Intent-based Management for Industrial Automation

Ahmet Cihat Baktir
Ericsson Research
Istanbul, Turkey
ahmet.cihat.baktir@ericsson.com

Elham Dehghan Biyar
Ericsson Research
Istanbul, Turkey
elham.dehghan.biyar@ericsson.com

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***Abstract*—An intent is the formal specification of all expectations including requirements, goals, and constraints given to a technical system. Intent-based management is considered as one of the key enablers of autonomous network management and service assurance mechanisms. However, the use of intents in industrial networks to achieve end-to-end automation has not been addressed yet. The intent handling operations in an industrial setting require particular vocabulary and semantics to provide specialized support for industrial requirements. Therefore, this paper proposes to extend the *intent common model* introduced by the TM Forum and defines an intent extension model to simplify the management of the industrial networks supporting enterprises. Besides, the vision towards achieving an integrated intent-based automation for industries is introduced.**

***Index Terms*—Intent-based automation, industrial networks, service assurance**

I. Introduction

Digitalization of the enterprises to provide added value to end customers requires greater levels of flexibility and efficiency. The factories of the future enabled by innovative technologies demand always-on and pervasive connectivity between the machines. Providing enhanced support for machine-type communication and mission critical services, the 5G network is a key enabler across verticals for autonomous operations. Private 5G networks deployed at the factory floor can enable a wide range of use cases and capabilities by providing faster data rate and lower latency. However, as the industrial use cases become more demanding with more stringent requirements, such as collaborative robots, the network should adapt and adjust itself to meet various expectations (e.g., latency, availability). In the direction of achieving industrial automation, the network should meet the availability, reliability, resilience, latency and data rate requirements of different processes. Even though the evolution in cellular technologies can provide improved performance, there is a need for higher degrees of automation and enhanced scalability.

The end-to-end automation of the smart factories will be built on top of the autonomous networks. The evolution of cellular network management will shift the focus from providing high performance connectivity services to the building blocks that empower rapid adaptation under dynamic conditions in heterogeneous settings. One promising solution for increasing automation degree is intent-based management, which is a declarative and abstract way of automating the network management processes. The TM Forum introduces intents as goals, targets and expectations to be achieved by the system [1].

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Intent-based automation is a key topic covered by the 3GPP SA5 working group, which focuses on developing standards for intent driven management services and information model [2]. Other than telecommunication domain, the intent common model allows to express the requirements in various industry sectors. Autonomous manufacturing is one example that can benefit from intent-based operations. Integrating intent-driven processes into production enables the automation of diverse industrial scenarios, where intent acts as a knowledge object to disseminate the requirements and provides cross-domain control mechanisms [1]. Bensalem et al. [3] presents an Intent-Based Networking (IBN) approach that aims to automate management and control of information and communications technology (ICT) supply chain networks via high-level intents. It proposes a general design for an intent-based translation system by utilizing artificial intelligence (AI) technologies to ensure the accurate translation of user requirements, network security, and scalability. Ustok et al. [4] demonstrate a solution that expands the intent-based automation of 5G networks into the Industry 4.0 (I4.0) domain. The proposed approach ensures interoperability across the operational domain to enhance efficiency and flexibility. To address the problem of mapping requirements across domains, one of the potential solutions introduces a Service Quality Assurance framework [5]. This solution is based on POMDP formulation to efficiently map industrial requirements to 5G network KPIs.

To achieve an integrated automation solution that spans domains both horizontally and vertically, further effort is required to enable not only a holistic view but also interoperability. For private network deployments, the main business value resides in simplified interaction with the 5G system. The factory operators would like to use the network as a black box, providing automated functionalities and services to meet the business and OT level requirements. Considering the overall evolution, cellular networks become a complex system providing more than just connectivity services for the industrial assets and processes. Furthermore, requirements to achieve interoperability and simplified interaction with the network, and long-term vision towards factories of the future lead to a promising approach to extend the intent-based automation principles to the industries. The enterprises, without dealing with the complexities of low-level network management functions, can give their requirements and expectations to the network. The intent interface between the owner and handler can be extended to handle industrial expectations as well.

In this paper, we explore the key requirements of novel industrial use cases and define an intent extension model. By extending the intent common model proposed by the TM Forum, the scope of intent-driven network management can be widened to address industrial requirements. The proposed idea is further assisted with a use case description. The end-to-end operations of the intent handling function in an industrial setting require particular vocabulary and hierarchy of requirements. Even though there exist studies in the literature that conceptually address the use of intent-based operations in industries, its semantics and required vocabulary have not been defined. In this direction, the main contribution of this study is creating an extension model for the industrial use cases to implement end-to-end autonomous operations through the intent transition across industrial domain and network.

