POLITECNICO DI TORINO

Master's Degree in Communications and Computer Networks Engineering

Master's Degree Thesis

Development of automation levels in railway transport systems: a state of the art and migration strategy analysis from the European Train Management Systems (ERTMS) towards the integration of Automatic Train Operations (ATO)

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Abstract

The use of high speed trains worldwide is becoming increasingly important. High speed freight trains and passenger trains are frequently preferred since they respect the evnvironment and the use of green renewable energies which are the key to an ecosustainable world. In Europe, typically these trains begin their journeys in one country, pass through other countries and terminate in yet another country. Consequently the concept of interoperability is a fundamental goal to reach and requires specific standards between countries to support safety and respect levels of energy consumption. The system which supports this requirement from the ERA (European Railways Agency) is the ERTMS (European Railway Traffic Management Systems) that was introduced in Italy in 2005. Currently Europe is considering this system to support traffic management and safety for each train, mainly due to the use of some specific braking curve models but the system may also require other updates. For example, the use of an automated system to improve the standard and the quality of the service is another key element to railways worldwide. This article focuses on the use of an autonomous system in railways management called ATO (Automatic Train Operations). The system is subdivided into four separate macro areas which were designed to obtain different goals or GoA (Grade of Automation). Italy has some specific piece of the standard to understand better how to implement in On Board trains and on trackside, mainly analyze the access radio part problems to support the protocol using the new communication radio system called FRMCS (Future Railway Mobile Communication System). The use of some experiment is required to obtain all of this. Finally Italy also collects all the experiments in order to be sure to update the standard in the fleet even for the future trends for the protocol.

Contents

Introduction

Automatic train operations are going to become a standard in the next years. From 2016 a system was developed which provided different kinds of train functions, mostly dependent from the high demand of train usage. In our days could be so simple watching a train passing from one city to another. In order to reach some more advantages in freight or passenger trains in railways system we need to add new key elements. Increasing capability, reducing energy consumption, increasing punctuality are the most important features to be followed to support the incredible demand for each type of customers. Moreover, the safety elements must be always used on the whole system. The vision of the next years and the steps that must be moved in order to satisfy all the major vendors requests and also satisfy interoperability and interchangeability, are some goals of the protocols which have to work in parallel, even using different vendor systems on board of the train. This last one is the most important motivation to understand why the usage of one safety system protocol was adopted in Europe. In order to achieve this challenge, a protocol called ERTMS was designed for this specific purpose: a safety system protocol which supports train integrity and management train control by the usage of a simple GSM-R call to exchange information between earth and train. This is actually the perfect vision of how interoperability among countries is satisfied in terms of safety and control system: from now on the evolution of ERTMS standard will be considered to update in terms of a better quality of service. So the new paradigm of the development of new automation levels in railways transport system will be taken into account and different vendors and European partners will work together to define the standard. Since the system is studied and projected by different countries, it should be clear that it must be configured by some subsets to satisfy each target for each block in the architecture. However the UNISIG ERTMS USER GROUP defined a full vision for the system in order to give a Form-Fit-Functional interface specification among blocks. Some system requirements specification follow. The division between what we see for the train (OB system) and what we see for the railway (Trackside system) are under control in a complete vision. General infrastructure blocks should be specified depending on goals to obtain starting to consider standard protocols.

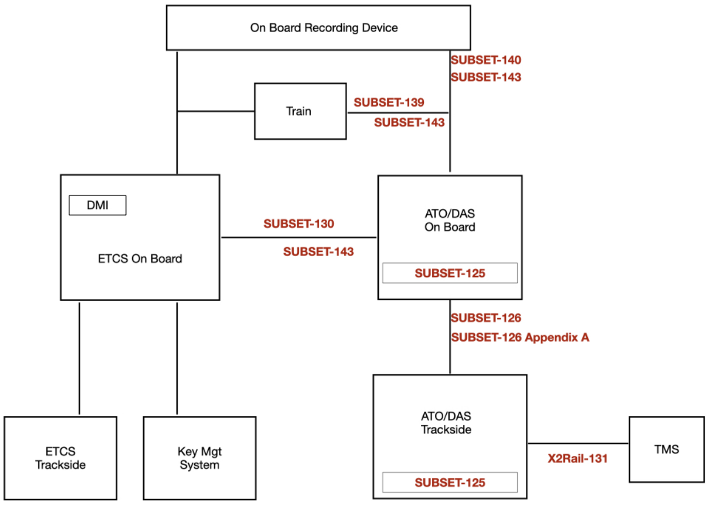

Figure 1: Block diagram of new standard ATO system

Figure 1 shows the system of the blocks. Starting from the core of the system the complete vision should be clear, but here could merge some critical points which could prevent the exchanging of information among the blocks. Technically it should be better to divide railway operations, including key management system or trackside management system, and the train operations, driving advisory system or train control management communications. In particular the subsystem is still under studies and some experiments become relevant in order to validate ATO principles and specifications.

Chapter 1 will review the general architecture of ERTMS standard, including a more detailed description of what is installed on-board of the train and on the trackside; chapter 2 will review the details of a safety system which is included on board the train with the construction of virtual braking curve model; chapter 3 will review the ATO principles and the first type of automation on board; chapter 4 will compare three types of optimization algorithms that could support the standard and chapter 5 will study new FRMCS standards and what are the limitations and the problems right now. Finally, Conclusion collects all the benefits and the drawbacks of this new standard.

CHAPTER 1

The "European Rail Traffic Management System"

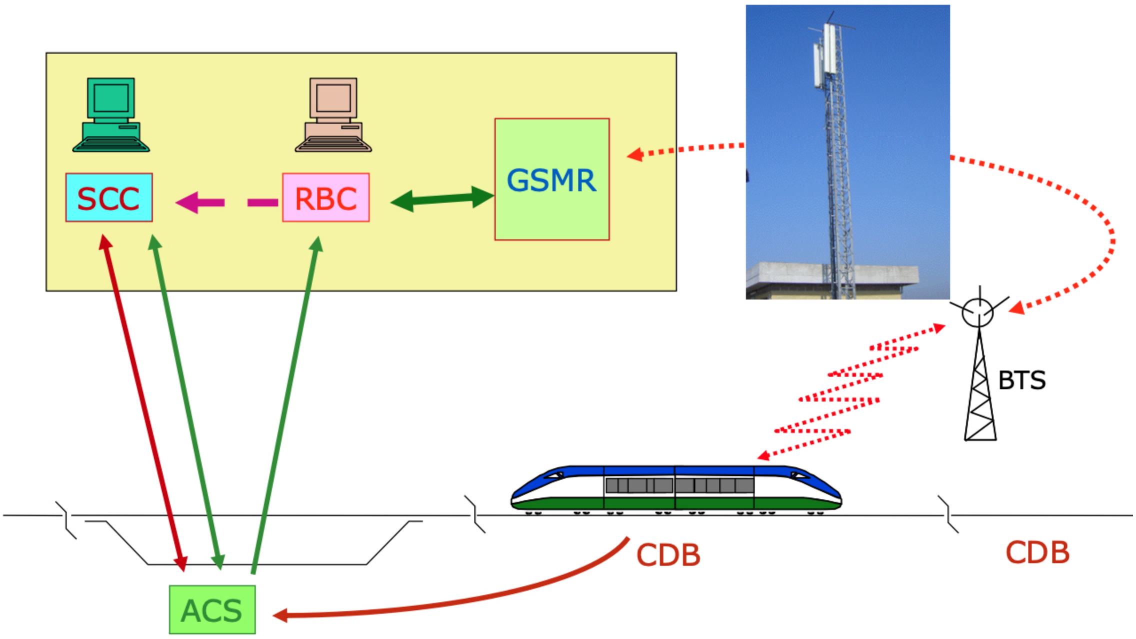

Figure 1.1: ERTMS general architecture's system block

1.1 Train Protection in the railways infastructure

The use of an autonomous system that controls the trip of a train is nowadays mandatory for each country. The complex evolution of computer machines are mostly expolited to perform specific logic functions that are applied to a safety and reliable transport. The use of an ATP (Automatic Train Protection) system is one of these. A train could be considered like a packet in a telecommunication network where each packet travels a list of paths starting from a point and ending in another point, with different time, speed and scheduling, traveling many many nodes which are responsible for the packet switching. The packet can be seen as a train, different paths are the railways infrastructure with different railways speed and the node are the stations that also define the forwarding detection. Moreover, since a specific section of a telecom system works with specific protocol, even train forwarding is using a type of standard system that is defined in a very clear normative that each train driver has to know. Infrastructure could be divided in different sections, or segments, that are assigned to be traveled by only one train at a time. Even if it seems very difficult to understand how to define at what time a specific train can override the section, in any case a train driver could decid only with just single side the perspective of view. Train driver should be able to define the possibility to pass or not using the same behaviour like while driving a car. The use of a traffic lights, which in railways are called signals, is the standard type of a train to perform all the above mentioned. Signaling has to be known and each color in a signal defines a specific procedure that a train driver must satisfy. In Italy, three or four aspects of signaling are a common system to perform train forwarding. Trains travel with just one of these colors in signaling, but the speed has to be controlled through the brake command every moment. It should be clear that not only a forwarding system but a command and a control system must be adopted. The train driver's responsibility can be relieved by some protections that make some emergency brakes work when the train exceeds the speed in that specific moment. Actually a safety system works for several aspect for each train, like train braking characteristic speed of the train, length and weight for example. These are defined in the On Board system which collects all of the parameters and performs the autonomous train protection to avoid some potential accidents. European Railways Agency defines the requirements to fulfill the use of a train for customers demand in each country by appling a specific Automatic Train Protection system. In Italy the system which performs this is called SCMT (Sistema di Controllo della Marcia del Treno). This is actually performed like an ATP system: an automatic system that realizes supervision to a train driver in order to respect the dynamic profile of an invisible braking curve to respect the signal above or some other limits in the infrastructure (like speed limits). Moreover, the demand always more frequent of interoperability in each country of Europe is asked in railways infrastructure and not only to perform management but even to satisfy safety in a continuos way. This is the definition of the ERTMS as an ATC (Automatic Train Control) system: automatic system that, in addition to the information and performance provided by ATP, can support all the information in order to drive a train respecting a speed limit every moment, using a braking curve that is showed on board of the train.

1.2 European standard radio-communication-based system

Europe and all of its states began to study a methodology to include a unique protection system that is supported by all of the vendors in the railways infrastructure. It is clear how this standard makes the interoperability and interchangeability more clearer by the vendor who supports this: in order to do this a clear separation between Trackside and On Board system has to be performed. Clearly, for any system block specific function is performed which support the standard. ERTMS (European Rail Traffic Management System) is one of the most important projects implemented by the European Union in order to achieve better safety and a more competitive rail transportation. In the last years, ERTMS became a trend topic when talking about European railways. It is a project driven for an European standard in order to obtain an ATC system and command and control system. Thanks to it a safer and more efficient interoperability amoung different railway systems in Europe is created and it contributes to make much easier rail operation between different states of Europe. ERTMS enforces speed restrictions and signaling status for different trains and due to its nature, the present system is installed On-Board and on the trackside. When we talk about ERTMS, we talk essentially of two systems:

- ETCS (European Train Control System) a type of ATC standard, which is able to control and to supervise the movement of the train and stop it if the train exceeds a permitted stopping point. The information are sent via three types of systems (Eurobalise, radio or satellite) and they used depends on which operation levels we are using. Train driver is costantly monitored and, if necessary, ETCS starts to intervene with the use of an emergency brake defined with specific braking curve models
- GSM-R (Global System for Mobile Communications-Railways) is an European Radio standard system for operations in railways infrastructure. Based on GSM radio technology, it uses slot frequency bands in order to communicate with the train and the traffic control center and trackside devices

ERTMS became the European standard which is based mostly on a radio-communication-based system to support the ATC system [17], train spacing and signaling on the cabin. It is based on a continuous bidirectional exchange of information between board and earth with the use of GSM-R system call. The position and direction of the train is fulfilled by the use of standard eurobalise points which are specific encoder placed in the trackside and give the train position where they are placed. All of them are collected in On Board system which calculates the instantaneous speed, gradient and transmits it in a specified central block called RBC (Radio Block Center). Both RBC and the Command and Control System take into account the journey profile using the GSM-R call giving a specific MA (Movement Authority). A train driver should be able to read out the specific speed and the final movement authority in the control monitor on the cabinet called DMI (Driver Machine Interface). This type of standard is clearly an ATC (Automatic Train Control) system: although the position of the train sent to trackside is discontinuous, the speed of the train is shown like an instantaneous speed that train driver must satisfy. If the train driver exceeds the speed, the system activates the automatic brake control as the train protection usually does. Train protection and train control system now are linked together in order to satisfy fully protection and punctuality of each train. For the next year the vision of this type of standard should be treated by all infrastructure managers in each country, including finalization, installation testing and certification by the ERA. In 1995 the European Economic Interest Group was established, which is responsible for developing and validating ERTMS. The simplicity of this standard makes the use of a train very comfortable from a train driver point of view. Perhaps different types of protocol to support the position of a train are performed: in fact the ERTMS is subdivided in different levels which are mostly depending on what standard is adopted in a wireless transmission access scenario depending if we use a radio system (L1) or a telecommunication network system (L2) or a GNSS (Global Navigation Satellite System) based global position report system (L3).

1.2.1 ERTMS Level 1

For the Level 1 it is imposed a continuous supervision of the train movement but the communication between train and trackside is non-continuous and it is generally done with the Eurobalise. Line side signals are necessary and perhaps the train integrity and its position are performed by equipment of the track using the aim of ERTMS.

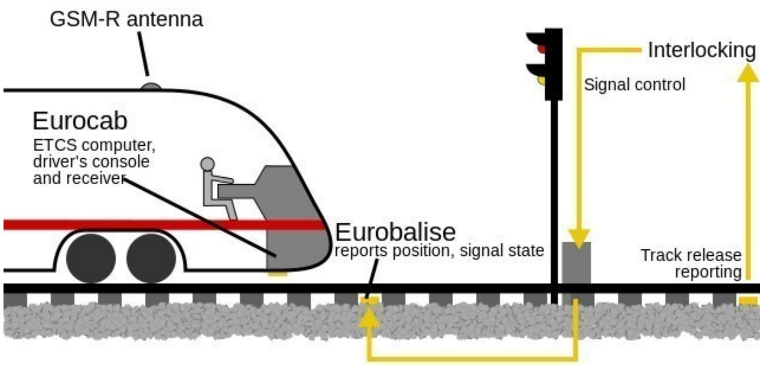

Figure 1.2: Architecture ERTMS Level 1

1.2.2 ERTMS Level 2

For the Level 2 the communication between train and trackside is performed by a continuous communication. So to perform it there is a continuous call between train and the track. Nevertheless, the position is updated discontinuously by the use of Eurobalise and the train integrity is guaranteed by using track circuits. Line side signals are not used in this case, so the result is obtained by achieving high speed and high capacity in the whole system.

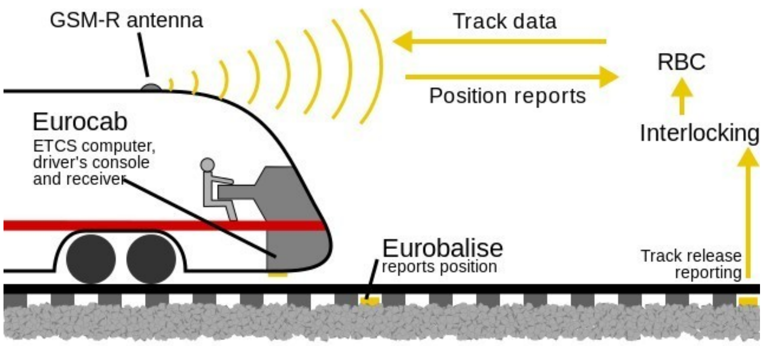

Figure 1.3: Architecture ERTMS Level 2

1.2.3 ERTMS Level 3

For the Level 3 the communication established between train and trackside is performed like Level 2 but the main difference is the continuous report for train detection and train integrity by the use of the satellite supervision performed on the train. A result that could be obtained in the future is the use of non fixed block size but moving block size as a consequently relevant impact for the capacity of the line using this system.

