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Supporting resilience with industrial 5G systems and Industrie 4.0

Gustavo Cainelli, Lutz Rauchhaupt, Lisa Underberg
Institut für Automation und Kommunikation e.V. Magdeburg
IKT

Werner-Heisenberg-Str. 1
39106 Magdeburg
gustavo.cainelli@ifak.eu
lutz.rauchhaupt@ifak.eu
lisa.underberg@ifak.eu

Abstract: In industry 4.0, production systems must be able to adapt to produce products with customer requirements. However, not only this kind of flexibility is needed. The system must also be able to adapt itself to keep working if unforeseen events occur. A system capable of this is called a resilient system. Resilience is the ability not to fail completely if a subsystem fails. This paper aims to introduce the concept of resilience in industrial 5G systems to avoid production downtime. Our approach is based on methods of the Industrie 4.0 concept in order to be able to create digital twins for 5G-networked automation systems. The digital twin, based on the Asset Administration Shell, will allow collaboration between automation and communication systems, adapting the behaviour of the process in case of unforeseen events. For this, the communication system must be considered during the development of the digital twin.

1 Introduction

Mass production, where the quantity of products that will be produced is known, does not require the automation system to have a high level of flexibility. However, one of the aspects of Industry 4.0 (I4.0) is the ability to adapt production to customer needs, without planning all the details of the production system in advance. Furthermore, in I4.0, the production system must be resilient, that is, it must adapt the process behaviour to avoids downtime in production in case of unforeseen events.

An alternative to dealing with the level of adaptability that I4.0 applications require and to make the system resilient are Cyber-Physical Systems (CPS). CPS are systems that integrate physics and computation components in a two way flow of information between them. For each physical device, a Digital Twin (DT) is developed. The DT is a digital representation of the real device. The Digital Twin and the physical part can exchange data for real-time awareness, control and decision making [SSPE16].

As the (wireless) communication system (WCS) is a subsystem of the automation system, it also must be considered during the development of the digital twin. Moreover, the communication system can't be planned and installed for the worst case. If changes are necessary, the WCS and/or its use of the medium should be adapted accordingly. This can only be done when data exchange is possible between the production system and the WCS. For this reason, the WCS must be also considered when modeling the Digital Twin.

The 5G-ACIA [5G-21] and Platform Industrie 4.0 (PI4.0) [Pla20b] have already started the discussion of the Digital Twin of the WCS considering 5G technology. The 5G technology is one of the most prominent communication system that aims to meet the industrial automation requirements. To allow the 5G system negotiate with the automation system, the properties of 5G devices and

5G network should also be considered in the digital model. The goal is bringing the information of the WCS to the digital domain to allow negotiation with the automation system.
This paper aims to introduce the concept of resilience in industrial 5G systems to avoid production downtime. The idea of the proposed paper has its origins in the following considerations:

- The current rigid planning and design of production facilities and their automation will give way to more flexible concepts such as Industrie 4.0 (I4.0) in order to better meet individual customer requirements and use production capacities more efficiently.
- The orientation of mobile networking towards data communication in application areas, starting with the 5th generation, gives further momentum to the desired networking in industrial applications.
- Industrie 4.0 and 5G use the virtualization of properties and functions of system elements to achieve the desired objectives.
- The collaborative use of digitization in industry and mobile networking offers new opportunities for resource-efficient industrial production.

In this context, the proposed paper addresses a way of collaboration between automation and communication. The presented approach is based on methods of the Industrie 4.0 concept in order to be able to create digital twins for 5G-networked automation systems. The digital twin will allow collaboration between automation and communication systems, adapting the behaviour of the process in case of unforeseen events. For our approach, this means that a "communication" sub-model must be available for relevant automation components.
The remainder of this article is organized as follows. Section 2 explain the principle of resilience in the 5G context. Section 3 shows the digital twin approach and the communication submodule. Finally Section 4 gives the summary and the outlook.

