Ansaldo STS

A Hitachi Group Company

The ERTMS Train Position Function Based on the GNSS Technology

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Summer School – Law and Technology
IMPERIA CAMPUS OF GENOA UNIVERSITY

EUSPACE
European Union in Space
JEAN MONNET MODULE

UNIVERSITÀ DEGLI STUDI DI GENOVA

Outline

Starting from:

- **Signalling Train Positioning** Principles
- **European Rail Traffic Management System (ERTMS)**
  - ✓ **System Structure**
  - ✓ ERTMS **Application Levels**
  - ✓ **Location Principles** and **Train Position**
  - ✓ ERTMS **Position Performance** and **Safety Requirements**

Outline (cont.)

To arrive to:

- Market Needs: a **Cost Effective Solution**
- European Union Agency for Railways (**ERA)** ERTMS **Roadmap Specification Evolution**
- Innovative Solution Based on the **Virtual Balise Concept**
- **GNSS Principles** and **GNSS Augmentation Systems**
- **Railway Environment**: a Challenge for GNSS
- Possible **ERTMS Enhancement Architecture** Suitable for the Virtual Balise Concept
- Bibliography

Signalling Train Positioning Principles

The main objective of **railway signalling systems** is to enable **safe train movements**.

As trains run on the track, a **railway signalling system must route trains** and **space them** so as to avoid **collisions** with one another.

Signalling Train Positioning Principles (cont.)

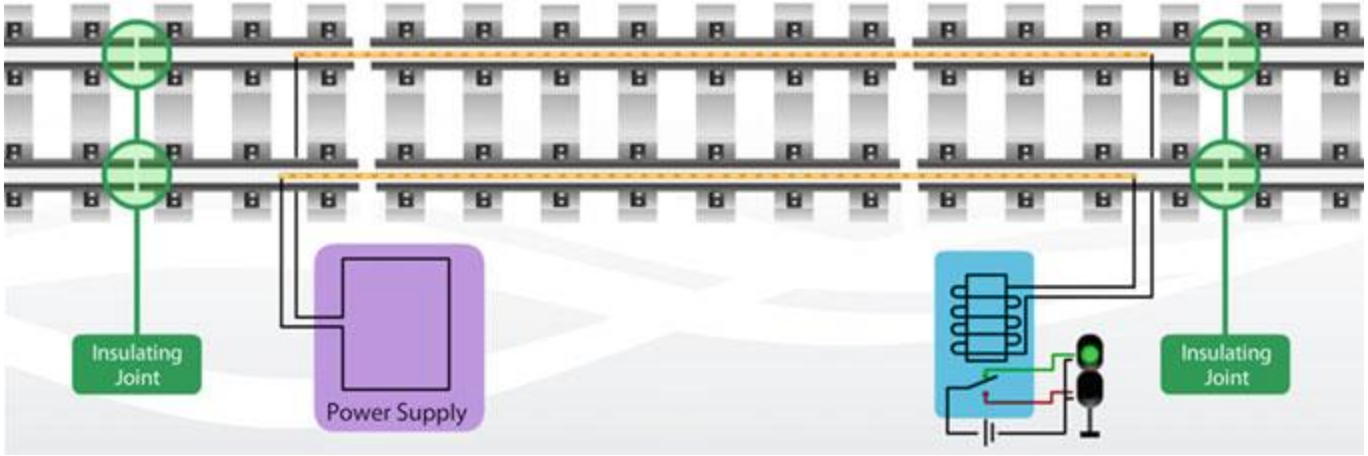
Trackside Train Detection Unit

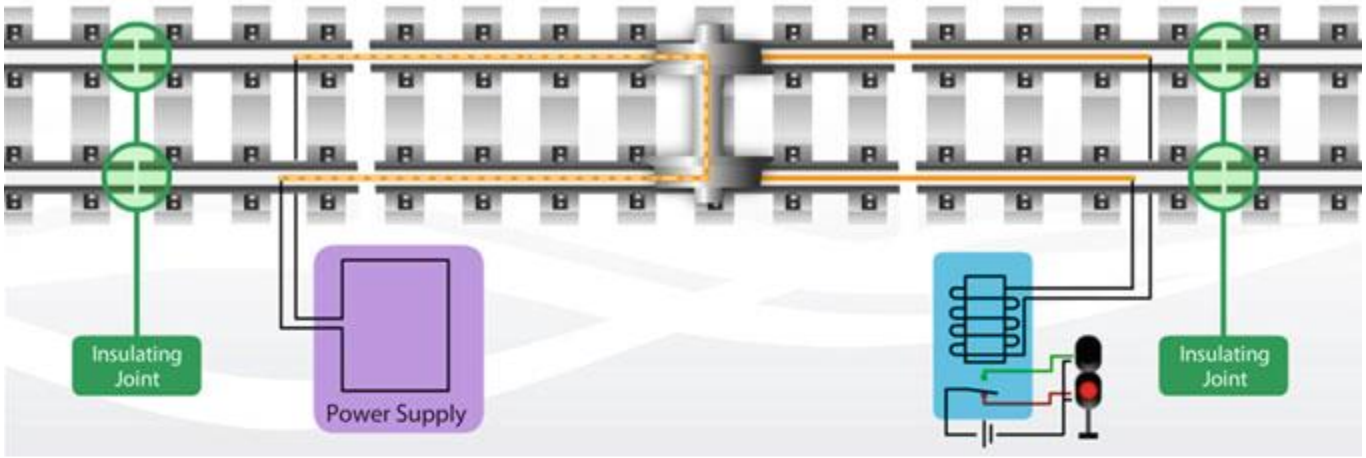
The train detection is a trackside **safe** function that aims to determine if a particular section (block) of track is occupied by a train or a bogie.

Almost all the train detection units automatically perform such a detection by using:

- **track circuits** or
- **axle counters**.

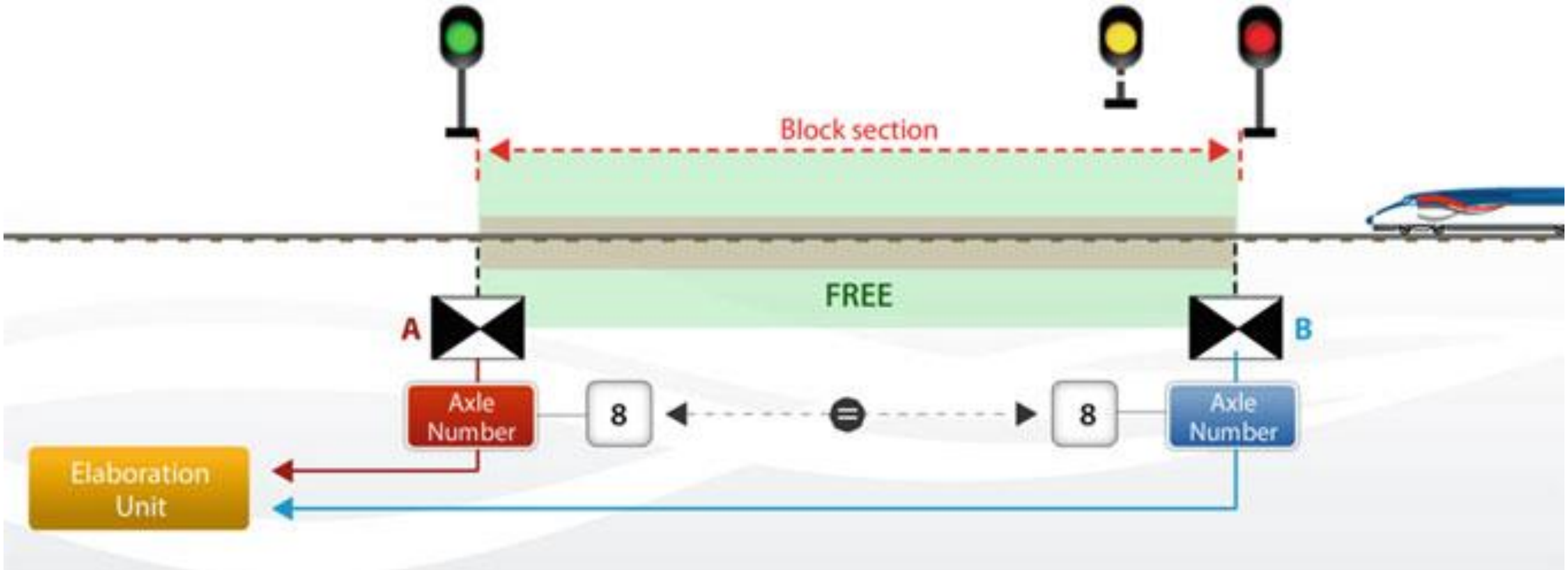
Signalling Train Positioning Principles (cont.)





Track Circuit

Signalling Train Positioning Principles (cont.)



Axle Counter

Signalling Train Positioning Principles (cont.)

Balise or Transponder

A balise is a **physical equipment** installed on a **sleeper** (e.g. wood or concrete sleeper). The balise does not require external power supply; it is activated/energized by a specific equipment and related antenna installed on a train. The function of a balise is mainly to **send information (fixed or variable) to the on-board** that energizes/activates it.

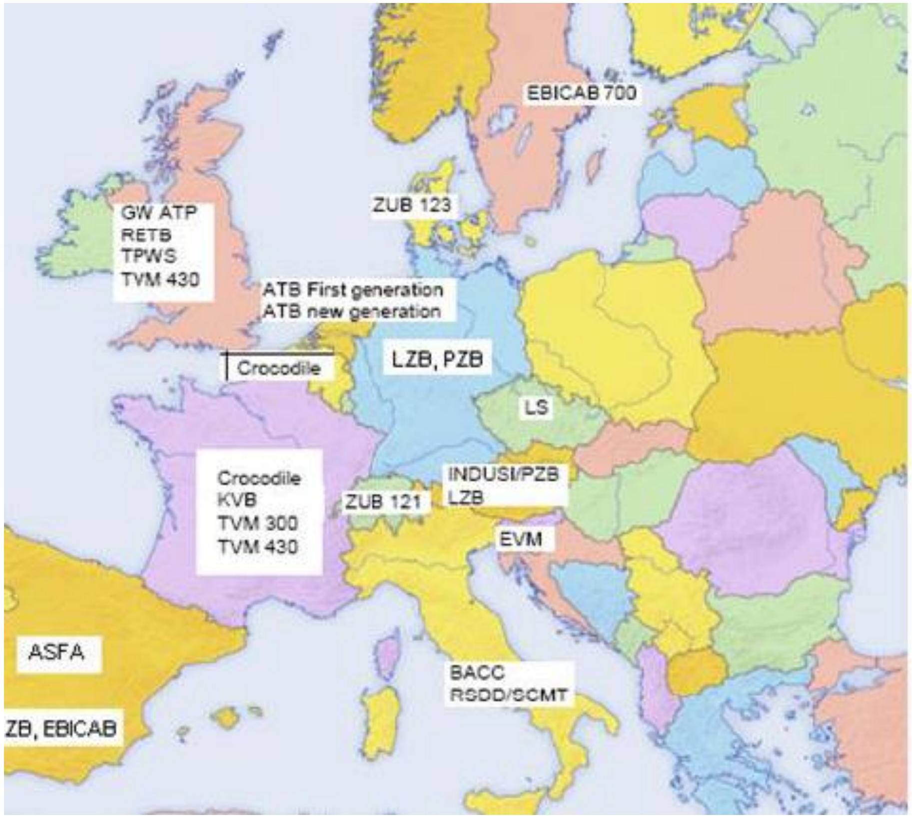
Signalling Train Positioning Principles (cont.)

On-Board Unit

It is the part (software and/or hardware) of the on-board equipment which implements the on-board functions of the railway signalling system. **It is responsible for supervising vehicle operations**.

Many different signalling systems have been developed. The simplest systems logically "**repeat**" the trackside signal aspect received from the balise or the coded track circuit and activate an audible warning to sound in the train cab; if the train driver fails to respond appropriately, after a short interval the train brake is **automatically applied**.

European Rail Traffic Management System (ERTMS)



Many different railway signalling subsystems have been developed and almost every single country used to have its own Automatic Train Protection (ATP). These ATP systems are normally **not compatible** with each other.

The **ERTMS** Standard leads to a **single harmonized Control, Command, Signalling and Communication system** that is fully interoperable across borders (i.e.SERA).

European Rail Traffic Management System (ERTMS): System Structure

Due to the nature of the required functions, the ERTMS/ETCS system is made up of **two** subsystems, the **on-board subsystem** and the **trackside subsystem**.

The **environment** of ERTMS/ETCS system is composed of:

- the **train**, which is then considered in the train interface specification;
- the **driver**, which is then considered via the driver interface specification;
- **other onboard interfaces**;
- **external trackside systems** (interlockings, control centres, etc.), for which no interoperability requirement is established.

European Rail Traffic Management System (ERTMS): System Structure (cont.)

Trackside Subsystem

Depending of the application level, the trackside subsystem can be composed of:

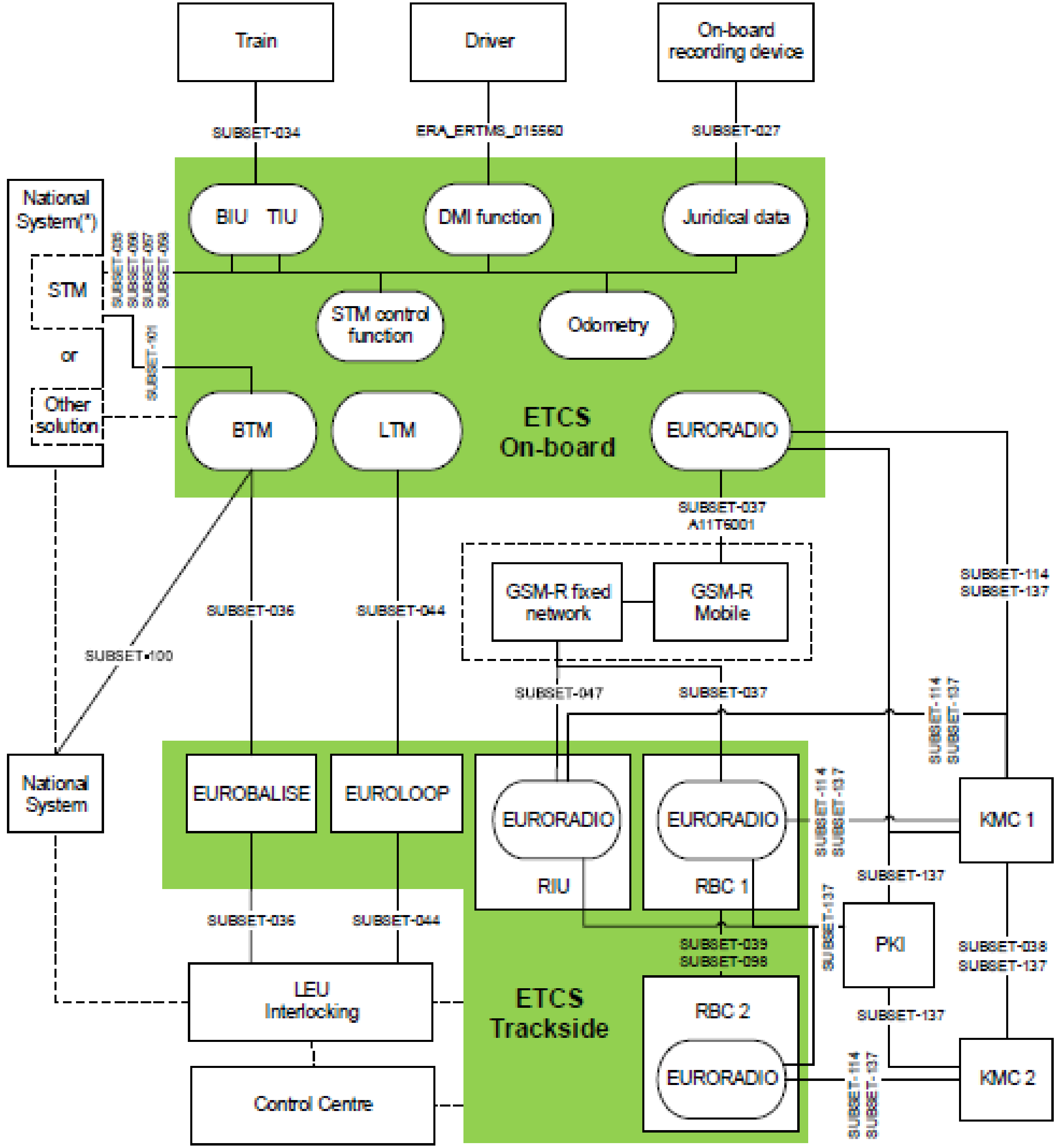
- **Balise**;
- Lineside Electronic Unit;
- *The Radio Communication Network (GSM-R);*
- The **Radio Block Centre** (RBC);
- Euroloop;
- Radio Infill Unit;
- Key Management Centre (KMC);
- Public Key Infrastructure (PKI).

On-Board Subsystem

Depending of the application level, the on-board subsystem can be composed of:

- The **ERTMS/ETCS on-board equipment**;
- *The on-board part of the GSM-R radio system.*

European Rail Traffic Management System (ERTMS): System Structure (cont.)



European Rail Traffic Management System (ERTMS): Application Levels (cont.)

