Empowering Smart Factories with Open RAN

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***Abstract*—It is envisioned that 6G mobile networks will enhance and majorly empower the Industry 4.0 paradigm, evolving towards smart factories with optimized and customized services. Especially the smart factory scenario with real-time and high-capacity data communication presents us with new challenges, both in communications (mmW/sub-THz) and networking. This article discusses these new challenges and proposes extensions to the current Open Radio Access Network (Open RAN) standards for 6G networks to enable further evolution of Industry 4.0 and beyond. We motivate the need for real-time functionalities in Open RAN and an extended interface to the user equipment (UE) to allow for its fine-grained control.**

I. INTRODUCTION

Smart factory automation presents one of the most promising use cases for 6G mobile networks, as it challenges the requirements on latency, bandwidth, and reliability/safety/dependability/security. In manufacturing and industrial IoT, multiple concurrent connections between machines and sensors exist, thus fully embracing the known service classes from the fifth-generation (5G) mobile networks, such as Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), and Ultra Reliable Low Latency Communication (URLLC) [1]. While today 3GPP defines the usage of the millimeter wave (mmWave) band for 5G, the sub-terahertz (sub-THz) bands are considered the next frontier to be explored in 6G networks [2]. In smart factories, the design of the Radio Access Network (RAN) control plane also demands real-time control loops to be executed at the distributed unit (DU) and Radio Unit (RU) function levels.

Today, efforts are underway in Open RAN standards specifications by O-RAN ALLIANCE (O-RAN) to especially address the near-real-time needs with constraints on completion times ranging from 10 milliseconds (above the real-time) up to 1 second (non-real-time). On the other hand, O-RAN does not specify a real-time controller in its current version. In the research literature, efforts are underway towards implementing real-time control in Open RAN, including a research report from the O-RAN's next Generation Research Group (nGRG) (RR-2024-10), to support various use cases including smart factories [3]–[5]. This is facilitated by the architectural component referred to as RAN Intelligent Controller (RIC). This new architectural component provides a centralized network abstraction, allowing operators to implement and deploy custom control loops in the RAN. The real-time RIC, considering the challenges of the new high-frequency bands in smart factories, can be identified as the key component for real-time control of future smart factories.

This article proposes extensions to the current O-RAN standards for 6G networks to enable further evolution of smart factory automation. We motivate the need for real-time functionalities in Open RAN and propose an extended interface to the user equipment (UE) to allow for its fine-grained control. We also present the opportunity of interfacing with novel technology solutions such as Reconfigurable Intelligent Surfaces (RISs) to provide reliability. Our analysis considers two main concepts and the related extensions for smart factories with Open RAN: functional disaggregation and centralized intelligent control RIC. To this end, the paper first provides a brief state-of-the-art discussion (Section II). After that, it surveys the key technologies for O-ORAN in smart factories (Section III). We provide our proposal for further evolution of standards (Section IV) and illustrate its envisioned benefits on a case study (Section V).

II. EVOLUTION OF MOBILE NETWORKS FOR SMART FACTORIES

Increasing bandwidth has historically driven mobile network generation (4G/5G/B5G). In the 5G evolution, smart factories were identified as promising user candidates, as they consist of a dense concentration of intelligent mobile robots requiring low latency and high reliability for control.

Non-public (private or campus) networks deployed in smart factories will bring a mix of URLLC and mMTC service features, also known as Massive URLLC (mURLLC) class of service [6]. This new class of service is expected to support, for example, a dense concentration of remote-controlled intelligent mobile robots operating on the factory floor. We envision this new service to deliver user-experienced data rates up to 1 Gbps while meeting latency requirements of sub-10 ns in the RAN. It is worth noting that the reliability Key Performance Indicator (KPI) of URLLC services is envisioned to rise by at least one order of magnitude (99.99999%) [6].

Another relevant use case scenario in smart factories, requiring high-capacity links is the computer vision-assisted

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quality assessment for automated quality control. In such visual inspection systems (VIS), industrial cameras installed above the production conveyor belt capture the video images of the manufactured artifacts, which are then transmitted in real time to an ML-assisted video analytics pipeline operating on the factory edge cloud (EC). The resulting aggregated traffic per VIS ranges between 1 Gbps and 20 Gbps [7], leading to high upstream traffic loads towards the EC.