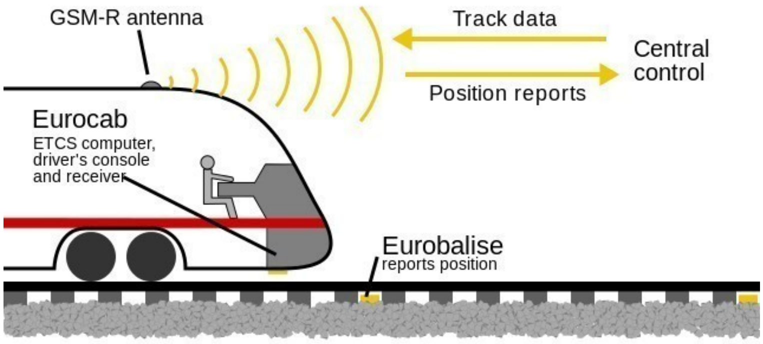

Figure 1.4: Architecture ERTMS Level 3

1.3 Internal Architecture

All the fleet in Italy has to have internal on-board system that is interfaced with the trackside system in order to communicate each other and signaling some vital information to help the train driver and make the driving experience safer and reliable. Anyway some of the fleet in Italy are equipped with the European system by using a cellular call in order to exchange information with earth and the board. Perhaps, it should be clear that it is necessary to have on board a system to record too and to diagnose every information included on board, even some events that could happen on the train. The subsystems that are included in the standard ERTMS are generally included to satisfy safety conditions and establish some known protocol adapted in the standard. An ETCS system also guarantees a major safety respect to actual systems, even for an high speed experience and a major capacity included in the railway. It consists of some essential parts:

- EuroBalise: ETCS transponder in order to transmit a discrete telegram from the railway and the vehicle when it is excited. The Eurobalise is a non continuous device installed on the track, saving information data like speed limits, position reference, slope of the line, or other safety information in order to excit the train antenna (BTM) when passing over the Eurobalise.
- LEU (Line side Electronic Unit): used to adapt signals and telegram. The LEU is the interface used to communicate from interlocking to Eurobalise: it receives information about the interlocking and comparing the line side signaling at that moment sends the information (called "telegram") to Eurobalise.
- Euroloop: this guarantees a semi-continuously transmission between earth and train. Euroloop is an optional component, used on ETCS Level 1 in order to increase the performance of the system. Euroloop send informations to ETCS On Board in advance of the next Eurobalise

- RIU (Radio Infill Unit): transmission protocol to ETCS packets. RIU is an optional component, used on ETCS Level 1 in order to increase the performance of the system. It is a radio transmission to send information to ETCS On Board in advance of the next Eurobalise.
- Radio Block Centre (RBC): RBC is the device used in Level 2 or Level 3 acting the core of a safety unit in order to receive the position of a train and send movement authority or other information for the train for its movement by using radio connection via GSM-R. The RBC is also strictly connected to interlocking to obtain signaling related information, route status etc. It is also able to communicate with other adjacent RBCs.
- Interlocking: Interlocking is not an ERTMS component. This is a vital component in order to establish a ruote for a specific train and avoid simultaneously route. This interface represents the command and control system over the trackside.
- Control Centre: Control Centre is a table which supports all the trains running in a specific area. A Control Centre usually commands several interlocking in order to create different paths for different trains. This interface represents the command and control system over the trackside
- Euro Vital Computer (EVC): EVC is the core of an ERTMS On Board device. It is part of ATC logic and it is the central computer where other functions interact, such as odometer or GSM-R data reception and elaborate them in order to create different safety parameters.
- Driver Machine Interface (DMI): DMI is the interface for the driver that reads the ETCS data received represented by its movement authority. It is an LCD touch screen where input data have to be entered for visualizing the final output data.
- Train Interface Unit (TIU): TIU is the interface that allows to ETCS to communicate from earth to the train, and sends command to the rolling stock (e.g. ETCS will send the command to rolling stock to apply the brakes)
- Juridical Record Unit (JRU): JRU is a legal component in order to store the most important data and other variables, for a later reference by the authorized authorities.
- Balise Transmission Module (BTM): This is the component that reads information on the Eurobalise. In fact the BTM is able to excit the Eurobalise and receive the information stored on it.
- Loop Transmission Module (LTM): LTM is an optional module on ETCS On Board which processes signals received from the antenna and data messages from Euroloop.
- On Board radio communication system (Euroradio): This is the GSM-R On Board system used for exchanging bi-directional information between the OnBoard train and RBC or radio infill unit.
- Odometry system: This is a set of components like tachometry or radar able to calculate speed, distance and acceleration for calculating the distance run by the train.
- Specific Transmission Module (STM): STM is the interface to communicate with On Board part for the existing National train Control system (like SCMT in Italy).

Some internal equipments to adjust the signal are also required since the continuous communication must be guaranteed even at a high speed or with weather conditions not sufficiently good. The vital interrelationship between the two systems has to be known, and some vital parameters are also required. Some vendors must fulfill all of these parameters. They can include some modification in order to give more service than requested but they have to specify all of these parameters, including the hardware and software architecture. In Italy two Italian historical vendors that supply ERTMS system on ETR 500 are Alstom and Hitachi companies, and they can work even together since they are using a specified protocol to satisfy everything.

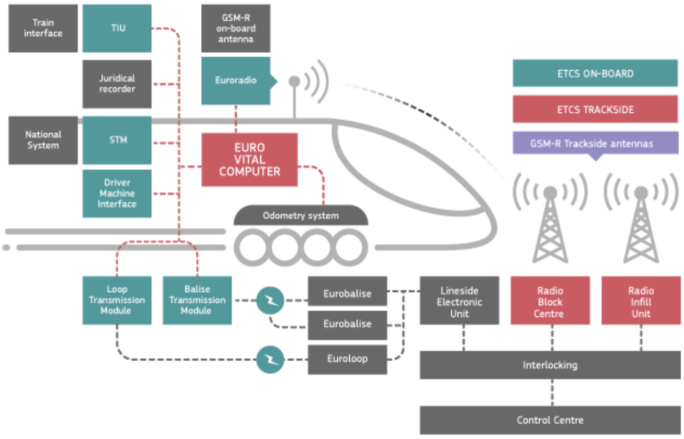

Figure 1.5: Subsystems and constituents of the ERTMS

Figure 1.5 is an overview of the most important block related an ERTMS system architecture, essentially divided into three main part: the equipment on trackside is organized in order to transmit on the railway infrastructure the journey time and journey profile for a train. The On-board system has to collect all the information kept from the railway and processed by the EVC to transmit in the DMI for a train driver, and the GSM-R call continues the communication between the On-Board and the earth by using GSM-R infrastructure. It is also important to exchange voice information between train driver and staff for critical situations (some important information about what is happening on the railway when a system doesn't recognize them).

1.3.1 On-Board internal architecture

Now we are going to analyze the internal architecture of the On-Board used in some fleet (passenger and High Speed Train) in Italy. As we will mention afterwards, the governing principle is to pick-up the telegram from the trackside, elaborate it and then transmit it in a visual mean to the train driver, even collecting data and recording some vital problems that may happen in some specific situations. We only describe the ETCS system responsible for safety and reliable communications.

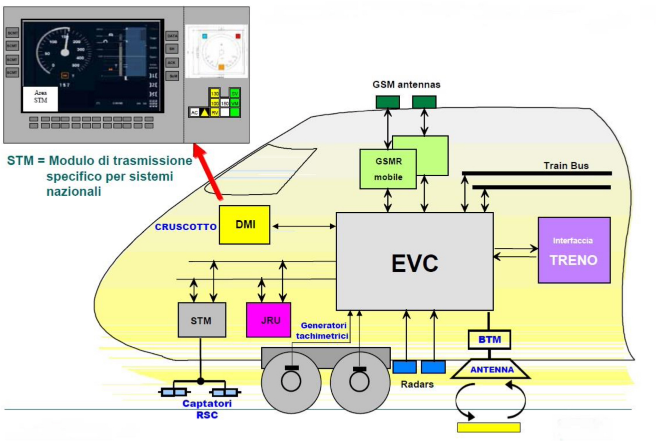

Figure 1.6: On Board architecture ERTMS Level 2

The core of the system is the EVC (European Vital Computer) that is responsible to collect all the data from trackside and train by using a serial communication between redundant channels. It is also possible to subdivide the rack EVC from the other two parts, in order to divide the section responsible to ERTMS by the section called EVC and the other sections SCMT for the STM part. The two are connected together with a bus channel with specific interface. Moreover, the EVC system must be able to collect the information and send on the train in order to apply emergency brake when some problems occur, by activating some interfaces with electro-valves that are excited, when EVC send some emergency data. Some discrete points placed on the trackside (Eurobalise) are fundamental in order to establish the position of the train since trackside must be uploaded during the journey time. To do it a special part called BTM (Balise Transmission Module) is used. This type of module is required to energize the EuroBalise on the trackside transmitting a tele-powering radio transmission of 27MHz and then it sends the information back to the BTM with a telegram using two different types of modulation. In fact, they are using ASK at 255 bit (STM system) or FSK at 2013 bit (ERTMS system). A specific shield is used to decode the telegrams which are synchronized at first and then converted in binary code. Moreover it also recognizes some errors and transmits all of them at the EVC even with the help of a component by filtering and amplifying the tele powering antenna placed at the bottom of the train. As the standard was developed to ensure safety and even transmit signaling on the cabin, to ensure a clear and unique vision of the speed a DMI (Driver Machine Interface) it also adopted. DMI is able to interact between human and the subsystem by inserting some special data that are not known to the railway: there are so many trains in the all country, each of which has its own specific technical characteristics. In order to give an example we are using an ETR 500 PLT system in perfect conditions initial data to make it clear:

- Speed of train (300 Km/h)
- Percentage of brake (135 %)
- Length of the train (330 meters)

They are important input parameters since the system has to know what is circulating on the railway infrastructure. As mentioned above, it is important to have a complet vision and interaction between train driver and the staff in order to recognize some particular problems that can come from on board the train (emergency situations for example). To do this that a Cab-Radio is used. Important equipment on board is the use of an ARB (Apparato Radio Bordo) equipment in order to be able to exchange any types of data amoung EVC, an antenna systems, and the Radio Block Center that coordinates the traffic in the railway. A module filter antenna system responsible of filtering and reduce some frequency that are in the bandwidth of the GSM-R is used. First, it is used to filter the signal with two pass-band filter in the frequency of 876-880MHz (uplink) and 921-925MHz (downlink). It is also responsible to adapt the signal in the input of the MT (Mobile Terminal) modules in order to increase the SNR ratio. The last part of on board ERTMS radio system is essentially designed to exchange information between the vital computer and the antenna using the ERTMS standard messages.

Finally, two other parts are used to collect and save all the data that are coming from the trackside and to elaborate them in the whole system. JRU is the memory where the data of actions and messages passing in the system are saved in a mandatory way. Data logger are supplied by each vendor for maintenance and diagnostic purposes only.

1.3.2 Trackside internal architecture

In the internal architecture of trackside it is important to have some consistency amoung vendors. In Italy two major vendors in this type of section are known: Alstom and Hitachi. They are responsible of the infrastructure from a central position which is placed in a big building where the staff is responsible to collect all the planning from each train. Anyway the staff is also helped by the use of an autonomous system which is activated by a control and command system called SCC. Moreover, the command is sent to the trackside using a Gigabit Ethernet fiber optics infrastructure with an ISDN protocol in the core.

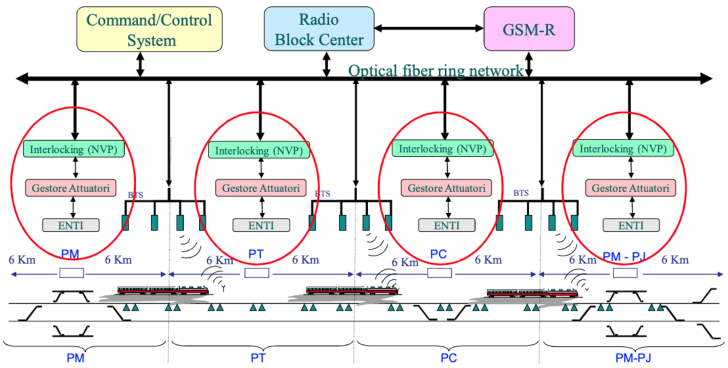

Figure 1.7: Trackside architecture

As it shown in the picture 1.7, the system is divided in many sections which are responsible of controlling a part of the trackside (in Italy we used to control 6 Kilometers) in order to move in a reliable and safe way a train. Using interlocking systems it is possible to move and command a railroad switch, control if the track is free and perform other safety functions. All of these commands are sent back to the central control of the moving of the train. The Radio Block Center RBC collects all these information and sends the authorization to the train to move. The information are coded by using standard ERTMS in order to have complete communications amoung track and trains. It is obviously important the position of the train in order to give the permission to move for other rolling stock from one side to other. This is required since the blocks are not mobile but they are fixed, so fixed blocks are used to establish the journey of the train even in a discrete way with the use of an eurobalise placed in a specific position known by the infrastructure manager. Eurobalise in the track can be used as fixed eurobalise or computably eurobalise. Some encoded messages are set in depending what they want to send on the internal vital computer on-board by using a LEU to encode the message.

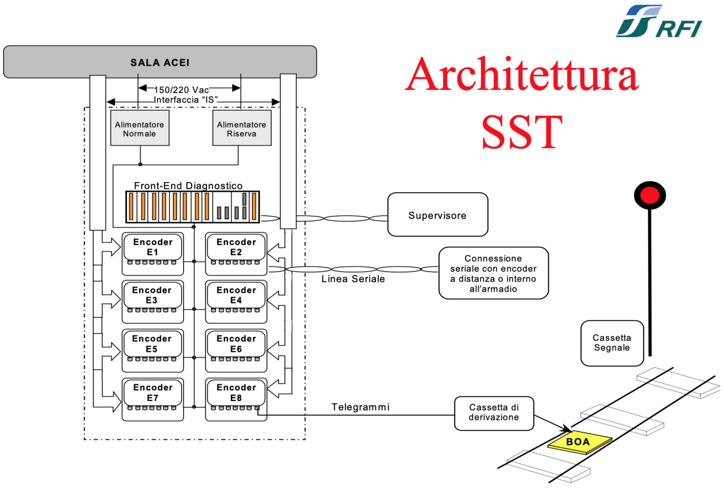

Figure 1.8: Eurobalise system

In ERTMS systems, the whole transmission is guaranteed from an eurobalise on the trackside to send some information on board the train using a Frequency-Shift Key (FSK) modulation at 1023 bit. Different bits are divided into packets and each is responsible for some coded information (for example when using packet 44 it is important to link the SCMT system to the ERTMS system in order to merge the two systems for a better interoperability among trains).

Figure 1.9: Physical Eurobalise

CHAPTER 2

Braking curve model for a On Board system on ERTMS

ERTMS/ETCS system supervises the position of a train and the speed, in order to give information between spacing distance and the authorization to move for a train, without exceeding the limit speed of the trackside and relative distance between one train and the other. It should be important to have a full vision of the parameters in order to collect them and if necessary ERTMS will act to intervene on the braking system to ensure safety and reliability for the whole trip. To do this, ETCS onboard computer (EVC) will predict the decrease of a train speed, by mathematical model of the braking of a train and track characteristics on the frontside of the train. This specific mathematical model is called “Braking Curve”. In order increase capacity, an analytical calculation of any parameter for all trains running on a specific track should be known. The ETCS system predicts this model and calculates many curves where train driver has to observe. But all of the curves calculated by the EVC have to satisfy the most important curve called Emergency Brake Intervention (EBI).

