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(71) Applicant: **Comesvil S.p.A.**
80010 Villaricca (NA) (IT)

(72) Inventor: **Donadio, Pasquale**
80010 Villaricca (NA) (IT)

(74) Representative: **Pietra, Giulia et al**
Marchi & Partners S.r.l.
Via Vittor Pisani, 13
20124 Milano (IT)

(54) **RADIO COMMUNICATION APPARATUS, SYSTEM AND METHOD FOR A RAILWAY INFRASTRUCTURE**

(57) A radio apparatus and system for a railway infrastructure are described. The apparatus comprises two separate radio units, operating in non overlapping frequency ranges (e.g. 2.4 - 5 GHz and 868 - 900 MHz). The system comprises a on-board radio apparatus and several trackside radio apparatuses, each radio apparatus having two separate radio units. In the on-board radio apparatus, the radio unit operating in the higher frequency range transmits/receives data using a radio link set up with a single trackside radio apparatus at a time. Besides, the radio unit operating in the lower frequency range transmits/receives the same data using radio links set up with multiple trackside radio apparatuses at the same time. The apparatus and system therefore have redundant structure, which allows the implementation of mechanisms for protecting transmission of data between trackside and on-board side (in particular data which is vital for the safety of the railway infrastructure).

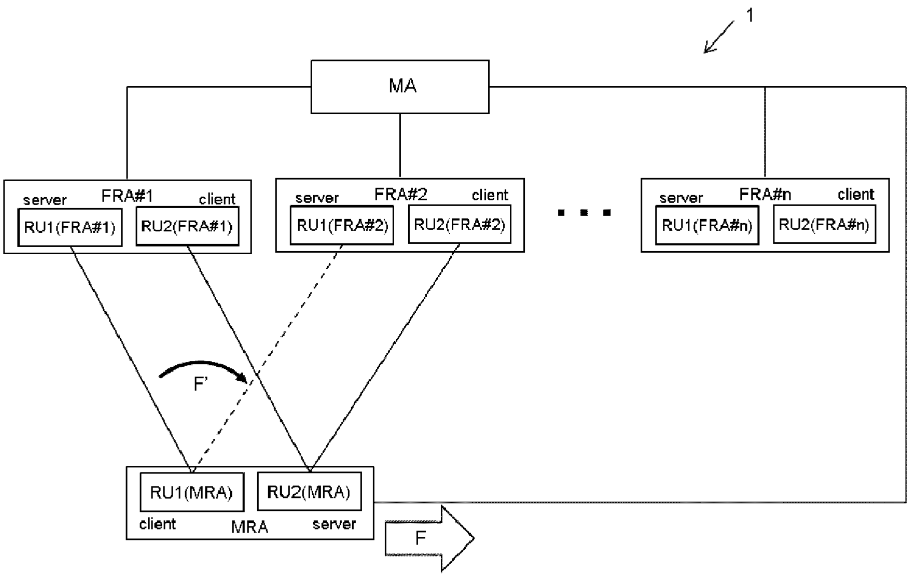

Figure 5

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Description

Technical field

[0001] The present invention relates in general to the field of radio communications. More particularly, the present invention relates to a radio communication apparatus, system and method for a railway infrastructure.

Background art

[0002] As is known, a railway infrastructure is generally provided with a radio communication system which comprises a radio apparatus situated on-board a train and a set of radio apparatuses distributed along the railway line. The on-board radio apparatus communicates with the radio apparatuses distributed along the line so as to transmit and receive:

(i) vital data, namely signalling messages for management, control and protection of railway traffic, such as signalling messages of the CBTC (Communication-Based Train Control) system; and
(ii) non-vital data, such as video data provided by any closed-circuit telecameras present on the trains, or service information for the passengers, etc.

[0003] Generally, the flow of vital data has a relatively low throughput, typically of less than 1 Mb/s. The flow of non-vital data instead typically has a higher throughput, generally of between 10 Mb/s and 100 Mb/s.

[0004] On the other hand, while the transmission of non-vital data does not require any protection or redundancy mechanism, the transmission of vital data instead requires this type of mechanism, because the continuity of transmission of vital data is essential for the safety of the train and its passengers.

[0005] The radio apparatuses currently used in railway infrastructures are generally Wi-Fi apparatuses in compliance with the standard IEEE802.11.

[0006] US 2003/0151520 discloses a railroad communication system wherein each radio apparatus comprises two radio communication units, one operating at 450 MHz and one operating in the ISM (Industrial Scientific Medical) band. The two bands are used for the transmission of data relating to two different train control systems, namely RC (Remote Control) and DP (Distributed Power).

Summary of the invention

[0007] The known Wi-Fi radio apparatuses compliant with the standard IEEE802.11 currently used in railway infrastructures are not specifically designed for this application, and therefore have a number of drawbacks.

[0008] Firstly, the known radio apparatuses generally have a single radio unit architecture. In order to implement redundancy mechanisms suitable for protecting the transmission of vital data it is therefore necessary to provide a pair of radio apparatuses, one of which has an operative function and the other a protective function. This results disadvantageously in the need to install double the number of radio apparatuses both on-board the train and along the railway line, with a consequent increase in the overall cost of the radio communication system. Moreover, since they operate at the same frequency, the two combined radio apparatuses are subject to mutual interference which negatively affects their performance in terms of signal/noise ratio. This deterioration in the signal/noise ratio results in the need to reduce the relative distance between the radio apparatuses which are distributed along the railway line and, if retransmission mechanisms are provided, also adversely affects the throughput and latency of the radio link between on-board radio apparatus and radio apparatuses distributed along the line.

[0009] Moreover, the handover procedures for transferring the connection of an on-board radio apparatus from a radio apparatus along the line to the next apparatus may cause a temporary interruption in the transmission of vital data. If this interruption is too long (more than 30 ms), the loss of vital data becomes critical and could have an impact on the safety of the train. The known radio apparatuses, however, disadvantageously are unable to perform such short handover procedures (< 30 ms).

[0010] Moreover, the known Wi-Fi radio apparatuses in compliance with the standard IEEE802.11 have a limited throughput, typically 100 Mb/s maximum.

[0011] Moreover, since they are not specifically designed for application in the railway field, the known Wi-Fi radio apparatuses in compliance with the standard IEEE802.11 all have an identical structure, irrespective as to whether they are installed on-board the train or along the line. Any specific functional features which are required on-board on the train or along the line (for example GPS location in the first case or access to the optical backbone network in the second case) must be implemented separately (for example installing a GPS locator cascade-connected to the on-board radio apparatus, or an optical module cascade-connected to each radio apparatus along the line).

[0012] Moreover, the known Wi-Fi radio apparatuses in compliance with the standard IEEE802.11 are generally monolithic, in the sense that - if one of their components is damaged - it is required to replace the entire apparatus. This disadvantageously increases the maintenance costs of the entire radio system.

[0013] Also the radio system and radio apparatuses described by US 2003/0151520 exhibits at least part of these drawbacks, even though they are designed for the railway field.

[0014] In particular, also the system described by US 2003/0151520 disadvantageously requires to double the number of network apparatuses in order to implement redundancy mechanisms for protecting transmission of the vital data relating to the RC system and/or to the DP system. Moreover, this system does not solve the aforementioned problem of the loss of vital data due to possible too long handover procedures.

[0015] An object of the present invention is therefore to provide a radio communication apparatus, system and a method for a railway infrastructure which solve at least one of the aforementioned problems.

[0016] In particular, an object of the present invention is to provide a radio communication apparatus, system and method for a railway infrastructure which (i) allow the transmission of vital data to be protected by means of a redundancy mechanism without requiring the installation of pairs of (operative/protective) radio devices on-board the trains and along the railway line and without causing a deterioration in the performance of the links between on-board radio apparatus and radio apparatuses along the line in terms of signal/noise ratio, latency or throughput, and (ii) minimize the risk of loss of vital data due to the known handover procedures.

[0017] According to embodiments of the present invention, these and other objects are achieved by a radio apparatus suitable for being installed in a railway infrastructure (namely on a train or along the railway line), comprising two separate radio units, each of which is able to support the transmission and the reception of data via radio autonomously. The first radio unit is configured to operate in a first frequency range (for example 2.4 - 5 GHz), while a second radio unit is configured to operate in a second, lower, frequency range (for example 868-900 MHz).

[0018] The radio apparatus according to the present invention therefore has a redundant structure (two radio units in a single apparatus) which, as will be described in greater detail below, allows the implementation of mechanisms for protecting the transmission of data (in particular vital data) without requiring duplication of the apparatuses. This allows the number of radio apparatuses in the system to be kept to a minimum, while reducing the installation time and overall cost thereof, without neglecting the safety of the trains and its passengers.

[0019] The two radio units present in the radio apparatus moreover, since they operate in different frequency ranges, are not subject to mutual interference. The protection mechanisms which can be implemented by this redundancy structure of the radio apparatus therefore do not cause any deterioration of the signal/noise ratio due to this effect and therefore do no require either a reduction in the relative distance between the radio apparatuses installed along the railway line nor re-transmission mechanisms which would negatively affect the throughput and latency of the radio link between on-board side and track-side.

[0020] According to a first aspect a radio apparatus for a railway infrastructure is provided, the radio apparatus comprising:

- a first radio unit configured to operate in a first frequency range; and
- a second radio unit configured to operate in a second frequency range lower than said first frequency range and non overlapping with the first frequency range,

wherein each one of the first radio unit and the second radio unit is configurable via software to receive and/or transmit data using any of a plurality of radio communication technologies or standards operating in a third frequency range comprising the first frequency range and the second frequency range.

[0021] Preferably, the first radio unit and the second radio unit comprise respective hardware components which are identical and which are capable of operating substantially in all of said third frequency range and at least one programmable component capable of being programmed to control said hardware component so as to receive and/or transmit data using a first radio communication technology or standard operating in the first frequency range or a second radio communication technology or standard operating in the second frequency range.

[0022] Preferably, the hardware component capable of operating substantially in all of the third frequency range comprises a radiofrequency transceiver and at least one antenna.

[0023] Preferably, the radio apparatus has a modular hardware structure.

[0024] In particular, the said radio apparatus comprises a base board in turn comprising a plurality of housings suitable for housing a corresponding plurality of modules selected from a set of interchangeable modules having identical hardware interfaces, the set of interchangeable modules comprising at least the first radio unit and the second radio unit, said radio apparatus being configurable as either a on-board radio apparatus suitable for being installed on board a train or as a trackside radio apparatus suitable for being installed along a railway line by suitably selecting said plurality of modules to be housed in said plurality of housings of said base board from said set of interchangeable modules.

