A Fair Signalling Architecture

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SUMMARY

Centralized or decentralized interlocking architecture? Centralized, decentralized, or distributed object controllers along the track? Where should interlockings' boundaries be located? Small or large interlocking domains? Answers to these questions are always difficult because they depend on several factors, including operational and organisational aspects. Then come questions related to the ERTMS signalling's implementation such as the location of ERTMS RBCs? Where to place the RBC/RBC borders? How to minimize their amount to reduce potential disturbances related to radio communication hand-overs? Is a high-capacity RBC the best choice? How to manage the line sustainability in a simple way?

Scalability is the word. Object controllers to be scalable in their form factor, capabilities and availability; the scalable RBC provides combination of RBCs clusters into a single RBC entity, jeopardizing the race to deliver super-capacity safe computers, but facilitating the operation and sustaining of the line and integration of interlocking and RBC functions opening the way to new signalling concepts.

1 INTRODUCTION

The choice to deploy a given interlocking architecture's type is mainly driven by deployment strategy, operability, availability, and maintainability needs. Object controllers, equipment housing, and interlocking capacity are also dependent on the interlocking architectures to address. Introduction of ETCS Level 3 hybrid may complexify the signalling logic, and the pure ETCS level 3 may require a change of paradigm in interlocking and RBC functional distribution. An interlocking domain is generally limited in its coverage, mostly to facilitate deployment phasing and the deployed base sustainability. For the ETCS level 2 & 3, the presence of RBC/RBC borders is not desired due to their inherent implementation constraints and to mitigate potential operational disturbances (ETCS radio communication issues or single radio operation during RBC hand-over, or driver using a wrong RBC ID at initialisation). Consequently, RBCs and interlockings domains are generally different in size and not aligned; small to medium size for interlockings, extended over several interlockings for the RBCs. To support the reduction of RBC/RBC border, the trend seems to continuously propose RBCs with increased capacity, capable of managing more trains and a larger ETCS domain. As a disadvantage, projects deployment phasing are made more complex to manage; a simple signalling modification requiring update of the overall RBC, imposing ETCS operation possessions over the extended domain. The same constrain applies for electronic interlocking or TMS extending over a large domain. The architecture becomes monolithic, less flexible. In case of (a rare but possible) failure an important area of the railway line is impacted. To compensate this risk, central safe computers must ensure very high availability, leading these to adopt potential complex architectures, with complex maintenance procedures.

Introduction of scalability in object controllers' architecture and capabilities and integration of interlocking and RBC through the scalable RBC solution may be the alternative way forward. Thanks to the Scalable RBC approach, RBC/RBC borders becomes seamless, allowing superposing of interlocking and RBC domains, and is later opening the doors to new principles setting. With the Scalable RBC a very wide ETCS Level 2/3 domain is then covered under a single RBC entity (i.e. without RBC/RBC radio hand-over) operating for example 1000 trains. By scalability, the operational availability, operability, and maintainability is enhanced, the ETCS based signalling system remains simple, more resilient and sustainable, jeopardizing the single computer big RBC, but keeps the architecture and its sustaining simple. A further step in delivering the signalling service with high resilience may come from Cloud approach. In such architecture central interlocking & RBC functions would be delivered by "signalling-as-a-service". A new paradigm where IMs would no longer own, host, and maintain the hardware, but be provided with the signalling application services (e.g. central interlocking, RBC) according to desired and agreed availability figure. The cloud data centre approach doesn't mean the use of high capacity safe computer, ICT technology COTS, etc… but mostly refers to an approach were signalling applications are hosted on safety platforms own and maintained by the signalling supplier. The PBS, the setting-up more complex maintenance and obsolescence management of central computers would no longer concern the Infrastructure Managers. Interfaces standardisation such as initiated by Eulynx or RCA is then essential for the sustainability of the investment.

2 INTERLOCKING ARCHITECTURES

2.1 Interlocking Distribution

When looking at the history of electronic interlockings since their introduction (ref. 1), we can observe that interlocking architectures are variable, not only from safe computers technology but also by other factors such as deployment and maintenance strategy. In the early days of electronic interlockings deployment, trends were diverse and often driven by infrastructure owners or local manufacturers market choice. In some cases, the architecture was defined according to the migration strategy (e.g. obsolete relay interlockings domains). Sometimes was the electronic interlocking location made to maximize the reuse of exiting signalling cables interfacing to wayside objects. In other cases, the structure was more organized in layers: the central electronic interlocking operating a macro logic and in distributed centres the logic for management of track objects according to interlocking requests and local control and command constraints; The architecture was therefore de facto distributed.

From the communication technology introduction, some have moved directly towards more centralized architectures using electronic computers, but these interlockings' action range was limited by computers and communication systems capacities. But one of the objectives of centralized architectures using object controllers placed in shelters/cabinets installed along the tracks is to reduce the quantity of signalling cables.

Both centralized and distributed approaches have both their advantages and disadvantages. Today, the architecture choices are more considering the maintenance organization, life cycle cost, and resilience to disaster (incident or deliberate act of vandalism/attack) who could affect the railway revenue and its operation.

The need to manage disaster situations is more particularly linked to the increase in transport needs and the subsequent need of service continuity. The need for geo-redundant or spare data centre, either activated from an imminent disaster (e. g. fire, alerts) or post-disaster situation to recover as quickly as possible an optimal line operation is a difficult economical choice. Disaster recovery is generally based on the level of the disaster; we could for example consider two situations: a service interruption that occurs in the case of an attack-type disaster with important loss of the data centre. Such risk is very low and mostly mitigated by means such as detection, security, and access protection. In the other case such of as a fire start detection, continuity of service would be expected, with very limited disturbance. This last risk is more real, and means are standardly in place to detect and contain such hazard. In the first case, the architectural orientation would be towards cold or warm redundancy, leading to the service recovery within, for example, one to few hours. In the second case, if the risk of not containing the danger is too high in relation to the importance of the line operation, a hot redundancy allowing transparent switching to the standby data centre after operator's decision or event detection (e. g. fire, water ingress, intrusion detection alarm) may be considered.

Hot redundancy is more particularly adapted to the highly centralized architecture of data centres (country or region level) and requires the permanent availability and maintenance of reserve centre equipment. The life cycle cost of the system is therefore higher. Warm or cold redundancy is more suitable for a semi centralized (line sector level) or decentralized (station level) data centre architecture. In this case, the reserve centre must be activated/configured (data and communication systems) when necessary to replace the former centre. In this case, as it is not necessary for the data centre's spare equipment to be active, these can be used for other purposes, such as training of operators and maintenance staff. The life cycle cost is lower, but the process should ensure 100% availability of the equipment to be configured in case of sudden need.

About data centres, nowadays, we are seeing the emergence of the notion of "In Cloud" computers moving towards the abstraction of the signalling function (e. g. interlocking, RBC, ATO, ...) separately to the machine running the function. In this approach, computers are still there, on earth, but not own by the Infrastructure Manager; The focus is on the service provided by this "cloud" computer which introduces the paradigm shift to "signalling-as-a-service". Such "In Cloud" data centre equipment would not be owned, hosted and maintained by the Infrastructure Managers, but by the signalling provider who would define central architecture, redundancy requirements, etc. according to the service availability allocated to the central interlocking, RBC, or TMS functions. The maintenance and obsolescence would then be performed by manufacturer's resources highly experimented in the specific technology and reducing the risk associated with the knowledge of that technology and its complexity.

Over the time, the principles offered by the latest advances in IT technology (virtualization, integrated management of service redundancy, etc.) and the use of technological COTS (Safe Operating systems, hypervisors, etc.) also developed for other industries such as the army, automotive or medical, may led to the evolution of safe computers towards pure IT platforms, leading to the complexity associated with the same field. This addition of such complexity is not compatible with the railway context, where complexity must be kept to a bare minimum in order to minimize the risk of human errors during testing, operation, and maintenance. We must ask ourselves whether the "Signalling-as-a-service" architecture would be a possible answer; Indeed, the regular practice of the maintenance team frequently managing a larger set of safe computers serving several projects and infrastructure managers would then reduce the risk inherent to the complexity and actions rarely practiced.