2.1 Spacing distance with EBI intervention

The impact of EBI intervention in a On Board system Baseline 2 defined in [1] follows this specific formula:

$$S_{EBI} = (h + t_f)V_\beta + \frac{V_\beta^2 - V_0^2}{2(d_p + d_i)} \tag{2.1}$$

- h : Delay of emergency intervention from on board $[sec]$
- t_f : Time considering no braking intervention $[sec]$
- V_b : Speed where braking intervention takes effect $[\frac{m}{sec}]$
- V_0 : Objective speed $[\frac{m}{sec}]$
- d_p : Deceleration by braking intervention $[\frac{m}{sec}]$
- d_i : Impact of slope line $[\frac{m}{sec^2}]$

2.1.1 Impact of braking intervention

As far as the train some physical models are even taken into account for the calculation of the curve mentioned above. One of them should be supposed to approximate the braking intervention with a step model, by differenting two specific phases: one is temporary and one is at regime. The temporary part should model the increase (or decrease) of the speed of the train since the depressor of the air in the train pipe should spread in some time. Knowing the speed of the air in the vacuum and the length of the train, some first approximation of time, considering no braking intervention, follow this formula [1]

$$t_f = Dt'_f \tag{2.2}$$

- D : Safety coefficient $[sec]$
- t'_f : Time of spread of the depressor in the main pipe $[sec]$

D safety coefficient, as a first hypothesis is supposed to be 1.30 sec. There are other parameters strictly related to the type of the brake system of the train. This parameter is t'_f and this is the time of spreading of the depressor in the main pipe. This works differently in a passenger train in respect to the freight trains. We consider the use of a passenger train, following this specific formula [1]

$$t'_f = a_v + b_v \frac{L(1-EP)}{100} + c_v[\frac{L(1-EP)}{100}]^2 \tag{2.3}$$

- a_v : Coefficient
- b'_v : Coefficient
- c_v : Coefficient
- L : Length of train [m]
- EP : Flag if the train uses or not the electro-pneumatic train brake

We define all the parameters which are used in the formula as first hypothesis. In particular some constant coefficients are fixed and should be: a_V coefficient supposed to be 3.50, b_v coefficient supposed to be 0.00, c_v coefficient supposed to be 0.15. One more parameter is the length of the train. We are using the specific train seen in Chapter 1, that should be ETR 500. For this specific train the L, length of the train, is supposed and fixed to be 350m. Even if the electro-pneumatic train brake is installed on board the fleet of ETR 500, is not in operation and consequently it should be fixed EP = 0 since this electro-pneumatic train brake is inefficient . Finally, the second part of the phase for this model is set to be considered at regime part, since braking intervention is taken into account to decrease the speed. Obviously the speed of the train could be increased or decreased at time t_f, since it strictly depends on the slope of the line. So it should be considered the speed V_b calculated for the immediate speed V in the time of the instant in which the train braking system intervention commands the emergency braking intervention [1]

$$V_\beta = V - d_i(t_f + h) \tag{2.4}$$

- V : immediate speed $[\frac{m}{sec}]$

In order to calculate this impact the slope of the line should be considered. In the Italian trackside this slope is the range of $-35\ ^0/_{00} \leq i \leq +35\ ^0/_{00}$.

2.1.2 Impact of deceleration by braking intervention

Vacuum brakes alway delay the braking effect on the whole train. As soon as all the brakes cylinders on each piston receive the corresponding air for brake, it is possible to include the effect of braking intervention in the deceleration. The model that describes this impact is considered in the following formula, deceleration by braking intervention [1]

$$d_p = K_0 * K_c * K_r * d_r \tag{2.5}$$

- K_0 : Coefficient
- K_c : Coefficient
- K_r : Coefficient
- d_r : Value depending on braking percentage λ

Each parameter is considered as a safety coefficient. As the target speed is supposed to be zero, K_0 is supposed to be 0. Even a safety coefficient for high velocity K_c should be supposed to be 0 for the same reason. So two parameters in the formula are relatively important: K_r coefficient that keeps the control of the braking performance of the materials is supposed to be 0.57 as first hypothesis; and d_r the value that is strictly dependent on braking percentage λ of the train is considered as the ratio between the sum of the brake masses divided by the sum of the masses of the vehicles. In order to do that the formula is [1]

$$d_r = A * \lambda + B \tag{2.6}$$

- A : Coefficient
- λ : Braking percentage
- B : Coefficient

Two are the coefficients: A = 0.00685, B = 0.094. So considering the braking percentage of the train, we need to suppose the ETR 500 as our model and in perfect conditions, it has a braking percentage of 135%.

2.1.3 Impact of slope lines

Even if the braking intervention has effects only to the effect of the train at regime, the impact of deceleration considering slope lines i could be also an important factor. For the models supposed, we need to differentiate three slopes :

- $+0\ {}^0/_{00} < i \leq +35\ {}^0/_{00}$

We considered the formula [1]

$$d_{i1} = K_{i1} * g * i = 0.90 * g * i \tag{2.7}$$

- $-21\ {}^0/_{00} < i \leq +0\ {}^0/_{00}$

We considered the formula [1]

$$d_{i2} = K_{i2} * g * i = 1 * g * i \tag{2.8}$$

- $-35\ {}^0/_{00} < i \leq -21\ {}^0/_{00}$

We considered the formula [1]

$$d_{i3} = Ki3 * g * i = 1.1 * g * i \tag{2.9}$$

Obviously the gravity mass must be included in the formula and it is $g = 9.81m/sec^2$.

2.1.4 MATLAB simulation of the curve

Considering all these parameters, a mathematical prediction of the train could be found in order to ensure safety on each train, considering different types of speed. By the usage of the MATLAB simulation software the relatively braking curve was created for an hypothetical passenger train to move until it reaches the condition of the static train. This actually was done by creating a vector of slope line from $-20\ {}^0/_{00}$ to $+30\ {}^0/_{00}$ and then simulating each curve considering this type of effective slope lines. So it was created a generic matrix of EBI intervention with different speeds and different slopes. The main script is shown below with the usage of MATLAB.

```
clear all;
close all;
clc;

V0=0;
h=1;

%% non cambia %%
Dt=1.30;
av=3.50;
bv=0;
L=350;
cv=0.15;
tf_primo=av+bv*L/100+cv*(L/100)^2;
tf=Dt*tf_primo;

%% non  cambia
V=linspace(0,300,1e4);
V=V./3.6;
%%%%%%%%%%%%
i1=0;
i2=-0.021;
Ki1 = 0.90;
Ki2 = 1;
Ki3 = 1.1;
g = 9.81;

i_vect = [-20/1000  -15/1000  -5/1000  0  5/1000  15/1000  30/1000];

for a = 1 : length(i_vect)
%% CAMBIA %%
if i_vect(a) > i1
    di(a)=Ki1*g*i_vect(a);
elseif i2 < i_vect(a) && i_vect(a)  <= i1
    di(a)=Ki2*g*i_vect(a);
elseif i_vect(a) <= i2
    di(a)=Ki3*g*i_vect(a);
end

%% CAMBIA %%
    Vb(a,:) = V-di(a)*(tf+h)  ;

%% non cambia
cr=0.05;
Ko=1;
Kc=1;
Kr=0.57;
A=0.00685;
lambda=135;
B=0.094;
dr=(A*lambda+B);
dp=Ko*Kc*Kr*dr;
%%%%%%%%%%%%

S_EBI(a,:) = (h + tf ) .* Vb(a,:) + (Vb(a,:).^2 - V0^2) ./ (2.*(dp+di(a)));

end
```

Listing 2.1: MATLAB code

A generic plot of the braking curve considering only the effect of Emergency Brake Intervention is plotted above, considering even different types of slopes line:

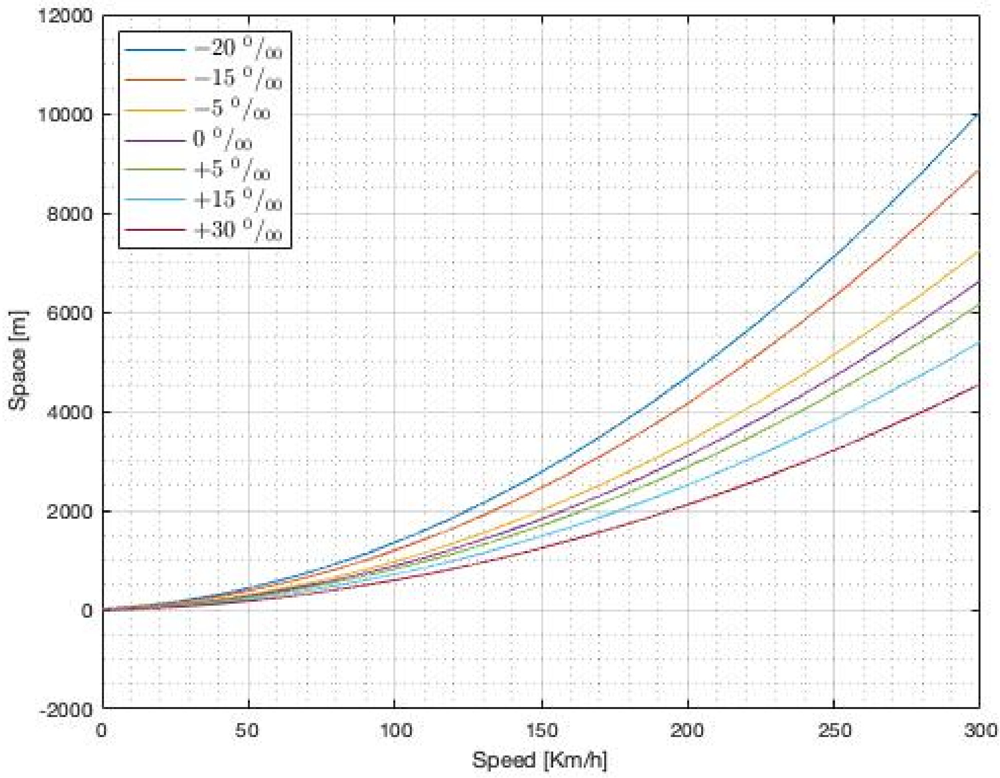

Figure 2.1: Effect of EBI intervention in a ERTMS scenario ($\lambda = 135\%, V_0 = 0\ Km/h$)

In figure 2.1 the effect of the emergency brake intervention is showed exponentially as the increasing speed of the train. The effect from low speed to maximum speed allowed in Italy (300 km/h for ETR 500 and ETR 1000) is plotted to give an idea. By increasing trains speed we reduce the capacity of a line even if a train could make a trip in less time than a local train. It is clear by now why the path of a controlled trackside in high speed train is almost 6 kilometers. Obviously the effect of permitting a movement authorization of a train in order to reach high speed, is closely dependent on the slope of lines: considering for example a train from Bologna to Florence in a gallery with high downhill slopes (about $-15\ ^0/_{00}$) is permitted a movement authorization of maximum 250 km/h. This shows clearly that the effect of reducing speed in high slopes in the temporary period, does not have any effect since the step model considering the time of propagation of depressor in main pipe is not immediate. On the other hand, positive slopes mean significantly shorter braking distance (almost 2 km of gain). It it showed as with the help of a planimetry of a particular track, it becomes so important the effect of the deceleration not considering a common system brake, but only the effect of coasting by performing a natural deceleration of a motor when the power is removed. It is really important to known the trackside and optimize the usage of coasting and prevent the brake pad wear by considering all these aspects. But, in local train, the effect of coasting could be increased rather in respect to high speed train. By optimizing the performance in local trains with automatic train operation with the aim of avoiding as much as possible the usage of the brake systems, it becomes a significant challenge in terms of optimization needs.

2.2 Effects of coasting

So the use of train coasting could be a key factor for speed deceleration only in a particular geographic area. Anyway, to understand how it could be possible and where optimize this concept with specific speed and time, we have to demonstrate it as first physical and hypothetical model by the usage of cinematic. In fact, in order to define the speed of a train with almost negligible effects of frictional force we could consider the cinematic formula

$$\frac{dV}{dt} = d_{i1} \tag{2.10}$$

And to give the speed as a function of time we need to define both of them

$$V(t) = \int_0^t d_{i1}\, dt = V(0) - d_{i1} * t \tag{2.11}$$

The usage of a minus factor in the deceleration only takes into account the deceleration as a positive factor, since it is opposite to the train motion. Obviously it could be important considering even the space for the train and considering the cinematic in the space as a derivate:

$$\frac{dS}{dt} = V(t) = V(0) - d_{i1} * t \tag{2.12}$$

And to give the relative space as a function of time

$$S(t) = \int_0^t V(t)\, dt = \int_0^t V(0) - d_{i1} * t\, dt = V(0) * t - \frac{1}{2} * d_{i1} * t^2 \tag{2.13}$$

It is clear by now how the effect of the train motion considered is a typical case of uniformly decelerated motion. This simple approximation becomes fundamental for optimization needs since it may reduce the time of searching the best speed. Anyway considering only these effects in high speed some divergency has to be created for the best solution since the resistivity force of aerodynamic resistance should be taken into account. But the model as first approximation may be very close to the best with low speed.

2.2.1 MATLAB simulation in high speed trains

Even in this case the MATLAB software tools were used to have a generic idea related to the effectiveness of coasting for trains which are traveling at high, medium-high and low speed. Even in this case a vector of only positive slope lines was created from $+1\ ^0/_{00}$ to $+30\ ^0/_{00}$. And then were created different types of lines reduction of speed in different scenarios by the usage of a matrix with different speed and slope lines. The main script is shown below with the usage of MATLAB.

```
clear all;
close all;
clc;

V0_high = 300/3.6;
V0_medium = 200/3.6;
V0_low = 100/3.6;
V0_verylow = 60 / 3.6;

i1=0;
i2=-0.021;
Ki1 = 0.90;
Ki2 = 1;
Ki3 = 1.1;
g = 9.81;


time = linspace (0,120,1e4);

i_vect = [1/1000  5/1000 10/1000  15/1000 20/1000 30/1000];

for a = 1 : length(i_vect)
%% CAMBIA %%
if i_vect(a) > i1
    di(a)=Ki1*g*i_vect(a);
elseif i2 < i_vect(a) && i_vect(a)  <= i1
    di(a)=Ki2*g*i_vect(a);
elseif i_vect(a) < i2
    di(a)=Ki3*g*i_vect(a);
end

Vfin_high(a,:) = V0_high - di(a)*time;
Sfin_high(a,:) = V0_high*time - 1/2*di(a)*(time.^2);

Vfin_medium(a,:) = V0_medium - di(a)*time;
Sfin_medium(a,:) = V0_medium*time - 1/2*di(a)*(time.^2);

Vfin_low(a,:) = V0_low - di(a)*time;
Sfin_low(a,:) = V0_low*time - 1/2*di(a)*(time.^2);

Vfin_verylow(a,:) = V0_verylow - di(a)*time;
Sfin_verylow(a,:) = V0_verylow*time - 1/2*di(a)*(time.^2);


end
```

