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Services interfaces for interoperability of signaling computer interlocking on borders

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ABSTRACT

Technological developments in the field of railway signaling have allowed more and more flexibility in the management of rail traffic, especially with computer interlocking. However, differences in signaling principles from one country to another as well as differences in the structure of interlocking software and communication protocols depending on suppliers lead to interoperability difficulties at the borders between computer interlocking. Some deployed projects deal with interoperability issues regarding the communication of signaling information between the train and interlocking like the European rail traffic management system (ERTMS) project. Unfortunately, the interoperability between interlocking themselves is still not achieved. Some deployed projects deal with interoperability issues regarding the communication of signaling information between the train and interlocking like the ERTMS project. Unfortunately, the interoperability between interlocking themselves is still not achieved. This article draws up a proposed model for interfacing at the interlocking boundaries based on service-oriented architecture (SOA). In addition, to ensure the coupling of SOA services to the internal functions of the signaling computer interlocking, a distributed architecture of programmable logic controller according to the IEC 61499 standard is suggested.

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1. INTRODUCTION

Rail transport is a mass transport, it participates both in economic development and in territorial and continental connectivity. To meet the safety requirement in the railway field [1], its signaling system has to rest and be faithful to its initial functional principles while accompanying the technological evolution that offers new facilities and new services. Except that, this technological evolution faces difficulties of interfacing and data exchange between systems of different suppliers or according to different local signaling principles. Then, the interfacing difficulties lead to an interoperability problem in signaling railway systems.

As Europe is the continent that offers the most interconnected railway network between countries, the European community has carried out several projects with a view to meeting this need for interoperability [2]. However, only European rail traffic management system (ERTMS) [3] has been able to reach the stage of deployment at the continental level and this system is in deployment in many countries outside Europe because it offers standard requirements that facilitate the purchase process through a large number of suppliers of subsystems are different. However, the interoperability between interlockings themselves still needed to get better use of the technological evolution of computer interlocking, especially on borders between countries.

In our project, we take inspiration from the success of the ERTMS system [4] to introduce an approach leading to solutions for interoperability between interlockings. This approach is an architecture based on the IEC 61499 standard [5] to execute internal functions of interlocking, coupled with an architecture permitting interfacing on borders for adjacent interlockings through a service-oriented architecture (SOA) [6].

In this paper, we present firstly a review of signaling systems and existing architectures of computer interlocking. After that, we dress a listing of projects for interoperability in railway signaling. In the third part, we explain our proposition of a distributed architecture for computer interlocking that can lead to a solution for interoperability on borders. Then, we expose how SOA [6] is coupled to the functional model of computer interlocking [7] to facilitate interfaces between interlockings. After that, we analyze the results of the execution of our proposed solution. Finally, we conclude and present project perspectives.

2. SIGNALING SYSTEM

2.1. Railways control system

The evolution of rail systems is part of the overall development of transport systems. Taking advantage of new technologies that allow both to improve operations and to offer new services. One of the components influencing this development is the signaling system which ensures the safety of rail traffic, in particular when it comes to an automatic command and control system [8], [9].

The automation of the rail command and control system makes it possible to command, control, and adjust railway operations in real time. Also, it ensures the safe mobility of trains through continuous communication between interlocking and field equipment and oversees the condition of field equipment, and react to maintenance need before failure through sensors and the definition of tolerance thresholds. By signaling system, we consider 3 components: supervision station, interlocking, and field equipment as shown in Figure 1.

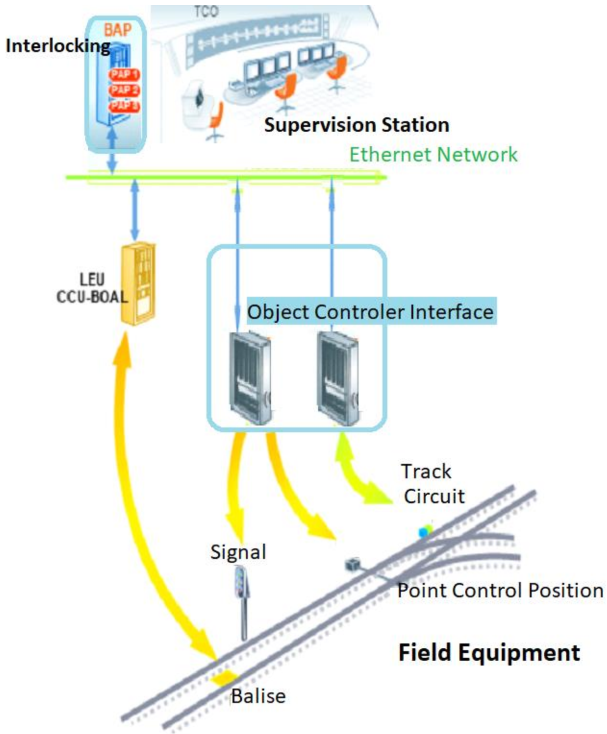

Figure 1. Railway control system architecture

The interlocking is in continuous communication with the supervision station to give information about field equipment and get commands that are established by the supervisor through the ethernet network. The same network is used for continuous communication between the Interlocking and field equipment, where the Interlocking sends orders to field equipment and gets their statutes. Since the field equipment is mainly mechanical or electrical equipment, the installation of an intermediate element is necessary to ensure communication with the computer interlocking called object controller. Then, the object controller communicates with the interlocking through the ethernet network and with field equipment through electrical interfaces (yellow linked in Figure 1).