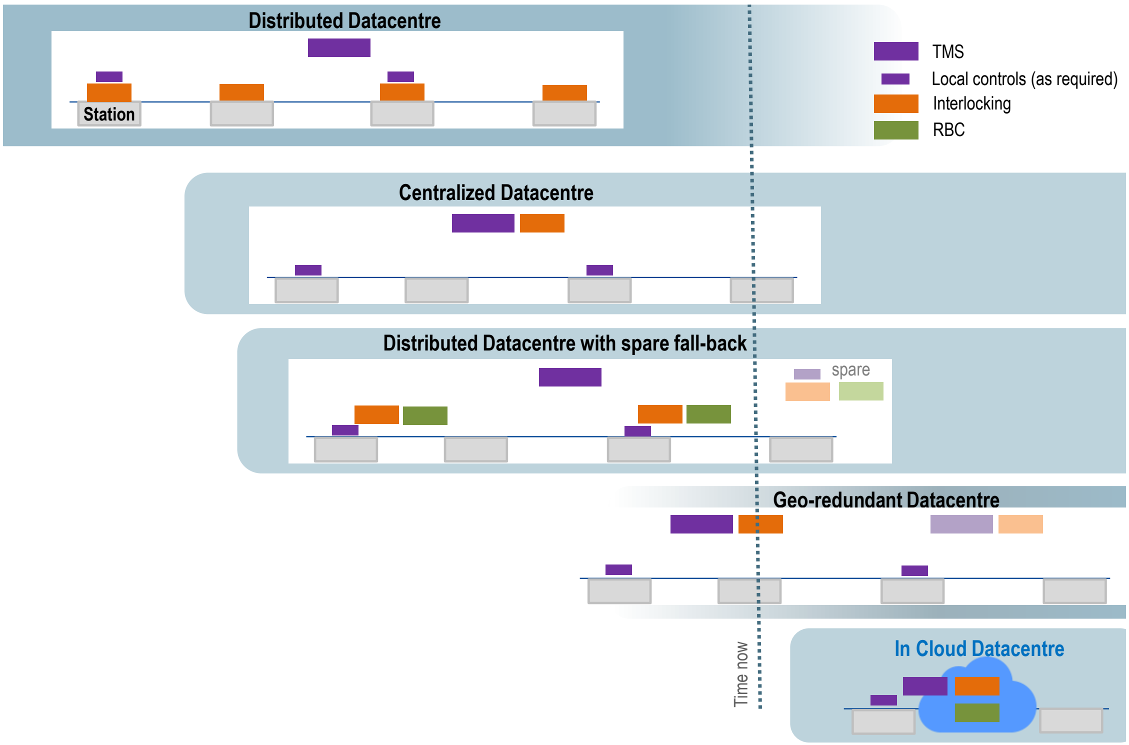


Figure 1 - Data Centre Architecture Evolution

Interlocking covered area are often determined according to engineering possessions management constraints, deployment phasing, domain of the replaced obsolete interlocking, and sometimes by the electronic interlocking capacity. This last criterion is however no longer true; the capacity of the latest platforms being highly increased. For example, the Alstom MooN safety platform, already composed of COTS hardware and COTS operating systems, is capable of managing nearly 1000 Ethernet interfaces to wayside object controllers, each object controller managing up to 10 wayside signalling objects.

In order to take advantage of the latest technology available in COTS, while keeping the safe computer as simple as possible, the MooN safety platform maintains a format based on a conventional LRU adapted to the railway domain. However, to take advantage of its overall capacity, the safety platform is ready to execute, for example, "virtual interlockings", each of which is defined by its own application data corresponding to each interlocking area and processed separately, but in a single cycle time, as if they were running on individual interlocking computers. Offering the latest technology, in full simplicity, this is key for the end-user.

2.2 Wayside Signalling Objects management

For the management and control of wayside objects and other signalling systems (e.g. level crossings), the three main trackside architectures are centralized, decentralized or distributed, referring to the location of object controllers. The trend is also set to highly distributed architectures with ("In Cloud") interlocking no longer interfacing with object controllers, but directly with the computerized object via an open computer network. This could then refer to as the "Signalling Internet of Rail" by analogy to the "Internet of Things"; the signalling object being a highly connected object to a central system. A beauty, but solutions for migration from conventional installations, as well as the objects' accessibility during maintenance, are topics to be carefully addressed when designing and deploying such solutions.

For centralized architecture, object controllers (or rather the physical interface between the computer world and the physical world) are grouped together either in stations or in equipment rooms located not far from the railway tracks. In decentralized mode, object controllers are usually located in shelters along the track. Finally, in distributed mode, object controllers are housed in boxes or cabinets; at a vicinity of the track in order to reduce the quantity of signalling cables.

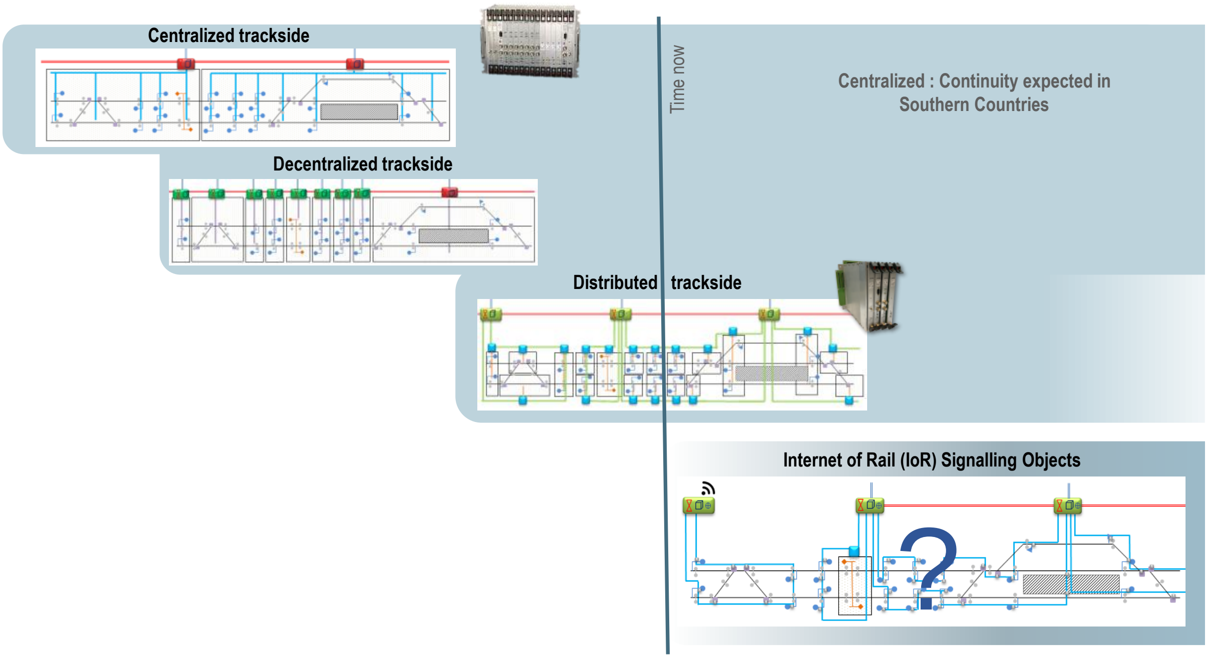


Figure 2 – A view of trackside architecture evolution

Each architecture has advantages and disadvantages. The choice of architecture is not only linked to technical or economic constraints, but also to environmental or logistical ones. In the southern regions, centralized or decentralized architectures are more common, while in the central and northern regions of Europe, preferences seems more for decentralized and distributed.