Listing 2.2: MATLAB code

A generic plot is shown

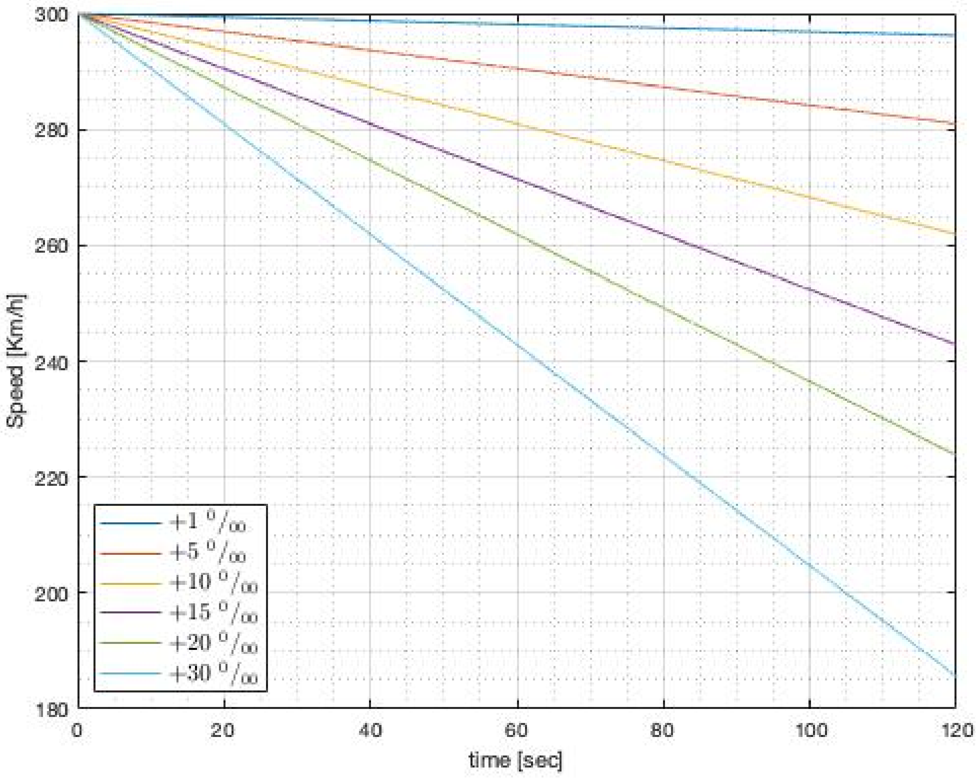

Figure 2.2: Effect of coasting for high speed ($\lambda = 135\%$)

The graph in figure 2.2 shows the speed of the train by considering maximum speed allowed in Italy, and it shows it in a time window of 120 seconds. Clearly the effects of negative slopes are not taken into account. But the impact of deceleration is relevant in high speed trains considering only the effect of geographic track. Reducing the speed of a train from almost 30 or 40 km/h is fundamental with this speed since it is even safer rather than system brake intervention and it will help to reduce the consumptions of the braking pads for a better quality of service and the reduction of the maintenance of the components. Furthermore it will reduce even the possibility of heating the bushes of the train, that could mean stopping trains and delays for passengers: in Italy many systems placed on the trackside are used only to monitoring axle temperature and reduce the risk of high temperature. This approach could be fundamental and it could permit to gain better safety. We cannot speak only of pad wear reduction but also of increasing reliability and punctuality for a passenger experience.

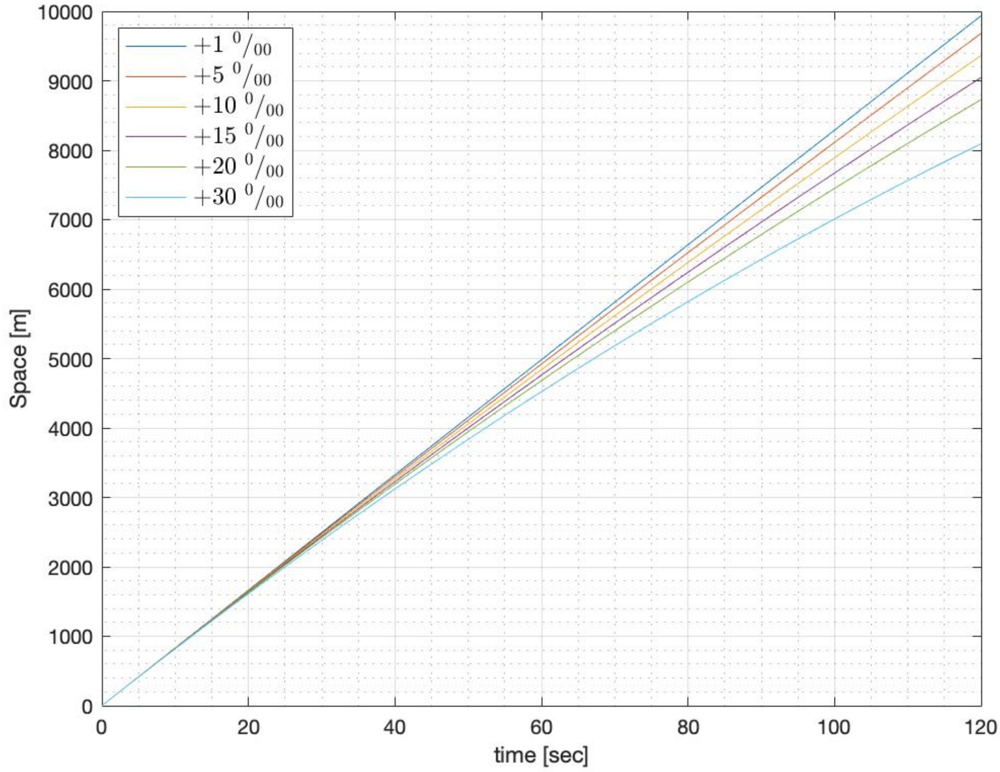

Figure 2.3: Effect of coasting considering space versus time ($\lambda = 135\%$)

Considering the coasting in high speed trains, it is essentially fundamental when the journey time is high. The space of the reduction of the speed for the values considered above is not so small. So these types of approach and even optimization speed problems could be used mostly when in a particular section of line the traffic management system is conditioned by the use of speed reduction; epecially for these types of speed: from 250 km/h to go up. For this reason the usage of this approach could be not considered at all for the timetable of specific trains, even if, as it was discussed above, the coasting increases the reliability for a high speed train. Anyway it could be possible to use it for some slowdowns along the railway line, to satisfy it just to leave the vehicles going in coasting mode some kilometers before the starting point. This consequently reduces the consumption of wear brake, and gives better comfort for passengers. Reducing maximum allowed speed in the track, increases the usage and the efficiency of coasting especially for line with slope up to $+10\ ^0/_{00}$. This could be done for a passenger train which starts to reduce its speed in order to get the next station: the system could calculate the distance between the position of the train and the next station, it calculates the slopes of the lines and so it starts to reduce its speed without any braking intervention.

2.2.2 MATLAB simulation in medium speed trains

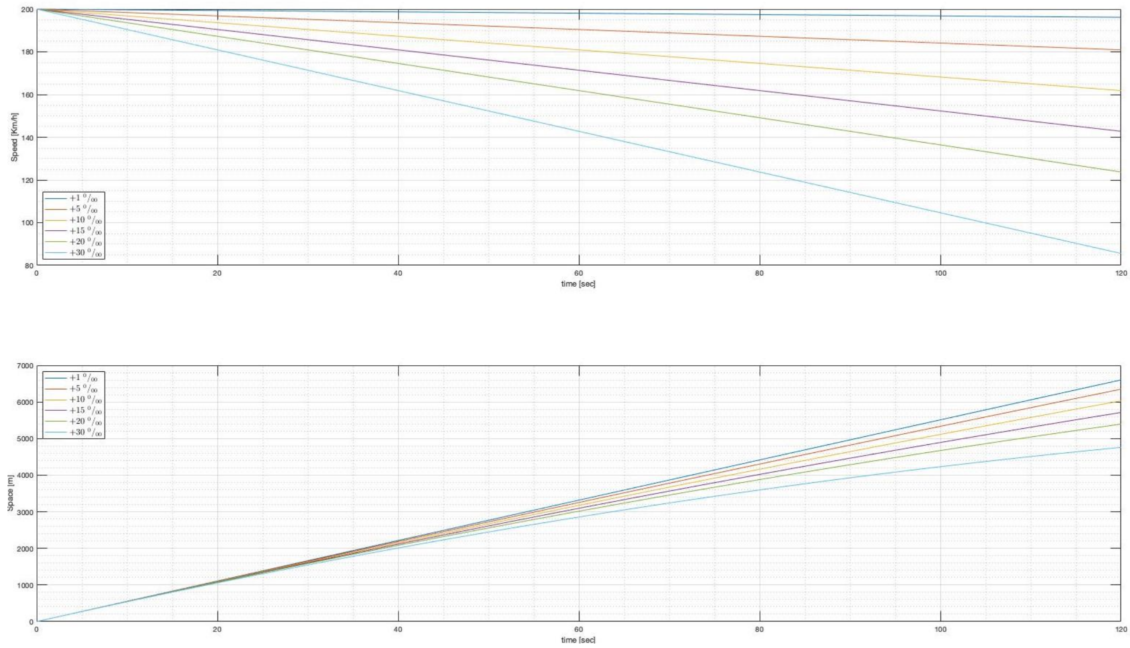

Figure 2.4: Effect of coasting for medium-high speed trains ($\lambda = 135\%$)

On the figure 2.4 results are showed in order to reduce the speed from about half of the maximum allowed. In this case better performance in terms of reducing wear consumptions are obtained. However, the spacing distance to obtaining these types of reduction is also significant. So, it could be a problem considering the minimum allowed in the space from one train to the other in this specific speed (almost 2/3 Km). This consequently makes this type of approach not so perfect in this range of speed, but even if the challenge to obtain solution in terms of optimal speed is not an easy task, reducing speed by coasting to slowdowns along the railway line could be used even for this range of speed. The usage of optimum speed in terms of coasting could be used at low speed. In fact the reduction of this speed in these types of railway lines considering only the slope effect gives more results. It is also more applicable for this speed even considering the minimum distance between one train to other than it could be comparable to reduce speed from maximum allowed at almost very low speed.

2.2.3 MATLAB simulation in low speed trains

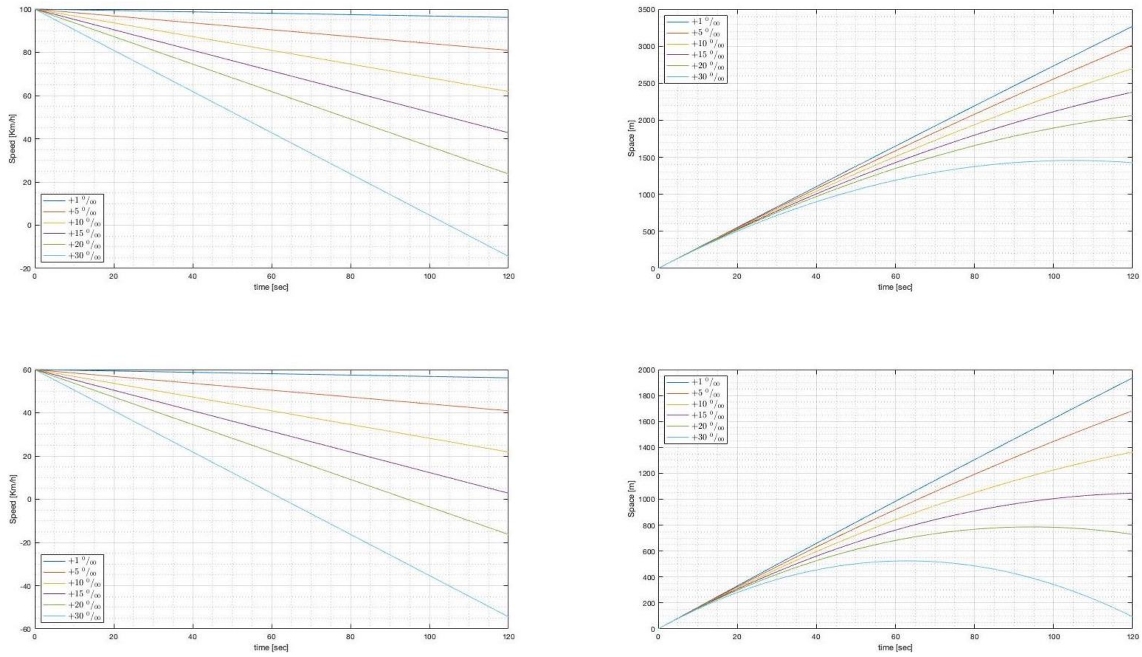

Figure 2.5: Effect of coasting in low speed ($\lambda = 135\%$)

These aspects are showed in the last figure 2.5 where it shows the maximum allowed speed for about 100 Km/h. Obviously it could be performed better for traisn which have brake percentage higher rather than a simulated one: to have an idea ETR1000 train has a brake percentage of 145% rather than 135% for ETR500. Furthermore this approach is used in local trains where to obtain even better performance increases the capacity of the train. So the usage of coasting at lower speed becomes more suitable at these speed, however some algorithms have to be used which perform the optimal speed solution in terms of time: the speed reduction from maximum to almost zero is done in less than a minute, so the prediction of this types of reduction must be done in the order of time of seconds.

CHAPTER 3

Automatic Train Operation over ERTMS

Railway market is always more and more competitive especially depending from the usage of renewable energies that are asked from the world and only the technology innovation can support a better quality of service. Safety is already the priority in railways but now ERTMS system needs to improve regularity and puncuality of the service given. Moreover the increasing of technology systems, more oriented to integration and digitalization, can guarantee operativity and also a better maintenance for the railways company. One of the standard able to support this, is actually the integration over ERTMS of the automatic train operations than can improve energy consumptions, a minor overuse of the service brake and optimal power distribution of the electric engine output. This is why automation on the train is increasingly in demand nowadays. ATO standard follows mostly this type of Goa (Grade of Automation):

- GoA 1: The train is driven by the train driver. The system GoA 1 only supports the train protection by using some specific ATC systems and including advisory information to assist the train driver.
- GoA 2: The train is automatically driven by the system. Furthermore the stopping points imposed by the system are adjusted from the train driver who is also responsible for door operation, close or open the door when the system asks to do it. In specific situation (in emergency for example) the use of manual drive is required.
- GoA 3: The train is completely driven by the system. Even some critic situations like handle doors in a specific time are operated by ATO. Nevertheless some events could require to be handled by the train attendant who is on board the train, even if he is not in the cabin.
- GoA 4: This is the standard which makes the system fully automated. So there is no competent staff on board the train, who can have the vision of what happens on board. All functions are automated even in case of emergency.

The base requirements of supporting ATO over ERTMS are the following:

- Intercheangeability: ATO must be intercheangeable among different vendors and guarantee standard interface between on board systems and trackside systems
- Interoperability (Goa levels): ATO must guarantee different types of levels on board of a train,different vendors on trackside need to be able to exchange information between different ATO, different clients and differents GoA.
- Interoperability (Goa countries): A train that travels through different countries has to be able to pass without any problem
- Adaptable and scalar: ATO must be configurable and manage evoulutions of trackside infrastructures
- Backward compatibility: A new version of ATO must be backward compatible with previous versions

In the first position the usage of an automated service which supports a train driver experience must be included. This is the definition of DAS (Driver Advisory System) and could be viewed like a first project to support automated system on board of the train. This type of vision must be supported by using some visual systems including some messages in order to warn a train driver who has to standardize his driving for each train. Anyway some problems need to be considered to make sure that the protocol works properly.

3.1 Principles

The use of an automated system in railways becomes so important, even to reduce the impact of the energy consumption and increase capacity from a train to another by reducing the headway as a function of speed. But the use of a completely autonomous system can also be used as the first in the railway, in order to increase the effective safety measure in the infrastructure like for example the railway, the gauge, the overhead contact line and so on. One of this examples was experimented in San Donato test loop in March 2020 with the use of the Unmanned Railway Vehicle (URV). Main features of the system are: i) mechanical feature: length 6.5m, width 2.9m, height 1.8m, maximum speed 200Km/h, hybrid traction power (batteries and diesel engine) and 4 hours autonomy; ii) artificial vision: long-distance vision, perimeter vision, run time detection and recognition of anomalies; iii) train control: Automatic Train Operation (ATO) over ETCS and Grade of Automation 4 [2]. Experimental tests are very important especially for a standard which is completely autonomous. It can be possible to move the standard first with the use of small and light vehicles, then choose more and more heavy vehicles as complexity increase even increasing the weight since the control of braking and traction are extremely dependent on the mass of a vehicle. In fact, the control dynamic model of the motion of the train can be first described in order to satisfy the control in a real model [2]

$$Ma(t) = F_t - R(v(t)) - F_g(r(t)) - F_c(r(t)) \tag{3.1}$$

Where $R(t)$, $v(t)$ and $a(t)$ are the train position, speed and acceleration; M is the mass of the vehicle; F_t is the traction or braking force command; $R(v)$ is the resistivity force depending on the vehicle with aero-dynamic resistance; $F_g(r(t))$ is the gradient force depending on curvature radius and $F_c(R(t))$ is the track gauge of the railway track.