2 Resilience in 5G networks for industry

A resilient system should not totally fail if a subsystem fails, or operates abnormally. This means that the system must auto adjust its parameters to keep working. In this way the essential characteristics of a resilient system are [5G-17]:

- Adaptability: It enables dynamic reactions in the event of disturbances and guarantees that minimum functional requirements are met, e.g. by reducing data traffic.
- Regenerability: It should be able to seamlessly return to a stable normal state after the disturbance has ended. It can also transfer functions to other parts of the system if irreversible damage occurs, e.g. by using a base station with a lower but still acceptable quality of service.
- Maturation: It improves its functionality by using experience gained during events, e.g. by having mobile equipment avoid the zones prone to faults due to disturbances.

The principle of resilience is explained with the help of the following figures. The state of the 5G system is expressed by the up state function according to [WKR17]. In Figure 1, the up state function is represented by the light blue graph. If the 5G communication is disturbed, for example by the transport of a large metallic item with a crane through the factory hall, it is possible that not all requirements of the application for the 5G communication are fulfilled anymore. It is expressed by the fact that the up state function falls below the threshold value for the up state. The states of the 5G system represented by the dark blue lines changes from up state to down state. After the disturbance is gone, the communication can continue unaffected and the 5G communication changes to the up state when the corresponding recovery threshold has been exceeded.

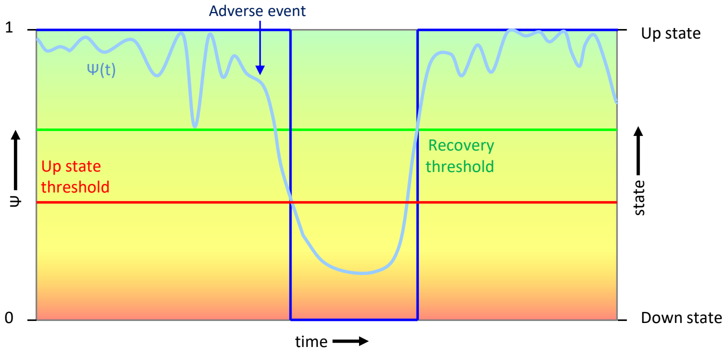


Figure 1: Up state function of a common communication system.

The up state function is determined according to [WKR17] on the one hand from measured variables that are used to specify the performance requirements of the application and on the other hand from measured variables that express the quality and use of the radio medium. In this way, it can be ensured that the application requirements are taken into account. On the other hand, the characterization of the radio medium also allows conclusions to be drawn about expected disturbances. The threshold values result from the requirement values, such as the data traffic to be handled in a certain period of time, and the values describing the conditions for 5G communication, such as the extent of the application.

In Figure 2, application requirements are reduced when an adverse event is detected. This is expressed in the lowering of the threshold for the up state. Practical examples include the termination of connections that are dispensable at that moment or the reduction of the performance of the production process. As illustrated in 2, this can prevent the application from failing due to a communication fault. When the up state function is back in the typical value range, the requirements can also be raised to the typical level again. This behaviour is called elastic response because the system reacts flexibly to adverse events.

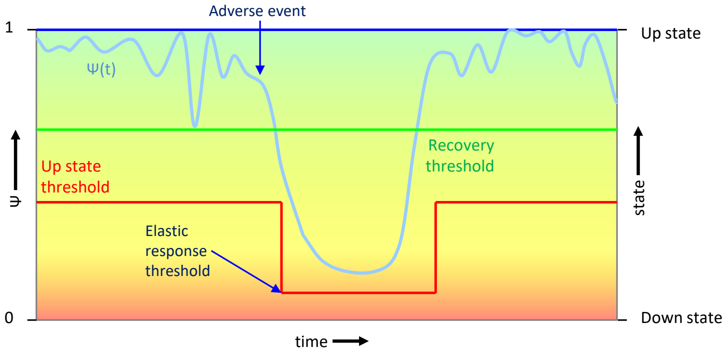


Figure 2: Elastic response of a resilient communication system.

In contrast to an elastic response of a system, a resilient system does not only react to disturbances in a fixed way, but has the ability to adapt through self-regulation. This can significantly increase the dependability of communication networks.