The rest of the paper organizes as follows. Section II introduces the concept of intent common models and extensions. Section III presents the intent extension model proposed by this study and introduces a use case. Section IV concludes the paper with potential future work.

II. Intent-based Automation for Industries

Extending the intent-based automation principles to the industries is a promising approach to realize the vision of fully automated factories. It requires clear understanding about how intent common models and extensions are structured. Furthermore, there are industry specialized KPIs and characteristics that can be added to intent management functions (IMFs) [1] scope to support industrial use cases. The IMFs are responsible for the lifecycle of the intent, communication with other IMFs over the intent interfaces and coordination for autonomous operations in various domains. Hence, defining industry requirements via intents and extending IMFs capability profile are important for coherent automation processes.

A. Intent Common Models and Extensions

The intent common model establishes the fundamental set of vocabulary and semantics that are domain independent [6]. It presents the basic artifacts such as classes and properties. Regardless of their application domain or operational scope, these generic artifacts are universally applicable to all the IMFs. Therefore, the intent common model is a compulsory component for each intent model federation. However, this model does not identify artifacts that are domain specific, and it does not provide vocabularies for optional functionalities. To match to the responsibility scope of the intent manager with domain specific additions, the combination of the intent common model with intent extension model is required. The intent extension models provide validity management of intents, request for proposals and feedback, and intent probing. To achieve these, intent extension models append optional additional vocabulary, an explanation of the meaning and how it is interpreted. The intent extension models increase the modular landscape on intent common models and enable model expansion supported by distinguished intent manager. IMFs based on the demands can provide required supports for intent extension models and notify this support via intent manager capability profile [7]. Moreover, by default, IMF is not obligated to implement the intent extension model. However, since these models contain domain specific expressions, they can be considered as compulsory for the IMFs that are implemented for that specific domain. The typical tasks to create the intent extension models are as follows: (1) Creating new subclasses of expectations, (2) collecting and adding new parameters with their properties, and (3) introducing new context, information, and metric classes.

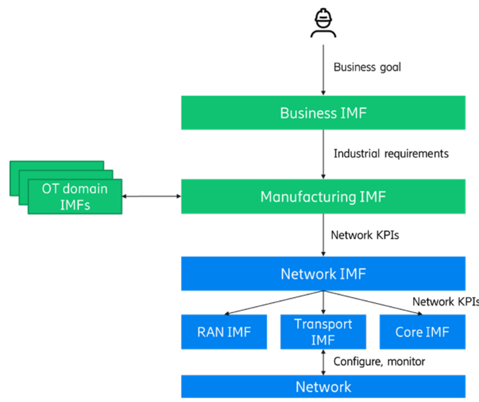

Fig. 1. Intent management hierarchy for industries.

B. Intent Translation Between Industrial Domain and Network

The integration of an end-to-end automation framework requires separate, but not independent, subsystems to interact. Similar to decomposing an end-to-end service intent to resource level expectations (e.g., RAN, core), an intent conveying industrial requirements should be translated to network KPIs. The envisioned architecture is depicted in Figure 1. Requirements of end-to-end automation and interoperable executions are two folds: (1) eliminating data model conversion, and (2) common understanding at semantic level. The concept of intent extension models satisfies the requirement of having a common data model for intent managers implemented for a particular domain. Processing intents in common RDF data model, on which the intent common model is based, at any layer is a significant step towards interoperable interaction throughout the IMF hierarchy. By achieving this, the proposed solution decreases the workload on IMFs due to language conversions. Still, IMFs in different domains need to have a common understanding about the KPIs, expectations and goals. To integrate private 5G network into enterprises, the entities responsible of the intent lifecycle management also require semantic interoperability. Therefore, mapping industrial requirements to network KPIs requires a solution providing smooth integration of intent hierarchy across domains.

A promising solution needs to provide interoperability in the industrial domain. The IMF in the industrial domain can be implemented by using the principles of Asset Administration Shell (AAS), which is a widely accepted solution for interoperability between I4.0 components. AAS can be positioned as a bridge between industrial domain and network [8]. In addition to storing the related knowledge about intent lifecycle, AAS can accommodate any decision-making capability to provide intelligent mapping. The standardized AAS structure commonly uses JSON serialization format, while standardized intent model is implemented in RDF. AAS can take the role of conversion between data models with different modelling languages (e.g., JSON and RDF) in order to meet the interoperability requirements. In practice, implementing such service in AAS requires domain knowledge on efficient mapping between data models.