[0025] Preferably, the set of interchangeable modules comprises, in addition to the first radio unit and the second radio unit:

- a programmable AC/DC converter configured to enable the selection of a voltage at the input of the radio apparatus and at the output of the radio apparatus;
- a network switch configured to implement an interconnection of the plurality of modules to a backbone network;
- a media converter configured to convert the format of data exchanged between the radio apparatus and the backbone network; and
- a geolocation module configured to detect geographic coordinates of the radio apparatus.

[0026] According to a second aspect, a radio communication system for a railway infrastructure is provided, said system comprising a on-board radio apparatus suitable for being installed on-board a train of the railway infrastructure and a plurality of trackside radio apparatuses suitable for being installed along a railway line along which the train travels, wherein:

- the on-board radio apparatus comprises a first on-board radio unit and a second on-board radio unit; and
- each trackside radio apparatus comprises a first trackside radio unit and a second trackside radio unit,

wherein the first on-board radio unit is configured to transmit and/or receive data using a first radio link set up with the first trackside radio unit of a trackside radio apparatus in a first frequency range,
and wherein the second on-board radio unit is configured to transmit and/or receive said data using at the same time at least two second radio links set up with the second trackside radio units of at least two trackside radio apparatuses in a second frequency range lower than the first frequency range and non overlapping with the first frequency range.

[0027] Preferably, the trackside radio apparatuses are distributed along the railway line at a mutual distance substantially equal to D, the distance D being variable between a minimum value Dmin and a maximum value Dmax, and the first frequency range, the second frequency range, the minimum value Dmin and the maximum value Dmax are selected so that:

- the first on-board radio unit is capable of setting up the first radio link with the first trackside radio unit of one trackside radio apparatus at a time; and
- the second on-board radio unit is capable of setting up K second radio links with the second trackside radio units of K trackside radio apparatuses at the same time, K being an integer equal to or higher than 3.

[0028] Preferably, the radio communication system further comprises a management apparatus configured to manage the on-board radio apparatus and the plurality of trackside radio apparatuses.

[0029] Preferably, the management apparatus is capable of configuring via software the first on-board radio unit and the first trackside radio unit to implement a first radio communication technology or standard operating in the first frequency range, and of configuring via software the second on-board radio unit and the second trackside radio units to implement a second radio communication technology or standard operating in the second frequency range.

[0030] Preferably, the management apparatus is also suitable for:

- configuring the first on-board radio unit as client of the first radio link and the first trackside radio unit as server of the first radio link; and
- configuring the second on-board radio unit as server of the at least two second radio links and the second trackside radio units of the at least two trackside radio apparatuses as clients of the at least two second radio links.

[0031] Preferably, the management apparatus is configured to, while the train travels along the railway line, control the first on-board radio unit of the on-board radio apparatus and the first trackside radio units of the plurality of trackside radio apparatuses to perform a handover procedure for moving the first radio link in the first frequency range from the first trackside radio unit of said trackside radio apparatus to the first trackside radio unit of the next trackside radio apparatus.

[0032] In particular, the management apparatus is configured to, while the train travels along the railway line, comparing a signal power received at the first trackside radio unit of the trackside radio apparatus and also a signal power received at the first trackside radio unit of the next trackside radio apparatus with a threshold value RSSI(th) and determine whether said handover procedure is required based on the result of said comparing.

[0033] Preferably, the management apparatus is configured to measure a throughput of radio links between the on-board radio apparatus and the trackside radio apparatuses and, based on said throughput, adjust a frame transmission rate from or to the on-board radio apparatus and/or a signal power from or to the on-board radio apparatus.

[0034] According to a third aspect, a method for transmitting and/or receiving data via radio in a railway infrastructure comprising a train and a railway line along which said train travels is provided, the method comprising:

- transmitting and/or receiving the data using a first radio link set up in a first frequency range between a first on-board radio unit comprised in a on-board radio apparatus installed on-board the train and a first trackside radio unit comprised in a trackside radio apparatus installed along the railway line; and
- transmitting and/or receiving the same data using at the same time at least two second radio links set up in a second frequency range lower than the first frequency range and non overlapping with the first frequency range between a second on-board radio unit comprised in the on-board radio apparatus and second trackside radio units comprised in at least two trackside radio apparatuses installed along said railway line.

Brief description of the drawings

[0035] The present invention will be illustrated in greater detail by means of the attached drawings which are provided by way of a non-limiting example and in which:

- Figure 1 shows in schematic form a radio communication system for a railway structure, according to embodiments of the present invention;
- Figures 2a and 2b show the structure of two components of an on-board radio apparatus and a trackside radio apparatus according to an advantageous embodiment of the present invention;
- Figures 3a, 3b, 3c and 3d show in schematic form the hardware structure of the apparatuses of the radio communication system according to an embodiment of the present invention;
- Figures 4a and 4b show in schematic form the software architecture of the on-board radio apparatus and the trackside radio apparatus and the software architecture of the management apparatus, according to an embodiment of the present invention;
- Figure 5 shows in schematic form the operation of the radio communication system according to embodiments of the present invention;
- Figure 6 is a flow diagram illustrating operation of the radio communication system according to an embodiment of the present invention;
- Figure 7 is a flow diagram illustrating the function of adaptation of the rate of transmission of the video frames, according to an advantageous variant of the present invention;
- Figure 8 is a flow diagram illustrating the function of adaptation of the signal transmission power, according to an advantageous variant of the present invention; and
- Figure 9 is a flow diagram illustrating the function of adaptation of geolocation, according to an advantageous variant of the present invention.

Detailed description of preferred embodiments of the invention

[0036] Figure 1 shows in schematic form a radio communication system 1 for a railway infrastructure 2, according to embodiments of the present invention.

[0037] The railway infrastructure 2 comprises a train 20 and a line (not shown for easier illustration) along which the train 20 travels in the direction indicated by the arrow F. The railway infrastructure 2 may be for example a metropolitan railway line, where the railway line has underground sections and/or sections passing inside a tunnel and/or along open sections.

[0038] The radio communication system 1 comprises a on-board radio apparatus and a plurality of trackside radio apparatuses FRA#1, FRA#2 ... FRA#n. The on-board radio apparatus MRA is preferably installed on-board the train 20, while the trackside radio apparatuses FRA#1, FRA#2 ... FRA#n are preferably installed along the railway line along which the train 20 travels. The trackside radio apparatuses FRA#1, FRA#2 ... FRA#n are preferably distributed along the railway line at a mutual distance D from each other, variable between a minimum value Dmin and a maximum value Dmax. The values of D, Dmin and Dmax are chosen according to criteria which will be described in detail in the remainder of the present description. The trackside radio apparatuses FRA#1, FRA#2 ... FRA#n may be situated at radio stations present on the line along which the train 20 travels. Alternatively, the trackside radio apparatuses FRA#1, FRA#2 ... FRA#n may be installed in special cabins situated in the vicinity of the railway line.

[0039] Preferably, the radio communication system 1 also comprises a management apparatus MA. The management apparatus MA is preferably situated at the control centre of the railway infrastructure 2 (not shown in the drawing). Preferably, the management apparatus MA is connected to the on-board radio apparatus MRA and to each of the trackside radio apparatuses FRA#1, FRA#2 ... FRA#n by means of respective connection interfaces, for example by means of Gigabit Ethernet interfaces. Preferably, the management apparatus MA is connected to each on-board or trackside radio apparatus by means of two different connection interfaces, so as to implement a redundancy mechanism for protection of the link.

[0040] According to particularly advantageous embodiments, the on-board radio apparatus MRA, the trackside radio apparatuses FRA#1, FRA#2 ... FRA#n and the management apparatus MA have a modular hardware structure. In particular, each of these apparatuses preferably comprises a base board BB which has a system of housings, connectors and connections which are identical for all the apparatuses.

[0041] The base board BB according to an embodiment is shown in Figure 3a. It preferably comprises six housings SL1, SL2, SL3, SL4, SL5, SL6, an electric connector EC suitable for connecting the board BB (and in particular the housing SL6 to an electric power supply source and a plurality of electrical connections which connect the housing SL6 to each of the housings SL1, SL2, SL3, SL4, SL5.

[0042] Each apparatus MRA, FRA#1, FRA#2 ... FRA#n and MA further comprises modules which are housed on the base board BB, in particular in the housings SL1, SL2, SL3, SL4, SL5, SL6 of the base board BB. The modules of the on-board radio apparatus MRA, of the trackside radio apparatuses FRA#1, FRA#2 ... FRA#n and of the management apparatus MA are preferably chosen from a set of interchangeable modules (namely modules having a same hardware interface), comprising:

- a multifrequency radio unit RU, namely a unit which can be configured to receive and transmit data using any radio communication technology or standard operating in a frequency range of between 40 MHz and 6 GHz (for example Wi-Fi a/b/g/n/ac, LTE, GSM, GSM-R, TETRA, etc.). As shown in Figures 2a, according to a preferred embodiment, each radio unit

RA comprises at least one network processor NP, at least one FPGA (Field Programmable Array Gateway) component, one or more GPU (Graphic Processing Units), a digital/analog converter D/A, a radiofrequency transceiver TX/RX and at least one antenna AN. The radio transceiver TX/RX and the antenna AN preferably are able to operate in the entire range of frequencies 40 MHz - 6 GHz. The FPGA component is preferably programmable so as to control the other components of the radio unit RU so that they may implement any radio communication technology or standard in the frequency range 40 MHz - 6 GHz supported by the transceiver TX/RX and the antenna AN, for example Wi-Fi. Therefore, if it is desired to modify the radio communication technology or standard implemented by the radio unit RU (for example if it is wished to switch from Wi-Fi to LTE) it is sufficient to reconfigure via software the radio unit RU, reprogramming the component FPGA in a suitable manner, without having to modify in any way the other hardware components of the radio unit.

- a radio network controller RNC configured to manage the transmission of data so as to optimize the performance and ensure the reliability and the safety of the entire radio communication system 1, as will be described in greater detail hereinbelow. As schematically shown in Figure 2b, according to a preferred embodiment, the radio network controller RNC comprises a network processor NP and a FPGA component.
- a programmable AC/DC converter PAD configured to allow the selection of the input and output voltage via software.
- a network switch NS configured to implement the interconnection of the other modules of the apparatus to the backbone network.
- a media converter MC configured to convert the data exchanged with the backbone network between the format of the board (Ethernet for example) and the optical format of the backbone network (for example format for mono-modal fibre or format for multi-modal fibre).
- A GPS (Global Positioning System) module GM configured to detect the geographical coordinates of the radio apparatus.
- a test board (or "dummy board") DB able to implement diagnostic tests or to test implementation of a new radio communication technology or standard on the trackside or on-board radio apparatus.

[0043] According to advantageous embodiments of the present invention, the on-board radio apparatus MRA, the trackside radio apparatuses FRA#1, FRA#2 ... FRA#n and the management apparatus MA comprise different combinations of the modules listed above.