It becomes so important to define all of these parameters in order to have a full description of the system in order to anticipate or posticipate a traction or braking command; even to perform the reduction of the impact of energy consumption by reducing the acceleration or increasing it exploiting the track gauge. These parameters in ATO systems define the concept of Coasting or Cruising for a vehicle. So every trackside performs every type of acceleration for any type of vehicle. In order to obtain energy efficiency, there are various strategies such as electrification losses reduction, usage of regenerative braking and improvement of comfort function and efficient driving techniques. Coasting control is more effective for long distance and the reduction of the maximum speed is more convenient for short distances. Furthermore the vehicle can save up to almost 10 up to 30% of energy compared to practical driving [3]. In the next future there will be an increasing of train capacity supported by railway improved infrastructures and interoperability protection systems as ERTMS does. Even if the rail system consumes less energy than other vehicles, the consumption is still high. So, it should be possible to find many methods for reducing the impact of energy consumptions. In fact some processes should be used like increasing voltage of electrification systems. In Italy in standard railways are used 3kVcc and in high speed lines are used 25kVac, so an increase of voltage in standard lines could help to reduce the energy consumption impact; it should be possible to reuse the regenerative braking energy from AC motors in order to reuse the energy in the whole system. In Italy the most important train which is conceived to reuse in a perfect way this type of energy is ETR 1000 train, designed by Hitachi. It is even possible to design a way to storage the energy and reuse it for other aspects such as that super-capacitor responsible to save the energy and exploit it for an user experience like charging the phone or supply a laptop. Moreover it is also possible to better people comfort, exploiting the weather in order to maintain the train carriages at a specific temperature. In the summer the cooling systems could be turned off when a train enters a gallery or in winter the system could be turned off when the sun warms up the train. Finally another important method, for a train driver, could be exploiting the infrastructure using cruising or coasting methods and respect the journey time in order to efficiently drive a train. Using the last method mentioned above a Driving Advisory System (DAS) will be implemented On-Board of the train which is responsible to do it.

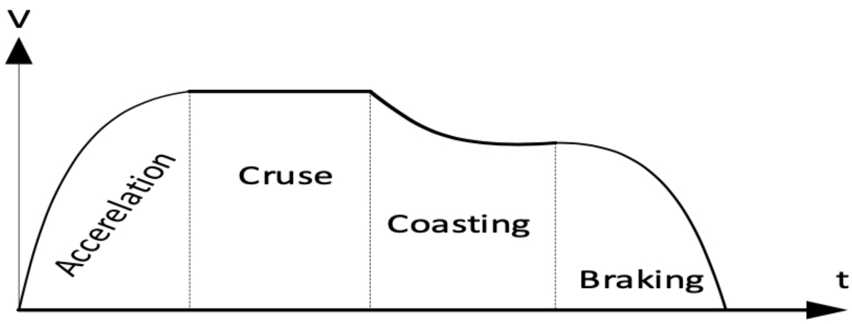

Figure 3.1: Different driving phases for a rail vehicle [3]

- Acceleration. As shown in Figure 3.1, the train driver needs to optimize his driving experience by using standard model of tractive effort curve for each vehicle. The acceleration to a vehicle could be applied considering the effect of the maximum speed allowed in a specific section of the track, knowing the maximum tractive effort of the vehicle. By including the effect of the track gauge, it could be possible to reduce the current request to maintain a certain speed. For example it may be possible to reduce the tractive effort at a low speed, and then when the speed increases it should be possible to increase even the traction, since the current absorption of a train is inversely proportional to the speed.
- Cruise and Coasting. As soon as the target speed is reached the traction is left and the forces applied to the system can be taken into account. As the rolling friction is considered like negligible in the railway, the train is able to maintaining the target speed for every slot of time. Then the resistivity force with aero-dynamic resistance takes place and speed of train starts to decrease proportionally to the design of the train, even considering the slope of the trackside. In this part of the section many algorithms were adopted in order to reach the target speed at the target time to respect the journey time of the next station and minimize the usage of braking command.
- Braking. In this section we are considering the braking commands. Some electric braking models of each train have to be known in order to exploit the reuse of regenerative braking of AC motors, to avoid the wear of the mechanical parts of the train. As in the case of tractive effort, electric braking is inversely proportioned to the speed.

3.2 Driver Advisory System: the application from manual driver towards first automation levels for an On Board system

Energy-saving is nowadays a fundamental requirement for the impact on the environment. The high coverage of the trains in the countries makes the train driver strictly connected with the reduction of the impact on reducing energy consumption in operations with an appropriate speed profile. The driver Advisory System aims to make a driver experience clearer. It has been demonstrated that energy consumption in powering has been reduced by 26.8% between two stations at maximum, and by 16.4% totally through the test held in TOKYO MONORAIL CO., LTD using a vehicle of type 1000 on March, 2017 by using the DAS [4]. ERTMS system is able to create a specific area on the

Driver Machine Interface which advices about cruising speeds or timing of coasting related to the journey profile and the time to reach the specific target (next station), since the architecture designed for this type of safety is to signaling the movement of the train on the cabin. This first automation levels could be implemented in techniqual requirements in the ATO GoA 1. Obviously the audio assistance could be used but it is important not to disturb the train driver. In the initial phase, the system knows the type of vehicle used, the percentage of braking mass and the Journey Profile with all the parameters of the infrastructure when the trip is going to start. Some parameters are inserted by the train driver, some other parameters could be imported by the Radio Block Center that transmits all the information about the structure of the trackside. ERTMS system needs to use coasting when the vehicle speed increases without powering, or anticipates the braking using only the electric braking command in a specific time defined by the system. So in the DAS a textual message like "start cruising" or "start coasting" should be displayed in advance, even considering the response time of the human. To preserve the energy consumption considering the dynamic motion of the train, the system should transmit on board the train the percentage of tractive or braking command by reaching the specified value, considering also the time to reach the objective. In other words, textual message like "start to insert 30% of electric braking command" or "start to insert 800A of current to reach the speed value shown" could be used. Obviously the technical parameters of the train should be known by the DAS system in every single moment. This is possible only using the Train Control Management System (TCMS) which is responsible to collect all the data and show them in real time on the DMI.

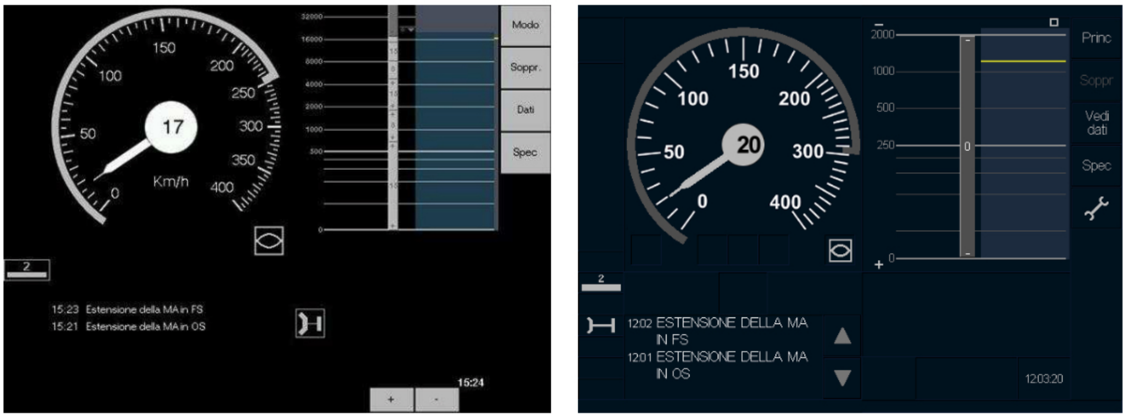

Figure 3.2: Alstom and Hitachi DMI

In figure 3.2 the textual messages to the train driver are shown and they are relate about to the movement authorization in order to pass from the On Sight to the Full Supervision. The Train driver is informed by the textual message that this specific section the train is fully controlled by the Radio Block Center. Any type of message could be sent in real time and shown On Board following this type of philosophy.

So in the case of manual driving the DAS system should be implemented in the cabin, communicating with the EVC and sending any type of textual messages. In particular, the Connected-DAS (C-DAS) is more dedicated in order to receive the update of the traffic in the railway system coming from the Traffic Management System (TMS). It provides, whenever it is possible, dynamically optimized profile based on the position and the journey time of the train. So the junction between C-DAS and TMS allows to receive in real time updating from the traffic especially when some perturbation is coming and consequently reprocess the driving profile in order to optimize the traffic. So it should be important to recognize static data (route data), dynamic data (timetable scheduling) and conflict resolution that may appear, in order to improve the driving experience and optimize the reduction of energy impact. With the definition of “Energy Saving”, Hitachi is working to experiment some specific algorithms that define a trajectory optimization in coherence with the timetable. The first tests taken are comparing in real situation with the collaboration of RFI/Trenitalia with regional track Firenze-Pisa Centrale. The first tests showed an interesting reduction of energy consumption respect to the scheduled timetable [5].

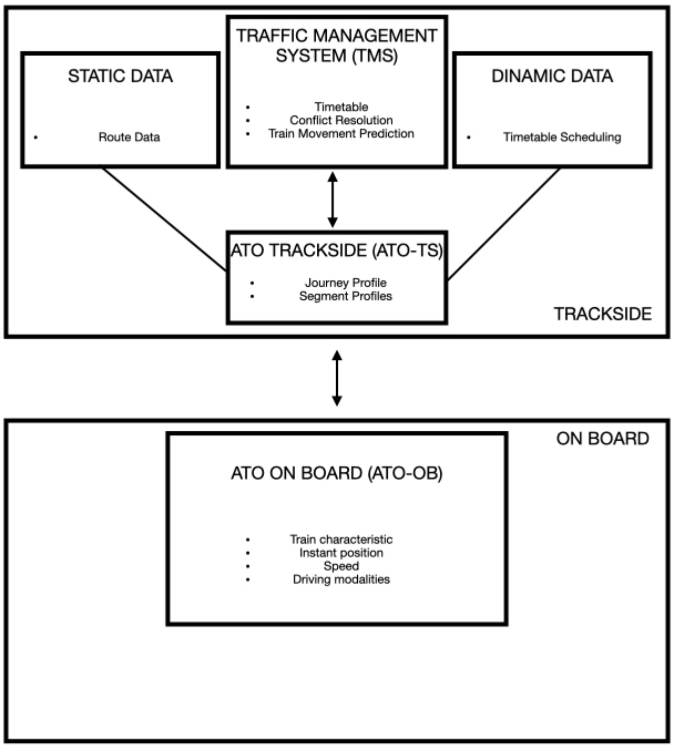

Figure 3.3: Trackside and OnBoard ATO DAS system

It must be clear that the most critical factor in the railways is always safety, which will be never placed in background. The use of a DAS system in the cabin has to be performed without any confusion or distraction by the train driver. In order to do this many feedback are provided by the train drivers in Sweden, given by a research from a Transrail Sweden AB [6]. In order to avoid confusion or distraction, some specific guidelines for the train driver’s interface were designed , collecting all the information provided. Following factor are listed below:

- Safety. By the use of main signaling colors used in the infrastructure, some deviations may be used for this type of signaling system. It is important to avoid color like red or green because they may interact and distract a train driver. Moreover, no more than one speed is directly presented on the display, since it may create confusion with the main speedometer relevated on board.
- Ergonomics. The use of colors, the contrast fonts and the position of elements for the textual messages may be presented in a specific way. For example it should be necessary to differentiate the contrast between static information or dynamic information, because the second element should be presented in a more distinctive way. In addiction, some other parameters like screen colors brightness may be adjusted by the train driver.

- Perception of the model presented On Board. It needs to be clear as much as possible that an important aspect which takes place is the driver's mental workload. As a primary consequence, one of the major conception of displaying the speed profile is represented in Y-axis rather then X-axis; this is appreciated for a train driver since the orientation of the train follows this type of strategies.
- Responding to drivers. DAS should continually display timetable information in order to represent current deviation from the wanted curves. This type of approach could encourage train driver to an on time departure and arrival, since he should be able to give good prediction about arrival times.
- User motivation. Finally, but most important is the habit to encourage to use of the system. For a train driver the vision of the percentage of energy saving using the DAS must be included, in order to understand and recognize that following the advisory coming from the train is good for the environmental impact.

All of these concepts may be easily implanted On Board of the train System. In particular, the reuse of economic arrangements of the areas of the ETCS layout used in the DMI could be redesigned for this type of purpose. By the way, CATO display showed at Transrail Sweden AB is very similar to the portion of the part on DMI called "planning area". The reuse of this type of planning information should be implemented on the fleet in an ERTMS scenario as first automation levels for an On Board perspective of view.

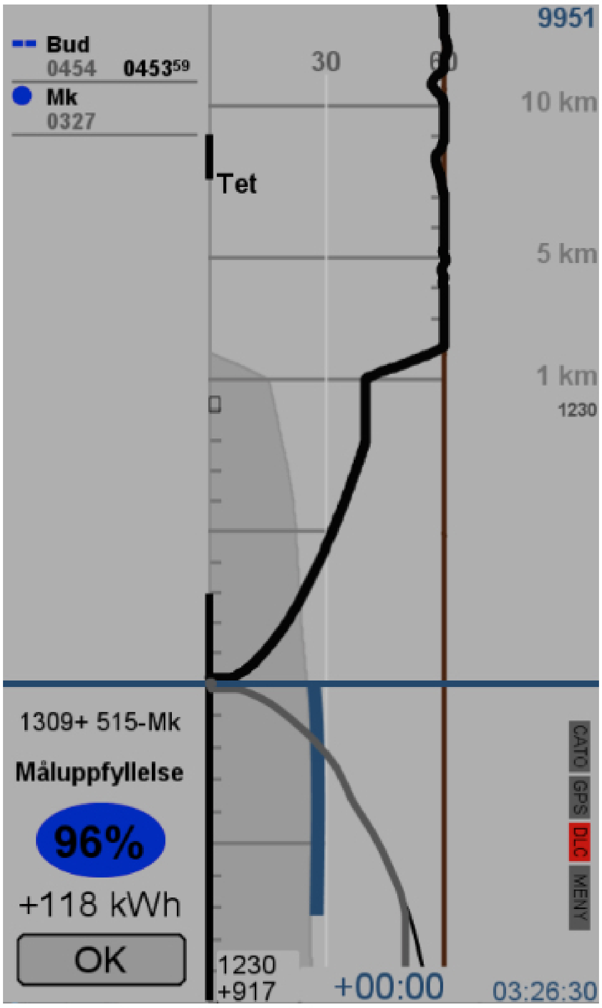

Figure 3.4: CATO display [6]

On figure 3.4 a simple CATO display is shown in order to advise a train driver on what could be the best optimization speed profile which takes into account the effect of the train dispatch in that moment. Usually the train drivers can only make some predictions about the arrival time in some specific points. Since these information depend on some other parameters in the trackside, it becomes impossible for a human to predict the delay for other trains or speed restrictions and so on. So the use of an advisory monitor for a train driver could be very important. For example, in the picture above, the speed profile for the next 10 Km is shown; it has to be maintained by the train driver in order to reduce energy consumption and increase better punctuality. This curve could have a minimum (obviously 0 Km/h when the train is stopping at a station) and have a maximum. In this example a maximum speed of 60 Km/h is shown. Since the parameters coming from the ATO trackside and those coming from the ATO on board are known, we can put them together and, using some specific ATO trajectory optimization algorithms, we can draw the perfect speed profile that the train driver has to respect . Moreover, a percentage value could be used for an user motivation with different colors, depending on how well the driver can respect the ATO speed profile and how much energy could be saved. These suggestion parameters could be fundamental since the system can reduce the performance improvement or even be counterproductive if the train driver doesn't follow this speed profile: a real problem not only for the train itself but for all the system.