The different ERTMS/ETCS application levels are a way to **express** the possible **operating relationships between track** and **train**. Level definitions are related to the trackside equipment used, to the way trackside information reaches the on-board units and to which functions are processed in the trackside and in the on-board equipment respectively.

European Rail Traffic Management System (ERTMS): Application Levels (cont.)

- ERTMS/ETCS Level 0 (train equipped with ERTMS/ETCS operating on a line not equipped with any train control system or on a line equipped with ERTMS/ETCS and/or national system(s) but operation under their supervision is currently not possible);
- ERTMS/ETCS Level NTC (train equipped with ERTMS/ETCS operating on a line equipped with a national system);
- ERTMS/ETCS Application Level 1 with or without infill transmission (train equipped with ERTMS/ETCS operating on a line equipped with **Eurobalises** and optionally Euroloop or Radio infill);

European Rail Traffic Management System (ERTMS): Application Levels (cont.)

- ERTMS/ETCS Application **Level 2** (train equipped with ERTMS/ETCS operating on a line controlled by a **Radio Block Centre** and equipped with **Eurobalises** and **Euroradio**) with **train position** and **train integrity proving performed by the trackside**;
- ERTMS/ETCS Application **Level 3** (similar to level 2 but with **train position** and **train integrity supervision based on information received from the train**).

European Rail Traffic Management System (ERTMS): Location Principles and Train Position

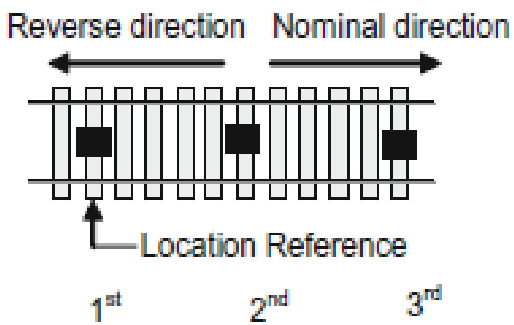
Eurobalese (Balise) - It is a transmission equipment installed on the track sleepers that can send **secure information**, named **telegrams**, to the on-board subsystem.

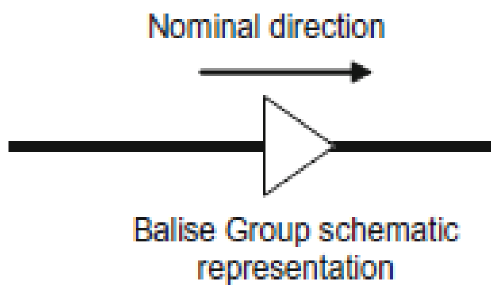
Balises can be organized to logically belong to a **group** (named **Balise Group**, **BG**); the combination of all telegrams sent by each balise of the Balise Group defines the message sent by the Balise Group. A Balise Group can be composed of from **one** balise to **eight** balises.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Each balise stores at least the following information:

- The internal number (from 1 to 8) of the balise;
- The number of balises inside the group;



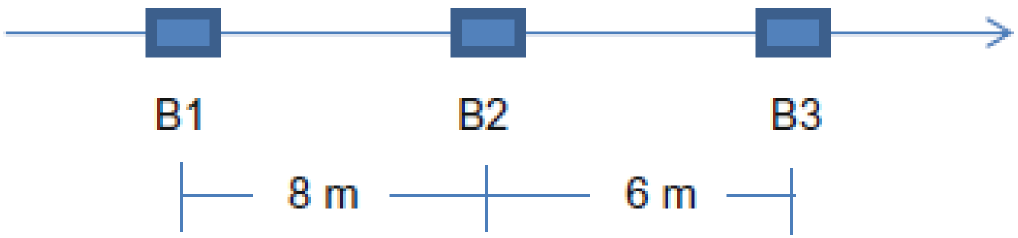


Every BG composed of at least two balises has its own **1D coordinate system**, with origin the balise number 1 (called **location reference**).

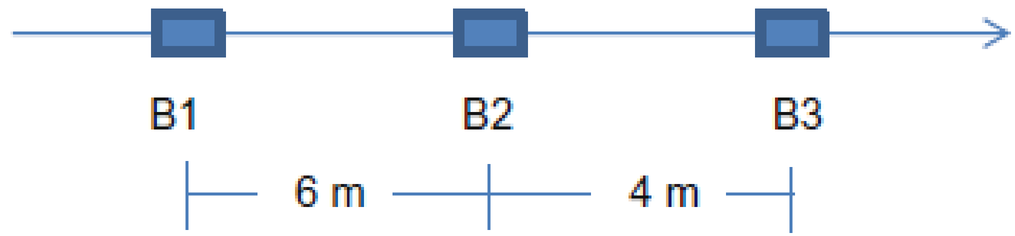
The orientation of the BG coordinate system (i.e. nominal or reverse direction) is identified as **Balise Group orientation**. The nominal direction of each Balise Group is defined by **increasing** internal balise numbers.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Declaring Missed a Balise of the Same BG



B2 declared missed if not found within $12m + 5\% * 12m + 1.3m$



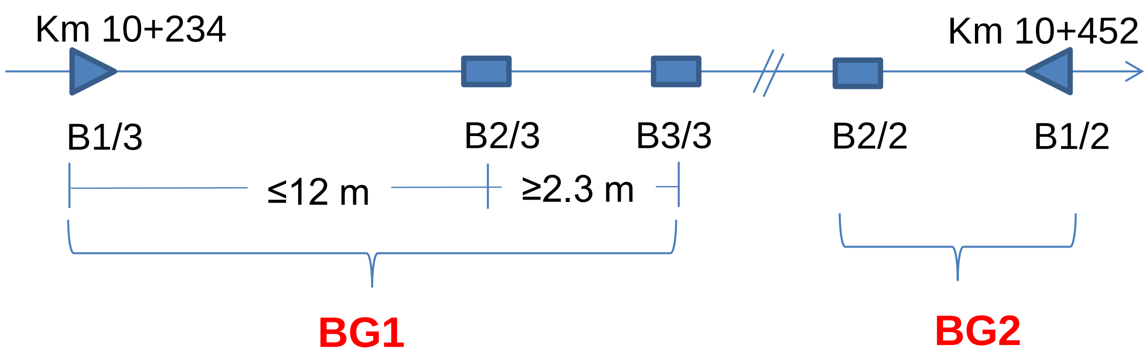
B2 declared missed if B3 has been passed

For reducing the probability of not detecting a BG or of losing the information transmitted from one balise of the BG, each balise can be **duplicated** (i.e. the duplicated balise contains the same signalling information of the balise to be duplicated).

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Balise Linking

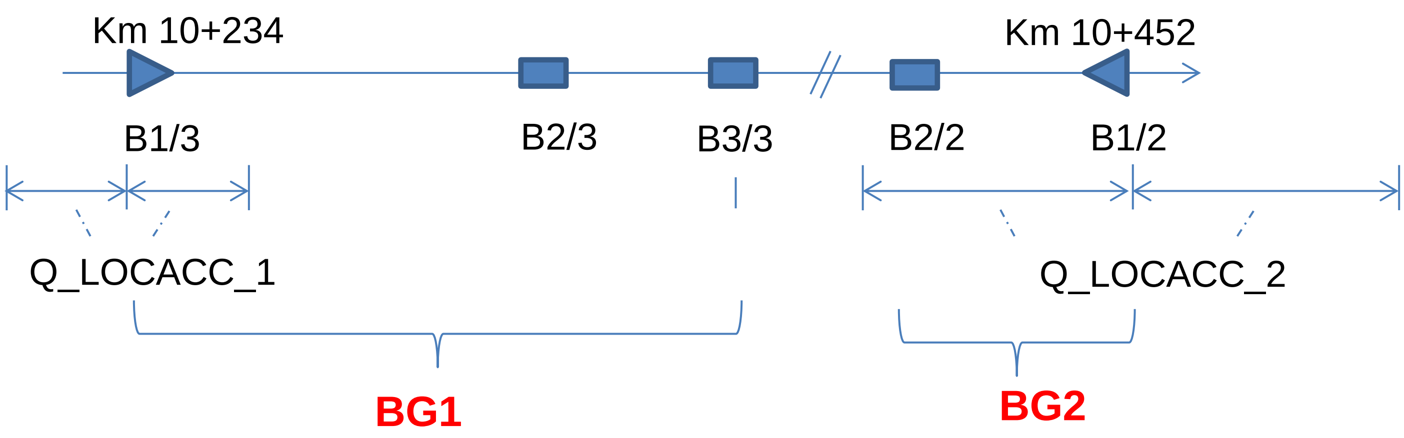
- Based on the balise telegram(s), a Balise Group can be marked as **linked** or **unlinked**.
- It is linked when its **linking information is known in advance**. Linking information, sent by Trackside, includes:
  - ✓ The identity of the linked Balise Group;
  - ✓ The location of the location reference of the Balise Group;



European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Balise Linking - Linking information:

- The position error of this location reference;
- The direction with which the linked Balise Group will be passed over (nominal or reverse);
- The linking reaction required if a data consistency problem occurs with the expected Balise Group.

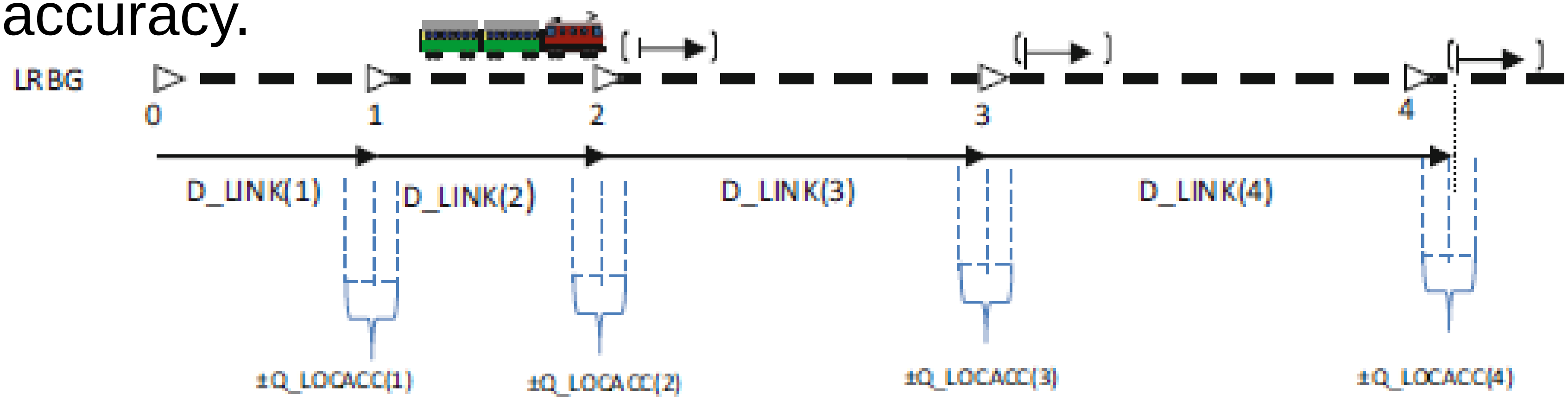


European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Scope of Balise Linking

The concept of linking can be used for:

- Determining whether a **BG** (i.e. its location reference) has been **missed** or **not found within the expectation window** and taking the **appropriate action**;
- **Assigning** a **coordinate system** to BGs consisting of **single** balises;
- Correcting the **train confidence interval** due to odometer inaccuracy.



European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

An **unlinked** BG contains information that must be processed by an on-board ETCS even when the **BG is not announced by linking**. Unlinked BGs consist **at minimum of two balises**.

Unlinked Balise Groups can never be used as Last Relevant Balise Group (LRBG). The LRBG is used as a common location reference between the ERTMS/ETCS on-board and trackside equipment in Levels 2 & 3

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

When no linking information is used **on-board**, on-board takes into account **all balise groups** (i.e. marked as linked or marked as unlinked).

When linking information is used on-board, **only** the following BGs are taken into account:

- balise groups marked as **linked and included in the linking information** and
- balise groups marked as **unlinked**

The BGs marked as linked and not included in the linking information are ignored.

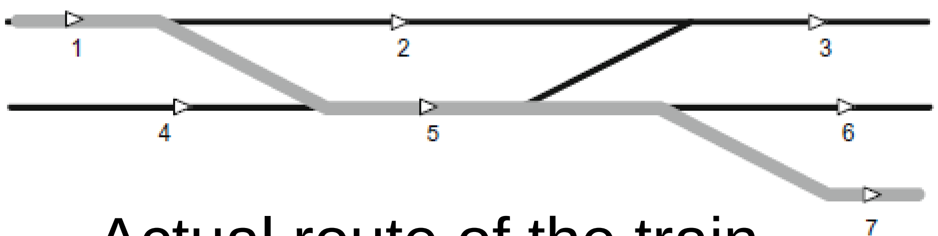
European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

For **each linked BG**, the **trackside** is responsible for commanding one of the following reactions to be used in case of data inconsistencies:

- **Train trip** (In general, train trip is initiated when a train erroneously passes a specified location, e.g. End Of Authority/Limit Of Authority);
- **Command service brake**;
- **No linking reaction**.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

The determination of the **train position** is **always longitudinal along the route**, even though the route might be set by the interlocking through a complex track layout.



Actual route of the train

Route known by the train

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

The **train position information** computed on-board defines the position of the **train front in relation to a Balise Group**, which is called Last Relevant Balise Group (LRBG).

Train position information includes:

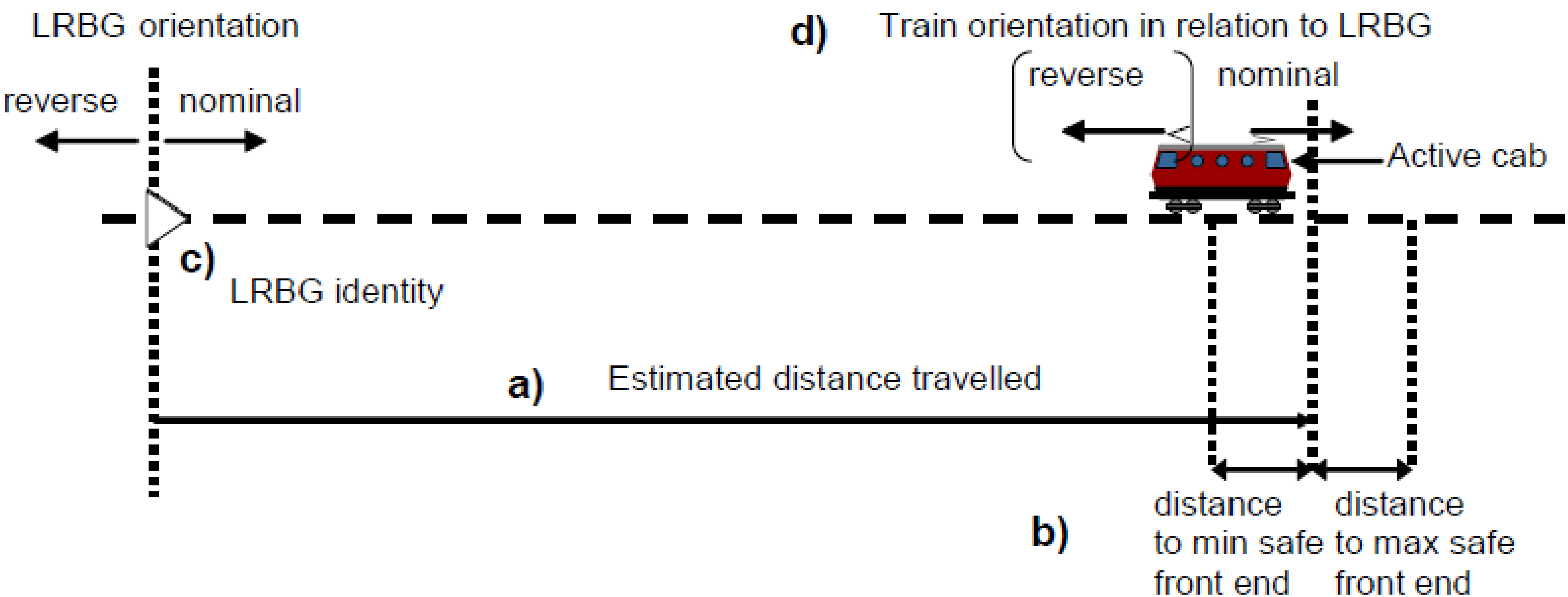
- The **estimated train front-end position** by on-board, defined by the **estimated distance measurement** (from the odometry function) between the LRBG and the front end of the train;
- The **train position confidence interval**;

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Train position information includes:

- **Directional train position information** in reference to the Balise Group orientation of the LRBG, regarding:
  - ✓ the position of the train front end (nominal or reverse side of the LRBG),
  - ✓ the train orientation. The "train orientation relative to LRBG" is defined as the train orientation with respect to the orientation of the LRBG. It can be either "nominal" or "reverse",
  - ✓ the train running direction;
- A **list of LRBGs**, which may alternatively be used by trackside for referencing location dependent information.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)