The behaviour of a resilient 5G system is shown in Figure 3. The adaptability is expressed by changing the threshold for the up state. The degree of adaptation depends on the identified event. Regenerability is expressed by lowering the threshold value for regeneration. Normal operation can be achieved more quickly through targeted measures. Maturation is expressed by the change in threshold values and the changed up state function. On the one hand, the values of a worst case no longer have to be assumed, since the response to adverse events can be faster and more targeted. On the other hand, measures gained through experience are expressed in a changed graph of the up state function.

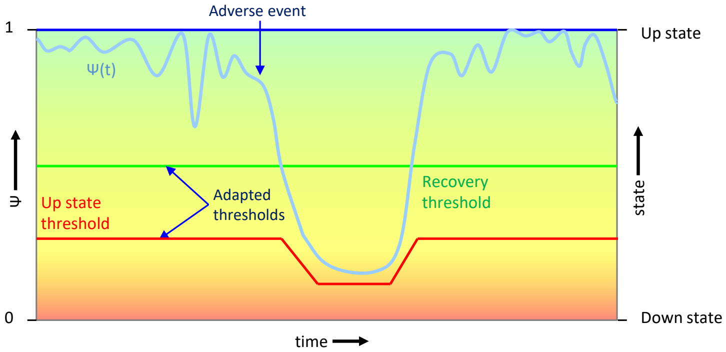


Figure 3: Adapted threshold of a resilient communication system.

3 Digital Twin Approach

3.1 Asset Administration Shell.

As stated before, the CPS can cope with the three main aspects of a resilient system: adaptability, regeneration, and maturation. One emerging category of CPS is the Asset Administration Shell (AAS). The AAS is the implementation of the Digital Twin for Industrie 4.0 from the point of view of the German initiative Platform I4.0 [Pla20b]. It represents the digital part in the Reference Architecture Model Industry 4.0 (RAMI 4.0), since the communication to business layers, [Pla18b]. The AAS contains information that represents characteristics and behaviours of an entity (asset). Assets are components that are valuable to an organisation and it includes devices, machines, documents or even software.

The AASs are key components of I4.0 as they provide all data and functions related to an asset. Through the AAS an asset become an I4.0 component. Industrie 4.0 components connect the physical and digital world robustly. An I4.0 component is formed by the asset (physical part) and the AAS (digital part) [YJL$^+$20]. Each asset is given an AAS which consists of a number of submodels in which all the information and functionalities of a given asset including its features, capabilities, status and measurement data are described [Pla20b]. The AAS should contain information related to the complete asset life cycle (type and instances). The AAS is composed by a passive part and an active part. The passive part are the asset's data which are readable and/or modifiable. The passive part is composed by submodels that describe asset's information. The AAS may incorporate general submodels (e.g. identification) and also specific submodels (e.g. communication). There is no limit to the number of submodels of an AAS, as they are defined according to the level of detail required for the model. Below the submodel level there are the submodel elements like SubmodelCollection and Properties. The submodel elements store specific data related to the submodel. For example, a property, which is a submodel element type, can contain a value that represents a physical variable of the asset. It can be of several types as INT, BOOL or STRING. An example is the transmission power of a 5G device.

On the other hand, the active part consists of procedures and algorithms performed by the asset and the AAS. The active part is composed by methods and can be used for example to read and write properties values in the AAS/asset. Moreover, the active part of an AAS has service-oriented communication capabilities and decision making functionalities [DI20].

An integration element is necessary to connected the asset and the AAS as shown in Figure 4. This component is responsible for translate the data from the assets and update the values in the AAS.

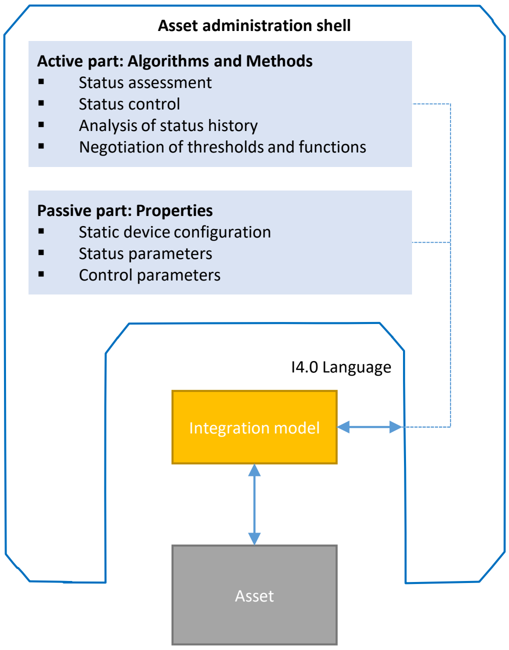


Figure 4: AAS, asset and integration model.

