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(54) **Title:** RECONFIGURABLE DEMODULATION AND DECODING

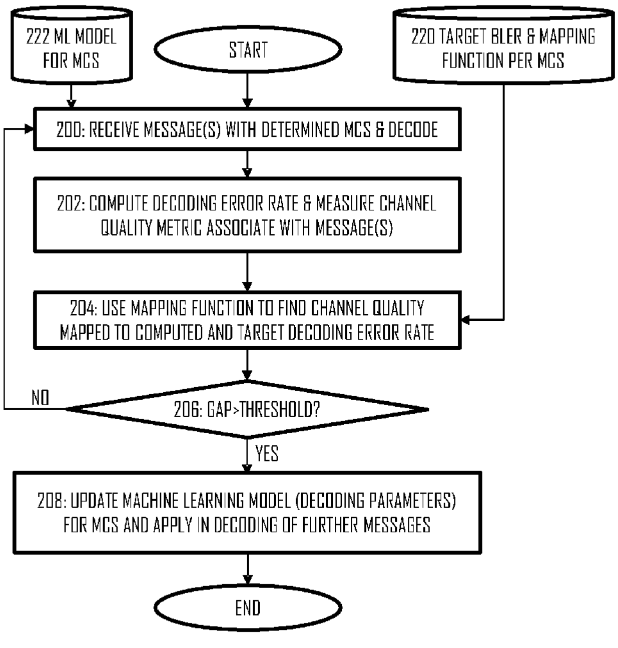


Fig. 2

(57) **Abstract:** This document discloses a solution for adapting a receiver. According to an aspect, a method comprises: storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; receiving at least one message from an access node, the at least one message associated with a determined modulation and coding scheme; decoding the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme; computing a decoding error rate for the at least one message; measuring a channel quality metric associated with the at least one message; comparing, by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate; in response to detecting, in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

WO 2023/083431 A1

Reconfigurable Demodulation and Decoding

Field

The exemplary and non-limiting embodiments of the invention relate generally to communication systems. Embodiments of the invention relate particularly to applying machine learning to demodulation and decoding of messages associated with various modulation and coding schemes.

Background

Machine learning (ML) based receivers have been shown to outperform traditional receivers under certain circumstances, especially with little or no demodulation reference symbols available. The ML-based receivers may be trained under a wide array of scenarios and environmental conditions in order to be able to operate with good reliability. One problem is that the ML models cannot be trained for all potential scenarios, e.g. all potential interference patterns or link adaptation errors.

Assuming an ML-based receiver, it is possible that the receiver is not working in the optimum conditions, e.g. because of unpredictable channel conditions, and the receiver ML model cannot adapt to those changes. This may result in an increased decoding error rate or, in general, degraded decoding performance. Better decoding performance could be achieved under the same conditions, if the receiver model was re-trained or updated. One of the main differences between traditional non-ML-based receivers and ML-based receivers is that the latter can be modified without hardware modifications. The update may be performed by means of loading a different ML model or re-training the current ML model.

Summary

The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to a more detailed description that is presented later.

According to an aspect, there is provided an apparatus comprising means for performing: storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; receiving at least one message from an access node, the at least one message associated with a determined modulation and coding scheme; decoding the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme; computing a decoding error rate for the at least one message; measuring a channel quality metric associated with the at least one message; comparing, by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate; in response to detecting, in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

In an embodiment, the decoding error rate is a coded bit error rate, an uncoded bit error rate, or a block error rate.

In an embodiment, the channel quality metric is a signal-to-interference ratio, signal-to-interference ratio, or a signal-to-noise ratio.

In an embodiment, the means are configured to apply the mapping function to the target decoding error rate, to shift thus applied mapping function along a dimension of the channel quality metric such that the mapping function intersects with the computed decoding error rate, and to use a value proportional to said shifting as the difference between the first decoding performance and the second decoding performance.

In an embodiment, the means are configured to apply the mapping function to the target decoding error rate and find, by using the mapping function, a target decoding error rate at the measured channel quality metric to represent the second decoding performance.

In an embodiment, the means are configured to: in response to detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, transmit to the access node a message indicating degradation in the decoding performance; receive, from the access node as a response to the message, an instruction to update the reconfigurable decoding parameters for at least the determined modulation and coding scheme; and in response to the instruction, to change the at least one of the reconfigurable decoding parameters.

In an embodiment, the reconfigurable decoding parameters before the change have been trained by using machine learning and wherein the reconfigurable decoding parameters after the change are default decoding parameters not employing the machine learning.

In an embodiment, the instruction indicates new decoding parameters for at least the determined modulation and coding scheme, and wherein the means are configured to perform the changing by adopting the new decoding parameters.

In an embodiment, the means are configured to indicate, in the message or in another message, to the access node incapability of performing retraining, and to receive instruction in response to the indication of the incapability.

In an embodiment, the means are configured to transmit to the access node at least one signal for training the new decoding parameters and to receive the new decoding parameters from the access node.

In an embodiment, the instruction indicates the apparatus to perform retraining of the reconfigurable decoding parameters, and wherein the means are configured, in response to the instruction, to receive a plurality of demodulation reference symbols from the access node, to use the plurality of demodulation reference symbols to learn new decoding parameters adapted to prevailing channel conditions, and to perform said changing by applying the new decoding parameters.

In an embodiment, the means are configured to transmit the new decoding parameters to the access node.

In an embodiment, the means are configured to: in response to said detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, search a memory for new decoding parameters; upon discovering such new decoding parameters, perform said changing by applying the discovered new decoding parameters; and upon discovering no such decoding parameters capable of bringing the difference below the threshold under the condition of the channel quality metric, transmit to the access node a message indicating degradation in the decoding performance.

In an embodiment, the means are configured to carry out the comparison under the condition where the computed decoding error rate is within a decoding error rate range that allows maintaining the determined modulation and coding scheme.

In an embodiment, the means are configured to configure a semi-static reporting scheme and to transmit the difference between the first decoding performance and the second decoding performance to the access node within the semi-static reporting scheme.

In an embodiment, the means are configured to receive the threshold from the access node.

According to an aspect, there is provided an apparatus comprising means for performing: storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; transmitting at least one message to a terminal device, the at least one message associated with a determined modulation and coding scheme; determining a channel quality metric associated with the at least one message; determining a difference between a first decoding performance of the terminal device and a second decoding performance of the terminal device, wherein the first decoding performance is at least partly based on the measured channel quality metric and a decoding error rate of the at least one message, wherein the second decoding performance represents the target decoding error rate, and wherein the difference is based on using the mapping function to bring the target decoding error rate and the decoding error rate of the at least one message comparable; in response to detecting that the difference between the first decoding performance and the second decoding performance is above a threshold, transmitting to the terminal device a command to change at least one of reconfigurable decoding parameters of the terminal device for the determined modulation and coding scheme and to apply thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

In an embodiment, the means are configured to receive the difference from the terminal device.

In an embodiment, the means comprises at least one processor and at least one memory including computer program code, wherein the at least one memory and computer program code configured to, with the at least one processor, cause the performance of the apparatus.

According to an aspect, there is provided a method comprising: storing, in a memory of an apparatus for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; receiving, by the apparatus, at least one message from an access node, the at least one message associated with a determined modulation and coding scheme; decoding, by the apparatus, the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme; computing, by the apparatus, a decoding error rate for the at least one message; measuring, by the apparatus, a channel quality metric associated with the at least one message; comparing, by the apparatus by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate; in response to detecting, by the apparatus in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

In an embodiment, the decoding error rate is a coded bit error rate, an uncoded bit error rate, or a block error rate.

In an embodiment, the channel quality metric is a signal-to-interference ratio, signal-to-interference ratio, or a signal-to-noise ratio.

In an embodiment, the apparatus applies the mapping function to the target decoding error rate, shifts thus applied mapping function along a dimension of the channel quality metric such that the mapping function intersects with the computed decoding error rate, and uses a value proportional to said shifting as the difference between the first decoding performance and the second decoding performance.

In an embodiment, the apparatus applies the mapping function to the target decoding error rate and finds, by using the mapping function, a target decoding error rate at the measured channel quality metric to represent the second decoding performance.

In an embodiment, the method further comprises by the apparatus: in response to detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, transmitting to the access node a message indicating degradation in the decoding performance; receiving, from the access node as a response to the message, an instruction to update the reconfigurable decoding parameters for at least the determined modulation and coding scheme; and in response to the instruction, changing the at least one of the reconfigurable decoding parameters.

In an embodiment, the reconfigurable decoding parameters before the change have been trained by using machine learning and wherein the reconfigurable decoding parameters after the change are default decoding parameters not employing the machine learning.

In an embodiment, the instruction indicates new decoding parameters for at least the determined modulation and coding scheme, and wherein the apparatus performs the changing by adopting the new decoding parameters.

In an embodiment, the apparatus indicates, in the message or in another message, to the access node incapability of performing retraining, and receives the instruction in response to the indication of the incapability.

In an embodiment, the apparatus transmits to the access node at least one signal for training the new decoding parameters and receives the new decoding parameters from the access node.

In an embodiment, the instruction indicates the apparatus to perform retraining of the reconfigurable decoding parameters, and wherein the apparatus receives, in response to the instruction, a plurality of demodulation reference symbols from the access node, uses the plurality of demodulation reference symbols to learn new decoding parameters adapted to prevailing channel conditions, and performs said changing by applying the new decoding parameters.

In an embodiment, the apparatus transmits the new decoding parameters to the access node.

In an embodiment, the method further comprises by the apparatus: in response to said detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, searching a memory for new decoding parameters; upon discovering such new decoding parameters, performing said changing by applying the discovered new decoding parameters; and upon discovering no such decoding parameters capable of bringing the difference below the threshold under the condition of the channel quality metric, transmitting to the access node a message indicating degradation in the decoding performance.

In an embodiment, the apparatus carries out the comparison under the condition where the computed decoding error rate is within a decoding error rate range that allows maintaining the determined modulation and coding scheme.

In an embodiment, the apparatus configures a semi-static reporting scheme and transmits the difference between the first decoding performance and the second decoding performance to the access node within the semi-static reporting scheme.

In an embodiment, the apparatus receives the threshold from the access node.

According to an aspect, there is provided a method comprising: storing, in an apparatus for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; transmitting, by the apparatus, at least one message to a terminal device, the at least one message associated with a determined modulation and coding scheme; determining, by the apparatus, a channel quality metric associated with the at least one message; determining, by the apparatus, a difference between a first decoding performance of the terminal device and a second decoding performance of the terminal device, wherein the first decoding performance is at least partly based on the measured channel quality metric and a decoding error rate of the at least one message, wherein the second decoding performance represents the target decoding error rate, and wherein the difference is based on using the mapping function to bring the target decoding error rate and the decoding error rate of the at least one message comparable; in response to detecting, by the apparatus, that the difference between the first decoding performance and the second decoding performance is above a threshold, transmitting to the terminal device a command to change at least one of reconfigurable decoding parameters of the terminal device for the determined modulation and coding scheme and to apply thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

In an embodiment, the difference is received from the terminal device.

According to an aspect, there is provided a computer program product embodied on a computer-readable medium and comprising a computer program code readable by a computer, wherein the computer program code configures the computer to carry out a computer process comprising: storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; receiving at least one message from an access node, the at least one message associated with a determined modulation and coding scheme; decoding the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme; computing a decoding error rate for the at least one message; measuring a channel quality metric associated with the at least one message; comparing, by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate; in response to detecting, in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

According to an aspect, there is provided a computer program product embodied on a computer-readable medium and comprising a computer program code readable by a computer, wherein the computer program code configures the computer to carry out a computer process comprising: storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; transmitting at least one message to a terminal device, the at least one message associated with a determined modulation and coding scheme; determining a channel quality metric associated with the at least one message; determining a difference between a first decoding performance of the terminal device and a second decoding performance of the terminal device, wherein the first decoding performance is at least partly based on the measured channel quality metric and a decoding error rate of the at least one message, wherein the second decoding performance represents the target decoding error rate, and wherein the difference is based on using the mapping function to bring the target decoding error rate and the decoding error rate of the at least one message comparable; in response to detecting that the difference between the first decoding performance and the second decoding performance is above a threshold, transmitting to the terminal device a command to change at least one of reconfigurable decoding parameters of the terminal device for the determined modulation and coding scheme and to apply thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

One or more examples of implementations are set forth in more detail in the accompanying drawings and the description below. Other features will be apparent from the description and drawings, and from the claims. The embodiments and/or examples and features, if any, described in this specification that do not fall under the scope of the independent claims are to be interpreted as examples useful for understanding various embodiments of the invention.

List of drawings

Embodiments of the present invention are described below, by way of example only, with reference to the accompanying drawings, in which

Figures 1 illustrates an example of simplified system scenario to which embodiments may be applied;

Figure 2 illustrates a process for adapting reconfigurable decoding parameters of a terminal device to changes in decoding performance according to an embodiment;

Figure 3 illustrates dependency of decoding performance on channel quality according to an embodiment;

Figures 4 to 7 illustrate various embodiments for involving an access node in updating of decoding parameters;

Figures 8 and 9 illustrate an embodiment of a process for a situation where current decoding performance is better than a target decoding performance;

Figure 10 illustrates an embodiment of a procedure for first exploring locally stored machine learning model before requesting assistance from a serving access node;

Figure 11 illustrates another embodiment of a process for adapting reconfigurable decoding parameters of a terminal device; and

Figures 12 and 13 illustrate simplified examples of apparatuses applying some embodiments of the invention.

Description of some embodiments

The following embodiments are only examples. Although the specification may refer to “an”, “one”, or “some” embodiment(s) in several locations, this does not necessarily mean that each such reference is to the same embodiment(s), or that the feature only applies to a single embodiment. Single features of different embodiments may also be combined to provide other embodiments. Furthermore, words “comprising” and “including” should be understood as not limiting the described embodiments to consist of only those features that have been mentioned and such embodiments may also contain features, structures, units, modules etc. that have not been specifically mentioned.