Each part of the signaling system has an essential role in ensuring the desired safety as described in [10]–[12]. Many signaling system architectures are up, allowing the interconnection and continuous exchange between field equipment and computer interlocking through object controllers. These architectures may also affect the type of interface with the supervisory station that interacts with the interlocking for control and supervision needs.

2.2. Computer interlocking architectures

To choose the architecture of a computer interlocking, three parameters are considered. First, we define desired functional particularities. Then, we study the overall geography where the stations concerned are located. Finally, we take into consideration the budget allocated to the project [13], [14]. Most types of architecture that are implemented are decentralized or centralized architectures.

2.2.1. Decentralized architecture

The decentralized architecture allows independent control between interlocking and control stations related to each station which is the area of control of the interlocking as shown in Figure 2, and the communication with field equipment is through the object controller. So, the communication between adjacent interlocking is made with a direct link. Communication via a direct link requires a common communication protocol except that currently, this solution is not available. Then an electro-mechanic interface uses most of the time.

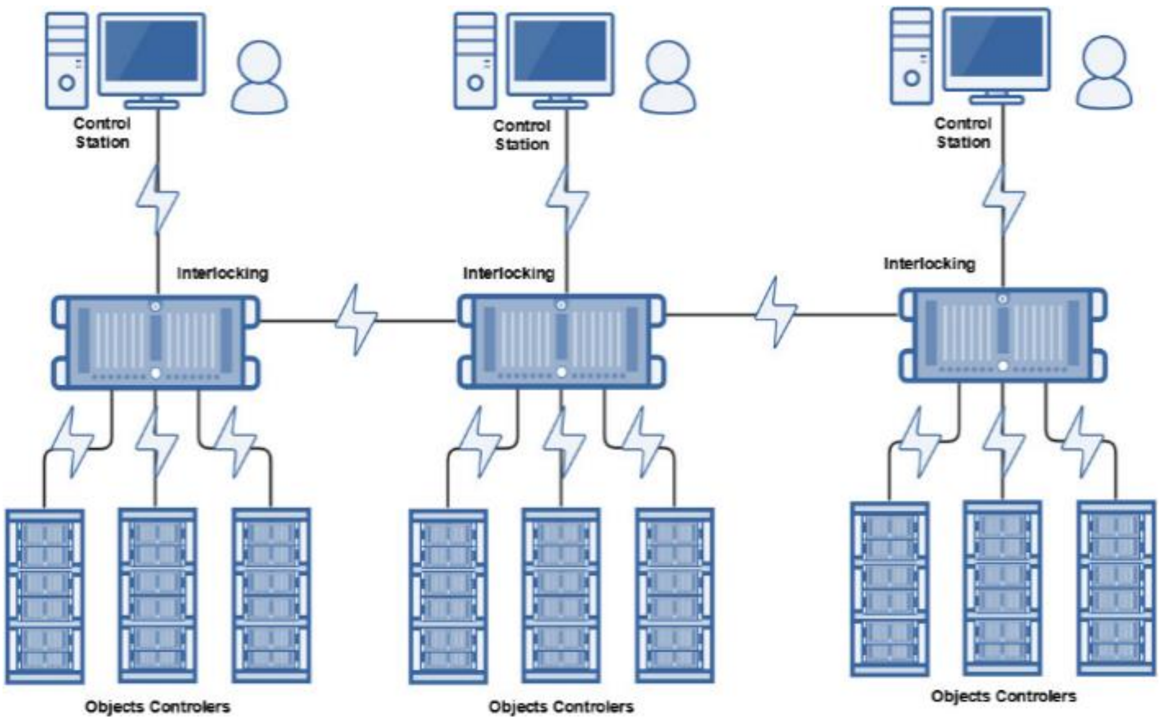

Figure 2. Decentralized architecture

2.2.2. Centralized architecture

The centralized architecture facilitates using centralized supervision as shown in Figure 3, where every interlocking sends information related to its area of control to the global supervisory station called the central command station. The centralized mode allows more functionalities and services like tracking trains' movement, a programmable list of itineraries, or automatic routing [12]. Some of those operations need interaction with the external system using the external server as an interface, but the difficulty of leading such centralized architecture is the need to get all interlocking from the same supplier because of the necessity to manage them from one central server with a common communication protocol.