European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Wheel Sensors

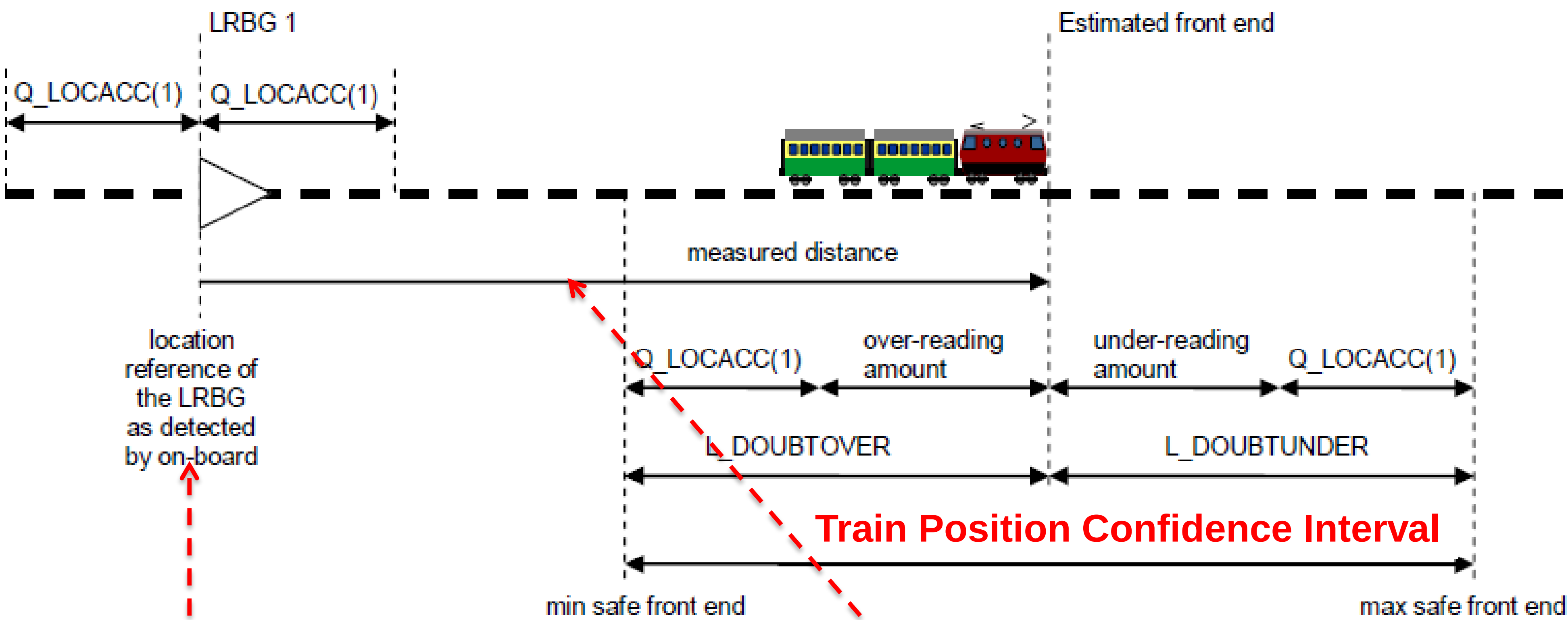
Odometry computes the travelled distance (relative measure) and the speed from the data measured by **angular speed sensors** positioned on independent wheels or a **combination** of more sophisticated **multi-kinematics** sensors.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

The **train front-end position** is identified by the on-board equipment in the following way:

- The **estimated front-end position**;
- The **maximum safe front-end position**, differing from the estimated front-end position by the **under-reading amount** in the distance measured from the LRBG plus the **LRBG location accuracy** (i.e. in relation to the orientation of the train this position is in advance of the estimated position);
- The **minimum safe front-end position**, differing from the estimated front-end position by the **over-reading amount** in the distance measured from the LRBG plus the **LRBG location accuracy** (i.e. in relation to the orientation of the train this position is in rear of the estimated position).

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)



Measurement Error in the Location of the Reference Balise ≤ ±1 m (in all conditions) [Subset 036]

Measurement Error in the measured travelled distance *s* (on-board fault-free conditions) due to <u>odometry only</u> [Subset 041] ≤ ± (4 m + 5% * *s*)

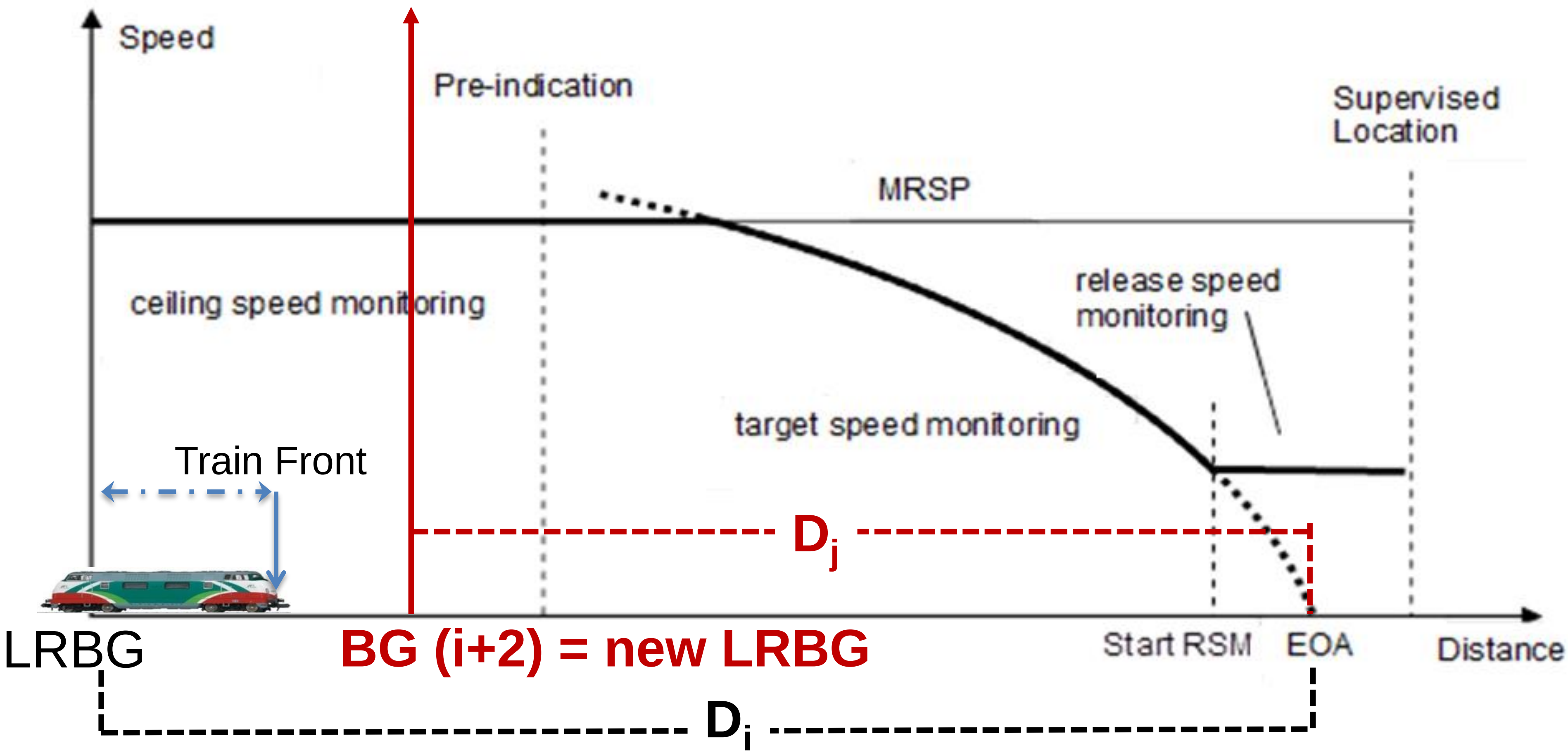
European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Inaccuracies in the Distance Measurement ≤ ±[Maximum Detection Position Error of the Reference Balise (in all conditions) + Maximum Odometry Error] = ± [1m + (4 m + 5% measured travelled distance)] [Subset 036, v310; Subset 041, v320]

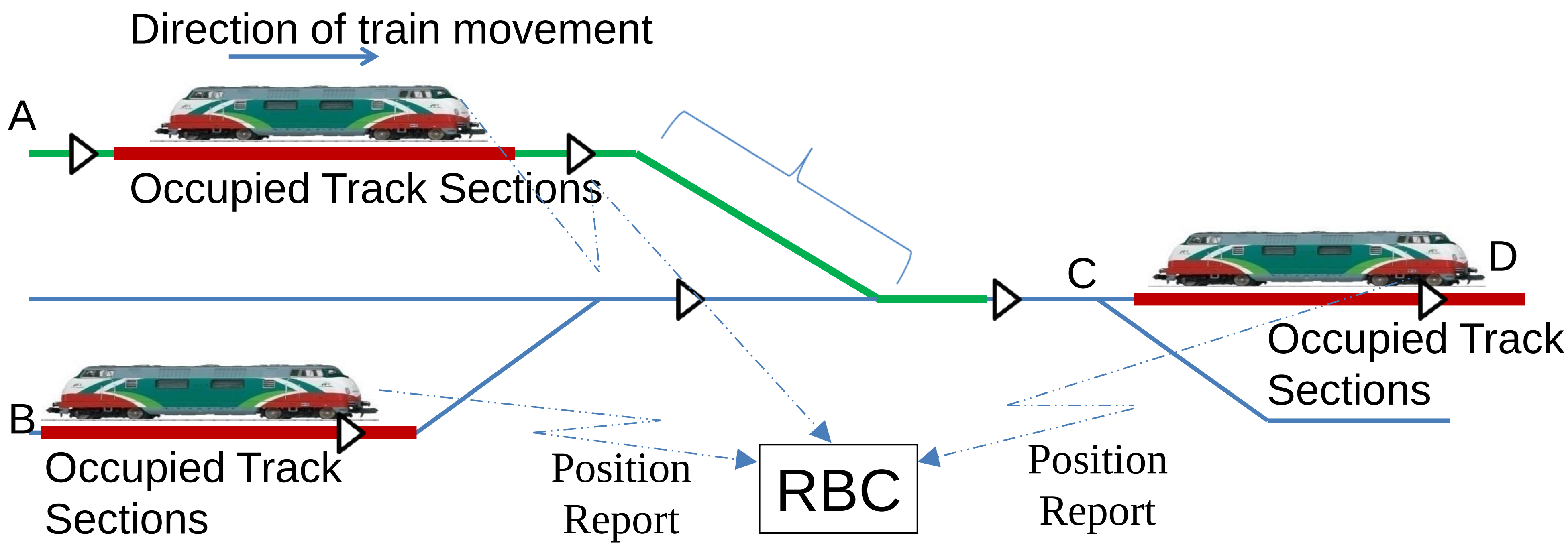
Inaccuracies in the Train Position Confidence Interval ≤ ±[Q_LOCACC(LRBG) + 1m + (4 m + 5% measured travelled distance)] [Subset 026, V360; Subset 041, v320]

Note: If the reference balise is duplicated, it is the trackside responsibility to define the location accuracy to cover at least the location of the two duplicated balises.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)



European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)



In Level 2, RBC **determines** movement authorities for **each train individually** according to the **underlying signalling system** and to **the train position reports**, and **transmits** movement authorities and track description to **each train individually**.

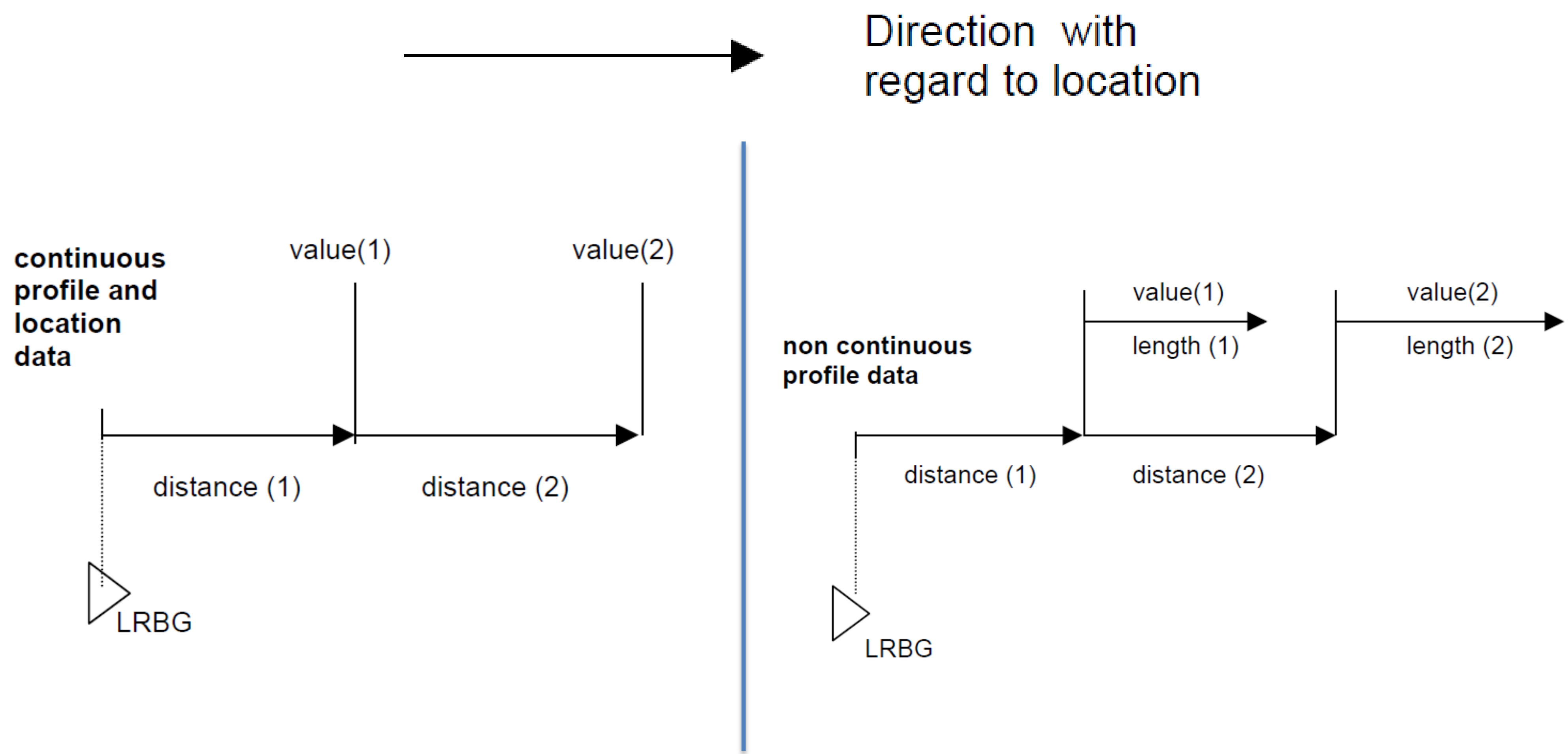
European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

With regard to location principles, ERTMS/ETCS identifies two types of data:

- Data that refer only to a given location, referred to as **location data** (e.g. level transition orders, linking);
- Data that remain valid for a certain distance, referred to as **profile data** (e.g. static speed profile, gradients).

All location and profile data transmitted by trackside **refer to the location reference** and **orientation** of a **well specified Balise Group**.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)



European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

All **location-related information** transmitted from trackside are used by the on-board equipment taking into account the train position **confidence interval**, if required for safe operation.

This train position confidence interval **refers to the distance measurement from the LRBG** and is a function of the following terms:

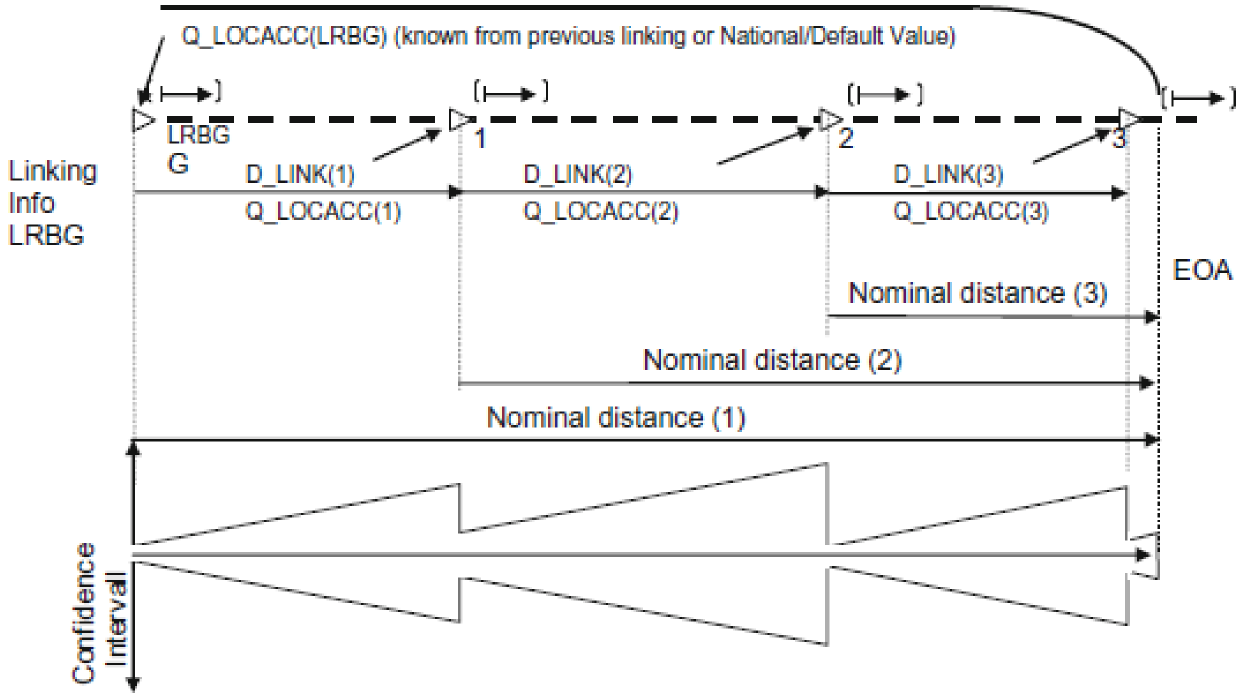
- **On-board over-reading amount** and **under-reading amount** (odometer accuracy plus the error in the detection of the Balise Group location reference);
- The **LRBG location** accuracy, a **fixed value** estimated during the **signalling design phase** and **verified** by means of the measurement at the time of balise installation.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

Based on the odometry error which is assumed and modelled as proportional to the train travelled distance, the **train position confidence interval increases** in relation to the distance travelled from LRBG **until it is reset** when another linked Balise Group becomes the LRBG

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

It is always the **trackside responsibility** to provide linking in due course or, where linking is not provided, the trackside can include provisions, if deemed necessary, during the signalling design phase for including such provisions in the distance information.