[0044] In particular, with reference to Figure 3b, the on-board radio apparatus MRA preferably comprises a first radio unit RU1, a second radio unit RU2, a network switch NS and a programmable AC/DC converter PAD housed on a base board BB, in particular in the housings SL1, SL2, SL3 and SL6, respectively. Optionally, the on-board radio apparatus MRA also comprises a test board DB, also housed on the base board BB (in particular, in the housing SL4). In addition, the on-board radio apparatus MRA preferably also comprises a module GM also housed on the base board BB (in particular in the housing SL5).

[0045] The network switch NS is connected to the radio unit RU1, RU2, to the GPS module GM and to the test board DB (if present), preferably by means of respective Ethernet connections.

[0046] The on-board radio apparatus MRA further comprises preferably, for each radio unit RU1, RU2, at least one radio antenna connector. According to an advantageous variant, the on-board radio apparatus MRA preferably comprises six radio antenna connectors RAC (namely three for each radio unit RU1, RU2) which allow each radio unit to implement a MIMO (Multiple Input Multiple Output) 3x3 connection.

[0047] With reference now to Figure 3c, each trackside radio apparatus FRA#k (k=1, 2, ... n) preferably has a hardware structure similar to that of the on-board radio apparatus MRA, with the sole difference that preferably a media converter MC, instead of the GPS module GM, is housed in the housing SL5, said media converter being connected to an optical connector OC suitable for connecting the trackside radio apparatus FRA#k to the optical fibre of the backbone network.

[0048] With reference now to Figure 3d, the management apparatus MA preferably also has a hardware structure similar to that of the trackside radio apparatuses FRA#k, with the sole difference that it does not have radio antenna connectors RAC and that, in the housings SI1, SI2, it comprises a first radio network controller RNC1 and a second radio network controller RNC2 instead of the radio units RU1, RU2.

[0049] Therefore, both the on-board radio apparatus MRA and each of the trackside radio apparatuses FRA#k advantageously has a redundant structure (two radio units RU1, RU2 in a single apparatus) which, as will be described in greater detail below, allows the implementation of mechanisms for protecting the transmission of data (in particular vital data) without requiring the duplication of the apparatuses. This allows the number of radio apparatuses in the system to be kept to a minimum, while reducing the installation time and overall cost thereof, without neglecting the safety of the train and its passengers. The inventors in particular have estimated that the number of apparatuses to be installed may be advantageously reduced by more than 50% compared to the case of known radio apparatuses, with a saving of about 80% in terms of costs for installation of the system.

[0050] Moreover, the fact that all the apparatuses MRA, FRA#k and MA are combinations of modules chosen from a same set of interchangeable modules advantageously reduces the warehouse costs and also the time and cost for assembly of the apparatuses, which may be assembled on a single production line.

[0051] Moreover, the modular structure of the apparatuses MRA, FRA#k and MA advantageously reduces the costs of maintenance of the radio communication system 1 since, in the event of a fault, it is sufficient to replace the faulty module with an identical one, without making any modifications to the rest of the apparatus and without having to fully replace it.

[0052] Moreover, because of the interchangeability of the modules, advantageously each (on-board or trackside) radio apparatus may be provided with modules which perform specific functions required on-board on the train (for example the GPS module GM which performs the geolocation function in the on-board radio apparatus MRA) and along the railway line (for example, the media converter MC and the optical converter OC which perform the function of accessing the backbone network in the trackside radio apparatuses FRA#k). The installation of separate apparatuses which perform these functions is therefore not required.

[0053] From a software point of view, the apparatuses MRA, FRA#1, FRA#2 ... FRA#n and MA preferably have a two-layer architecture.

[0054] In particular, with reference to Figure 4a, the software architecture of the on-board radio apparatus MRA preferably comprises a radio communication layer and a radio service layer, while the software architecture of each trackside radio apparatus FRA#k (k=1, 2 ... n) preferably comprises a radio communication layer and a radio management layer.

[0055] The radio communication layer common to the software architecture of the on-board radio apparatus MRA and of each trackside radio apparatus FRA#k is preferably designed to execute the protocols of the radio communication technology or standard used by the radio unit of the apparatus. In particular it comprises a radio operating system which performs the following functions:

- control of the packet flow, i.e. sending and reception of packets of user data and control of the flow of signalling packets;
- management of the connections, namely activation and deactivation of radio requests depending on the requirements of the management apparatus MA and management of the user packet flows;
- management of the resources, namely management of the computational resources for sharing thereof and verification as to actual execution of the sharing; and
- management of the configuration, namely installation/uninstalling, creation/cancellation of radio requests and management of access to the radio parameters.

[0056] The radio communication layer preferably also comprises a plurality (three, according to an advantageous embodiment) of radio plug-ins, each of which comprises a software component able to enable radio communication in a respective subrange of the range 40 MHz - 6 GHz supported by the hardware of the radio unit. In particular, the radio communication layer preferably comprises:

- a low-frequency radio plug-in which allows the use of radio communication technologies or standards operating in a first frequency range (for example 60 MHz - 1 GHz), such as LoRa (868/900 MHz), GSM and GSM-R (900 MHz), TETRA (380/462 MHz) or LTE (800-900 MHz);
- a medium-frequency radio plug-in which allows the use of radio communication technologies or standards operating in a second frequency range (for example 1 GHz - 3 GHz), such as Wi-Fi IEEE 802.11 legacy, Wi-Fi IEEE 802b/g (2.4 GHz), GSM or GSM-R (1.8 GHz), Wi-Max (2.3-2.5 GHz and 3.4-3.5 GHz) or LTE (1.8-2.6 GHz); and
- a high-frequency radio plug-in which allows the use of radio communication technologies operating in a third frequency range (for example 4 GHz - 6 GHz, such as Wi-Fi IEEE 802.11a/n/ac (5.2, 5.4 and 5.8 GHz).

[0057] As regards the radio service layer of the on-board radio apparatus MRA, it is configured to implement at least one specific service of the on-board side. In particular, according to an advantageous variant, the radio service layer of the on-board radio apparatus is preferably configured to implement a service for location of the radio signal, which will be described in greater detail hereinbelow.

[0058] As regards instead the radio management layer of each trackside radio apparatus FRA#k, it is preferably configured to implement the management of the on-board radio apparatus MRA and the trackside radio apparatuses FRA#k so as to optimize the performance of the radio links between the trackside and the on-board side. In particular, according to an advantageous variant, the radio management layer of each trackside radio apparatus FRA#k is preferably configured to adapt the transmission rate of the video frames and adapt the signal power, as will be described in greater detail hereinbelow.

[0059] With reference now to Figure 4b, the management apparatus MA preferably also has a two-layer software architecture which preferably comprises a network communication layer and a global radio management layer.

[0060] The network communication layer preferably comprises a network operating system configured for management and control of the layer L2 and L3 traffic generated by the on-board and trackside radio apparatuses.

[0061] On the other hand, the overall radio management layer is configured to implement one or more of the following services:

- Radio management, i.e. management of the installation, creation or cancellation of radio requests. This service preferably includes the definition of information about the spectral and computational requirements of each radio request, its state, etc.
- Management of radio mobility, i.e. monitoring of the radio environment and in particular the capacity of the radio apparatuses MRA and FRA#k, requests for activation/deactivation of the radio requests and definition of information about the list of radio requests. This service preferably also manages the different radio communication technologies or standards and detects the apparatus in order to determine the best combinations of apparatuses and manage the handover procedures; and
- radio monitoring, i.e. presentation of context information, including RSSI (Received Signal Strength Indication), the packet error rate, pre-coding matrix indicator, etc.

[0062] With reference to Figure 5, the operation of the radio communication system 1 according to preferred embodiments of the present invention will now be described.

[0063] As described above and as shown in Figure 5, the on-board radio apparatus MRA comprises a first radio unit RU1(MRA) and a second radio unit RU2(MRA), which are also referred to below more simply as "first on-board radio unit" and "second on-board radio unit". Similarly, each trackside radio apparatus FRA#k (k=1, 2 ... n) preferably comprises a first radio unit RU1(FRA#k) and a second radio unit RU2(FRA#k), which are also referred to below more simply as "first trackside radio unit" and "second trackside radio unit".

[0064] Preferably, the management apparatus MA controls the on-board radio units RU1(MRA) and RU2(MRA) and the trackside radio units RU1(FRA#k) and RU2(FRA#k) so as to set up between them radio links which allow the on-board radio apparatus MRA to exchange data flows (for example a vital data flow and a non-vital data flow) with the trackside radio apparatuses FRA#k (k=1, 2 ... n), while the on-board radio apparatus MRA (which is installed on the train 20) is travelling in the direction indicated by the arrow F.

[0065] More particularly, the management apparatus MA preferably configures the first on-board radio unit RU1(MRA) and all the first trackside radio units RU1(FRA#k) (k=1, 2 ... n) so as to use a first radio communication technology or standard operating in a first frequency range, for example Wi-Fi in the frequency range 2.4 - 5 GHz. According to an advantageous variant, the management apparatus MA preferably configures the first radio unit RU1(MRA) as client and the first trackside radio units RU1(FRA#k) as servers according to this first radio communication technology or standard. In this way, the configuration of the radio links between trackside and on-board side in the first frequency range is established by the trackside radio apparatuses FRA#k, while the on-board radio apparatus MRA cannot modify the configuration of these radio links.

[0066] Moreover, preferably, the management apparatus MA preferably configures the second on-board radio unit RU2(MRA) and all the second trackside radio units RU2(FRA#k) k (k=1, 2 ... n) so as to use a second radio communication technology or standard in a second frequency range lower than the first frequency range, for example Lo-Ra in the frequency range 868-900 MHz.

[0067] According to an advantageous variant, the management apparatus MA preferably configures the second radio unit RU2(MRA) as server and the second trackside radio units RU2(FRA#k) as clients according to this second radio communication technology or standard. In this way, the configuration of the radio links between trackside and on-board side in the second frequency range is established by the on-board radio apparatus MRA, while the trackside radio apparatuses FRA#k cannot modify the configuration of these radio links.

[0068] Preferably, the first frequency range and the mutual distance D between the trackside radio apparatuses FRA#1, FRA#2, ... FRA#n along the railway line are chosen so that, while it travels in the direction of the arrow F, the first on-board radio unit RU1(MRA) is able to set up a radio link with the first trackside radio unit RU1(FRA#k) of one trackside radio apparatus FRA#k at a time, namely that which is closest to it (for example FRA#1 in Figure 5).

[0069] Preferably, the distance D between trackside radio apparatuses FRA#1, FRA#2 ... FRA#n along the railway line is variable between a minimum value Dmin (along sections with high electromagnetic disturbance and interference, for example inside tunnels) and a maximum value Dmax (along sections with low electromagnetic disturbance and interference, such as open sections). For example, if the first frequency range is 2.4 - 5 GHz it is possible to set Dmin=300 and Dmax=500 m.