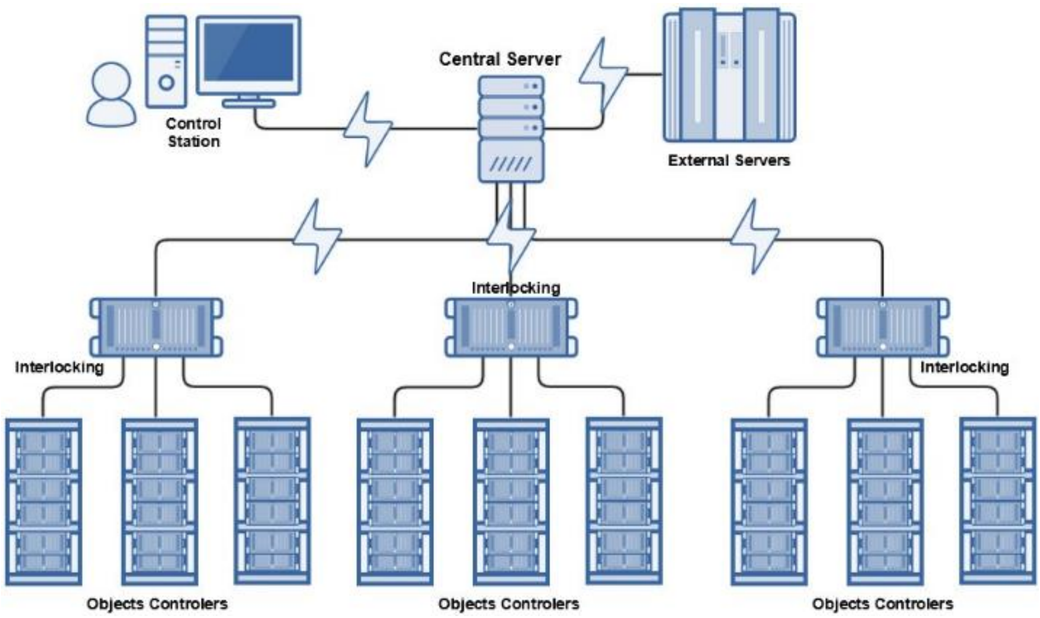

Figure 3. Centralized architecture

2.3. Interoperability issues of computer interlocking

2.3.1. European initiatives for interoperability

The importance of interoperability in the railway sector and especially at the level of signaling has aroused interest globally in the world [15], but especially on the European continent where mobility between countries is obvious. Thus, several initiatives focusing on interoperability have emerged as listed in [2] with a focus on managing interfaces in borders as mentioned in [16]. We consider as examples:

a. ERTMS: The ERTMS [4] is the standard system managing the interpretation of signaling information by the onboard system to significantly increase the safety, efficiency of rail transport, and cross-border interoperability of rail transport in Europe. It is led by the European Union Railway Agency (ERA) and consists of two parts:
   – European train control system: interpreted signaling information from trackside to on-board system to ensure the control of speed and the respect of restrictions transmitted.
   – GSM–R [17]: wireless communication supports between on-board and track-side systems.
b. EULYNX [18]: It is a European initiative by 13 infrastructure managers to standardize interfaces between interlocking and field equipment.
   – Euro-Interlocking: It is a project launched by the International Union of Railways (UIC) in a common interest supported by all members of the infrastructure forum. Euro-Interlocking [2] requirements are developed on a common platform, with the use of a standardized glossary, standardized commands and statuses, and standardized requirement structures.
c. INESS: This project [2] defines and develops specifications for a new generation of interlocking systems. The project aims to produce a common core of validated standardized functional requirements for future interlockings. It concerns harmonizing data file formats, design tools, data transfer for production, data flows linked with system architectures, and identifying an efficient way to an interpretation of the safety case process according to the relevant CENELEC standard [7].

2.3.2. Our proposition for interlocking interoperability

As mentioned in the previous section, only two projects are interested to harmonize the architecture of interlocking and data exchange (Euro-interlocking and INESS) [2] but still not effectively at a standardized level of discussion. So, dealing with the same problem of interoperability in the Moroccan railway system, we proposed a new strategy to face this issue. Firstly, we were inspired by the interoperability proposed in the industrial field in general [19]–[23] where standards like IEC 61499 [24] are used to harmonize the architecture and the exchange form between automation systems. Then, we rely on a coupling between functional blocks regarding IEC 61499 [5] requirements for interlocking's internal architecture and SOA [6] for the architecture of exchanges between adjacent interlockings. The functional model proposed for this coupling is explained in [7] with a focus on each family of functions composing the interlocking as in Figure 4.