Figure 1 illustrates the state-of-the-art Open RAN architecture to be used in smart factories. Two critical components are to be noted, namely the non-real-time (non-RT) RIC, inside the Service Management and Orchestration (SMO), and the near-RT RIC. The SMO framework connects to RAN nodes of the network through the A1 and O1 open interfaces. The Non-RT RIC focuses on RAN policy management, updates/upgrades, and radio resource management. Moreover, it guides the near-RT RIC via the A1 interface. The policies and higher-layer procedures to be applied on the RAN are handled with the help of rApps running on the non-RT RIC. The near-RT RIC component is located on the network's edge, connecting to the O-CU and O-DU through the E2 open interface, and runs xApps. Intelligent network orchestration can be achieved by deploying AI/ML algorithms on rApps/xApps.

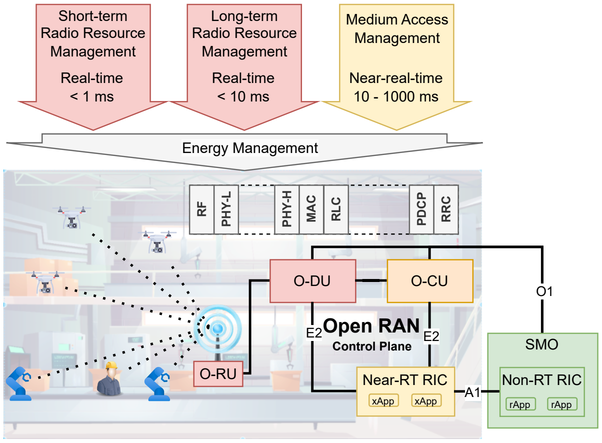

Fig. 1. RAN Management requirements (top), the smart factory network (left), and the Open RAN control plane (right).

Figure 1 also illustrates a simplified view of the RAN control protocol stack with disaggregated units, as proposed by O-RAN. It includes physical and link layer functions that are used for three categories of radio management: (i) short-term, which deals with decisions that must be taken within the channel coherence time (such as in multi-antenna processing), and strict latency constraints (such as dynamic scheduling of URLLC traffic). This includes robots/human proximity detection for human safety assurance; (ii) long-term, which deals with decisions that can be taken based on large-scale channel variations (such as power control and beam management) and looser latency constraints (such as dynamic scheduling of eMBB traffic), which is employed in Autonomous Guided Vehicle (AGV) tracking and control; and (iii) medium-term, which controls the channel multiplexing, RAN slicing, etc., which ensures data security and privacy in the network. The lower the function (closer to the O-RU), the faster its execution needs to be. For higher functions (closer to the O-CU), there is more time flexibility, thus entering the domain of the near-real-time RIC. Finally, a transversal and crucial concern is energy management, one of the 6G's KPIs [6]. The Open RAN architecture enables flexible and programmable energy-saving measures through rApps and xApps, which can, for instance, control when a cell, carrier, or RF channel switches to sleep or off states upon certain conditions. Currently, O-RAN focuses on offering AI-based control to the higher layers of the protocol stack, with limited flexibility for the lower layers hosted at O-DUs/O-RUs, which is relevant to smart factories. Indeed, limiting the execution of control applications to the near-RT and non-RT RICs prevents the use of data-driven solutions where control decisions and inference should be made in real-time or within temporal windows shorter than the 10 ms supported by near-RT control loops, which is necessary for several smart factory use cases [8].

Related work on real-time control solutions for Open RAN includes [3], which implements dApps, distributed applications that run at the O-CUs/O-DUs. One benefit of pushing the computation to the network's edge is lower overall latency and overhead. The caveat is that this solution requires enough computational power (hardware acceleration) at the CU and DU nodes, given the high coupling with the dAPPs. Another solution, EdgeRIC, is presented in [5]. EdgeRIC is a real-time RIC co-located with, but decoupled, from the DU that implements μApps. By co-locating with the RAN, EdgeRIC does not interfere with latency-constrained RAN tasks but can access information and provide real-time control. Finally, in addition to a real-time RIC, [4] introduces the Multi-access Edge Computing (MEC) control loop concept to indirectly allow the UE to communicate with the near-real-time RIC.

III. TECHNOLOGY FOR OPEN RAN IN SMART FACTORIES

To allow for real-time data-driven decisions, radio access networks for future smart factories bring RIC closer to the radio interface (O-RU/UE). We dedicate this section to discussing technology and the related features in Open RAN, including control-data exchange (telemetry and monitoring) among UE, RAN functions (O-RU, O-DU, and O-CU), and RIC, and an efficient access/transport network (X-haul). Table I summarizes the enabling technologies discussed.