[0070] On the other hand, since the second on-board radio unit RU2(MRA) and the second trackside radio units RU2(FRA#k) (k=1, 2 ... n) use a frequency range lower than that used by the first on-board radio unit RU1(MRA) and by the first trackside radio units RU1(FRA#k), the second on-board radio unit RU2(MRA) will be able to set up simultaneously radio links with the second trackside radio units RU2(FRA#k) of K (K>2) trackside radio apparatuses, namely the K trackside radio apparatuses FRA#k closest to it. By way of example, Figure 5 shows the second on-board radio unit RU2(MRA) simultaneously connected both to the second trackside radio unit RU2(FRA#1) and to the second trackside radio unit RU2(FRA#2).

[0071] Preferably, the second frequency range at which the second radio units RU2(MRA) and RU2(FRA#k) operate is chosen so that the second on-board radio unit RU2(MRA) is able to set up a radio link with the second trackside radio units RU2(FRA#k) of at least k=3 trackside radio apparatuses FRA#k. More particularly, preferably, the second frequency range at which the second radio units RU2(FRA) and RU2(FRA#k) operate is chosen so that the second on-board radio unit RU2(MRA) is able to set up a radio link with any second trackside radio unit RU2(FRA#k) which is located at distances greater than 5 km, so as to ensure that the second radio unit RU2(MRA) is connected to the second trackside radio unit RU2(FRA#k) of at least K = 5 km/500 m = 10 trackside radio apparatuses FRA#k (in the case where Dmax=500 m).

[0072] For example, in the case where Lo-Ra technology is used in the frequency range 868-900 MHz, the second on-board radio unit RU2(MRA) is able to set up links with any second trackside radio unit RU2(FRA#k) which is situated within a distance of about 20 km. In this case, therefore, the second on-board radio unit RU2(MRA) is able to connect simultaneously to the second trackside radio unit RU2(FRA#k) of at least K = 20 km/500 m = 40 trackside radio apparatuses FRA#k (again in the case where Dmax=500 m).

[0073] Therefore, while the train 20 moves in the direction of the arrow F, in order to maintain the continuity of the radio link between on-board side and trackside in the first frequency range, the management apparatus MA preferably controls the first on-board radio unit RU1(MRA) and the first trackside radio units (RU1(FRA#k) so that they perform a handover procedure, which allows the link in the first frequency range to be moved from the first trackside radio unit (FRA#k) of a trackside radio apparatus FRA#k to the first trackside radio unit RU1(FRA#k+1) of the next trackside radio apparatus FRA#k+1 along the direction of the arrow F. Figure 5 shows by way of example the handover from the first trackside radio unit RU1(FRA#1) to the next first trackside radio unit RU1(FRA#2), indicated schematically by the arrow F'.

[0074] On the other hand, while the train 20 moves in the direction indicated by the arrow F, the continuity of the radio link between on-board side and trackside in the second frequency range is advantageously ensured without the need to perform any handover procedure. While in fact the train 20 moves, the radio link between the second on-board radio unit RU2(MRA) and the second trackside radio unit RU2(FRA#k) - which between the units currently connected is furthest away in the opposite direction to that of the arrow F - will be interrupted, but the continuity of the radio link in the second frequency range is in any case ensured by the other K-1 radio links to the other K-1 second trackside radio units RU2(FRA#k) which are still located in the coverage area of the second on-board radio unit RU2(MRA).

[0075] Moreover, while the train 20 moves, for each second trackside radio unit RU2(FRA#k) which leaves the coverage area of the second on-board radio unit RU2(MRA) there is at least one which enters, such that the second on-board radio unit RU2(MRA) is substantially always connected to K second trackside radio units RU2(FRA#k).

[0076] According to an embodiment of the present invention, the first radio unit RU1(MRA) and the first trackside radio units RU1(FRA#k) (k=1, 2 ... n) - which use the higher frequency range and therefore may reach higher throughputs - exchange both vital data (such as signalling messages for managing, controlling and protecting the railway traffic, for example signalling messages of the CBTC system) and non-vital data (such as video data provided by any closed-circuit TV cameras present on the train 20, or service information for passengers, etc.). Preferably, the vital data is transmitted on a first VLAN and the non-vital data is transmitted on a second VLAN of the radio link between the first on-board radio unit RU1(MRA) and the first trackside radio units RU1(FRA#k) (k=1, 2 ... n).

[0077] At the same time, the second on-board radio unit RU2(MRA) and the second trackside radio units RU2(FRA#k) (k=1, 2 ... n) - which use the lower frequency range and therefore may reach lower throughputs - exchange only vital data, thus providing a protection mechanism which ensures the continuity of the transmission of the vital data in the event that the transmission thereof in the first frequency range is interrupted. Preferably, the vital data is transmitted simultaneously on K different VLANs used on the K radio links between the second on-board radio unit RU2(MRA) and the second trackside radio units RU2(FRA#k) (k=1, 2 ... n).

[0078] According to this embodiment, therefore, the vital data is transmitted both with a high throughput on the radio link between on-board side and trackside in the first higher frequency range, and with a lower throughput on the K radio links between on-board side and trackside in the second lower frequency range. If therefore, during the course of the handover procedure of the radio link between on-board side and trackside in the first frequency range, there is an interruption in the transmission of vital data, said data nevertheless continues to be exchanged between on-board side and trackside (albeit with a lower throughput) by the K radio links in the second lower frequency range. In other words, the duration of the vital data handover procedure is reduced substantially to zero.

[0079] The transmission of the vital data on the K radio links in the second lower frequency range, on the other hand, is advantageously very robust since it is redundant and intrinsically not affected by handover procedures. It constitutes therefore a very reliable protection system.

[0080] The transmission of vital data is therefore advantageously protected by means of a redundancy mechanism which does not require the installation of pairs of (operative/protective) radio devices on-board the trains and along the railway line. This, as mentioned above, allows the number of radio apparatuses in the communication system 1 to be kept to a minimum, while reducing the installation time and overall cost thereof, without neglecting the safety of the train and its passengers.

[0081] It must also be pointed out that the transmission of vital and non-vital data in the first frequency range and the transmission of vital data in the second frequency range are not subject to mutual interference, precisely because they are performed in different frequency ranges. There is therefore no deterioration in terms of signal-noise ratio due to this effect and therefore it is not required either to reduce the distance D between the trackside radio apparatuses FRA#k nor to employ any re-transmission mechanism which would worsen the throughput and the latency of the radio link between on-board side and trackside.

[0082] Below, operation of the radio communication system 1 according to this embodiment will be described in greater detail with reference to the flow diagram in Figure 6.

[0083] Initially, the management apparatus MA preferably configures as active radio unit on the on-board side the first on-board radio unit RU1(MRA), setting it as client using the first radio communication technology or standard operating in the first frequency range, for example Wi-Fi in the frequency range 2.4 - 5 GHz (step 601). Similarly, the management apparatus MA preferably configures as active radio unit on the trackside the first fixed radio unit RU1(FRA#k), setting it as server using the first radio communication technology or standard (step 602).

[0084] The first on-board radio unit RU1(MRA) therefore is preferably associated with the first trackside radio unit RU1(FRA#k) and communicates to the management apparatus MA the corresponding radio association request (step 603).

[0085] At the same time, the second on-board radio unit RU2(MRA) preferably is associated with the second trackside radio unit RU2(FRA#k) and communicates to the management apparatus MA the corresponding radio association request (step 604).

[0086] The management apparatus MA therefore preferably compares the power of the signal received at the first trackside radio unit RU1 (FRA#k) and also the power of the signal received at the next first trackside radio unit RU1(FRA#k+1) along the direction F with a threshold value, for example RSSI(th) = -70 dB (step 605).

[0087] If both these values are less than the threshold RSSI(th), the management apparatus MA concludes that the first on-board radio unit RU1(MRA) is not connected to any first trackside radio unit (step 606). In other words, the on-board radio apparatus MRA is not connected to any trackside radio apparatus FRA#1, FRA#2, ... FRA#n in the first frequency range, namely the transmission of vital and non-vital data in the first frequency range is interrupted.

[0088] Therefore, the management apparatus MA preferably configures as active radio unit on the on-board side the second on-board radio unit RU2(MRA), setting it as server using the second radio communication technology or standard operating in the second frequency range, for example Lo-Ra in the frequency range 868-900 MHz (step 607). Similarly, the management apparatus MA preferably configures as active radio unit on the trackside the second trackside radio unit RU2(FRA#k), setting it as client using the second radio communication technology or standard (step 608).

[0089] The communication system 1 thus starts to use as vital data the data transmitted with low throughput in the second lower frequency range. The transmission of the non-vital data continues instead to be interrupted, until the radio link between trackside and on-board side in the first frequency range is restored.

[0090] If instead the power of the signal received at the first trackside radio unit RU1(FRA#k) is less than the threshold RSSI(th), but the power of the signal received at the next first trackside radio unit RU1(FRA#k-1) is greater than the threshold RSSI(th), the management apparatus MA establishes that a procedure for handover from the apparatus FRA#k to the apparatus FRA#k+1 is required (step 609).

[0091] For this purpose, the management apparatus MA preferably leaves as active radio unit on the on-board side the first on-board radio unit RU1(MRA) set as client (step not shown) and further preferably configures as active radio unit on the trackside the next first trackside radio unit RU1(FRA#k+1), setting it as server. In this way, the first on-board radio unit RU1(MRA) carries out its procedure for handover from the first trackside radio unit RU1(FRA#k) to the next first radio unit RU1(FRA#k+1) in the direction F. If the handover procedure is carried out correctly, the transmission of the vital and non-vital data continues therefore without interruption in the first frequency range.

[0092] Moreover, the management apparatus MA preferably configures as active radio unit on the trackside also the next second on-board radio unit RU2(FRA#k+1) in the direction F, setting it as client (step 611) and preferably configures as active radio unit on the on-board side also the second on-board radio unit RU2(MRA), setting it as server (step 612).

[0093] In this way, during the handover procedure, the communication system 1 uses as vital data not only the data transmitted with high throughput in the first higher frequency range, but also the data transmitted with low throughput in the second lower frequency range. This advantageously ensures that there is no loss of vital data during the handover procedure, irrespective of its duration which - owing to this redundancy mechanism - is basically reduced to zero.

[0094] If instead the power of the signal received at the first trackside radio unit RU1(FRA#k) is greater than the threshold RSSI(th) and the power of the signal received at the next first trackside radio unit RU1 (FRA#k-1) in the direction F is less than the threshold RSSI(th), the management apparatus MA establishes that for the moment no further handover procedure is required (step 613). The active radio unit on the on-board side therefore remains the first on-board radio unit RU1(MRA) and the active radio unit on the trackside remains the first trackside radio unit RU1(FRA#k) (step not shown).