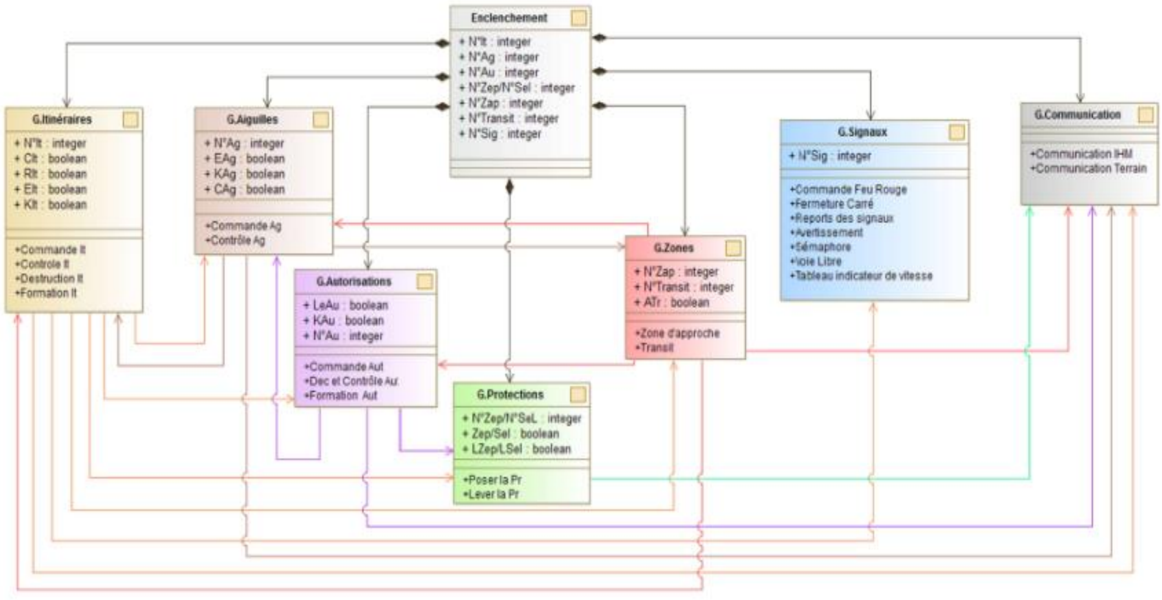

Figure 4. Functional block diagram interlocking–SysML

3. BORDERS INTERFACES USING SERVICES

3.1. Distributed architecture for computer interlocking

The complexity of the architecture of computer interlocking lies not only in the development of its functions and the software structure but also in the adaptation to the geographical context where the software is executed and where the control and supervision are extended [13]. To deal with this complexity, a distributed architecture, accompanying the functional model [7] of computer interlocking has been proposed in [12] based on the recommendations of formal modeling of signaling systems [13]. Our proposal is also concerned with a lightening of the calculation of the central interlocking level and a reduction in the flow exchanged in the local network linking the interlocking to the field equipment [12]. On the other hand, it opens on a facility of exchange with the adjacent interlockings.

Other projects have treated the distributed architecture component, as Siemens initiative distributed in cloud, but with a view to linking the interlocking to a cloud network [25]. This perspective is a departure from the strategy adopted locally in Morocco which our research project is intended to accompany to respond to the problem of interoperability. The Moroccan strategy is based on technical and physical control of the facilities and managing the safety of rail traffic.

As a result, to perform the proposition of interoperability through functional blocs, we consider a distributed architecture for signaling interlocking, as can be seen in Figure 5. In the central architecture, the central calculator is connected directly to object controllers as shown in Figure 6 that collect signals and information from field equipment and all functions are executed in the central calculator. However, our proposed architecture distributes the execution of function through a network of mini calculators linked to a central calculator as shown in Figure 5.

So, the distribution of functions allows principal functions to be executed in the central calculator, functions commanding or giving values of field equipment located in the station to be executed on an auxiliary station calculator, and only needed information for supervision or for principal functions' calculations is sent to the central calculator and functions managing field equipment located at the outside area between stations are executed on an auxiliary block calculator and only needed information is sent to the central calculator.

Therefore, by joining the logic of SIFB according to the IEC 61499 Standard [5], the information exchanged is automatically fed to the SIFB concerned with the communication with the adjacent interlocking. In addition, when the communication between adjacent interlocking is limited to the communication of the status of field equipment, the information is transmitted directly from the auxiliary computer (station or block) to the SIFB concerned and does not interfere with the operation of the central computer. Moreover, the coupling of SIBFs with services of SOA architecture makes communication easier to integrate when deploying new interlockings in the rail network.