2.2.1 Centralize Trackside Architecture

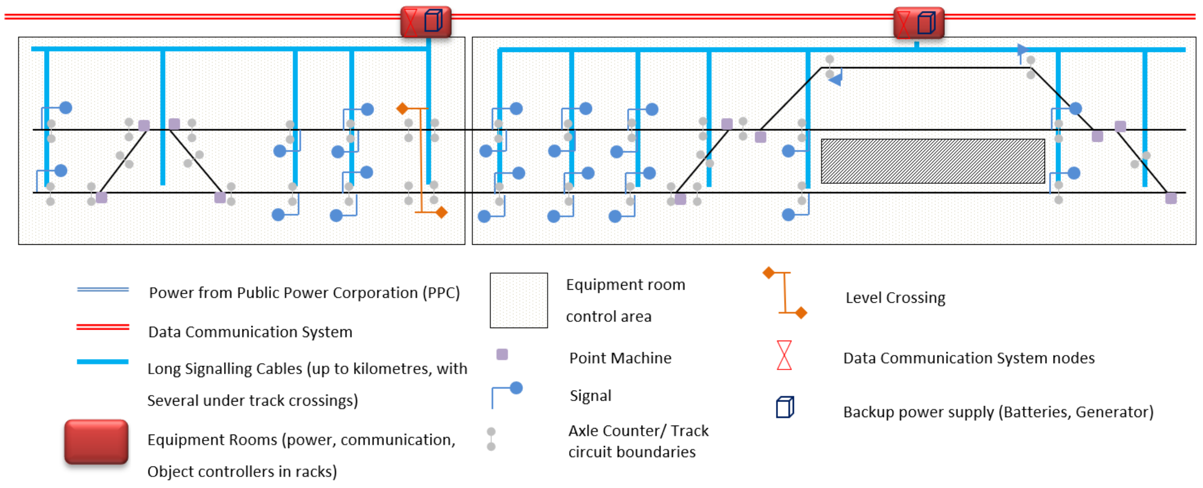


Figure 3 - Centralized Trackside Architecture

Main characteristics:

- Objects controllers are mostly in racks, each rack addressing different types of objects (Signals, Points, ETCS balises, …)
- Objects controllers are concentrated in equipment rooms located in stations or in specific equipment rooms along the line.
- The size of the equipment room depends on the amount of equipment to be controlled on the area.
- Every equipment rooms are connected to communication access node, local power supply system, and all the standard ancillary systems (alarm systems, fire prevention systems and gas extinguishers, ventilation and cooling system (when required) and facilities (EHS signage, desk, a/c plugs, light, back-up light, ...)
- Many signalling objects are controlled from each equipment room.
- Object Controllers are connected to wayside objects via long cables of up to several kilometres.
- Cable distribution box and shaft under track crossing regularly located along the track.
- Interlocking, RBC cubicle and associated peripherals may be in control centre, houses with these equipment rooms.
- Signalling and ancillary equipment local power supply system are attached to the equipment rooms. batteries are generally separated from the signalling system (e.g. in a specific closed enclosure or generally a separate room).
- Maintenance activities on object controllers are provided in the equipment rooms; under permanent protection against weather adverse effects (rain, snow, ...).
- In case of a disaster to an equipment room, an important portion of the line may be affected.

2.2.2 Decentralized Trackside Architecture

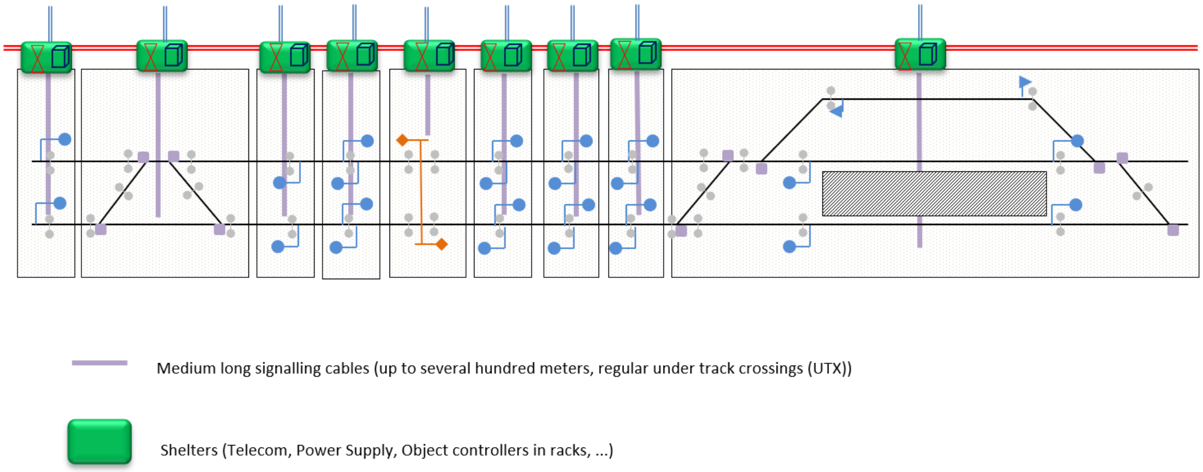


Figure 4 - Decentralized Trackside Architecture

Main characteristics:

- Objects controllers are in racks or as modules.
- Objects controllers are in human accessed shelters or cabinets located along the track or in stations.
- Every shelter is connected to communication access node, and provided with local power supply system, and all the standard ancillary systems and facilities.
- From each shelter are controlled several wayside signalling objects.
- Wayside signalling objects are connected to object controllers by medium long cables of up to several hundred meters.
- Cable distribution box and shaft under track crossing are located along the track.
- Maintenance activities on Object Controllers are provided in the shelters; under permanent protection against weather adverse effects (rain, snow...) of open air when in cabinets. Object controller’s LRU IP grade code must be adequate.
- In case of a disaster to an equipment room, only few wayside signalling object command/controls may be affected.

2.2.3 Distributed Trackside Architecture

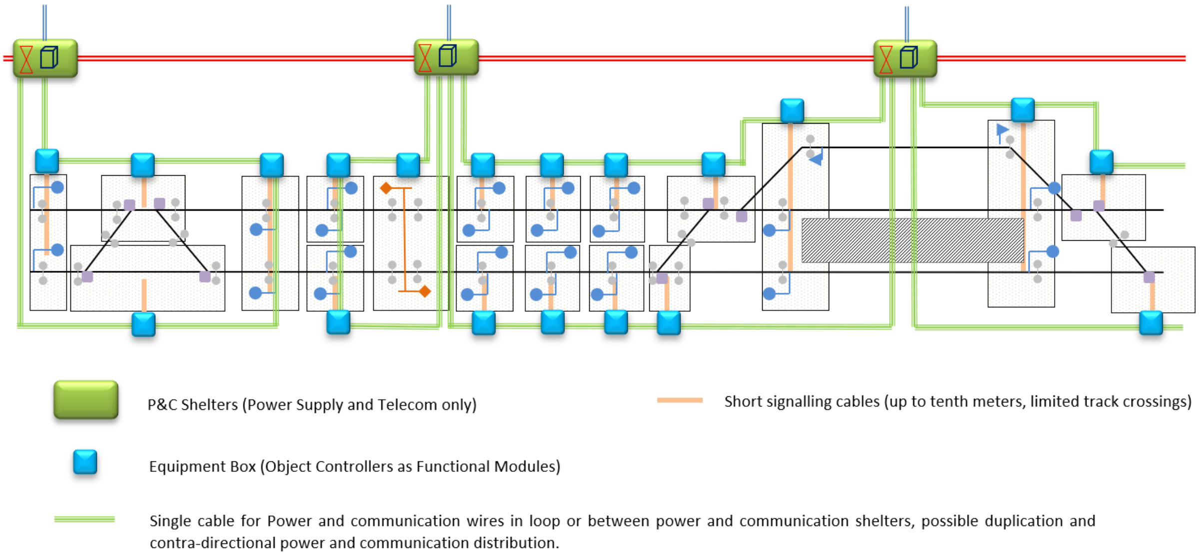


Figure 5 - Distributed Trackside Architecture

Main characteristics:

- Objects controllers are generally functional modules, each functional module specialized in one type of signalling object (Signals, ETCS balises, Points, generic I/Os, ...)
- Functional Modules are in cabinets or boxes located at a close distance from the signalling objects.
- IP Code of object controllers LRU must be adapted to the maintenance operations in open air.
- Cabinets or equipment boxes are provided with light, communication interface, and small power adapters.
- Power and Communication human accessed shelters (P&C Shelters) are located along the track, preferably at stations. They are separated by several kilometres.
- Every P&C shelter is connected to communication access node, and provided with local power supply system, and all the standard ancillary systems and facilities.
- Each cabinet or equipment box interface a limited number of wayside objects.
- Wayside objects are interfaced using short cables of up to several tenth meters.
- Cable distribution boxes and under-rail cable crossing are limited.
- The communication access node interfaces are only at P&C shelters.
- Low voltage and communication cables are connecting cabinets and equipment box in secondary loops to P&C shelters, in contra-directional redundant mode to mitigate first failure impact.
- Ancillary equipment and power supply system are in P&C shelters.
- Cabinets or equipment boxes are accessed from along the track path potentially requiring look-out.
- Maintenance activities on functional modules are provided without permanent protection against weather adverse effects. Functional modules shall have an adapted IP grade code or specific weather protection shall be temporarily installed.
- Maintenance activities in P&C equipment are generally provided in the shelters; under permanent protection against weather adverse effects.
- In case of a disaster to a cabinet, only very few signalling objects are impacted. In case of a disaster at a P&C the effect may be mitigated thanks to duplication of power supply distribution and communications.