Confidence Interval = Function [Q_LOCACC; Odometer Error]

When the ERTMS/ETCS on-board has read the Balise Group 1

- the Confidence Interval is reset taking into account the location accuracy of Balise Group 1, and on-board tolerances when determining the reference location of the Balise Group,
- the nominal distance to EOA is relocated by subtracting D_LINK (1) from nominal distance (1), resulting in nominal distance (2). (Nominal distance (1) may be the distance to EOA received in the MA or the result of a previous relocation.)

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

On-Board Rules for Accepting Linked Balises

Due to the location accuracies of both the LRBG and the announced Balise Group, the space interval between the first possible location and the last possible location to accept the Balise Group defines the **expectation window**.

The on-board equipment accepts a Balise Group (i.e. the balise giving the location reference) marked as **linked** and **included in the linking information** from

- when the **max safe front end** of the train has passed the **first** possible location of the Balise Group until
- the **min safe front end** of the train has passed the last possible location of the Balise Group taking the offset between the front of the train and the balise antenna into account.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

On-Board Rules for Accepting Linked Balises

If linking information is used, the on-board reacts according to the linking reaction information in the following cases:

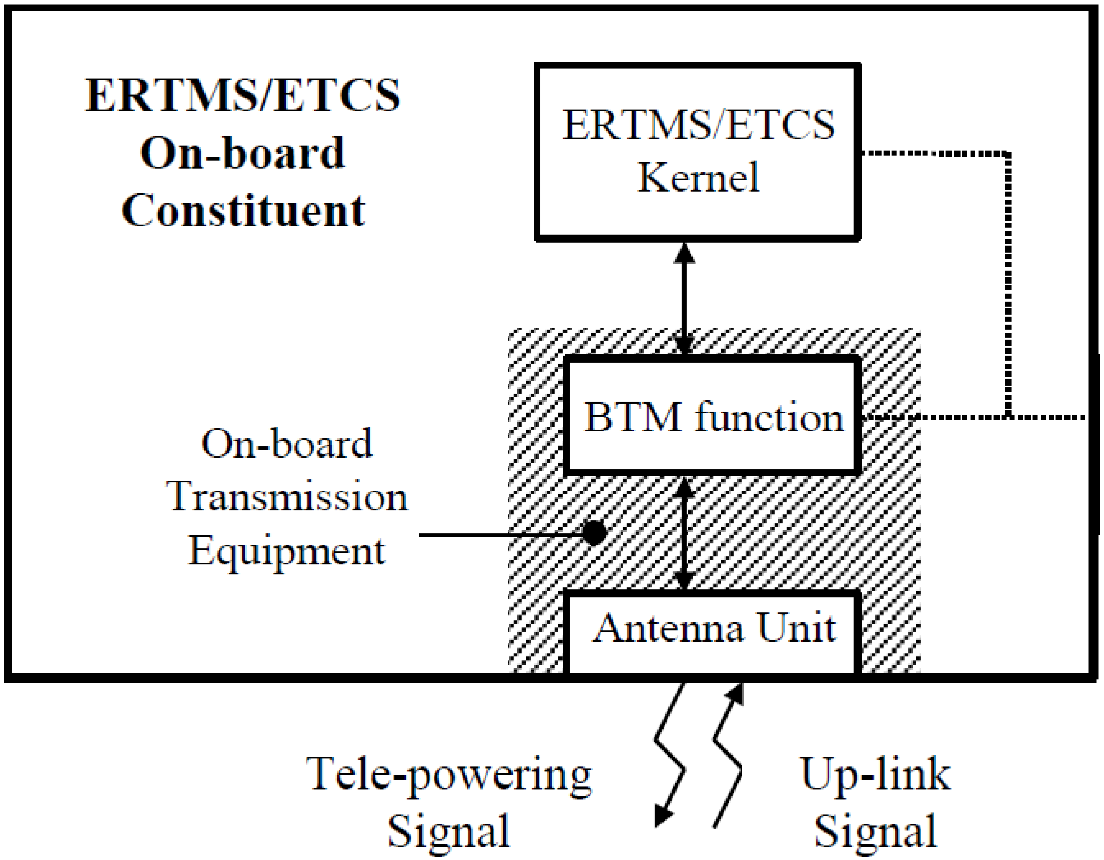
- If the location reference of the expected BG is found **in rear** of the expectation window;
- If the location reference of the expected BG is **not found** inside the expectation window (i.e. the end of the expectation window has been reached without having found the expected BG);
- If inside the expectation window of the expected BG **another announced BG** (i.e. another Balise Group included in the linking information), expected later, is found.

European Rail Traffic Management System (ERTMS): Location Principles and Train Position (cont.)

On-Board Rules for Accepting Linked Balises

Independently of the linking reaction set by trackside, if **two consecutive linked BGs** announced by linking information are not detected and the **end** of the expectation window of the second Balise Group has been **passed**, the ERTMS/ETCS on-board **commands the service brake** and the driver is informed. At standstill, the location-based information (i.e. location data, this is the set of the data that refer only to specific locations) stored on-board shall be shortened to the current position determined by the train odometry.

ERTMS Position Performance and Safety Requirements



The location error shall be within ±1 m for each Balise, when a Balise has been passed [Subset 036, v310].

Note: 1 m is the maximum absolute error.

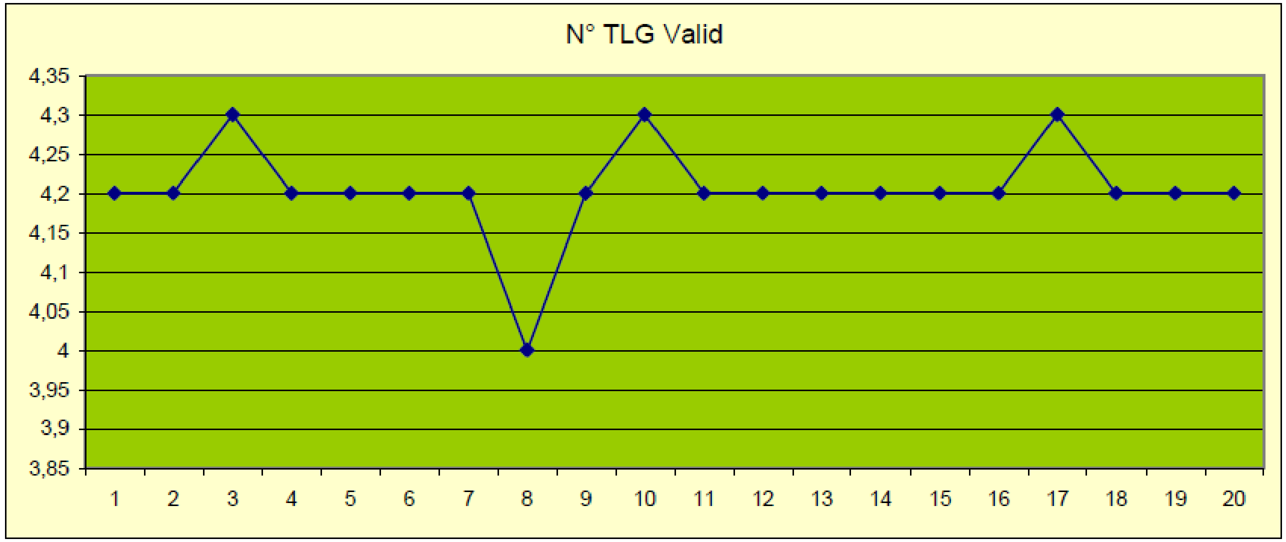
ERTMS Position Performance and Safety Requirements (cont.)

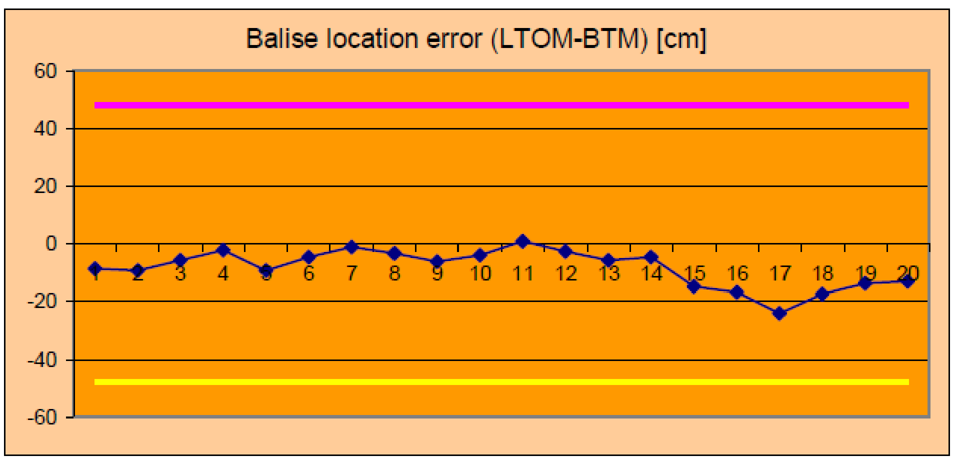
Debris defined for the Eurobalise [Subset 036, v310]

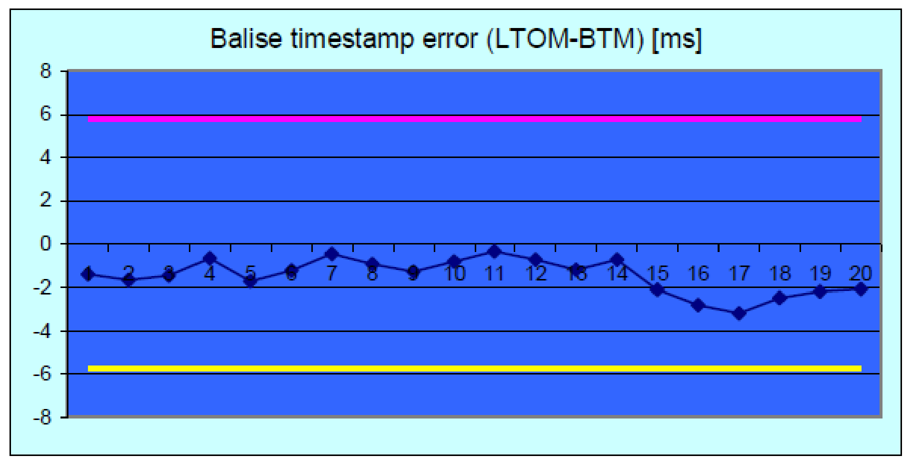
Material	Description	Layer on top of Balise, [mm]	
		Class B	Class A
Water	Clear	100	200
	0.1 % NaCl (weight)	10	100
Snow	Fresh, 0 °C	300 (Note [36])	300 (Note [36])
	Wet, 20 % water	300 (Note [36])	300 (Note [36])
Ice	Non porous	100	100
Ballast	Stone	100	100
Sand	Dry	20	20
	Wet	20	20
Mud	Without salt water	50	50
	With salt water, 0.5 % NaCl (weight)	10	50
Iron Ore	Hematite (Fe_2O_3)	20	20
	Magnetite (Fe_3O_4)	2	20
Iron dust [37]	Braking dust	10	10
Coal dust	8 % sulphur	10	10
Oil and Grease		50	50

±1m guaranteed also under the debris conditions as specified in sections B5.2.2 and B5.2.3 of SUBSET-085.

Date:	28/02/2012 14.29
Debris:	Free Air
Speed:	300
Reference Loop:	Reduced TRV
Balise	Weak
Telegram	18
Height	Zmax
Lateral deviation	60 mm
Operator	
File name	TestRep_2012_02_2

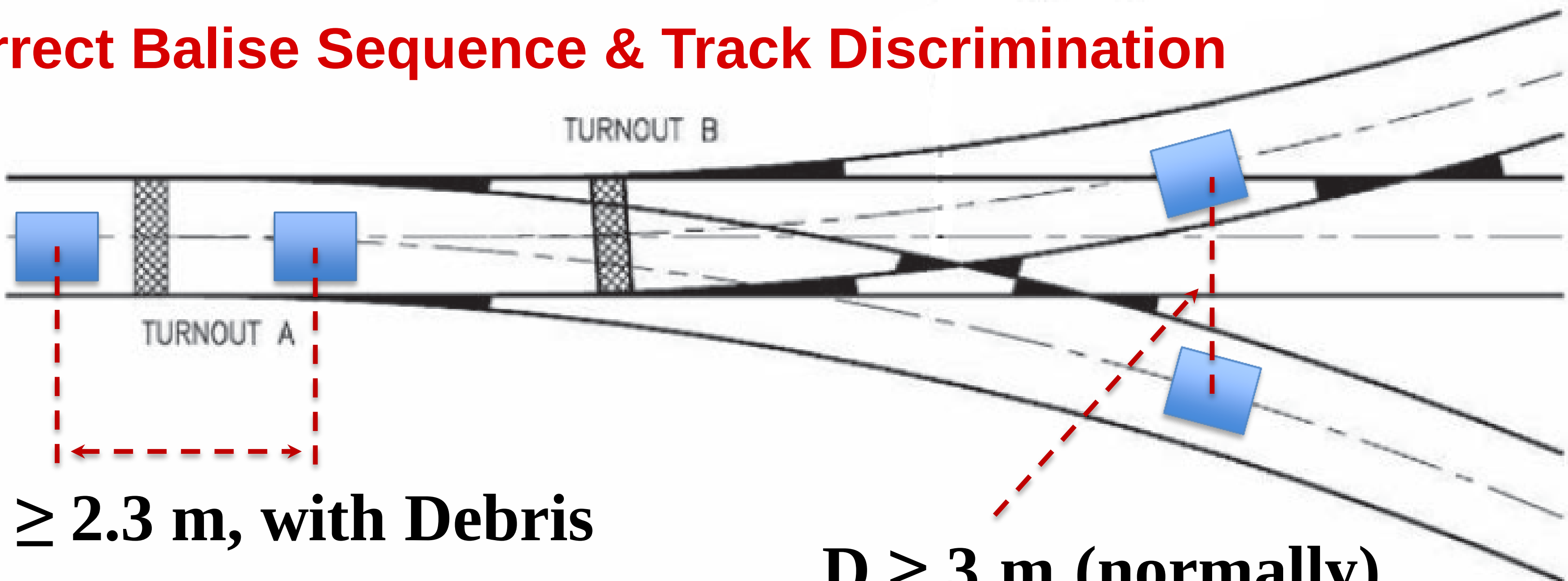






ERTMS Position Performance and Safety Requirements (cont.)

Correct Balise Sequence & Track Discrimination



D ≥ 2.3 m, with Debris

(to delivery information with the correct sequence)

D ≥ 3 m (normally), with Debris

Target THR = 1E-9 / h (Subset 091)

ERTMS Position Performance and Safety Requirements (cont.)