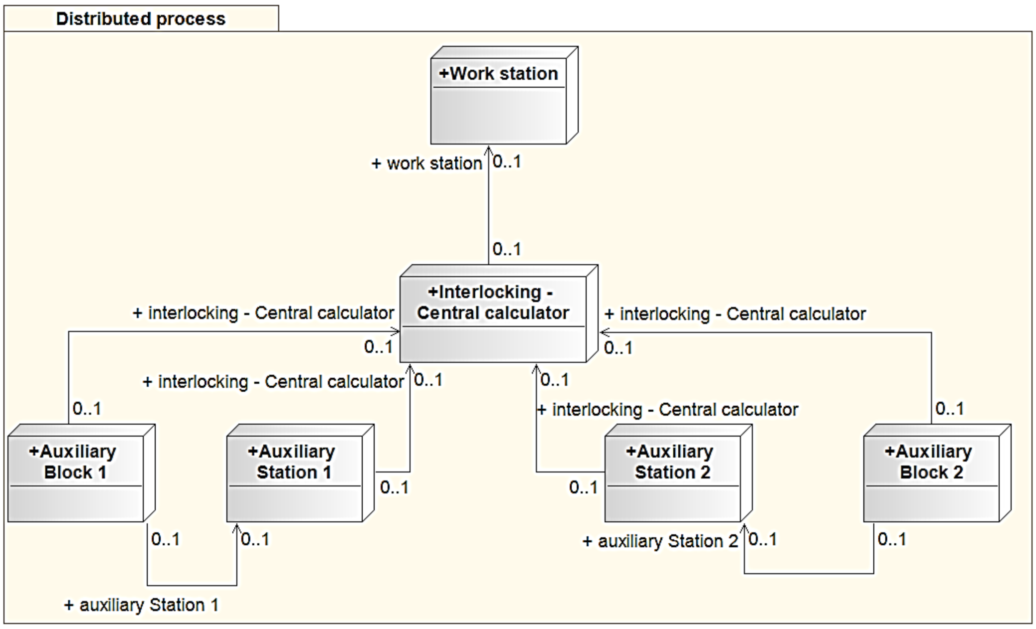

Figure 5. Distributed process deployment

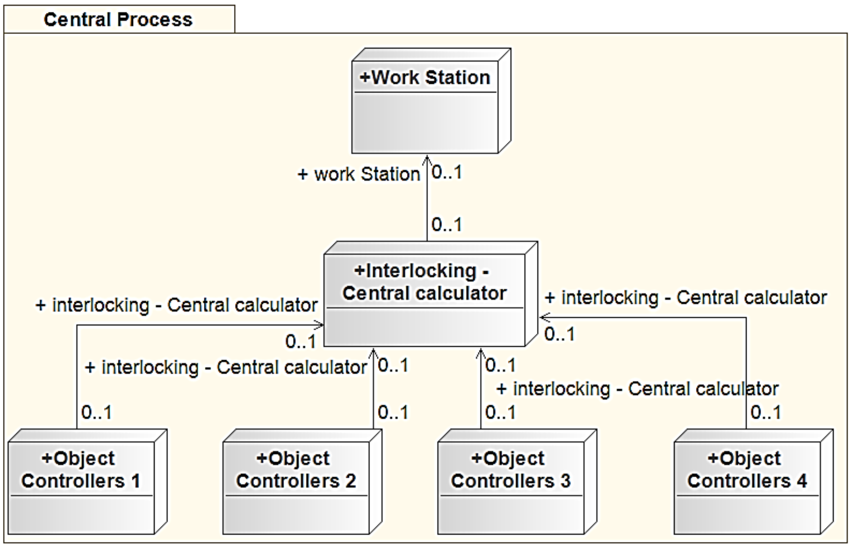

Figure 6. Central process deployment

3.2. Functional blocks interfaces

Functional modeling was the first step in providing an overview of the system and concluding with a function/service architecture. The model represented in Figure 4 is a global modeling of the interlocking with categories or families of functions regarding Moroccan signaling principles. To ensure the communication of interlockings in borders, especially because of the use of different signaling principles, we choose to rely on ERTMS [11] background needs to define service interface functional block (SIFB).

Indeed, ERTMS [4] messages give a movement authority (MA) that depends on the aspect of one or many successive signals. In addition, the behavior is different if we have a block or a station signal. So, we chose to link the functional block of signal (*G.Signaux*) to the SIFB on borders. For that, we distinguish two functional blocks for signal interface. The first one is block signal, which represents the functional block of block signal that ensures the succession of trains between stations as shown in Figure 7. The second one is station signal: it represents the functional block of station signal that is related to an itinerary in a specific station as shown in Figure 8.