[0095] If instead both the power of the signal received at the first trackside radio unit RU1(FRA#k)and the power of the signal received at the next first trackside radio unit RU1(FRA#k-1) in the direction F are greater than the threshold RSSI(th), the management apparatus MA establishes that for the moment a procedure for handover is not required (step 614). The management apparatus MA however preferably configures as active radio unit on the trackside the first trackside radio unit RU1(FRA#k+1), setting it as server (step 615). In this way, advantageously the coverage of the on-board radio apparatus MRA is extended as far as possible, and the number of handovers is minimized, with a consequent reduction of computational resources and greater stability of the entire radio communication system 1.

[0096] As mentioned above, the radio management layer of the software architecture of each trackside radio apparatus FRA#k (k=1, 2 ... n) preferably is configured to adapt the frame transmission rate and adapt the signal power.

[0097] In particular, adaptation of the frame transmission rate advantageously allows the transmission rate of the video frames generated by any closed-circuit TV cameras present on the train 20 to be adapted so as to ensure that the throughput of high-priority packets (for example, packets which transport vital data such as signalling messages of the CBTC system) does not fall below a guaranteed minimum value.

[0098] Adaptation of the frame transmission rate will now be described in detail with reference to Figure 7.

[0099] Preferably, the management apparatus MA collects information about the throughput of the (vital and non-vital) data transmitted overall between the on-board radio apparatus MRA and the trackside radio apparatus FRA#k (step 701). For this purpose, the management apparatus MA preferably consults a list of the active radio units on the trackside which are communicating with the on-board radio apparatus MRA and for each of them establishes the throughput THR(MRA→FRA#k) from the on-board radio apparatus MRA and the throughput THR(FRA#k→MRA) to the on-board radio apparatus MRA (for example using the SNMP protocol).

[0100] The management apparatus MA then preferably analyzes the throughput values THR(MRA→FRA#k) and THR(FRA#k→MRA) read and processes them in order to correct suitably the transmission rate of the video frames.

[0101] In particular, according to an advantageous variant, the management apparatus MA preferably compares the throughput THR(MRA→FRA#k) from the on-board radio apparatus MRA and the throughput THR(FRA#k→MRA) to the on-board radio apparatus MRA with three different threshold values TH1, TH2, TH3 (step 702). For example, TH1=1 Mb/s, TH2=5 Mb/s and TH3=10 Mb/s. The first threshold TH1 preferably represents the minimum throughput guaranteed for the flow of high-priority packets in each of the two directions (from on-board side to trackside and vice versa).

[0102] If both the values THR(MRA→FRA#k) and THR(FRA#k→MRA) are less than TH1, the management apparatus MA preferably sets to zero the frame transmission rate (step 703) and, preferably, sets the status of an alarm to the "critical" value (step 704).

[0103] If, instead, both the values THR(MRA→FRA#k) and THR(FRA#k→MRA) are comprised between TH1 and TH2, the management apparatus MA preferably sets the frame transmission rate to a first value v1 (for example 10 frames/second) (step 705) and, preferably, sets the status of an alarm to the "high" value (step 706).

[0104] If, instead, both the values THR(MRA→FRA#k) and THR(FRA#k→MRA) are comprised between TH2 and TH3, the management apparatus MA preferably sets the frame transmission rate to a second value v2 (for example 20 frames/second) (step 707) and, preferably, sets the status of an alarm to the "low" value (step 708).

[0105] If, instead, both the values THR(MRA→FRA#k) and THR(FRA#k→MRA) are greater than TH3, the management apparatus MA preferably sets the frame transmission rate to a third value v3 (for example 30 frames/second) (step 709) and, preferably, sets the status of an alarm to the "alert" value (step 710).

[0106] In this way, the radio communication system 1 is advantageously able to ensure that the throughput of the vital data does not fall below a minimum value. The transmission of this data with a throughput which does not fall below a minimum value advantageously ensures that the train 20 is driven in a safe and reliable manner. The safety of the entire railway infrastructure is therefore advantageously increased.

[0107] As regards the adaptation of the power of the signal implemented by the radio management layer of the software architecture of each trackside radio apparatus FRA#k (k=1, 2 ... n), it advantageously allows the power of the radio signal transmitted by an active radio unit of the on-board radio apparatus MRA and/or by a trackside radio apparatus FRA#k to be modified so as to optimize the performance of the radio link.

[0108] Adaptation of the signal power will now be described in detail with reference to Figure 8.

[0109] Preferably, the management apparatus MA collects information about the power of the signal received from the on-board radio apparatus MRA and the trackside radio apparatuses FRA#k (step 801). For this purpose, the management apparatus MA preferably consults a list of the active radio units on the trackside which is communicating with the on-board radio apparatus MRA and, for each of them, determines the power of the signal RSSI(FRA#k←MRA) which the active radio unit on the trackside radio apparatus FRA#k is receiving from the on-board radio apparatus MRA and the power of the signal RSSI(MRA←FRA#k) which the on-board radio apparatus MRA is receiving from that active unit on the trackside radio apparatus FRA#k.

[0110] The management apparatus MA then preferably analyzes the power values of the signal RSSI(FRA#k←MRA) and RSSI(MRA←FRA#k) which have been read and processes them so as to correct suitably the transmission power values of the signal at the on-board radio apparatus MRA and/or at the on-board radio apparatus MRA and/or at the trackside radio apparatuses FRA#n.

[0111] In particular, according to an advantageous variant, the management apparatus MA preferably compares the values RSSI(FRA#k←MRA) and RSSI(MRA←FRA#k) with a threshold RSSI(TH), for example equal to -70 dB (step 802).

[0112] If the power of the signal RSSI(FRA#k←MRA) received at the active radio unit on the trackside radio apparatus FRA#k from the on-board radio apparatus MRA is less than the threshold RSSI(TH), the management apparatus MA preferably increases the transmission power of the signal Ptx(MRA) at the on-board radio apparatus MRA (step 803).

[0113] If instead the power of the signal RSSI(MRA←FRA#k) received at the on-board radio unit MRA from the active radio unit on the trackside radio apparatus FRA#k is less than the threshold RSSI(TH), the management apparatus MA preferably increases the transmission power of the signal Ptx(FRA#k) at the active radio unit on the trackside radio apparatus FRA#k (step 804).

[0114] As mentioned above, the radio service layer of the software architecture of the on-board radio apparatus MRA preferably comprises a radio signal location service which allows the radio signal emitted by the on-board radio apparatus MRA to be located in real time. More particularly, this service allows the data relating to geolocation to be combined with the data relating to the power of the signal received RSSI, so as to provide a geographical map of the RSSI signals.

[0115] This service will now be described in detail with reference to Figure 9.

[0116] Preferably, the management apparatus MA consults a list of the active radio units on the on-board side and, for each of them, sends a request to receive current RSSI and geographical coordinates (step 901).

[0117] In response, each on-board radio apparatus MRA which has received the request reads its geographical coordinates by means of its GPS (Global Positioning System) module GM, for example in terms of altitude, latitude and longitude (step 902). Each on-board radio apparatus MRA then preferably combines the coordinates with the current RSSI and sends off all the data to the management apparatus MA (step 903). The management apparatus 903 analyzes the data received and displays it on a map (step 904) which shows the geographical distribution of the RSSI values for the on-board radio apparatus MRA.

[0118] The radio communication system 1 for a railway infrastructure offers therefore various advantages.

[0119] It is able to guarantee the continuity of transmission of the vital data, minimizing the risk of data loss due to handover procedures, is able to implement a redundancy mechanism for protecting the transmission of the vital data without requiring the duplication of the apparatuses, thus allowing the installation of a minimum number of radio apparatuses with a consequent reduction in installation time and costs, and without a worsening of signal/noise ratio throughput or latency.

[0120] Owing to the modularity of the radio apparatuses, moreover, the costs for production and maintenance thereof are reduced and specific functions for the trackside and the on-board side may be implemented in each radio apparatus.

[0121] Moreover, owing to their programmability of the radio apparatuses (and in particular their radio units), the apparatuses may be advantageously configured so that they are able to support any radio communication technology or standard, without the need for any modification of their hardware.

Claims

1. Radio apparatus (MRA, FRA#k) for a railway infrastructure (2), said radio apparatus (MRA, FRA#k) comprising:

    - a first radio unit (RU1(MRA), RU1(FRA#k)) configured to operate in a first frequency range; and
    - a second radio unit (RU2(MRA), RU2(FRA#k)) configured to operate in a second frequency range lower than said first frequency range and non overlapping with said first frequency range,

    wherein each one of said first radio unit (RU1(MRA), RU1(FRA#k)) and said second radio unit (RU2(MRA), RU2(FRA#k)) is configurable via software to receive and/or transmit data using any of a plurality of radio communication technologies or standards operating in a third frequency range comprising said first frequency range and said second frequency range.

2. Radio apparatus (MRA, FRA#k) according to claim 1, wherein said first radio unit (RU1(MRA), RU1(FRA#k)) and said second radio unit (RU2(MRA), RU2(FRA#k)) comprise respective hardware components (TX/RX, AN) which are identical and capable of operating substantially in all of said third frequency range and at least one programmable component (FPGA) capable of being programmed to control said hardware component (TX/RX, AN) so as to receive and/or transmit data using a first radio communication technology or standard in said first frequency range or a second radio communication technology or standard in said second frequency range.

3. Radio apparatus (MRA, FRA#k) according to claim 2, wherein said hardware component (TX/RX, AN) capable of operating substantially in all of said third frequency range comprises a radiofrequency trans-

ceiver (TX/RX) and at least one antenna (AN).

4. Radio apparatus (MRA, FRA#k) according to any of the preceding claims, wherein said radio apparatus (MRA, FRA#k) has a modular hardware structure.

5. Radio apparatus (MRA, FRA#k) according to claim 4, wherein said radio apparatus (MRA, FRA#k) comprises a base board (BB) in turn comprising a plurality of housings suitable for housing a corresponding plurality of modules selected from a set of interchangeable modules having identical hardware interfaces, said set of interchangeable modules comprising at least said first radio unit (RU1(MRA), RU1(FRA#k)) and said second radio unit (RU2(MRA), RU2(FRA#k)), said radio apparatus (MRA, FRA#k) being configurable as either a on-board radio apparatus (MRA) suitable for being installed on board a train or as a trackside radio apparatus (FRA#k) suitable for being installed along a railway line by suitably selecting said plurality of modules to be housed in said plurality of housings of said base board (BB) from said set of interchangeable modules.

