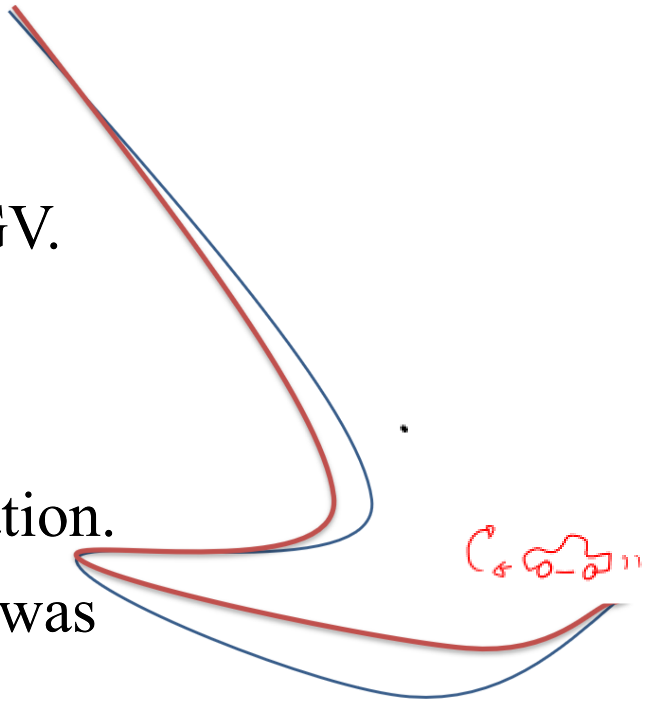
[*]: F. Ohori et al., "Performance Evaluation of Wireless Switching for Indoor AGV," in 2021 24th International Symposium on Wireless Personal Multimedia Communications (WPMC), IEEE, pp. 1-5, 2021

Wireless communication protocols - 5G

- **Deviation** between the AGV's **actual and correct path** [*].
  - safety, energy.

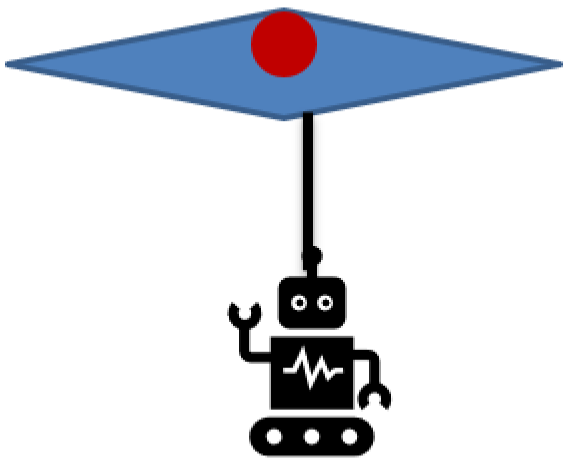
- A 5G communication solution was used to remotely control the AGV.

- A delay of up to 50ms had little impact on the result,
- Increasing the delay beyond 50ms substantially increased the deviation.
- Packet loss increased to more than 10%, the impact on correctness was severe.
- A loss of more than 30% resulted in unacceptable performance.



[*]:W. Nakimuli, J. Garcia-Reinoso, J. E. Sierra-Garcia, P. Serrano, and I. Q. Fernández, "Deployment and evaluation of an industry 4.0 use case over 5G," IEEE Communications Magazine, vol. 59, no. 7, pp. 14-20, 2021.

Wireless communication protocols – 5G

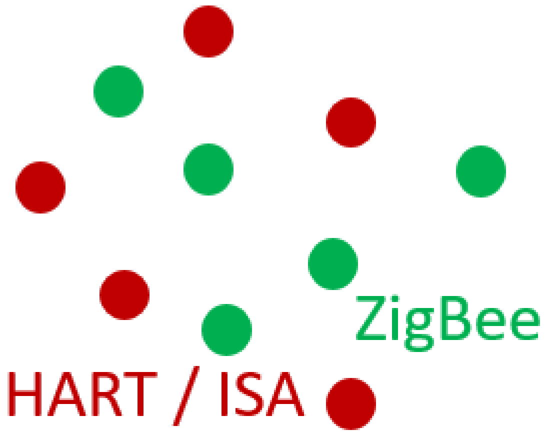


- **Offload processor-, energy- and memory-consuming tasks** to servers or cloud solutions**.**
- Use 5G's Ultra-Reliable Low-latency Communications (URRLC) to offload computational-exhaustive computation to control the time-critical balancing assignment [*]
- Balance a ball on a glass surface while the robot moved.
- **No other** wireless devices or machines that generated interference were present on site.
- The end-to-end latency was around **2ms**, and the test showed stable balancing.