A. Sub-THz communication and Reconfigurable Intelligent Surfaces (RISs)

Figure 2 illustrates a smart factory network based on sub-THz communications and an Open RAN control plane. By transitioning to sub-THz communication systems and away from the traditional sub-6GHz frequency range, the communication systems migrate from an omnidirectional model of communications to a directional beamformed transmission regime; this is necessary to provide sufficient signal strength. This requires a beam alignment phase during the initial access of a UE (e.g., UE_1), a procedure that increases complexity in

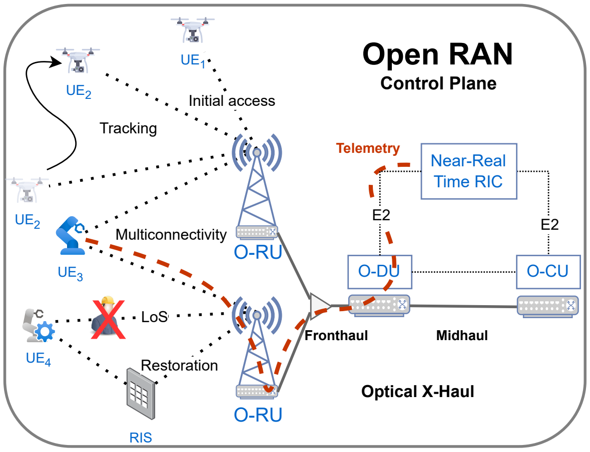

Fig. 2. Smart factory sub-THz networks with Open RAN control plane, and X-Haul network.

higher frequency ranges and with narrower beams. Moreover, as UE moves (e.g., UE_2), it is necessary to maintain the beam alignment condition between the UE and the O-RU, thus requiring fast beam-tracking procedures. Furthermore, due to the physical characteristics of high-frequency beams, obstacles can easily absorb them. Thus, they are susceptible to line of sight (LoS) blocking, which will require multi-connectivity solutions (e.g., UE_3). Alternatively, another new technology can be considered, i.e., RIS (e.g., UE_4). Finally, the high bandwidth provided by sub-THz allows the system to achieve high data rates with simpler transmission schemes, requiring less complex hardware, thus reducing costs. From a physical layer perspective, sub-THz smart factory networks are expected to operate under the following conditions:

- highly directional beamforming along unobstructed propagation paths;
- dense network deployments;
- low complexity hardware and signal processing.

The beam alignment procedure can be implemented at the physical layer using sophisticated hardware (e.g., fully digital beamforming architectures) and signal processing techniques. In practice, however, due to the need for low-complexity hardware and signal processing, beamforming is typically implemented using the so-called “beam management” protocols that select the best beams from a predefined list of available ones. Table I summarizes the need for high bandwidth capacity with low complexity signal processing, thus motivating the need for sub-THz bands. In its current specification, however, O-RAN does not define the related aspects of real-time control.

Figure 2 (e.g., UE_4) also illustrates RISs as a promising technology to support 6G networks based on sub-THz enabling the so-called *virtual LoS*, i.e., when the direct line of sight is lost between the UE and the RIS [9]. RISs enables novel ways of manipulating and extending the wireless channel to establish the desired communication link, thus increasing communications reliability. When integrating RIS into smart factories, the following features need to be considered: (i) RIS is an external element, not a part of the O-RU, and deserves special consideration; (ii) RIS can be shared among different O-RUs, so an entity needs to decide which surface should be allocated to which UE/O-RU and (iii) RIS lacks the computational capacities of O-RUs and thus needs to be controlled entirely by the previously mentioned entity. Thus, novel concepts will be required to offload the computations while keeping the tight latency requirements for mechanisms such as beam steering.

It is an open issue regarding what type of information is needed to control RISs, such as UE location or channel conditions. When deploying RIS, a trade-off between delay and channel quality needs to be considered. It is also critical to mitigate unintentional interference. Unlike O-RUs, RISs themselves are not capable of collecting such metrics. Instead, they rely on data gathered by O-RU and evaluated by another entity to be configured, which, too, is an open challenge. For example, initial access requires new approaches for RISs. Commonly, O-RU performs beam sweeping to find new UEs and determine the best beam. If a new user instead is located inside the area only covered by RIS, the RIS has to perform the beam sweeping. The management and control of this process is an open challenge. Finally, efficient control algorithms need to be developed to manage real-time interactions between O-RUs, RIS, and UEs (see Table I).