The information stored in the AASs are available to external users (other AASs) through external application program interfaces (APIs) using IIoT communication protocols like MQTT and OPC-UA.[5]. The AASs can communicate with each other to exchange information or to resources negotiation.

As depicted in Figure 5 the AAS of the 5G system can negotiate with the AAS of the automation system concerning the parameters of the up state function. Parameters as the up state threshold, recovery threshold and elastic response can be exchange between the AASs. Moreover, the lessons learned during a disturbance event are also shared between the AAS.

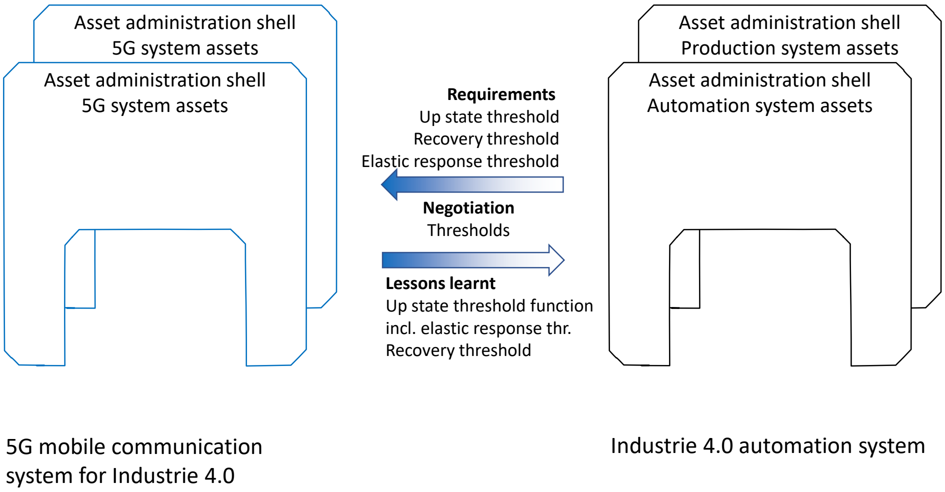


Figure 5: Negotiation between automation system and communication system (5G system).

It is necessary to develop AASs for all parties involved to allow this type of negotiation between the 5G system and the automation system. However, due to the high complexity of the 5G system and possibly the automation system, it is important to determine the necessary components in advance, otherwise, the description of all the existing components in the network may require high and possibly unnecessary efforts. Therefore, one of the first steps is to determine what are the necessary components of the systems that should be described using AAS. In this work a submodel for 5G device is shown with the submodels that a 5G enabled device can have. Moreover, one main module is described that include the wireless module information.