Some embodiments of the present invention are applicable to a user terminal, a communication device, a base station, eNodeB, gNodeB, a distributed realisation of a base station, a network element of a communication system, a corresponding component, and/or to any communication system or any combination of different communication systems that support required functionality.

The protocols used, the specifications of communication systems, servers and user equipment, especially in wireless communication, develop rapidly. Such development may require extra changes to an embodiment. Therefore, all words and expressions should be interpreted broadly and they are intended to illustrate, not to restrict, embodiments.

In the following, different exemplifying embodiments will be described using, as an example of an access architecture to which the embodiments may be applied, a radio access architecture based on long term evolution advanced (LTE Advanced, LTE-A) or new radio (NR, 5G), without restricting the embodiments to such an architecture, however. The embodiments may also be applied to other kinds of communications networks having suitable means by adjusting parameters and procedures appropriately. Some examples of other options for suitable systems are the universal mobile telecommunications system (UMTS) radio access network (UTRAN), wireless local area network (WLAN or WiFi), worldwide interoperability for microwave access (WiMAX), Bluetooth®, personal communications services (PCS), ZigBee®, wideband code division multiple access (WCDMA), systems using ultra-wideband (UWB) technology, sensor networks, mobile ad-hoc networks (MANETs) and Internet Protocol multimedia subsystems (IMS) or any combination thereof.

Fig. 1 depicts examples of simplified system architectures only showing some elements and functional entities, all being logical units, whose implementation may differ from what is shown. The connections shown in Fig. 1 are logical connections; the actual physical connections may be different. It is apparent to a person skilled in the art that the system typically comprises also other functions and structures than those shown in Fig. 1.

The embodiments are not, however, restricted to the system given as an example but a person skilled in the art may apply the solution to other communication systems provided with necessary properties.

The example of Fig. 1 shows a part of an exemplifying radio access network.

Fig. 1 shows devices 100 to 102. The devices 100 to 102 are configured to be in a wireless connection on one or more communication channels with a node 104. The node 104 is further connected to a core network 110. In one example, the node 104 may be an access node such as (e/g)NodeB serving devices in a cell. In one example, the node 104 may be a non-3GPP access node. The physical link from a device to a (e/g)NodeB is called uplink or reverse link and the physical link from the (e/g)NodeB to the device is called downlink or forward link. It should be appreciated that (e/g)NodeBs or their functionalities may be implemented by using any node, host, server or access point etc. entity suitable for such a usage.

A communications system typically comprises more than one (e/g)NodeB in which case the (e/g)NodeBs may also be configured to communicate with one another over links, wired or wireless, designed for the purpose. These links may be used for signalling purposes. The (e/g)NodeB is a computing device configured to control the radio resources of communication system it is coupled to. The NodeB may also be referred to as a base station, an access point or any other type of interfacing device including a relay station capable of operating in a wireless environment. The (e/g)NodeB includes or is coupled to transceivers. From the transceivers of the (e/g)NodeB, a connection is provided to an antenna unit that establishes bi-directional radio links to devices. The antenna unit may comprise a plurality of antennas or antenna elements. The (e/g)NodeB is further connected to the core network 110 (CN or next generation core NGC). Depending on the deployed technology, the (e/g)NodeB is connected to a serving and packet data network gateway (S-GW +P-GW) or user plane function (UPF), for routing and forwarding user data packets and for providing connectivity of devices to one or more external packet data networks, and to a mobile management entity (MME) or access mobility management function (AMF), for controlling access and mobility of the devices.

Exemplary embodiments of a device 100, 101, 102 are a subscriber unit, a user device, a user equipment (UE), a user terminal, a terminal device, a mobile station, a mobile device, etc

The device typically refers to a mobile or static device (e.g. a portable or non-portable computing device) that includes wireless mobile communication devices operating with or without an universal subscriber identification module (USIM), including, but not limited to, the following types of devices: mobile phone, smartphone, personal digital assistant (PDA), handset, device using a wireless modem (alarm or measurement device, etc.), laptop and/or touch screen computer, tablet, game console, notebook, and multimedia device. It should be appreciated that a device may also be a nearly exclusive uplink only device, of which an example is a camera or video camera loading images or video clips to a network. A device may also be a device having capability to operate in Internet of Things (IoT) network which is a scenario in which objects are provided with the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction, e.g. to be used in smart power grids and connected vehicles. The device may also utilise cloud. In some applications, a device may comprise a user portable device with radio parts (such as a watch, earphones or eyeglasses) and the computation is carried out in the cloud.

The device illustrates one type of an apparatus to which resources on the air interface are allocated and assigned, and thus any feature described herein with a device may be implemented with a corresponding apparatus, such as a relay node. An example of such a relay node is a layer 3 relay (self-backhauling relay) towards the base station. The device (or in some embodiments a layer 3 relay node) is configured to perform one or more of user equipment functionalities.

Various techniques described herein may also be applied to a cyber-physical system (CPS) (a system of collaborating computational elements controlling physical entities). CPS may enable the implementation and exploitation of massive amounts of interconnected information and communications technology, ICT, devices (sensors, actuators, processors microcontrollers, etc.) embedded in physical objects at different locations. Mobile cyber physical systems, in which the physical system in question has inherent mobility, are a subcategory of cyber-physical systems. Examples of mobile physical systems include mobile robotics and electronics transported by humans or animals.

Additionally, although the apparatuses have been depicted as single entities, different units, processors and/or memory units (not all shown in Fig. 1) may be implemented.

5G enables using multiple input – multiple output (MIMO) antennas, many more base stations or nodes than the LTE (a so-called small cell concept), including macro sites operating in co-operation with smaller stations and employing a variety of radio technologies depending on service needs, use cases and/or spectrum available. 5G mobile communications supports a wide range of use cases and related applications including video streaming, augmented reality, different ways of data sharing and various forms of machine type applications (such as (massive) machine-type communications (mMTC), including vehicular safety, different sensors and real-time control. 5G is expected to have multiple radio interfaces, e.g. below 6G Hz or above 24 GHz, cmWave and mmWave, and also being integrable with existing legacy radio access technologies, such as the LTE. Integration with the LTE may be implemented, at least in the early phase, as a system, where macro coverage is provided by the LTE and 5G radio interface access comes from small cells by aggregation to the LTE. In other words, 5G is planned to support both inter-RAT operability (such as LTE-5G) and inter-RI operability (inter-radio interface operability, such as below 6 GHz – cmWave, 6 or above 24 GHz – cmWave and mmWave). The next generation (6G) may continue to use the same frequency band(s) as the 5G systems and, further, employ different frequency bands. In one scenario, 6G might comprise an air interface optimized and/or designed for artificial intelligence / machine learning (AI/ML) based transmitters and receivers (so-called AI-native air interface). One of the concepts considered to be used in 5G networks is network slicing in which multiple independent and dedicated virtual sub-networks (network instances) may be created within the same infrastructure to run services that have different requirements on latency, reliability, throughput and mobility.

The current architecture in LTE networks is fully distributed in the radio and fully centralized in the core network. The low latency applications and services in 5G require to bring the content close to the radio which leads to local break out and multi-access edge computing (MEC). 5G enables analytics and knowledge generation to occur at the source of the data. This approach requires leveraging resources that may not be continuously connected to a network such as laptops, smartphones, tablets and sensors. MEC provides a distributed computing environment for application and service hosting. It also has the ability to store and process content in close proximity to cellular subscribers for faster response time. Edge computing covers a wide range of technologies such as wireless sensor networks, mobile data acquisition, mobile signature analysis, cooperative distributed peer-to-peer ad hoc networking and processing also classifiable as local cloud/fog computing and grid/mesh computing, dew computing, mobile edge computing, cloudlet, distributed data storage and retrieval, autonomic self-healing networks, remote cloud services, augmented and virtual reality, data caching, Internet of Things (massive connectivity and/or latency critical), critical communications (autonomous vehicles, traffic safety, real-time analytics, time-critical control, healthcare applications).

The communication system is also able to communicate with other networks 112, such as a public switched telephone network, or a VoIP network, or the Internet, or a private network, or utilize services provided by them. The communication network may also be able to support the usage of cloud services, for example at least part of core network operations may be carried out as a cloud service (this is depicted in Fig. 1 by "cloud" 114). The communication system may also comprise a central control entity, or a like, providing facilities for networks of different operators to cooperate for example in spectrum sharing.

The technology of Edge cloud may be brought into a radio access network (RAN) by utilizing network function virtualization (NFV) and software defined networking (SDN). Using the technology of edge cloud may mean access node operations to be carried out, at least partly, in a server, host or node operationally coupled to a remote radio head or base station comprising radio parts. It is also possible that node operations will be distributed among a plurality of servers, nodes or hosts. Application of cloudRAN architecture enables RAN real time functions being carried out at or close to a remote antenna site (in a distributed unit, DU 105) and non-real time functions being carried out in a centralized manner (in a central unit, CU 108).

It should also be understood that the distribution of labour between core network operations and base station operations may differ from that of the LTE or even be non-existent. Some other technology advancements probably to be used are Big Data and all-IP, which may change the way networks are being constructed and managed. 5G (or new radio, NR) networks are being designed to support multiple hierarchies, where MEC servers can be placed between the core and the base station or nodeB (gNB). It should be appreciated that MEC can be applied in 4G networks as well.

5G may also utilize satellite communication to enhance or complement the coverage of 5G service, for example by providing backhauling via one or more satellite access nodes 109. Possible use cases are providing service continuity for machine-to-machine (M2M) or Internet of Things (IoT) devices or for passengers on board of vehicles, or ensuring service availability for critical communications, and future railway/maritime/aeronautical communications. Satellite communication may utilise geostationary earth orbit (GEO) satellite systems, but also low earth orbit (LEO) satellite systems, in particular mega-constellations (systems in which hundreds of (nano)satellites are deployed). Each satellite in the mega-constellation may cover several satellite-enabled network entities that create on-ground cells. The on-ground cells may be created through an on-ground relay node or by a gNB located on-ground or in a satellite.

It is obvious for a person skilled in the art that the depicted system is only an example of a part of a radio access system and in practice, the system may comprise a plurality of (e/g)NodeBs, the device may have an access to a plurality of radio cells and the system may comprise also other apparatuses, such as physical layer relay nodes or other network elements, etc. At least one of the (e/g)NodeBs or may be a Home(e/g)nodeB. Additionally, in a geographical area of a radio communication system a plurality of different kinds of radio cells as well as a plurality of radio cells may be provided. Radio cells may be macro cells (or umbrella cells) which are large cells, usually having a diameter of up to tens of kilometers, or smaller cells such as micro-, femto- or picocells. The (e/g)NodeBs of Fig. 1 may provide any kind of these cells. A cellular radio system may be implemented as a multilayer network including several kinds of cells. Typically, in multilayer networks, one access node provides one kind of a cell or cells, and thus a plurality of (e/g)NodeBs are required to provide such a network structure.

For fulfilling the need for improving the deployment and performance of communication systems, the concept of “plug-and-play” (e/g)NodeBs has been introduced. Typically, a network which is able to use “plug-and-play” (e/g)Node Bs, includes, in addition to Home (e/g)NodeBs (H(e/g)nodeBs), a home node B gateway, or HNB-GW (not shown in Fig. 1). A HNB Gateway (HNB-GW), which is typically installed within an operator’s network may aggregate traffic from a large number of HNBs back to a core network.

5G systems already employ artificial intelligence and machine learning with various functions. Some exemplary functions that already employ the machine learning and artificial intelligence are network planning, automation of network operations, fraud detection, provisioning, optimization, fault prediction, security, network slicing, and improving quality of service and user experience. The embodiments described below relate to a scenario where a terminal device 100 uses machine learning (ML) in demodulation and decoding of messages received from an access node 104. Such a ML receiver may be considered as a receiver with reconfigurable demodulation and decoding parameters that may be configured to operate under certain conditions via training. Literature in the art discloses how to use, for example deep learning or reinforcement learning (and associated training) in link adaptation in a 5G system described above in connection with Figure 1. Similar ML receivers can be applied to older evolution versions of the cellular communication systems. The literature discloses various different ML receiver models and how the ML models are trained, so the description below does not address these details for the sake of conciseness. It suffices to say that the ML receivers and ML models can be understood as being reconfigurable by software without requiring any hardware changes to implement a change in the operation of the ML receivers and ML models, i.e. in reconfigurable decoding parameters. The embodiments described below focus on performing, by using the ML models, decoding of messages associated with various modulation and coding schemes (MCSs). One or more ML models may be trained per MCS, e.g. for different channel conditions, wherein each ML model has a unique combination of decoding parameters that define how a received message (signal) is processed to perform demodulation and channel decoding (decoding in general). The terminal device may then be configured by certain rules to change an ML model, thus implementing a change to the decoding parameters.

An MCS defines a number of payload bits carried by one symbol. As known in the art the MCS is a combination of a modulation method and a channel coding scheme. The modulation method defines how the symbols are represented by parameters of waveforms (phase and/or amplitude, for example). A modulation order defines the number of bits per modulation symbol. Modulation can be performed via phase shift keying or quadrature amplitude modulation, for example. A channel coding rate defines the information bit rate per total bit rate, wherein the total bit rate equals to a modulation symbol rate * the modulation order. The channel coding may be implemented by various techniques where redundancy bits or redundancy information is added to the payload bits to combat adverse channel effects such as signal distortion and interference.