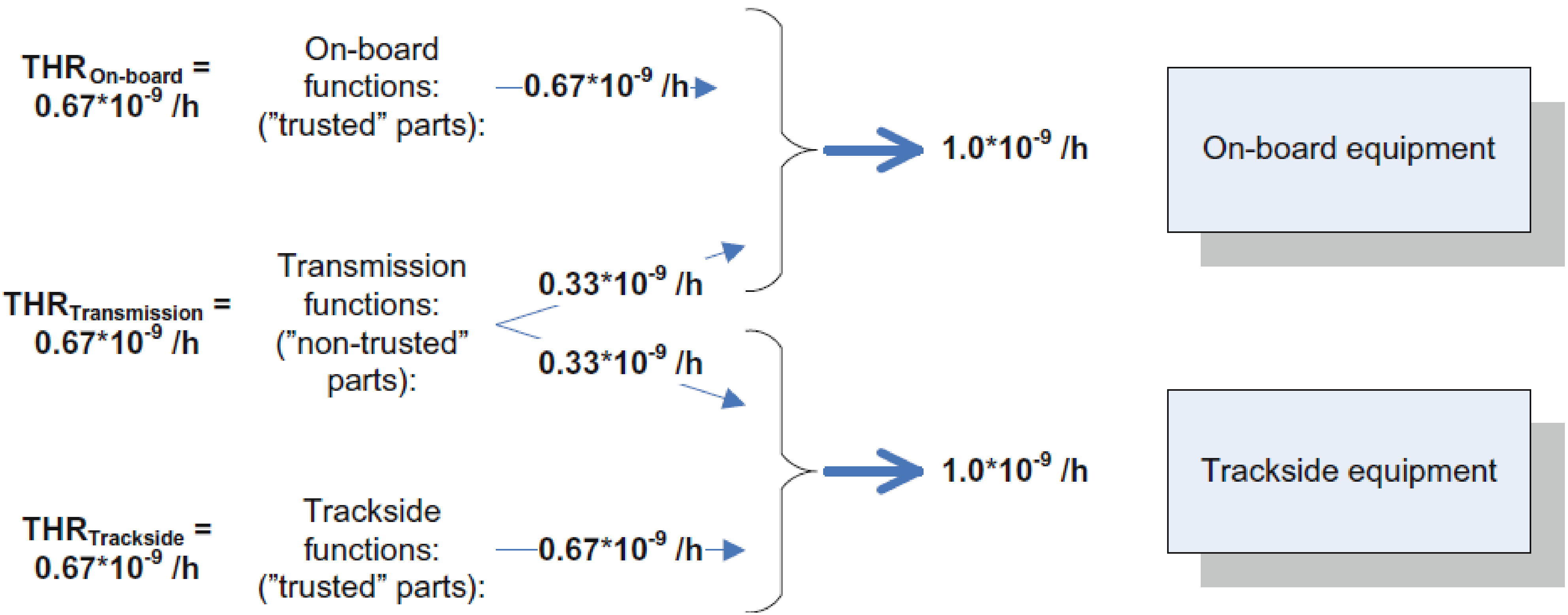
The role of ETCS as train protection:

To provide the Driver with information to allow him to drive the train safely and to enforce respect of this information to the extent advised to ETCS.

The **ETCS Core Hazard** for the reference architecture is defined as:

Exceedance of the safe speed or distance as advised to ETCS.

The maximum allowed rate of occurrence of the ETCS Core Hazard is 1.0*10-9 / hour for ETCS onboard installed on a train and 1.0*10-9 / hour for ETCS trackside installed in an area visited by a train during a reference mission.



Outline (cont.)

To arrive to:

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Market Needs: a Cost Effective Solution

- Competitive, cost **effective** and **safe** railways signaling solutions suitable for **local** and **regional lines.** The current standard requires a huge amount of investment;
- Improvement of Operational Requirements (i.e. **Intrusiveness** and **Schedule Adherence**);
- **Interoperable** and **Standards**;
- Railways signalling solutions suitable for **hostile environments** (e.g. extreme climates, hard to reach, high mechanical stress, …);
- Robustness with respect to **cybersecurity requirements**.

ERA ERTMS Roadmap Specification Evolution

Evolution in the ERTMS Specifications Roadmap

The users have been requested to identify the main contributors (potential ‘**game changers**’) which can have a significant impact on the **ERTMS business case** (due to significant increase in operational performance and/or due to significant cost reduction for the overall ERTMS system).

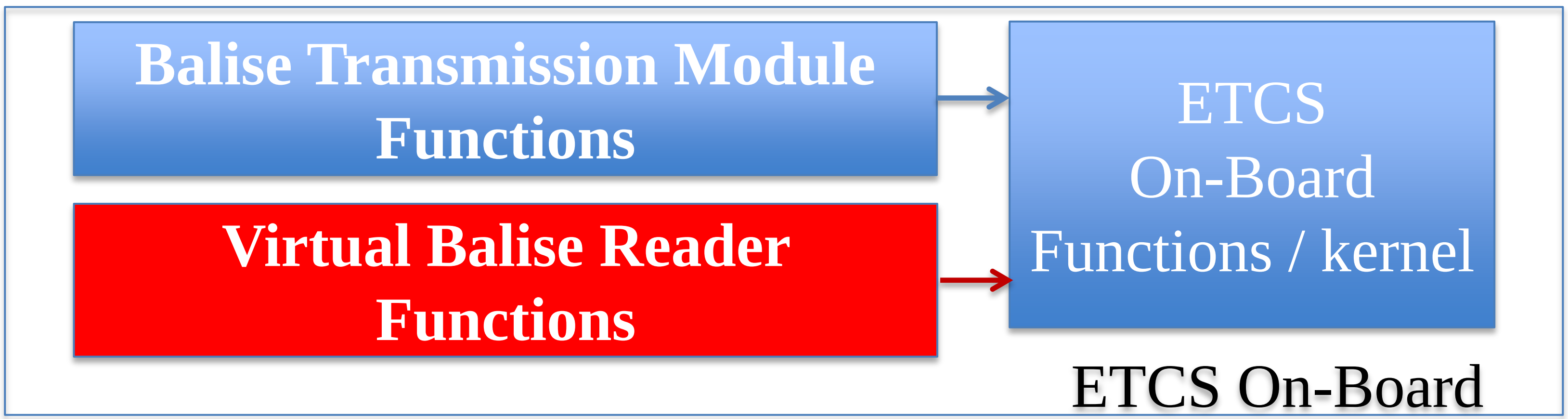
ERA ERTMS Roadmap Specification Evolution (cont.)

Main contributor	**Impact - Business case**
ETCS L3	Potential increase of capacity and/or reduction of trackside life cycle costs due to less train detection systems to be installed;
ATO	Potential reduction in energy consumption costs and/or increase in capacity due to optimal train speed setting and/or more robustness in operation (better respect of timeplan);
Braking curves model	Increase of capacity due to further optimisation/balancing the safety and capacity requirements in different operational scenarios;
Next Generation Communication System(s)	Obsolescence management and potential reduction in costs due to non dedicated railway radio communication technology/network model and/or potential use of capacity increase due to increased spectrum efficiency;
Satellite positioning	Potential reduction in deployment and maintenance of balises and improved performance due to more accurate odometry;

Innovative Solutions Based on the Concept of Virtual Balise

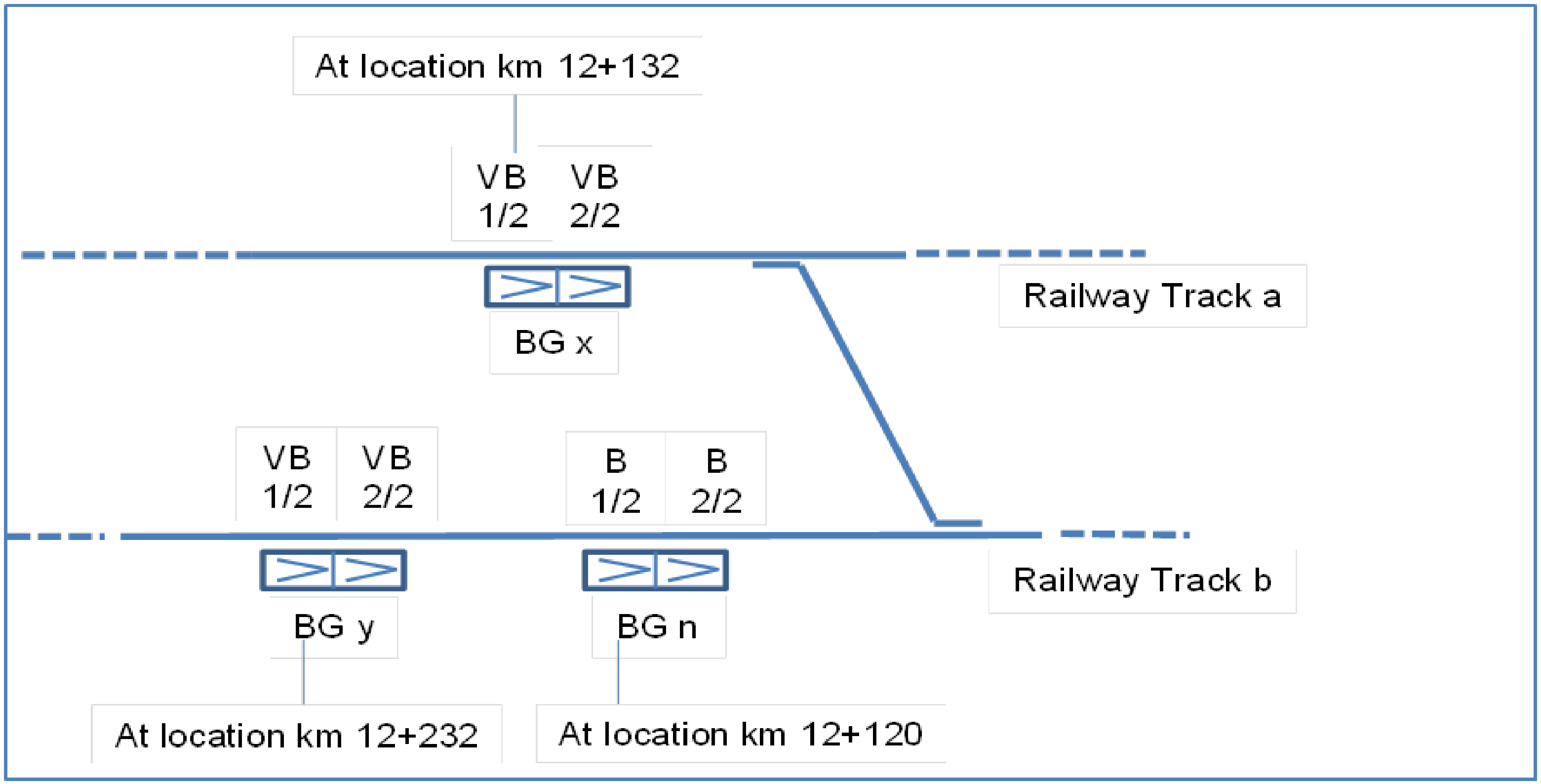
To reduce the **modifications** to the existing ERTMS Standard, the identified solution preserves the existing ERTMS principles to determine the Train Position, i.e. **Balises**, the **related functions** (e.g. liking), and the relative **measured distance** by odometer.

The **virtual balise concept** has been introduced and the use of **IP-based Radio TLC Networks** have been foreseen.

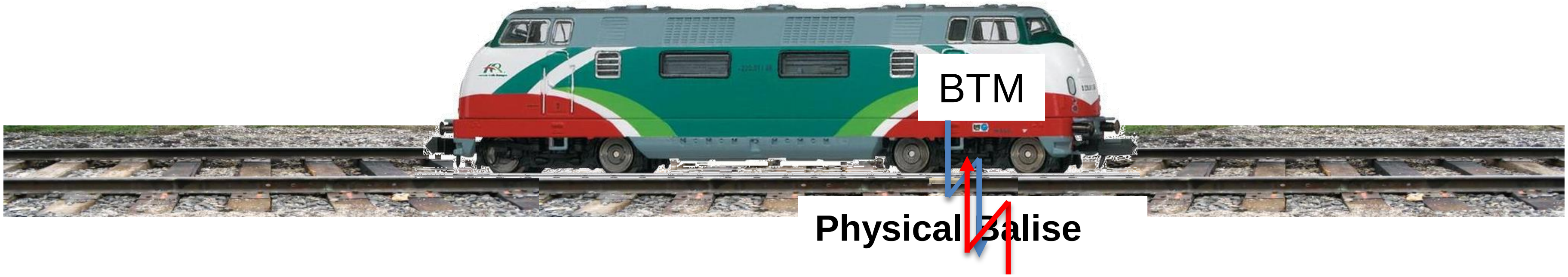


Innovative Solutions Based on the Concept of Virtual Balise (cont.)

The **virtual balise** is an **abstract data type** capable of storing the fixed Eurobalise user bits associated with a balise telegram.



Innovative Solutions Based on the Concept of Virtual Balise (cont.)



BTM provides:

- User Bits
- Nominal Balise Location (e.g. km 12+132)
- Max/Min Balise Detection Error = +/- 1m

GNSS Position matches the VB Position on the track

VBR provides:

- User Bits
- Nominal Balise Location (e.g. km 12+132)
- Max/Min Balise Detection Error = f(**Prot. Level**, …)

Innovative Solutions Based on the Concept of Virtual Balise (cont.)

To **trust** on the GNSS PVT, the use of **GNSS receiver stand alone is NOT enough**.

An Augmentation System is **required**: the **integrity** information is mandatory for safe applications

	Accuracy		Integrity				Continuity
GBAS Service Level	Lateral NSE Accuracy 95% (1)(3)	Vertical NSE Accuracy 95% (1)(3)	Integrity Probability (2) (4)	Time to alert (6)	Lateral Alert Limit (1)	Vertical Alert Limit (1)	Continuity Probability
GSL A	16.0 m (52 ft)	20 m (66 ft)	1-2x10^{-7} in any 150 sec	10 s	40.0 m (130 ft)	50 m (160 ft)	1-8x10^{-6} in any 15 s
GSL B	16.0 m (52 ft)	8.0 m (26 ft)	1-2x10^{-7} in any 150 sec	6 s	40.0 m (130 ft)	20 m (66 ft)	1-8x10^{-6} in any 15 s

Innovative Solutions Based on the Concept of Virtual Balise (cont.)

[RTCA DO-229D, Appendix E] **Integrity**. Integrity is the **measure** of **trust** that can be placed in the correctness of the information supplied by the total GNSS system.

Integrity includes the ability of the system to provide **timely** and **valid warnings** to the user (alerts) when the system should **not** be used for the **intended operation**.

Integrity requirements for positioning include three elements: (1) the **probability** that the position error is larger than can be tolerated without annunciation, (2) the **length of time** (time to alert) the error can be out-of-tolerance prior to annunciation and (3) the **size of the error** (alert limit) that determines the out-of-tolerance condition.

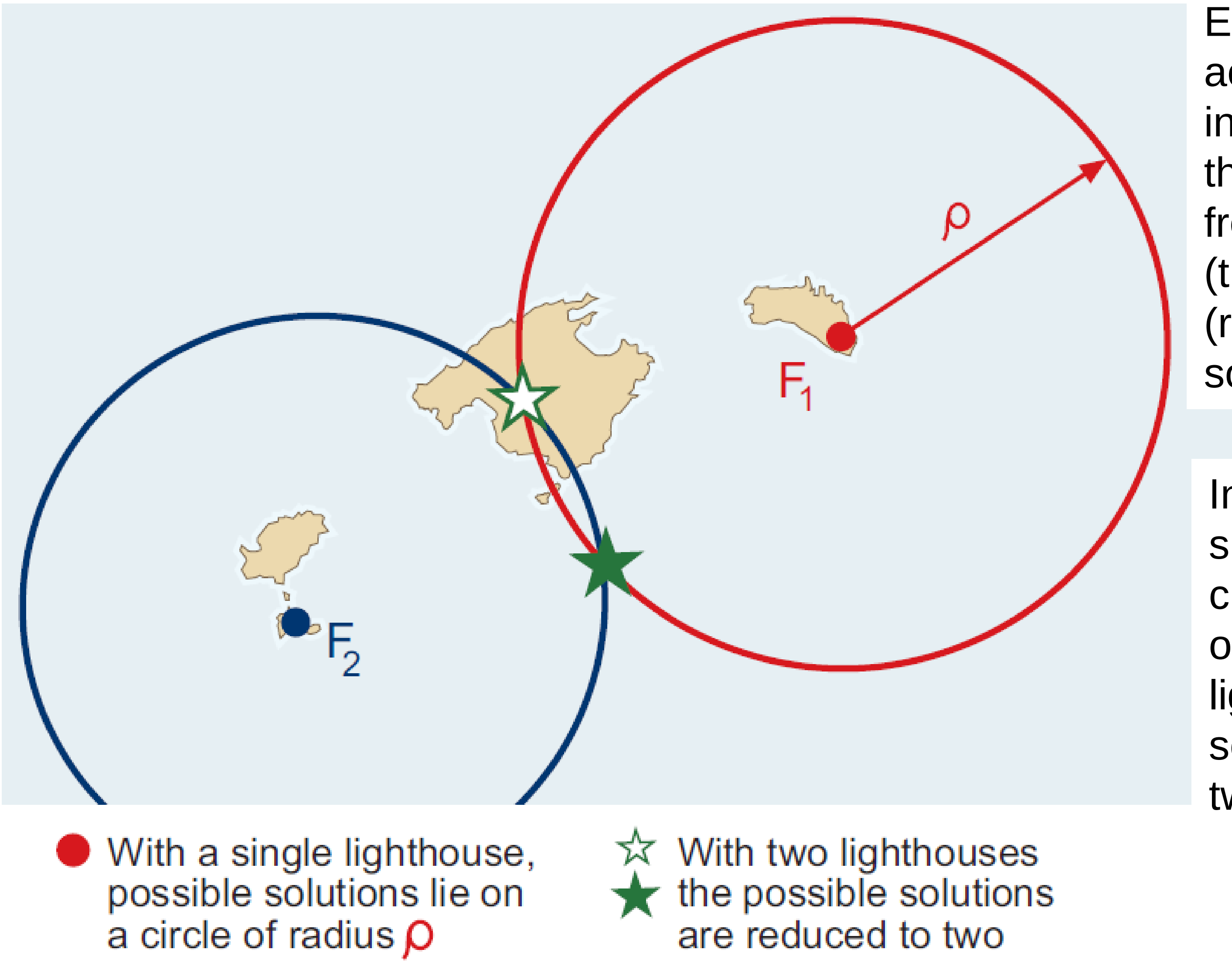
At signal-in-space (SIS) level, the out-of-tolerance condition is a position error that exceeds the alert limit for longer than the SIS time to alert. The true error position cannot be known.