3.2 Model elements of the industrial 5G digital Twin.

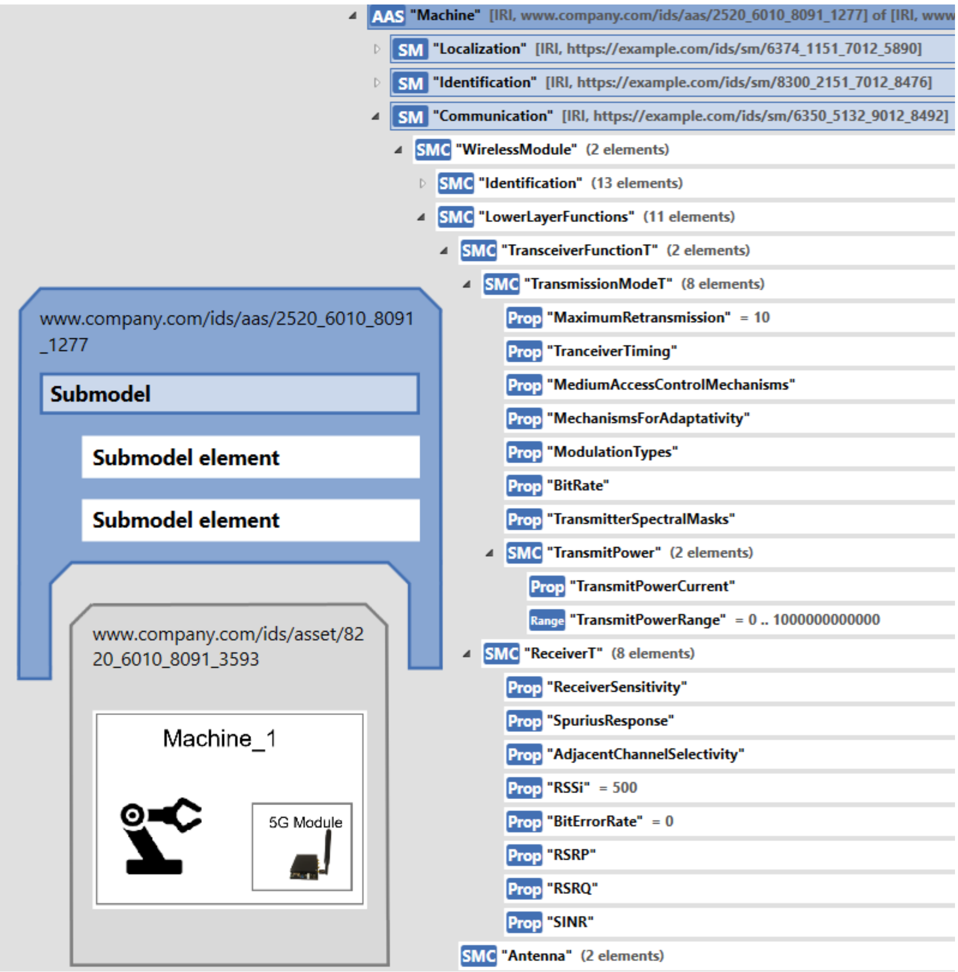
Describing the 5G system as an AAS (DT) is not simple due to the number of different components and also the complexity of each one. The Platform I4.0 proposes describe the 5G system as different AAS entities, e.g. for the 5G automation device (5G-UE AAS), for the Radio Access Network (5G-RAN AAS) and for the Core Network (5G-CN AAS). The 5G-ACIA [5G-21] proposes the use of two AAS called 5G-UE-AAS for 5G automation devices and 5G-NW-AAS for the entire 5G network (RAN and CN). The 5G-UE-AAS represents the endpoint of a 5G link on the device side while the 5G-NW AAS includes the nodes and functions of the 5G RAN and 5G CN. All 5G-UEs are represented by an individual AAS while the User Plane Function (UPF) is part of 5G-NW-AAS. Therefore, as mentioned previously, it is necessary to carefully define which components of the system will be described through the AAS that will allow introducing resilience in an industrial 5G system. Here in this section we describe what are the capabilites of the the active part and what are the submodels of the passive part. Some of the active parts of an AAS should include functions responsible for:

- Continuous monitoring of the network status.
- Regeneration capabilities to avoid or minimize downtimes.
- Adaptive capabilities to adjust the communication system to a state which even with disturbances the applications requirements are met.
- Negotiation of quality of service with the applications.
- Coexistence and interference management between different radio systems.

Figure 4 shows that the active part includes functions related with the up state function and the recovery response. These functions are related with the negotiation between the AAS. The passive part includes static device properties and status parameters. In case of a 5G system, examples of static properties could be data sheet related as supported bandwidth, bit rate and transmit power. Status parameters can be related with connectivity QoS as status of QoS monitoring (off/on) and characteristics parameters measurements (e.g. update time and number of received messages) [5G-21].