A reason to change the ML model may be degradation in decoding performance of the currently applied ML model. A channel quality metric such as a received signal strength indicator (RSSI), a signal-to-interference ratio (SINR), or a reference signal reception power (RSRP) may be used as a metric of the decoding performance but it does not necessarily reflect the true decoding performance of the applied ML model. In the context of this description, the SINR may encompass its known variants such as signal-to-noise ratio SNR (without interference), signal-to-interference ratio SIR (without noise components such as additive white Gaussian noise), or the SINR (covering both noise and interference). Because the training is performed by using measurement data having various characteristics, the training may result in varying performance. Figure 2 illustrates a procedure for adapting the ML model based on the decoding performance of the terminal device. Referring to Figure 2, the process performed in the terminal device comprises:

storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function (database 220) describing dependence of a decoding error rate and channel quality; receiving (block 200) at least one message from an access node, the at least one message associated with a determined modulation and coding scheme; decoding the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme; computing (block 202) a decoding error rate for the at least one message; measuring a channel quality metric associated with the at least one message; comparing (block 204), by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate; in response to detecting (block 206), in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing (block 208) at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

The reconfigurable decoding parameters (in database 222) for block 200 may employ machine learning (ML) and be based on an ML model that defines the configuration of the decoding parameters.

The mapping function may be defined by the network and provided by the serving access node 104 with which the terminal device has a radio resource control (RRC) connection. The mapping function may be based on certain channel conditions, e.g. an additive white Gaussian noise (AWGN) channel, or based on multiple channel models. The mapping function may be a static function, or it may be updated by the access node 104 or another element of the network based on measurements and performance of the mapping function. The mapping function may be based on long-term measurements, e.g. signal-to-interference ratio (SINR) measurements in the access node or in the network, meaning that the mapping function is relatively static. In other embodiments, the mapping function may be adjusted during a radio resource control connection so that it better adapts to changes in the radio channel of the connection.

The threshold may be understood as a parameter indicative of a maximum margin allowed for deviating from a target performance level set by the target decoding error rate, together with the mapping function. The threshold may be common to some or all supported MCSs, or it may be specific to each MCS. The terminal device may thus store a separate threshold for each MCS. In an embodiment, the terminal device receives the threshold(s) from the access node.

Binding the decoding performance in the form of the decoding error rate with the channel quality metric provides more accurate information on the true decoding performance of the terminal device than the channel quality alone. Accordingly, the decision about changing the ML model can be made more efficiently and improved overall performance can be achieved. Improved performance results in lower decoding error rate and fewer retransmissions of messages that failed in the decoding.

In an embodiment, the decoding error rate is a block error rate (BLER). The BLER can be defined as a ratio between a number of erroneously decoded transport blocks and a total number of received transport blocks. Decision about whether or not a transport block is successfully or erroneously decoded may be based on a cyclic redundancy check (CRC) result, as known in the art.

In an embodiment, the channel quality metric is a signal-to-interference (SINR) ratio. Interference can be understood to include both noise (including thermal noise) and interference from other transmitters. Another channel quality metric such as the RSSI or RSRP can be equally used. Alternatively, another metric representing the quality (or equivalently state) of the radio channel between the terminal device and the access node may be used. An example of such another metric is a Doppler frequency or a Doppler spread that is also measurable. In yet further embodiments, the channel quality metric may be a combination of multiple channel quality metrics of the same type or of different types. For example, the channel quality metric may be averaged over multiple received decoded messages taken into account in the process of Figure 2. As another example, the mapping function may define the decoding error rate as a function of multiple different channel quality metrics, e.g. as a function of both the SINR and Doppler frequency. In this manner, the mapping function is better adapted to various different types of channel conditions. In general, the channel quality metric may be described as a channel quality metric measured from one or more reference signals associated with the received message(s). Accordingly, the channel quality metric represents conditions of a radio channel between the terminal device and the access node during the reception of the message(s).

Block 204 may be alternatively understood as comparing, by using the mapping function to bring the target decoding rate and the computed decoding rate comparable, decoding performance represented by the computed decoding error rate with target decoding performance represented by the target decoding error rate. In other words, the channel state represented by the channel quality metric may be used as a reference point to determine the difference between the current decoding performance and the target decoding performance for the determined MCS under the prevailing channel conditions. If the difference is above the threshold, updating of the ML model is triggered. The decoding performance may alternatively be evaluated as receiver sensitivity: greater sensitivity results in greater decoding performance under particular channel conditions, and if the sensitivity reduces too far away from a target sensitivity, the updating of the ML model may be triggered.

Figures 3A and 3B illustrate example illustrations of the mapping function and how the comparison in block 204 may be understood. The mapping function may be understood as a curve, a table, or generally mapping between the decoding error rate (e.g. the BLER) and the channel quality metric (e.g. the SINR). A target decoding error rate may also be defined per MCS for a given channel quality metric, and the mapping function allows mapping the target decoding error rate for the other values of the channel quality metric. As a consequence, the curve illustrated with the solid line for MCS1 can be formed. This curve represents the target decoding performance under different channel conditions, e.g. as a function of the channel quality metric. Now, in block 202 the decoding error rate is measured under the prevailing conditions (the applied ML model and the prevailing channel conditions) which is represented by the mark indicating the measured, current BLER. This is measured under the current channel conditions represented by the measured channel quality metric (SINR2 in Figure 3A). Now, the difference to the target decoding performance (target BLER), and/or to the point {target BLER, SINR Y} may be realized by shifting the curve along the horizontal axis (axis of the channel quality metric SINR) so that the curve intersects with the measured BLER, and/or with the point {measured BLER, SINR2}. When evaluating a certain point of the curve, e.g. the BLER that is equal to the measured BLER and is in the mapping function associated with a value SINR1 of the channel quality metric in Figure 3A, the certain point shifts along the horizontal axis by a certain amount. The amount of the shifting (SINR gap represented by the difference between SINR1 and SINR2 in Figure 3A) represents the difference between the first (measured) decoding performance and the second (target) decoding performance. In this case, the difference is represented by the SINR gap which can be understood as a difference in the channel quality metric (SINR) required for the current ML model to reach the target decoding performance. In other words, increase in the SINR proportional (or equal) to the SINR gap is required to reach the target decoding performance with the current ML model under the prevailing channel conditions. The SINR gap is thus an indicator of how sub-optimal the current ML model is for the prevailing channel conditions.

Figure 3B illustrates another embodiment where the target decoding error rate is shifted along the mapping function to the same level as the measured decoding error rate. In this manner, the same difference as in the values of the channel quality metric (SINR1 and SINR2) as in the embodiment of Figure 3A can be acquired. According to an embodiment using Figure 3B, the terminal device may apply the mapping function to the target decoding error rate and find, by using thus applied mapping function, a target decoding error rate at the measured channel quality metric to represent the second decoding performance.

Yet another embodiment would be to shift the measured decoding error rate along the mapping function to the same (horizontal) level as the target decoding error rate and then compute the difference between the SINR values associated with the target decoding error rate and the measured decoding error rate.

By using the channel quality metric in the manner as described in connection with Figures 3A and 3B, an embodiment of block 204 is thus a step where the mapping function is adapted to the computed decoding error rate and a first value of the channel quality metric (SINR2 in Figure 3) mapped to the computed decoding error rate in the mapping function is found; the found value SINR2 of the channel quality metric is then compared with a second value of the channel quality metric (SINR1 in Figure 3A) that is mapped to a target decoding error rate of the determined modulation and coding scheme in the mapping function. The difference in the channel quality metrics (SINR1 and SINR2) thus represents the difference between the current decoding performance and the target decoding performance.

Since the decoding performance vs. the channel quality metric is dependent on the MCS, different mapping functions may be stored for different MCSs, as illustrated in Figure 3 for another mapping function (another curve) for another MCS (MCS2). Similarly, the target decoding error rate may be separately stored for each MCS supported by the terminal device. In summary, the terminal device may store, per MCS, the target decoding error rate (e.g. as a single value and mapped to a certain default value of the channel quality metric), the threshold(s), and the mapping function representing the dependence of the target decoding error rate on the channel quality metric, thus enabling determination of the target decoding performance under the various channel conditions for the particular MCS. This enables the terminal device then to evaluate the difference between the current decoding performance (represented by the computed decoding error rate) and the target decoding performance (the target decoding error rate) under the particular channel conditions (represented by the measured channel quality metric) used to bring the decoding performances on the same scale.

In an embodiment, the process of Figure 2 and the updating of the decoding parameters and the ML model is performed within the determined MCS, i.e. without changing the MCS. Accordingly, this embodiment may be understood as a mechanism for improving data throughput within the same MCS. In other words, this embodiment aims to proactively manage the degradation in the decoding performance without changing to a MCS with lower throughput. The procedure of Figure 2 may thus be carried out in a state where the terminal device operates ‘normally’, e.g. in a state where no radio link failures have been detected.

In an embodiment, if the comparison indicates that the difference between the current and target decoding performance is below the threshold, the terminal device may maintain the current ML model.

In an embodiment, the computed current decoding error rate (BLER) may be an average of multiple observation points of the decoding error rate. For example, the terminal device may accumulate the decoding error rate over a determined time interval while monitoring that the channel quality metric stays within a determined range to ensure that the channel remains substantially constant. In another embodiment, the terminal device may compute multiple BLER vs. SINR points such that deviation is allowed in the dimension of the channel quality metric as well. Then, the averaging may be performed across the decoding error rate (BLER) dimension and the channel quality metric (SINR) dimension, allowing more flexibility to changes in the channel conditions during the accumulation.

Figures 4 to 7 illustrate various embodiments for implementing block 208. In Figures 4 to 7, the same reference numbers refer to the same or substantially similar steps or functions. Referring to Figure 4, the terminal device and the access node may establish a radio resource control (RRC) connection in block 400. Block 400 may comprise configuring various parameters of the connection for the transfer of the messages decoded by the terminal device. Step 402 may comprise the terminal device indicating its capability for reconfiguring the decoding parameters during the connection and, upon indicating such capability, configuring the ML models for the different MCSs. At least one ML model per MCS may be configured, in some embodiments multiple ML models per MCS (for different channel conditions, for example). The terminal device may carry out a learning phase where at least some of the ML models are trained, or the terminal device may employ ML models trained in earlier RRC connections. Yet another embodiment of step 402 is transfer of one or more ML models from the access node 104 to the terminal device. The access node may employ ML models trained by other terminal devices or trained by the access node itself. The radio channel is reciprocal in many communication scenarios (e.g. TDD communications) so the same demodulation and decoding functions may be applied in the access node and in the terminal device.

Each ML model may have a unique set of decoding parameters. The decoding parameters may include a set of rules how to perform demodulation and decoding, e.g. how to make symbol decisions under the influence of various types of noise in the received messages. With ML models, the decoding parameters may be implemented by layers of the ML model, each layer having a certain architecture and weights or functions that define how the layer processes its input(s) and converts the input(s) to its output(s). The reconfigurability is then in the reconfiguration of one or more layers and associated functions and/or weights.

In an embodiment, block 400 comprises the access node transferring the target error coding rate and the mapping function per MCS to the terminal device. The terminal device may then store this information and provide the records 220, 222 of Figure 2. The mapping function and/or the target decoding error rate may be location-dependent because a location with respect to the access node has correlation with channel conditions. Therefore, the location of the terminal device may be determined in block 400 and mapping functions mapped to the location or area of the terminal device may be loaded into the terminal device for use when carrying out the process of Figure 2 or its embodiments.

In step 404, the messages (e.g. data packets) are transferred from the access node to the terminal device, and the terminal device performs the above-described blocks 202 to 206. Let us now assume that the comparison results in detection of degradation of the decoding performance above the threshold. In response to detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, the terminal device may transmit to the access node a message indicating the degradation in the decoding performance (step 406). The access node may then evaluate the need to change the ML model in block 408. For example, the access node may select a method for updating the ML model amongst a plurality of different options. Some of the options are described in connection with Figures 4 to 7. Let us in this case assume that the access node 104 determines to instruct the terminal device to update to a new ML model for the MCS. The instructions to update the ML model may be transmitted to the terminal device in step 410 and, upon receiving the instruction in step 410, the terminal device may update the decoding parameters and implement the new ML model for the MCS. Figures 5-7 illustrate various embodiments of steps 408 and 410.

In an embodiment, the terminal device reports the difference between the decoding performances (e.g. the SINR gap) regularly to the access node, e.g. even in a situation where the difference is below the threshold.

Figure 5 illustrates an embodiment that may comprise the same steps as Figure 4 until step 406. Upon receiving the indication of the degraded decoding performance of the terminal device in step 406, the access node selects in this embodiment a retraining option for the ML model. The access node may then send to the terminal device an instruction to retrain the ML model and, thus update the decoding parameters to implement a new, retrained ML model for the MCS (step 500). The access node may then send a special set of (demodulation) reference symbols in step 502 to enable efficient retraining in the terminal device. As known in the art, the reference symbols can be used for retraining because they contain symbols having a waveform known to the terminal device. The terminal device may then use the training symbols to find out (train) the decoding parameters that would convert the received reference symbols corrupted by noise in the channel into the known output. The retraining on the basis of the special set of reference symbols is performed in block 504 by the terminal device. The actual retraining may be made according to the state of the art retraining principles, and detailed description is now omitted. In this manner, the terminal device may update the ML model. This procedure may be used to adapt the decoding parameters to the prevailing channel conditions. The terminal device may be, for example, under influence of interference that is has not experienced earlier, thus degrading the decoding performance. The retraining may allow the terminal device to learn the decoding parameters applicable to the new channel conditions.

In an embodiment, the terminal device indicates in step 400 its capability of performing the retraining to the access node. In other words, the terminal device may indicate whether or not it is capable of performing the retraining. In a case where there are multiple alternative implementations for the retraining, e.g. the retraining embodiments described herein, the terminal device may indicate its capability for each alternative implementation. Some terminal devices may even lack the capability (hardware or processing power) to perform the retraining at all. The access node may use the information in block 408, e.g. decide whether to proceed with the retraining according to Figure 5 or to use an alternative solution, e.g. the embodiment of Figure 4 or 7.