2.2.4 Connected Signalling Objects Trackside Architecture

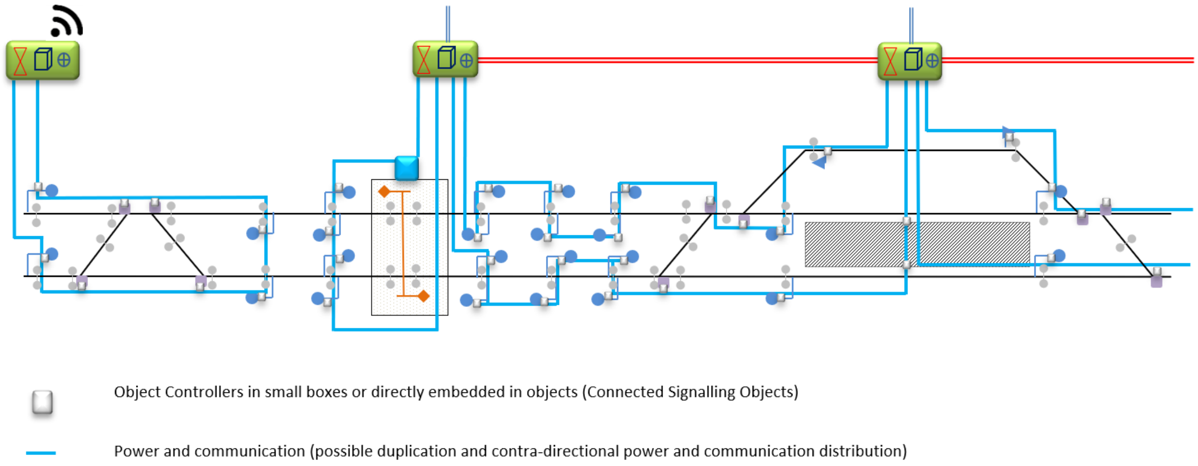


Figure 6 - Highly Distributed Trackside Architecture

Main characteristics:

- Objects controllers are either in small boxes or even integrated with the wayside object.
- Object controllers could address simple or complex objects (e.g. Level Crossing), for some systems, specific additional equipment may require the use of shelters.
- Object controllers are at very close distance of the object or directly embedded in them.
- Object controllers' interfaces with specific modems modules (e.g. Power Line Communication, SHDSL, FO, ...), and small power adapter (when required).
- Power and Communication man accessed shelters (P&C Shelters) are located along the track, preferably at stations. They are separated by several kilometres.
- Every P&C shelter is connected to communication access node, and provided with local power supply system, and all the standard ancillary systems and facilities.
- Each object controller interfaces with very few (one or two) signalling objects.
- Object controller connect to wayside objects by very short cables of few meters or may be embedded with wayside objects.
- Cable distribution box and under-rail under track cable crossings are very limited.
- Isolated object controller may be radio interfaced to the communication backbone and sustained in energy by standalone energy systems (solar panel, fuel cell).
- Equipment boxes are accessed from along the track path potentially requiring look-out.
- P&C Shelters are accessed either in station, without track access/look-out or from along the track with track access, look-out.
- Maintenance activities on functional modules are provided without permanent protection against weather adverse effects. Functional modules should have an adapted IP grade code or specific weather protection must be temporarily installed.
- Maintenance activities in P&C equipment are generally provided in the shelters or rooms; under permanent protection against weather adverse effects.
- In case of a disaster to a box or cabinet only one or very few signalling objects are impacted. In case of a disaster at a P&C the effect may be mitigated thanks to duplication of power supply distribution and communications.

2.2.5 Scalable Object Controllers

Logically, the optimal structure of object controllers would be different (rack, functional module) for each type of architecture. For a centralized architecture, the sharing of resources (communication interfaces, power, etc.) justifies a rack approach containing module boards specific to each type of wayside signalling object. This reducing the life cycle cost and the PBS and facilitates maintenance. Hot-replacement of defective module boards inserted in the racks is then the advantage ensuring continuity of service until corrective maintenance. In a decentralized architecture, the rack or functional module approach will depend on the number of wayside signalling objects to interface. In distributed architecture, a module-based approach is more appropriate, and the object controller is more compact, but should offer more versatility to manage ancillary functions (local alarms, cyber security, etc.). A railway network generally requires different situations of concentration (low and high density) and constraints (availability, access, risk of vandalism), which still makes it difficult to choose the optimal choice for a single architecture.

For an optimal approach, object controllers must therefore be smart and offer a level of scalability that allows adapting these to the specific application context. Ideally, such adaptability is required in terms of form factor (rack or modules), availability figure (high or very high availability), and maintainability (LRU at module board or functional module level). This adaptability is possible thanks to scalable object controllers composed of standard module boards, inserted either in racks or in functional modules. The scalability in redundancy of object interfaces and hot replaceability of module boards. Type of modules boards and their redundancy selection are used to adapt at a glance the object controller architecture in function of the architecture and required RAM figures. The use of a standard set of module boards for all architectures optimizes the life cycle cost while facilitating maintenance organization, spare parts logistics and maintenance activities through global homogeneity.

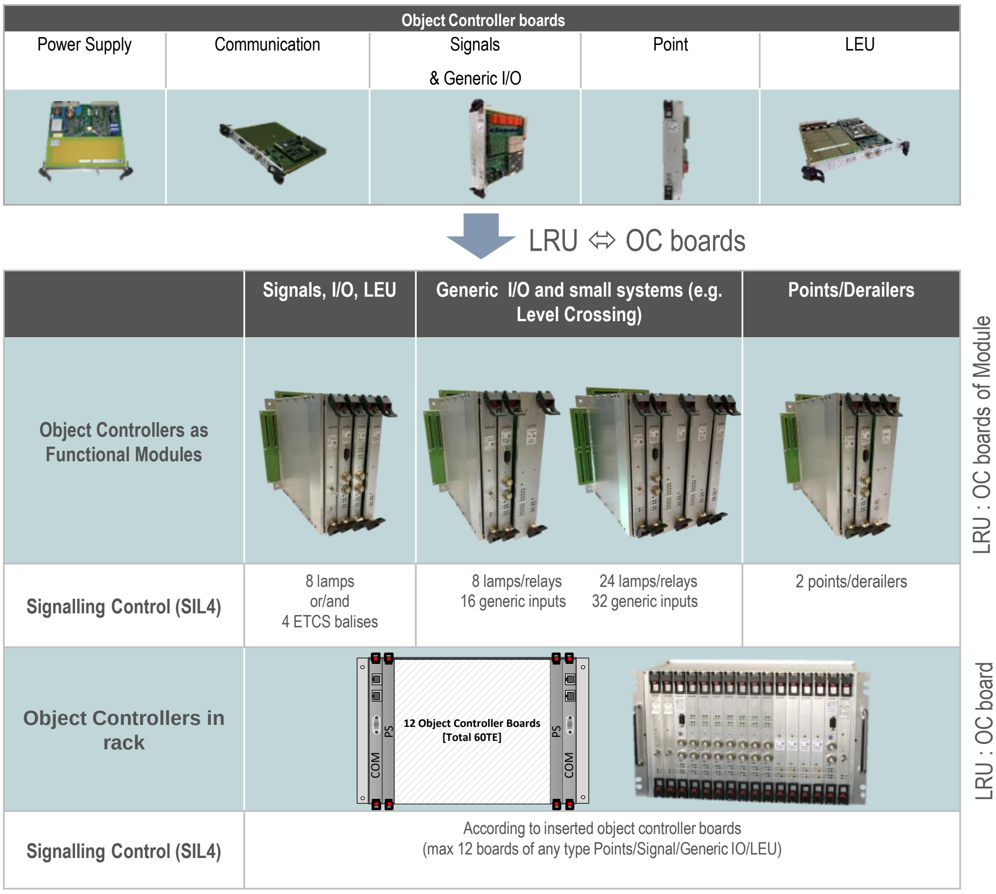


Figure 7 – Scalable Object Controllers Principle

Availability requirement have generally a direct impact on constitution and cost of the object controller. For example, it is not expected to invest in object controllers having very high availability for standard or low traffic density line equipment that are not critical for the network operation. However, it may be valuable to invest more in object controllers to ensure a high level of service continuity for certain railway lines critical to operations or on low-density lines but to the advantage of reducing maintenance organisational costs and its execution.