6. Radio apparatus (MRA, FRA#k) according to claim 1, wherein said set of interchangeable modules comprises, in addition to said first radio unit (RU1(MRA), RU1(FRA#k)) and said second radio unit (RU2(MRA), RU2(FRA#k)):

- a programmable AC/DC converter (PAD) configured to enable the selection of a voltage at the input of said radio apparatus (MRA, FRA#k) and at the output of said radio apparatus (MRA, FRA#k);
- a network switch (NS) configured to implement an interconnection of said plurality of modules to a backbone network;
- a media converter (MC) configured to convert the format of data exchanged between said radio apparatus (MRA, FRA#k) and said backbone network; and
- a geolocation module (GM) configured to detect geographic coordinates of said radio apparatus (MRA, FRA#k).

7. Radio communication system (1) for a railway infrastructure (2), comprising a on-board radio apparatus (MRA) suitable for being installed on-board a train (20) of said railway infrastructure (2) and a plurality of trackside radio apparatuses (FRA#1, FRA#2, ... FRA#n) suitable for being installed along a railway line along which said train (20) travels, wherein:

• said on-board radio apparatus (MRA) comprises a first on-board radio unit (RU1(MRA)) and a second on-board radio unit (RU2(MRA)); and
• each trackside radio apparatus (FRA#k) comprises a first trackside radio unit (RU1(FRA#k)) and a second trackside radio unit (RU2(FRA#k)),

wherein said first on-board radio unit (RU1(MRA)) is configured to transmit and/or receive data using a first radio link set up with the first trackside radio unit (RU1(FRA#k)) of a trackside radio apparatus (FRA#k) in a first frequency range,
and wherein said second on-board radio unit (RU2(MRA)) is configured to transmit and/or receive said data using at the same time at least two second radio links set up with the second trackside radio units (RU2(FRA#k)) of at least two trackside radio apparatuses (FRA#k) in a second frequency range lower than said first frequency range and non overlapping with said first frequency range.

8. Radio communication system (1) according to claim 7, wherein said trackside radio apparatuses (FRA#1, FRA#2, ... FRA#n) are distributed along said railway line at a mutual distance substantially equal to D, said distance D being variable between a minimum value Dmin and a maximum value Dmax, and wherein said first frequency range, said second frequency range, said minimum value Dmin and said maximum value Dmax are selected so that:

• said first on-board radio unit (RU1 (MRA)) is capable of setting up said first radio link with the first trackside radio unit (RU1(FRA#k)) of one trackside radio apparatus (FRA#k) at a time; and
• said second on-board radio unit (RU2(MRA)) is capable of setting up K second radio links with the second trackside radio units (RU2(FRA#k)) of K trackside radio apparatuses (FRA#k) at the same time, K being an integer equal to or higher than 3.

9. Radio communication system (1) according to claim 7 or 8, further comprising a management apparatus (MA) configured to manage said on-board radio apparatus (MRA) and said plurality of trackside radio apparatuses (FRA#1, FRA#2, ... FRA#n).

10. Radio communication system (1) according to claim 9, wherein said management apparatus (MA) is capable of configuring via software said first on-board radio unit (RU1(MRA)) and said first trackside radio unit (RU1(FRA#k)) to implement a first radio communication technology or standard operating in said first frequency range, and of configuring via software said second on-board radio unit (RU2(MRA)) and said second trackside radio units (RU2(FRA#k)) to implement a second radio communication technology or standard operating in said second frequency range.

11. Radio communication system (1) according to claim 9 or 10, wherein said management apparatus (MA) is further suitable for:

- configuring said first on-board radio unit (RU1(MRA)) as client of said first radio link and said first trackside radio unit (RU1 (FRA#k)) as server of said first radio link; and
- configuring said second on-board radio unit (RU2(MRA)) as server of said at least two second radio links and said second trackside radio units (RU2(FRA#k)) of said at least two trackside radio apparatuses (FRA#k) as clients of said at least two second radio links.

12. Radio communication system (1) according to any of claims 9 to 11, wherein said management apparatus (MA) is configured to, while said train (20) travels along said railway line, control said first on-board radio unit (RU1(MRA)) of said on-board radio apparatus (MRA) and the first trackside radio units (RU1(FRA#1), RU1(FRA#2), ... RU1(FRA#n)) of said plurality of trackside radio apparatuses (FRA#1, FRA#2, ... FRA#n) to perform a handover procedure for moving said first radio link in said first frequency range from said first trackside radio unit (RU1(FRA#k)) of said trackside radio apparatus (FRA#k) to the first trackside radio unit (RU1 (FRA#k+1)) of the next trackside radio apparatus (FRA#k+1).

13. Radio communication system (1) according to claim 12, wherein said management apparatus (MA) is configured to, while said train (20) travels along said railway line, comparing a signal power received at said first trackside radio unit (RU1(FRA#k)) of said trackside radio apparatus (FRA#k) and also a signal power received at said first trackside radio unit (RU1(FRA#k+1)) of said next trackside radio apparatus (FRA#k+1) with a threshold value RSSI(th) and determine whether said handover procedure is required based on the result of said comparing.

14. Radio communication system (1) according to ant of claims 9 to 12, wherein said management apparatus (MA) is configured to measure a throughput of radio links between said on-board radio apparatus (MRA) and said trackside radio apparatuses (FRA#1, FRA#2, ... FRA#n) and, based on said throughput, adjust a frame transmission rate from or to said on-board radio apparatus (MRA) and/or a signal power from or to said on-board radio apparatus (MRA).

15. Method for transmitting and/or receiving data via radio in a railway infrastructure (2) comprising a train (20) and a railway line along which said train (20) travels, said method comprising:

- transmitting and/or receiving said data using a first radio link set up in a first frequency range between a first on-board radio unit (RU1(MRA)) comprised in a on-board radio apparatus (MRA) installed on-board said train (20) and a first trackside radio unit (RU1(FRA#k)) comprised in a trackside radio apparatus (FRA#k) installed along said railway line; and
- transmitting and/or receiving said data using at the same time at least two second radio links set up in a second frequency range lower than said first frequency range and non overlapping with said first frequency range between a second on-board radio unit (RU2(MRA)) comprised in said on-board radio apparatus (MRA) and second trackside radio units (RU2(FRA#k)) comprised in at least two trackside radio apparatuses (FRA#k) installed along said railway line.