CHAPTER 4

ATO Trajectory Optimization algorithms

The research of the optimum train speed trajectory can be a hard task to implement, especially when parameters of the best trajectory are extremely dependent on certain operations, geographic, and physical constraints. In order to do that some algorithms could be implemented using even some artificial intelligence to find better stability and quality for the results. The parameters of the trajectory are related to the speed and the distance or the position along the journey of a train. Combinatorial algorithms can be even used. In order to satisfy all of them, it will be required to construct a specific weighted and directed graph $G = (N; A)$ where a set of N nodes are the train state, including estimated speed and distance, and A is the set of arcs connecting to the nodes. Since we are working with graphs, it will be the best solution to work create matrixes.

4.1 Ant Colony Optimization

In computer science, the ant colony optimization algorithm (ACO) is a technique to solve some computational problems following the behavior of the ants to find the best path. They release a specific trace (for ants is the pheromone) when the path good in order to communicate with the other ants. Using this type of approach the "artificial" ants will learn the final track in order to converge to the best solution using the optimization process. By using this, at first the original pheromone trail is constant and is defined c_{lnk} as it will be shown on the Algorithm 4.2 [7]. For each step ant k chooses the next speed and preset the position preferring a random proportional value. For example, if the ant is currently in index i and the possibility speed j is selected for the next, preset position will be defined as follow [7]:

$$p_{i,j}^{k} = \frac{[LNK(i,j)]^{\alpha}[ECH(i,j)]^{\beta}[TCH(i,j)]^{\gamma}}{\sum_{n \in \Omega_i^k}[LNK(i,n)]^{\alpha}[ECH(i,n)]^{\beta}[TCH(i,n)]^{\gamma}} \tag{4.1}$$

Where $LNK(i,j)$ is the link information space matrix used to link connection two nodes, $ECH(i,j)$ is the sparse matrix to store heuristic energy consumption of between two nodes, and $TCH(i,j)$ is the sparse matrix to store heuristic time consumption between two nodes. Other parts are α, β, γ parameters to determine relative influence of the pheromone and heuristic information, and Ω_i^k is feasible neighborhood of ant k being at node i. While the train is not running enough, it will be set γ as a higher value in order to attract ants for choosing the less time cost switch. Vice-versa, if the train is running too fast, β will be set at a higher value to attract ant for more energy-efficient node switch. Note that in this case α remains constant. Each "artificial" ant so could be able to decide which is the next indexed speed for the next preset position, in order to show the speed of the train at each preset position. The pheromone trail could be constructed with specific step algorithm using the formula described above. Based on this it should be used the algorithm to update the vector UPD, the update vector of the pheromone trail. The update procedure could be implemented in two different parts, first update the vector UPD and then the pheromone trail matrix LNK using UPD and SOL. Following procedure[7]:

Require: $eval_{min} \leftarrow min(EVAL)$
  for $i = 1$ *to* n_a **do**
    $\overline{eval} = EVAL(i) - eval_{min}$
    $UPD(i) = 2 * c_{lnk} * exp(-\overline{eval})$
  end for
(4.2)

Where $EVAL$ denote the 1-D matrix to store evaluation function output for each row of constructed solution and n_a denotes the ants in a group:

$LNK(r_i, c_i) \leftarrow (1 - c_e)LNK(r_i, c_i)$
  for $i = 1$ *to* n_a **do**
    for $j = 1$ *to* $n_p - 1$ **do**
      $r_i \leftarrow SOL(i,j)$
      $c_i \leftarrow SOL(i,j+1)$
      $LNK(r_i, c_i) \leftarrow LNK(r_i, c_i) + UPD(i)$
    end for
  end for
(4.3)

The termination condition follows two types of criteria. First, the ants numbers exceed maximum allowable and then sol_{bsf} remains the same for a selected number of iterations.

4.2 Genetic Algorithm

Genetic Algorithm is a heuristic algorithm used to solve particular problems in optimization matters. Other algorithms, with linear or polynomial complexity, cannot do the same. This is a not deterministic algorithm which means that not always it converges in optimal solution or behavior in the same manner when the same input is selected for it. The use of "Genetic" derives from natural selection introduced by Charles Darwin where survival and reproduction of individuals are possible due to the differences of phenotypes in different countries. The first important thing is to define two steps to create the solution of the problem and apply the Genetic Algorithm:

1. Generate the equivalent genotypes by creating population of strings
2. Create a function defined "fitness function" in order to find the better string applied to it

In the trajectory optimization, it could be defined each eligible speed at each specific position. It could be done by creating many section or paths to the trackside dividing them in two neighbor positions and allocating a specific control index number: this represents the next speed selected to be evaluated in order to find the final best solution. Assuming that the speed at a specific position is V_i, the V_j is the next speed selected defined between minimum and maximum possible speeds . Moreover, two more speeds are known as V_{ee} as the possible speed used in a most energy-efficiency operation, like coasting operation, and V_{cur} which denotes the speed selected and used for cruising operation. This table clarifies what was explained above:

Control index i_c	Next speed selected
0	v_{ee} or v_c whichever exists
$1 \sim 6$	$V_{min} + (V_{max} - V_{min}) * \frac{i_c - 1}{5}$
7	V_{cur} if feasible

Table 4.1: Selection based speed with control index number [7]

According to this table strings could be used for each element with N elements, where each element is define as control index associated to the N preset position along the journey. For initial population we created M strings. After that, the Genetic Algorithm will perform operations in order to find the final best solution for trajectory optimization.

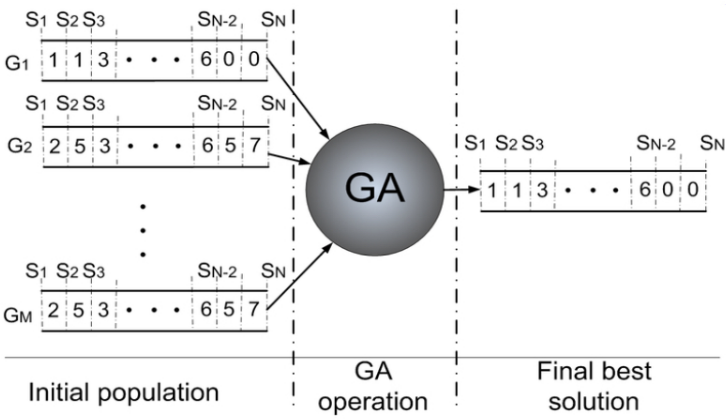

Figure 4.1: Schematic Block of GA optimization [7]

4.3 Dynamic Programming

The Dynamic Programming is a particular algorithm technique following the strategy to subdivide the problem into various subproblems and considering the fact that the optimal solution of the final problem is strictly depending on the optimal solution of subproblems. It is much more time and resources consuming to perform it. In the case of optimization trajectory problems it is solved dividing the trajectory into sub-trajectory and apply the optimization. A vehicle state Θ is composed by four physical elements: distance s, speed v, journey time t, and energy consumption e. In the initial state it could be expressed as the vehicle state in the following matrix [7]:

$$\Theta_0 = [s_0, v_0, t_0, e_0] = [0, 0, 0, 0] \tag{4.4}$$

Using the Dynamic Programming algorithm, the state different from zero is created using the index control number defined in Figure 4.2. So in order to pass from one state to the other, it can be represented with the use of the control index number i_c^1 defined in Table 4.1:

$$s_0 \rightarrow i_c^1 \rightarrow s_1 \tag{4.5}$$

$$v_o \rightarrow i_c^1 \rightarrow v_1 \tag{4.6}$$

Assuming that time cost t_c and the energy cost e_c are found by using the sparse matrixes TC and EC:

$$t_1 = t_0 + t_c \tag{4.7}$$

$$e_1 = e_0 + e_c \tag{4.8}$$

so the new state is produced by using the previous one, with different index control number, in order to define all the vehicle substate Θ_n and find the optimal trajectory.

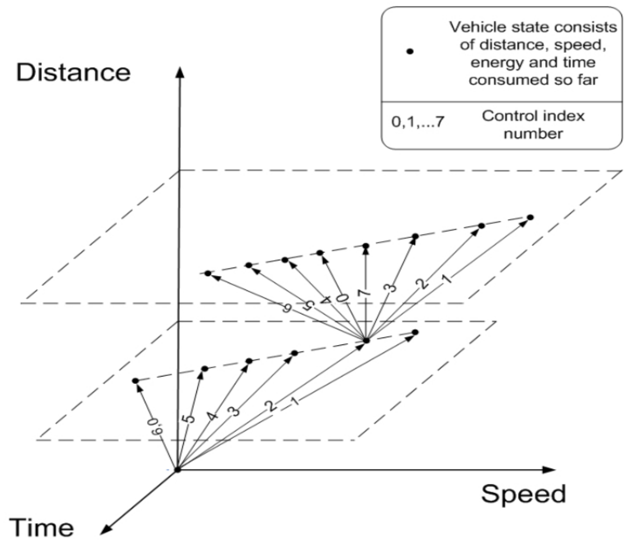

Figure 4.2: DP algorithm and different states generations [7]

The algorithm performs like the standard "divide et impera" algorithms even if it is more efficient in terms of iterations to find sub-optimal solutions. In fact is important to avoid duplicate sub-states in order to kept only the state that has the minimum energy cost: the state with more energy will be removed. As a consequence, a table to save the sub-optimal state needs to be created and saved, optimizing the resources and increasing the speed access to the table. Anyway, the use of this type of algorithm follows some specific rules in order to make it more efficient. In the Dynamic Programming some rules are followed:

- It is used to solve optimization problems
- The original problem is divided in sub-problems and they are not independent one from the other
- Some sub-problems share some parts with others in order to allocate the resource one time and give them the access to be used when they need
- Sometimes it is not so clear how the problems must be sub-divided
- Calculating the solution for all sub-problems and use it to reach the solution for the original problem (bottom-up philosopy)

4.4 Comparison and final results

Figure 4.3: ACO simulation algorithm [7]

The effects of optimized trajectory algorithm are shown on figure 4.3 using Ant Colony Optimization algorithm with different journey times. As it can easily seen from the three graphs, especially for the long journey time, using these types of algorithms it is not so good in terms of cruising or coasting. Moreover, there is a big difference between maximum and minimum speeds, especially in the central part of the journey. The optimization speed algorithm for short journey time tends to reach the maximum speed allowed in the central part, and consequently it is not so good in terms of energy saving efficiency.

Figure 4.4: GA simulation algorithm [7]

On figure 4.4, a Genetic Algorithm optimization approach is used for different journey times. Even if the curves are smoother than ACO, the use of coasting is not so optimized in long period of journey time by using this algorithm. Consequently, the energy saving efficiency for these types of approach could be used only for short periods of journey time. Whereas the algorithm is not deterministic, it may happen that, under certain conditions, the GA performs very badly and even fails to converge. This problem may occur especially on long period of journey times, so the use of GA in high speed trains is not considered so good.

Figure 4.5: DP simulation algorithm [7]

On figure 4.5 the last algorithm, Dynamic Programming, is shown. This type of algorithm performs very well especially in long journey times, considering a much better constant optimum speed reached for coasting, below the maximum speed allowed. Anyway the problem for this type of algorithm is related to the cost of computational resources, much more than the other two. Considering all of this, it is more suitable in the train optimization speed problems, but it requires more resources, that could be a problem considering short journey time.

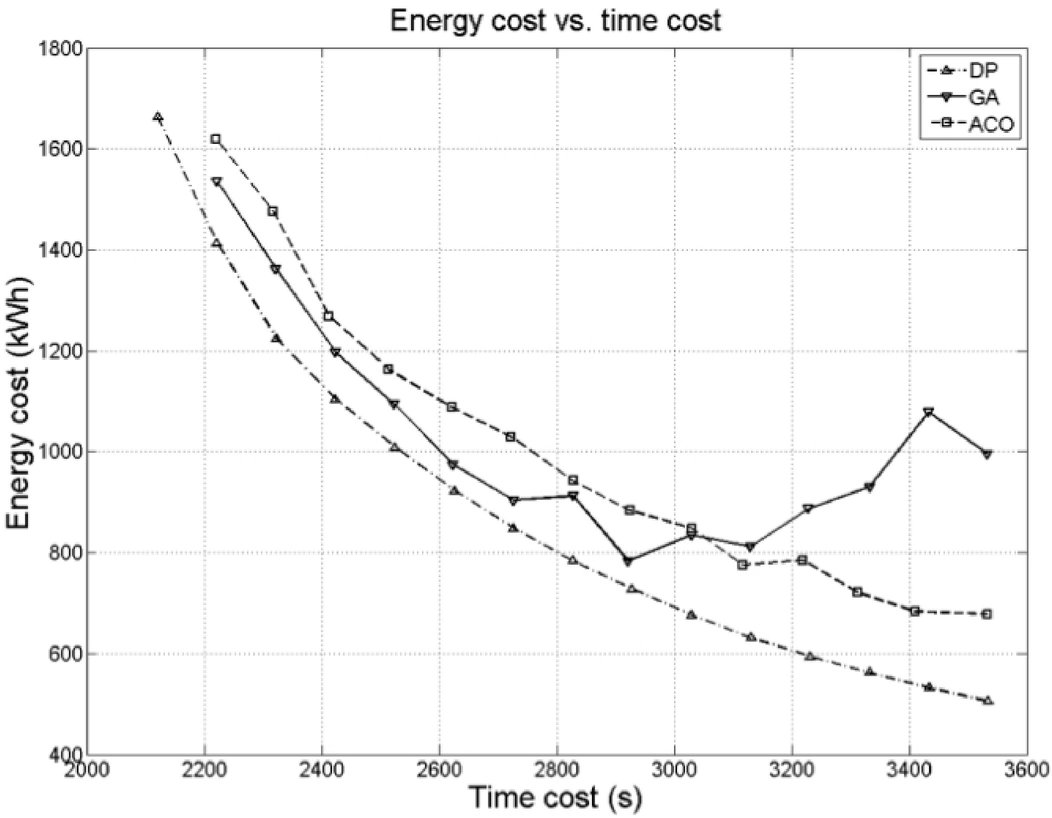

Figure 4.6: Algorithms in comparison [7]

Comparing all of the three algorithms in terms of energy cost, it is clearly showed how the usage of DP algorithm always performs better, and increasing the journey time reducing the effects of energy cost, and thus gaining better performances. Moreover, the two other algorithms have some problems and tend to converge below a journey time of almost 2100 sec. On the other hand, GA algorithm is not suitable for a long journey time, since the energy cost increases more and more for journey time above 3000 sec. This tells us how the usage of a DP algorithm could be more suitable in high speed train, to prevent the energy consumption problem and to improve a driving experience. The costs of energy are significantly reduced, and the DP algorithm obtains better performance respect the two others for almost 10% of energy saving, even in short journey times.