To answer these different situations, one approach is to provide scalability in duplication of object controller interfaces. In this solution, the interfaces from object controllers to signalling objects are duplicated or not depending on the required MTBSF and desired Mean Time To Repair (MTTR = site access time + Mean Repair Time). The objective of this redundancy is to adapt the composition of the object controller in function of the RAM figures but always using the same object controller components for critical and non-critical railway lines.

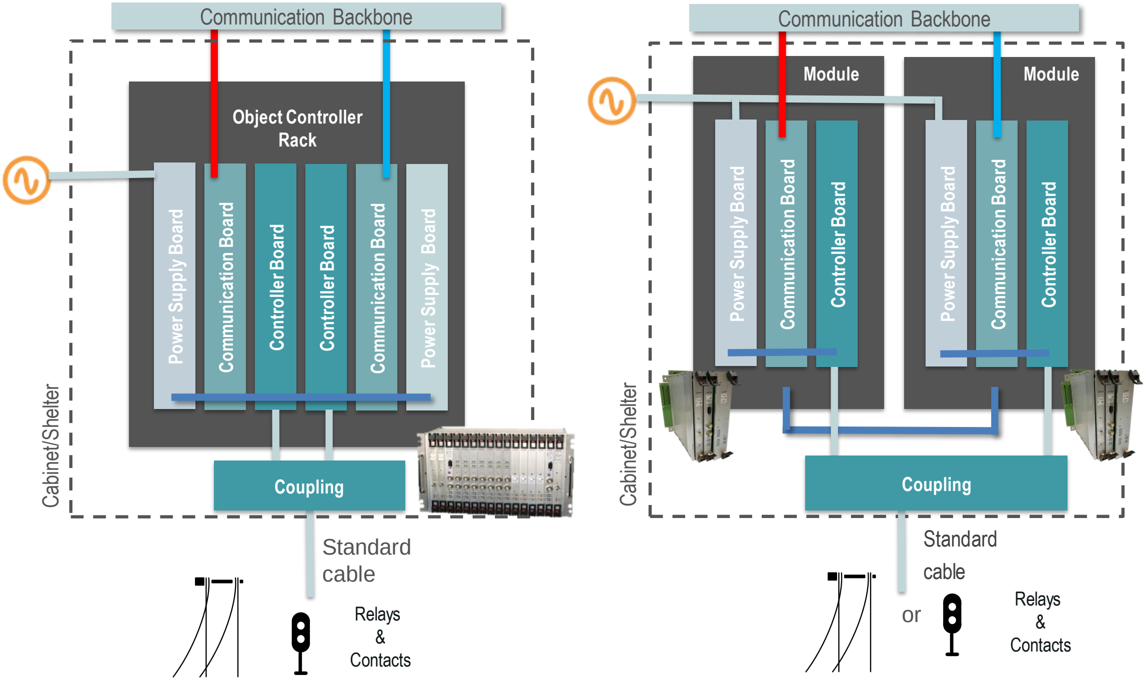


Figure 8 – MTBSF scalability by Object Controllers interfaces redundancy

2.3 Intelligent Object Controllers

The centralizing of the interlocking logic and the use of "dumb" object controllers (i.e. Object Controllers acting only as direct interface between the interlocking's control/command and wayside signalling objects) require that the wayside objects management logic is processed by the central interlocking computer. In this standard approach, more logics are then required by the interlocking computer and more exchanges are required between the object controller and the interlocking computer, resulting in some longer reaction times (e.g. Junction Direction Indicator, signal's graceful degradation, point machine and point locking controls, etc.). To mitigate these effects, some object controllers such as the Trackside Functional Module (TFM) of the SSI-based interlocking deployed by Infrabel (Belgium) are embedding a logic that, for instance, locally manages the signal graceful degradation and only reporting the controlled aspect to the central interlocking.

Extending this principle and increasing the capabilities and capacity of the safe local logic is the basis for intelligent object controllers; the commands and controls exchanged between the interlocking computer and object controllers are no longer switch, signal/lamp, or track occupancy controls and status, but, for example, route requests though a subset of track objects (signals, switches, train detection, etc.); route controls are processed by the object controller itself. This concept is similar to the geographical circuitry or functional signalling approaches, but with more flexibility and at an object controller level, which reduces the effort in case of signalling engineering changes. The logic could then be standardized or adapted to specific needs, allowing the use of object controllers to manage local systems such as level crossing, tunnel gates, movable bridges, … With this method the central interlocking logic is simplified, and engineering changes become easier to manage, system reaction time is enhanced by the local processing.

In addition, an intelligent object controller can always behave like a "dumb" object controller, only using its logic to adapt to the format of the data exchanged with the interlocking computer. The use of a standardized transport layer safe protocol then facilitates the use of object controllers and central interlocking from different suppliers.

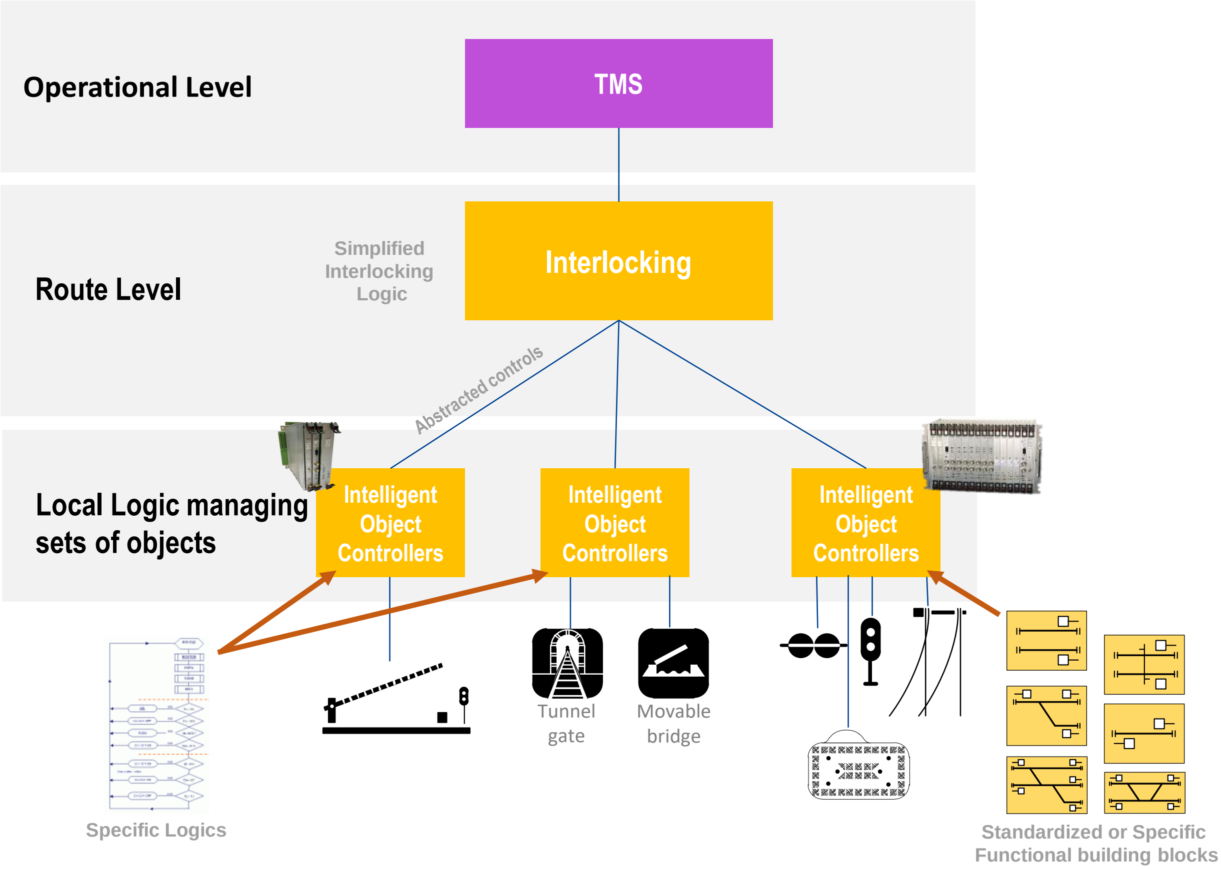


Figure 9 - Architecture with Intelligent Object Controllers

As shown in Figure 9, an intelligent object controller can be used either:

- For a safe logic composed of predefined and validated “building blocks”. Each “building block” corresponding to a given signalling “building block”. The labelled parameters of the safety logic building blocks are used to align the data interfacing to the interlocking or to another “building block”. Non-applicable parameters corresponding to unused elements of the “building block” are stubbed to downgrade the capabilities of the building block according to it specific application.
- For safety logic specific to a sub-system, either interfaced with the electronic interlocking or in a stand-alone. Examples of use are the management of movable bridges, tunnel gates, or more frequently, level crossings commands and controls as shown in Figure 10.