In an embodiment of Figure 5, the access node may request the terminal device to transmit the new, updated ML model to the access node (step 506). The purpose may be to add the new ML model to a pool of ML models stored in the access node. The use of such a pool is described in greater detail below. Upon receiving the request in step 506, the terminal device may send the decoding parameters of the new ML model to the access node in step 508, and the access node may store the new ML model for later use in block 510.

Figure 6 illustrates an embodiment that is similar to the embodiment of Figure 5 except that the retraining is performed in the access node 104. The access node has greater computational resources than the terminal device and, thus, the access node may be capable of running a more complex retraining algorithm. Upon selecting the retraining as the option in block 600, the access node may carry out transfer of downlink (data) messages to the terminal device in a conventional manner while the access node performs the retraining (block 604) on the basis of reference signals received from the terminal device in step 602. Upon computing the new decoding parameters and the associated new ML model for the MCS in block 604, the access node may transmit the decoding parameters of the new ML model to the terminal device 100 in step 606. The terminal device may then update the decoding parameters and use them to decode further messages received from the access node (block 208). The embodiment of Figure 6 thus exploits the reciprocal nature of the radio channel, e.g. in time-domain duplexing (TDD) systems. Some frequency-domain duplexing (FDD) systems may also have reciprocal or quasi-reciprocal radio channel, and the procedure of Figure 6 may be applied to such systems as well.

In an embodiment that is a hybrid of the embodiments of Figures 5 and 6, the retraining is split between the terminal device and the access node. The split may be understood such that the terminal device may perform coarse retraining of the decoding parameters with its more limited processing capacity and, then, transfer the decoding parameters to the access node for further retraining. An alternative solution would be to configure the terminal device to retrain one subset of layers of the ML model, while the access node retrains another, different subset of the layers of the ML model. As known in the art, a neural network for example is formed by a set of interconnected layers. Similarly, a layer in a deep learning model is a structure or network topology in the ML model. A layer takes information from one or more previous layers and then pass information to the next layer. Layers in the deep learning convolutional network are called a convolutional layer and a maximum pooling layer that are listed here as examples of various possible layers. Similar layered structures can be found in other ML topologies. The access node may then continue the retraining of the ML model by using a greater number of reference symbols and/or a more complex retraining algorithm, thus providing a more refined version of the decoding parameters for the new ML model. The new ML model may then be transferred to the terminal device according to Figure 6.

Yet another hybrid of the embodiments of Figures 5 and 6 is that the access node transmits the special demodulation reference symbol, DM RS sequence(s) to the terminal device, as described in step 502, and the terminal device then transmits measurement data measured on the DM RS sequence(s) to the access node. The access node may then carry out the retraining according to block 604 and transfer the new ML model to the terminal device in step 606.

Figure 7 illustrates an embodiment where the access node selects a new ML model for the MCS (block 700). Let us remind that the access node is readily aware of the currently applied MCS because it transmits the messages with the determined MCS. The access node may store several ML models per MCS and select one of the ML models that have not yet been provided to the terminal device, e.g. in block 400. The access node may then transmit decoding parameters of the new ML model to the terminal device in step 702, together with an instruction to apply the decoding parameters of the new ML model. Upon receiving, from the access node in step 702 as a response to the message transmitted in step 406, the instruction to update the machine learning model for the determined modulation and coding scheme, the terminal device may carry out block 208 and apply the at least one of the decoding parameters of the new ML model.

With respect to a case where the terminal device reports its incapability for the retraining, e.g. in block 400 or in another step, the access node may disable the embodiments using the retraining in the terminal device. Instead, the access node may select an embodiment where the access node performs the retraining (Figure 6) or an embodiment where the access node provides the terminal device with the new ML model for the MCS (Figure 7).

The embodiments of Figures 4 to 7 may comprise the access node 104 gathering a pool of ML models per each MCS by carrying out training in connection with various terminal devices with which the access node operates the RRC connections. The terminal devices reside under various different channel conditions, and the access node may then acquire numerous (e.g. dozens or more) different ML models for the various channel conditions. The access node may thus store almost an infinite pool of ML models per MCS to be used as a reserve for the situation where the degradation in the decoding performance occurs. However, the threshold may be set to such a high level that the terminal device would not constantly trigger the change of the ML model. Accordingly, unnecessary signalling may be reduced.

Step 406 may comprise the terminal device simply indicating the degraded decoding performance as an indicator (e.g. one bit or a flag). In another embodiment, the terminal device also transmits a metric indicating the degree of degradation, e.g. the SINR gap or another metric indicating the difference to the target decoding performance metric. The access node may then use the available information when making the decision, e.g. which one of the options of Figures 4 to 7 to select. For example, if the difference is below a first threshold, the access node may select the retraining by the terminal device. If the difference is above the first threshold, the access node may select the retraining according to the hybrid embodiment or retraining according to Figure 6 to exploit the greater capacity of the access node. If the difference is above another threshold, the access node may select a new ML model according to Figure 7.

As described above, the reconfigurable decoding parameters may be based on machine learning principles, and the reconfiguration may be carried out by changing to another readily available ML model with respective (different) decoding parameters, or by retraining a new ML model or an existing ML model to adopt new decoding parameters better suited to the prevailing channel conditions. Yet another option is to disable the machine learning and to revert to 'default' decoding parameters that do not employ the machine learning. Accordingly, in an embodiment of Figure 4 the access node may instruct in step 410 to disable the machine learning with respect to the demodulation and decoding and to employ decoding parameters that are not based on the machine learning. Such decoding parameters can be understood as default parameters in a sense that they are substantially static decoding parameters.

Sometimes, a situation may occur where the difference between the current decoding performance and the target decoding performance is negative, meaning that the ML model performs better than what is the target. Figures 8 and 9 illustrate such an embodiment. The reason may be that the ML model performs under certain channel conditions better than what was expected. Accordingly, the target decoding performance may be adjusted to the current decoding performance, e.g. the target decoding error rate may be replaced by the current decoding error rate. Figure 8 illustrates a process for adjusting the target decoding performance, while Figure 9 illustrates the situation that may occur. The dashed line representing the current decoding performance for the MCS1 indicates that the same decoding performance can be acquired with a lower channel quality (SINR), thus providing performance better than the target performance. Referring to Figures 8 and 9, upon performing blocks 200 to 204 and discovering in the comparison of decoding performances (block 800) that the difference (e.g. the SINR gap) is negative, the terminal device may perform block 802 where the mapping function and/or the target decoding error rate is adjusted. A simple solution would be to store the current decoding error rate as the new target decoding error rate and to maintain the mapping function. In an alternative solution, also the mapping function may be updated. This substantially equals to shifting the mapping function so that it intersects with the current decoding error rate. In such a case, the terminal device may also transmit the new mapping function and the target decoding error rate to the access node. In an embodiment, the terminal device may cause switching to a higher order MCS (more bits per symbol) upon detecting decoding performance that exceeds the target level set by the target decoding error rate. The terminal device may report to the access node performance exceeding the target level, and the access node may determine and potentially reconfigure the higher order MCS.

As described above, the terminal device may readily store multiple ML models per MCS. The same ML model may be applied to multiple MCSs, or a dedicated (unique) ML model may be associated with each MCS. Before indicating the degraded decoding performance to the access node, the terminal device may browse through the other available ML models in an attempt to find the ML model with decoding parameters that would bring the decoding performance closer to the target decoding performance such that the difference would fall below the threshold. Figure 10 illustrates a procedure for such an embodiment of Figure 2. Referring to Figure 10, the terminal device may perform the blocks 200 to 206 in the above-described manner. Upon determining in block 206 that the difference between the decoding performances is above the threshold, the process may proceed to block 1000 where it is determined whether or not there is another ML model available for the MCS that has not yet been tried. If no such ML model is available, the terminal device may proceed to block 1002 to inform the access node of the degraded decoding performance. In case there is another ML model for the MCS available, the process proceeds to block 1004 where one of the available ML models is selected and, then, the process may return to block 200 to decode further messages by using the decoding parameters of the newly selected ML model. In an embodiment, the terminal device may buffer the received messages and, upon performing block 206, 1000, and 1004, the same messages may be decoded again with the newly selected ML model. In this manner, it can be evaluated whether or not the newly selected ML model improves the decoding performance. The iterations via block 1000 may be carried out until a ML model with acceptable decoding performance is found or until all the ML models available for the MCS have been tried.

As described above, the comparison and the selection of the new ML model for the MCS may be carried out under the condition where the computed decoding error rate or the channel quality is within a decoding error rate range or a channel quality range that allows maintaining the determined modulation and coding scheme. In other words, another mechanism for adapting the MCS to the channel quality or decoding performance may run in parallel with the embodiments described herein.

In an embodiment, the terminal device employs a semi-static reporting scheme for transmitting the difference(s) computed in block(s) 204. The semi-static reporting may employ a scheduled semi-static uplink resource for transmitting the difference. The difference can be reported as a (quantized) numerical value indicating explicitly a degree of the difference. Alternatively, the difference may be reported as a flag indicating, for example, whether or not the difference is above or below the threshold. The meaning of semi-static may be understood such that the scheduled resource is persistent such that it is periodic or in another manner regular and need not to be scheduled separately for every transmission. The terminal device may report the difference irrespective of whether the difference is above or below the threshold. In other words, one transmission may indicate to the access node that the difference above the threshold, as described above, while another transmission may indicate to the access node that the difference is below the threshold. The access node may then monitor the trend of the reported difference and, in some embodiments, react before the difference reaches or exceeds the threshold. The access node may trigger, for example, the retraining or update of the ML model even before the difference exceeds the threshold.

The embodiment where the terminal device reports the difference regularly to the access node enables the access node to carry out block 206 for the terminal device, i.e. the decision of whether or not to update the decoding parameters in an attempt to improve the decoding performance of the terminal device. Figure 11 illustrates such an embodiment for the access node. Referring to Figure 11, the following steps may be carried out by an apparatus for the access node: storing (220), for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality; transmitting (block 1100) at least one message to a terminal device, the at least one message associated with a determined modulation and coding scheme; determining (block 1102) a channel quality metric associated with the at least one message; determining (block 1104) a difference between a first decoding performance of the terminal device and a second decoding performance of the terminal device, wherein the first decoding performance is at least partly based on the measured channel quality metric and a decoding error rate of the at least one message, wherein the second decoding performance represents the target decoding error rate, and wherein the difference is based on using the mapping function to bring the target decoding error rate and the decoding error rate of the at least one message comparable; in response to detecting (in block 206) that the difference between the first decoding performance and the second decoding performance is above a threshold, transmitting (block 1106) to the terminal device a command to change at least one of reconfigurable decoding parameters of the terminal device for the determined modulation and coding scheme and to apply thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

As described above, the access node may receive the difference from the terminal device as a part of the semi-static reporting.

In an embodiment, the terminal device measures the channel quality metric and transmits the channel quality metric to the access node to be received in block 1102. The channel quality metric may be any one of the above-described metrics. In an embodiment, the channel quality metric is the same used for providing channel quality information (CQI) or, equivalently, channel state information (CSI). Accordingly, the same channel quality metric may be used for both making a decision of whether or not to change the MCS for the terminal device and whether or not to change the reconfigurable decoding parameters of the terminal device.

In an embodiment, the demodulation and decoding described above is carried out without using demodulation reference symbols. At best, the ML models learn the characteristics of the channel without the help of the demodulation reference symbols, thus enabling significant reduction in signalling overhead.

Figure 12 illustrates an apparatus comprising a processing circuitry, such as at least one processor, and at least one memory 20 including a computer program code (software) 24, wherein the at least one memory and the computer program code (software) are configured, with the at least one processor, to cause the apparatus to carry out the process of Figure 2 or any one of its embodiments described above. The apparatus may be for the terminal device. The apparatus may be a circuitry or an electronic device realizing some embodiments of the invention in the respective device. The apparatus carrying out the above-described functionalities may thus be comprised in such a device, e.g. the apparatus may comprise a circuitry such as a chip, a chipset, a processor, a micro controller, or a combination of such circuitries for the respective device. The at least one processor or a processing circuitry may realize a communication controller 10 controlling radio communications with the cellular network infrastructure and/or with other terminal devices or peer devices of the terminal device. The communication controller may be configured to establish and manage radio connections and reception of data over the radio connections, including reception of data modulated according to various modulation and coding schemes, as described above.

The communication controller may comprise a radio resource control (RRC) controller 12 configured to manage RRC connections with other radio devices, such as the access node as described above. The features of RRC connections are described in greater detail in 3GPP specifications for LTE and 5G, for example. In other networks, a similar radio controller may be implemented for managing connections with other radio devices.

The communication controller may further comprise a machine learning agent 14 configured to implement the ML functions in the demodulation and decoding, as described above. The ML agent may comprise a demodulator and channel decoder 17 configured to carry out the demodulation and decoding by using retrainable or reconfigurable decoding parameters, as described above. The reconfigurability may be understood to be more than simply adapting to the changing channel conditions. It may mean that the actual mechanism of the demodulation and decoding is changed, e.g. the internal structure of the ML layers is changed to change the internal functions of the demodulator and decoder 17. It means that different ML models provide different outputs for the same input, because of the different internal structures.

The ML agent 14 may further comprise a performance evaluation circuitry 16 configured to compute the decoding performance and the difference between the current and target decoding performance according to any one of the above-described embodiments. The performance evaluation circuitry 16 may use the measured channel quality as an input to the performance evaluation, as described above. The ML agent may further comprise a ML model selection circuitry 15 configured to select a new ML model upon detecting the difference in the decoding performance with respect to the target decoding performance being above the threshold. The ML selection may be carried out according to any one of the above-described embodiments of Figures 4-7 or 10.