B. *RAN Telemetry*

Network telemetry solutions are critical to all domains of mobile networks, including mobile RAN, transport, and cloud network infrastructure to enable smart factories. To this end, O-RAN proposed standards for the E2 interface and the near-RT RIC module to enable telemetry for control and management [10]. E2 interface enables self-optimizing networks, anomaly detection, and allocation of radio resources at a coarse-grained level. These telemetry events are expected to occur relatively infrequently, ranging from tens to hundreds per second. The relatively slower pace enables xApps, applications running on the Near-RT RIC, to gather telemetry data, make inferences, and adjust RAN functions based on predefined control policies. The O-RAN has defined different ways for the Near-RT RIC to interact with E2 nodes, so-called *E2 interface service models* (E2SMs).

Telemetry technologies in Open RAN face several significant challenges that need to be addressed in the context of smart factories. One notable challenge is transporting all necessary uplink signals from the physical layer (PHY) to the RIC because RAN generates significant volumes of data at a high frequency. Developing a single API that collects information for different purposes is inefficient. Service models are specialized static APIs integrated into the RAN functions and designed based on specific use cases to capture only the essential information. This service model specifies the particular data that can be collected and the level of granularity at which it is collected. Whenever an xApp developer aims to introduce a new telemetry system, they must create a dedicated service model. However, this kind of data collection architecture cannot scale as the number of xApps increases

TABLE I
OPEN RAN CHALLENGES FOR ENABLING SMART FACTORY DEPLOYMENT

RAN target	Smart factory requirements	Enabling technology	Open RAN features to be addressed
Radio interface	High capacity	Sub-THz	Specification needed of real-time controllers and interfaces.
	High reliability	RIS	
Monitoring	High-velocity monitoring data	Telemetry	More flexible control interfaces.
X-haul	High data rate + Low latency	Full-Fibre Connection	Better definition of interfaces on different RAN functional splits.

and evolves. Hence, in the smart factory context, the scope of telemetry needs to be well-designed.

Applications that require real-time control loops can use a set of pre-defined policies offered by service models, which can run inside the RAN functions to eliminate control plane intervention latency. However, the current approach requires implementing control policies on a use-case basis and has scalability issues. The current E2 interface architecture does not provide the required flexibility for smart factories, as noted in Table I.

C. X-haul Challenges

In future 6G smart factories, optical fiber will serve as the primary transmission medium for wired manufacturing and production components, delivering high bandwidth, low latency, and reliability through the Full-Fibre Connection (FFC) and Guaranteed Reliable Experience (GRE) features of the Fifth Generation Fixed Network (F5G) technology [11], as presented in Fig. 2. The main X-haul-related characteristics that need to be considered in smart factories are from the current optical standards and interfaces that must be considered in Open RAN architecture, as summarized in Table I. In particular, open X-haul (O-X-haul) interfaces need to be defined and established, depending on the chosen Open RAN functional split. In other words, the way RAN functions are split among O-RU, O-DU, and O-CU determines whether the front- or midhaul protocols and traffic traverse the optical transport network or remain local, defining the latency and throughput requirements towards the underlying optical X-haul. As such, an F5G use-case scenario defines a passive optical network (PON)-based fronthaul for smart factory deployments, in which the transmission delay can be controlled to less than 1 ms for some specific applications, with additional synchronization functions and Time Sensitive Networking (TSN) capabilities [11]. Moreover, with the FFC feature envisioned and standardized for future fronthauls, where E2E fiber connectivity will be established between the O-RUs and O-DU, the delays associated with the fronthaul transmission will become very small. Finally, integrating any optical access or transport X-haul technology with the Open RAN may also require an adaptation and extension of O-RAN's native interfaces and protocols to seamlessly integrate the optical transport while preserving a cohesive overall performance and functionality of the Open RAN system.

IV. OPEN RAN EVOLUTION TOWARDS 6G SMART FACTORIES

Driven by the technology evolution of Open RAN, smart factories are expected to introduce new components, features, and interfaces. These will include the components required to provide real-time control and proper control data. This section presents a possible evolution of the O-RAN standard towards smart factories and discusses the main components of interest, most notably the evolution of real-time RIC and U1 interface. We finish this section with a short discussion of other technologies and their embedding in smart factories.