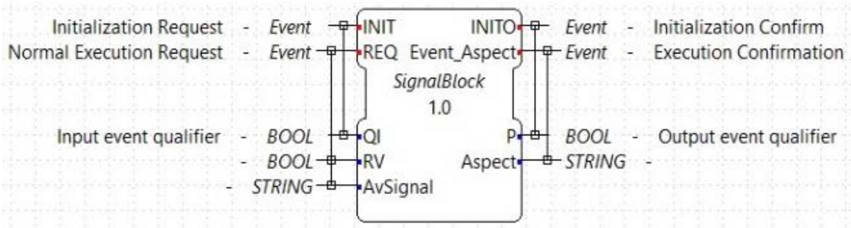

Figure 7. Signal block-service interface

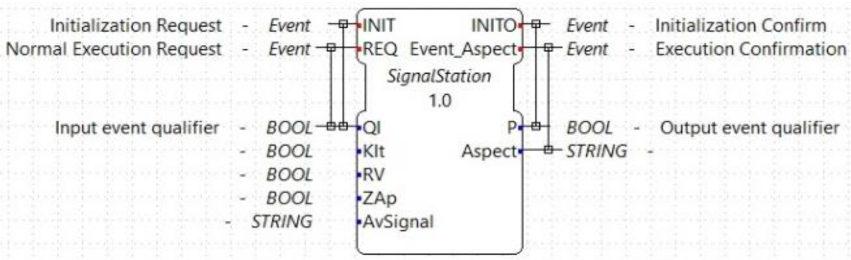

Figure 8. Signal station-service interface

On the other hand, we notice that every interlocking receiving train needs to localize the position of the train. Then, to get the occupation in borders, we need an additional SIFB linked to the functional block of the area limit. This SIFB gives information about its occupation by train as shown in Figure 9.

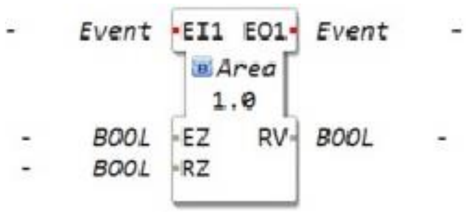

Figure 9. Area limit - service interface

3.3. Soa interface for interoperable interlocking

3.3.1. Service oriented architecture

SOA [6] is a response to interoperability issues and the reduction of coupling between systems that interact with each other in a perspective of common execution in a global railway network. Thus, SOA is distinguished into 3 types of services [6]: service provider, which provides the information or the service/function; service requester, which requests the information or the service/function, and service repository, which is the directory of all available services.

3.3.2. Security of SOA interfaces

Safety is not only a requirement of rail transport, but it is a pillar ([1], [26], [27]), and interlocking is the core of railway signaling on which the guarantee of safe train movement is based. So, respecting the requirement of security leads our system to be in compliance with CENELEC Standards [7], and IEC 62443 Standards; especially IEC 62443-3-3 Chapter related to systems to ensure a secure execution of interlocking functionalities and exchange between interlocking and with other applications.

Regarding the need for a secure exchange between interlocking, the choice of SOA is supported by the safety evidence confirmed through previous studies [28], [29] and recommendations emanating from [30]. Then, the design of SOA for an interface on borders must respect security requirements [28]: identity requirements, authentication and authorization requirements, confidentiality, and integrity requirements and availability.

3.4. SoaML modeling of interfaces

SoaML [31] is a modeling language that helps to define different levels of SOA, composed of services, requests, and participants and their properties. In our proposal, two services are needed from each interlocking related to signal and area located in the limit on borders. Each service is requested by a participant and given by the other as shown in Figures 10 and 11.