The memory 20 may be implemented using any suitable data storage technology, such as semiconductor-based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The memory 20 may comprise a database 26 storing the decoding parameters for the various ML models for different MCSs, for example. The memory 20 may further store a data buffer 28 for the received messages.

The apparatus may further comprise a communication interface 22 comprising hardware and/or software for providing the apparatus with radio communication capability with one or more access nodes, as described above. The communication interface 22 may include, for example, an antenna, one or more radio frequency filters, a power amplifier, and one or more frequency converters. The communication interface 22 may comprise hardware and software needed for realizing the radio communications over the radio interface, e.g. according to specifications of an LTE or 5G radio interface.

The apparatus of Figure 12 may further comprise an application processor operating as a source or a sink for application data to be communicated, e.g. application data contained in the received messages. The application data may relate to a primary purpose of an apparatus comprising the transmitter. Such an apparatus may be a mobile phone, a tablet computer, a smart watch, or another personal communication device, or it may be a sensor device or another industrial device with cellular communication capability. Accordingly, the application data may comprise various data. In a case of the apparatus being comprised in the access node, the application processor may be omitted.

Figure 13 illustrates an apparatus comprising a processing circuitry, such as at least one processor, and at least one memory 60 including a computer program code (software) 64, wherein the at least one memory and the computer program code (software) are configured, with the at least one processor, to cause the apparatus to carry out the process of Figure 11 or any one of its embodiments described above. The apparatus may be for the access node. The apparatus may be a circuitry or an electronic device realizing some embodiments of the invention in the access node. The apparatus carrying out the above-described functionalities may thus be comprised in such a device, e.g. the apparatus may comprise a circuitry such as a chip, a chipset, a processor, a micro controller, or a combination of such circuitries for the access node. The at least one processor or a processing circuitry may realize a communication controller 50 controlling radio communications with terminal devices served by the access node and with other network nodes of the cellular network infrastructure. The communication controller may be configured to establish and manage radio connections and to transmit and receive data over the radio connections, including transmission of data modulated according to various modulation and coding schemes, as described above.

The communication controller may comprise a radio resource control (RRC) controller 52 configured to manage RRC connections with other radio devices, such as the terminal device as described above. The features of RRC connections are described in greater detail in 3GPP specifications for LTE and 5G, for example. In other networks, a similar radio controller may be implemented for managing connections with other radio devices.

The communication controller may further comprise a machine learning agent 54 configured to implement the machine learning functions for the reconfigurable decoding parameters of the terminal device(s) served by the access node, as described above for the terminal device. The ML agent may comprise a performance evaluation circuitry 56 configured to determine the difference between the current and target decoding performance of the terminal device according to any one of the above-described embodiments. The ML agent may further comprise a ML model selection circuitry 55 configured to select a new ML model (new decoding parameters) upon detecting the difference in the decoding performance with respect to the target decoding performance being above the threshold. The ML selection may be carried out according to any one of the above-described embodiments of Figures 4-7, for example.

The memory 60 may be implemented using any suitable data storage technology, such as semiconductor-based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The memory 60 may comprise a database 66 storing the decoding parameters for the various ML models for different MCSs, for example. The memory 20 may further store a data buffer 68 for data to be added to the messages transmitted to the terminal device(s).

The apparatus may further comprise a communication interface 62 comprising hardware and/or software for providing the apparatus with radio communication capability with one or more terminal devices and optionally with other access nodes, as described above. The communication interface 62 may include, for example, an antenna, one or more radio frequency filters, a power amplifier, and one or more frequency converters. The communication interface 62 may comprise hardware and software needed for realizing the radio communications over the radio interface, e.g. according to specifications of an LTE or 5G radio interface.

As used in this application, the term 'circuitry' refers to all of the following: (a) hardware-only circuit implementations, such as implementations in only analog and/or digital circuitry, and (b) combinations of circuits and software (and/or firmware), such as (as applicable): (i) a combination of processor(s) or (ii) portions of processor(s)/software including digital signal processor(s), software, and memory(ies) that work together to cause an apparatus to perform various functions, and (c) circuits, such as a microprocessor(s) or a portion of a microprocessor(s), that require software or firmware for operation, even if the software or firmware is not physically present.

This definition of 'circuitry' applies to all uses of this term in this application. As a further example, as used in this application, the term 'circuitry' would also cover an implementation of merely a processor (or multiple processors) or a portion of a processor and its (or their) accompanying software and/or firmware. The term ‘circuitry’ would also cover, for example and if applicable to the particular element, a baseband integrated circuit or applications processor integrated circuit for a mobile phone or a similar integrated circuit in a server, a cellular network device, or another network device.

An embodiment provides a computer program embodied on a distribution medium, comprising program instructions which, when loaded into an electronic apparatus, are configured to control the apparatus to execute the embodiments described above.

The computer program may be in source code form, object code form, or in some intermediate form, and it may be stored in some sort of carrier, which may be any entity or device capable of carrying the program. Such carriers include a record medium, computer memory, read-only memory, and a software distribution package, for example. Depending on the processing power needed, the computer program may be executed in a single electronic digital computer or it may be distributed amongst several computers.

The apparatus may also be implemented as one or more integrated circuits, such as application-specific integrated circuits ASIC. Other hardware embodiments are also feasible, such as a circuit built of separate logic components. A hybrid of these different implementations is also feasible. When selecting the method of implementation, a person skilled in the art will consider the requirements set for the size and power consumption of the apparatus, the necessary processing capacity, production costs, and production volumes, for example.

It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

Claims

1. An apparatus comprising means for performing:

storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality;

receiving at least one message from an access node, the at least one message associated with a determined modulation and coding scheme;

decoding the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme;

computing a decoding error rate for the at least one message;

measuring a channel quality metric associated with the at least one message;

comparing, by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate;

in response to detecting, in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

2. The apparatus of claim 1, wherein the decoding error rate is a coded bit error rate, an uncoded bit error rate, or a block error rate.

3. The apparatus of claim 1 or 2, wherein the channel quality metric is a signal-to-interference ratio, signal-to-interference ratio, or a signal-to-noise ratio.

4. The apparatus of any preceding claim, wherein the means are configured to apply the mapping function to the target decoding error rate, to shift thus applied mapping function along a dimension of the channel quality metric such that the mapping function intersects with the computed decoding error rate, and to use a value proportional to said shifting as the difference between the first

decoding performance and the second decoding performance.

5. The apparatus of any preceding claim, wherein the means are configured to apply the mapping function to the target decoding error rate and find, by using the mapping function, a target decoding error rate at the measured channel quality metric to represent the second decoding performance.

6. The apparatus of any preceding claim, wherein the means are configured to:

in response to detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, transmit to the access node a message indicating degradation in the decoding performance;

receive, from the access node as a response to the message, an instruction to update the reconfigurable decoding parameters for at least the determined modulation and coding scheme; and

in response to the instruction, to change the at least one of the reconfigurable decoding parameters.

7. The apparatus of claim 6, wherein the reconfigurable decoding parameters before the change have been trained by using machine learning and wherein the reconfigurable decoding parameters after the change are default decoding parameters not employing the machine learning.

8. The apparatus of claim 6, wherein the instruction indicates new decoding parameters for at least the determined modulation and coding scheme, and wherein the means are configured to perform the changing by adopting the new decoding parameters.

9. The apparatus of claim 7 or 8, wherein the means are configured to indicate, in the message or in another message, to the access node incapability of performing retraining, and to receive instruction in response to the indication of the incapability.

10. The apparatus of claim 8 or 9, wherein the means are configured to transmit to the access node at least one signal for training the new decoding

parameters and to receive the new decoding parameters from the access node.

11. The apparatus of claim 6, wherein the instruction indicates the apparatus to perform retraining of the reconfigurable decoding parameters, and wherein the means are configured, in response to the instruction, to receive a plurality of demodulation reference symbols from the access node, to use the plurality of demodulation reference symbols to learn new decoding parameters adapted to prevailing channel conditions, and to perform said changing by applying the new decoding parameters.

12. The apparatus of claim 11, wherein the means are configured to transmit the new decoding parameters to the access node.

13. The apparatus of any preceding claim, wherein the means are configured to:

in response to said detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, search a memory for new decoding parameters;

upon discovering such new decoding parameters, perform said changing by applying the discovered new decoding parameters; and

upon discovering no such decoding parameters capable of bringing the difference below the threshold under the condition of the channel quality metric, transmit to the access node a message indicating degradation in the decoding performance.

14. The apparatus of any preceding claim, wherein the means are configured to carry out the comparison under the condition where the computed decoding error rate is within a decoding error rate range that allows maintaining the determined modulation and coding scheme.

15. The apparatus of any preceding claim, wherein the means are configured to configure a semi-static reporting scheme and to transmit the difference between the first decoding performance and the second decoding performance to the access node within the semi-static reporting scheme.

16. The apparatus of any preceding claim, wherein the means are configured to receive the threshold from the access node.

17. An apparatus comprising means for performing:

storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality;

transmitting at least one message to a terminal device, the at least one message associated with a determined modulation and coding scheme;

determining a channel quality metric associated with the at least one message;

determining a difference between a first decoding performance of the terminal device and a second decoding performance of the terminal device, wherein the first decoding performance is at least partly based on the measured channel quality metric and a decoding error rate of the at least one message, wherein the second decoding performance represents the target decoding error rate, and wherein the difference is based on using the mapping function to bring the target decoding error rate and the decoding error rate of the at least one message comparable;

in response to detecting that the difference between the first decoding performance and the second decoding performance is above a threshold, transmitting to the terminal device a command to change at least one of reconfigurable decoding parameters of the terminal device for the determined modulation and coding scheme and to apply thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

18. The apparatus of claim 17, wherein the means are configured to receive the difference from the terminal device.

19. The apparatus of any preceding claim, wherein the means comprises at least one processor and at least one memory including computer program code, wherein the at least one memory and computer program code configured to, with the at least one processor, cause the performance of the apparatus.

20. A method comprising:

storing, in a memory of an apparatus for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality;

receiving, by the apparatus, at least one message from an access node, the at least one message associated with a determined modulation and coding scheme;

decoding, by the apparatus, the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme;

computing, by the apparatus, a decoding error rate for the at least one message;

measuring, by the apparatus, a channel quality metric associated with the at least one message;

comparing, by the apparatus by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate;

in response to detecting, by the apparatus in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

21. The method of claim 20, wherein the decoding error rate is a coded bit error rate, an uncoded bit error rate, or a block error rate.

22. The method of claim 20 or 21, wherein the channel quality metric is a signal-to-interference ratio, signal-to-interference ratio, or a signal-to-noise ratio.

23. The method of any preceding claim 20 to 22, wherein the apparatus applies the mapping function to the target decoding error rate, shifts thus applied mapping function along a dimension of the channel quality metric such that the mapping function intersects with the computed decoding error rate, and uses a value proportional to said shifting as the difference between the first decoding performance and the second decoding performance.

24. The method of any preceding claim 20 to 23, wherein the apparatus applies the mapping function to the target decoding error rate and finds, by using the mapping function, a target decoding error rate at the measured channel quality metric to represent the second decoding performance.

25. The method of any preceding claim 20 to 24, wherein the method further comprises by the apparatus:

in response to detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, transmitting to the access node a message indicating degradation in the decoding performance;

receiving, from the access node as a response to the message, an instruction to update the reconfigurable decoding parameters for at least the determined modulation and coding scheme; and

in response to the instruction, changing the at least one of the reconfigurable decoding parameters.

26. The apparatus of claim 25, wherein the reconfigurable decoding parameters before the change have been trained by using machine learning and wherein the reconfigurable decoding parameters after the change are default decoding parameters not employing the machine learning.

27. The method of claim 25, wherein the instruction indicates new decoding parameters for at least the determined modulation and coding scheme, and wherein the apparatus performs the changing by adopting the new decoding parameters.

28. The method of claim 27, wherein the apparatus indicates, in the message or in another message, to the access node incapability of performing retraining, and receives the instruction in response to the indication of the incapability.

29. The method of claim 27 or 28, wherein the apparatus transmits to the access node at least one signal for training the new decoding parameters and receives the new decoding parameters from the access node.

30. The method of claim 25, wherein the instruction indicates the apparatus to perform retraining of the reconfigurable decoding parameters, and wherein the apparatus receives, in response to the instruction, a plurality of demodulation reference symbols from the access node, uses the plurality of demodulation reference symbols to learn new decoding parameters adapted to prevailing channel conditions, and performs said changing by applying the new decoding parameters.

31. The method of claim 30, wherein the apparatus transmits the new decoding parameters to the access node.

32. The method of any preceding claim 20 to 31, further comprising by the apparatus:

in response to said detecting that the difference between the first decoding performance and the second decoding performance is above the threshold, searching a memory for new decoding parameters;

upon discovering such new decoding parameters, performing said changing by applying the discovered new decoding parameters; and

upon discovering no such decoding parameters capable of bringing the difference below the threshold under the condition of the channel quality metric, transmitting to the access node a message indicating degradation in the decoding performance.

33. The method of any preceding claim 20 to 32, wherein the apparatus carries out the comparison under the condition where the computed decoding error rate is within a decoding error rate range that allows maintaining the determined modulation and coding scheme.

34. The method of any preceding claim 20 to 33, wherein the apparatus configures a semi-static reporting scheme and transmits the difference between the first decoding performance and the second decoding performance to the access node within the semi-static reporting scheme.