To structure the digital information of the asset into distinguishable parts, each AAS' submodels describe a specific asset's aspect. The submodels are formed by submodel elements hierarchically organized. There is a set of submodel elements types defined by the Plattform I4.0 [Pla18a]. These elements are used to represent data or functions related to the asset. A typical submodel element is a property. A property is a variable which has a value and a type as int, float, string, etc. Another kind of submodel element is a range, which has a minimum and a maximum value for the variable.

Figure 6 shows an AAS of an machine that has a 5G device. The figure is an excerpt of the AASX Package Explorer [Pla20a]. This is an open source tool that supports XML and JSON serialization of the AAS's data. Moreover, the tool also provides server generation for OPC UA and export formats for AutomationML. Three submodels are presented: Identification, Localization and Communication. Other possible submodels could be related to machine's functions (bending, drilling, moving, etc...). The focus of this work is on the communication submodel. Currently, within the communication submodel, one of the main submodels is the *WirelessModule*. It refers to the characteristics of the module itself considering datasheet parameters and current measurements. Other submodules like *QoS*, wich stores information related with the quality of service, should also be consider. Moreover, a submodel for the the SIM card, containing information as IMSI, ICCID, and PIN should also be defined.



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AAS "Machine"  [IRI, www.company.com/ids/aas/2520_6010_8091_1277] of [IRI, www
  SM "Localization"  [IRI, https://example.com/ids/sm/6374_1151_7012_5890]
  SM "Identification"  [IRI, https://example.com/ids/sm/8300_2151_7012_8476]
  SM "Communication"  [IRI, https://example.com/ids/sm/6350_5132_9012_8492]
    SMC "WirelessModule"  (2 elements)
      SMC "Identification"  (13 elements)
      SMC "LowerLayerFunctions"  (11 elements)
        SMC "TransceiverFunctionT"  (2 elements)
          SMC "TransmissionModeT"  (8 elements)
            Prop "MaximumRetransmission"  = 10
            Prop "TranceiverTiming"
            Prop "MediumAccessControlMechanisms"
            Prop "MechanismsForAdaptativity"
            Prop "ModulationTypes"
            Prop "BitRate"
            Prop "TransmitterSpectralMasks"
            SMC "TransmitPower"  (2 elements)
              Prop "TransmitPowerCurrent"
              Range "TransmitPowerRange"  = 0 .. 1000000000000
          SMC "ReceiverT"  (8 elements)
            Prop "ReceiverSensitivity"
            Prop "SpuriusResponse"
            Prop "AdjacentChannelSelectivity"
            Prop "RSSi"  = 500
            Prop "BitErrorRate"  = 0
            Prop "RSRP"
            Prop "RSRQ"
            Prop "SINR"
        SMC "Antenna"  (2 elements)
```

Figure 6: AAS description using the AASExplorer.

The information stored in this submodel can be divided in static and dynamic. Static ones are the capabilities of 5G module as delivered. This data generally can be find in the module's documentation (data sheets). Examples are frequency band and maximum transmit power. Information related with identification (e.g. manufacturer) are also static. The dynamic ones are updated during the operational process. It includes RSSI, RSRP and current output power.
Within the submodel *TransceiverFunction*, two submodels element collection are defined: *Transmiter* and *Receiver*. Under this two elements are properties as bitrate, modulation type and receiver sensitivity. A management system can use information from the AAS related to the wireless signal as RSSI and RSRP to monitor the conditions of the radio channel. The management system can take actions based on these values.

4 Summary and further steps

This work presented a digital twin approach to support resilience in industrial 5G systems. The submodule *WirelessModule* brings information of the wireless module to the digital domain. It includes static information as manufacturer name and dynamic information as RSSI. With these information, the system can be adapted in case of unforeseen events happens increasing the system resilience.
The authors are working in a simulation model using the Simu5G [NSS20] simulator. In this model, the resilience use case presented here is being implemented. This implementation will allow the authors to validate the current approach.
The approaches of the I4.0 platform and the 5G ACIA are to be validated and further developed. The development of the digital twins will follow the asset administration shell concepts. The authors plan to bring the results of the approach presented here into the 5G-ACIA with their

activities.

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