The use of the same LRUs for object controllers and for the management of specific sub-systems (e.g. level crossings – figure 10) reduces LRU variability, simplifying maintenance, spare parts management and global costs.

The standardization of interlocking interfaces as proposed by RCA/Eulynx should provide enough flexibility in the definition of the process data interface language to allow an evolution towards such interface principles.

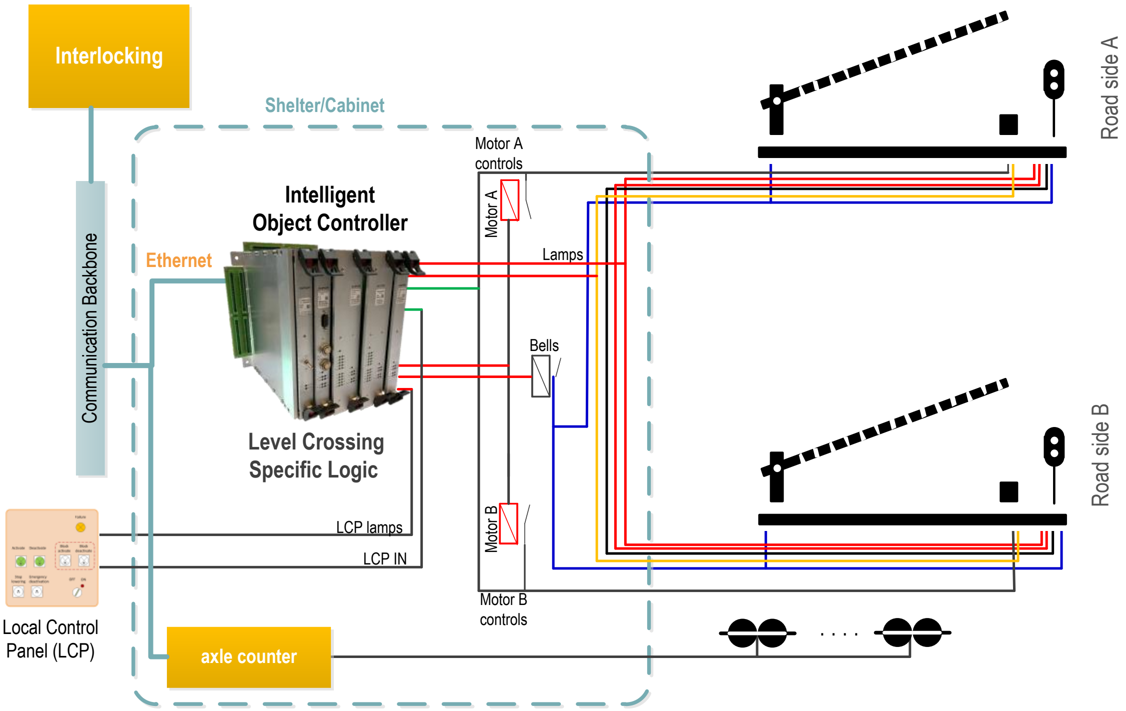


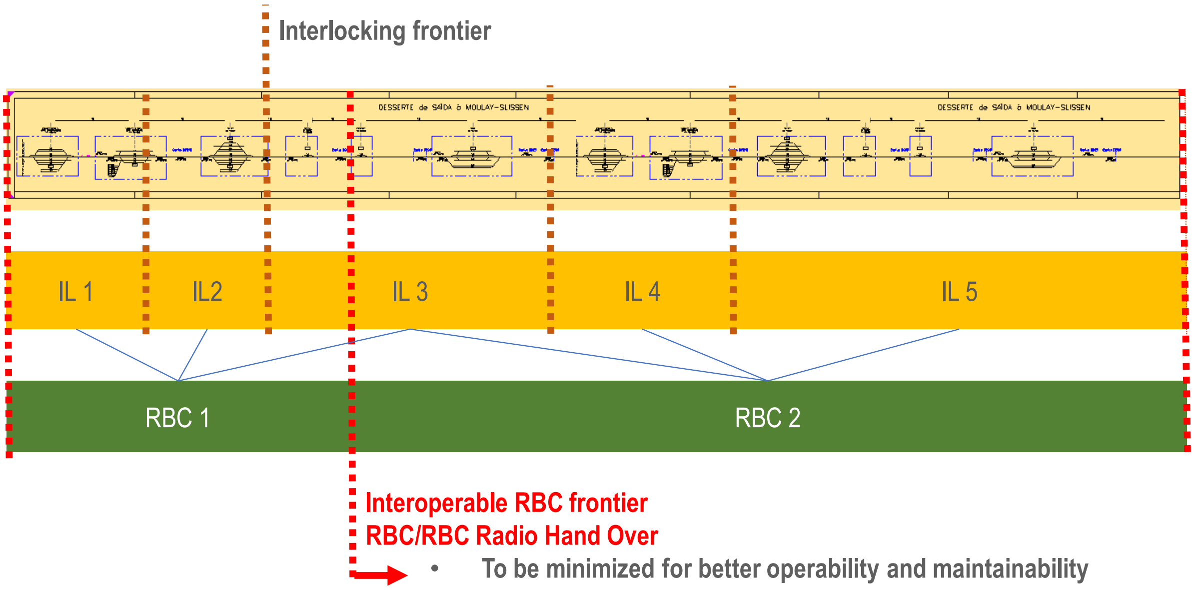
Figure 10 - Level Crossing management using intelligent Object Controller

3 RBC ARCHITECTURE

3.1 Constraints of RBC/RBC borders

In the case of radio-based ETCS levels, RBCs are interfaced with the interlockings. Interlockings are managing track movement authorizations, RBCs are building ETCS trains individual supervision information and data exchanges with ETCS on board units (OBUs). As a general observation, RBCs and interlockings does not supervise the same line portions (Figure 11). This difference is mainly due to the fact that at the RBC/RBC border crossing it is necessary for the train to transfer the radio connection to the next RBC; to operate this transfer, the on-board ETCS system receives the necessary information to connect to the next RBC, and then manages radio connections and disconnections for the transfer of supervision without communication discontinuity. To carry out this operation, a certain distance, proportional with the line speed, is required around the border. Also, more radio frequencies (in GSM-R Circuit Switching) are needed (because the OBU must connect to both RBCs during the RBC/RBC hand-over process). This makes it very difficult, if not impossible, to implement RBC/RBC borders in junctions or station areas. These are, therefore, generally located in open track with enough space providing minimum constraints. In addition, to reduce operational disturbances caused by driver manipulation errors (e. g. incorrect entry of RBC ETCS ID at the Start Of Mission) or potential online braking following a radio connection failure in hand-over area, Infrastructure Managers prefer to minimize the number of RBC/RBC borders. In order to reduce the number of RBC/RBC borders, ETCS suppliers offer high-capacity RBCs managing extended ETCS domains (e.g. >250km) with the ability to manage more ETCS trains. The drawback of this approach is the cost and complexity in staggering technical and engineering updates, managing line possessions, and implications in the event of a (rare but possible) RBC failure.

For small RBC domains (e.g. the equivalent of the interlocking domains), the number of hand-over increases and becomes a threat to the line's operation; operational and constructional measures must then be put in place to ensure availability of two functional on-board radio modems for the RBC/RBC borders crossings.