By analyzing the literature on real-time control solutions [3]–[5], one can see that a modular real-time RIC implementation is a good choice for reducing the coupling with other functions of the RAN, allowing it to be used without dependencies. Moreover, the new RIC must be placed at the edge, closer to the DU.

Figure 3 presents a schematic based on the O-RAN standard [12] that introduces the Real Time RIC and RIS components, their companion interfaces A1* and E2*, and the novel U1 interface between the UE and the Near-RT RIC (dashed lines). It additionally shows the F1 and Open Fronthaul interfaces, connecting the O-CU to the O-DU, the O-DU to the O-RU, and the Uu interface that connects the UE to the radio base station (composite of O-RU, O-DU, and O-CU). We note that the proposed architecture is meant for a private network deployment in a smart factory. Thus, its fronthaul is short-distance, making the propagation delay negligible for Open Fronthaul and E2*.

A. Real Time RIC

We describe the architecture of Real time RIC in Fig. 4. This architecture is intended to be high-level and not exhaustive. At its core, Real time RIC has the RT RIC platform, which enables time-critical applications (tApps) via the RT RIC APIs. It consists of various subsystems like a messaging subsystem for internal messaging, a storage subsystem for storing various kinds of data, and an orchestration and management subsystem for tApps management. The RT RIC Platform also hosts terminations for A1*, O1, and E2* interfaces (Fig. 3).

1) A1 Interface:* This interface is similar to the A1 interface. It will enable a bidirectional flow of enrichment information between near-RT RIC and RT RIC. This information may include policies, intents, predictions, etc.

2) E2 Interface:* The E2* interface is an extension of the current E2 interface that allows RT RIC to communicate with O-DU and RIS with very low latency. It supports new service

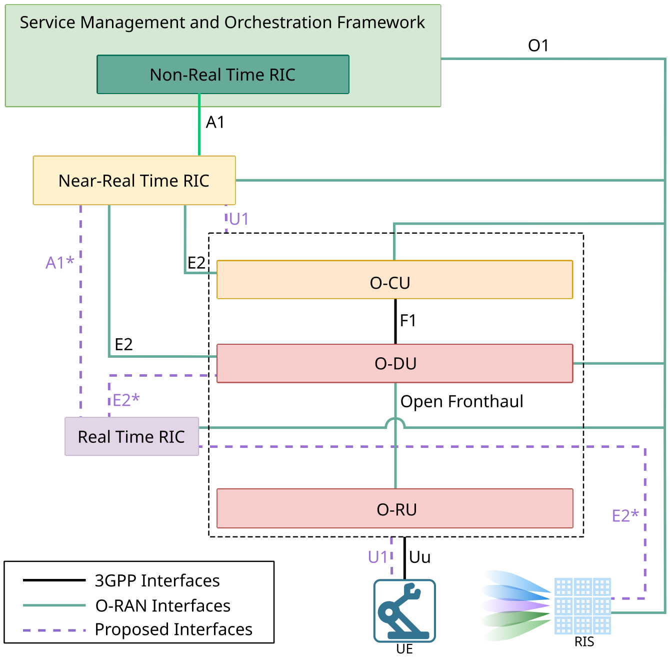

Fig. 3. Proposed extensions to O-RAN standard.

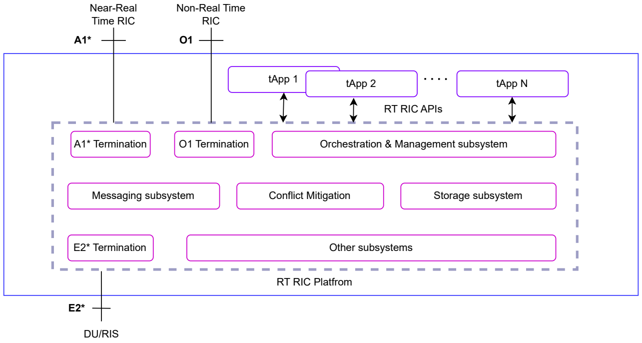

Fig. 4. Real Time RIC architecture.

models that enable real-time data collection and control operations from the O-DU to RT RIC. The E2* interface enables RT RIC to (i) access data like signals sampling data, which is critical for low latency applications but is not available over the regular E2 interface, and (ii) to control operations like beam forming at lower latency than that offered by the regular E2 interface. However, the tight latency constraints on the E2* interface mean that its implementation needs to be significantly faster than the regular E2 interface [3].