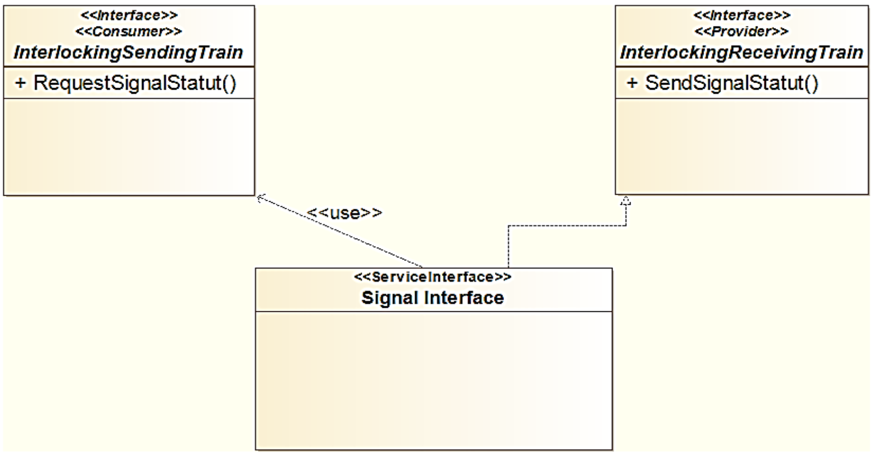

Figure 10. Service interface diagram – signal

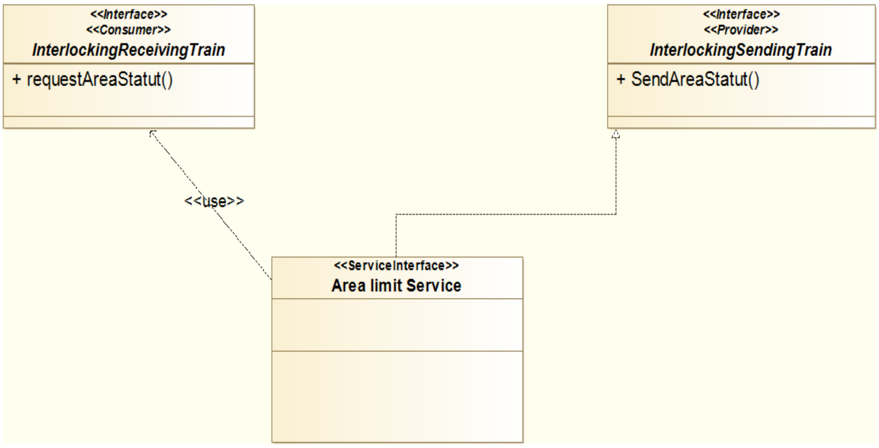

Figure 11. Service interface diagram area

3.4.1. Signal interface

The interlocking sends the train's request signal status from the interlocking receiving the train. The signal related to this request is the first signal in the domain managed by the interlocking receiving the train and called the signal interface as shown in Figure 10. Because in railway signaling each restrictive information of a signal must be announced in the previous signal met by the train.

3.4.2. Area interface

The interlocking receiving the train needs information about the last element referring to the position of movement of the train because the approach of a train imposes restrictions on the management of the interlocking in the station. So, continually, the interlocking receiving train requests area status from the interlocking sending train as shown in Figure 11. Finally, the participants' diagram summarizes the interaction of each participant with the services concerned by the interfacing as shown in Figure 12. The interlocking sending train requests signal interface status and provides area limit status. The interlocking receiving train requests area limit status and provides signal interface status.

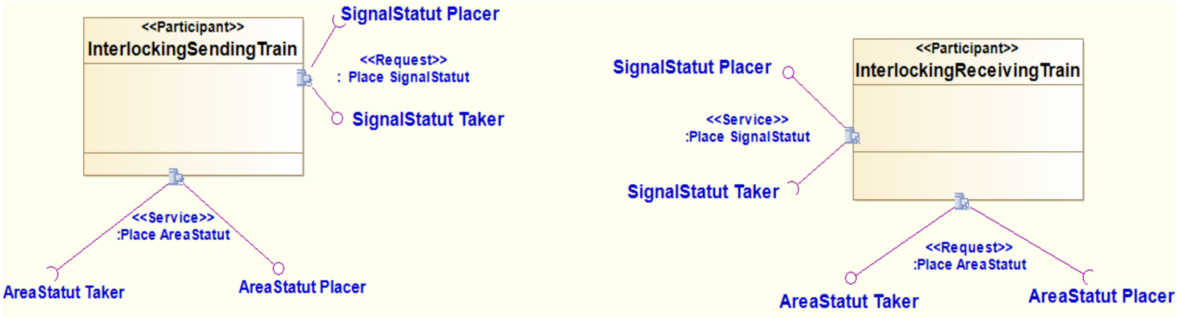

Figure 12. Participants diagram

4. RESULTS AND ANALYZES

The use of service-oriented architecture (SOA) [6] for interfacing adjacent interlockings facilitates the availability of useful information without requiring additional configuration for dedicated interfaces. Moreover, both architectures through IEC 61499 standard and SOA allow exchange by XML files. So, the form used as an output form calculator is consistent with that generated from the execution of services.

As a result of a simulation done for testing the interaction through services. We notice that the Execution of the SoaML model generated a need for continuous monitoring of changes in the status of the services offered. Then, considering that the itinerary is commanded in the next station before sending the train, two approaches are possible to manage services.

4.1. Continuous requests

In a cyclic execution of functions, each interlocking request needed information at the end of the execution cycle. Also, the requested information is sent at the end of the cycle’s execution. These interactions are mentioned in the interaction diagram in Figure 13.

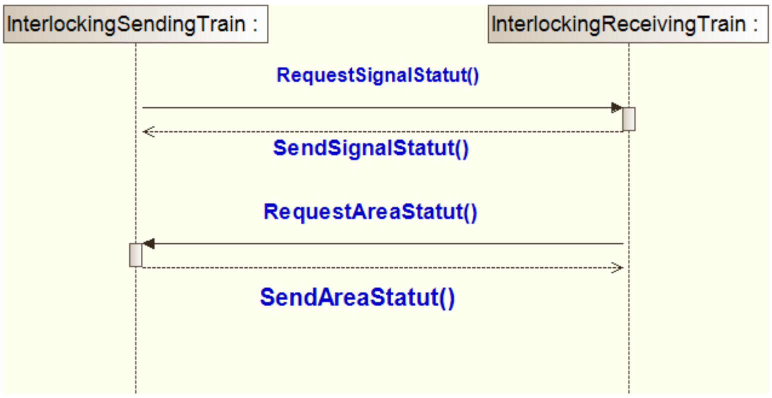

Figure 13. Sequences diagram

4.2. Event-driven requests

For an event-driven system, the execution of functions is related to the event input. So, requesting information or sending it is also related to an event. For that, a new service is proposed to listen continually to every status change linked to a service and notice it to the participant concerned as shown in Figure 14.