CHAPTER 5

Future Railway Mobile Communication Systems over ATO

FRMCS

Future Railway Mobile Communication System

5.1 GSM-R limitations and disappearing

One of the most important aims in the rail transport system is to exploit the future digitalization to support reliability and efficiency in terms of quality of service in the railways infrastructure and for the passengers. The development of wireless communication is going to increase in railway to support train operations and passenger services. Using different types of RATs (Radio Access Techniques) such that Wi-Fi, LTE, 5G, and Satcoms, in the next future they are going to become more flexible and reliable. The trends for the future are to apply the ERTMS in all the railways infrastructure of Italy before the 2036 [8], so it is important to support not only the equipment on earth but even the equipment On Board of the train. The increasing of these components and the increasing of digitalization may lead to limitations in the use of the actual standard of GSM-R, since physical problems may occur. First of all one of this problems may occur in the channel access in a train to support ERTMS safety. This is a physical problem since there are not enough resources to support the standard for any train in a node like Milan for example. On the high-speed Rome-Naples road section there are about 60 BTS distanced 3 Km one from the others. The GSM-R component operates in a bandwidth of 4MHz with 19 carrier frequencies with almost 200KHz of width. The problem is related to the maximum number of trains that can be freely connected to the base-station: the number is 19 trains every 3 Kilometers. Even if this number may seem very high in a high-speed road, physical access problems may occur in a node scenario. For example, the evolution of HD-ERTMS (High-Density ERTMS) could be lead to have more than 19 trains in about 3 Kilometers of trains: this is a very big problem in terms of QoS (Quality of Service) and moreover it is not physically acceptable!

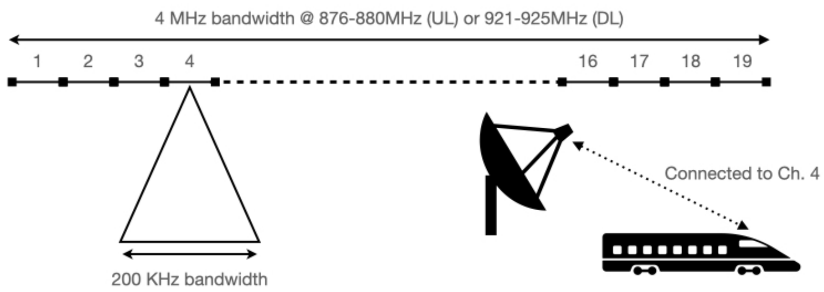

Figure 5.1: Channell allocation in 4MHz bandwidth for GSM-R connection

Moreover, it is not only a radio access problem, but the use of high bandwidth to support difference types of service is strictly related to a transmission type of IP based. Actually, the standard GSM-R transmission is a type of communication based on a circuit switch communication and this is not useful to support some of QoS required by different types of services on the train like broadband passenger services, IoT (Internet of Things) services, train services, staff communication and so on. One of these examples if the first step towards FRMCS: today rail operators start planning to migrate the existing networks to the introduction of IP-based transmissions in a GSM-R networks. This planning is going to start in 2022 [8]. The trend to support communication based on packet switching communications will bring revolutions in terms of supporting every type of service that railway transport system needs, as far as reliability, safety and interoperability.

Since GSM-R is expected to be supported until 2030 by major vendors, as a consequence this standard will become obsolete. This new type of communication systems are now beginning to be supported and placed on the railways infrastructure. FRMCS (Future Railway Mobile Communication System) is the new future telecommunication standard system worldwide designed by UIC (International Union of Railways) and this is the successor of GSM-R but also a standard for rail transport digitalization. FRMCS is still under development but based on the concept of testing the standard in the laboratory to avoid expensive trials on real site, and to investigate even any type of unusual situations [9]. This new standard is important to create a new future vision of the railways access to any service that railway transport system needs.

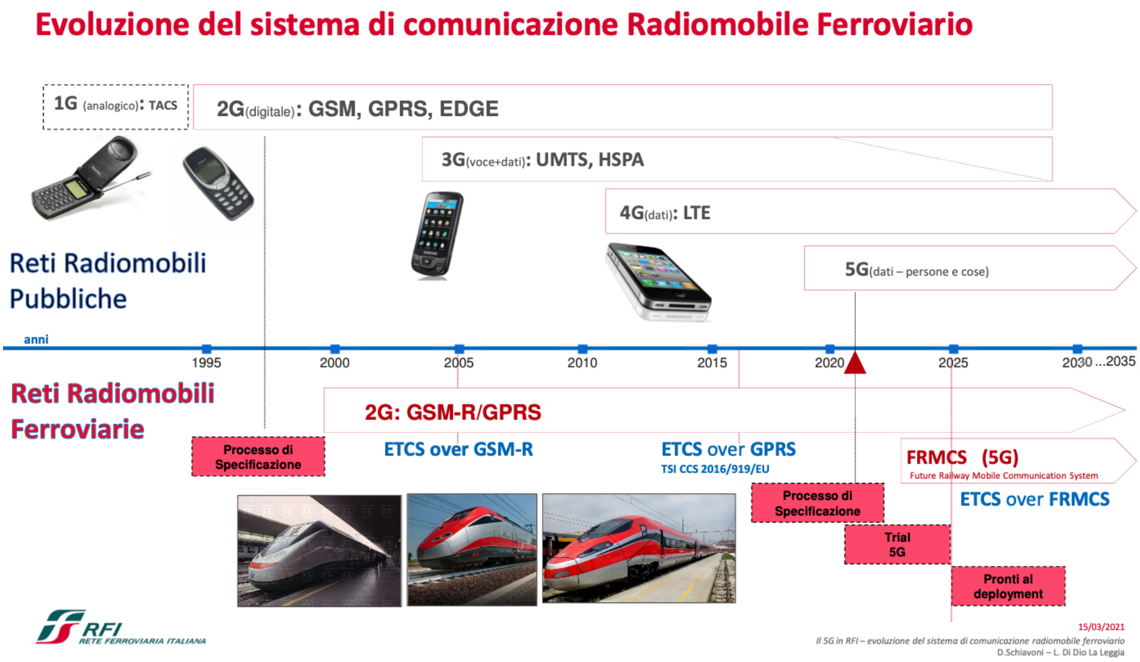

Figure 5.2: Evolution for railways mobile communications in Italy[10]

5.2 FRMCS spectrum requirements

An important aspect is the future standard in terms of spectrum requirements. The existing GSM-R spectrum at bandwidth of 900 MHz is suitable for low bandwidth applications and is still too small. With the growing of digitalization and automation the throughput of the scenario has to be much higher. One of the estimate throughput references calculated by UIC (International Union of Railways) with the future services is showed in the table below:

Reference train	Traffic uplink	Traffic downlink
Scenario future evolution	7.42 Mb/s	4.38 Mb/s
Scenario co-existence migration	3.49 Mb/s	3.50 Mb/s

Table 5.1: UIC FW/ATWFG (1903 v2.2.0)

Combining all of them it should be demonstrated that the throughput needs to be support all of the services (including ATO performance) that should be more or less 19 Mb/sec capacity per train in uplink and downlink . The estimate density rail segment calculated by UIC is showed in the table below and is different for any type of reference:

Reference rail segment	# trains per cell
Reference low density rail segment	2.64
Reference high-density rail segment	5.36
Reference high-speed rail segment	4.00

Table 5.2: UIC FW/ATWFG (1903 v2.2.0)

If we now multiply with a maximum number of concurrence trains on the cells in high-speed rail segment for example, it ends with a number of more or less 75 Mb/s for each cell we need. The existing GSM-R spectrum @ 900 MHz guarantees a throughput of about 3.5 Mb/s for each cell. This is in strong contrast to the actual need for future applications. In fact with the need of more bandwidth, there is an older bottleneck that we have to overcome. This is the reason why the transition phase from GSM-R to FRMCS will operate in parallel over a long period of time. This need raises because an additional spectrum allocation is required.

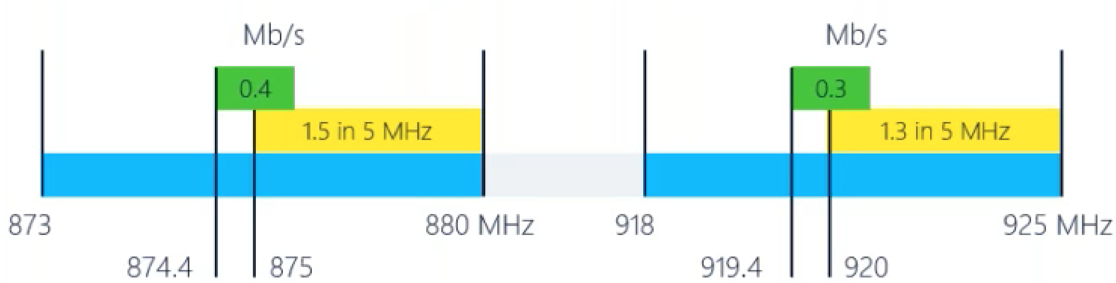

Figure 5.3: Guaranteed throughput @ 900 MHz (TR 103 554 V1.2.1 and high-density scenario)

To overcome this kind of problems, three types of main options are under study:

1 1900 - 1910 TDD. Using 10 MHz of bandwidth with Time-Division Duplexing @ 1900 MHz.

2 2290 - 2300 TDD. Using 10 MHz of bandwidth with Time-Division Duplexing @ 2300 MHz

3 Public MNO. Using bandwidth allocation with specific public Mobile Network Operators. This could be a problem in contrast to QoS for critical applications.

Anyway, since as first it will be enabled with the same GSM-R standard, it could be used on the same bandwidth allocation of 900MHz with a bandwidth of 7MHz, so it will use the GSM-R bandwidth of 873-880MHz in uplink and 918-925MHz in downlink. This is clearly a problem with bandwidth interference and also for Doppler effects.

5.3 FRMCS interferences with cellular GSM @ 900 MHz

The use of bandwidth allocation using public MNO should be one of the most cheaper requirements in terms of migration towards FRMCS. However, the allocation in terms of frequency using other terminal clients should increase the problem of interference and could disturb the fast train communication system that will be implemented. To analyze this type of problems, the Telkom University in INDONESIA evaluates the BER (Bit Error Rate) against SNR (Signal to Noise power Ratio) for the railway and customer viewpoint with the use of Indonesian GSM channels obtained from New York University Simulation [11]. To analyze them, since FRMCS was based on tests in laboratory, one kind of system model could be used in order to achieve some final results analyzed with simulator tools like MATLAB. The GSM-R system model is basically GSM model with the usage of GMSK modulation (Gaussian Modulation Technique Minimum Shift Keying) [12]:

$$S(t) = \frac{1}{2}[erf(R_a) + erf(R_b)] \tag{5.1}$$

$$R_a = -\sqrt{\frac{2}{ln2}}\pi B_{3dB}(t-a) \tag{5.2}$$

$$R_b = \sqrt{\frac{2}{ln2}}\pi B_{3dB}(t+a) \tag{5.3}$$

- $S(t)$: resulting modulation
- B_{3dB} : bandwidth @ 3dB [13]

With the simulation, it has also been used the modulation technique called C-BPSK (Complex-Binary Phase Shift Keying) with the resulting equation:

$$x = \frac{1}{\sqrt{2}}[1 - 2b(i)) + j(1 - 2b(i)] \tag{5.4}$$

For the channel model the frequency used for the simulation by FRMCS is 873-880 MHz for uplink and 918-925 MHz for downlink [14] and the use of a broadband channel with bandwidth of 7MHz in the working frequency.

5.3.1 FRMCS BER performance with stationary trains

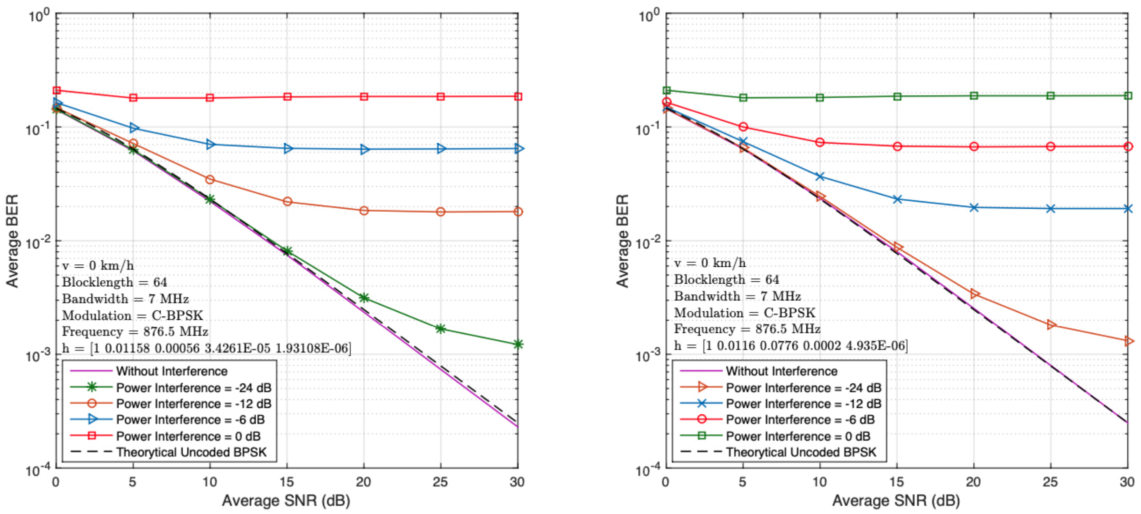

Figure 5.4: BER performance with stationary trains [11]

The effects of the interference when the train is in the stationary mode (for example when it stops at the station) is represented in figure 5.4. When the train stops at the Jakarta station, with the ideal condition of no interference, it should get a BER of almost $2x10^{-4}$, and with a power interference of 0 dB it should get a BER of 0.185. When the train stops at the Bandung station it will get a performance with BER equal to $2.75x10^{-4}$ with the ideal performance and a BER of 0.189 with the worst performance. Finally, it may be expected that the interference in FRMCS with cell GSMs could be the same from one station to the other, so the problems are likely the same and the study could be done in general for all the GSM basestations of the world (like in Italy).

5.3.2 FRMCS BER performance with high-speed trains

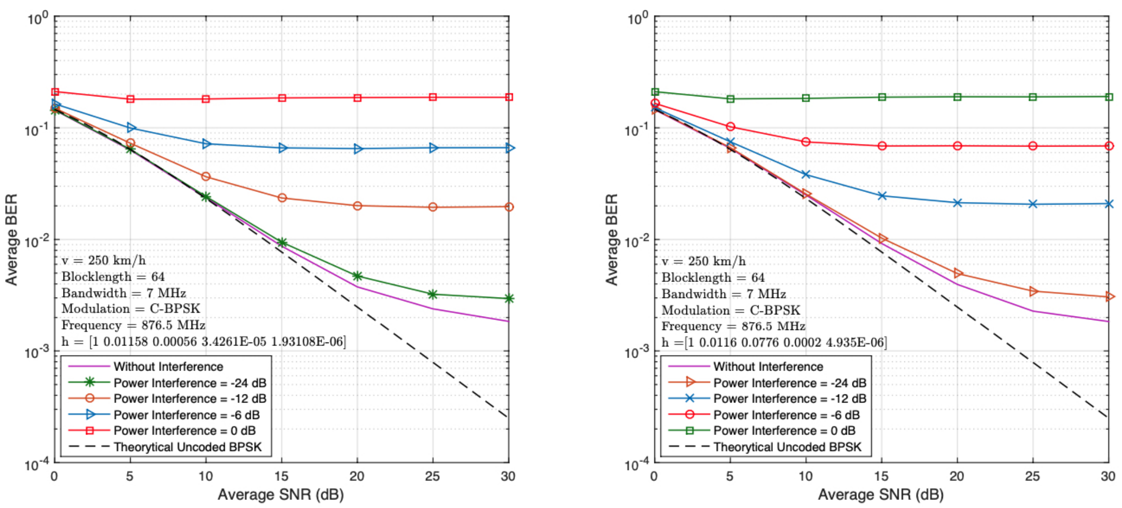

Figure 5.5: BER performance in high-speed trains [11]

The effects of the interference when the train is on the road (for example when it is reaching the high speed of 250 Km/h) is represented in figure 5.5. When the train is travelling to the Jakarta station, with the ideal condition of no interference, it should get a BER of almost $6.9x10^{-3}$ with SNR of 30 dB, and with a power interference of 0 dB it should get a BER of 0.191. When the train is travelling at the Bandung station it will get a performance with BER equal to $7.1x10^{-3}$ with the ideal performance, and a BER of 0.195 with the worst performance. Even in this case, it should be demonstrated that numerically BER resulting with the use some simulator could be the same from one country to other. Moreover, when the train moving very fast, the value of received BER could be the same with an SNR more than 25 dB: this means that it should be used a power efficiency in high-speed by reducing the use of power consumption rather than in a station where the power could be increased a little bit to get the same performances. Even in this case the study done in INDONESIA could be the same even in Italy.