C. *Common Non-functional Requirements in Industry 4.0*

The exact scope of intent handling capabilities to automate industrial processes integrated with wireless connectivity relies on a set of both functional and non-functional requirements. To have a clear description of a non-functional requirement to be achieved for a smart manufacturing use case, such as collaborating robots, we need to first find out the precise and proper cluster of performance indicators (i.e., KPIs).

The first step of extending the scope of intent-based automation to process industry for achieving end-to-end automation is to compile a set of common KPIs. One of the most comprehensive studies is made by ISO/IEC. For example, ISO 22400 introduces the commonly used KPIs for industrial production and manufacturing operations management along with their formulations [9]. An exemplary set of KPIs includes mean time to failure, setup rate, availability, overall equipment efficiency index, inventory turns and finished goods ratio. Another solid study in this domain is executed by 5G-ACIA [10], which defines a list of industrial automation requirements related to availability, cycle time, number of devices, and service area. 5G-ACIA also defines operational and functional requirements related to safety, integrity, security, and cost efficiency. The EU-funded project TARGET-X [11] describes KPIs of forward-looking manufacturing use cases such as cycle time, throughput, overall equipment efficiency, error rate, quality rate, environmental impacts, energy consumption and accident rate. A similar analysis is made by 5G-SMART, which provides I4.0 KPIs such as first pass yield, quality ratio and rework ratio [12]. These metrics or KPIs are important to achieve maximized benefit of the use cases and processes.

III. Intent Extension Model for Industries

The proposed intent extension models present how an extension of the intent common model can be built for an industrial specific domain as specializations. Therefore, they can be easily integrated into the intent model federation. RDF representation of the intent extension model defines expectations, various classes, properties, and relationships specific to an industrial use case. It includes subclasses of expectation, parameters with properties and metrics classes. These elements provide a structured framework for expressing and managing intents related to industrial processes, equipment maintenance, and performance optimization. The intent manager scope is an important entry in the intent manager capability profile that summarizes and demonstrates responsibilities and range of operations. The well-defined scopes and capabilities as well as optional additions should be clarified through collaboration of multiple Standards Defining Organizations and working groups specialized in respective technologies and use cases. In this respect, since optional additions can provide ability to fulfil domain specific requirements, strict governance of intent management scopes is not required. Moreover, intent management scope definition is closely connected to the explanation of domain specific intent extension models.

A. *Details of Intent Extension Model*

To demonstrate how we can formulate industrial extension models for various use cases, we can go through a particular one. In this direction, we can make use of the common set of KPIs introduced in Section II. Device location tracking and analysis of the duration between downtime leads to optimizing the predictive maintenance in I4.0 scenarios. Proactive maintenance scheduling can take place by accurate tracking the real-time location of devices, controlling the duration of the downtime and minimizing power consumption for devices.

One example for intent can be “For 80% of the devices the max duration of the downtime should be 20s, these devices should only operate within a specific region with minimum power consumption.” The RDF snippet below gives an overview of the described industrial intent with multiple expectations. This intent contains numerical requirements and target values based on identified metrics and KPIs. The example first identifies a set of prefixes for models utilized in the intent expression. Each model resides on its own particular namespace referred to by the prefix. This intent introduces dedicated namespaces referring to the used KPIs and specifications of conditions, targeted regions, user groups in the industrial domain. This allows referring to entries in the catalog directly through IRI/URI (e.g., referenced through the prefix kpi:, ind:). The parameters kpi:powerConsumption, kpi:downtime, kpi:deviceLocation, kpi:accidentRate, kpi:effiencyIndex, kpi:deviceAvailability as defined below are production line parameters, and they are assigned to their respective expectations using the icm:hasParameter property. These parameters establish the requirements that the industrial use case shall be compliant to the referenced descriptions and can be added to the list of vocabularies in the KPI catalog.

```
@prefix icm: <http://tio.models.tmforum.org/tio/v2.0.0/IntentCommonModel/> .
@prefix kpi: <http://www.sdo3.org/KPI/Version2/> .
@prefix ind: <http://www.sdo3.org/industry/Version2/> .
@prefix : <http://www.operator.org/IntentNamespace/intent20220322_12345/> .
------------------- Parameters --------------------
:ProductionLine
  a rdfs:Class ;
  rdfs:subClassOf :IndustrialFunction ;
  rdfs:label " ProductionLine class" .
# Defined properties kpi:powerConsumption ,
#                    kpi:downtime ,
#                    kpi:deviceLocation ,
#                    kpi:accidentRate ,
#                    kpi:effiencyIndex ,
#                    kpi:deviceAvailability .
kpi:powerConsumption
  a rdf:Property ;
  rdfs:label "Power " ;
```

```
  rdfs:comment "power consumption value of the production line".
kpi:downtime
  a rdf:Property ;
  rdfs:label "Down Time " ;
  icm:unitOfMeasurement :second ;
  rdfs:comment "The duration of the downtime" .
kpi:deviceLocation
  a rdf:Property ;
  rdfs:label "Location" ;
  rdfs:comment "current device location" .
kpi:effiencyIndex
  a rdf:Property ;
  rdfs:label "Efficiency Index " ;
  rdfs:comment " Overall equipment efficiency index " .
kpi:deviceAvailability
  a rdf:Property ;
  rdfs:label "Availability" ;
  icm:unitOfMeasurement :Percent ;
  rdfs:comment "Current device availability" .
```