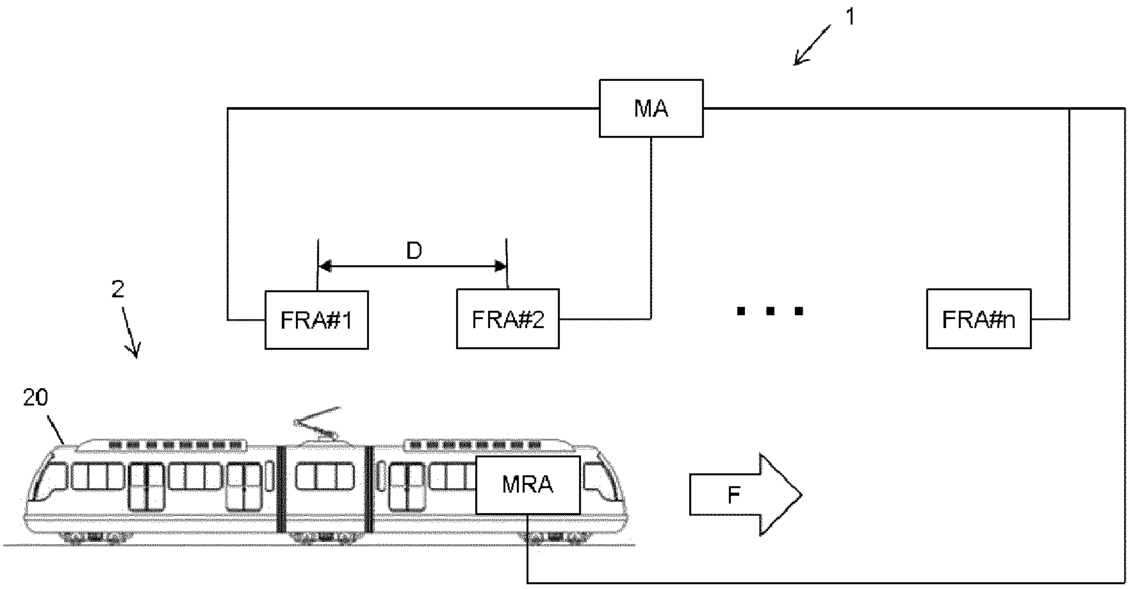

Figure 1

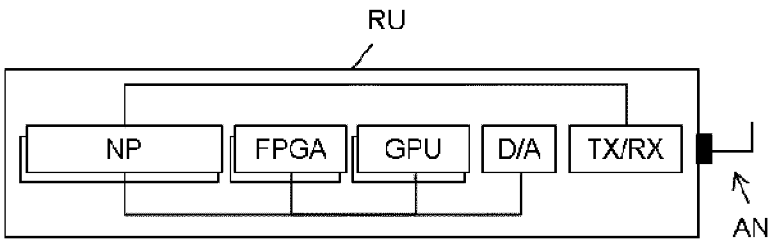

Figure 2a

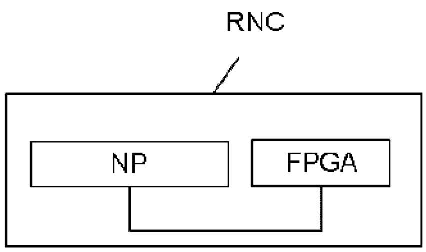

Figure 2b

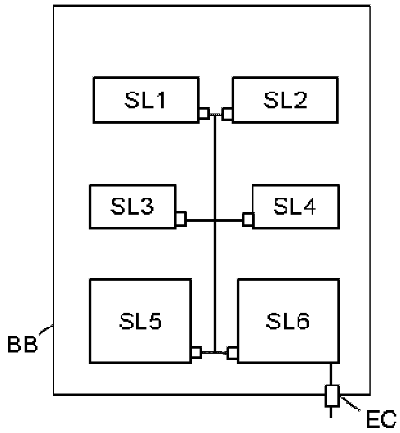

Figure 3a

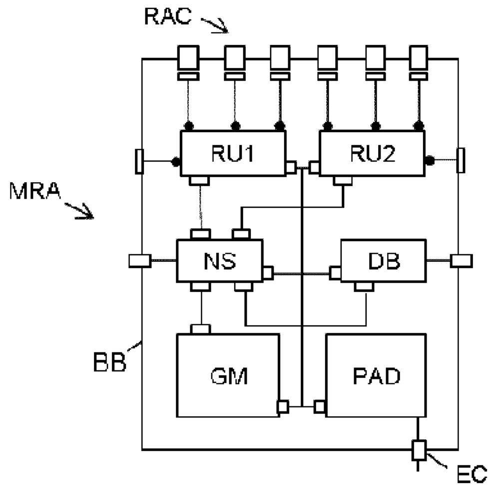

Figure 3b

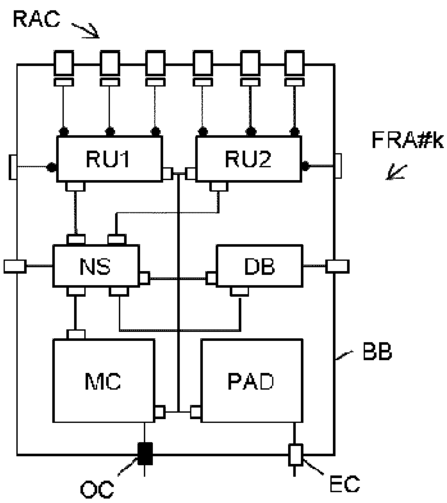

Figure 3c

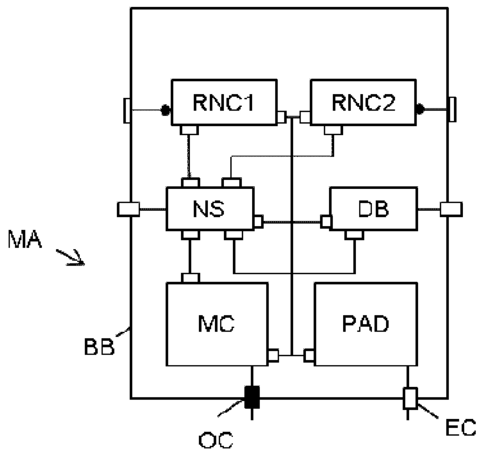

Figure 3d

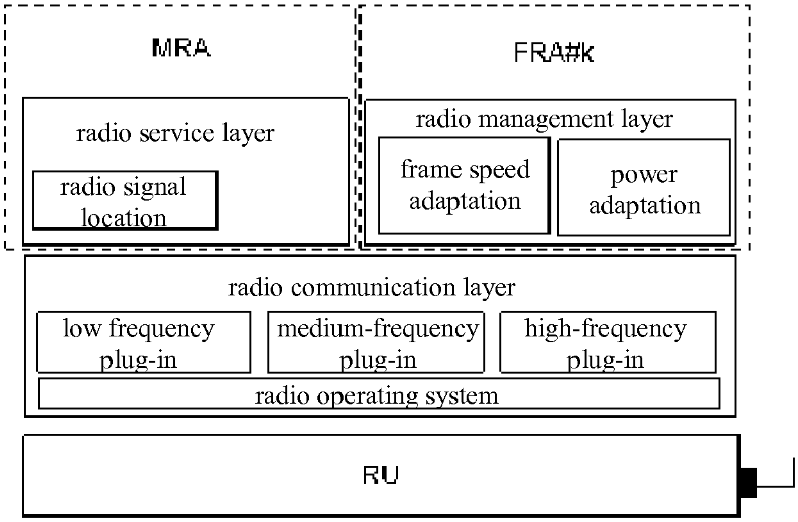

Figure 4a

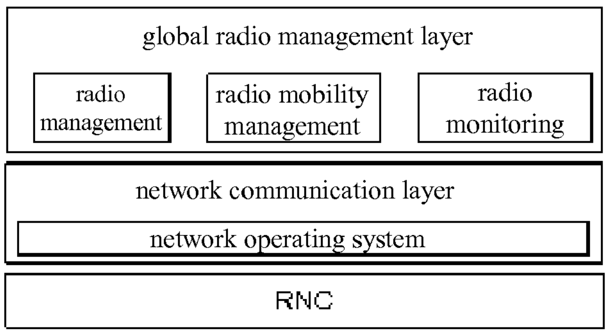

Figure 4b

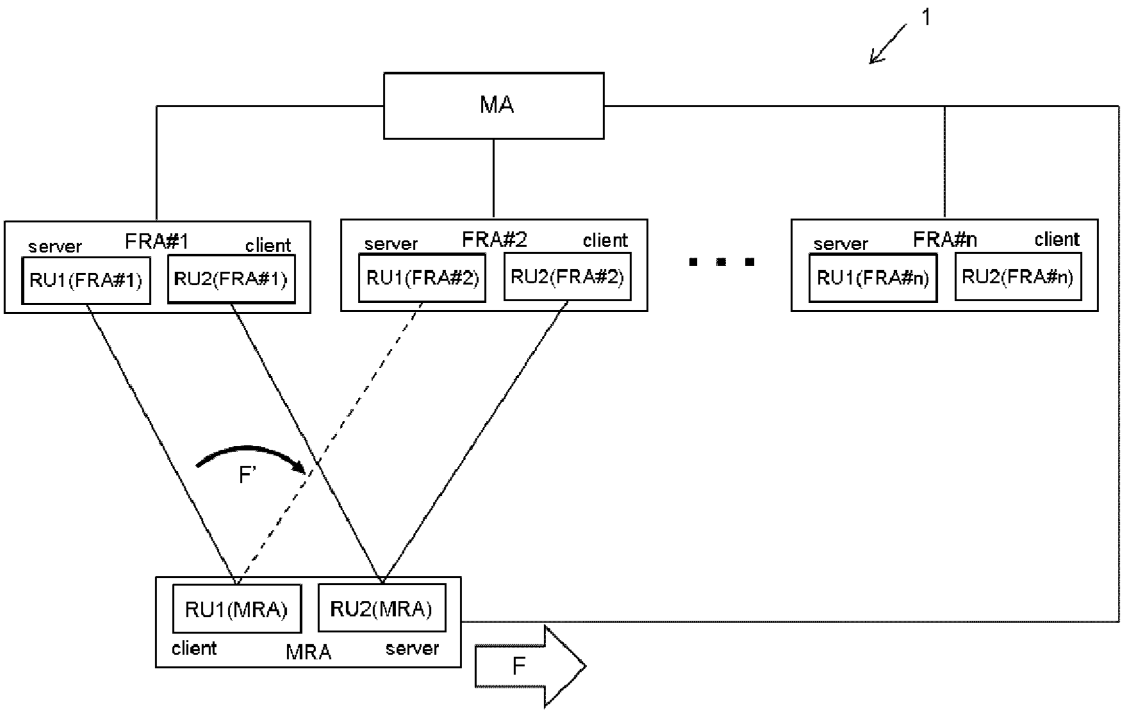
1
MA
server
FRA#1
client
RU1(FRA#1)
RU2(FRA#1)
server
FRA#2
client
RU1(FRA#2)
RU2(FRA#2)
server
FRA#n
client
RU1(FRA#n)
RU2(FRA#n)
F'
RU1(MRA)
RU2(MRA)
client
MRA
server
F

Figure 5

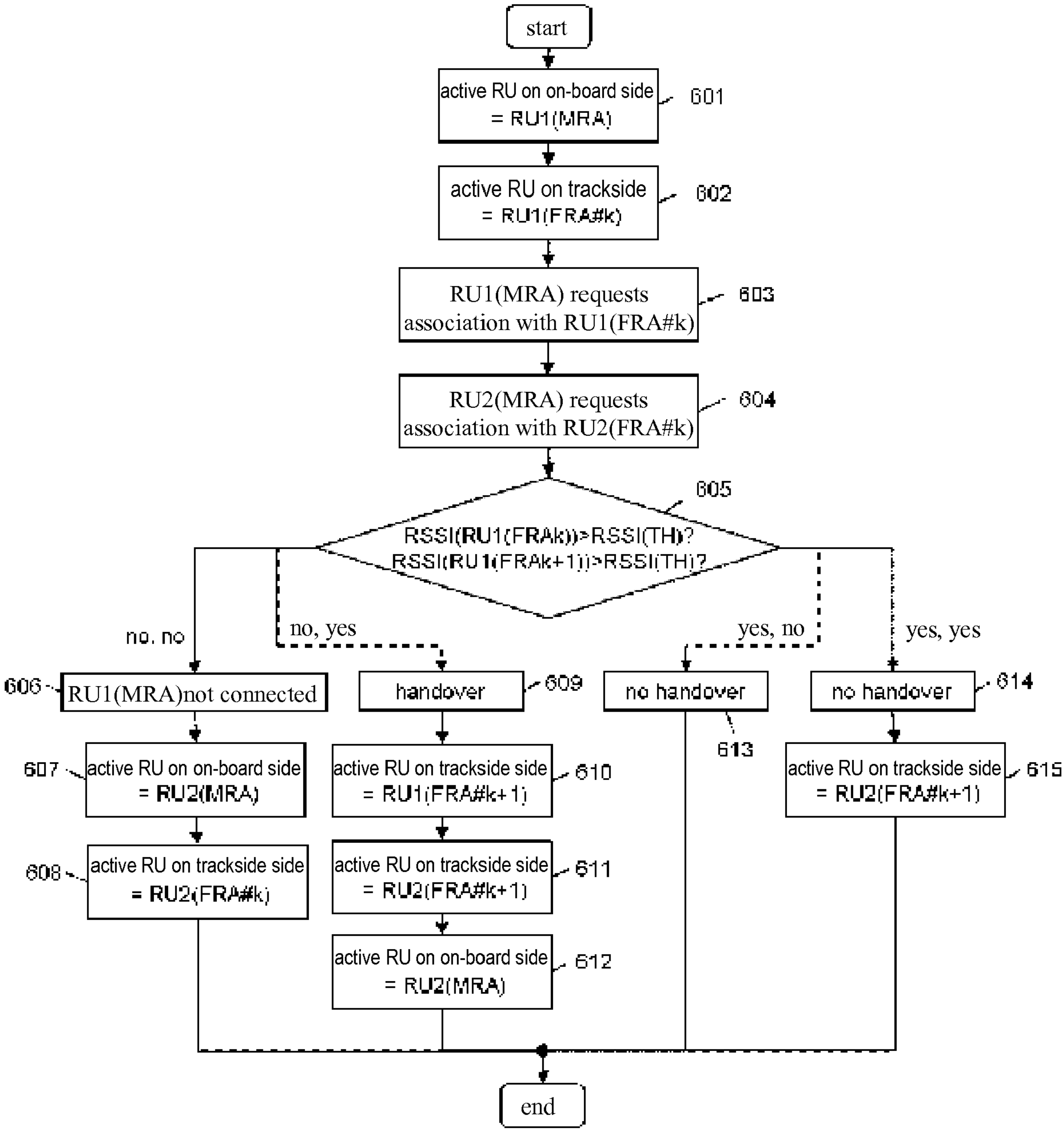
start
active RU on on-board side = RU1(MRA)
601
active RU on trackside = RU1(FRA#k)
602
RU1(MRA) requests association with RU1(FRA#k)
603
RU2(MRA) requests association with RU2(FRA#k)
604
605
RSSI(RU1(FRAk))>RSSI(TH)?
RSSI(RU1(FRAk+1))>RSSI(TH)?
no, no
no, yes
yes, no
yes, yes
606
RU1(MRA)not connected
handover
609
no handover
no handover
614
613
607
active RU on on-board side = RU2(MRA)
active RU on trackside side = RU1(FRA#k+1)
610
active RU on trackside side = RU2(FRA#k+1)
615
608
active RU on trackside side = RU2(FRA#k)
active RU on trackside side = RU2(FRA#k+1)
611
active RU on on-board side = RU2(MRA)
612
end