35. The method of any preceding claim 20 to 34, wherein the apparatus receives the threshold from the access node.

36. A method comprising:

storing, in an apparatus for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality;

transmitting, by the apparatus, at least one message to a terminal device, the at least one message associated with a determined modulation and coding scheme;

determining, by the apparatus, a channel quality metric associated with the at least one message;

determining, by the apparatus, a difference between a first decoding performance of the terminal device and a second decoding performance of the terminal device, wherein the first decoding performance is at least partly based on the measured channel quality metric and a decoding error rate of the at least one message, wherein the second decoding performance represents the target decoding error rate, and wherein the difference is based on using the mapping function to bring the target decoding error rate and the decoding error rate of the at least one message comparable;

in response to detecting, by the apparatus, that the difference between the first decoding performance and the second decoding performance is above a threshold, transmitting to the terminal device a command to change at least one of reconfigurable decoding parameters of the terminal device for the determined modulation and coding scheme and to apply thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

37. The method of claim 36, wherein the difference is received from the terminal device.

38. A computer program product embodied on a computer-readable medium and comprising a computer program code readable by a computer, wherein the computer program code configures the computer to carry out a computer process comprising:

storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality;

receiving at least one message from an access node, the at least one message associated with a determined modulation and coding scheme;

decoding the at least one message by using reconfigurable decoding parameters adapted to the determined modulation and coding scheme;

computing a decoding error rate for the at least one message;

measuring a channel quality metric associated with the at least one message;

comparing, by using the mapping function to bring the target decoding error rate and the computed decoding error rate comparable, a first decoding performance that is at least partly based on the computed decoding error rate and the measured channel quality metric with a second decoding performance representing the target decoding error rate;

in response to detecting, in the comparison, that a difference between the first decoding performance and the second decoding performance is above a threshold, changing at least one of the reconfigurable decoding parameters and applying thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

39. A computer program product embodied on a computer-readable medium and comprising a computer program code readable by a computer, wherein the computer program code configures the computer to carry out a computer process comprising:

storing, for at least one modulation and coding scheme, a target decoding error rate and a mapping function describing dependence of a decoding error rate and channel quality;

transmitting at least one message to a terminal device, the at least one message associated with a determined modulation and coding scheme;

determining a channel quality metric associated with the at least one message;

determining a difference between a first decoding performance of the terminal device and a second decoding performance of the terminal device, wherein the first decoding performance is at least partly based on the measured channel quality metric and a decoding error rate of the at least one message, wherein the second decoding performance represents the target decoding error rate, and wherein the difference is based on using the mapping function to bring the target decoding error rate and the decoding error rate of the at least one message comparable;

in response to detecting that the difference between the first decoding performance and the second decoding performance is above a threshold, transmitting to the terminal device a command to change at least one of reconfigurable decoding parameters of the terminal device for the determined modulation and coding scheme and to apply thus updated decoding parameters to decode further messages associated with the determined modulation and coding scheme.

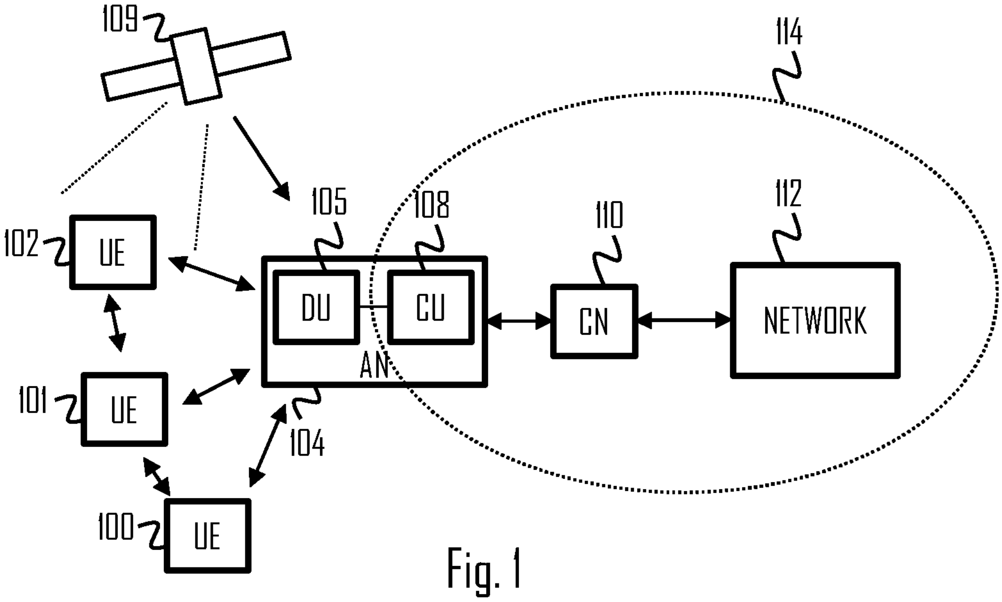
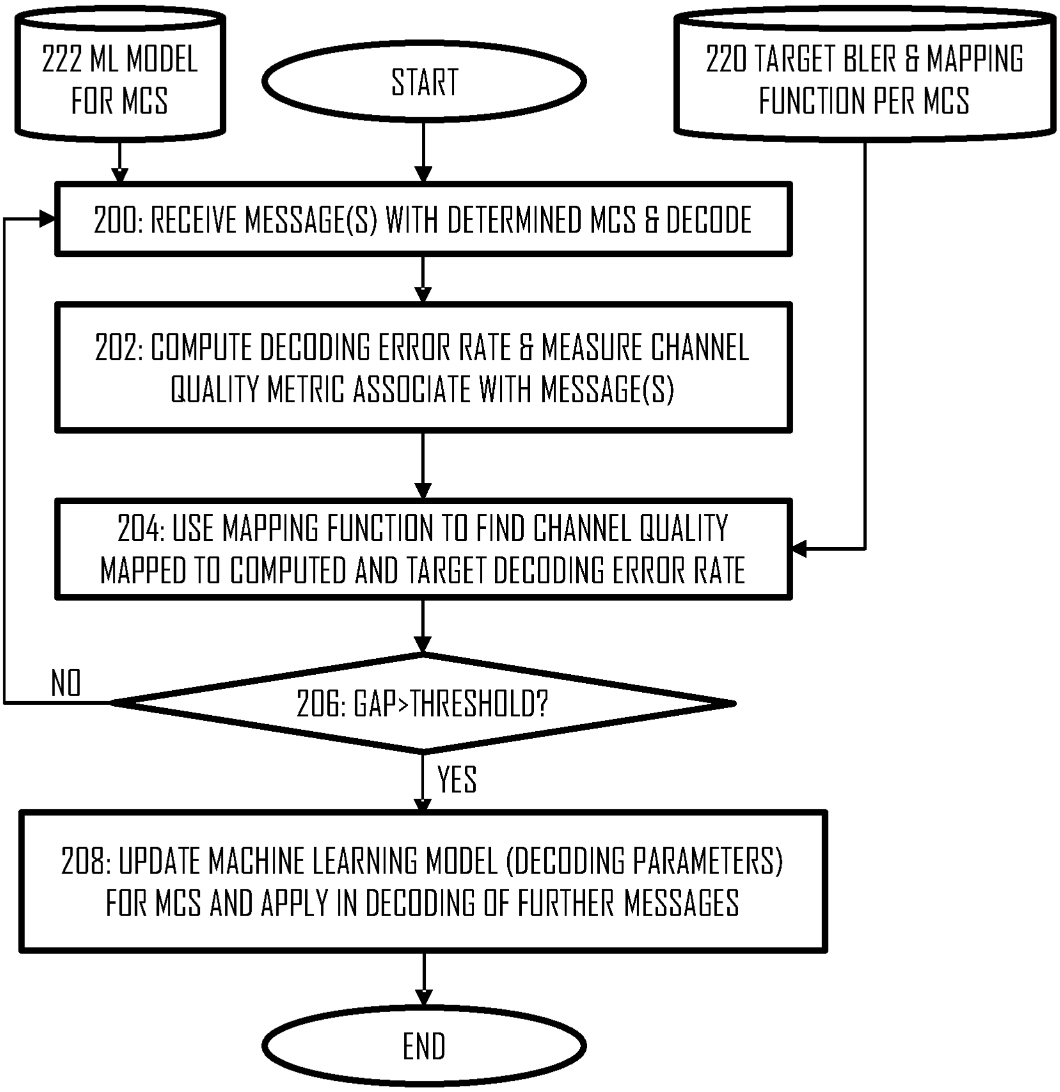

109
114
105
108
110
112
102
UE
DU
CU
CN
NETWORK
AN
101
UE
104
100
UE

Fig. 1



222 ML MODEL FOR MCS
START
220 TARGET BLER & MAPPING FUNCTION PER MCS
200: RECEIVE MESSAGE(S) WITH DETERMINED MCS & DECODE
202: COMPUTE DECODING ERROR RATE & MEASURE CHANNEL QUALITY METRIC ASSOCIATE WITH MESSAGE(S)
204: USE MAPPING FUNCTION TO FIND CHANNEL QUALITY MAPPED TO COMPUTED AND TARGET DECODING ERROR RATE
NO
206: GAP>THRESHOLD?
YES
208: UPDATE MACHINE LEARNING MODEL (DECODING PARAMETERS) FOR MCS AND APPLY IN DECODING OF FURTHER MESSAGES
END

Fig. 2

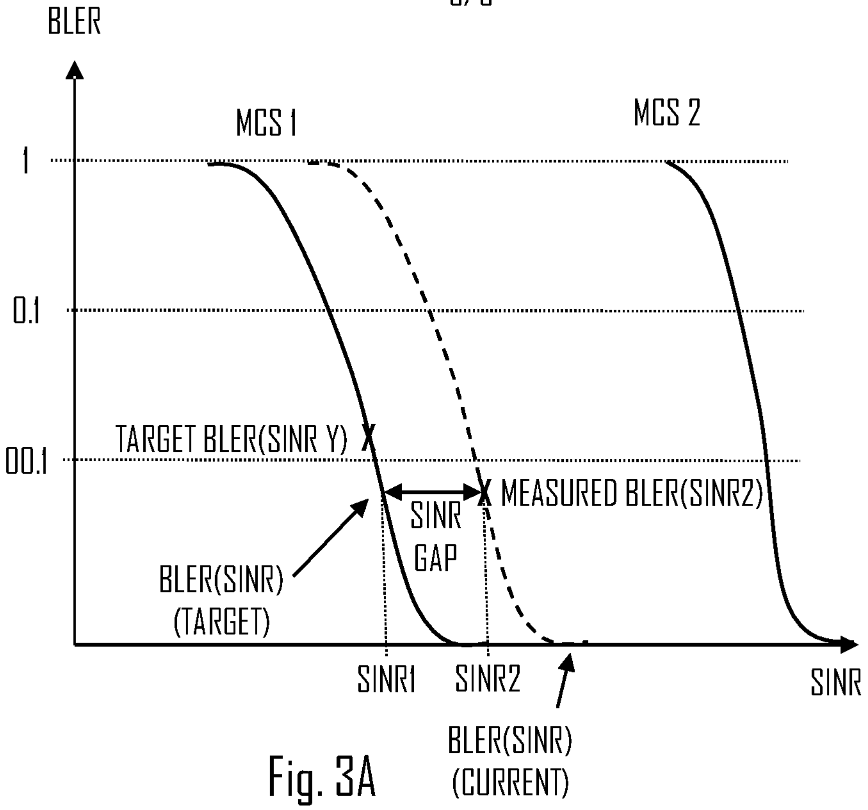

BLER
MCS 1
MCS 2
1
0.1
00.1
TARGET BLER(SINR Y)
MEASURED BLER(SINR2)
SINR
GAP
BLER(SINR)
(TARGET)
SINR1
SINR2
SINR
BLER(SINR)
(CURRENT)