B. U1 Interface

Unlike in public networks, UEs in smart factories tend to be not just communication devices with a human interface but platforms with diverse capabilities. These UEs may have their local controllers to manage these functionalities. They might run their apps (uApps) like xApps on the near-RT RIC. Allowing these controllers to exchange enrichment information with near-RT RIC is essential for better control decisions, joint optimizations, etc. Currently, User Equipment (UE)s have two control interfaces- Non Access Stratum (NAS) for the core network and Radio Resource control (RRC) for the RAN. NAS is used for procedures like registration, authentication, session management, etc., while the RRC interface is used for bearer management, cell selection, power control, etc. Neither of these interfaces allows UE to communicate to near-RT RIC. Therefore, we propose a new interface named U1.

U1 provides a channel for sharing enrichment information between the UE and near-RT RIC (Fig. 3). This could also be used to share AI models between Near-RT RIC and UE [13]. U1 messages are tunneled from UE to the O-CU and, from there, sent through another tunnel to Near-RT RIC (using the same logical connection as E2). The UE is responsible for discovery and tunnel setup to the near-RT RIC. Once the connection is setup, the enrichment information can be exchanged as service models.

U1 can provide enrichment information in both directions—from UE to near-RT RIC and near-RT RIC to UE. For example, it could be used to share the robot's planned route in a factory with the near-RT RIC, creating a beam steering strategy to have reliable connectivity along the entire route (UE to near-RT RIC sharing). The xApp could also send predicted radio link degradations to the factory robot (near-RT RIC to UE). Based on this, the robots could take actions like appropriate tuning of congestion control algorithms to mitigate the effects of link degradation.

C. Further technology evolution

Further technology evolution will be driven by ever-evolving softwarization and virtualization of upcoming 6G smart factory networks. Take an example of In-band Network Telemetry approaches, such as In situ Operations, Administration, and Maintenance (IOAM) or In-band Network Telemetry (INT), that can be included in the O-RAN specification to monitor and verify the correct operation of the network [14]. For instance, INT enables realizing AI/ML-based self-driving mobile networks by collecting fine-grained and real-time telemetry data for use cases beyond 5G.

Although packet-sampling-based techniques such as sFlow, Netflow, and IPFIX have been proposed in recent decades, they have struggled to keep up with the need for real-time, accurate, and fine-grained measurements. While various methods have been proposed for in-band network measurement, adopting P4-based in-band network telemetry architecture has gained significant momentum due to the advent of programmable data planes. In-band telemetry is a promising concept for Open RAN architecture to adapt 6G smart factories, providing end-to-end QoS measurements and visibility in the network.

X-haul evolution will also mark the smart factory network architectures. For instance, the fronthaul control and user plane interfaces between O-RU and O-DU are expected to require Ethernet encapsulation as a prerequisite, with IP encapsulation as optional. At the same time, the payload is defined by one or multiple eCPRI transport headers with the corresponding application data [15]. With Software Defined Networking (SDN) becoming an integral part of the control and management planes, APIs and protocols such as RESTful APIs or

OpenFlow might be needed and adapted to facilitate communication between SDN controllers and Open RAN components. Moreover, the ongoing efforts towards open-source, vendor-neutral SDN platforms for network management, as well as the continuous standardization of new PON generations, the optical components that will dominate the future smart factory X-haul will slowly become inter-vendor compatible, such that the factory operators will be able to mix and match different optical NEs from different vendors, choosing the most optimal solution for their requirements and use-cases' needs.

V. CASE STUDY: MULTI-LEVEL CONTROL

A case study of multi-level control in smart factories exemplifies several of the proposed technology features and standard extensions to the O-RAN. We discuss the communication among AGVs and Autonomous Mobile Robots (AMRs) operating in a time-critical smart factory environment.

Figure 5 presents the main components of the robots' control process. Three control loops define iterations at different levels of the RAN, including data gathering from the network, decision-making, and signaling back to the controlled devices. Decision-making is made on the RICs, and control data is sent and received to/from the E2 and E2* nodes, i.e., O-CU, O-DU, and RIS.