Interlocking frontier

Interoperable RBC frontier
RBC/RBC Radio Hand Over

- **To be minimized for better operability and maintainability**
- **Radio hand-over constraints impose locating in plain line**

Figure 11 – Standard RBC and Interlocking domains

3.2 Scalable RBC Approach

The scalable RBC avoids the constraints of the conventional RBC/RBC border. It makes an abstraction between the RBC logical entity and the physical machine that runs the RBC safe application (Figure 12). With this concept, the RBC ETCS ID seen and used by ETCS trains no longer belongs to a physical RBC, but to a logical RBC consisting of several Scalable RBCs composing a super-RBC. OBUs connect by radio to a logical RBC composed by the assembly of scalable RBCs running on several safe computers (MooN or 2oo3SP platforms). The driver only needs to use one RBC ETCS ID number or, for an entire country, a very small set. The operational crossing between Scalable RBCs is totally transparent for ETCS OBUs, drivers and operators. The ETCS system is then resilient to the failure of a radio interface at borders between Scalable RBCs; an ETCS trains with only one radio modem available is no longer likely to affect the railway operation. Another key advantage is the possibility to place Scalable RBC borders in a nearly constraints-free manner (e.g. in stations, railway nodes, etc.).

The scalable RBC being completely transparent to the ETCS OBUs, any type of interoperable ETCS OBU can operate on a line equipped with Scalable RBCs. At the ETCS start of mission/first connection, the non-localized OBU is not associated to the Scalable RBC of its position. But once the OBU reports a valid location for the logical-RBC, the OBU's radio connection is routed seamlessly, and becomes supervised by the Scalable RBC relevant to the reported train location. When crossing a Scalable RBC border, the OBU's safe connection is transferred from one Scalable RBC to another, instantly, safely and securely. This operation is called virtual hand-over (VHO) and is performed between Scalable RBCs composing the logical-RBC.

The quantity of Scalable RBCs that compose a super-RBC can vary from 1 to N; N being limited only by the trackside radio sub-system's interface capacity and not by the capacity of the safe computer that hosts the RBC application as it is the case for a conventional RBC.

The interoperable RBC/RBC hand-over (HO) as defined in the ERTMS/ETCS Technical Specifications for Interoperability (TSI) remains applicable when interfacing with other RBC suppliers, or when the radio system interface's capacity is reached.

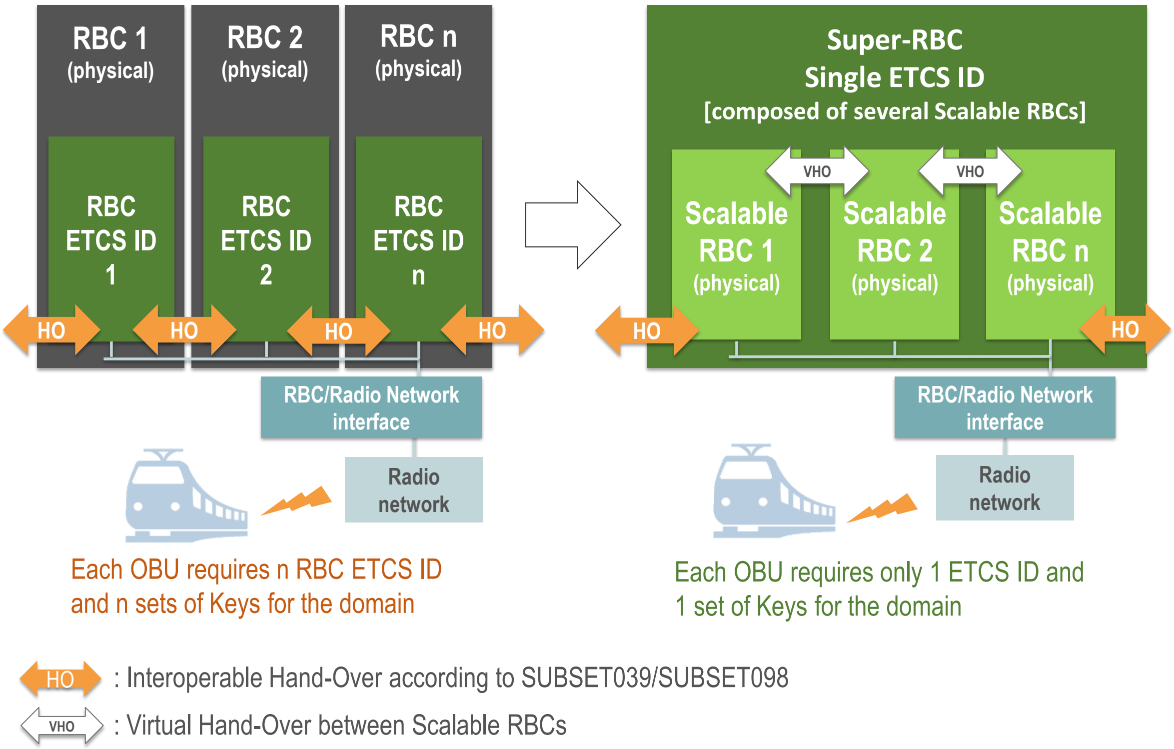


Figure 12 - Scalable RBC joining RBCs transparently and under a single logical ETCS ID

The Scalable RBC is fully compliant with interoperability requirements and offers a series of technical and operational advantages to the ETCS deployment and operation:

- It allows the coverage of an entire line or a global network under a single logical RBC area (single ETCS ID).
- Phased deployment of the ETCS trackside is highly facilitated and costs is reduced: a line could be divided into several scalable RBCs. The phasing of an ETCS line deployment and its upgrade are operated by modification of the Scalable RBC data, without the need to re-validate neighbouring Scalable RBCs.
- RBC/RBC radio communication hand-over between jointed physical RBCs are suppressed, providing a reliable line operation,
- RBC/RBC borders could be placed in stations, railway nodes, ... The conventional track space required for the radio communication hand-over process is no longer required,
- hand-overs are operationally transparent to the train driver,
- amount of RBC ID that train drivers must use for the data entry at the start of mission process is significantly reduced,
- Reduction of Euroradio Keys (KMAC) and less complexity during phased ETCS trackside deployment,
- In GSM-R Circuit Switching communication, the ETCS capacity in the hand-over area is enhanced, permitting release of 50% of the GSM frequency slots at hand-over locations,
- the need balises specific to hand-over is highly reduced. Just a balise group remains at the RBC border,
- in comparison with the standard method to mitigate failure of a radio, the train safety movement during hand over is enhanced: RBC/RBC hand-over is performed with radio communication continuity to the logical RBC, even in the case of a single radio failure of an OBU equipped with a duplicated radio system.

The first Scalable RBC is in implementation on the Network Rail's Paddington-Heathrow line and the hand over between two Scalable RBCs will be in operation mid-2020.

Advantages offered by the solution are applicable in GSM-R Circuit Switching or Packet Switching data communication. And most of the advantages remain applicable with the future radio mobile communication system (FRMCS) as expected for the TSI 2022.