Fig. 3A

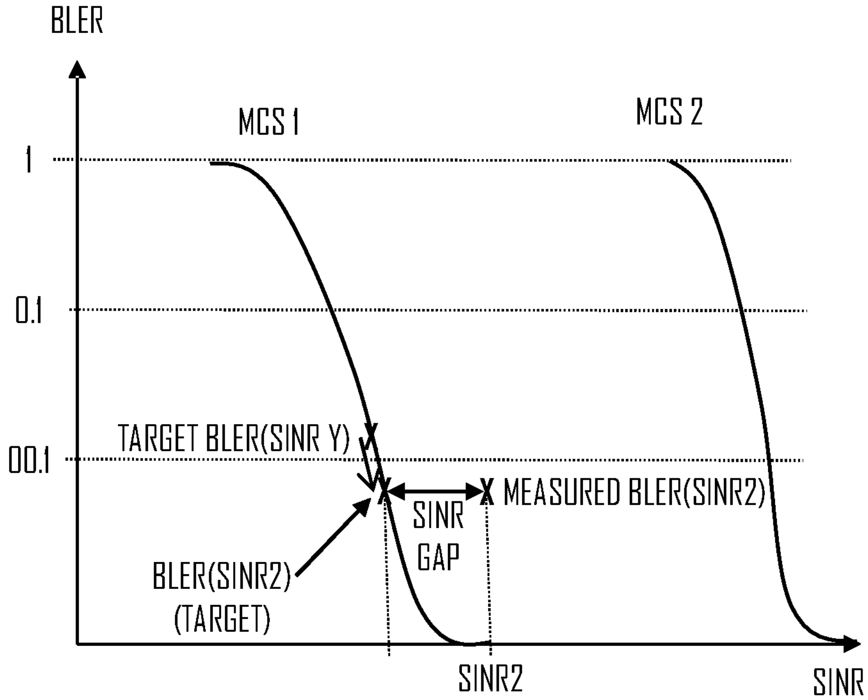

BLER
MCS 1
MCS 2
1
0.1
00.1
TARGET BLER(SINR Y)
MEASURED BLER(SINR2)
SINR
GAP
BLER(SINR2)
(TARGET)
SINR2
SINR

Fig. 3B

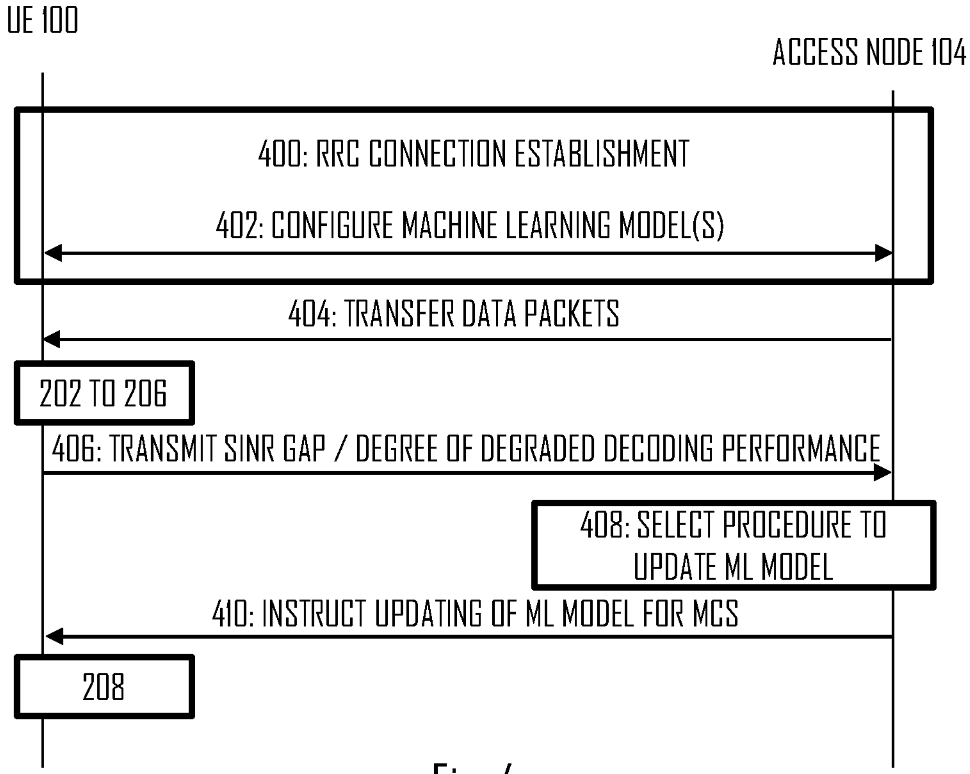

UE 100
ACCESS NODE 104
400: RRC CONNECTION ESTABLISHMENT
402: CONFIGURE MACHINE LEARNING MODEL(S)
404: TRANSFER DATA PACKETS
202 TO 206
406: TRANSMIT SINR GAP / DEGREE OF DEGRADED DECODING PERFORMANCE
408: SELECT PROCEDURE TO UPDATE ML MODEL
410: INSTRUCT UPDATING OF ML MODEL FOR MCS
208

Fig. 4

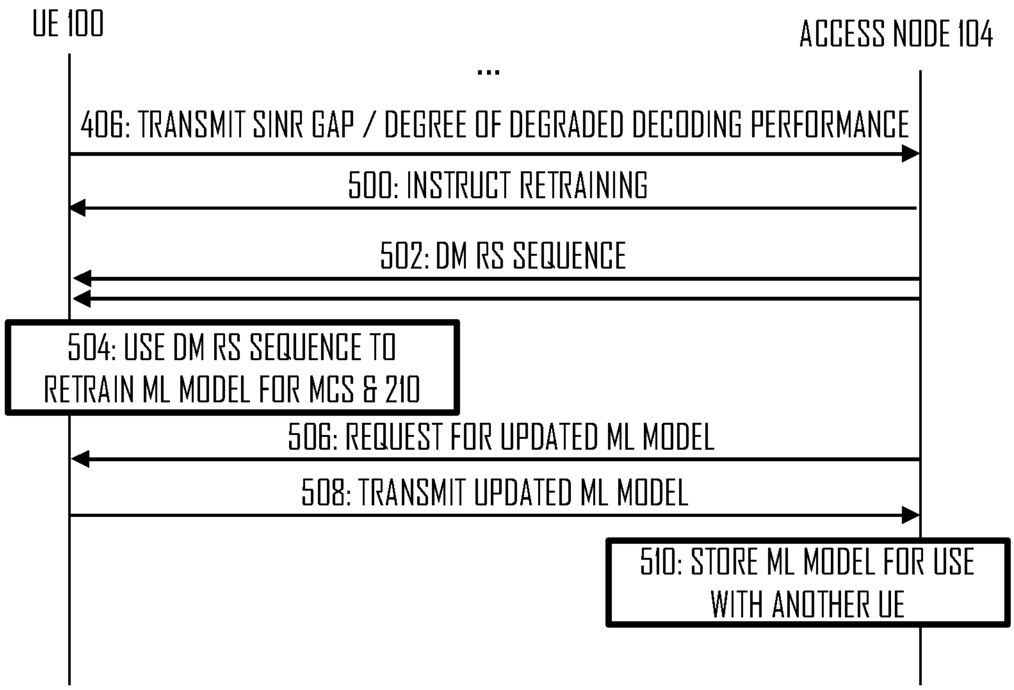

UE 100
ACCESS NODE 104
...
406: TRANSMIT SINR GAP / DEGREE OF DEGRADED DECODING PERFORMANCE
500: INSTRUCT RETRAINING
502: DM RS SEQUENCE
504: USE DM RS SEQUENCE TO RETRAIN ML MODEL FOR MCS & 210
506: REQUEST FOR UPDATED ML MODEL
508: TRANSMIT UPDATED ML MODEL
510: STORE ML MODEL FOR USE WITH ANOTHER UE

Fig. 5

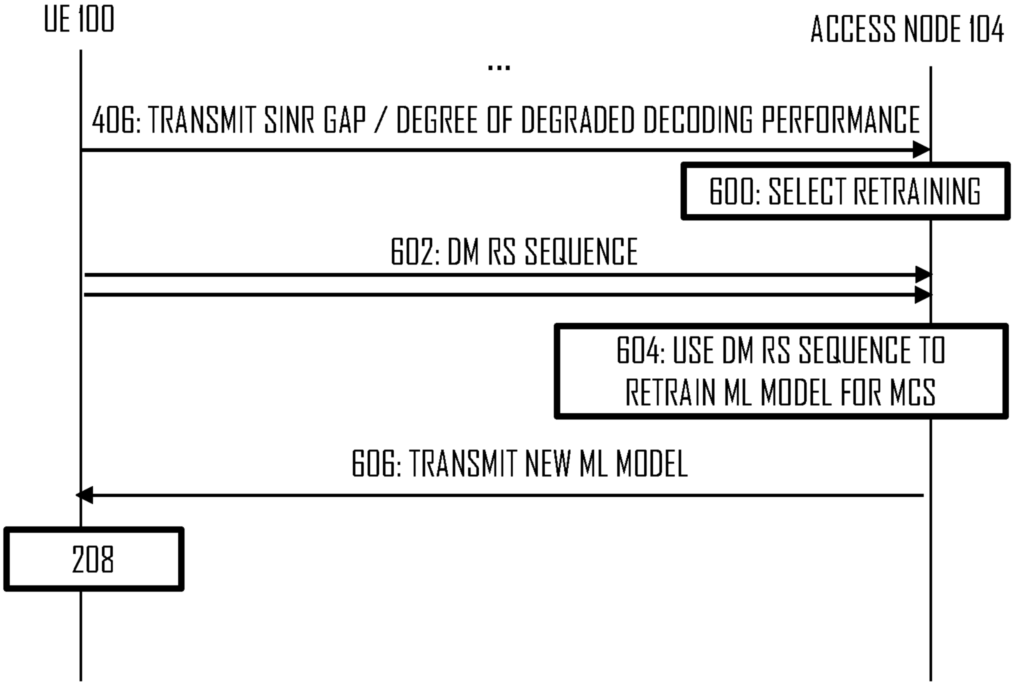

UE 100
ACCESS NODE 104
...
406: TRANSMIT SINR GAP / DEGREE OF DEGRADED DECODING PERFORMANCE
600: SELECT RETRAINING
602: DM RS SEQUENCE
604: USE DM RS SEQUENCE TO RETRAIN ML MODEL FOR MCS
606: TRANSMIT NEW ML MODEL
208

Fig. 6


UE 100
ACCESS NODE 104
...
406: TRANSMIT SINR GAP / DEGREE OF DEGRADED DECODING PERFORMANCE
700: SELECT NEW ML MODEL
702: TRANSMIT NEW ML MODEL
208

Fig. 7

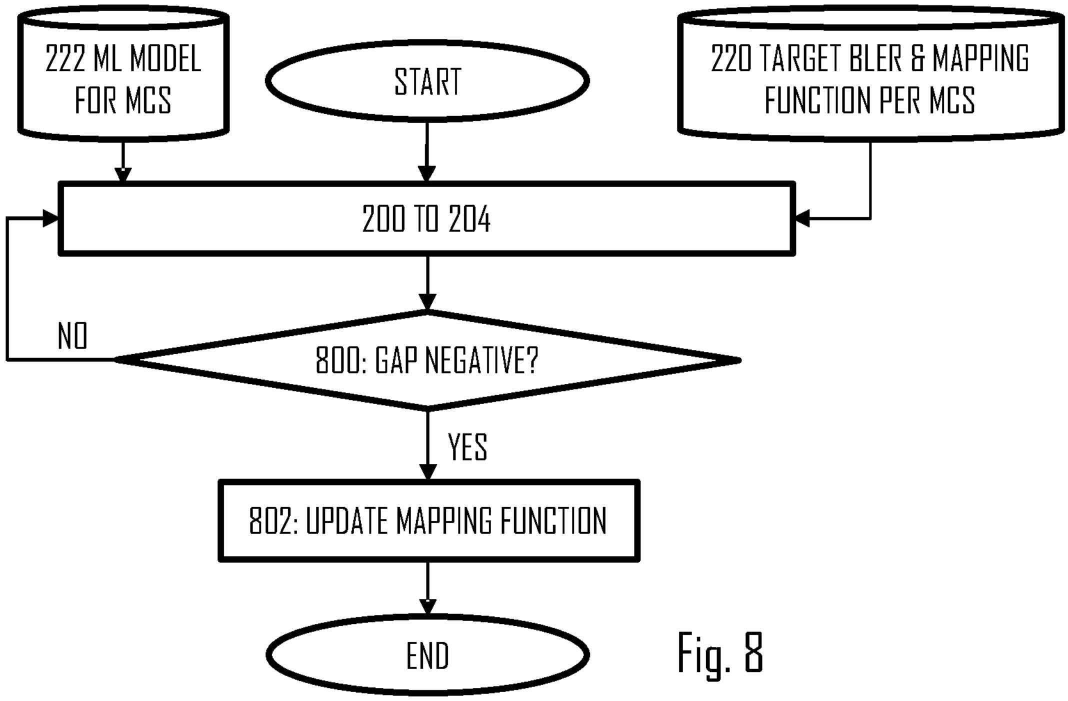

222 ML MODEL FOR MCS
START
220 TARGET BLER & MAPPING FUNCTION PER MCS
200 TO 204
NO
800: GAP NEGATIVE?
YES
802: UPDATE MAPPING FUNCTION
END

Fig. 8

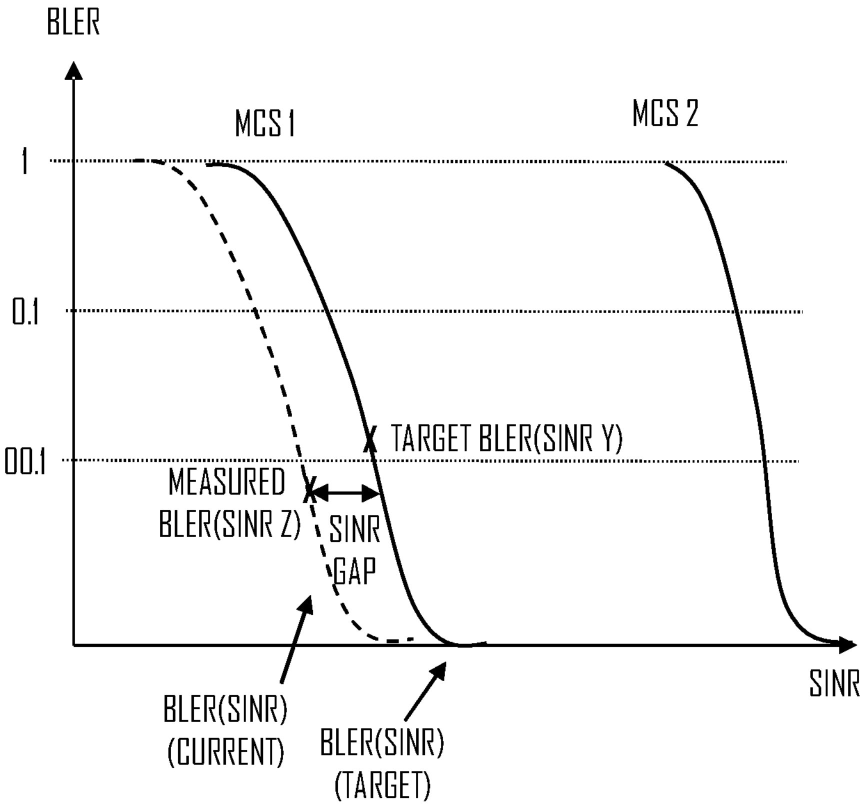

BLER
MCS 1
MCS 2
1
0.1
00.1
TARGET BLER(SINR Y)
MEASURED BLER(SINR Z)
SINR GAP
BLER(SINR) (CURRENT)
BLER(SINR) (TARGET)
SINR