Figure 6

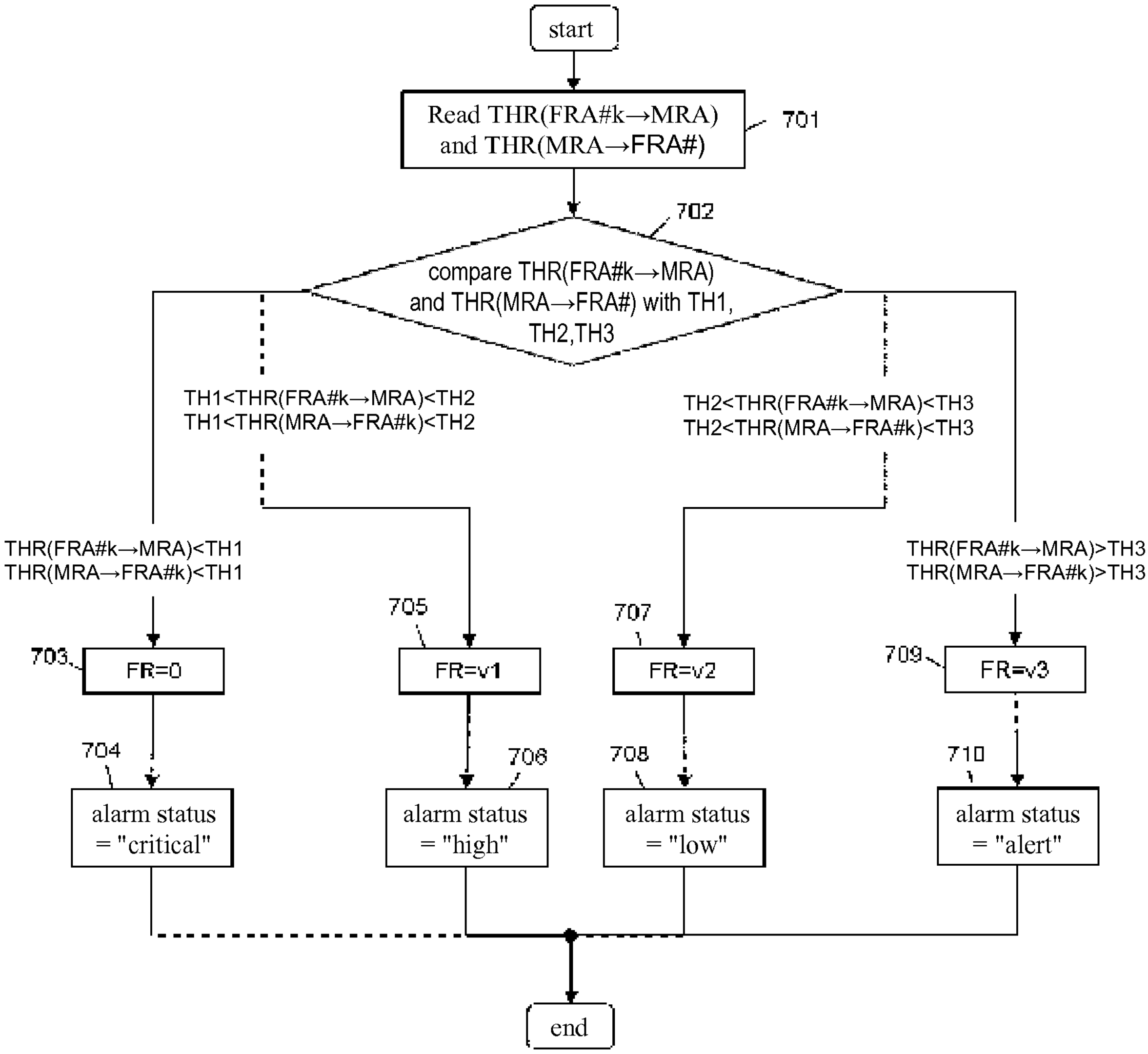
start
Read THR(FRA#k→MRA)
and THR(MRA→FRA#)
701
702
compare THR(FRA#k→MRA)
and THR(MRA→FRA#) with TH1,
TH2,TH3
TH1<THR(FRA#k→MRA)<TH2
TH1<THR(MRA→FRA#k)<TH2
TH2<THR(FRA#k→MRA)<TH3
TH2<THR(MRA→FRA#k)<TH3
THR(FRA#k→MRA)<TH1
THR(MRA→FRA#k)<TH1
THR(FRA#k→MRA)>TH3
THR(MRA→FRA#k)>TH3
703
FR=0
705
FR=v1
707
FR=v2
709
FR=v3
704
alarm status
= "critical"
706
alarm status
= "high"
708
alarm status
= "low"
710
alarm status
= "alert"
end

Figure 7

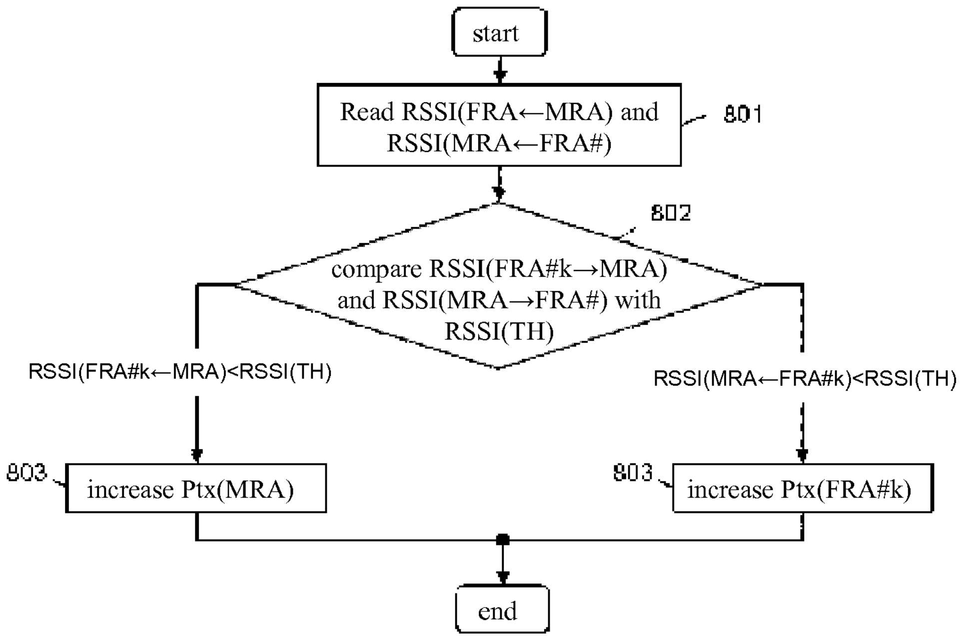

Figure 8

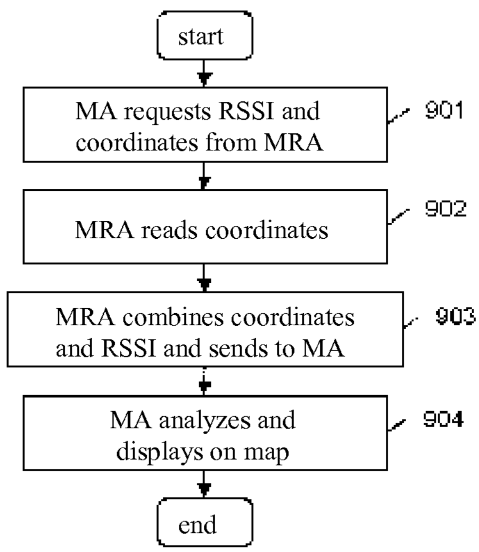

Figure 9

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EUROPEAN SEARCH REPORT

Application Number
EP 17 15 2760

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	US 2003/151520 A1 (KRAELING MARK BRADSHAW [US] ET AL) 14 August 2003 (2003-08-14) * abstract * * paragraph [0005] - paragraph [0006] * * paragraphs [0011], [0017] * * paragraph [0024] * * figures 1-3 * -----	1-6 7-15	INV. B61L15/00 B61L27/00
A	JIA-YI ZHANG ET AL: "A Multi-Mode Multi-Band and Multi-System-Based Access Architecture for High-Speed Railways", VEHICULAR TECHNOLOGY CONFERENCE FALL (VTC 2010-FALL), 2010 IEEE 72ND, 1 September 2010 (2010-09-01), pages 1-5, XP055311671, Piscataway, NJ, USA DOI: 10.1109/VETECF.2010.5594223 ISBN: 978-1-4244-3573-9 * the whole document * -----	7-15	
A	AU 2009 251 096 A1 (TECH RESOURCES PTY LTD) 8 July 2010 (2010-07-08) * the whole document * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC) B61L
A	EP 1 603 280 A2 (GSP SPRACHTECHNOLOGIE GES FUER [DE]) 7 December 2005 (2005-12-07) * figure * * paragraph [0003] - paragraph [0008] * * paragraph [0010] * * paragraph [0013] - paragraph [0019] * * paragraph [0022] - paragraph [0024] * * paragraph [0030] * -----	1-15	

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	5 April 2017	Robinson, Victoria

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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European Patent Office
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Application Number

EP 17 15 2760

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☒ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 17 15 2760

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-15

Radio apparatus for a railway infrastructure

1.1. claims: 1-6

Radio apparatus configurable to operate in multiple frequency bands and using multiple communications protocols

1.2. claims: 7-15

Radio communication system wherein the on-board radio apparatus is configured to simultaneously set up one communications link in a first frequency range and at leat two second radio links with at least two trackside apparatuses in a second, lower, frequency range.

Please note that all inventions mentioned under item 1, although not necessarily linked by a common inventive concept, could be searched without effort justifying an additional fee.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 17 15 2760

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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05-04-2017

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		BR 0307700 A	04-01-2005
		CN 1630596 A	22-06-2005
		RU 2312783 C2	20-12-2007
		US 2003151520 A1	14-08-2003
		WO 03068579 A1	21-08-2003
AU 2009251096 A1	08-07-2010	NONE	
EP 1603280 A2	07-12-2005	AT 500697 T	15-03-2011
		DE 102004027352 A1	29-12-2005
		EP 1603280 A2	07-12-2005

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Patent documents cited in the description

- US 20030151520 A **[0006] [0013] [0014]**