GNSS Principles and GNSS Augmentation Systems

The positioning principle is based on solving an elemental geometric problem, involving the **distances** (**ranges**) of a user to a set of **at least four** GNSS satellites with **known coordinates**. These ranges and satellite coordinates are determined by the user's receiver using signals and navigation data transmitted by the satellites

The basic observable in a GNSS is the **time** required for a signal to travel from the satellite (transmitter) to the receiver. This travel time, multiplied by the **speed of light**, provides a measure of the **apparent distance** (**pseudorange**) between them.

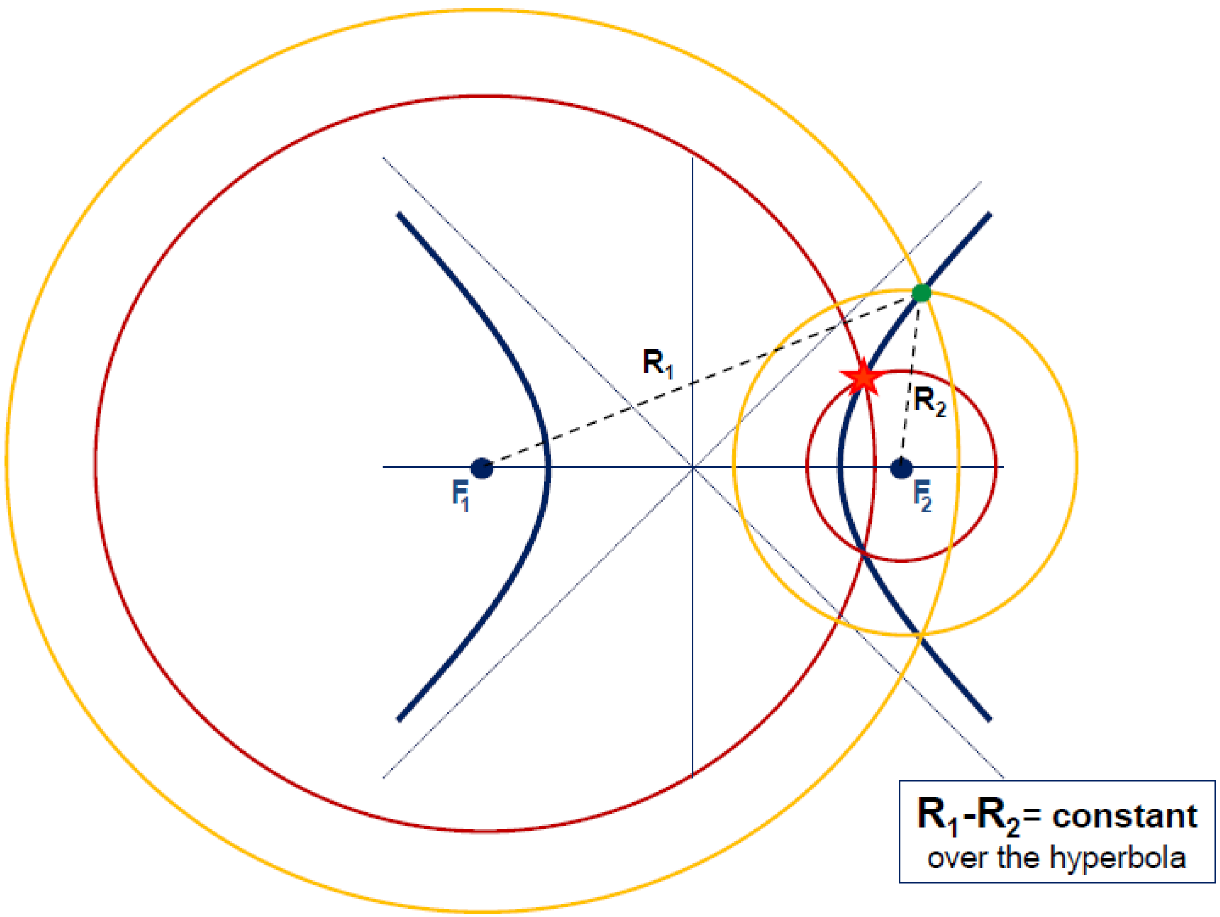
GNSS Principles and GNSS Augmentation Systems (cont.)



Each lighthouse is emitting acoustic signals at regular intervals and Δt correspond to the propagation time of sound from the lighthouse (transmitter) to the ship (receiver): $\rho = \Delta t * \text{speed of sound}$.

In 2D positioning, with a single lighthouse there is a circle of possible locations of the ship. With two lighthouses, the possible solutions are reduced to two.

GNSS Principles and GNSS Augmentation Systems (cont.)



A **synchronization error** between the lighthouse and the receiver clocks will produce an erroneous measure of signal propagation time (i.e. an error in the range measurements).

Assume that the ship's clock is biased by an **offset dt** from the lighthouse clocks (which are supposed to be fully synchronized). Then, the measured ranges, R_1 and R_2 , will be shifted by an amount **dr = v dt**:

$$\mathbf{R_1 = \rho_1 + dr, \; R_2 = \rho_1 + dr}$$

GNSS Principles and GNSS Augmentation Systems (cont.)

Translation to 3D GNSS Positioning

Satellites: In the case of lighthouses, their coordinates are assumed to be known. For GNSS satellites, the coordinates are calculated from the **navigation data (ephemeris) transmitted by the satellites**.

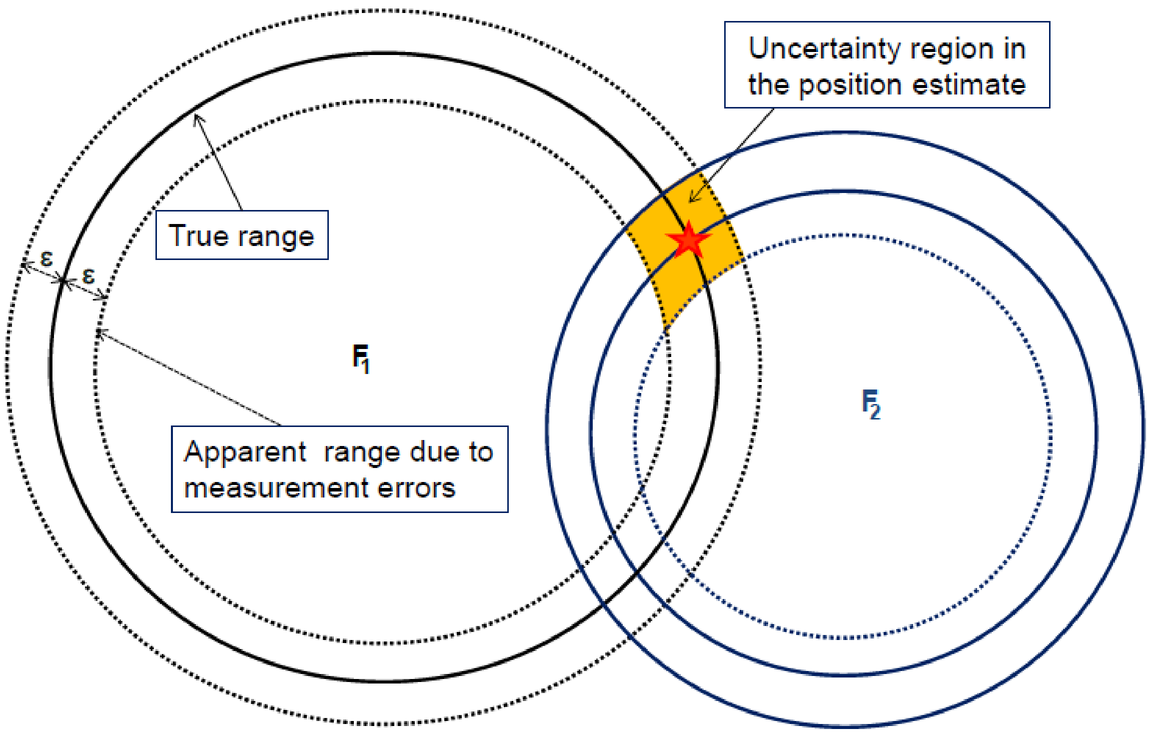
Pseudorange measurements: In GNSS positioning, the distances between the receiver and satellites are measured from the travel time of a **signal** from the satellite to the receiver.

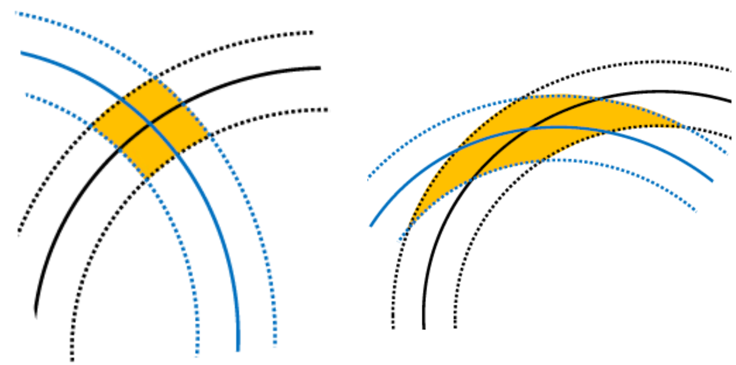
Clock synchronization: To ensure the stability of satellite clocks, GNSS satellites are equipped with atomic oscillators with high daily stabilities However, despite this high stability, satellite clocks accumulate some offsets over time. These **satellite clock offsets** are continuously estimated by the **ground segment** and **transmitted** to users to correct the measurements. The receivers are equipped with quartz-based clocks (poorer stability). This inconvenience is overcome by estimating the **clock offset** together with **the receiver coordinat**es.

GNSS Principles and GNSS Augmentation Systems (cont.)

Translation to 3D GNSS Positioning

Dilution Of Precision (DOP): The geometry of the satellites (i.e. how the user sees them) affects the positioning error.





The size and shape of the region change depending on their relative positions.

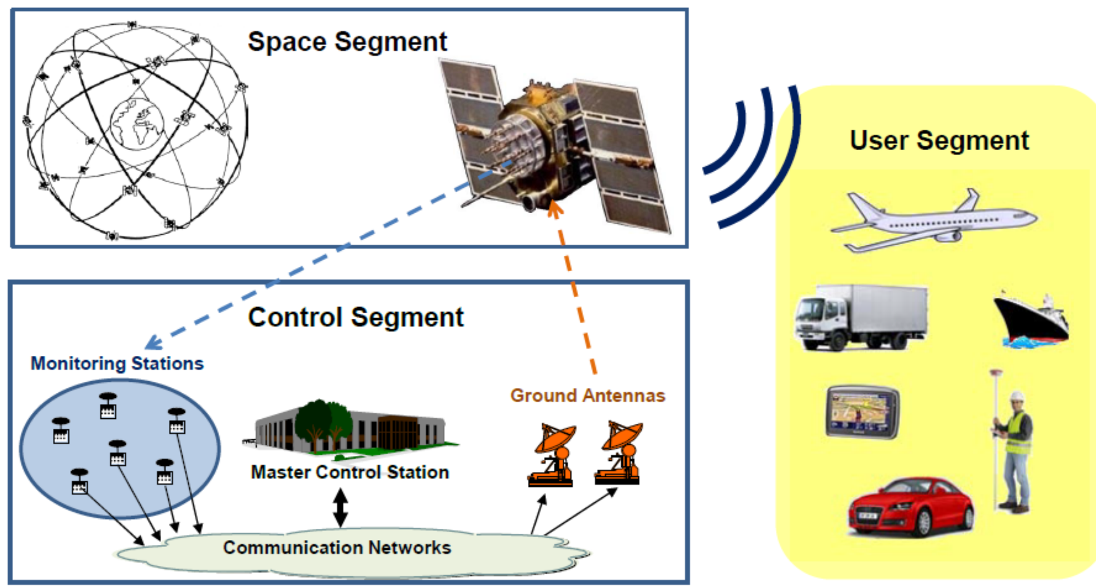
The **measurement error ε** is translated to the position estimate as an **uncertainty region**.

GNSS Principles and GNSS Augmentation Systems (cont.)

GNSS Architecture

Global Navigation Satellite System (GNSS) basically consists of **three** main segments:

- the **space segment**, which comprises the satellites;
- the **control segment** (also referred to as the ground segment), which is responsible for the proper operation of the system; and
- the **user segment**, which includes the GNSS receivers providing positioning, velocity and precise timing to users.



GNSS Principles and GNSS Augmentation Systems (cont.)

Space Segment

Main functions are to generate and transmit **code** and **carrier phase signals**, and to store and broadcast the **navigation message** uploaded by the control segment. These transmissions are controlled by highly stable atomic clocks onboard the satellites.

The GNSS space segments are formed by satellite constellations with enough satellites to ensure that users will have **at least four satellites** in view simultaneously from any point on Earth's surface at any time.

GNSS Principles and GNSS Augmentation Systems (cont.)

Control Segment

The control segment (also referred to as the ground segment) is responsible for the proper operation of the GNSS. Its basic functions are:

- to **control** and **maintain** the status and configuration of the satellite constellation;
- to **predict ephemeris** and **satellite clock evolution**;
- to **keep** the **corresponding GNSS time scale** (through atomic clocks), and
- to **update the navigation messages** for all the satellites.

GNSS Principles and GNSS Augmentation Systems (cont.)

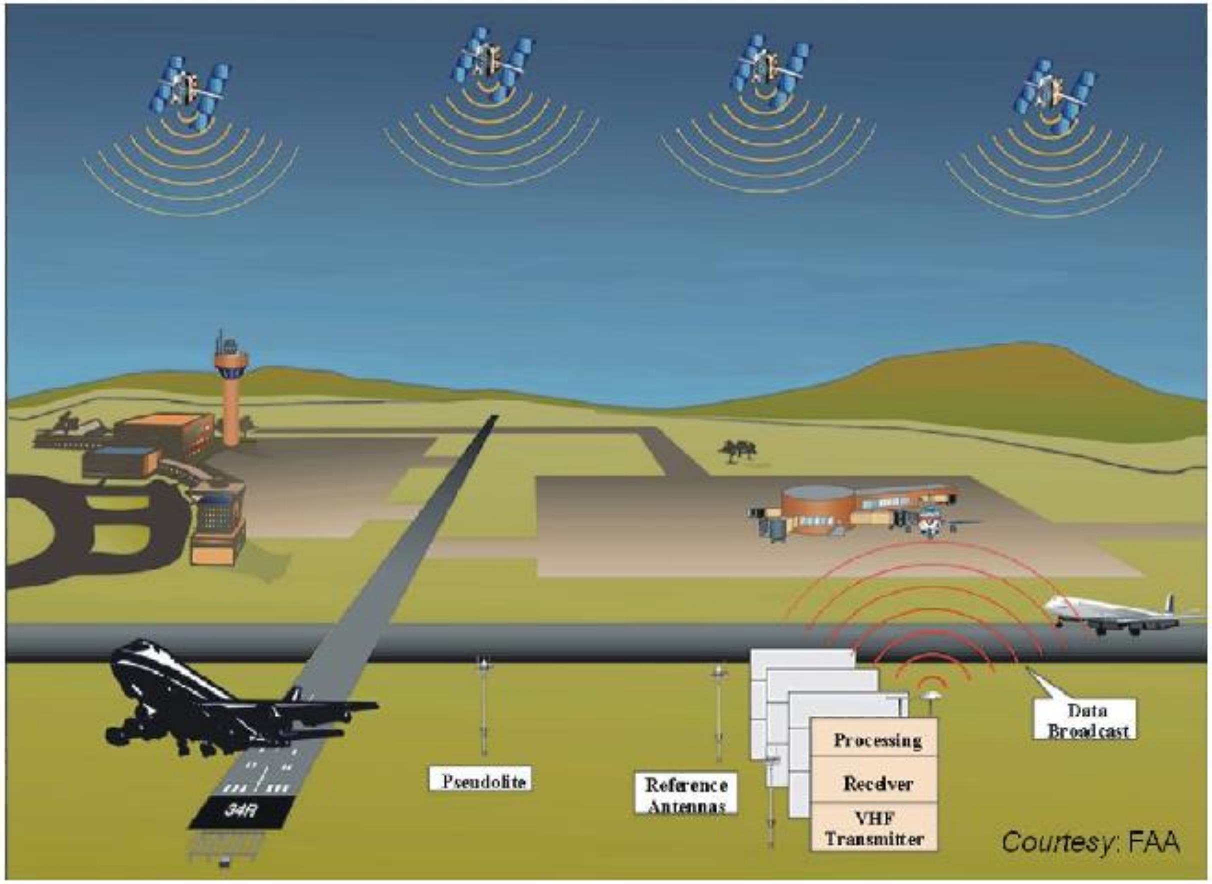
User Segment

The user segment is composed of **GNSS receivers**. Their main function is to receive **GNSS signals**, determine **pseudoranges** (and other observables) and solve the **navigation equations** to obtain the coordinates and provide a very accurate time.

The basic elements of a generic GNSS receiver are: an antenna with pre-amplification, a radio frequency section, a microprocessor, an intermediate-precision oscillator, a feeding source, some memory for data storage and an interface with the user. The calculated position is referred to the antenna phase centre.

GNSS Principles and GNSS Augmentation Systems (cont.)