[*]: F. Voigtländer, A. Ramadan, J. Eichinger, C. Lenz, D. Pensky, and A. Knoll, "5G for robotics: Ultra-low latency control of distributed robotic systems," in 2017 International Symposium on Computer Science and Intelligent Controls (ISCSIC), IEEE, pp. 69-72, 2017

Wireless communication protocols – IEEE802.15.4/ 802.15.4e

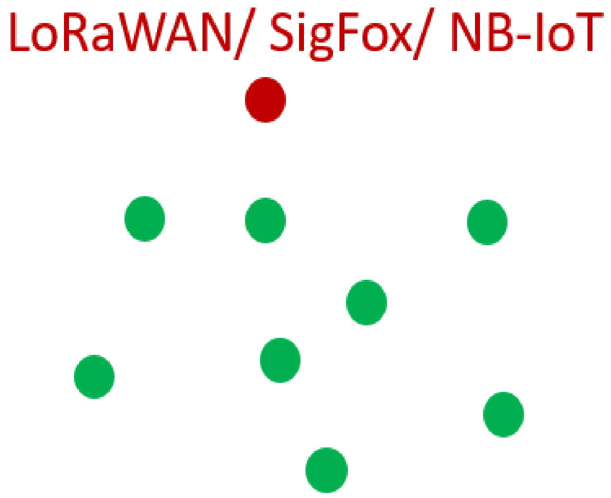
- Wireless Highway Addressable Remote Transduce Protocol (**WirlessHART**), and **ISA100.11a** are evaluated in [*].
  - Time Slotted Channel Hopping (**TSCH**) is used to reduce any interference from co-located devices



- The main advantage of **ZigBee** is the reduced energy consumption due to its efficient sleep protocol.

[*]: A.-L. Kampen, M. Fojcik, R. Cupek, and J. Stoj, "The requirements for using wireless networks with AGV communication in an industry environment," in 2021 17th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), IEEE, pp. 212-218, 2021

Wireless communication protocols - LPWA



- Low Power Wide Area (LPWA) protocols such as LoRa-WAN [16], SigFox [17], and NB-IoT [*].
    - NB-IoT: licensed frequency band
    - LoRa-WAN, SigFox: license-free ISM band

    - Reduces energy consumption and increases the transmission range.
    - The trade-off is an increased delay and low data rate.

[*]: M. Kanj, V. Savaux, and M. Le Guen, "A tutorial on NB-IoT physical layer design," IEEE Communications Surveys & Tutorials, vol. 22, no. 4, pp. 2408-2446, 2020.

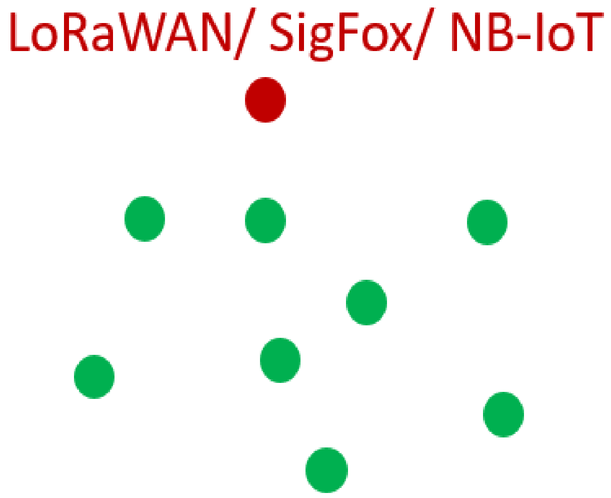
Wireless communication protocols - LPWA

- The comparative study [*]:

  - Reportes that LoRaWAN and Sigfox have a better interference immunity than NB-IoT.

  - Sigfox :The end devices transmit the messages three times on different frequency channels.
  - LoRaWAN : The Chirp Spread Spectrum (CSS) spreads the narrow band signal over a wider channel bandwidth.

  - NB-IoT has better Quality of Service (QoS) characteristics.



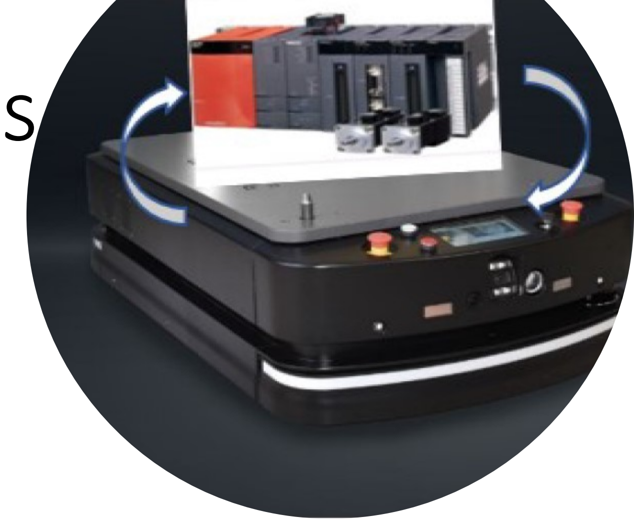
[*]:K. Mekki, E. Bajic, F. Chaxel, and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," ICT express, vol. 5, no. 1, pp. 1-7, 2019.

Conclusion – Case study experience

- Our case study demonstrates that an AGV should wirelessly communicate with its environment
  - to determine the routing path
  - correctly dock to a workstation
  - to send/ receive updates from the TMS/ MES

- The requirements for the communication span from
  - supporting this high volume of data to
  - guaranteeing near real-time transmission for safety traffic and to prevent collisions.

Conclusion – Candidate communication solutions



- 5G could support a range of requirements.
  - However:
  - The frequency spectrums used are more susceptible to attenuation and are subject to charge.

- Another solution is, therefore, to combine protocols in order to support various traffic streams. (duplicate collocated)
  - However:
  - Management of different systems
  - Gateways between the protocols, add additional delays.

- Duplication of wireless interfaces may be used to reduce communication disruption.

Thank you !