Afterward, the expectations are identified for device availability, downtime duration of the device, device location and power consumption. This shows how metrics from different sources and models can be used in any required permutation. In the :industrial-intent, the :ProductionTarget1 requires 3 different conditions. :condition-1 represents duration of the downtime for the associated production target, according to the set operations in [13], :condition-2 introduce the targets for RegionA that contains two device groups.

```
ind:RegionA
  a rdfs:Container ;
  rdfs:member ind:Devicegroup1 ;
  rdfs:member ind:Devicegroup2 .
```

In this condition, devices belonging to ind:Devicegroup1 should operate within the region in ind:RegionA. Finally, :condition-3 expresses the power consumption requirement.

```
@prefix icm: <http://tio.models.tmforum.org/tio/v2.0.0/IntentCommonModel/> .
@prefix kpi: <http://www.sdo3.org/KPI/Version2/> .
@prefix ind: <http://www.sdo3.org/industry/Version2/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix log: <http://tio.models.tmforum.org/tio/v3.2.0/LogicalOperators/> .
@prefix : <http://www.operator.org/IntentNamespace/intent20220322_12345/> .
# --- Intent --------------------
:IndustrialIntentExample
a icm:Intent ;
rdfs:comment " 80\% of the devices shall have downtime < 20s,
shall be in Region A, and shall operate with minimum power consumption.
log:allOf ( :industrial-intent )
.
# --- Targets --------------------
:ProductionTarget1 a icm:Target ;
rdfs:member :Devicegroup1 , :Devicegroup2 ,
:Devicegroup3 , :Devicegroup4 .
# --- Expectations --------------------
:industrial-intent
a  :ProductionExpectation ;
icm:target :ProductionTarget1 ;
:percent 0.8 ;
log:allOf ( :condition-1 :condition-2 :condition-3 ) .
:condition-1
a icm:Condition ;
log:allOf ( : quan:smaller ( [ met:lastValue
( kpi:downtime ) "20s"^^quan:quantity ] ) .
:condition-2
a icm:Condition ;
set:elementOf ( ind:Devicegroup1 ind:RegionA ) .
:condition-3
a icm:Condition ;
quan:smaller ( [ met:lastValue ( kpi:powerConsumption ) 0 ] ) .
```

In addition to the described use case, we can add specialized industrial expectations to intent extension models. One example is :ProductionExpectation that is depicted below. According to the requirements, production expectations can be extended, two examples are :DeviationExpectation and :EfficiencyExpectation. For the first expectation, if the statistical or deviation expectation is violated (e.g., the error rate of the devices exceeds a certain threshold) then production control line would start collecting more detailed data or taking other actions to resolve the issue. For the :EfficiencyExpectation, production line can specify constraints and indexes in the catalog to reach out a certain level of the production efficiency that refers to the ability of the manufacturing processes to produce maximum level of outputs leveraging such as optimal resources and minimizing production time.

```
:ProductionExpectation
 a rdfs:Class ;
 rdfs:subClassOf icm:Expectation ;
 rdfs:comment "Abstract class of expectation that have instance target".
:DeviationExpectation
 a rdfs:Class ;
 rdfs:subClassOf :ProductionExpectation ;
 rdfs:comment "Expectation to allow deviation from standard procedures".
:EfficiencyExpectation
 a rdfs:Class ;
 rdfs:subClassOf :ProductionExpectation;
 rdfs:comment "Expectation to provide a certain level of
 production efficiency".
```

IV. Conclusion

In this paper, we proposed an intent extension model to expand the scope of intent-based management for industries and enable a holistic automation view for digitalized enterprises. The main outcome of this study is that the use of intent extension model for industries, which is an ongoing work for the time being, enables the end-to-end automation by leveraging the common understanding across domains. The future work may define further vocabulary for the proposed extension model to widen the spectrum of supported use cases and corresponding requirements. Besides, further work on intent translation could help enhancing the performance of the envisioned automation framework for industries.

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