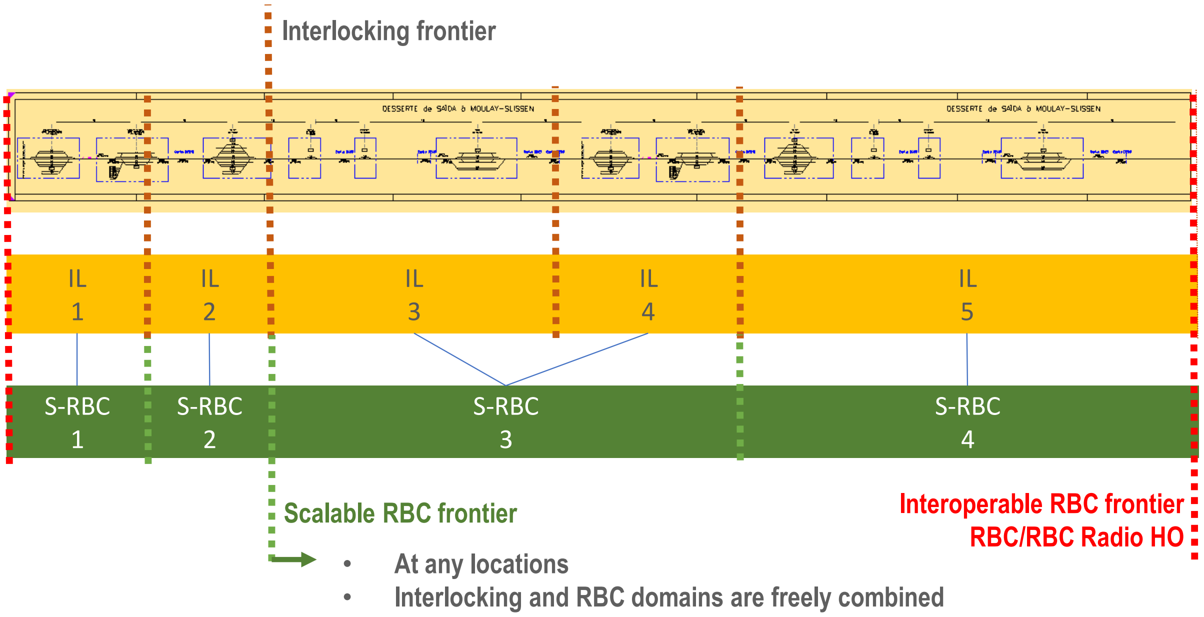


Figure 13 - Scalable RBC (S-RBC) and Interlocking coverages

4 INTERLOCKING AND RBC INTEGRATION

As we have seen above, a railway network is divided into interlocking areas according to different criteria (e. g. according to replaced interlockings' areas, to limit complexity at interlocking borders, ease of engineering, operational availability in case of degraded/disaster modes, etc.). In the case of an ETCS Level 2/3 using the interoperable RBCs hand-over (i.e. without Scalable RBC), RBC borders positioning is driven by standard engineering rules making it hardly for these to correspond with interlockings' borders: integrating the interlocking and the RBC application into a single Interlocking-RBC component makes little sense.

Thanks to the Scalable RBC principle, RBC's border placement constraints are drastically reduced and becoming almost equivalent to those of interlockings' borders placement; The overlapping of RBC borders with interlockings ones then becomes possible and without impact on the ETCS operation. After decades of separation, it becomes then evident to integrate interlocking and RBC (Figure 14) into a single entity called "Interlocking RBC" (RBC IL).

Integrating both systems offers a series of advantages:

- Improved reaction time and signalling headway through cancellation of interfaces and communication processing,
- facilitates the engineering by using the same information for the interlocking and RBC engineering,
- facilitates implementation of ETCS Level 3 Hybrid principles and management of virtual sections status,
- facilitated engineering life cycle (signalling layout evolution management),
- simplified line engineering possessions,
- simplified design and installation by reduction of interfaces,
- reduction in the equipment quantities and availability enhancement,
- matching of RBC and interlocking areas at no cost (no supplementary hardware),

The Scalable RBC is therefore the basis for the evolution towards new signalling architectures. The integration of the two systems simplifies of the central computer architecture, hence reducing the risk of human errors during corrective maintenance activities.

As with the Smartlock 400 interlocking (ref. 2) using the notion of virtualization allowing a single safe computer to execute several interlocking data sets, a future very high-capacity safe computer with a very high availability (and resilience) architecture can then be used to virtualize multiple RBC ILs. Such a virtualization approach allows to take full advantage of the new technological advances of new safe computers without creating drawbacks on engineering activities, maintenance, etc. associated to big capacity RBCs or interlockings.

The RBC IL is also a necessary benefit for the deployment of ETCS Level 3. Indeed, the Positive Train Detection in level 3 determining "virtual sections" occupations based on OBU reported train positions is a concept obliged by the functional separation of the interlocking and ETCS worlds: An interlocking knows the railway tracks occupations, switches, tracks lockings, etc. but not the trains, an RBC knows the trains, their types, ETCS modes, speeds, applied ETCS authorities, etc. For the ETCS Level 3, but also in Level 2, all the notions are necessary for an efficient and reliable operation. An initiative going in this direction is, for example, already studied in the concept of "geometric safety logic" proposed by RCA and SBB digitalisation program of Smartrail 4.0. This is a start, but it opens the reflection towards this need leading to a paradigm shift of our standard signalling architectures.

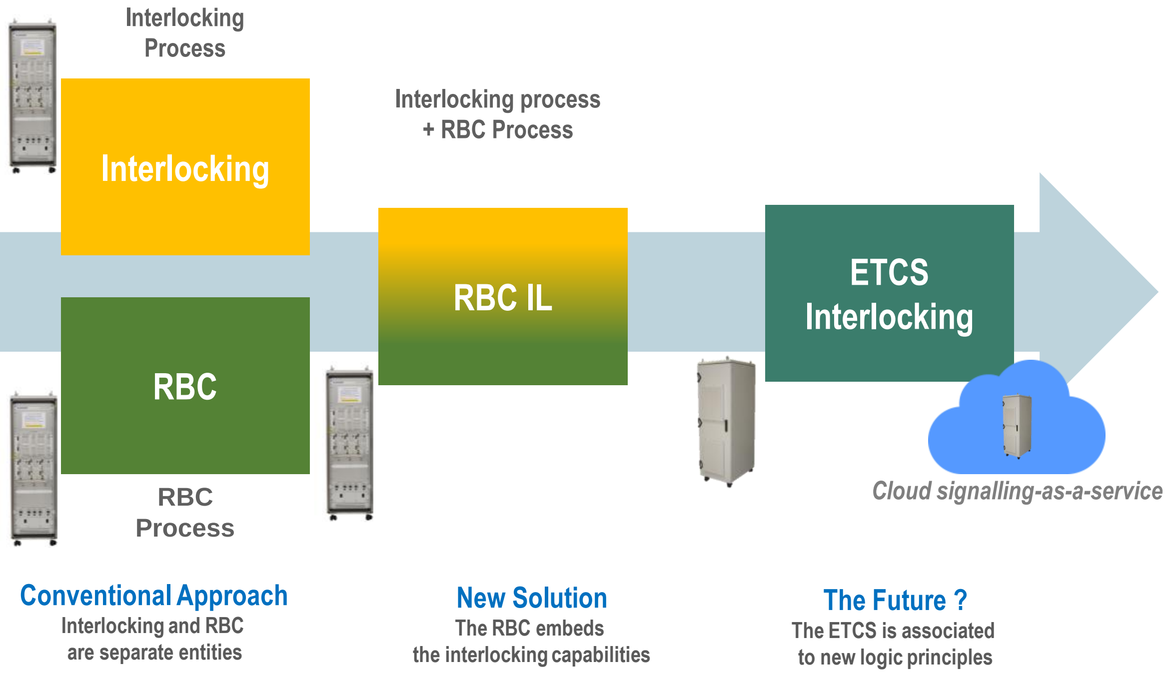


Figure 14 – RBC IL – A change of Paradigm

5 CONCLUSION

A fair signalling architecture is a smart architecture capable of adapting to the application contexts (e.g. high density, standard, and low density) of a railway project through scalability at each level. Such scalability is achievable:

- On the first hand, by the balanced allocation of roles and responsibilities of each architectural layer of the system, using scalability in object controllers' capabilities ("dumb" or "intelligent"),
- By the scalability of object controllers to adapt in their form factor (e.g. racks or modules) according to the concentration of signalling objects, housing constraints, and the level of resilience while establishing the right level of optimization of the overall Life Cycle Cost.
- Through the scalability of the interlocking and ETCS RBC architecture: by removing the constraints imposed by the interoperable RBC/RBC hand-over, the Scalable RBC architecture facilitates the signalling engineering and deployment of the ETCS Level 2 and 3 trackside, and provides resilience to radio transmission failures, thereby improving the line operability and sustainability.
- Combining the interlocking and RBC functions, opening the way for further integration of their logical processing into the "ETCS interlocking" concept, reducing the system reaction time, engineering efforts, and key to the new signalling logic needed for the deployment of the pure ETCS Level 3.

A further step in the implementation of resilient architectures could be the concept of "In Cloud" / "signalling-as-a-service" solution. The central safe computers would not belong to the Infrastructure Manager, who would normally have to maintain it, but to the signalling manufacturer. IMs would then rent the central system service according to the desire availability needs, which would make out of date the discussions about redundancy strategy, electronic computer capacity, disaster resilient architectures, maintenance, and obsolescence management of central systems. In this approach, the standardisation of interfaces makes all his sense. To reach this evolution, Infrastructure Managers and signalling manufactures must prepare and organize themselves for this paradigm shift.

6 REFERENCES

1. Bailey C. *European Railway Signalling* London: A&C Black, 2009.
2. Raimondi V., Lauthier J. *A successful approach to Solid State Alstom Transport Interlocking (SSI) modernisation*. Conference AusRAIL PLUS 2009, 17-19 November 2009.