Fig. 9

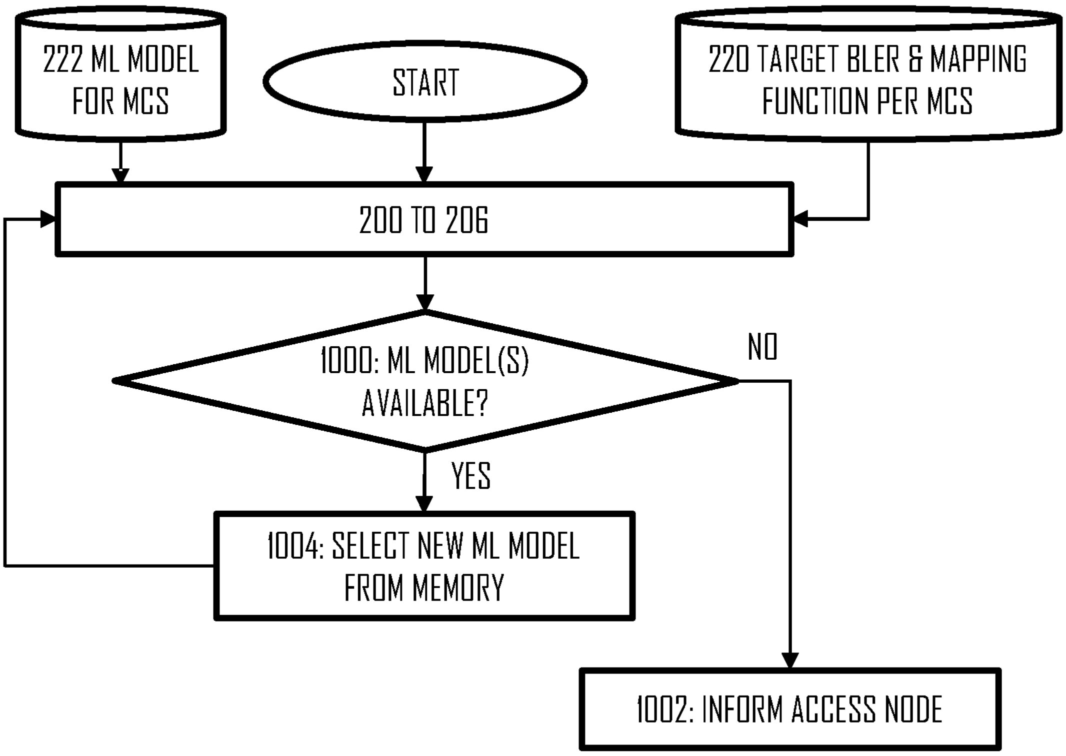

222 ML MODEL FOR MCS
START
220 TARGET BLER & MAPPING FUNCTION PER MCS
200 TO 206
1000: ML MODEL(S) AVAILABLE?
NO
YES
1004: SELECT NEW ML MODEL FROM MEMORY
1002: INFORM ACCESS NODE

Fig. 10

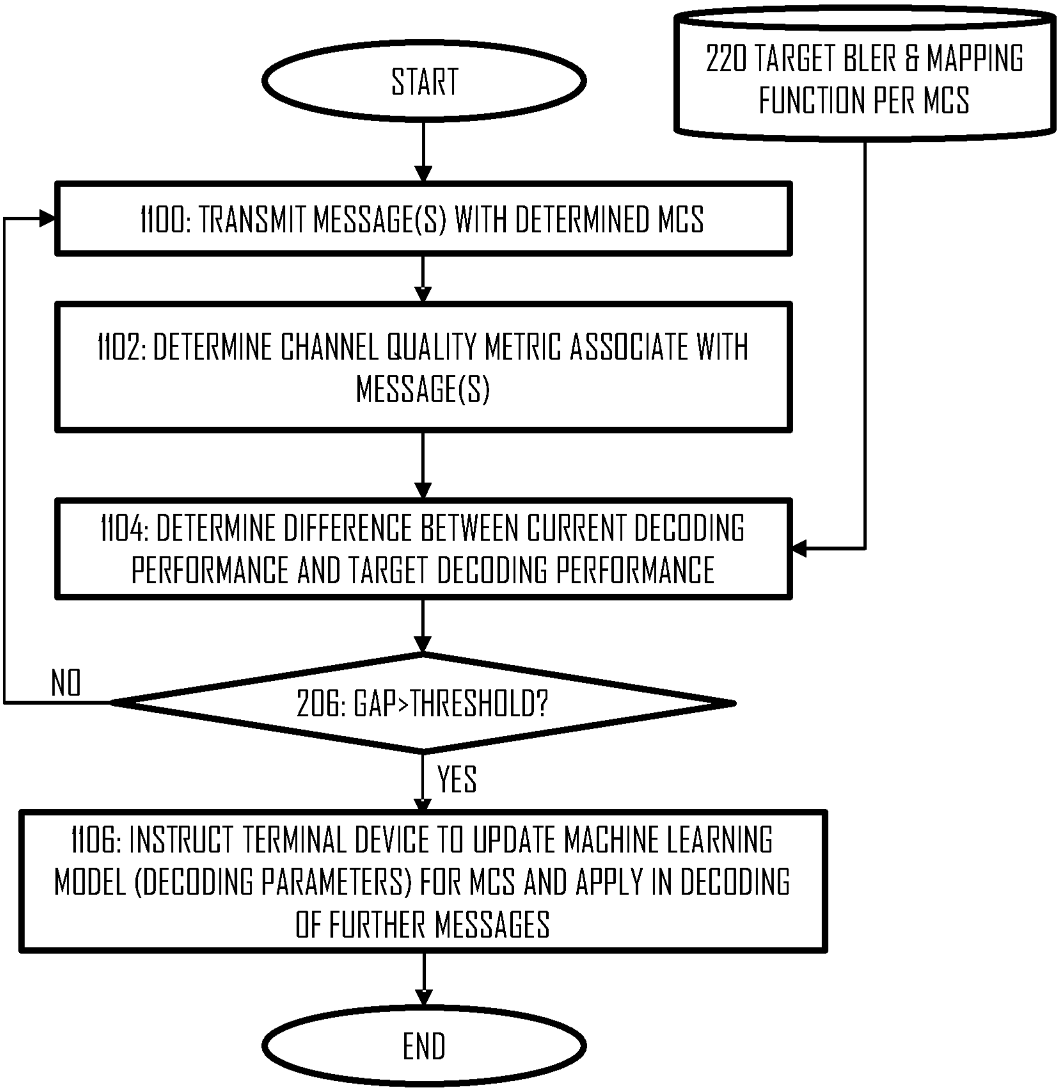

START
220 TARGET BLER & MAPPING FUNCTION PER MCS
1100: TRANSMIT MESSAGE(S) WITH DETERMINED MCS
1102: DETERMINE CHANNEL QUALITY METRIC ASSOCIATE WITH MESSAGE(S)
1104: DETERMINE DIFFERENCE BETWEEN CURRENT DECODING PERFORMANCE AND TARGET DECODING PERFORMANCE
NO
206: GAP>THRESHOLD?
YES
1106: INSTRUCT TERMINAL DEVICE TO UPDATE MACHINE LEARNING MODEL (DECODING PARAMETERS) FOR MCS AND APPLY IN DECODING OF FURTHER MESSAGES
END

Fig. 11

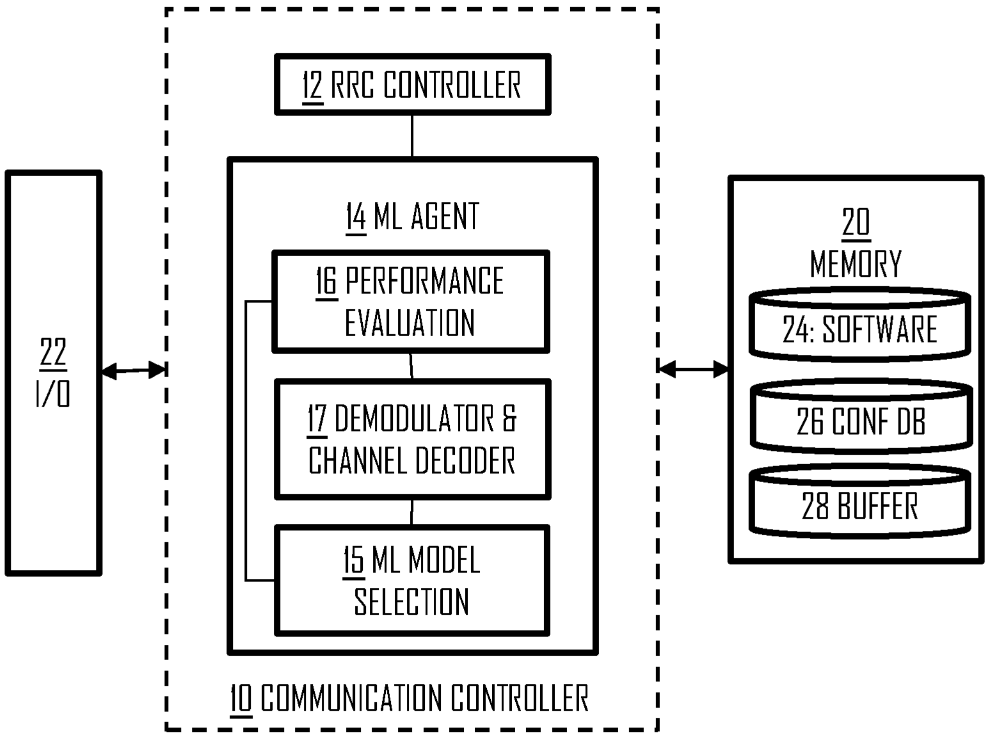

12 RRC CONTROLLER
14 ML AGENT
16 PERFORMANCE EVALUATION
17 DEMODULATOR & CHANNEL DECODER
15 ML MODEL SELECTION
10 COMMUNICATION CONTROLLER
22 I/O
20 MEMORY
24: SOFTWARE
26 CONF DB
28 BUFFER

Fig. 12

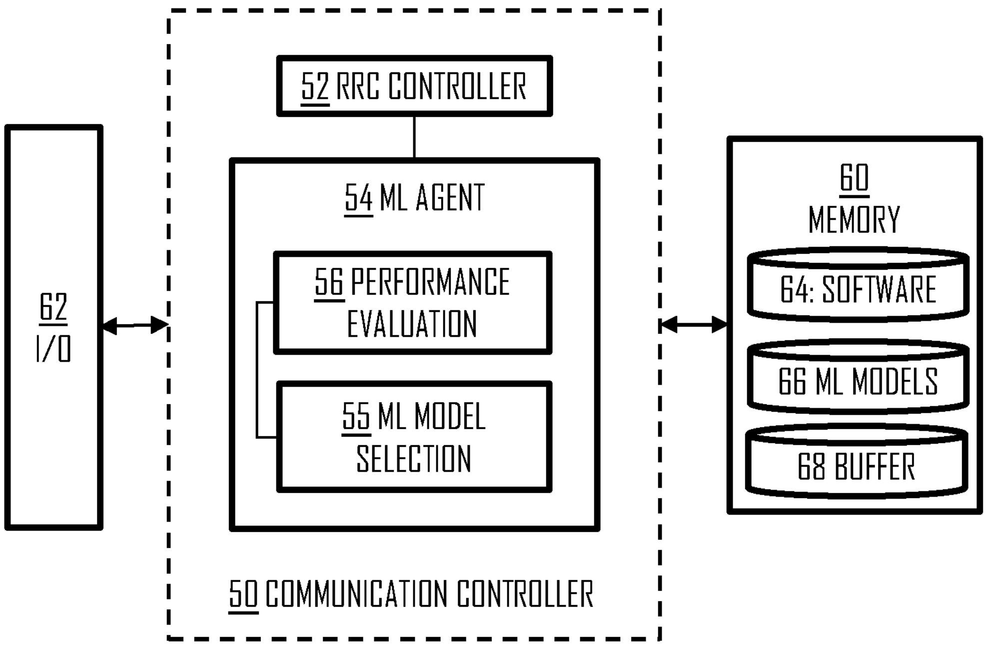

52 RRC CONTROLLER
54 ML AGENT
56 PERFORMANCE EVALUATION
55 ML MODEL SELECTION
50 COMMUNICATION CONTROLLER
62 I/O
60 MEMORY
64: SOFTWARE
66 ML MODELS
68 BUFFER

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/081033

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L1/00
ADD. G06N3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L G06N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/322388 A1 (O`SHEA TIMOTHY JAMES [US]) 8 November 2018 (2018-11-08) abstract paragraphs [0025], [0093] paragraph [0108] - paragraph [0125] figure 7 -----	1-39
A	WO 2020/190181 A1 (ERICSSON TELEFON AB L M [SE]) 24 September 2020 (2020-09-24) abstract paragraph [0006] paragraph [0053] - paragraph [0067] paragraph [0087] - paragraph [0092] figures 1, 10 ----- -/--	1-39

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 July 2022	29/07/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Garrammone, Giuliano

2

International application No
PCT/EP2021/081033

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	THOMAS KELLER ET AL: "Adaptive Modulation Techniques for Duplex OFDM Transmission", IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, IEEE, USA, vol. 49, no. 5, 1 September 2000 (2000-09-01), XP011064120, ISSN: 0018-9545 abstract -----	1-39

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2021/081033

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2018322388 A1	08-11-2018	CN 111512323 A	07-08-2020
		EP 3619656 A1	11-03-2020
		JP 6758524 B2	23-09-2020
		JP 2020520497 A	09-07-2020
		KR 20200004340 A	13-01-2020
		US 2018322388 A1	08-11-2018
		US 2019188565 A1	20-06-2019
		WO 2018204632 A1	08-11-2018
WO 2020190181 A1	24-09-2020	EP 3942719 A1	26-01-2022
		US 2022149980 A1	12-05-2022
		WO 2020190181 A1	24-09-2020