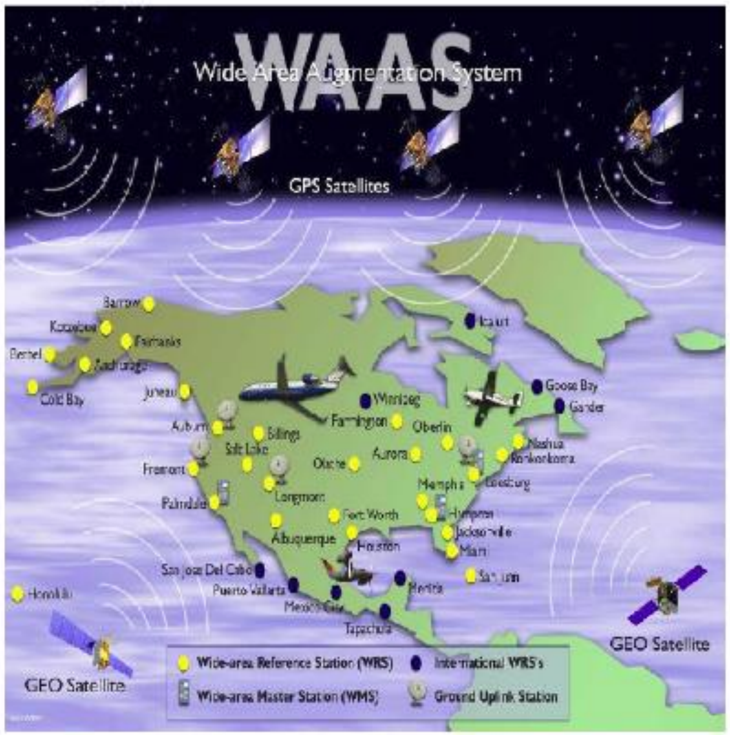
GBAS (LAAS) Architecture Pictorial



GNSS Principles and GNSS Augmentation Systems (cont.)

SBAS (WAAS) Architecture Pictorial

Source: Leo Eldredge, "WAAS and LAAS Program Status," CGSIC, Sept. 2010



38 Reference Stations

3 Master Stations

4 Ground Earth Stations

2 Geostationary Satellite Links

2 Operational Control Centers

Railway Environment: a Challenge for GNSS

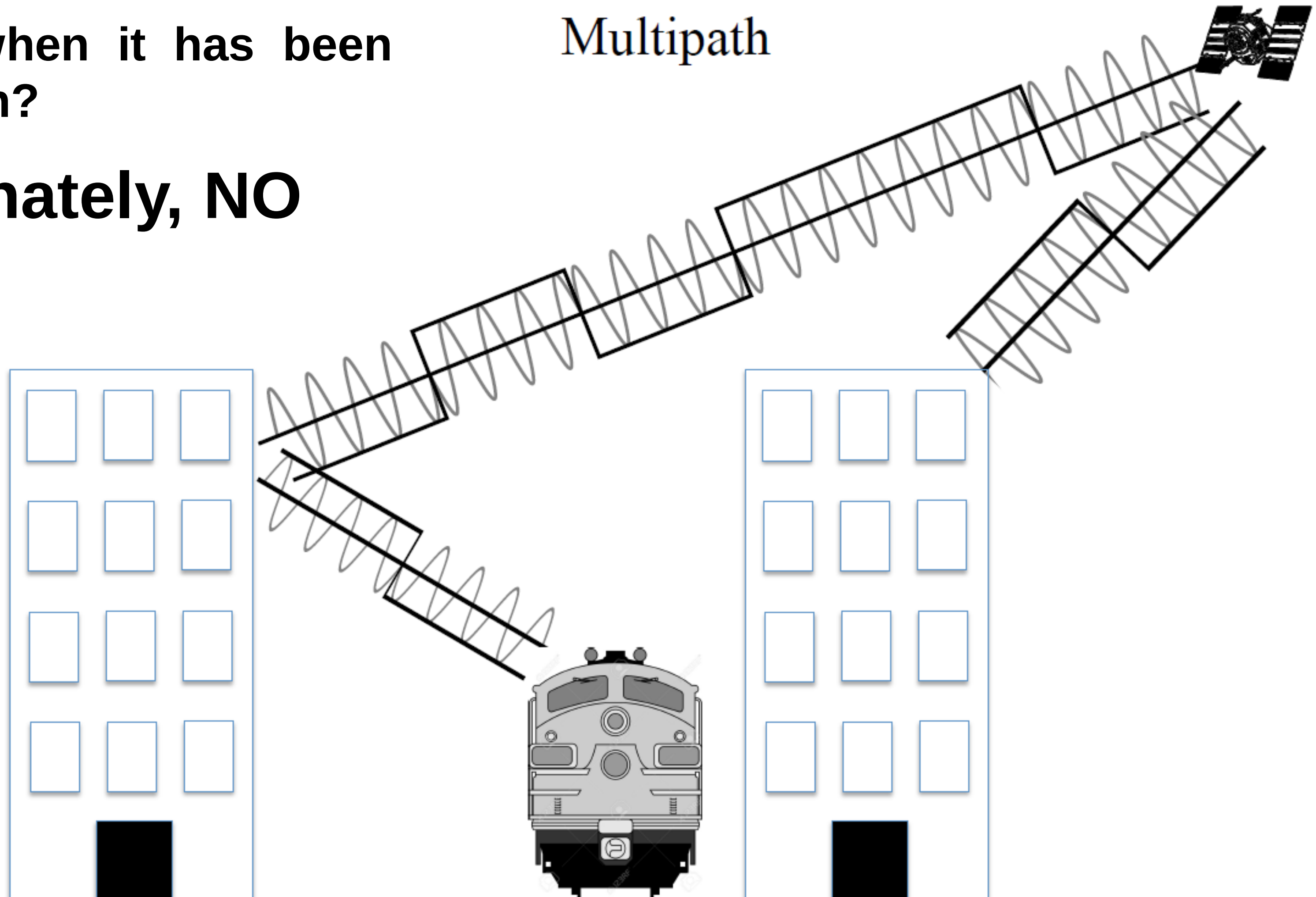
An **augmentation system** is responsible for providing **corrections** that improve GNSS positioning performance (e.g. accuracy and precision) and **barriers** that protect the estimation of the position against **system feared events** originating from the total Global Navigation Satellite System (GNSS) (i.e. the combined space and ground segments) and the ionosphere effects.

A **feared event** is any event that can lead to hazardous consequences (e.g. one or more unbounded pseudorange errors can lead to **unbounded position error**).

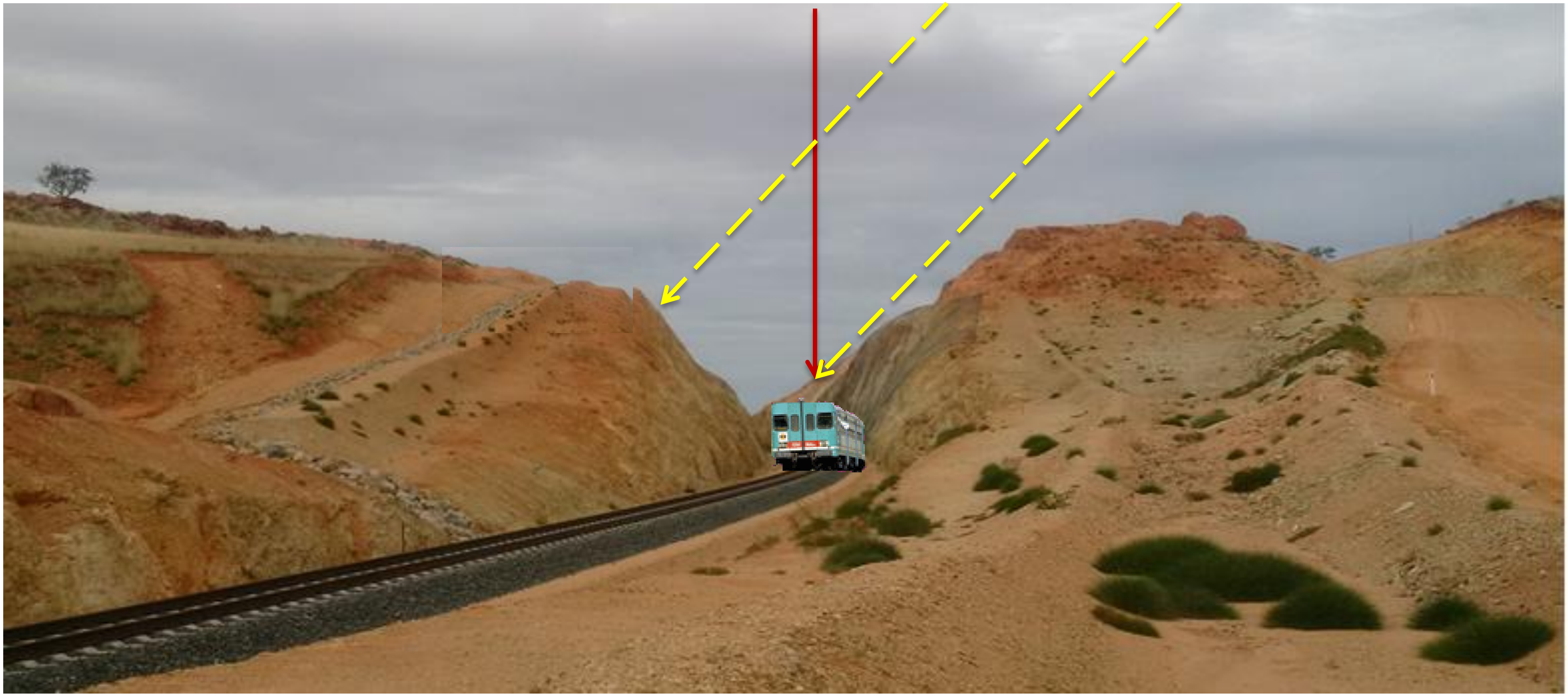
Railway Environment: a Challenge for GNSS (cont.)

Can we use when it has been done in aviation?

Unfortunately, NO



Railway Environment: a Challenge for GNSS (cont.)



Railway Environment: a Challenge for GNSS (cont.)

Multipath and Non-Line of Sight Conditions: critical issues for the on-board PNT component

Railway Environment: a Challenge for GNSS (cont.)

Intentional and/or Not Intentional Radio Frequency Interferences

Railway Environment: a Challenge for GNSS (cont.)

A **local feared event** is a feared event that may not be detectable by a large area augmentation network such as SBAS. Examples are:

- **an interference at a specific track location area**,
- a **multipath** associated with the passage of an adjacent train or obstacles,
- a **non-line-of sight phenomena** due to a bridge,
- a **tropospheric effect** in the local area where the train is moving or planned to move.

Local feared events play a **crucial** role in the railway environment because they can lead to **unbounded position errors**.

Railway Environment: a Challenge for GNSS (cont.)

CENELEC EN 50159 - Railway applications - Communication, signalling and processing systems - Safety-related communication in transmission systems

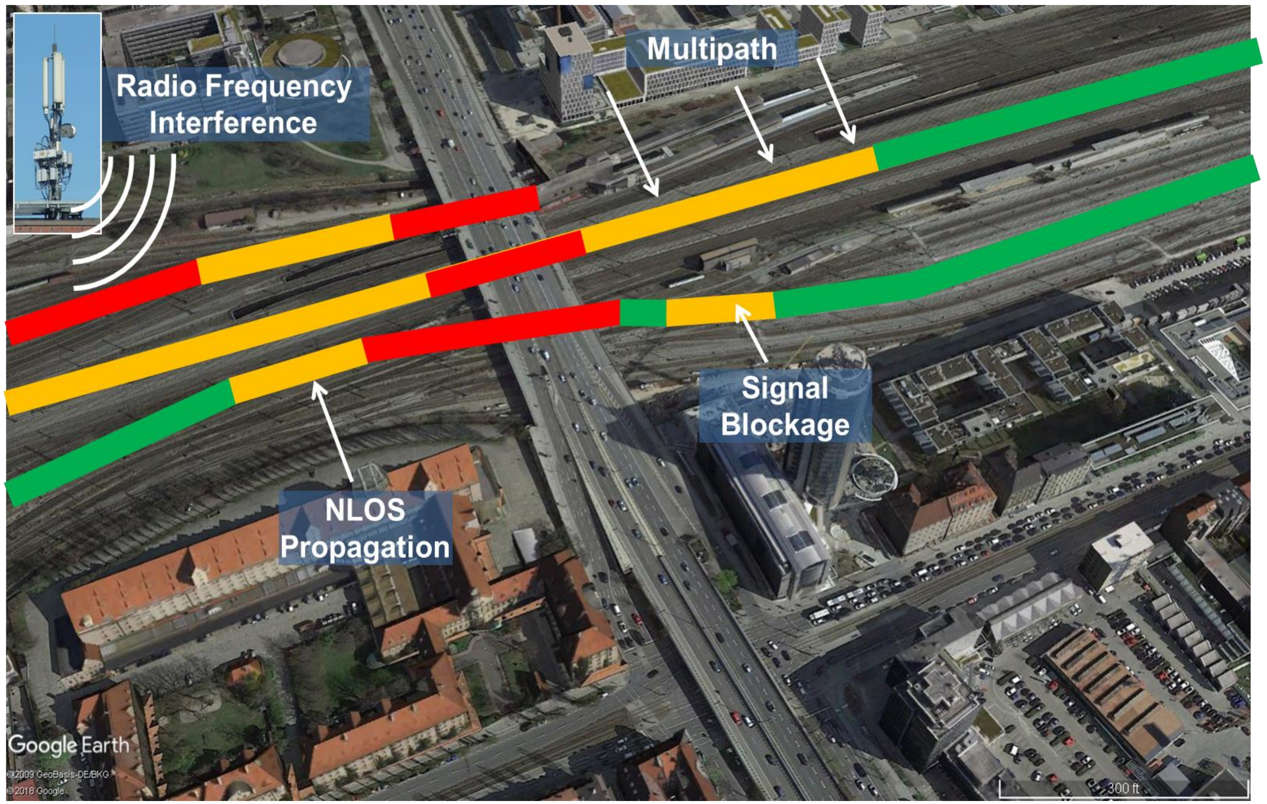
If a **safety-related electronic system** involves the transfer of information between different locations, **the transmission system** then forms an integral part of the safety-related system and it shall be shown that the end to end communication is safe in accordance with EN 50129.

The transmission system considered in this standard, which serves the transfer of information between different locations, has in general no particular preconditions to satisfy. **It is from the safety point of view not trusted, or not fully trusted**.

Railway Environment: a Challenge for GNSS (cont.)

The SECURITY must be addressed at system level, based on the Signalling Properties

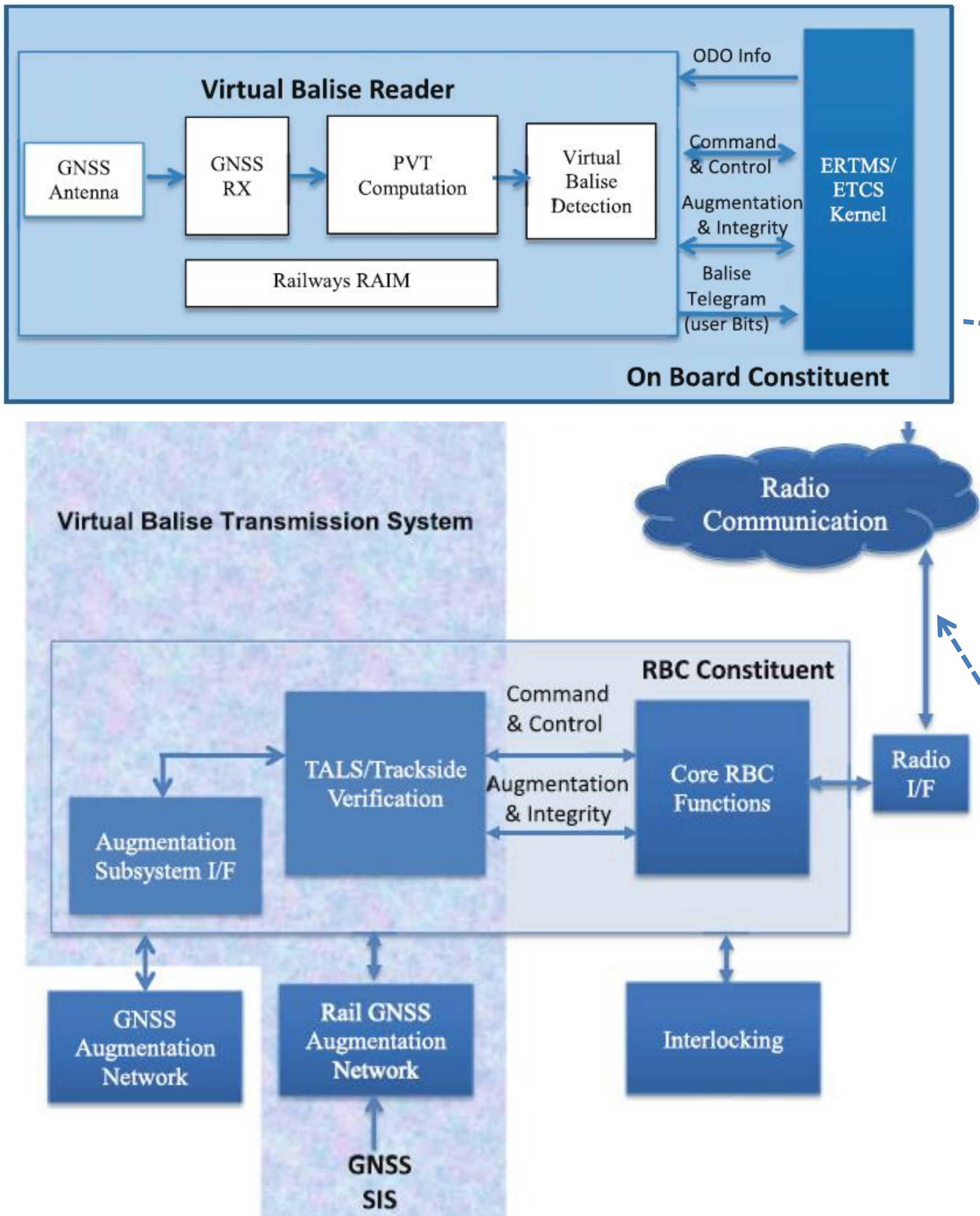
Railway Environment: a Challenge for GNSS (cont.)