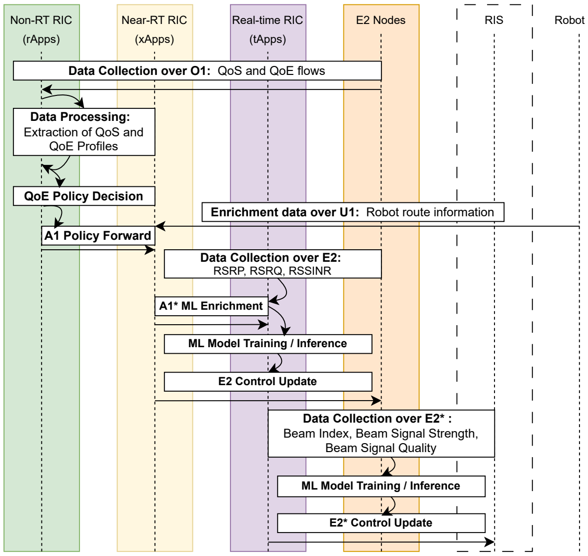

Fig. 5. Information flow of multi-level control loops.

Starting from the first control loop, from the bottom up, as shown in Fig. 5, UE-specific telemetry will be obtained through DL/RL-Assisted Beam Mobility Management tApps running on RT RIC. Real-time tApps will consider Beam Index, Beam Signal Strength, Beam Signal Quality (Signal-to-Noise Ratio and Signal-to-Interference-plus-Noise Ratio), and Beam direction metrics in Beamforming. Telemetry data such as speed, acceleration, handover data, and connection history could be used to predict the path of the AGV. However, path prediction may not yield 100% accuracy and might also use significant computing resources. To address this, the planned path of AGV could be retrieved over the U1 interface, guaranteeing path accuracy and using fewer compute resources. U1 could be realized using protocol buffers and gRPC protocol. The E2* interface will benefit the O-RAN architecture at the physical layer, by using OpenAPI standards and gRPC or MQTT protocols to support low-latency communication. Through tApps running on real-time RIC, incoming AGV or AMR localization data will be used in RIS configuration. To achieve this, a modular, microservices-based architecture for Real-Time RIC is required to enable flexible scaling and independent deployment of control functions. Industry standards like IEEE 802.11ay (for mmWave) or custom protocols based on open-source frameworks like OpenAirInterface can be used for RIS command protocols.

In the second control loop, signal data can be fed to the near-RT RIC via the A1* interface, and the second loop can be triggered there. Extended applications such as anomaly detection or traffic steering xApps are designed for different purposes and work on near-RT RIC to detect UEs containing anomalies and take action. However, in the current O-RAN architecture, low-latency data communication cannot be provided for these applications to operate with high reliability and precision. UE-telemetry coming through our proposed A1* interface will allow xApps to work much more efficiently. Signal power information and Physical Resource Block (PRB) data from the UE must be transmitted to anomaly detection or traffic steering xApps with high precision. Collecting this data through RT RIC will fulfill this requirement and increase the learning ability of the AI/ML models running in the second control loop during the offline training phase.

The third and last control loop is Quality of Experience (QoE) rApps running on non-RT RIC via R1 open APIs. Designing QoE rApps for 6G smart factory networks on top of the RIC requires a thorough understanding of the lower control loops, network architecture, the specific requirements of the use case, and the expected user experience. Thus, overall network optimization is achieved through three multi-level control loops.

Proposed A1*, E2*, and U1 interfaces are necessary for real-time communication and robust and efficient operation of multi-level control loops. Resource allocation management based on QoS demand and RAN Slicing competency will become more optimized through tApps, xApps, and rApps, which will communicate through the mentioned interfaces. While ensuring that offline and online training and classification are sufficient through xApps developed on Near-RT RIC, UE-Centric operations are handled with RT-RIC and tApps.

VI. SUMMARY AND FINAL REMARKS

This paper focused on the challenges of implementing next-generation mobile networks in smart factory scenarios. To this end, it proposed extensions to the current O-RAN standards. Especially the notion and standardization of a Real-Time RIC module were proposed, as the related interfaces, including the support for various novel technology solutions, such as RISs. In addition, we proposed a novel interface between the Near-Real Time RIC and the UE and discussed ways to enable tighter coordination of the Open RAN control and the underlying optical transport X-haul control plane. We showed that the roadmap to proposing, standardizing, and implementing an architecture supporting the future smart factory mobile networks is still an open challenge but full of opportunities for technology innovation in both sectors.

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