For the execution of our proposed system, which is compliant with the IEC 61499 Standard, functions are linked to the Event-In. So, to ensure that the value of a variable that the interlocking gets from an interface is the last update available, a listener service that notifies changes for each interlocking is needed. So, we consider the architecture of services mentioned in Figure 15.

Then, the use of a listener service reduces the number of request messages sent from each participant when information is not changed, especially when the train is not yet sent, and the interlocking is just on the stage of commanding or forming the itinerary. This meets the optimization of data exchanged aimed by the distributed architecture [12] of calculators and the interoperability between adjacent interlocking.

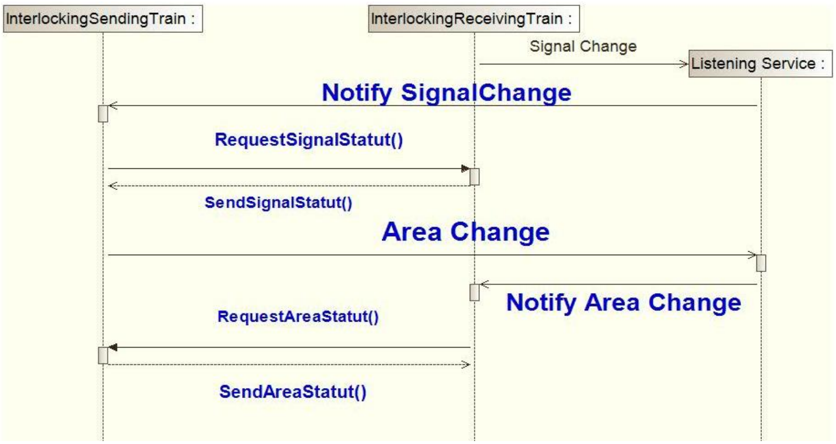

Figure 14. Sequences *diagram_listener*

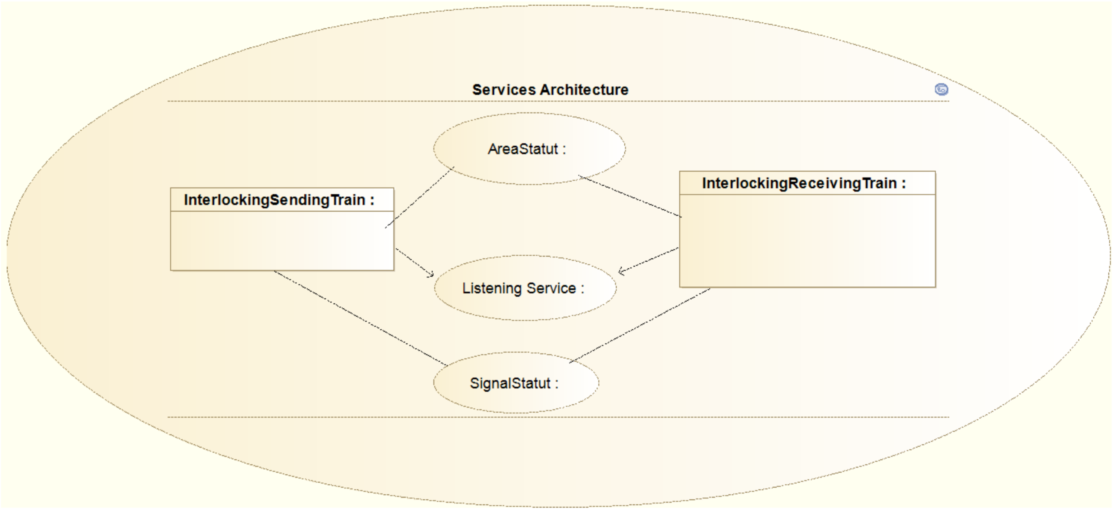

Figure 15. Service architecture diagram with listener service

5. CONCLUSION

Technological development has allowed a continuous improvement of the railway system as a whole and in particular the field of signaling. Being a critical part in terms of train traffic safety, the signaling field offers safe command and control facilities and is open to possible interfaces and interactions to perform operations. Our proposition combines interoperability needs and security requirements through the use of SOA architecture combined with functional blocks model according to the IEC 61499 standard. A simulation confirming the relevance of the model is realized and the challenge currently set is the preparation of the solution for a standardization proposal in compliance with current projects, especially the EULYNX project. In the upcoming work, we aim to dress an automatic test process to check the execution of our model for any type of signaling station regarding signaling principles of Morocco in a first step and an adaptation to other railway networks.

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