The classification of track area as **suitable** or **not suitable** for locating virtual balises must guarantee the ERTMS interoperability requirements.

A **standard track area classification process and procedures must be defined and used.**

Possible ERTMS Enhancement Architecture Suitable for the Virtual Balise Concept



Internal Communication Network Based on Field Busses such as Profibus or CAN Bus (data rate less than 1.5 Mbps)

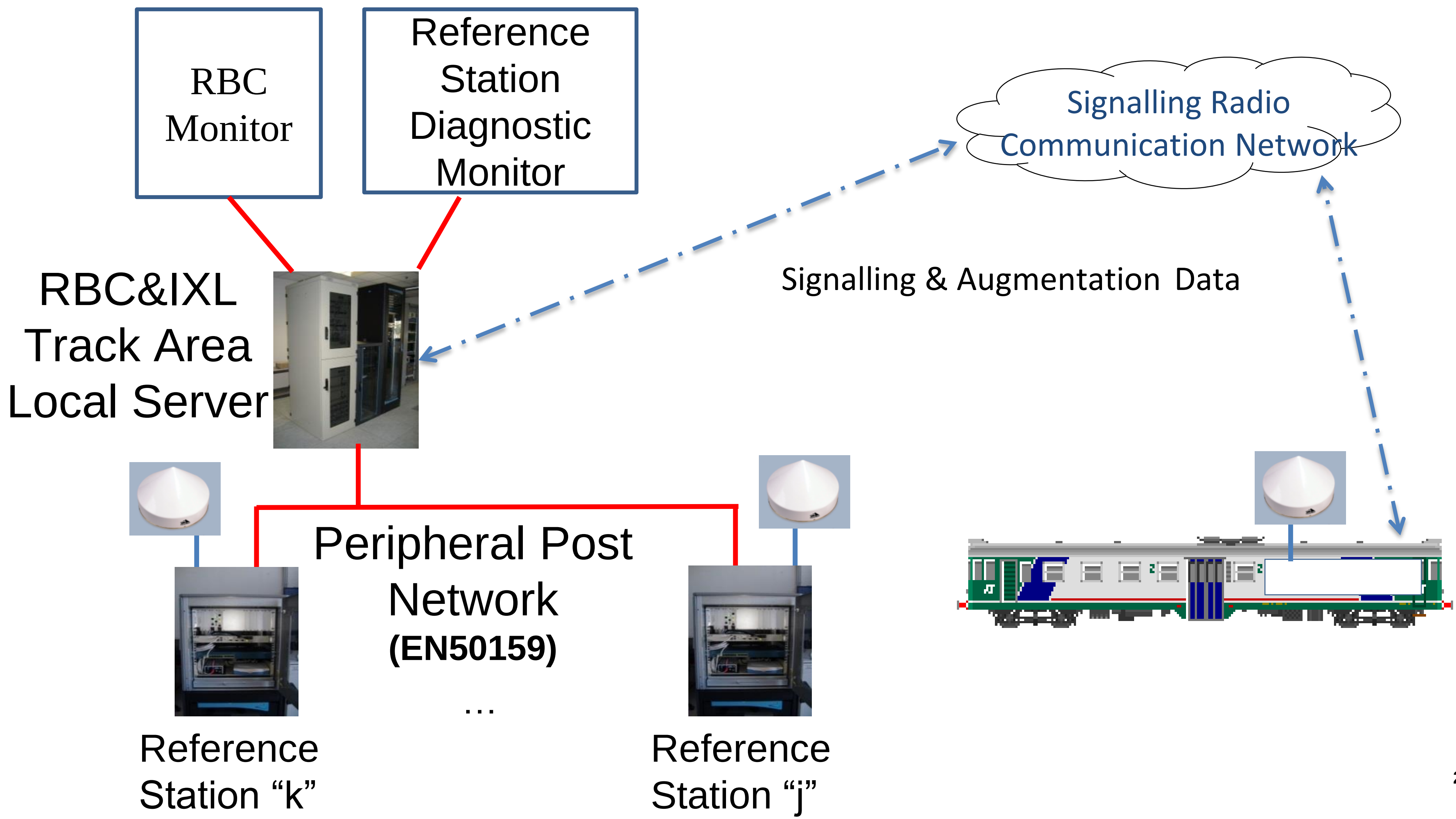
Safe Communication Session Based on the Euroradio Protocol Stack for Open Networks (CENELEC 50159)

Current Data Rate 4.8 Kbps

Possible ERTMS Enhancement Architecture Suitable for the Virtual Balise Concept (cont.)

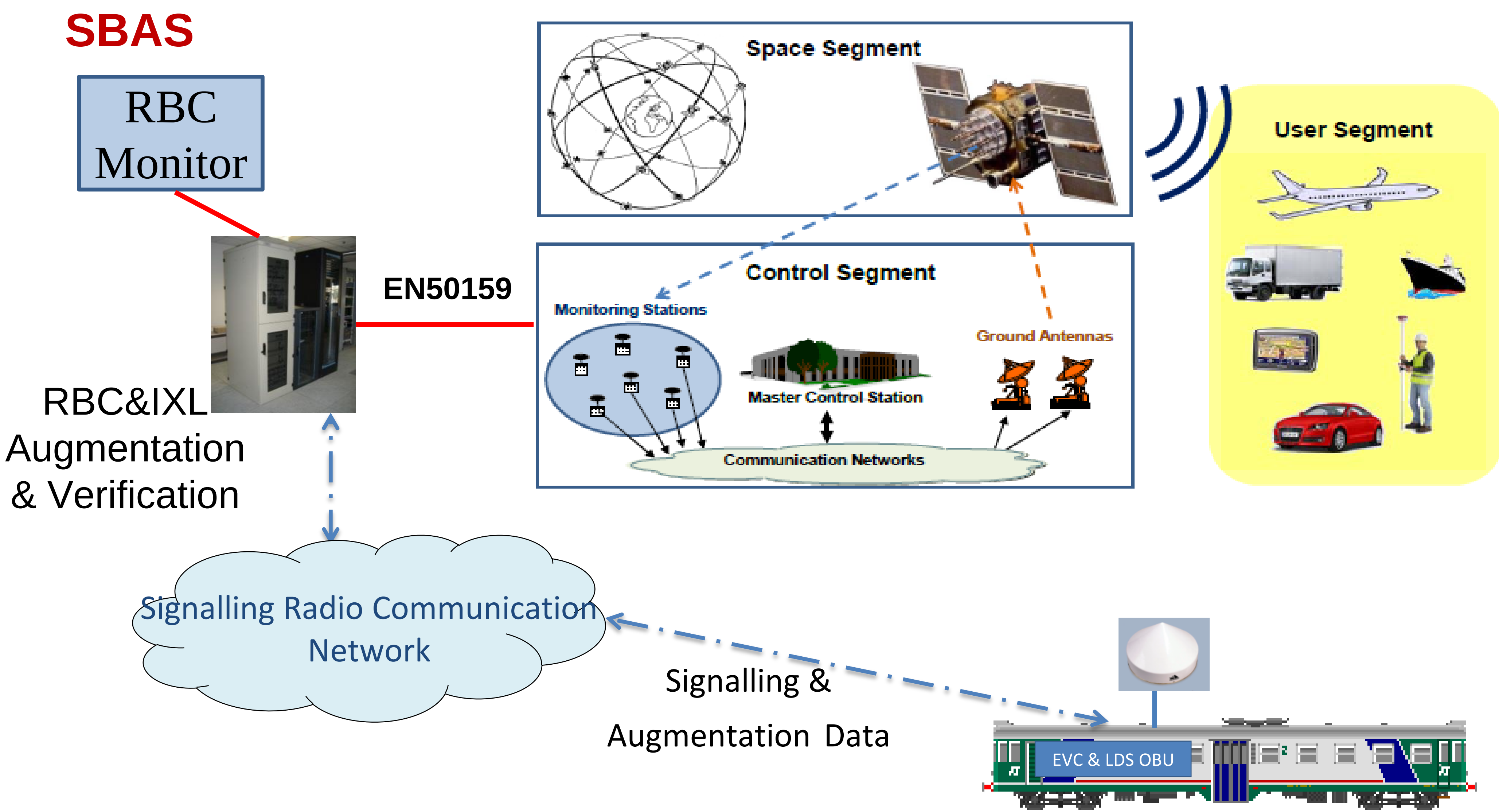
Ansaldo STS A Hitachi Group Company

Railway GBAS

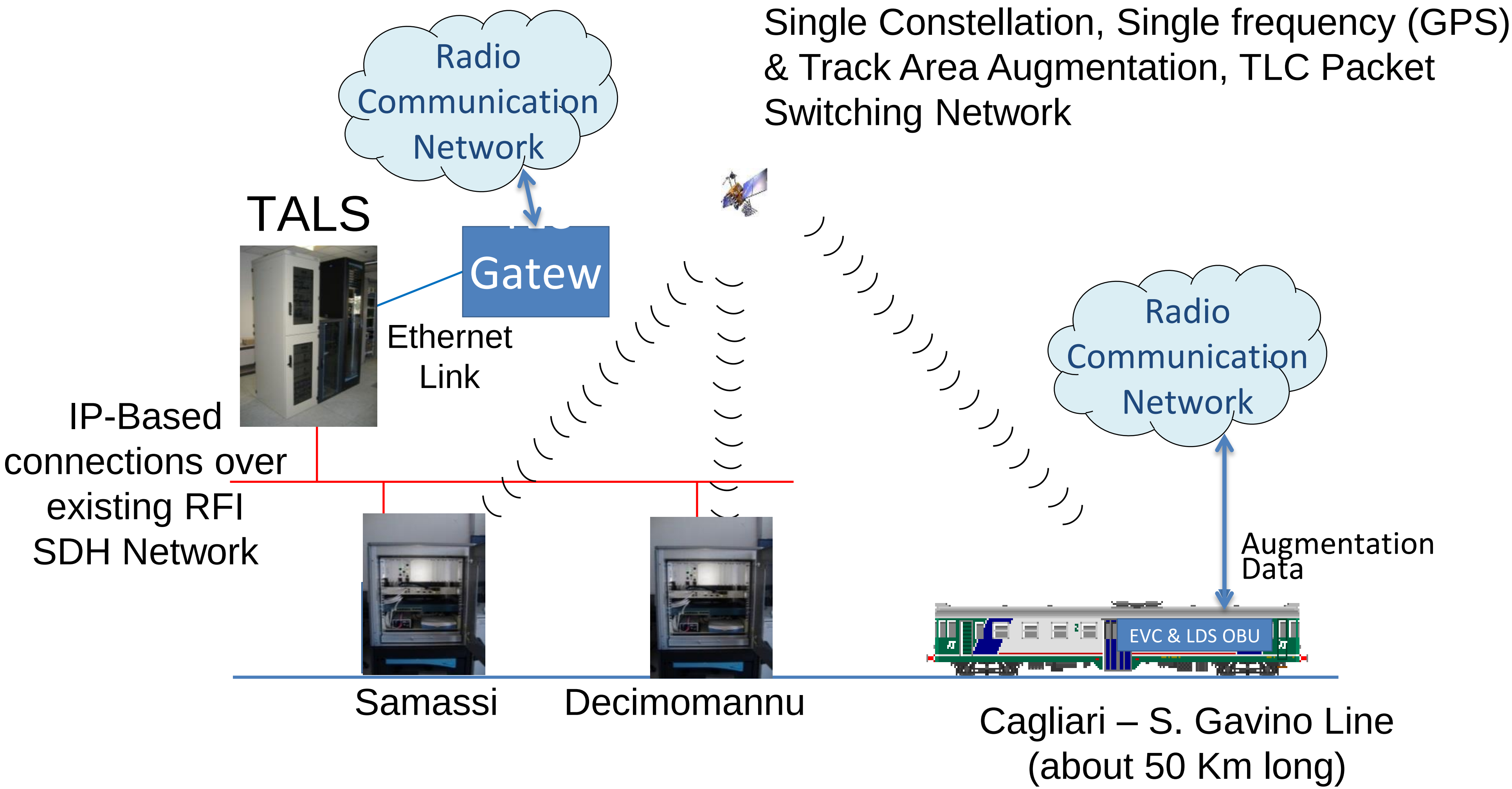


Possible ERTMS Enhancement Architecture Suitable for the Virtual Balise Concept (cont.)

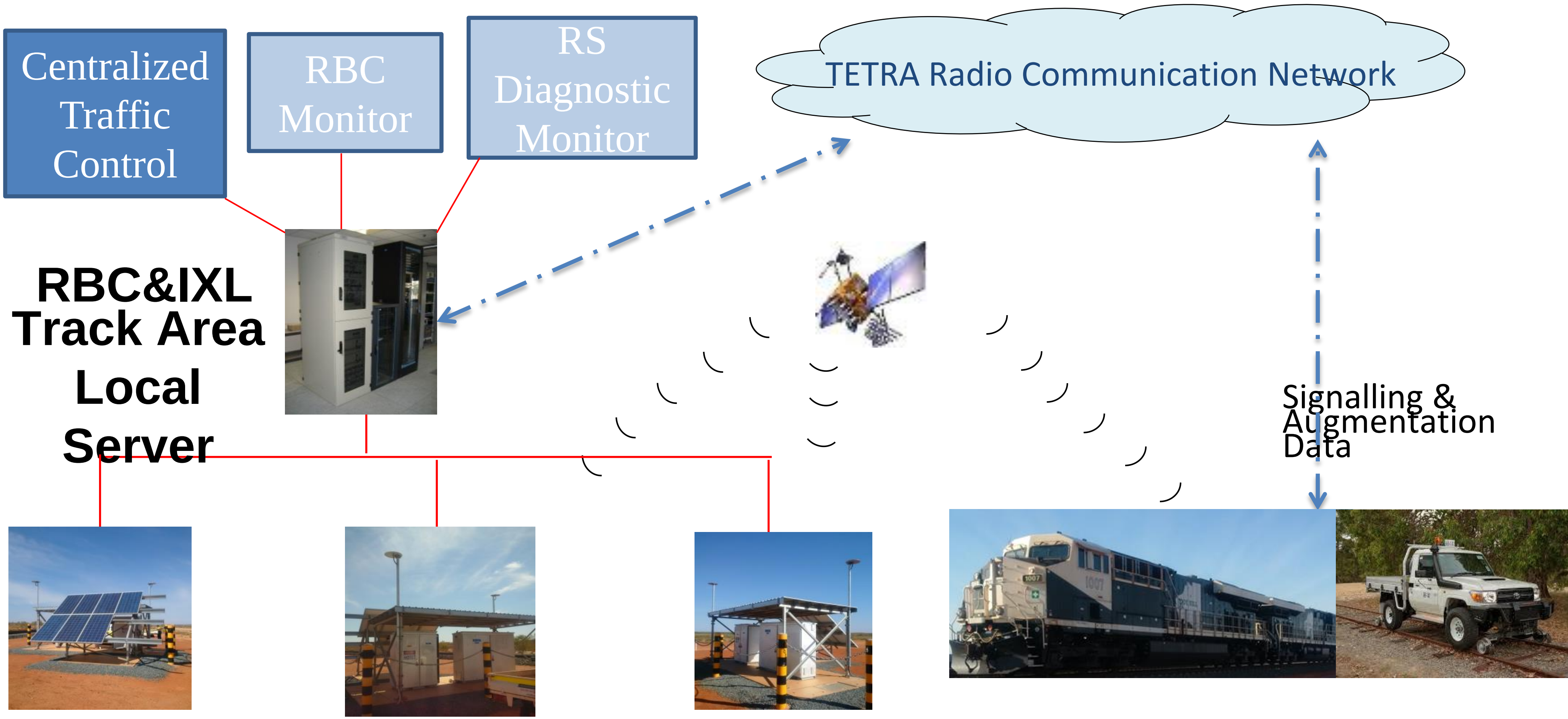
Ansaldo STS A Hitachi Group Company



Sardinia Trial Site



Australia Roy Hill



12 Reference Stations

Railway Line: 350 km
Virtual Balise Only

The **current GNSS Technology cannot** enable a **SIL 4 track discrimination**

A tight integration of ERTMS Signalling and GNSS Technology allows the development of the SIL 4 Train Position Function

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THANK YOU FOR YOUR ATTENTION