5.3.3 Analysis on Doppler Effect

FRMCS working at speed over 200 Km/h and in the frequency band of 873-925 MHz could be more sensitive to Doppler effect for the environmental conditions since the speed and the attenuation play a fundamental role in the scenario. Same study done in Telkom University in INDONESIA shown that FRMCS is very sensitive to the block length and the speed, moreover the use of prefixed orthogonal frequency division multiplexing (CP-OFDM) and the low modulation code could help FRMCS to achieve the target BER [15]. First of all the Doppler effect is the change of central frequency f_0 with another frequency that we define as f_d when an observer is moving following the wave source and this can be expressed by:

$$f_d = \frac{v * 1000}{60 * 60 * \lambda} * f_0 \tag{5.5}$$

where:

- v is the speed in Km/h
- c is the speed of light equal to $3 * 10^8 m/s$
- f_0 is the central frequency to match the condition in original state

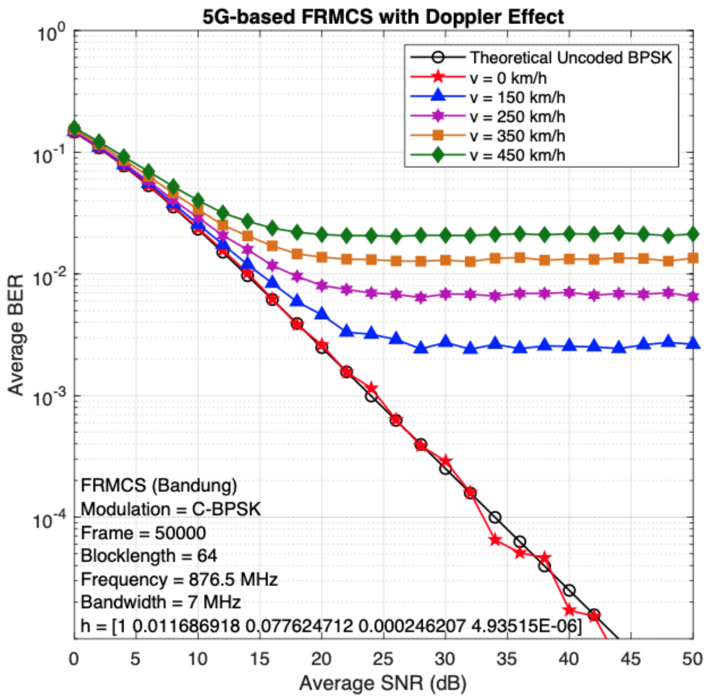

Figure 5.6: Doppler effect performance [15]

Analyzing the impact of the doppler effects in a 900 MHz of central frequency and using CBPSK modulation, it is shown that the use of FRMCS in high speed trains could give the error probability of BER equal to 10^{-2}. It must be clear that the use of ATO communications in high speed trains require more technical error corrections. All of this in order to avoid the problem of high packet error rate and to retransmit the packet itself, increasing the speed of the communication in the whole system. Perhaps this kind of problems could be increased by using a strong system that could avoid the Doppler effect by using some filters in the radio receiving part.

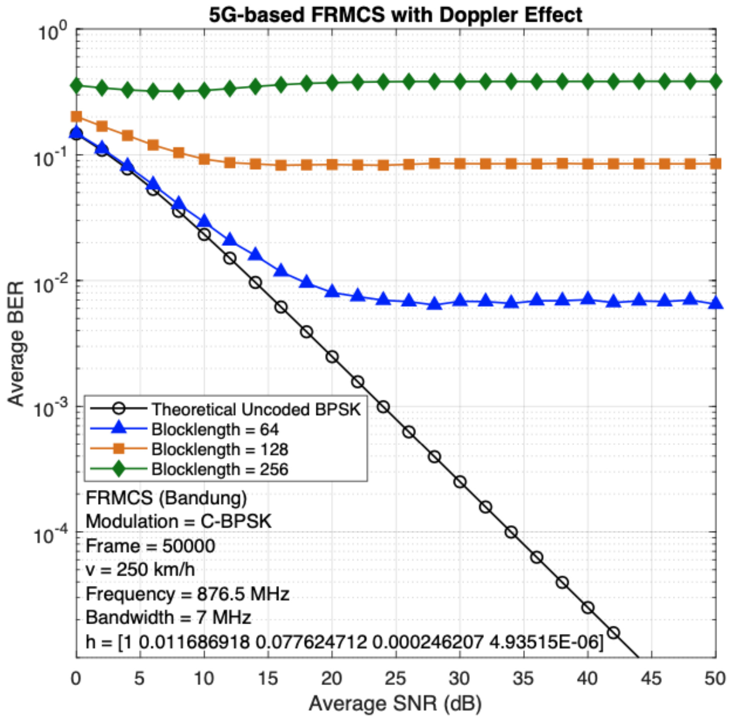

Figure 5.7: Doppler effect performance[15]

Some experimental tests could demonstrate that, changing the number of packet information possibly sent, the performance of the system could be decreased. For example, as it is showed in the figure above, for a high speed train travelling approximately to 250 Km/h, the impact of changing the target block length from 64 to 256, the performance of a FRMCS communication in this target bandwidth can be tremendously decreased, reaching even a target of BER less of 0.1 even using high power to transmit. This typical problem shows that FRMCS is much more vulnerable when the train is moving at a high speed and there is a change in the data sent. So, in order to achieve good performances all the system in the frequency range of 900 MHz with bandwidth of 7MHz, it is better to use very little packet data to transmit, adding an efficient system to check and correct, if possible, the bit that is wrongly received. The use of CP-OFDM and low modulation levels could increase the performance of the system and will help the FRMCS to obtain the required BER in order to ensure a reliable communication that is clearly a challenge in ATO system of mass transportation modes that use a communication based on wireless communication.

5.4 FRMCS using 5G new radio over ATO

Using the radio access techniques working on 5G NR (New Radio) communication systems is important to get the spectrum efficiency required. In fact the usage of new types of radio access in the band of 900 MHz with channel bandwidth of 5MHz or 7MHz is suitable to support the new standard incoming ATO to maintain safety as the highest priority with critical communication train control. The standard 5G is suitable for this application since the three most important challenges achieved are: the extreme mobile broadband techniques increasing bandwidth of 10 Gb/s peak data rates, the critical machine communication with ultra reliable low latency communications in less than 1 microsecond and finally machine to machine communications at ultra low cost. The migration of supporting the autonomous train operations in the radio 5G systems is able to support in main line railways some challenges, like precise affordable location, obstacle detection, remote control, sufficient and reliable communication. In terms of driving experience some challenges like the increasing operational and energy efficiency, the increasing of train density and punctuality, the decrease of the human error factor, and, most important, the increased safety and quality of service can be obtained using 5G in the railway communication. Moreover, some case examples with 5G in the railway communications are required:

- Precise positioning for obstacle detection, remote control and automation
- Direct communication without network connection in the original state
- Support of driverless trains (ATO level 3 + 4) critical video
- Future ETCS, including train integrity
- Shunting automation
- Virtual coupling
- Video-based remote train control

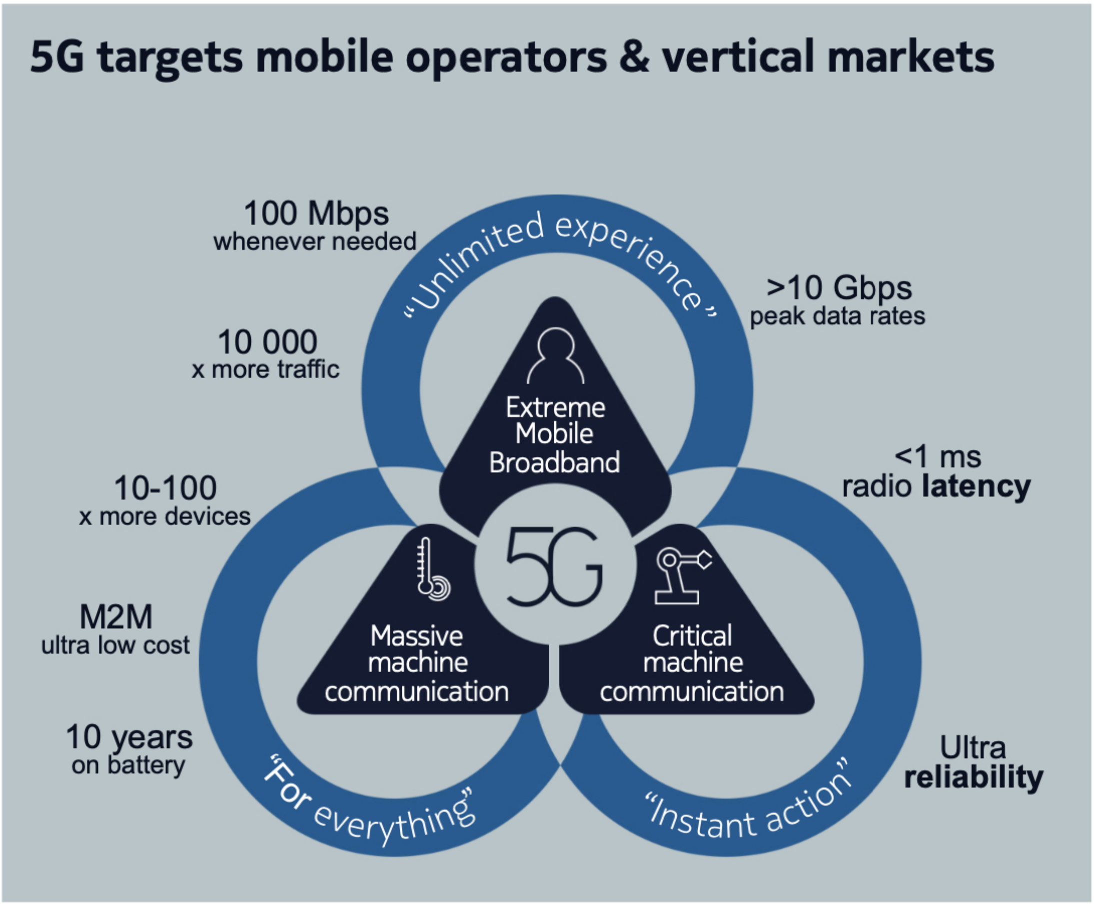

Figure 5.8: 5G target mobile operators and vertical markets [16]

All of them are represented in the 5G triangle in the two parts:

1 Extreme Mobile Broadband Enhanced: Always increasing bandwidth (10 Gb/s peak data rates)

2 Critical Machine communication: ultra reliability low latency ($\leq$1ms)

The first company that was involved in the project is Nokia, which first implemented the concept of autonomous driving system using 5G radio. Nokia has been involved even to support and deploy for more than 30 years the GSM-R standard, and now it is working with major European companies to employ new FRMCS standards. Nokia is now working with the German Rail in order to establish even the usage of an ipotetical FRMCS bandwidth carrying out LTE 1900 MHz Time Division Duplex (TDD) radio frequency by using a fully driverless shunting of empty trains in Begerdorf station. It is clear now why a first testing of the new architecture requirements follows this strategy to achieve a full vision of the problem in terms of data transmission and of the problems releated to Doppler effects at a high speed. So moving the standard towards 5G within FRMCS should be carried out through some of the lessons learned in the creation of the success of GSM-R standard, which was the outcome of railways industry in terms of market, safety and control system.

Conclusion

ERTMS standard will able to reach the interoperability demands requiried by major vendors to satify a unique safety standard in all Europe. Obviously with the advent of new technologies, modernization, digitalization this type of task can be achieved without too much difficulty. And overlapping automation will be the future trend in conjunction with the ERTMS standard. Europe wants to obtain all of this even because the reduction the impact of pollution is a challenge financed by every country. In Italy, the project to implement the standard by 2036 has started and this was requested from now on by the Europe [8]. By the way, it will be not an hard task to reach, thanks to the particular braking curve model which describes and performs train protection without too much difficulty in terms of resources and response time. Actually the standard is being updating for new usage of braking curve model: in this thesis it was referred to braking curve model defined in baseline version 2, but by now the standard starts to refer on baseline version 3 from this year, in order to reach a better accuracy braking curve model to increase a better puntcuality and a major capacity for the train on the trackside. The new version will be able to define a better usage of coasting or cruising for a train driver. Furthemore the new usage of driver assistance on board of the train to support a driving experience is a well appreciated challenge nowadays by the new young resources, more and more linked to the use of a level of assistance developed by each mobile phone that has become part of our daily life. The problem will be releated to ethics: how much can we rely on a system that fully assist us driving a train? The answer is extemely difficult to reach. Since the artificial intelligence is now consolidated on mobile phones, so this type of vision on the future can be accepted. Algorithms have now become truly efficient in terms of speed and computational time, also achieving important final results that can significantly reduce the impacts of energy consumption on trains. However, any perturbations during the running of a train are difficult to predict, and so their management could risk to make the optimization diverge very far from the expected value: a more accurate study on the case is necessary. Moreover, with the increasing of bandwidth demands used for any purposes, GSM-R standard will be not able to reach an appropriate required bandwidth and levels of quality of service that ATO requires. New FRMCS standard will be the solution capable to support new types of networks standard like 5G that can perform new services by using the new paradigm 5G network slicing, but actually the main problem is related to the access radio part with spectrum requirements since the doppler effects in terms of quality could drop significantly the performance. ATO requires a very high efficiency in the definition of error rate and from now on the standard used at high speed will not be able to support it: the solution can be found using a very efficient optimization filter and best error detecting code commonly used in digital networks to obtain better performances.

Finally, the vision about what will be discovered and studied is difficult to predict. In terms of project it will be more and more relevant the usage of new network technologies that are able to support the standard about this new vision of driving making trains increasingly important for transport of people and goods every day, for a totally eco-sustainable future.

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Glossary

ACO = Ant Colony Optimization

ARB = Apparato Radio Bordo

ASK = Amplitude Shift Keying

ATC = Automatic Train Control

ATO = Automatic Train Operator

ATP = Automatic Train Protection

BER = Bit Error Rate

BTM = Balise Transmission Module

CBPSK = Complex - Binary Phase Shift Keying

CP-OFDM = Complex Prefix Orthogonal Frequency Division Multiplexing

DAS = Driver Advisory System

DMI = Driver Machine Interface

DP = Dynamic Programming

EBI = Emergency Brake Intervention

ERA = European Railways Agency

ERTMS = European Railway Traffic Management System

ETCS = European Train Control System

EVC = European Vital Computer

FRMCS = Future Railway Mobile Communication System

FSK = Frequency Shift Keying

GA = Genetic Algorithm

GMSK = Gaussian Modulation Technique Minimum Shift Keying

GOA = Grade of Automation

GSM-R = Global System for Mobile Communication-Railways

HD-ERTMS = High Density ERTMS

IOT = Internet of Things

IP = Internet Protocol

LEU = Lineside Electronic Unit

LTM = Loop Transmission Module

MA = Movement Authority

MNO = Mobile Network Operator

MT = Mobile Terminal

NR = New Radio

OB = On Board

PER = Packet Error Rate

QOS = Quality of Service

RAT = Radio Access Technique

RBC = Radio Block Center

RIU = Radio Infill Unit

SCMT = Sistema di Controllo Marcia Treno

SNR = Signal to Noise Ratio

STM = Specific Transmission Module

TCMS = Train Control Management System

TIU = Train Interface Unit

TMS = Traffic Management System

JRU = Juridical Record Unit

UIC = International Union of Railways

URV = Unhamed Railway Vehicle